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HIGH ALTITUDE REVEGETATION WORKSHOP

NO. 18

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March 4-6, 2008

Edited by

Joe E. Brummer
Colorado State University
Department of Soil and Crop Sciences
1170 Campus Delivery
Fort Collins, CO 80523

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PREFACE

The 18th biennial High Altitude Revegetation Workshop was held at the Hilton Fort Collins in Fort Collins, Colorado on March 4-6, 2008. The Workshop was organized by the High Altitude Revegetation (HAR) Committee in conjunction with the Departments of Soil and Crop Sciences and Forest, Rangeland and Watershed Stewardship at Colorado State University. The Workshop was well attended this year by 241 people from a broad spectrum of universities, government agencies, and private companies. Discussions centered on the revegetation of disturbed lands always seem to be of interest to many people as evidenced by the number in attendance this year at the Workshop. The HAR Workshop is somewhat unique in that it focuses on the practical, on-the-ground application of revegetation techniques. People come away from the Workshop with new information and new ideas that they can take home and apply directly to their specific situations.

This Workshop would never happen without the dedication and contributions from the many people on the HAR Committee. This is an all volunteer organization and everyone that contributed to this years Workshop is to be commended for their efforts.

The Committee tried something different this year and sent out a solicitation for volunteer papers instead of inviting speakers as was done in the past. This approach worked very well and we would like to thank all the people who took time to prepare not only a presentation or poster, but also a paper or abstract for inclusion in these proceedings. The proceedings consist of 21 papers and 3 abstracts grouped into 8 workshop sessions, 6 poster papers, and 3 poster paper abstracts.

In addition to the papers and posters presented on March 5 and 6, a special Practical Revegetation Session was held on March 4 at Rocky Mountain National Park. This session was well received and attended by approximately 80 people.

For current information on upcoming High Altitude Revegetation Committee events, visit our website at: www.highaltitudereveg.org.

Joe E. Brummer
Editor

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THE SOUTHWEST ECOLOGICAL RESTORATION INSTITUTES: FILLING THE INFORMATION GAP

Daniel Binkley, Director
Colorado Forest Restoration Institute
Colorado State University
Forest, Rangeland and Watershed Stewardship Department
Fort Collins, CO 80523

ABSTRACT

In 2004, Congress and the President enacted the "Southwest Forest Health and Wildfire Prevention Act." The Act established forest restoration institutes in Arizona, New Mexico, and Colorado, with the mission of restoring the health of southwestern forests and reducing severe wildfires. This goal develops the abilities of universities to provide critical information in forms that are most useful to ecosystem managers. The Institutes fill a void between the discovery of best available social and biophysical science, and applying it on the ground. We collaborate to provide a full menu of services including: research, outreach, and translation of scientific findings into forms that can be used by land managers and stakeholders to design effective forest health restoration treatments. The workshop presentation will provide an overview of the history and approach of the Institutes, and highlight an evidence-based approach (developed from the health-care field) to understanding the needs of restoration practitioners, developing collaborative approaches to systematic reviews of current knowledge, and making management recommendations.

ALTERNATIVES TO TOPSOIL:
A FIVE-YEAR CASE STUDY IN MINE SITE REVEGETATION

Steven L. McGeehan

Analytical Sciences Laboratory
University of Idaho
Moscow, ID 83844-2203

ABSTRACT

Quality topsoil is often a limited resource in mine site revegetation. For this reason, a series of demonstration plots was installed to evaluate the suitability of alternative growth media for revegetation projects in the Coeur d'Alene Mining District of northern Idaho. Plot treatments included biosolids, composts, log yard wastes, and two organic soil treatments. Each plot was seeded with a standardized seed mix and evaluated for revegetation success, nutrient runoff, and soil erosion from 2003 through 2007. All treatments were successful in promoting a self-sustaining vegetative cover. The level of available nitrogen had a strong impact on vegetation coverage, species distribution and extent of unseeded vegetation. For example, high nitrogen treatments promoted a grass-dominated/low forb profile with a low content of unseeded vegetation. In contrast, low nitrogen treatments promoted a more diverse grass-forb mixture with greater susceptibility to unseeded vegetation establishment. The species distribution within most plots also changed over time. In grass-dominated plots, wheatgrass declined with a concurrent increase in brome and fescue. The remaining plots exhibited increases in yarrow, white clover, and milkvetch. More detailed information on plot dynamics and treatment costs will be covered in the presentation.

INTRODUCTION

Remediation projects throughout the Coeur d'Alene Mining District consume large quantities of topsoil. The State's RI/FS team has estimated that approximately 600,000 cubic yards of growth media will be needed to complete all anticipated remedial actions. Available topsoil resources are insufficient to meet this need. Hence, there is an urgent need to identify topsoil alternatives that are locally available and can promote a self sustaining vegetative cover.

A variety of materials have been investigated for their suitability as soil amendments, or as components of a manufactured soil. For example, surface applications of composts, consisting of municipal solid waste and biosolids, have been used to control erosion and revegetate steep slopes on the Quall Cherokee Reservation of North Carolina (EPA, 1997). Li et al. (2000) found that composted, limed biosolids were superior to conventional fertilizer plus lime treatments in revegetating a Cd/Zn contaminated soil near Palmerton, PA. A biosolids/yard waste compost was used by Glanville et al. (2004) to establish a vegetative cover on new highway embankments. A related study showed that these compost treatments provided erosion control prior to plant establishment (Persyn et al., 2002) but also resulted in increased runoff P concentrations (Glanville et al., 2002).

Zeng et al. (1993) reported that log yard fines (LYF) improved soil physical properties including water holding capacity, bulk density, and porosity. Although orchard grass biomass decreased with increasing LYF application rates, alfalfa growth improved, suggesting that the high C/N impeded grass growth but did not adversely affect legumes. Brown et al. (2005) reported that municipal biosolids mixed with agricultural limestone were beneficial for establishing a plant cover on mine tailings near Leadville, CO. This study also observed decreased plant diversity (i.e. a high percentage of grasses relative to forbs) on the biosolids-amended plots. This effect was attributed to the high N content of the biosolids.

A range of solid materials, including municipal biosolids, woody debris, wood ash, pulp and paper sludge, and compost was tested for reclamation of metal-contaminated mine wastes at the Bunker Hill Superfund site in northern Idaho (Brown et al., 2003). These researchers found that biosolids in combination with wood ash, with or without the other materials, were able to promote a vegetative cover in acidic soils with elevated Pb and Zn. This study also tested two commercially available soil restoration products, Biosol® and Kiwi Power™, which are designed to enhance microbial activity and stimulate nutrient cycling. While Brown et al. (2003) observed superior initial germination in the Biosol® and Kiwi Power™ treatments, these amendments were not effective in sustaining plant growth. In contrast, some studies suggest that enhanced bioactivity can be a key factor in successful reclamation of severely disturbed soils. Noyd et al. (1996) reported that plant cover and biomass, percent seeded species, and mycorrhizal infectivity were positively associated in reclamation of iron ore tailings. Furthermore, decreased mycorrizal activity was identified as a major factor in poor plant establishment following long-term stockpiling of topsoil during mining operations (Schuman, 1999).

Another key factor in amendments used for revegetation is nitrogen availability. The dynamic nature of the nitrogen cycle and its association with soil organic matter and soil biota impacts a host of secondary properties or processes including water quality, plant diversity, and the ability of seeded vegetation to compete with weed species. For example, Reever-Morghan and Seastedt (1999) reported decreased knapweed biomass as a result of reduced N availability. Reduction of available nitrogen was also used to suppress growth of introduced grasses, which improved the establishment of native species (Wilson and Gerry, 1995). Redente et al. (1992) found that high N levels produced more biomass in early seral species but, as N availability decreased, late seral species appeared to gain a competitive advantage. Additional studies have shown that high nitrogen availability leads to higher overall productivity but lower diversity (Willems and van Nieuwstadt, 1996; Baer et al., 2003).

Given the importance of these impacts to the long-term success of revegetation projects, additional studies (particularly those conducted under differing environmental and topographic conditions) are useful. In October 2002, the Idaho Department of Environmental Quality initiated a study to investigate topsoil alternatives for mine site revegetation. A key feature of this study was the desire to compare the performance of topsoil alternatives, and conduct cost evaluations, using side-by-side comparisons. The specific objective was to use demonstration plots to evaluate a variety of amendments, including biosolids, composts, log yard wastes, plus the Biosol and Kiwi Power treatments, for 1) revegetation sucess, 2) nutrient runoff; 3) erosion control, and 4) relative cost of each treatment.

METHODS

Site Description

The Silver Dollar Mine site is located west of Osburn, Idaho (47° 30.22' N; 115° 59.39' W). The site is dominated by a waste rock pile produced during mine development and sorted from the ore during the mining process (Figure 1). Milling and smelting activities took place off-site so heavy metal concentrations are a minor issue (relative to low fertility) for plant growth. The waste rock pile rests on a north-facing slope at an elevation of about 2500 feet. Average total monthly precipitation ranges from 1.5 inches in July to 4.5 inches in November, with a total annual precipitation of 38 inches. Average monthly temperatures are 32.9/21.3 °F (max/min) in January and 78.6/47.2 °F in August.

Figure 1. Waste rock pile at the Silver Dollar Mine site prior to start of project (date: May 2002).

Site Preparation/Plot Installation

The site was regraded using a Cat D5 Dozer and ten plots (20' X 100') were installed with a berm (3' X 2') separating each plot (Figure 2A). Nelson Construction of Boise, ID completed all earth-moving activities. The western- and eastern-most plots were reserved for controls; the remaining plots were assigned to participants on a random basis. Project participants were solicited and selected by IDEQ (Table 1).

Installation of the plots began September 25, 2002 and concluded October 23, 2002 (Figure 2B). Each plot was seeded, either by hand or by hydroseeding, using a standardized seed mix (Table 2). Following plot installation, the lower access road was closed using an earthen berm and a barbed wire fence was installed around the perimeter of the site. None of the participants conducted additional work, modification, or maintenance on their plots following the initial installation work was completed. However, Nick Zilka (IDEQ) reseeded Plot C (St. Maries Log Yard Waste) in August 2003. This was necessary due to a complete failure of germination and growth on this plot during Year 1. In addition, the plots were periodically spot-treated with herbicide by Zilka and McGeehan to control knapweed.

Table 1. Demonstration plot amendments, rates, and project participants.

Plot	Amendment	Affiliation	Amendment Rate
A	Control (topsoil)	IDEQ	40 yd^3 of topsoil was spread to a depth of approximately 6”
B	Biosolid + Woodash (0.75:1)	Coeur d'Alene Wastewater Treatment Plant	26 yd^3 of Class B biosolids mixed with wood ash (0.75:1) was spread to a depth of approximately 4”
C	Potlatch Log Yard Waste	Potlatch Corp.	Log yard fines (<3/4”) were mixed with urea fertilizer (10 % v/v); 48 yd^3 was spread to a depth of approximately 6”
D	Kiwi Power	Quattro Environmental, Inc.	Fertile Fibers Plus, Kiwi Power, Strong Hold + Tacker and Atlas Soil Lock was mixed and applied using the hydroseeder
E	Eko Compost	Eko Compost	20 yd^3 of compost was spread to a depth of approximately 4”
F	Glacier Gold Compost	Glacier Gold, LLC	20 yd^3 of compost was spread to a depth of approximately 4”
G	Biosol	Rocky Mountain Bio Products	83 lb Biosol Mix (7-2-3) plus 5 lb Wood Fiber Mulch seed mix was applied using the hydroseeder. Wheat straw was spread over plot and 4 lb Guardian Tackifier applied.
H	Glacier Gold Log Yard Waste	Glacier Gold, LLC	20 yd^3 of log yard waste was spread to a depth of approximately 4”
I	Biosolid + Woodash (1:1)	Coeur d'Alene Wastewater Treatment Plant	26 yd^3 of Class B biosolids mixed with wood ash (1:1) was spread to a depth of approximately 4”
J	Control (fertilizer)	IDEQ	50 lb of fertilizer (16-16-16), seed mix, and tackifier were applied with the hydroseeder. Bluegrass straw was applied as a mulch on bottom-half of plot

Vegetation Assessment

Steven McGeehan (UI) inspected the plots on a monthly basis during each field season, beginning in April and concluding in August. The early season assessments (April, May, and June) visually estimated plant coverage and overall condition of the plot. In addition, a qualitative assessment of leaf color was made as this can provide clues to nutrient sufficiency/deficiency and plant stress due to diseases and pests. Uniformity of coverage was also noted for each plot. Detailed field notes and montly plot assessments are included in the Individual Plots section of this report.

Quantitative determination of revegetation success was conducted each July using Bureau of Land Management standard methods (Elzinga et al., 1998). Percent coverage was measured using a cover-point optical projection scope[1]. One hundred points were recorded at 1-m intervals along a randomly located transect within each plot. Each point identified an individual plant, rock,bare soil,or litter.

[1] ESCO Associates. Cover-point optical projection device, Operation Manual – Models 4 and 5.

Figure 2. Site of demonstration plots (A) following site preparation (date: September 2002) and (B) following addition of amendments (date: October 2002).

Table 2. Seed mix used on the Silver Dollar Demonstration Plots.

Common Name	Scientific Name	Amount/Acre	Pct by wt.	Min. pct.
Slender wheatgrass	*Elymus trachycaulus* ssp. *Trachycaulus* var. Revenue	14 lbs	22.3	21.9
Idaho fescue	*Festuca idahoensis* var. Joseph	8 lbs. 7 oz	13.4	13.2
Sheep fescue	*Festuca ovina* var. Covar	7 lbs	11.1	10.9
Mountain brome	*Bromus marginatus* var. Bromar	7 lbs. 11 oz	12.2	12.0
Meadow brome	*Bromus biebersteinii* var. Paddock	8 lbs. 7 oz	13.4	13.2
White Yarrow	*Achillea millefolium*	11 oz	1.1	1.1
Blue flax	*Linum lewisii* var. Appar	4 lbs. 3 oz	6.7	6.6
Rocky Mountain penstemon	*Penstemon strictus*	1 lb. 6 oz	2.2	2.2
White dutch clover	*Trifolium repens* L.	8 oz	0.8	0.8
Canada bluegrass	*Poa compressa*	11 oz	1.1	1.1
Big bluegrass	*Poa ampla* var. Sherman	1 lb. 7 oz	2.3	2.3
Canby bluegrass	*Poa canbyi* var. Canbar	1 lb. 6 oz	2.2	2.2
Cicer milkvetch	*Astragalus cicer*	7 lbs.	11.1	10.9
Fireweed	*Epilobium angustifolia*	1 oz	0.1	0.1
Weed seed				0.5 (Max)
Inert and other crop				1.5 (Max)

Plant density (plants/m^2) was also determined for each plot within one week of the coverage measurements. Density was evaluated at two sampling areas per plot, 10 m in from the bottom and top of the plot. The exact location of the sampling area was randomly selected - the observer faced away from the plot and tossed a 1-m^2 PVC hoop over their head into the plot. Each individual plant within the hoop was tallied and identified, including plants that were not a component of the original seed mix. The mean value of the replicate density assessments is reported in the following figures and tables. All plant identifications were made by Jill Blake (Consulting Botanist) at the time of the coverage and density measurements.

Assessment of Erosion, Runoff, and Soil Properties

Erosion traps, consisting of a 10' X 20' pit, were installed at the toe of each plot (Figure 3). The traps were covered with landscape fabric to allow water infiltration while collecting eroded soil. Erosion was visually estimated on a monthly basis by examining the solid material accumulated in the traps. The presence and approximate size of rills within each plot was also noted. Runoff flumes were also installed at the bottom of each plot (Figure 3). The flumes were constructed using PVC rain gutters (4" X 2.5" X 10') fitted with a perforated leaf guard and covered with landscape fabric. The ends of the flume were capped and one end was fitted with a drain hose leading to a 4-L plastic bottle. Each flume was placed into a trench dug at the bottom of the plot (1-2' above the erosion trap). The flumes were situated in the trench such that the tops were continuous with the soil surface and slope of each plot.

Surface runoff was collected monthly, coinciding with a significant rain event, and analyzed for ammonia-N, nitrate-N, and orthophosphate using EPA Methods 350.1, 353.2, and 365.2, respectively (EPA 1982, 1883). Duplicate soil samples were collected from the control plots following regrading but prior to addition of plot amendments; these results are reported as the Unamended Control in the following figures and tables. At the end of the Year 1, 3, and 5 field seasons, a composite (3x) soil sample was collected from the 0-10 cm depth of each plot. Soil fertility parameters (ammonia-N, nitrate-N, available P and K, pH, and EC) and physical properties (percent sand, silt, clay, coarse fragments, and textural class) were determined using standard methods (Miller et al., 1997). Organic matter content was determined by colorimetry (Sims and Haby, 1971). Total recoverable metals were determined using EPA Method 3050B/6010 (EPA, 1986A). All laboratory work was conducted at the University of Idaho Analytical Sciences Laboratory. Standard quality assurance/quality control protocols were followed for all analytical work (ASL, 2003).

Cost Evaluation

Information for the cost evaluation was received from the vendors, subcontractors working at the site, and vendor invoices. This invoice was collected and compiled by Kathy Lombardi and Carl Johnson (SAIC) and submitted to Nick Zilka (IDEQ) via a Technical Memorandum dated February 5, 2004. Technical Memorandum included both 'actual' and 'normalized' costs, the latter reflecting adjustments to allow a more equitable comparison of alternative costs.

RESULTS

Soil and Amendment Properties and Surface Runoff

Following site preparation but prior to amendment application, the site surface material was a mixture of waste rock and fine material. The unamended control (Table 3 and Figure 3) exhibits properties endemic to the Silver Dollar site: an alkaline, sandy growth media with a high percentage of coarse (> 2 mm) fragments and low native fertility. The alkaline pH is typical of soils derived from the dolomitic and calcareous quartzite parent materials present in the Wallace Formation, which is penetrated by the Silver Dollar workings.

Texture analysis indicated a very cobbley sandy loam with 58% coarse fragments (Table 4). The electrical conductivity (EC) of the unamended control was 0.35 dS/m, which is well below the critical level at which salinity can limit performance of agronomic crops (typically 2-4 dS/m). The highest EC values were observed on the Biosolids and Potlatch Log Yard Waste Plots (Table 3). This is due to the addition of woodash or urea fertilizer, respectively. Despite these higher EC values, none of these plots exhibited any indication of a salinity problem.

The total recoverable metals profile of the amended soils did not differ appreciably from the unamended control (Table 4). The primary differences observed were elevated levels of Ca, K, and Na in the Biosolid/Wood Ash plots, no doubt due to the presence of alkaline earth oxides in wood ash. Elevated total phosphorus concentrations were exhibited by the Biosolids, Potlatch Log Yard Waste, Eko Compost, and Glacier Gold Compost plots. Given that the milling and smelting activities are known to have taken place off-site, the lack of elevated metal concentrations is not surprising. Thus, the chemical and physical data summarized in Tables 4 and 5 clearly indicate that low soil fertility is the primary factor limiting sustainable plant growth at this site, with a secondary factor being low water holding capacity.

Most of the amendments decreased the plot pH relative to the initial value of 8.3 (Figure 3A). The pH of the amended plots ranged from 6.3 to 8.3 with the 1:1 woodash/biosolid mixture exhibiting the highest pH. Overall, the pH was relatively consistent among the amended plots throughout the study period. The organic matter content varied from ~1% in the controls and liquid-based amendments to 15-34% in the solid-based amendments (Figure 3B).
Each of the plot treatments significantly increased the available P and K content, with the extent of increase being strongly dependent on the nature of the amendment (Figures 3C,D). Available P values ranged from <2 to >600 ug/g while available K ranged from 80 to 1000 ug/g. To put these numbers into perspective, available P and K levels in excess of 8 and 100 ug/g, respectively, are considered sufficient for non-irrigated legume and legume-grass pastures in northern Idaho (Mahler, 2005). Thus, each of the amended plots contained adequate to excessive P and K relative to typical plant requirements. The ammonia-N level in the unamended soil-waste rock was 1.8 ug/g while the amended plots exhibited concentrations ranging from <1 to >600 ug/g (Figure 3E). Similarly, nitrate-N was initially low and varied significantly among the amended plots, ranging from <2 to >60 ug/g (Figure 3F).

Erosion was minimal to non-existent during the study. A minor amount (< 5 kg) of sediment was observed in the traps of the Kiwi Power, Eko Compost and Glacier Gold Compost plots during Year 1 and rills (3-5" wide X 1-3" deep) were present in bottom half of these plots. In addition, large rills (8-12" X 4-6" were present on upper-half of the Control Fertilizer plot. This plot was designed with sporadic berms, which trapped the eroded sediment within the plot and no sediment was found in the trap at the bottom of the plot. No additional evidence of erosion was observed during Years 2-5.

Table 3. Electrical conductivity and particle size distribution for the unamended control and each amended demonstration plot.

	Electrical Conductivity (dS/m)	Particle Size Sand (%)	Clay (%)	Silt (%)	U.S.D.A Texture	Coarse Fragments (% >2mm)
Control (unamended)	0.35	66	16	18	Sandy Loam	58
Control (topsoil)	0.24	46.4	9.6	44.0	Loam	59
Biosolid + Woodash I	3.8	72.4	7.6	20.0	Sandy Loam	35
Potlatch Log Yard Waste + Urea Fertilizer	3.4	52.4	7.6	40.0	Sandy Loam	38
Kiwi Power	0.78	70.4	11.6	18.0	Sandy Loam	57
Eko Compost	1.3	56.4	7.6	36.0	Sandy Loam	34
Glacier Gold Compost	0.31	66.4	9.6	24.0	Sandy Loam	51
Biosol	1.6	60.4	15.6	24.0	Sandy Loam	57
Glacier Gold Log Yard Waste	0.54	64.4	9.6	26.0	Sandy Loam	33
Biosolid + Woodash II	2.2	62.4	5.6	32.0	Sandy Loam	19
Control (fertilizer)	0.80	66.4	13.6	20.0	Sandy Loam	68

As would be expected, runoff nitrogen and phosphorus concentrations closely reflected the available nutrient contents of each amendment (compare Figure 4 to Figures 3C,E,F). Both controls exhibited low runoff concentrations of ammonium-N, nitrate-N, and orthophosphate as did the Biosol and Glacier Gold Log Yard Waste Plots. Intermediate runoff concentrations were observed in the Kiwi Power, Eko Compost, and Glacier Gold Compost plots. The highest runoff ammonia- and nitrate-N concentrations (5.3 and 34 mg/L, respectively) were observed in the Potlatch Log Yard Waste (Figures 4A,B). This is undoubtedly due to the very high rate of urea fertilizer (10% v/v) mixed into the log yard waste by the vendor. Significant N runoff was also observed in the Eko Compost and Biosolids + Woodash II plots. Despite having very high available N (~2500 lb/ac), runoff ammonia- and nitrate-N concentrations were low in the Biosolids + Woodash I plot.

A wide range of runoff orthophosphate concentrations were observed which, like the nitrogen results, correlated with the available nutrient content of the amendment (Figures 3C and 4C). The highest runoff P values were observed in the Eko Compost, Glacier Gold Compost, and Biosolid II plots, where concentrations ranged from 1 to as high as 3 mg/L for the much of the study. Although critical levels for phosphorus in surface runoff from agricultural fields have not been established, the USEPA recommends a limit of 0.05 mg/L total phosphorus in streams that enter lakes and 0.1 mg/L total phosphorus in flowing streams (EPA, 1986B). Regulatory criteria for ammonia and nitrate have not been promulgated by the USEPA, due in part to the fact that surface waters are typically considered 'P-limiting' with respect to eutrophication. Despite the lack of formal regulations, both nitrogen and phosphorus continue to be recognized as important nonpoint pollutants of surface waters (Carpenter et al., 1998) and should be carefully managed in revegetation projects utilizing biosolids, composts, and other high nutrient materials.

Available soil nitrogen levels ranged from <20 to >2500 lb/ac during Year 1 of the study and decreased significantly between 2003 and 2005 (Figure 5). The greatest decline in available N was observed in plots with the highest initial levels, including the Biosolids, Potlatch Log Yard Waste, and Eko Compost plots. Potential fates of available N include leaching, plant uptake, and volatilization. It is clear that a significant fraction of available N was lost via surface runoff and this was most significant in the biosolids and urea-amended log yard waste, particularly during the first year (Figures 4A,B). The high available N associated with these plots also supported very heavy vegetative growth, primarily of perennial grasses which exhibit high uptake rates and N sequestration (Sullivan et al., 1997; Miller et al., 2001). However, given the magnitude of declines observed, it is likely that ammonia volatilization played the most significant role in decreased available N. Large and rapid loss of N is commonly observed in surface-applied biosolids with volatilization rates exceeding 50% of total N (Robinson et al., 2002; Robinson and Roper, 2003, Mendoza et al., 2006). This mechanism was further enhanced by the high pH levels of the demonstration plots, particularly in the wood ash amended biosolids. Although volatilization represents a major loss of available N, it also greatly decreases the risk of nitrogen leaching from nutrient rich amendments used in revegetation projects.

The addition of the various amendments had differing impacts on the soil profile of each plot. It should be noted that a true pedogenic soil profile takes hundreds to thousands of years to form. Thus, it is somewhat of a stretch to describe the profile of each plot using standard soils terminology. None-the-less, the amendments did alter the surface properties of each plot in ways that will have lasting impacts on the sustainability of a plant cover. For example, the addition of roughly 20 yd^3 of biosolids, compost, or log yard waste resulted in an overburden depth of 4-6 in. This overburden tended to be dark in color with a very friable (easily crumbled) texture. Such characteristics are associated with highly productive and fertile topsoil and, hence, these plots supported very good plant growth resulting in the presence of profuse fine roots in the overburden. Since the organic materials were spread but not incorporated, there was an abrupt boundary between the overburden and underlying waste rock, with very few roots penetrating this boundary. Also, the physical condition of the overburden improved over the course of the 5 year study. For example, the biosolids were very sticky and tended to smear when the Dozer attempted to spread this material. However, as this material dried and weathered for several years, the result was a very light material with physical properties that are ideal for plant growth. Likewise, the log yard waste and composts underwent both physical and biological weathering, resulting in a very friable material with excellent tilth and other desirable physical properties.

Table 4. Total recoverable metals[1] for the unamended control and each amended demonstration plot.

	As	Ba	Be	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Mo	Na	Ni	P	Pb	S	Zn
	ug/g																		
Control (unamended)	59	220	<0.38	20000	0.08	15	13	81	20000	1400	7500	1400	<3.8	<150	16	370	100	1400	170
Control (topsoil)	16	240	1.1	5500	<0.75	13	54	25	27000	3900	8500	830	<3.8	<150	32	850	19	540	91
Biosolid + Woodash I	34	850	0.70	59000	2.8	11	58	130	16000	7100	10000	2200	<3.8	1800	45	15000	34	2300	470
Potlatch Log Yard Waste	12	310	0.44	15000	<0.75	11	71	33	22000	3700	4200	930	<3.8	420	43	1100	22	630	110
Kiwi Power	46	230	0.63	36000	<0.75	18	35	140	29000	1700	15000	2400	4.6	<150	32	440	26	1600	74
Eko Compost	22	260	0.43	23000	0.75	13	63	110	22000	3300	7000	1400	4.6	64	41	3600	37	2900	190
Glacier Gold Compost	33	400	0.49	20000	<0.75	8.8	74	130	17000	2200	6600	1500	<3.8	<150	41	2700	29	1600	110
Biosol	47	480	0.63	24000	<0.75	12	66	96	23000	2300	8400	2000	<3.8	<150	39	460	80	1800	150
Glacier Gold Log Yard Waste	23	240	0.49	16000	<0.75	7.3	62	35	16000	2500	8100	1100	<3.8	<150	36	760	16	900	78
Biosolid + Woodash II	36	940	0.67	74000	3.3	11	140	110	19000	11000	10000	2900	<3.8	2900	83	12000	34	2000	530
Control (fertilizer)	62	350	0.64	21000	3.7	11	46	86	22000	2200	8200	1300	<3.8	690	31	490	99	2000	920

[1] EPA Method 3050

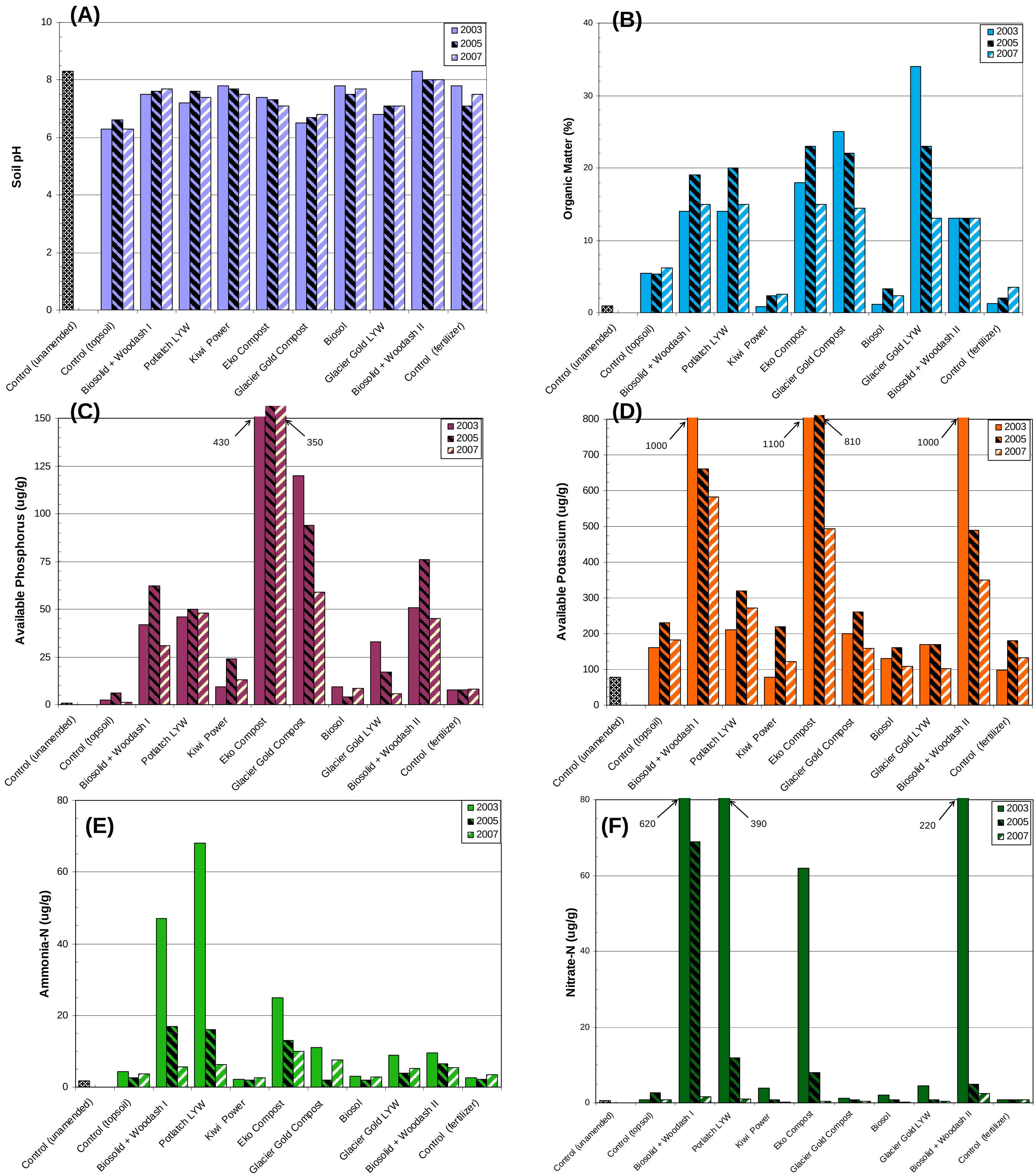

Figure 3. Soil parameters in 2003, 2005, and 2007: (A) soil pH, (B) organic matter, (C) available potassium, (D) available phosphorus, (E) ammonia-N, and (F) nitrate-N.

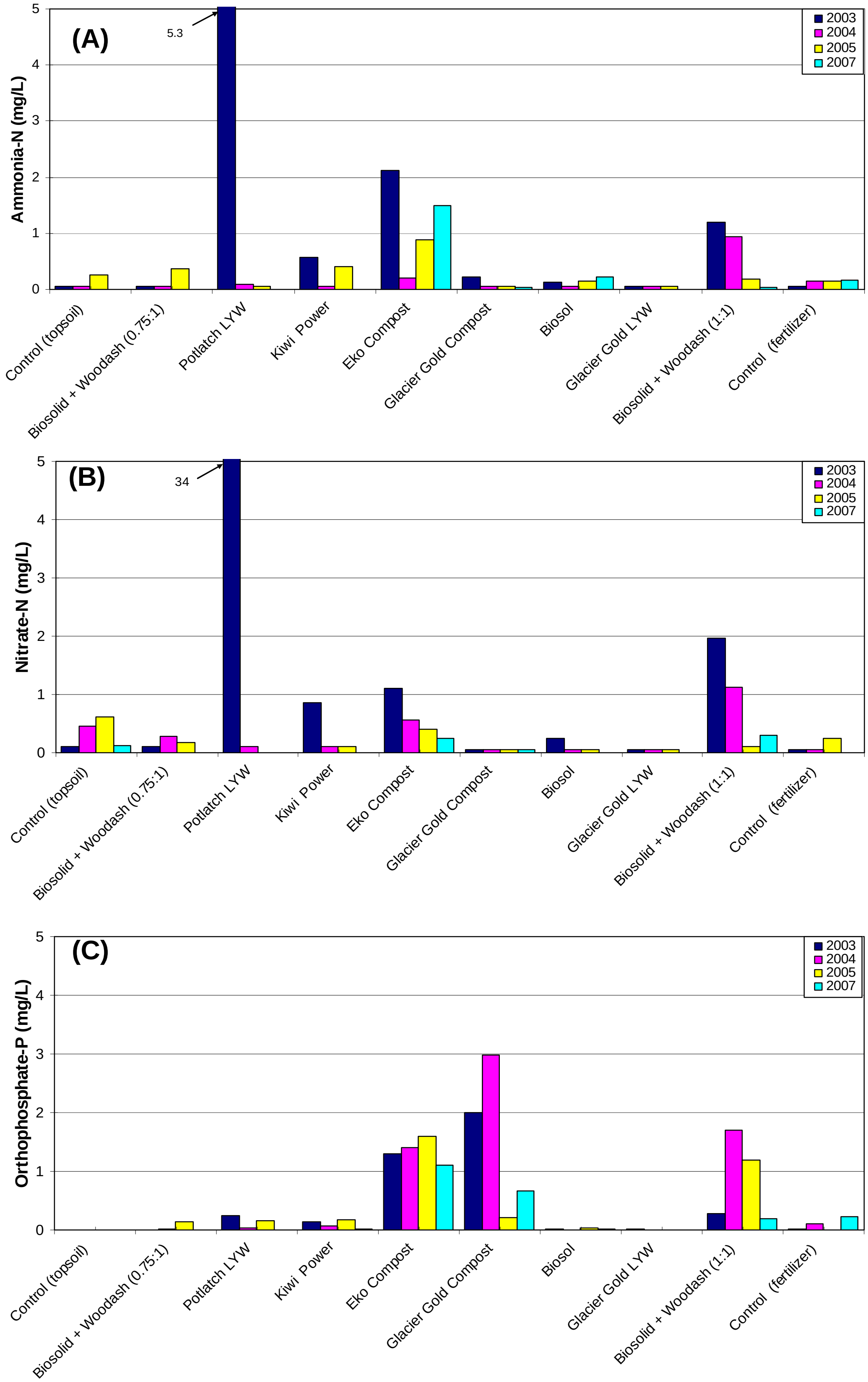

Figure 4. Mean seasonal runoff concentrations of (A) ammonia-N, (B) nitrate-N, and (C) orthophosphate-P in 2003, 2004, 2005, and 2007. Data represent three-month averages (April, May, June) for each year.

In contrast, the Kiwi Power, Biosol, and Fertilizer Control did not receive large quantities of organic amendments. Consequently, these plots exhibited a thin organic surface layer developed from decaying plant debris. Despite the lack of a thick, organic overburden, these plots still supported good plant growth as evidenced by the moderate root presence. It is likely that these plots will continue to build organic matter content over time and slowly develop desirable properties like water holding capacity, nutrient cycling, and physical tilth.

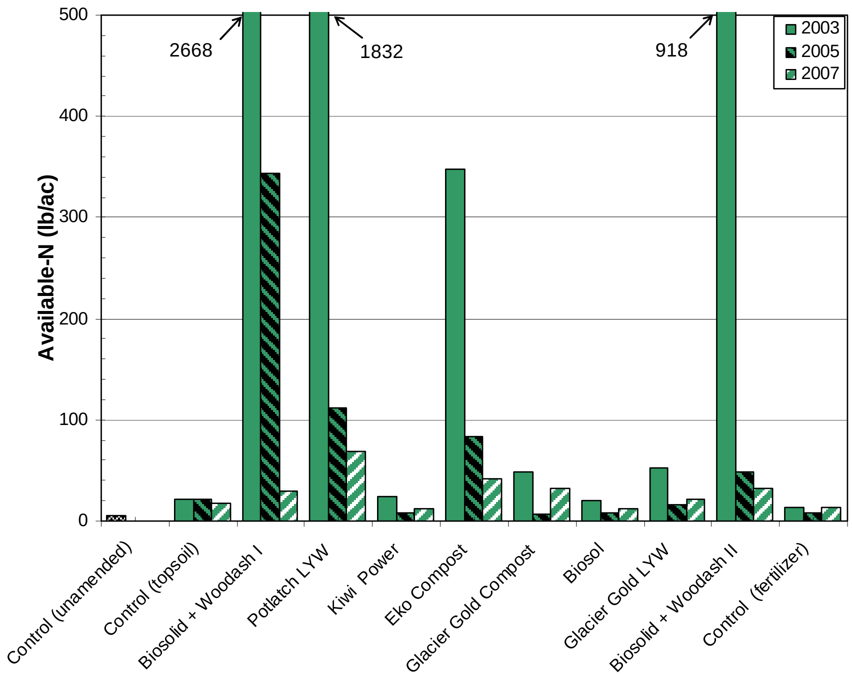

Figure 5. Available soil nitrogen in 2003, 2005, and 2007.

Vegetation Assessment

Figures 7 and 8 provide a comparison of plant coverage and plant density across all plots. Each plot has five data bars corresponding to coverage or density results for 2003, 2004, 2005, 2006, and 2007. More detailed assessment information, including the distribution of plant species, is included in the Individual Plot section of this report.

Plant Coverage

Plant coverage describes the probability of finding any plant, or a particular species, at a given point along a transect line. Coverage is expressed as a value between 0% and 100%, representing the percentage of sampling points where a plant was observed during sampling.

Each treatment was successful in promoting a self-sustaining plant cover during Year 1 and maintaining plant growth throughout the five-year study. The extent of coverage varied considerably among the treatments, ranging from 30% in the Biosol plot to 77% in the Eko Compost and Biosolids II plots (2003 data). Plant coverage increased significantly between Years 1 and 2 (Figure 6). These increases can be attributed to increased grass growth in the

Biosolids, Eko Compost, and Biosol plots and increases in forb growth in the Kiwi Power, Glacier Gold Compost, and Glacier Gold Log Yard Waste plots. Slender wheatgrass and brome species were the most extensive grasses observed during Years 1 and 2 while yarrow and white dutch clover were the most frequently observed forbs. Unseeded vegetation, primarily black medic and hares foot clover, accounted for the increase in coverage observed in both control plots.

In general, the total plant coverage did not change significantly in the Silver Dollar plots from Year 3 to Year 5 (Figure 6). The majority (9 of 10 plots) maintained plant coverage in the 75 - 90% range. Three plots – Kiwi Power, Glacier Gold Compost, and Control-Fertilizer – did exhibit increased coverage and this change was due to an increase in unseeded vegetation in each case. The proportion of grasses relative to forbs was also consistent between 2005 and 2007. That is, the frequency with which of grasses were encountered remained relatively constant within a given plot. Several plots – Biosolids, Potlatch Log Yard Waste, and Eko Compost – continued to be dominated by grasses with wheatgrass, bromes, and fescues comprising at least 75% of the total plant cover.

Forb coverage was consistent between from Year 3 to Year 5 (Figure 6). However, in three plots (Kiwi Power, Glacier Gold Compost, and Control Fertilizer), total forb coverage declined slightly. As mentioned above, this decline was accompanied by an increase in unseeded vegetation. Substantial increases in cicer milkvetch were observed in the Glacier Gold Compost and Glacier Gold Log Yard Waste plots. Significant decreases in yarrow were observed in the Kiwi Power, Eko Compost, and Glacier Gold Compost plots.

It should be noted that the large forb coverage reported for the Glacier Gold Log Yard Waste plot in 2004 (Figure 6) was primarily due to the growth of clover. This observation was erroneously reported as white clover in 2004 but was later confirmed to be sweet clover. The significant increase in unseeded vegetation for this plot in 2005 and 2006 reflects the correct classification of these plants as sweet clover. As Figure 6 indicates, sweet clover (plotted as unseeded vegetation) almost completely disappears in 2007, apparently being displaced by cicer milkvetch.

Plant Density

Density describes the number of individual plants observed within a specified area. A one square meter sampling area is frequently used for rangeland and vegetation restoration studies involving non-woody species. Two randomly-placed density measurements were conducted per plot and the mean of these measurements summarized in Figure 7.

Plant density varied considerably among the plots, ranging from 145 to 327 plants/m^2 in the Glacier Gold Compost and Biosol plots, respectively (2003 data). Plant density increased significantly between Years 2 and 3, tended to peak in Year 4, and often declined in Year 5 (Figure 7). This is in contrast to the coverage measurements which, as discussed above, increased in most plots between Years 1 and 2 and remained relatively constant in Years 3-5. The increased density was due greater numbers of grass species (primarily Brome sp.) in the Potlatch and Eko plots. The Glacier Gold Compost, Glacier Gold Log Yard Waste, and Kiwi

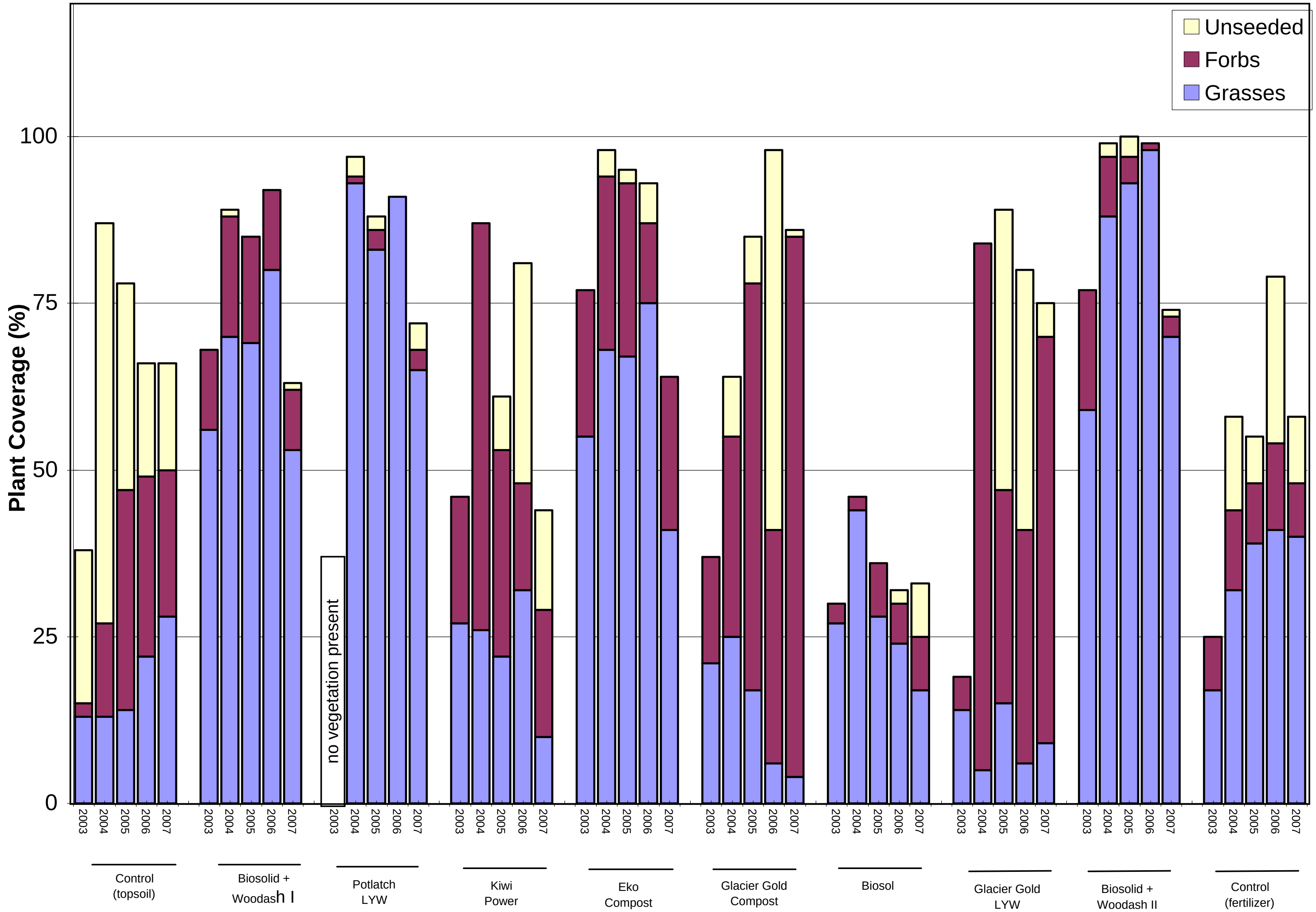

Figure 6. Plant coverage in each of the demonstration plots from 2003 to 2007.

Power plots exhibited significant increases in unseeded vegetation, largely due to the spread of sweet clover and black medic (Table 5).

An important, and potentially misleading, aspect of the density data are the relatively low densities exhibited by both Biosolid plots as well as the Potlatch Log Yard Waste and Eko Compost plots, particularly in 2003 and 2004. While these treatments exhibit some of the lowest density values in Figure 7, these plots are not exhibiting poor performance. To the contrary, these plots exhibit very large and thriving vegetation relative to the same species growing on the other plots. As pointed out earlier, this exceptional growth is in response to high available nitrogen. It is likely that the sheer size of the vegetation is a limiting factor for density in these high fertility plots. This observation is further supported by evaluating the density data for the Topsoil Control, Kiwi Power, Biosol, and Glacier Gold plots. These plots appear to be sparsely vegetated relative to the Biosolid, Potlatch, and Eko Compost plots. This is consistent with the lower fertility growth media added to these plots. A closer examination indicates that each of these low fertility amendments is supporting large numbers of small plants (note: in some cases, the vegetation is exhibiting signs of nutrient deficiency (i.e. stunting, chlorosis, reddish leaves). Thus, in terms of sheer numbers of plants per unit area; these plots exhibit relatively high plant densities (Figure 7). In most cases, an inverse relationship exists between plant coverage and plant density within a given plot. These observations clearly indicate that neither coverage nor density data alone can completely portray the overall quality and performance of a given plot.

Changes in Species Distribution

An additional trend is apparent when comparing the year-to-year data – the species distribution within the plots changed over time. While the total coverage and density of grasses in many plots did not change significantly from Year 3 to Year 5, marked changes in individual species did take place. For example, wheatgrass was clearly the dominant grass in the Biosolids amendments in 2003 (Year 1). However, the 2004-2007 (Years 2-5) data show a more equal distribution between wheatgrass, bromes, and fescues. This general trend of declining wheatgrass with concurrent increases in bromes and fescues was evident in most of the grass-dominated (higher fertility) plots. It is unclear whether the gradual decline in wheatgrass is a natural successional characteristic or a response of this species to a decrease in available N.

The lower fertility plots tended to exhibit greater plant diversity throughout the study period but significant species changes were evident as well. Yarrow tended to increase steadily in most of the plots through Years 1, 2, and 3. White clover was common on several of the lower fertility plots in Year 1 but was rarely encountered during Years 2-5. In contrast, cicer milkvetch was not observed during Years 1 and 2 but increased significantly during the final three years of the study. Both yarrow and cicer milkvetch produce many profuse seed heads, which suggests the presence of these species is likely to increase in the future.

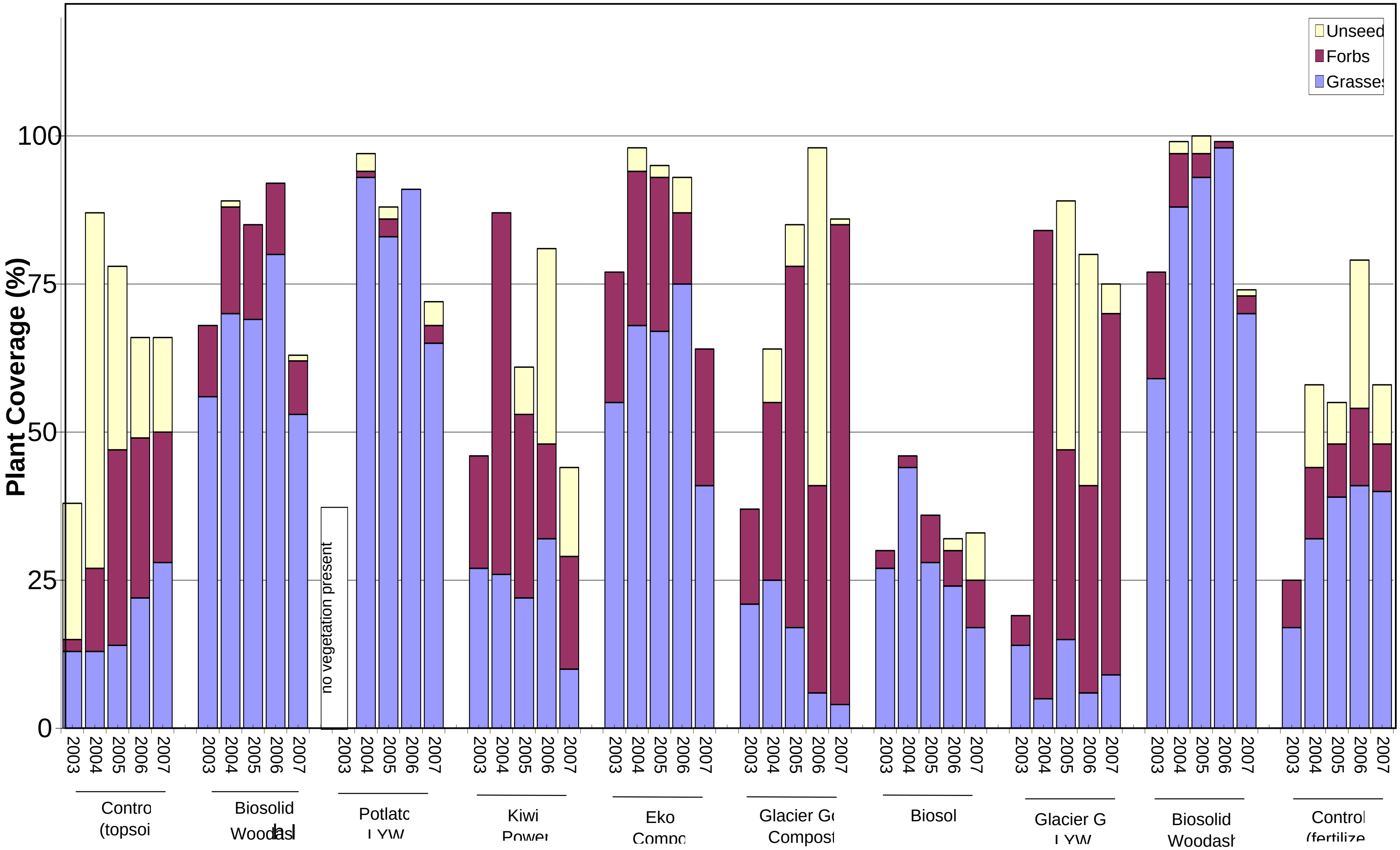

Figure 7. Plant density in each of the demonstration plots from 2003 to 2007.

Impact of Surface Residue

Another consistent trend among the high fertility (grass dominated) plots was the gradual build up of surface residue. As described above, these plots exhibited very high plot coverages, which led to large quantities of plant debris carrying over to the succeeding year. By the fifth year of the study, a thick surface layer of organic material had developed, consisting of undecomposed residue overlying partially to fully decomposed organic matter. It is likely that development of this surface layer has and will continue to impact plot performance in several ways (both positive and negative):

1. Reduced surface evaporation and higher available soil moisture throughout the summer months.
2. Increased nutrient retention and enhanced nutrient cycling (including nitrogen, phosphorus, and most micronutrients) due to incorporated humic components.
3. More rapid warming of soil surface during the spring due to dark colored surface horizon.
4. Decreased plant coverage and more patchy growth due to pockets of excessively thick mulch.

Most of the impacts, while difficult to quantify, are positive in nature. However, the vegetation assessments clearly show a decline in coverage in the Biosolids, Potlatch Log Yard Waste, and Eko Compost plots and this is due almost entirely to decreased grass growth (Figure 6). For example, coverage on the Biosolids I and Eko Compost plots decreased from roughly 92% in 2006 to 63% in 2007. Field observations on each of these plots confirmed sporadic clumps of decomposing residue in areas with little or no grass growth. In contrast, the lower fertility plots, such as Kiwi Power, Biosol, Glacier Gold Log Yard Waste, and the Fertilizer Control, did not exhibit heavy grass growth and, hence, did not build up the thick surface residue. Thus, these plots did not experience suppressed plant growth due to thick mulch. Finally, it should be noted that, although coverage did decrease in the high fertility plots, it still exceeds that observed in the lower fertility plots (Figure 6). Furthermore, the high fertility plots maintained excellent plant vigor, plant size, and leaf color throughout the study suggesting that the negative impacts of surface residue were relatively insignificant in overall plot performance.

Unseeded Vegetation

Significant increases in both the coverage and density of unseeded vegetation were observed in several of the plots during the study period. As Figures 6 and 7 show, the Topsoil Control plot exhibited a high incidence of beginning in Year 1 and throughout the study. For example, this plot contained 60% unseeded species and the weed density increased from 186 to 280 plants/m^2 between 2004 and 2005. The majority of this increase was due to the establishment and growth of hare's foot clover. However, as Table 5 indicates, the frequency of hare's foot declined during Years 4 and 5, with a significant increase in black medic and knapweed.

In contrast, Kiwi Power, Glacier Gold Compost, and Glacier Gold Log Yard Waste did not exhibit substantial increases in weeds until Year 3 (Figure 6, Table 5) with 25 to 50% of the total plant coverage occupied by unseeded species (Figure 6). These large increases were primarily the result of black medic and sweet clover, although spotted knapweed was a significant problem on the Fertilizer Control (Table 5). It should be noted that, while sweet clover is listed as an unseeded species, this should not imply that sweet clover growth is necessarily an undesirable result. Also, it is important to note that several plots (i.e. Biosolids, Potlatch Log Yard Waste, Eko Compost, and Biosol) exhibited very little to no weed species.

The majority of the unseeded species can be classified as common weeds of the northwest (Whitson, 1999) that are easily disseminated by wind, animals, and other vectors. However, given the disproportionately high percentage of unseeded vegetation present in the Topsoil Control in Year 1, it is likely that many weed seeds were transported to the site in the topsoil amendment. The role of topsoil as a seed bank is well established and imported soil has been reported to introduce both desirable and undesirable invasive species (Zhange et al., 2001; Polster et al., 2006). In addition to introduction via topsoil, the 2004 data indicate that weeds endemic to the surrounding landscape are beginning to invade the plots. In particular, sweet clover, black medic, and knapweed numbers have increased significantly. Although knapweed was not perceived to be a major problem during the July 2004 plot assessments, a significant invasion was observed by the end of August. Project personnel (McGeehan and Zilka) decided to cut and remove the aboveground knapweed plants in an effort to reduce reseeding. Knapweed was judged to be a continuing problem in 2005 and, as such, the plots were spot-treated with RoundUp herbicide (containing triclopyr and clopyralid as active ingredients).

One additional note regarding unseeded vegetation – moss (of an unknown species) was observed to actively growing on every plot. Active moss growth occurred early in the season (i.e. May-June), afterwhich it appeared to flower and eventually die back. The extent of moss coverage varied with the plot amendment and tended to be more extensive on heavily vegetated plots. These plots maintained a thick layer of decomposing plant residue and relatively high surface moisture, which appears to create favorable conditions for the moss. It is unclear as to the significance of moss growth in the overall revegetation picture.

Impact of Available Nitrogen

Several studies in the literature show that the impact of nitrogen in mine site reclamation projects goes beyond basic plant nutrition considerations. For example, high nitrogen availability was found to improve overall productivity but at a cost of lower diversity (Willems and van Nieuwstadt, 1996; Baer et al., 2003). This was certainly the case in the Silver Dollar study - plots receiving high nitrogen amendments (i.e. Biosolids, Eko Compost, and Potlatch Log Yard Waste) favored the establishment and growth of grasses over forbs, and this pattern was consistent throughout the five year study. As Figure 6 illustrates, between 75 and 90% of the total vegetation is accounted for by grass species in these high fertility plots. A visual inspection of these plots confirms the presence of large, very robust plants; a growth habit that is characteristic of high levels of available nitrogen. In contrast, plots receiving lower N inputs (i.e. both Controls, Kiwi Power, and Glacier Gold plots) exhibited a greater diversity of forbs (including yarrow, clovers, and milkvetch) intermixed with the grasses.

An additional characteristic of the high nitrogen plots is an almost complete lack of unseeded vegetation (Figure 7). Several studies report increased weed growth and competition in high nitrogen environments (Carlson and Hill, 1985; Jornsgard et al., 1996). However, in the case of the Silver Dollar plots, just the opposite was observed. As Figure 9 clearly shows, an inverse relationship between available nitrogen and unseeded vegetation is evident. That is, high available N is associated with low weed density and vice versa. In contrast, low nitrogen fertility lead to a high incidence of weed species. It should be stressed that, while this relationship is very clear across the ten Silver Dollar plots, different sites are likely to exhibit different interactions between nitrogen and weeds. In particularly, the nitrogen use efficiency of the weed vs. the species of seeded vegetation is expected to play a critical role (Carlson and Hill, 1985; Jornsgard et al., 1996).

Table 5. Density of unseeded vegetation on the demonstration plots.

Plot	Common Name	Scientific Name	Weed Density (plants/m^2)				
			2003	2004	2005	2006	2007
A	Sedge	*Carex sp.*	53	0	0	0	0
	Black Clover (black medic)	*Medicago lupulina*	31	175	154	224	36
	Hare's Foot Clover	*Trifolium arvense*	9	29	102	4	12
	Oxeye Daisy	*Leucanthemum vulgare*	6	7	12	14	42
	Moss	unknown	0	0	0	26	0
	*encountered infrequently: toadflax, potentilla, knapweed, chickweed, mullin						
B	Sedge	*Carex sp.*	8	0	0	0	0
	Moss	unknown	0	0	0	4	0
C	Cheatgrass	*Bromus tectorum.*	NA	2	0	0	0
	Moss	unknown	0	0	0	4	0
D	Sedge	*Carex sp.*	22	0	0	0	0
	Black Medic	*Medicago lupulina*	5	2	54	18	38
	Sweet Clover	*Melilotus albus*	0	0	76	52	198
	Moss	unknown	0	0	0	18	0
	*encountered infrequently: knapweed, lambsquarter						
E	Sedge	*Carex sp.*	2	0	0	0	0
	Sweet Clover	*Melilotus albus*	0	0	10	2	6
	Moss	unknown	0	0	0	26	0
F	Sedge	*Carex sp.*	10	1	0	0	0
	Black Medic	*Medicago lupulina*	0	19	0	0	0
	Sweet Clover	*Melilotus albus*	0	0	276	22	0
	Moss	unknown	0	0	0	24	0
G	Sedge	*Carex sp.*	27	4	0	0	0
	Black Medic	*Medicago lupulina*	0	19	0	4	0
	Moss	unknown	0	0	0	0	0
	*encountered infrequently: horsetail, black clover, common tansy						
H	Sedge	*Carex sp.*	7	0	0	0	0
	Black Medic	*Medicago lupulina*	0	0	6	0	0
	Sweet Clover	*Melilotus albus*	0	0	348	698	102
	Moss	unknown	0	0	0	40	0
	*encountered infrequently: red clover, prickly lettuce, maple						
I	Sedge	*Carex sp.*	14	0	0	0	0
	*encountered infrequently: moss, knapweed						
J	Sedge	*Carex sp.*	24	0	0	0	0
	Spotted Knapweed	*Centaurea maculosa*	0	0	42	39	90
	Sweet Clover	*Melilotus albus*	0	0	68	98	96
	*encountered infrequently: red clover, lotus clover, oxeye daisy, sweet clover						

Several mechanisms have been proposed to explain the relationship between high nutrient availability and low species diversity. Once nutrient limitations are removed, diversity is believed to be controlled by competition for light as a result of dense above-ground biomass, as well as above- and below-ground competition between neighboring roots and shoots (Wilson and Tilman, 1991; Rajaniemi, 2002; Baer et al., 2003). Thus, it appears that high levels of available nitrogen provide robust grasses such as wheatgrass and bromes with a competitive advantage relative to other vegetation. This has the desirable outcome of promoting high plant coverage while also controlling invasive unseeded vegetation, but at a cost of low species diversity (essentially producing a monoculture).

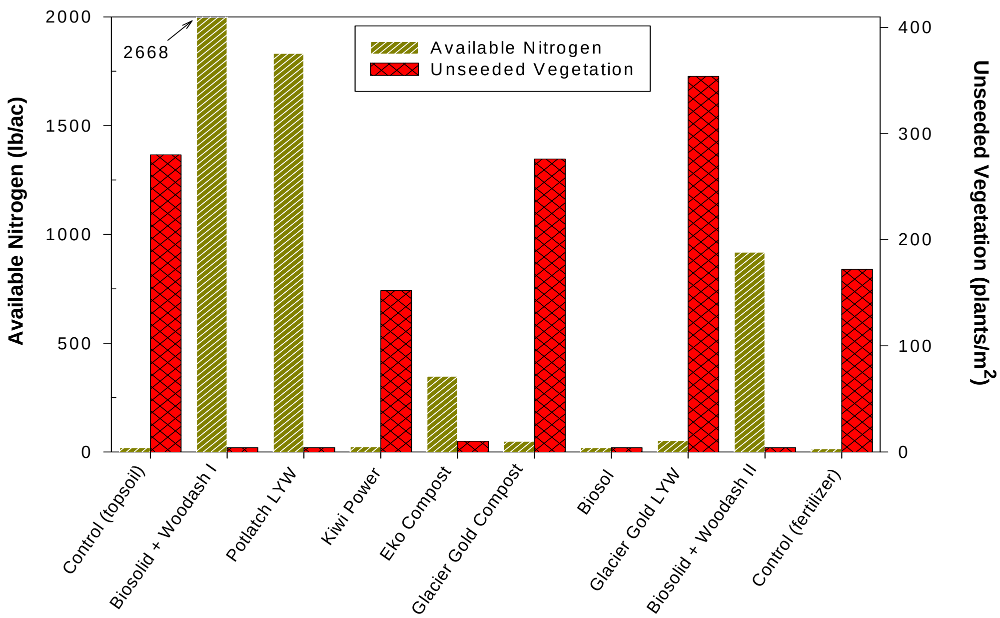

Figure 9. The relationship between available nitrogen and density of unseeded vegetation.

Generalized Vegetative Profiles

The plot assessments suggest that the plant growth tended to fall into one of two generalized vegetative profiles, and the specific profile appears to be selected by the nature of the amendment. In particular, available nitrogen appears to be a key variable in determining the vegetative profile and dominant characteristics of each plot. Although this categorization grossly oversimplifies the very complex nature of plot assessment, it is worthwhile as a beginning step in understanding the interrelationships between vegetation in response to the properties of the growth media:

Profile #1: Higher Plant Coverage/Lower Plant Density

- associated with higher fertility amendments; available N generally >100 lb/ac
- coverage generally > 75%, density generally < 450 plants/m^2
- characterized by large robust vegetation and very full canopies

- lower diversity, dominated by grasses, low density of weeds
- e.g. Biosolid/Wood Ash, Eko Compost, Potlatch Log Yard Waste (urea amended)

Profile #2: Lower Plant Coverage/Higher Plant Density:

- associated with lower fertility amendments; available N generally <100 lb/ac
- coverage generally <75%, density generally >450 plants/ m^2
- characterized by small thrifty vegetation and sparse and open canopies
- higher species diversity, but also greater density of weeds
- e.g. Kiwi Power, Biosol, Glacier Gold Compost and Log Yard Waste

Cost Evaluation

Costs for the demonstration plots were broken down as follows:

- cost of the amendment or treatment material
- cost of hauling the material to the site
- cost of placing or installing the material
- cost of seed
- cost of placing the seed

This information was obtained directly from the vendors, or vendor's invoices, and from subcontractors working at the site. Given the diverse nature of the amendments and treatments, not all of the above can be uniformly applied to each plot. Additionally, in some cases, assumptions were made using the best available information (i.e. topsoil costs, hauling costs). These cost data are expressed as total cost per 2000 ft^2 plot and also extrapolated to cost per acre (Table 6).

Actual costs ranged from $5276 per acre for the Fertilizer Control plot to $41,899 per acre for the Potlatch Log Yard Waste + Fertilizer plot. The remaining plots ranged from $9447 (Biosol) to $15, 637 (Glacier Gold Compost). Seed costs were a constant $15.46 for each plot and hydroseeding costs were also fairly consistent ($175). Note that seed placement costs for Kiwi Power and Biosol were factored into the material placement costs. Another exception was the Eko Compost plot, which was hand-seeded by the vendor. It is assumed that under a more typical (project-level) scenerio, the Eko amendment would also undergo standard hydroseeding resulting in a higher seeding cost than is listed in Table 6.

Price of the amendment material plus cost to place the material represented the majority of overall amendment cost, exceeding 60% of the total cost in all cases and over 90% in the Potlatch, Kiwi Power, Eko Compost, and Biosol plots. A wide range in material costs is evident in Table 7. The highest material cost ($1687 per plot) belongs to the Potlatch plot. This very high material cost is due primarily to the mixing of urea fertilizer with the log yard waste at a rate of 10% by volume. This rate is significantly above accepted agronomic nitrogen rates and much higher than necessary to offset nitrogen immobilization by the high carbon organics. Hence, it is likely that this amendment cost could be decreased significantly by a lower fertilizer addition, although the costs of debris processing and hauling would still be significant. Although the Coeur d'Alene Waste Water Treatment Plant does not charge for biosolids, transportation of this material to the site is a significant cost (assumed to be $9 per yard in Table 6). With fuel costs continuing to rise, it stands to reason that hauling costs will remain a significant factor for solids-based amendments like biosolids, composts, and log yard waste. In contrast, transportation costs are minimized for liquid-based amendments (i.e. Kiwi Power and Biosol) as these materials are hauled in a concentrated dry formulation and mixed with water on-site.

It was recognized that the data listed in Table 6 do not account for several factors that would impact the true costs of each treatment for future work at project-level. Table 7 lists adjusted treatment costs in an effort to normalize these factors and provide an equitable comparison of treatment alternatives.

As mentioned above, cost of seed placement should be considered in evaluation of the Eko Compost plot. For this reason, this cost has been adjusted upward to account for the cost of hydroseeding (Table 7). The cost of the Biosol treatment was adjusted downward slightly to reflect the cost of straw mulch recommended by the vendor. The cost for both Glacier Gold products (compost and log yard waste) was adjusted downward to account for reduced placement labor if the material was shipped in open trucks instead of the Super Sacs. And, as already discussed, the cost for the Potlatch Log Yard Waste could be reduced by decreasing the amount of urea fertilizer added.

The adjusted cost data show a range of $5276 per acre (Fertilizer Control) to $31,706 per acre for the Potlatch plot. Of the remaining treatments, three (Biosol, Glacier Gold Log Yard Waste, and Kiwi Power) are below $10,000 per acre and all (except the Topsoil Contro and Potlatch Log Yard Wastel) are below $15,000 per acre. This last point bears emphasis since topsoil placement is a very typical approach to revegetation of mine-impacted sites. As the results clearly show, there are many treatment options that promote a sustainable plant cover at a lower cost than topsoil placement.

It should be noted that, while the cost data are specific this study, they do provide a useful means to compare treatment alternatives. However, additional factors, including vegetative performance, nutrient dynamics and runoff, and long-term sustainability must be considered for any revegetation or reclamation project. Additionally, costs are continually changing and up-to-date numbers will be critical when evaluating each treatment alternative in the future.

Table 6. Actual cost of amendment materials and seeding for each demonstration plot.

Amendment	Material Used	Material Cost	Material Placement Time	Material Placement Cost	Seed Placement Time & Materials	Seed Placement Cost	Total Cost Per Plot	Total Cost Per Acre	Notes
Control (topsoil)	40 yd^3	$400.00	1 h	$80.00	3 bags mulch 1 h hydroseeder	$204.85	$700.31	$15,253	Assumed $10/ yd^3 topsoil cost
Biosolid + Woodash I	26 yd^3	$234.00	0.75 h	$60.00	3 bags mulch 1 h hydroseeder	$204.85	$513.75	$11,190	Assumed $9/ yd^3 hauling cost from CDA; no cost for material from vendor (if material is available)
Potlatch Log Yard Waste	48 yd^3	$1,687.20	0.75 h	$60.00	3 bags mulch 1 h hydroseeder	$204.85	$1,967.51	$42,852	Material cost includes debris processing: $3.15/$yd^3$, urea fertilizer: $19.50/$yd^3$, and hauling cost from St. Maries: $12.50 yd^3
Kiwi Power	0.25 gal Kiwi Power 200 lb Fertil-Fibers	$87.34	2 h (hydroseeder)	$350.00	NA (in material placement cost)	NA	$452.80	$9,862	None
Eko Compost	20 yd^3	$360.00	1.25 h	$100.00	NA (hand placement by vendor)	NA	$475.46	$10,356	No seed placement cost since vendor applied by hand; if applied by hydroseeder (1 h), representative costs would be $650.48 per plot or $14,167 per acre
Glacier Gold Compost	20 yd^3	$280.00	2.25 h	$248.00	1 h hydroseeder	$175.00	$717.96	$15,637	Placement cost includes 1.5 h to unload Super Sacs; representative cost without Super Sacs would be $530.46 per plot or $11,553 per acre
Biosol	83 lb Biosol 5 lb mulch	$68.28	2 h (hydroseeder)	$350.00	NA (in material placement cost)	NA	$433.74	$9,447	None
Glacier Gold Log Yard Waste	20 yd^3	$180.00	2.25 h	$248.00	1 h hydroseeder	$175.00	$617.96	$13,459	Placement cost includes 1.5 h to unload Super Sacs; representative cost without Super Sacs would be $430.46 per plot or $9375 per acre
Biosolid + Woodash II	26 yd^3	$234.00	1.5 h	$120.00	3 bags mulch 1 h hydroseeder	$204.85	$574.31	$12,508	Assumed $9/$yd^3$ hauling cost from CDA; Note: greater material placement time since these biosolids were wetter and more difficult to spread
Control (fertilizer)	50 lb fertilizer	NA	NA	NA	4 bags mulch 1 bag fertilizer 1 h hydroseeder	$226.26	$242.26	$5,276	None

General Notes:
1. Plot size: 20 X 100 ft or 2000 ft^2
2. Seed cost: $15.46 per plot or $336.76 per acre
3. Unit costs: D5 Dozer $50/h; backhoe/tractor $30/h; Operator $30/h; Superintendent $65/h; hydroseeder $175/h
4. Place ment of material was by D5 Dozer and Operator unless otherwise noted
5. Cost/acre data represent actual 'as-placed' costs and are not normalized

Table 7. Cost per acre for each amendment (adjusted where applicable).

Amendment	**Total Cost Per Acre**	**Cost Adjustment**
Control (topsoil)	$15,253	none
Biosolid + Woodash I	$11,190	none
Potlatch Log Yard Waste	$31,706	Cost reduced to reflect 50% less fertilizer
Kiwi Power	$9,862	none
Eko Compost	$14,167	Cost increased to reflect the cost of hydroseeding
Glacier Gold Compost	$11,553	Cost reduced to represent labor savings if material shipped in trucks instead of Super Sacs
Biosol	$9,261	Cost reduced to reflect the cost of straw recommended by vendor
Glacier Gold Log Yard Waste	$9,375	Cost reduced to represent labor savings if material shipped in trucks instead of Super Sacs
Biosolid + Woodash II	$12,508	none
Control (fertilizer)	$5,276	none

CONCLUSIONS AND RECOMMENDATIONS

The overall goal of this study was to identify alternatives to topsoil that are suitable for reclamation and revegetation of waste rock piles and other disturbed sites in the Coeur d'Alene Mining District. This goal was achieved by each of eight treatments (in addition to the two controls) as each plot was successful in establishing plant cover during the first growing season and sustaining this cover throughout the five-year study. In addition, each amendment resulted in significant improvements in soil fertility parameters and soil physical properties.

The fertility status of each amendment had a strong impact on the type of cover produced. More specifically, available nitrogen was a critical factor in determining the species distribution and incidence of unseeded vegetation. For example, high nitrogen amendments promoted a grass-dominated cover with low numbers of forbs. Wheatgrass was the dominant species in these plots during Years 1 and 2 but a more equal distribution of wheatgrass, bromes, fescues, and bluegrass was observed in Years 3-5. Throughout the study, these plots had the highest plant coverage and maintained very robust and thick grass growth. These characteristics were successful in preventing the establishment and spread of invasive weed species. In contrast, amendments with lower available nitrogen promoted a more diverse grass-forb mixture. No single grass species was dominant; instead a variety of grasses was intermixed with white yarrow, white clover, and cicer milkvetch. These plots had lower plant coverage and more patchy plant growth. Consequently, a higher incidence of invasive weed species (including black medic, knapweed, and yellow sweet clover) was observed.

The fertility status of each plot also had a strong impact on the nutrient content of the surface runoff. As would be expected, amendments associated with high available nitrogen and phosphorus also exhibited high N and P concentrations in the runoff. Although runoff nutrient levels decreased substantially by Year 5, phosphorus concentrations exceeded EPA criteria for surface water quality in several early samplings. Erosion was minimal to non-existent during the study. A minor amount of sediment was observed in the erosion traps of several plots during Year 1 and small to medium rills were present. However, additional evidence of erosion was not observed during Years 2-5.

This study has shown that each treatment is capable of promoting rapid plant establishment and growth and, in this respect, each is quite suitable for meeting future project goals such as establishing a vegetative barrier, controlling erosion, and improving aesthetics of disturbed sites. In addition to vegetative success, other criteria will be equally important in selecting an approach to a future revegetation problem. Each amendment has specific advantages and, in some cases, disadvantages, with respect to initial nutrient availability, the ability to promote long-term nutrient retention and nutrient cycling, and enhancing soil physical properties such as water holding capacity and overall tilth. In addition, each revegetation project will pose its own set of unique challenges, including the presence of contaminants, low fertility, poor seed bed characteristics, steep slopes, and other access limitations. In some cases, the method of application will be a major consideration. Many reclamation projects are located in remote sites with very limited access. Long hauling distances and the difficulties associated with spreading solid materials, versus application of amendments via hydroseeding, could be an important consideration in selecting a treatment. Cost is a critical factor and this study provides the basis to compare relative plot performance to treatment cost, and also provides several options to reduce costs. Furthermore, in all but one case, the cost of the treatment alternatives was lower than the standard topsoil placement approach.

The overall revegation objective should be carefully considered when evaluating treatment alternatives. If a thick, grass-dominated, low weed system is the primary objective, a high nitrogen amendment must be considered. But, care should be taken in avoiding excessive nutrient addition for the sake of controlling surface runoff quality. If a more diverse mixture of grasses and forbs is sought, a lower available nitrogen amendment might be more suitable. However, this can result in a patchy, more open vegetative cover that is susceptible to invasive weeds.

This study answered many questions and provided a unique opportunity to compare eight alternatives to topsoil placement in revegetation projects. Despite the large amount of information contained in this report, there are several questions left unanswered. It is recommended that attempts be made to answer these questions, either by additional field studies or through use of other reports, as part of the evaluation process for future revegetation projects:

1. How would these treatments perform on a metals-impacted site? Some evidence suggests that organic amendments can mobilize heavy metals and facilitate both phytotoxicity and leaching. Other studies have shown that organic materials, particularly humic acids, can immobilize heavy metals.
2. How would these treatments perform under lower amendment rates? Optimization work is needed to identify the minimum rate necessary achieve acceptable performance. This will reduce the overall treatment costs and also minimize nutrient runoff.
3. Should the seed mix be blended to match the fertility status of the amendment? As the results clearly show, some seed components did not grow in the high fertility plots whereas a more diverse plant cover grew on the lower fertility amendments. It might be possible to reduce seed costs by omitting species unlikely to grow on a given amendment.
4. Will the characteristics of the plots continue to change? Previous reports suggest this will be the case. It would be worthwhile to conduct low-cost monitoring of the plots on a periodic (i.e. 3-5 y) basis in an effort to collect longer-term performance results.

As a final thought, it should be clearly stated that the goal of this study was not to select winners and losers. Instead, the objective was to develop a set of tools that can be used for future revegetation projects. This was done using side-by-side, ‘apples-to-apples’ comparisons under ‘real world’ conditions in order to identify the beneficial characteristics of each treatment alternative. It will be the task of future project managers to select the alternative that best addresses the unique challenges of their respective revegetation project.

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TEST PLOT DESIGN TO EVALUATE ORGANIC AMENDMENTS AND PLANTING DENSITIES ON OVERBURDEN MINESOILS AT A LIMESTONE QUARRY IN TIJERAS, NM

Kenneth E. Carlson and Wayne R. Erickson

Habitat Management, Inc.
Englewood, CO 80112

ABSTRACT

The goal of this study was to identify and evaluate specific methods and practices having the potential to enhance reclamation efforts on redbed geologic materials used in lieu of salvaged topsoil for soil growth medium reconstruction at GCC Rio Grande, Inc's Tijeras Cement Plant and Limestone Quarry located in Tijeras, New Mexico. Specifically, the test plots investigate two primary variables that can be controlled during the reclamation process, organic soil amendments of 0 tons/acre (control), 2 tons/acre (hay mulch), 20 and 30 tons/acre (manure) and seeding/planting density of 5, 10 and 20 pls/square foot. These variables have the potential to significantly affect vegetation stand characteristics including vegetative cover, species diversity and shrub density within the reclaimed area. Construction of the test plots, located between 6,400 and 6,525 feet in elevation, began in May 2003 utilizing standard mining equipment. Seeding and shrub seedling transplanting was completed in January 2004, monitoring is on-going.

INTRODUCTION

Permit No. BE001RE conditions requires Rio Grande Portland Cement Corporation's (RGPC) Tijeras Cement and Limestone Quarry (the quarry), located in Tijeras, New Mexico, to develop and implement a reclamation test plot study. Primary objectives of the test plot study are to identify and evaluate various top dressing materials, soil amendment methods and reclamation practices having the potential to improve and enhance future reclamation efforts at the quarry. The proposed reclamation test plot study plan was submitted to the New Mexico Mining Act Reclamation Bureau (MARB) on June 30, 1999 and was approved on November 20, 2002. This report discusses the plot study design, construction and revegetation.

RGPC contracted Habitat Management, Inc. to assist with development of the test plot study design, construct the test plots and to conduct annual field monitoring. To ensure that the test plot study is responsive to site-specific needs and consistent with the reclamation process required by the permit, RGPC personnel and Habitat Management, Inc. reviewed the permit and conducted site inspections to evaluate quarry environmental and ground conditions.

Because no topsoil was salvaged during previous mining activities that occurred between the early 1950's and 1995, redbed interburden material was evaluated for suitability as a topdressing soil material. The test plots will investigate two reclamation variables and the potential for revegetation of the site. The test plots will evaluate the following primary treatments:

1. Organic amendment (Santa Fe Downs manure wastes) applied at two rates (20 and 30 tons per acre), native hay mulch applied at a rate of 2 tons per acre, and untreated or bare (no organic amendments or mulch);

2. Three broadcast seeding rates (5, 10, and 20 pure live seeds per square foot) to evaluate expression of seed mixture diversity and while concurrently providing adequate vegetation cover for enhancing site stability; and

3. Transplanting 12 woody plant species to evaluate their establishment and growth potential.

The test plot study was constructed in 2003 and revegetated in January 2004 and was projected to run for a monitoring period of 5 to 7 years depending on the annual precipitation received during the study period. If normal or wetter conditions prevailed during the initial germination and establishment period it was anticipated that the study would be performed over a 5 year period. If drier conditions prevailed and plant establishment was adversely impacted, the study could be extended to allow adequate time to evaluate the treatments used on the various plots. After four years, the test plots are well established and Habitat Management and RGPC will evaluate in 2008 if additional monitoring will be required to ensure that fair and unbiased evaluation of treatments is realized.

During the monitoring period, seedling germination, establishment and growth; cover; productivity; and woody stem density (including woody species established from the seed mixture and volunteer species) will be observed. Additionally, transplanted woody species will be evaluated for mortality and plant growth. Interim vegetation monitoring results are presented in another paper in this volume (Bay, Erickson, and Carlson 2008). At the end of the test plot period, soil pedologic development, organic matter accumulation and fertility will be monitored. Ultimately, data collected from the test plots will be used to evaluate the effectiveness of the different reclamation variables and treatments tested. RGPC anticipates using substantiated results to formulate practices and methods for the successful rehabilitation of mined lands at the quarry.

SITE EVALUATION

Potential test plot site evaluations were performed February 5, 1999 and May 2-3, 1999. RGPC indicated that previously mined Areas B and C were best suited operationally for test plot purposes. We also completed a general tour of the quarry operations as labor, equipment and materials for test plots and future reclamation work will depend in part upon ongoing operations.

At the February site evaluation we compiled a list of identifiable plant species present on the mine area, inventoried soil conditions and characteristics, observed runoff and erosion patterns, and discussed any other physical site conditions that could potentially affect reclamation processes and success.

During the May 1999 site visit, Habitat Management collected composite highwall redbed interburden samples. These soil samples to be analyzed for selected topdressing suitability parameters. Information obtained during these site evaluations and from soil laboratory analyses have been evaluated and considered in development of the test plot study.

Vegetation

Vegetation was dormant at the time of the February site evaluation limiting the number of identifiable species. Dormancy conditions also made it more difficult to assess plant health and vigor. Nonetheless, about thirty species of plants were observed at the quarry during this evaluation (Table 1). The surface disturbance condition of lands where plants were observed included disturbed, reclaimed and undisturbed.

Table 1: Plant Species Observed During the February 1999 Site Visit

Species	**Common Name**
Agropyron cristatum	Crested wheatgrass
Agropyron smithii	Western wheatgrass
Agropyron spicatum	Bluebunch wheatgrass
Androgopgon hallii	Turkeyfoot
Aristida spp.	Three-awn
Bouteloua curtipendula	Side-oats grama
Bouteloua gracilis	Blue grama
Chrysothamnus nauseousus	Rubber rabbitbrush
Chrysothamnus viscidiflorus	Green rabbitbrush
Cowania neomexicana	New Mexico cliffrose
Elmus spp.	Chinese Elm (associated with impounded water)
Festucua spp.	Fescue
Guiterrezia sarothrae	Broom snakeweed
Hilaria jamesii	Galleta
Juniperus utahensis	Utah juniper
Oryzopsis hymennoides	Indian Ricegrass
Pinus edulis	Pinyon pine
Pinus ponderosa	Ponderosa pine
Poa spp.	Bluegrass
Quercus spp.	Oakbrush
Rosa woodsii	Wood’s Rose
Sarcobatus vermiculatus	Greasewood
Yucca glauca	Spanish bayonet

Volunteer vegetation within Area C showed evidence of reasonable growth and generally good vitality on the interbed redbed material. The plants in this area appeared to be growing and developing normally. Also, ponderosa pines (*Pinus ponderosa*) transplanted in this area several years ago, had established and appeared to be developing normally.

In Area B the plants also showed reasonable growth and development patterns where soil stability was adequate to allow seedling germination and establishment. However, excessive sheet and concentrated flow erosion has severely impacted the establishment and growth of vegetation across most of Area B. Run-on of surface water runoff from the undisturbed area above this location appears to contribute significantly to this instability. It is important to note that the site has not been reclaimed and is still scheduled for mining, with quarrying having only been temporarily ceased. Our conclusions regarding this erosion are based upon the visible characteristics of surface water flow erosion noted on the surface soil materials in Area B and the degree to which volunteer plant life has established itself during the current temporary cessation of mining activity. Site observations indicate that the redbed material is suitable for use as a plant growth medium as long as erosion is adequately controlled.

Soils

Both potential test plot sites (Areas B and C) have been quarried in the past. Soil material remaining on the surface in Area B was an in-situ redbed stratum located immediately below the quarried limestone.

The Area B site is approximately 1 acre in size with an east aspect. The site is immediately down gradient from an area of large maverick blocks of limestone that may be fragmented and removed in the future. Above the Area B disturbance lies an undisturbed site that drains from the ridgeline. The in-situ redbed material had limited vegetative cover with evidence of sheet, rill and gully erosion. Given Area B's limited size, the potential for equipment traffic, and the potential rock debris generated by maverick block removal operations, this site had minimal usefulness for long-term reclamation studies.

Area C is approximately 17.6 acres in size with a north-facing aspect and approximately 5h:1v slopes with a range of elevation between 6,400 and 6,525 feet. The in-situ redbed material on the lower 2/3 of the site had higher vegetative cover and less evidence of sheet, rill and gully erosion than Area B. In addition to vegetative and litter cover, the surface also had a rock mulch cover of approximately 20%. The upper 1/3 of the site was terraced in-place redbed material. This portion of Area C had visibly greater vegetation cover on the terrace benches than on its 3h:1v terrace outslopes. Rock mulch cover was less in this upper area, than the lower 2/3 of Area C. There is a small amount of watershed above the disturbed area that has the potential to drain across the site. The access road traversing this ridge diverts some of this surface runoff away from the test plot study area. Diversion of the remaining overland flow away from Area C could be accomplished relatively easily. Therefore, Area C was the recommended location for the test plot study.

Soil Sampling Procedures

In-situ redbed material and highwall sampling was conducted May 2-3, 1999 on the three potential test plot areas: 1) Area B; 2) Lower 2/3 of Area C; and 3) Upper 1/3 of Area C. We also sampled the redbed borrow area highwall which was proposed for use during the next 5-10 years of soil reconstruction activities associated with reclamation at the quarry.

A total of two composited samples were taken from each of the three test plot sample areas for a total of six samples (Area B, Area C-lower and Area C-upper). Sampling areas were determined by similarities in location, substrate, vegetation and management inputs and their boundaries were identified on a 1" = 200' map. Each sampling area was divided into five sub-areas of approximately equal surface area. A sample site within each of the five sub-areas was located and staked in the field. Each sample's approximate location was mapped. Each sub-sample was collected from an area representing the average conditions for that particular sub-area. Vegetation cover, soil color, soil texture, and erosional features were observed and recorded for each sub-sample location. Depth specific samples were collected from within each of the five sub-areas. One composited sample interval was taken from 0-12" in depth and another composted sample taken from 12-24" in depth. Excavated soil materials from each of the five sub-area samples were separated by their respective depth intervals and placed in one of two 5-gallon plastic buckets for compositing. The soil samples in each bucket were mixed thoroughly and transferred to a large plastic bag. Each sample consisted of approximately 2 kg of soil. The soil samples were split in the lab and retained for subsequent secondary additional analysis, if needed.

To collect typical redbed material samples from the highwall at the potential borrow area, a sampling area was selected that visually represented the average conditions of the borrow area. The redbed material texture, color, depth and amount of concretions or cementation were taken into account. Safe access to the highwall for sampling also influenced selection of the sampling site. A 17-ft vertical length of highwall was selected within the redbed material borrow area. A 2-ft wide section of highwall along the selected vertical transect was cleaned and lithologic units were identified. Sufficient weathered material was removed to get a clean sample face. Sampling was initiated at the bottom of the selected vertical sampling line to prevent contamination of the sampling face. A similarly sized volume of sample was retrieved along each foot of the sampling face to allow for unbiased sample compositing. Color, texture and other physical parameters were used to identify four lithologic units with similar visual and physical characteristics at various depths. Because the redbed will be mixed by the borrow operation, the four redbed samples taken for laboratory analyses from the highwall were composited by depth and their respective depth intervals below ground level. Percentage of sample composited for each interval was weighted by the depth of their respective lithologic units (i.e. 0-3' at 17.6%; 3.0'-6.6' at 21.2%; 6.6'-11.2' at 27.1%; and 11.2'-17.0' at 34.1%). Composited samples were mixed and bagged as described above and sent to the laboratory for analyses.

Soil Analysis procedures

All soil samples were sent to Soils Analytical Services, Inc. in College Station, TX to be analyzed for pH and electrical conductivity (Saturated Paste Extract); calcium, magnesium and sodium (Saturated Paste Extract) to determine Sodium Absorption Ratio (Calculated); texture and texture class; sand fraction analysis; calcium carbonate %; and nitrate nitrogen. The New Mexico Mining and Mineral Division's ("MMD") Overburden and Soils Inventory and Handling Guidelines also require additional suitability parameters to be analyzed: saturation %, % coarse fragments, erosion factor K, acid-base potential, boron, total selenium, and water soluble selenium.

Plant available phosphorous, plant available potassium, and total organic carbon were also analyzed to further define redbed fertility and organic content. This information was useful in identifying and assisting in the formulation of potential soil amendments that were required for the test plot study. Additionally, these analyses assisted in the development of more accurate cost estimates for any necessary fertilizers and organic amendments.

Soil Testing Results

The results for soil analyses demonstrate that MMD Overburden and Soils Inventory and Handling Guideline parameter requirements for soil suitability were met by all samples with ratings of "good" for tested chemical parameters. Parameters of particular concern, including EC, SAR, Selenium, Boron and Acidity, fell well within acceptable ranges of suitability for all but one sample. A pH value of 8.8 from the 12-24" depth interval at one site fell within the "marginal" category for use as topdressing. The 0-12" depth of this same composited sample was rated with "good" suitability for pH. Mixing anticipated during redbed recovery and soil reconstruction should ameliorate these marginal pH levels and lower them to more suitable ranges. Therefore, soil pH is not expected to be a problem in the test plot study area.

The K-factor results from the highwall composite samples rate the redbed material as "marginal". Signs of erosion noted during site survey support this rating. However, areas with gravel mulch and good vegetative cover in Area C exhibited few indications of active or excessive erosion. The quarry's current permit requires the placement of gravel mulch at various concentrations with redbed topdressing on reclaimed slopes that are 5h:1v or steeper to ensure their stability.

The site conditions and soil analytical results suggested that test plot evaluations should primarily consider methods or practices that improve redbed topdressing fertility, while simultaneously contributing to soil stability if possible. We also determined that the test plot study should evaluate physical or other site modifications capable of harvesting precipitation, increasing infiltration, reducing surface water runoff volumes or increasing the time of runoff concentration.

Surface Water Runoff and Erosion Control

Because the redbed materials proposed for use as a plant growth medium were susceptible to erosion from concentrated surface flow and were essentially devoid of organic material it was important that care be exercised to ensure that the reclamation test plots were adequately protected against excessive erosion. Concentrated flows had to be routed through reclamation areas in suitably protected channels and potentially disruptive overland flow from areas above the test plot study area were diverted as necessary.

The redbed materials had a good infiltration rate, therefore, sheet erosion was not of great concern except where excessively long reclaimed slope lengths were created. It was important to control sheet erosion and surface drainage from adjacent areas that had the potential to adversely affect test plot integrity. Therefore, it was recommended that gradient terraces, fascines or erosion blanket vegetative filters be provided, either singly or in combination, to control such erosion and runoff within the test plot study area. These types of surface structures have demonstrated their adequacy to control excessive erosion and runoff on other reclaimed areas in New Mexico.

Based on site inspection observations and soil analytical results, it was concluded that preparing a stable, suitable plant growth medium was the most important goal for quarry reclamation. Providing a fertile, stable growth medium for the germination, establishment and normal growth of plant species adapted to the area is critical to establishing revegetation capable of supporting the designated postmining land uses and meeting revegetation success standards. Therefore, the test plot study focused on methods, practices and techniques that will serve to improve the fertility, suitability and stability of the redbed material as a plant growth medium.

Organic Amendment Evaluation

The Downs of Santa Fe horse racing facility was operated from the early 1970's until 1997. During that time, stable waste (horse manure, straw and some trash) was stockpiled west of the track and grandstand. In January 2003 Habitat Management obtained continuous core samples from five selected locations across the top of the capped manure pile to evaluate its suitability for organic amendment on the test plots. Samples from five depths (0-260", 0-120", 0-220, 0-282", and 0-240") were sent to ServiTech soils testing laboratory to be analyzed for reclamation suitability criteria.

The coring and analytical results revealed several potential concerns regarding the effective use of the manure at the quarry including weed seed contamination, trash and debris content, and transportation. Test plot design requires that weed-free materials be used in their construction in order to protect the integrity of the plots and minimize variable inputs potentially affecting study outcome. Thus, viable seed testing in the manure was performed. Because the soil cap currently supports vegetation, this testing was vertical profile sensitive to determine the potential for differential handling of the manure. The presence of noxious or targeted weed species would have most likely precluded the use of this manure. However, results of testing suggested that no viable seed were present.

Coring activities encountered a variety of stable trash that had apparently been periodically disposed of during manure stockpiling including feed bags/sacks and wire or cord baling materials. Due to the concentrated, limited distribution of these materials throughout the stockpiled manure, laborers from the

Pohoaque Pueblo were used to remove, collect and bag the material as it was encountered during truck loading operations.

Trucking bids were obtained for the transportation of organic amendment from Santa Fe Downs to the quarry and the Pojoaque Pueblo managed necessary transportation services and shared the cost of transportation with RGPC. Based on our evaluation the volume of the stockpile was between 65,000 and 70,000 yards^3. Only 5,000 yards^3 were required for 2003 reclamation; however, should the organic amendment prove to be essential in the quarry reclamation process, RGPC will be interested in procuring adequate quantities of this material to support its long term reclamation needs over the next 50 years.

TEST PLOT DESIGN AND LAYOUT

After evaluation of all the data, the revegetation test plot study area was located in Area C (Figure 1). Several factors contributed to the final decision. The watershed area above the test plots was relatively small and it could be readily diverted and controlled. The north aspect of Area C is similar to the majority of the lands currently disturbed or scheduled to be disturbed at the quarry and the slopes are characteristic of those expected in the postmining topography at the quarry. The test plot elevation covers a fairly central range within the permitted quarry and no further quarry disturbance is scheduled for this area. Finally, access to the base of the proposed test plot site already exists and is maintained by the quarry in support of its ongoing operations.

The environmental characteristics and location of the test plots will serve to ensure that the results of the study are universally applicable to the quarry to the extent this is physically possible. Although the test plot area does not contain all elevations, slopes and aspects potentially occurring on the site, the reclamation treatments evaluated by the study are expected to perform satisfactorily within the full range of quarry conditions. As future reclamation proceeds, reclamation methods and treatments may be modified as necessary to meet the unique characteristics of quarry areas whose characteristics differ significantly from test plot conditions.

Test Plot Layout

Each test plot was constructed and reclaimed using the same methods, practices and amendment applications, with the only variables being the type and amount of organic amendment, or pure live seed (PLS) application rates. The test plot design includes three repetitions of all 16 treatment combinations, a full factorial design. To facilitate cost effective construction of field test plots, the levels of one factor, organic amendment, were applied to the rows of a rectangular layout, while the levels of the other treatment, seeding rate, were applied to the columns of the layout. This is known as a strip plot experimental design (Milliken and Johnson 1984). The row sequence (across the hill) of the 4 seeding/tranplanting application rates was randomly varied within each of the 3 replications to avoid/minimize statistical bias in the study. The organic treatments assigned to the test plot columns have also been randomly varied. This plot configuration facilitates treatment plot construction by taking into consideration heavy equipment usage and limitations. The test plot study area was divided into 48 plots that are about 0.09 acres (50 feet x 75 feet) in size (Figure 1). The test plots were further divided into 3 replications of 16 plots that are of similar size and shape. Each of the replications received the 16 different treatment combinations of seed rate and organic matter. To the extent practicable, test plot replication blocks were arranged within the test plot area so that they are aligned vertically with and horizontally across the prevailing slope (i.e., 4 vertical and 4 horizontal treatment strips that are perpendicular to one another and aligned up and down, and across the slope).

Figure 1: Tijeras Limestone Quarry Vegetation Test Plots Location and Layout

Seeding Rates

Traditional revegetation practices have been developed to a large degree from agricultural experience on croplands and from limited rangeland improvement plantings conducted by various government agencies on overgrazed or historically under-managed public lands in the western United Sates. Revegetation practices adopted by the coal mining industry immediately following the passage of SMCRA (1977) depended heavily upon these sectors to provide the expertise needed to meet the newly established standards for revegetation efforts. A critical component in early coal mine reclamation was the rapid establishment of vegetative cover designed to reduce sediment pond size and maintenance requirements. The need for greater biological diversity in reclamation plantings designed to restore wildlife habitat and rangelands has been increasingly recognized and promoted in the last decade. However, the literature documenting the success of non-traditional agricultural plantings has lagged behind the revegetation practices and methods being developed to provide increased floral diversity on reclaimed lands.

In the reclamation of arid and semi-arid lands, the goal of establishing of diversity appears dependent upon broadcasting one or more seed mixtures containing greater species diversity at lower application rates. This is contrary to traditional reclamation and rehabilitation seeding literature, which provides sound revegetation advice when efforts are geared towards the enhancement of only a few selected species. It has not adapted itself to the diversity challenge now posed by newer reclamation pressures and requirements for western rangelands.

To illustrate the need for modification of western rangeland revegetation practices it is useful to consider the most important life-limiting factor in the arid and semi-arid western United States, water. Soil moisture availability is the single most important element that affects germination, establishment and growth of diverse species seed mixtures. Competition for this water can be fierce and is often the factor that most influences the expression of seed mixture diversity. Seed application rates that are too dense suppress the expression of plant diversity that is designed into and can be realized from a multiple plant species mixture. Conversely, seed density application rates that are too low risk lengthy or inadequate development of plant density and may be more susceptible to the invasion of undesirable or weedy plant species. Also, entirely too often design of hydrologic control depends upon plant covers that are too high or do not consider the dramatic fluctuations in plant cover that can occur during drought periods in arid and semi-arid regions. Typically these designs use averages, rather than low values, for vegetation cover. Thus, placing increased emphasis on the development of thicker stands of rhizomatous grasses that smother species diversity. In the short-term, traditional high density cool-season plantings normally increase plant cover and root structure, adding stability to the soil, and improving soil moisture retention and subsequent plant use. Invariably in the long-term they eventually experience drought and die-back which can expose soil to significant erosion and permanently damage soil resources.

In reclaiming arid and semi-arid western rangelands the most important phase of reclamation planning is development of a stable postmining topography and the provision of adequate surface water drainage systems and controls. It is most important to provide an inherently stable landform. When suitable plant growth mediums are reconstructed on such landforms they can be expected to support the establishment of vigorous reclaimed plant communities. This can be accomplished by adjusting seed application rates to site-specific moisture availability conditions. The goal, which can be difficult, is to ensure that adequate plant cover is provided to assist with soil stabilization, while simultaneously encouraging optimum expression of seed mixture diversity during the germination and establishment period. For the reclamation test plot area care was taken to ensure that the topography was stable and that the potential for excessive erosion of soil by surface runoff was avoided or adequately controlled.

We proposed testing three seed application rates of the same seed mix (Table 2) that are significantly lower than traditionally recommended application rates for seed drilling or broadcasting. These rates are based upon observation of plant density at the site, expected germination failures and seedling mortality, and the physical characteristics of seeds typically included in arid and semi-arid rangeland revegetation seed mixtures. Mature vegetation communities on arid and semi-arid lands normally have five or fewer plants growing within one square foot. If desiccation, germination failure, wildlife seed consumption and seedling mortality can be expected to range between 50% to 75%, then PLS application rates between 5 and 20 PLS per square ft represent the range for plantings that approximate soil-water vegetation carrying capacity on a square foot basis. Thus, we proposed rates of 5, 10 and 20 PLS per square foot. A fourth test plot type seeded at the 20 PLS per square foot rate and was transplanted with selected woody species.

Obviously, the amount and timing of precipitation impacts the successful germination and establishment of revegetation plantings. Native western rangeland plants have developed various adaptations for ensuring their survival in low moisture conditions. Germination in many western plants is triggered by certain environmental or climatic conditions. These conditions may not occur every year. As a result, full germination of the seed contained in a diverse native plant seed mixture on arid and semi-arid land may take one or more years to occur. Native plant seed adapted to western arid and semi-arid regions may remain viable for many years (5+ years). It is important to allow adequate time for seed mixture germination and establishment before deciding that revegetation is a failure or substandard and initiating interseedings. Patience must be exercised in determining whether or not a specific revegetation seeding is a success or failure. Premature application of additional seed is a frequent mistake that can adversely impact diversity in western rangeland reclamation.

Table 2. Permanent Revegetation Seed Mixture

Species	Common Name	Desired Species %
Grasses		
Agropyron smithii	Western Wheatgrass: arriba	5
Agropyron spicatum	Bluebunch Wheatgrass: Secar	5
Andropogon hallii	Sand Bluestem	5
Bouteloua curtipendula	Sideoats grama: Butte	5
Bouteloua gracilis	Blue grama: S Native	5
Hilaria jamesii	Jame's Galletta	5
Oryzopsis hymenoides	Indian ricegrass	5
Sporobolus cryptandrus	Sand dropseed	5
Stipa neomexicana	New Mexican feathergrass	5
Grass Total (%, PLS/Acre, PLS Pounds/Acre, PLS/Foot2)		45.0
Forbs		
Achillea millifolium	White yarrow	3.5
Astragalus cicer	Cicer milkvetch:lutana CT	3.5
Gaillardia aristata	Indian blanket flower	3.5
Linum lewissii	Lewis (Blue) flax	3.5
Lupinus argenteus	Silver mountain lupine	3.5
Onobrychis viceafolia	Sainfoin: eski	3.5
Penstemon angustifolia	Narrow-leaf penstemon	3.5
Ratibida columnifera	Cone flower	3.5
Sphaeralcea coccinea	Scarlet Globemallow	3
Forb Total (%, PLS/Acre, PLS Pounds/Acre, PLS/Foot2)		31.0
Shrubs		
Atriplex canescens	Four-wing saltbush	3
Kraschenninikovia lanata	Winterfat	3
Cercocarpus montanus	Mountain mahogany	3
Chrysothamnus nauseosus	Rubber rabbitbrush (“RB”)	3
Chrysothamnus viscidiflorus	Yellow rabbitbrush (“RB”): Douglas	3
Cowania neomexicana	New Mexico cliffrose	3
Purshia tridentata	Antelope bitterbrush	3
Rosa woodsii	Wood's rose	3
Shrub Total (%, PLS/Acre, PLS Pounds/Acre, PLS/ Ft^2)		24
Seed Mixture Total (%, PLS/Acre, PLS Pounds/Acre, PLS/ Ft^2)		100.0

Vegetation was growing within most of Area C at the time of test plot construction and all of the existing vegetation was disturbed during development of the test plot study area. Disturbance of the test plot site was required to place runoff control and water harvesting features, for the placement of additional red bed materials and for seedbed preparations. Because this mechanical disturbance will remove the existing vegetation, herbicides were not applied to the test plot area. Any residual plant species should be readily discernable during test plot study monitoring and therefore should not adversely affect study findings.

Organic Amendment and Mulch Application

The redbed interburden material proposed for use as topdressing is essentially devoid of organic material. Organic material plays an important role in plant growth and vitality, providing many of the exchange sites necessary for plant nutrient cycling and storage. Soil organic content is a key component for improving soil moisture holding capacities and increasing infiltration rates. Organic matter has proven critical in the successful reclamation of problematic mine tailings in the western United States during the last decade. In terms of organic content, redbed material is very similar to these mine tailings, thus organic matter applications were a primary focus of the test plot study. We tested two organic amendment treatments using the Santa Fe Down manure (20 tons/acre and 30 tons/acre), a traditional hay mulch treatment (2 tons/acre), and a control (untreated bare ground).

Surface Water Control

Surface water control is a critical component for minimizing erosion and supporting reclamation success. Water and Earth Technology, Inc. modeled two watersheds on the test plots to design controls for surface water runoff, erosion and sedimentation. Soil parameters including soil texture, structure, organic matter and infiltration were used along with slope, surface roughness and coarse rock content to model the site in SEDCAD™ 4. Runoff from the upper test plot was controlled using a containment berm. The berm was designed to completely contain the runoff resulting from the 10-year, 24-hour rainfall event of 2.3 inches, with a minimum of one foot of freeboard. Runoff from the lower test plot was controlled using a self-draining berm and a down drain designed to safely pass the peak flow resulting from a 100-year, 6-hour rainfall event of 2.8 inches, with a minimum of one foot of freeboard.

TEST PLOT CONSTRUCTION

Test plot construction was completed with standard equipment available at most mining operations including large track excavators, loaders, articulated 6x6 haul trucks and dozers.

Slope

During test plot preparation a certain amount of backfilling and grading was performed to remove existing drainage and erosion features. As a result of this process the variability of slopes within the test plot area decreased and became more uniform. The maximum slopes within the test plot area are 3.5H:1V, with most of them being 4H:1V or flatter. The range of slopes existing within the study area are represented within the treatments and applications studied. By incorporating a range of slopes into the design, the results of the treatments and applications may be evaluated without bias, while providing an opportunity to evaluate of their effectiveness on a variety of slopes expected in the postmining landscape.

Redbed Excavation and Placement

Soil depth of the redbed topdressing soil is uniform across the test plot area. The current reclamation plan requires the replacement of a two-foot deep topdressing to create a suitable plant growth medium. When redbed soil reconstruction materials were initially removed from the borrow area, they characteristically contain a noticeable portion of rock fragments. Redbed materials were selectively removed and redistributed during the soil reconstruction process, with care being taken to ensure that all plots received reasonably uniform concentrations of rock fragments. Large rocks that would interfere with test plot results were removed from the test plot area. Site observations indicate that the redbed material is very susceptible to weathering and slaking once fragmented and exposed to the elements. Redbed rock fragments placed on the test plots readily decomposed during their first several years of weathering. Therefore, coarse soil fragments were considered a constant for the purposes of this study.

Surface Water Control Structure Construction

Two draining terraces were constructed to design criteria by transporting redbed material from the borrow area and placing it directly on the test plot site. This eliminated the need to excavate the terrace, over steepen the approach slope from the test plot side and minimized the area affected by the terrace.

Organic Amendment

The organic matter and ash analyses of the Santa Fe Downs manure were used to determine estimated organic matter application rates on the 20 tons/acre and the 30 tons/acre test plots. Average organic matter and ash composition of the stockpiled manure are shown in Figure 2 with an average actual organic matter content of 24 percent, 54 percent ash and 21.8 percent moisture. To estimate the amount of manure to be placed on each of the 20 tons/acre and the 30 tons/acre plots, a calculation was made that evaluated the average amount of ash, organic matter and moisture content of the sampled manure pile. The calculations estimated that each 0.086 acre plot would be amended with 7.19 tons manure at the 20 tons of actual organic matter per acre rate and 10.78 tons of manure at the 30 ton rate. This estimate was used to determine the approximate amount of material that would have to be hauled from Santa Fe Downs to the quarry.

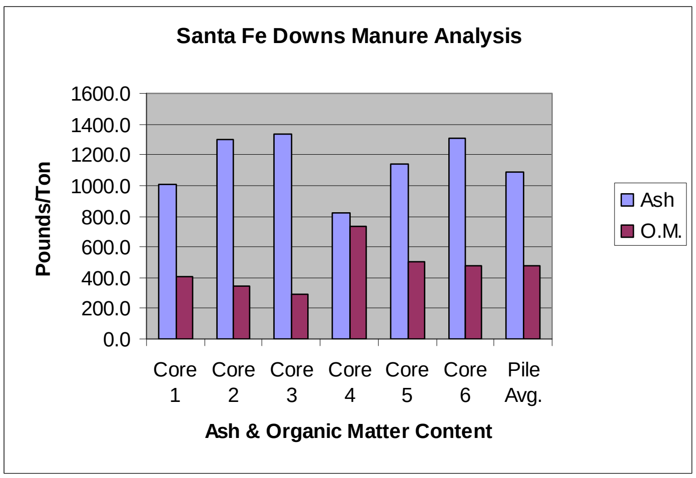

Figure 2. Average organic matter and ash composition of manure from Santa Fe Downs.

Trash removal and a thorough mixing of the manure were conducted at the stockpile/load out site resulting in a more uniform organic amendment product for placement on the test plots. The mixed manure material was delivered to the test plot area with a potentially different chemical and physical content than the in-place stockpile testing. The mixed manure was stockpiled in May 2003 at the base of the test plot area and mixed thoroughly to result in a more uniform material prior to amending the test plots.

A three-yard front loader was used to weigh and deliver manure to the plots. The average loaded weight of the full bucket with strike-off was 5,760 pounds. Critical to this effort was determining the bulk density of the manure and its relationship to volume within a front loader bucket so that an accurate application rate could be determined. The scale at the Tijeras plant was used to determine bulk density and the amount of manure to deliver and spread on each plot. Using the bulk density, organic matter, ash and moisture assumptions developed from initial coring of the manure stockpile at Santa Fe Downs, two loader buckets were placed on each 20 tons/acre plot and three loader buckets on each 30 tons/acre plot. After the placement of the initial piles on each of the amended plots, manure samples were collected and composited from each test plot. The manure samples from each amended plot were analyzed by ServiTech Lab to determine actual chemical and physical results of the manure applied to each test plot.

Analytical results including percent organic matter and ash content were again evaluated to determine how much additional manure needed to be added to each plot to meet the organic amendment treatment rate of either 20 or 30 tons per acre of actual organic matter. On-plot testing analytical results showed an average organic matter of 10.4 percent, 84.1 percent ash and 5.5 percent moisture. Due to the significant differences between the initial stockpile testing results and the on-plot manure testing, additional organic materials for each test plot were calculated based on the final on-plot testing results. An average of 3.5 additional manure loads were required for the 20 ton plots and 6.0 loads for the 30 ton plots that resulted in total manure applied to the amended plots of approximately 500 tons.

Manure was spread evenly across each plot with a D-5 dozer. Spreading activities were first conducted on the contour then finished perpendicular to the contour to get an even spread of organic material across each amended plot. Final manure depth on the 20 ton plots was approximately one inch deep and 1.5 inches deep on the 30 ton plots before incorporation.

Soil Sampling and Fertility Amendments

Two soil sampling events were conducted on the test plots to determine baseline redbed soil chemical and physical properties. Complete soil profile sampling and testing was performed in April 2003 after construction, but prior to organic amendment application. This initial sampling and analysis was performed to establish baseline soil chemical and physical properties for reclamation suitability, fertility status and to enable soil pedogenic comparisons over time. An important goal of the test plot design is to ensure to the extent practicable that nutrient availability is uniform across test plots. Because the redbed material is reasonably uniform in terms of inherent fertility each test plot was sampled from 0-6 inches, 6-12 inches and 12 to 18 inches in depth. Four cores were collected with a Giddings soil rig inset from each test plot corner in an “X” pattern and one core from the middle of the plot. Continuous core spacing was approximately 20 feet apart along the “X” pattern starting from the exact center of the plot and transecting outward approximately 20 feet to each plot corner. Each of the five continuous cores were split into each of the six-inch depth increments, then collated and mixed by depth increment for a representative sample for analysis.

The summary data suggest that the redbed soil on the test plots is very uniform (Table 3) for all parameters tested except for phosphorous. Plots 23, 24, 25 26 and 27 were elevated significantly above the usual 1 ppm bicarbonate test for phosphorous.

Table 3. Baseline Soil Data Summary by Depth

Depth	pH (Saturated Paste)	O.M. (%)	NO_3-N (ppm)	Bicarb-P (ppm)	K (ppm)	SAR	EC (mmhos/cm)
0-6"	8.0	0.3	3.8	3.4	185.9	1.0	0.6
6-12"	8.1	0.2	7.0	2.6	194.9	1.0	0.5
12-18"	8.1	0.3	3.5	2.9	199.2	1.1	0.4

Fertilizer application rates were determined for the reconstructed soil to ensure that availability of plant macronutrients is approximately equivalent on a per unit volume of soil basis in all reconstructed soils. Plot-specific fertilizer applications were developed after organic amendment applications were finalized. The inherent macronutrient fertility of the manure precludes the need for fertility amendments on the 20 and 30 ton per acre plots. The fertilization goal was to equalize nutrient availability to accepted plant establishment levels so it is not a variable factor influencing plant establishment and growth. Target soil fertility levels for critical macronutrients were set at concentrations equal to or slightly above typical rangeland values.

Baseline soil data suggested that nitrogen and phosphorous levels were very low and potassium was sufficient. Current accepted reclamation practices suggest that no more than 20 lb/acre of actual nitrogen should be applied to mine soils prior to revegetation. Excessive nitrogen can result in excessive growth of weedy annuals during the germination and establishment period. These weedy annuals can out-compete the seeded native species. Excess nitrogen fertility can also enhance the growth of cool season grasses in the seed mix and potentially decrease establishment of warm season grasses, forbs and shrubs thereby adversely impacting species diversity. These baseline data also showed that phosphorous levels were extremely low with most plots at 1 ppm with a target level of 15 ppm. Nitrogen and phosphorous levels on the plots with manure amendments were higher than the minimum fertility requirements suggested for plant establishment.

Fertilizer was applied in two split applications to each plot receiving nitrogen and/or phosphorous. Because phosphorous is not volatile, it was applied prior to manure application at a rate of 300 pounds per acre of 0-46-0. Urea nitrogen as 46-0-0 was applied to the control and to the 2 tons/acre hay amended plots immediately prior to ripping to incorporate the fertilizer to six inches and minimize volatilization.

Amendment Incorporation and Surface Roughening

Incorporation of organic and fertilizer amendments and surface roughening (i.e., contour furrowing) was performed on all test plots in June 2003 with the first equipment pass up and down slope and the second pass along the contour. Contour furrowing results in surface roughening sufficient to capture and reduce surface water runoff and increase moisture harvesting. Precipitation harvesting can be expected to improve soil moisture content and stimulate plant growth and development while the plots lie fallow. Due to the extremely dry weather during and after plot construction, seeding and transplanting operations were delayed until soil moisture conditions improved. Contour furrowing was again performed immediately before broadcast seeding in January 2004 to break up soil surface crusting.

Broadcast Seeding

All plots were broadcast seeded between January 11 and 14, 2004 after redbed materials were prepared for planting and when soil moisture conditions were suitable. When done properly, broadcast seeding is superior to drill seeding for establishment of native species seed mixtures because it distributes seed more evenly across the ground surface. This limits competition and maximizes the nutrient and water availability for seedlings and young plants, resulting in an optimal expression of the diversity contained in the seed mixture and fostering improved plant growth.

Bulk application rates for the seed mixture on the various test plots were developed at the time that the seed was purchased from the supplier based on the purity and germination of seed lots used. The seed mix was split into three sub-mixtures based on the seeding rates of 5, 10 and 20 PLS/ft^2 by plot. Rice hulls were used as a seed extender to allow for the even application of the seed. Three varied amounts of rice hull extender were added to each of the three sub-mixtures to result in a final bulk seed/extender mix of equal volume. Each plot's specific sub-mixture was split in half to allow for a perpendicular split application of seed on the plot for more even distribution. Due to the variable seed size and morphology, the bulk seed was applied by hand from a five gallon bucket by one person for all of the plots.

Shrub and Tree Transplanting

The reestablishment of tree and shrub communities is a special concern at the quarry and to the surrounding community of Tijeras. To evaluate the potential establishment of woody species, bare root or containerized materials were transplanted in one series of test plots seeded at 20 PLS/ft^2. All four of the organic treatment types were represented in the woody transplant plot series. Woody species were transplanted at a density of 60 per plot (≈ 666 per acre). Spacing between transplants was approximately 7.9 feet (≈ 62 square feet per transplant). Five individuals each of 12 woody species were planted randomly in the typical pattern shown on Figure 3. Species planted included ponderosa pine (*Pinus ponderosa*), pinyon pine (*P. edulis*), oneseed juniper (*Juniperus monosperma*), Mexican cliffrose (*Purshia mexicana*), antelope bitterbrush (*P. tridentata*), Gambel oak (*Quercus gambelii*), Wood's rose (*Rosa woodsii*), rubber rabbitbrush (*Ericameria nauseosa*), yellow rabbitbrush (*Chrysothamnus viscidiflorus*), mountain mahogany (*Cercocarpus montanus*), winterfat (*Krascheninnikovia lanata*), and skunkbush sumac (*Rhus trilobata*).

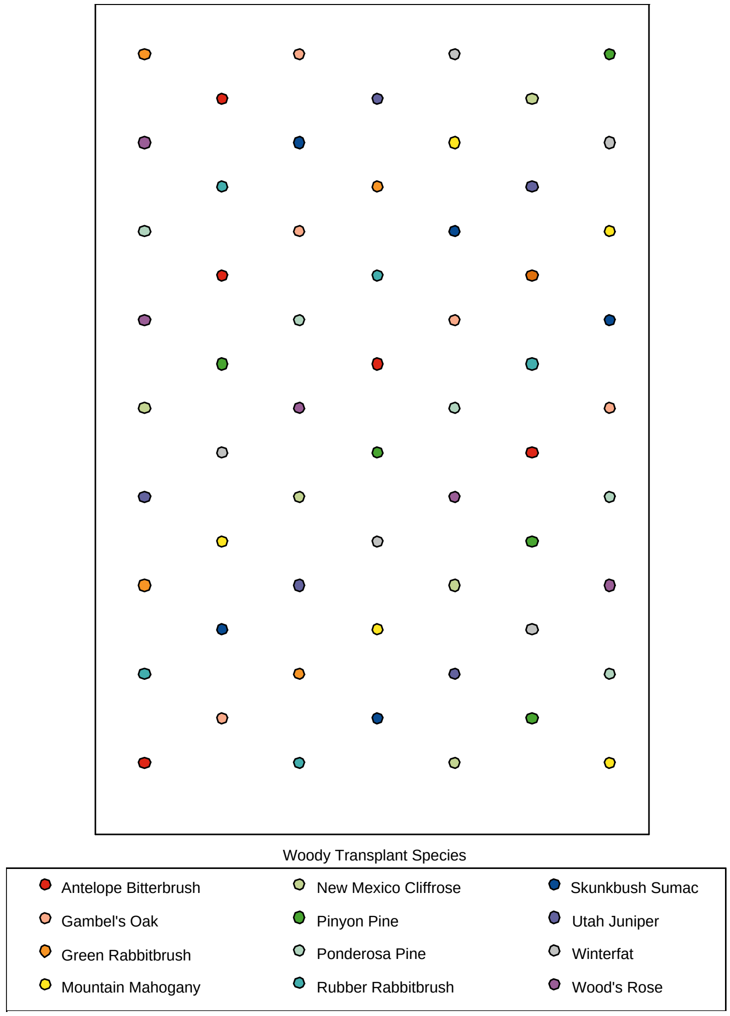

Figure 3. Revegetation Test Plot-Typical Woody Transplanting Arrangement

Transplants were watered prior to transplanting with Diehard™ endo- and ectomycorrhizal inoculants. Each transplant hole was treated with TerraSorb™ a water retention polymer and was fertilized with a 10 gram Agriform™ 20-15-5 NPK for the smaller tubling containerized material and 25 gram tablet for the 1-gallon containerized material. Each transplant was irrigated after planting and backfilling to settle the soil around the root ball. Transplanting was performed following manure amendment applications and ripping, but prior to straw mulch and seeding to minimize trampling of the soil surface after mulching and seeding.

Native Hay Mulch Amendment

After seeding, native hay mulch was hand applied each treated plot at a rate of 2-tons per acre. Because New Mexico does not have a certified weed-free hay program, weed-free hay was purchased from a local supplier advertising noxious weed free hay. Hay bales averaged 65 pounds per bale and approximately 344 pounds of hay were applied to each of the 12 mulch treatment plots. A guar gum tackifyer, RTack™

was applied at a rate of 150 pounds per acre mixed in 1,000 gallons of water (13 lbs mixed with 100 gal water per plot) to hold the mulch together and on the plot to prevent mulch loss due to wind and water erosion.

MONITORING

To date the test plots have been monitored annually from 2003 through 2006 for vegetation cover, diversity, and health; seedling germination and establishment; woody plant density; and transplant survival and growth on applicable test plots. Monitoring results are presented in Bay et al. (this volume). Year five monitoring will be conducted in September 2008. At that time, RGCP and Habitat Management will evaluate whether continued monitoring is necessary.

REFERENCES

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EVALUATING SEEDING TECHNIQUES AND NATIVE PLANT ESTABLISHMENT IN THE PINEDALE ANTICLINE, WYOMING

Susan R. Winslow[1,2], Karen J. Clause[3,4], Roger Hybner[5,2], and Jim Jacobs[6,7],
[1]Agronomist, USDA NRCS Plant Materials Center
[2]98 South River Road, Bridger, MT 59014
[3]Rangeland Management Specialist, USDA NRCS
[4]P.O. Box 39, Pinedale, WY 82941
[5]Manager, USDA NRCS Plant Materials Center
[6]Plant Materials Specialist, USDA NRCS
[7]10 East Babcock Street, Bozeman, MT 59715

ABSTRACT

Critical wildlife habitat supporting mule deer, antelope, and sage-grouse in high elevation rangeland and sagebrush ecosystems of southwest Wyoming is threatened by energy development, residential sprawl, and agriculture. The objective of the field studies is to evaluate the restoration of native plant species after disturbance. In October 2005, 72 entries of 50 native species were drill-seeded on a well-pad site, in single species plots, in a randomized complete block design with four replications. Also, two seed mixtures were broadcast- and drill-seeded, and one seed mixture was hydro-seeded on disturbed areas adjacent to the plots. Cover and density were sampled in July 2006 and September 2007. The best performers in the replicated plots, determined by 2007 density counts, were ‘Sodar’ streambank wheatgrass, L-46 basin wildrye, Copperhead slender wheatgrass, Rocky Mountain beeplant, yarrow, ‘Appar’ blue flax, Richfield Eaton’s penstemon, ‘Wytana’ and Snake River Plains fourwing saltbush, and Open Range and Northern Cold Desert winterfat. Establishment of the broadcast-seeded plots in the Bridger and Shell mixtures was 1.0 and 0.7 plants/ft^2, respectively, and of the drill-seeded plots 0.4 and 0.3 plants/ft^2, respectively. Establishment of the hydro-seeded Shell mix was 0.09 plants/ft^2. Low precipitation and high temperatures may have reduced establishment. On a second disturbed site, 25 shrub species were mechanically planted in single species replicated plots in October 2006. Density counts taken in 2007 showed extremely poor establishment. Short-term results provide recommendations for native grass restoration, however, low establishment of forbs and shrubs indicate more work is needed to develop plant materials and technology.

INTRODUCTION

With national attention on issues associated with sagebrush systems and sensitive species such as sage-grouse, there is a need to prioritize vegetative restoration efforts in oil and gas development areas on both private and public lands in southwestern Wyoming (Holechek, 2006). The Shell and Questar Exploration and Production Companies (hereby referred to as Shell and Questar), Sublette County Conservation District, Bureau of Land Management (BLM), Wyoming Game and Fish Department (WGFD), and USDA Natural Resources Conservation Service (NRCS) have teamed up to adopt appropriate reclamation techniques in association with oil and gas production activities taking place in the Pinedale Anticline and Jonah Gas Field regions located in Sublette County. Local resource professionals and land managers entered into discussions that led to the signing of a cooperative working agreement. Their common goal was to develop reclamation and rangeland restoration trials to determine the best native plants and establishment techniques for restoring, enhancing, and maintaining native rangeland and sagebrush ecosystem diversity, forage production, and wildlife habitat. The working agreement, to date, encompasses two projects: the first tests plant materials in Field Evaluation Plantings (FEPs) in cooperation with Shell, and the second tests shrubs in cooperation with Questar (fig. 1). Challenges to restoration of native plant species in the ecosystem include a short growing season, low and uncertain precipitation, high summer temperatures during drought periods, coarse soils with low water-holding capacity, invasive plant species, and domestic and native ungulate herbivory (Newhall et al, 2004). Loss of soil structure and compaction associated with drill site disturbance may impede restoration under these site conditions.

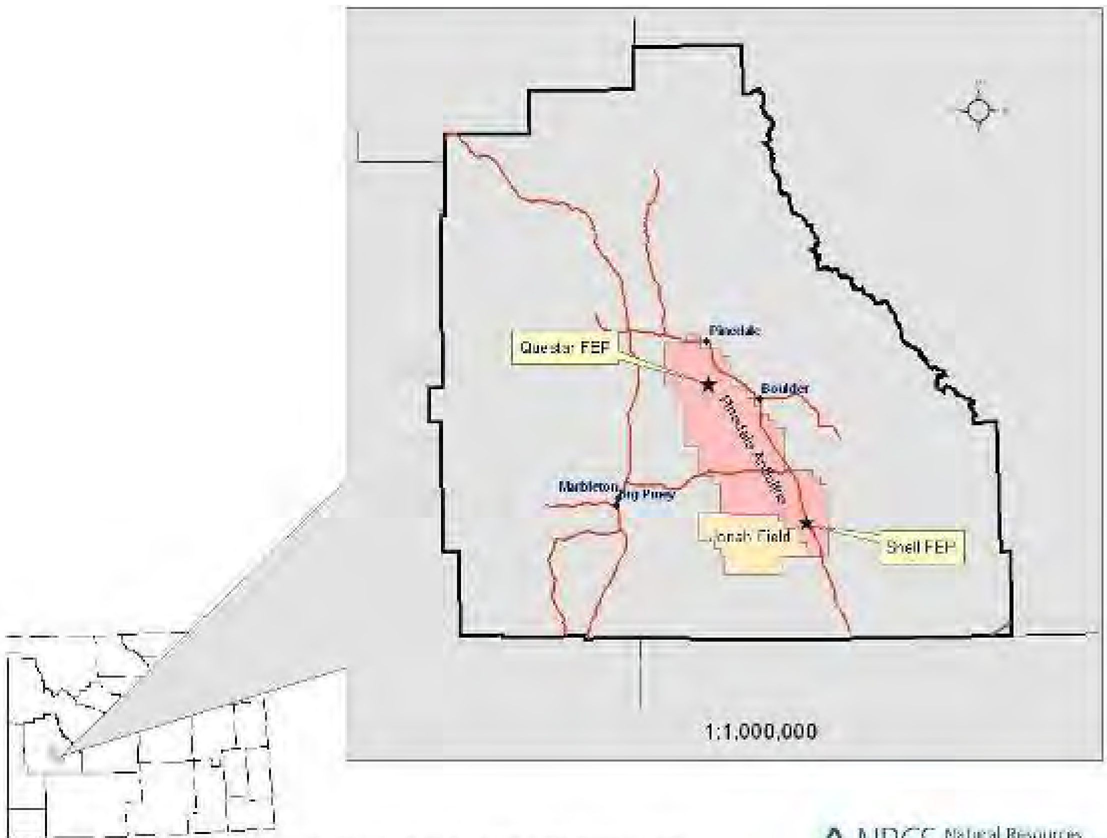
OBJECTIVES

The major objectives coincide with objectives outlined in the Pinedale Resource Area Cooperative Working Agreement (PRACWA, 2005), which will:

1. Test cultivars, varieties, and germplasms of grass, forb, and shrub species for adaptation to the Pinedale Resource Area. Emphasis is on plant species native to the Rocky Mountain Region that provide forage production, a diverse ecosystem, and habitat for sage-grouse, mule deer, antelope, and other wildlife species dependent upon sagebrush communities.
2. Test seeding methods, mixtures, and rates for adaptation and desired ecological diversity in the Pinedale Resource Area.
3. Distribute results to public and private land managers, as well as other interested individuals.

SITE DESCRIPTIONS

The two sites, Shell and Questar, are previously disturbed well-pads. The Shell project area is approximately 30 miles south of Pinedale, Wyoming (N ½ SW ¼ Section 10, T29N R107W), and the Questar project area is 9.5 miles south of Pinedale (SW ¼ SW ¼ Section 34, T33N R109W). The sites fall within the Cool Central Desertic Basins and Plateaus Major Land Resource Area (MLRA 34A) at elevations of 7,195 and 7,515 feet. Annual precipitation is approximately 10 inches, mainly in the form of snow. Peak growing season (60 to 70 days) precipitation is from May to June. The soils are mostly deep and well drained, and slope commonly ranges from 2 to 15%. Surface layers are 5 inches or more thick with sandy clay loam subsoils. The major soil series include Bluerim-Forelle complex and Bluerim-Cotha complex. Soil texture is sandy loam to calcareous shallow loam. The Questar site has moderately deep soils with root growth restricted by high amounts of lime or rock fragments at 10- to 12-inch depths. The dominant vegetative cover type is classified as sagebrush steppe and the potential natural vegetation is estimated at 70% grass and grass-like plants, 10% forbs, and 20% woody plants. The key grass species are needle and thread, thickspike wheatgrass, Indian ricegrass, bluebunch wheatgrass, and bottlebrush squirreltail. The forbs include aster, buckwheat, clover, evening primrose, fleabane, and phlox.



NRCS Natural Resources Conservation Service

Fig. 1. Locational map of the Shell and Questar Field Evaluation Plantings in Sublette County, near Pinedale, Wyoming.

Shrub cover is dominated by Wyoming big sagebrush with minor components of other shrubs, including green and rubber rabbitbrush, Gardner's saltbush, and winterfat. The potential total annual production (air-dry weight) ranges from 350 lb/acre in unfavorable years up to 1,500 lb/acre in favorable years.

METHODS AND MATERIALS

Shell. The 4.5-acre site was disturbed in 2002 and an oil and gas well-pad was constructed. Approximately 6 inches of topsoil was stripped and stockpiled for 37 months and re-applied to the pad following development. The soil was ripped to mitigate heavy equipment compaction and restore infiltration, then firmed and smoothed. Seedbed conditions were moderately fluffy and less than ideal for precise seed placement.

Adaptation of 15 grass, 22 forb, and 13 shrub species, mostly native to the Pinedale Resource Area, were tested in a randomized complete block study with four replications (tables 1-3). Plots were 4 feet by 20 feet (80 ft^2), and the 72 entries were dormant-seeded in the fall of 2005 as monocultures using a Kincaid Precision Cone-seeder. Two seeding mixtures, Bridger and Shell (see tables 4 and 5 for species composition), were tested on adjacent plots. Each mixture was seeded with a Truax drill (1-acre plots) and an ATV-mounted broadcast seeder (0.5-acre plots).

Table 1. Mean values generated from ANOVA of the 2007 data for density, height, vigor, and relative stand establishment of 32 grass accessions seeded in replicated plots at the Shell Field Evaluation Planting near Pinedale, Wyoming--Means followed by the same letter are not significantly different determined by LSD (P<0.05).

Accession/Common Name	Scientific Name	Plants/ft^{2}†	Height (in)	Vigor‡	Stand‡
Sodar streambank wheatgrass	*Elymus lanceolatus*	4.30 a	4.35 bcdefg	4.00 abcd	5.34 ab
L-46 basin wildrye	*Leymus cinereus*	4.26 a	5.43 abc	3.75 abc	3.84 a
Copperhead slender wheatgrass	*Elymus trachycaulus*	3.87 ab	3.60 efgh	3.50 ab	3.97 a
Continental basin wildrye	*Leymus cinereus*	3.67 abc	5.10 abcd	4.00 abcd	5.08 ab
P-24 bluebunch wheatgrass	*Pseudoroegneria spicata*	3.30 abcd	4.98 abcde	4.25 abcde	5.81 abc
San Luis slender wheatgrass	*Elymus trachycaulus*	2.61 abcdef	6.10 a	4.00 abcd	5.81 abc
Critana thickspike wheatgrass	*Elymus lanceolatus*	2.56 abcdef	4.85 abcde	4.00 abcd	5.15 ab
Bannock thickspike wheatgrass	*Elymus lanceolatus*	2.51 abcdefg	4.73 abcdef	4.00 abcd	5.45 ab
Pryor slender wheatgrass	*Elymus trachycaulus*	2.50 abcdefg	4.35 bcdefg	4.75 abcdef	6.18 bcd
Magnar basin wildrye	*Leymus cinereus*	2.36 bcdefgh	5.10 abcd	5.00 bcdef	6.59 bcdef
Anatone bluebunch wheatgrass	*Pseudoroegneria spicata*	2.29 bcdefgh	5.23 abc	5.25 bcdefg	7.30 cdefg
Washoe basin wildrye	*Leymus cinereus*	2.06 cdefgh	5.10 abcd	5.50 cdefgh	6.59 bcdef
P-19 bluebunch wheatgrass	*Pseudoroegneria spicata*	1.99 defghi	4.98 abcde	6.50 fghi	6.76 bcdef
Rosana western wheatgrass	*Pascopyrum smithii*	1.89 defghij	3.35 fghi	6.50 fghi	6.54 bcdef
Goldar bluebunch wheatgrass	*Pseudoroegneria spicata*	1.55 efghijk	4.85 abcde	5.00 bcdef	6.67 bcdef
P-22 bluebunch wheatgrass	*Pseudoroegneria spicata*	1.39 efghijkl	3.60 efgh	6.00 efghi	8.54 ghi
9019219 bottlebrush squirreltail	*Elymus elymoides*	1.26 efghijkl	4.85 abcde	3.00 a	6.30 bcde
Salina wheatgrass	*Elymus salinus*	1.25 fghijkl	4.10 cdefgh	6.25 fghi	7.58 defgh
Rodan western wheatgrass	*Pascopyrum smithii*	1.11 ghijklm	4.60 bcdef	4.25 abcde	7.79 efghi
Trailhead basin wildrye	*Leymus cinereus*	1.03 hijklm	5.60 ab	3.50 ab	7.02 bcdefg
E-45 Snake River wheatgrass	*Elymus wawawaensis*	0.88 ijklmn	3.35 fghi	7.50 i	7.83 efghi
Secar Snake River wheatgrass	*Elymus wawawaensis*	0.78 jklmno	4.85 abcde	5.75 defghi	7.76 defghi
Nezpar Indian ricegrass	*Achnatherum hymenoides*	0.65 klmnop	4.85 abcde	5.25 bcdefg	8.29 ghi
Sherman big bluegrass	*Poa secunda (P. ampla)*	0.58 klmnop	4.10 cdefgh	6.00 efghi	8.26 ghi
Pueblo bottlebrush squirreltail	*Elymus elymoides*	0.55 lmnop	3.60 defghi	6.00 efghi	8.06 fghi
9092261 prairie Junegrass	*Koeleria macrantha*	0.38 mnop	4.43 bcdefg	6.25 fghi	8.51 ghi
Rimrock Indian ricegrass	*Achnatherum hymenoides*	0.36 mnop	4.60 bcdef	6.50 fghi	8.76 hi
High Plains Sandberg bluegrass	*Poa secunda (P. sandbergii)*	0.32 mnop	2.98 ghij	7.00 ghi	8.29 ghi
Wapiti bottlebrush squirreltail	*Elymus elymoides*	0.31 mnop	2.10 ij	7.50 i	8.54 ghi
Opportunity Nevada bluegrass	*Poa secunda (P. nevadensis)*	0.20 nop	2.85 hij	7.25 hi	9.00 i
9087539 prairie Junegrass	*Koeleria macrantha*	0.19 op	1.85 j	6.25 fghi	9.00 i
Covar sheep fescue	*Festuca ovina*	0.13 p	2.10 ij	7.00 ghi	8.76 hi

† Seeding rate 30 pure-live-seeds/ft^{2}; ‡ Rated 1-9 with 1 best.

Table 2. Mean values generated from ANOVA of the 2007 data for density, height, vigor, and relative stand establishment of 24 forb accessions seeded in replicated plots at the Shell Field Evaluation Planting near Pinedale, Wyoming--Means followed by the same letter are not significantly different determined by LSD (P<0.05).

Accession/Common Name	Scientific Name	Plants/ft^{2}†	Height (in)	Vigor‡	Stand‡
9087543 Rocky Mountain beeplant	*Cleome serrulata*	2.54 a	13.50 a	3.50 ab	4.00 a
9087541 native yarrow	*Achillea millefolium*	1.29 b	1.85 cde	6.75 cdefg	8.25 def
Appar blue flax	*Linum perenne*	0.75 bc	0.75 def	7.25 cdefg	7.25 bc
Richfield Eaton's penstemon	*Penstemon eatonii*	0.71 bc	1.87 cd	5.00 abc	6.75 b
Old Works fuzzytongue penstemon	*Penstemon eriantherus*	0.50 bc	1.25 cdef	5.50 bcde	6.75 b
Maple Grove prairie flax	*Linum lewisia*	0.33 c	2.88 bc	5.75 bcdef	8.00 cde
9087545 Eaton's penstemon	*Penstemon eatonii*	0.29 c	1.00 def	5.25 bcd	7.50 bcd
9087553 gray aster	*Eurybia glauca*	0.25 c	2.75 bc	5.00 abc	8.50 ef
9087546 Palmer penstemon	*Penstemon palmeri*	0.21 c	4.00 b	2.75 a	7.00 b
9081632 silverleaf phacelia	*Phacelia hastata*	0.09 c	0.75 def	8.50 g	8.75 ef
9087549 showy evening primrose	*Oenothera speciosa*	0.04 c	0.13 ef	8.00 fg	9.00 f
Stillwater prairie coneflower	*Ratibida columnifera*	0.04 c	1.00 def	7.50 defg	9.00 f
9087540 American vetch	*Vicia americana*	0.04 c	0.25 def	8.50 g	9.00 f
Great Northern western yarrow	*Achillea millefolium* var. *occidentalis*	0	0	0	0
9087542 wavyleaf Indian paintbrush	*Castilleja applegatei*	0	0	0	0
Antelope white prairie clover	*Dalea candida*	0	0	0	0
9087544 aspen fleabane	*Erigeron speciosus*	0	0	0	0
9087552 sulfurflower buckwheat	*Eriogonum umbellatum*	0	0	0	0
9087548 pale evening primrose	*Oenothera pallida*	0	0	0	0
9087547 littleflower penstemon	*Penstemon procerus*	0	0	0	0
Clearwater Venus penstemon	*Penstemon venustus*	0	0	0	0
9087550 scarlet globemallow	*Sphaeralcea coccinea*	0	0	0	0
9087551 Munroe's globemallow	*Sphaeralcea munroana*	0	0	0	0
9087554 Pacific aster	*Symphyotrichum chilense* var. *chilense*	0	0	0	0

† Seeding rate 30 pure-live-seeds/ft^{2}; ‡ Rated 1-9 with 1 best.

Table 3. Mean values generated from ANOVA of the 2007 data for density, height, vigor, and relative stand establishment of 16 shrub accessions seeded in replicated plots at the Shell Field Evaluation Planting near Pinedale, Wyoming--Means followed by the same letter are not significantly different determined by LSD (P<0.05).

Accession/Common Name	Scientific Name	Plants/ft^{2†}	Height (in)	Vigor‡	Stand‡
Wytana fourwing saltbush	*Atriplex aptera*	0.58 a	7.00 ab	4.23 ab	5.50 a
Snake River Plains fourwing saltbush	*Atriplex canescens*	0.34 b	9.50 a	2.75 a	5.00 a
Northern Cold Desert winterfat	*Krascheninnikovia lanata*	0.17 bc	4.75 bcd	5.00 abc	9.00 b
Open Range winterfat	*Krascheninnikovia lanata*	0.13 bc	4.00 bcde	4.50 abc	7.75 b
9087557 black sagebrush	*Artemisia nova*	0.13 bc	3.00 cdef	6.25 bcd	8.75 b
9087558 basin big sagebrush	*Artemisia tridentata* ssp. *tridentata*	0.08 c	6.75 ab	4.75 abc	8.50 b
Hatch winterfat	*Krascheninnikovia lanata*	0.08 c	4.00 bcde	5.00 abc	8.00 b
9016134 Gardner's saltbush	*Atriplex falcata (A. gardnerii)*	0.04 c	5.25 bc	4.25 ab	8.00 b
9087560 basin saltbush	*Atriplex tridentata*	0.04 c	2.75 cdef	6.50 bcd	9.00 a
9087555 fringed sagewort	*Artemisia frigida*	0	0	0	0
9087556 prairie sagewort	*Artemisia ludoviciana*	0	0	0	0
9087559 Wyoming big sagebrush	*Artemisia tridentata* ssp. *wyomingensis*	0	0	0	0
9087561 shadscale saltbush	*Atriplex confertifolia*	0	0	0	0
9087563 spiny hopsage	*Grayia spinosa*	0	0	0	0
Maybell antelope bitterbrush	*Purshia tridentata*	0	0	0	0
9087562 antelope bitterbrush	*Purshia tridentata*	0	0	0	0

† Seeding rate 20 pure-live-seeds /ft^2; ‡ Rated 1-9 with 1 best.

Table 4. The species composition and seeding rates of the Bridger Mixture at the Shell Field Evaluation Planting near Pinedale, Wyoming.

Common Name	Scientific Name	Seeds	Mix	PLS†	Seeding Rate†	Drill Rate†	Broadcast Rate†
		lb	*%*	*%*	*lb/acre*	*seeds/ft²*	*seeds/ft²*
Pryor slender wheatgrass	*Elymus trachycaulus*	95,000	12.8	87.44	2.3	5	10
Critana thickspike wheatgrass	*Elymus lanceolatus*	145,000	12.8	~90.00	1.5	5	10
Rosana western wheatgrass	*Pascopyrum smithii*	93,000	12.8	87.90	2.3	5	10
High Plains Sandberg bluegrass	*Poa secunda* (*P. sandbergii*)	925,000	12.8	~80.00	0.25	5	10
Rimrock Indian ricegrass	*Achnatherum hymenoides*	155,000	12.8	98.83	1.4	5	10
Trailhead basin wildrye	*Leymus cinereus*	125,000	7.7	85.85	1.0	3	6
Great Northern western yarrow	*Achillea millefolium* var. *occidentalis*	4,500,000	5.1	~90.00	0.02	2	4
Stillwater prairie coneflower	*Ratibida columnifera*	600,000	5.1	93.16	0.15	2	4
Maple Grove prairie flax	*Linum lewisii*	278,000	5.1	90.25	0.31	2	4
Silverleaf phacelia	*Phacelia hastata*	454,000	5.1	91.57	0.19	2	4
Scarlet globemallow	*Sphaeralcea coccinea*	500,000	2.6	71.56	0.17	1	2
Wytana fourwing saltbush	*Atriplex aptera*	49,000	1.3	48.05	0.45	0.5	1
Open Range winterfat	*Krascheninnikovia lanata*	352,000	1.3	~90.00	0.06	0.5	1
Wyoming big sagebrush	*Artemisia tridentata* ssp. *wyomingensis*	2,400,000	1.3	13.38	0.01	0.5	1
Fringed sagewort	*Artemisia frigida*	4,550,000	1.3	85.71	0.005	0.5	1
Totals:	15 species	-	99.9	-	10	39	78

† Pure Live Seed.

Table 5. The species composition and seeding rates of the Shell Mixture at the Shell Field Evaluation Planting near Pinedale, Wyoming.

Common Name	Scientific Name	Seeds	Mix	PLS†	Seeding Rate†	Drill Rate†	Broadcast Rate†
		lb	*%*	*%*	*lb/acre*	*seeds/ft²*	*seeds/ft²*
Wyoming big sagebrush	*Artemisia tridentata* ssp. *wyomingensis*	2,500,000	41.50	5.269	0.50	28.70	57.40
Sandberg bluegrass	*Poa secunda (P. sandbergii)*	925,000	30.71	10.539	1.00	21.24	42.48
Fringed sagewort	*Artemisia frigida*	4,536,000	7.53	0.530	0.05	5.21	10.42
Rydberg's penstemon	*Penstemon rydbergii*	4,400,000	7.30	0.525	0.05	5.05	10.10
Indian ricegrass	*Achnatherum hymenoides*	141,000	4.68	10.541	1.00	3.245	6.48
Native yarrow	*Achillea millefolium*	2,770,000	4.60	0.529	0.05	3.18	6.36
Winterfat – bearded	*Krascheninnikovia lanata*	56,700	1.88	10.537	1.00	1.30	2.60
Fourwing saltbush	*Atriplex canescens*	52,000	0.86	5.268	0.50	0.60	1.20
Scarlet globemallow	*Sphaeralcea coccinea*	500,000	0.50	3.096	0.03	0.34	0.68
Silvery lupine	*Lupinus argenteus*	13,000	0.43	10.544	1.00	0.30	0.60
Totals:	10 species	-	99.99	-	5.18	69.16	138.16

† Pure Live Seed.

Following planting of the broadcast-seeded plots, the area was roughened with a wooden pallet pulled behind the ATV. In addition, the Shell mixture was hydro-seeded to a 1-acre plot on a smooth slope in a one-step mulch application. Scientific plant nomenclature standardized by the USDA NRCS Plants Database (USDA, 2008*a*).

Questar. The 0.69-acre site was disturbed in 2005 and site preparation was conducted in 2006. The area was ripped and reshaped prior to topsoil placement to assure no compaction layer existed. Weeds were controlled prior to planting with an English harrow and chemical application of glyphosate at 2 quarts/acre. Soil was packed for firmness so no more than a 1/8-inch imprint was left when walking over the site (USDA, 2007*b*). Substantive debris that could prevent consistent seeding, such as large rock or sagebrush litter, was removed. The study site was fenced with an 8-foot deer-proof fence prior to planting to prevent grazing by wildlife and domestic livestock.

On October 10, 2006, a total of 116 plots were seeded with 29 shrub entries of 25 species in a randomized complete block design with four replications (table 6). Three, single-row belt seeders were used to plant shrub entries in 4-row plots, 8 ft wide by 20 ft long (160 ft^2). The shrub seeding rate was dependent on seed size and ranged from 10 to 40 pure-live-seed per foot. Seeding depth ranged from nearly surficial to 1 inch, depending on seed size. Five bluebunch wheatgrass varieties were broadcast seeded as a small observation area on the east end of the study site. The 0.23-acre grass plots were planted at 40 pure-live-seeds/ft^2.

Shell replicated plots, October 2005

According to the PRACWA, evaluations will be conducted for a minimum of 5 years post-planting on the Shell site and 15 years on the Questar site. In the event of a total stand failure (2 consecutive years with no establishment of planted species), replanting will be considered based on site and climatic conditions, as well as other factors. If there is partial stand failure (a large portion of plot area with no establishment), replanting with alternative or known adapted species will be considered.

Table 6. The native shrub species and seeding rates of the Questar Field Evaluation Planting, established on October 11, 2006, near Pinedale, Wyoming.

Accession/Common Name	Scientific Name	Pure-Live-Seed	Seeds	Seeds	Seeding Depth
		%	*lb*	*ft*	*in*
9087655 Saskatoon serviceberry	*Amelanchier alnifolia*	70.52	82,000	20	0.5
9087656 Utah serviceberry	*Amelanchier utahensis*	86.24	25,800	20	0.5
9087658 fringed sagewort	*Artemisia frigida*	87.65	4,550,000	40	<0.5
9087659 prairie sagewort	*Artemisia ludoviciana*	88.92	3,750,000	40	<0.5
9087660 black sagebrush	*Artemisia nova*	9.16	952,700	40	<0.5
9087661 basin big sagebrush	*Artemisia tridentata* ssp. *tridentata*	17.64	2,358,000	40	<0.5
9087663 Wyoming big sagebrush	*Artemisia tridentata* ssp. *wyomingensis*	23.67	2,400,000	40	<0.5
9087662 mountain big sagebrush	*Artemisia tridentata* ssp. *vaseyana*	8.75	1,360,000	40	<0.5
9087657 silver sagebrush	*Artemisia cana*	18.40	850,000	40	<0.5
Wytana fourwing saltbush	*Atriplex aptera*	32.20	49,000	20	0.5
Snake River Plains fourwing saltbush	*Atriplex canescens*	51.40	49,000	20	0.5
9016134 Gardner saltbush	*Atriplex falcata (A. gardnerii)*	29.45	70,000	20	0.5
9087664 curlleaf mountain mahogany	*Cercocarpus ledifolius*	55.92	51,900	20	0.5
9087665 alderleaf mountain mahogany	*Cercocarpus montanus*	82.00	47,406	20	0.5
9087666 rubber rabbitbrush	*Ericameria nauseousus*	16.83	693,000	40	<0.5
Open Range winterfat	*Krascheninnikovia lanata*	96.47	111,000	20	0.5
Northern Cold Desert winterfat	*Krascheninnikovia lanata*	74.99	111,000	20	0.5
9087667 chokecherry	*Prunus virginiana*	95.89	4,790	10	1.0
Maybell antelope bitterbrush	*Purshia tridentata*	65.69	15,400	20	0.5
9087668 antelope bitterbrush	*Purshia tridentata*	95.67	15,400	20	0.5
9087669 skunkbush sumac	*Rhus trilobata*	87.03	20,300	20	0.5
9087670 golden currant	*Ribes aureum*	77.60	233,000	20	0.5
9087671 wax currant	*Ribes cereum*	59.48	251,000	20	0.5
9087672 Wood's rose	*Rosa woodsii*	87.39	50,000	20	0.5
Prospectors common snowberry	*Symphoricarpos albus*	75.49	76,000	20	0.5
9087673 western snowberry	*Symphoricarpos occidentalis*	78.27	75,033	20	0.5
Trapper western snowberry	*Symphoricarpos occidentalis*	96.83	75,033	20	0.5
9087674 mountain snowberry	*Symphoricarpos oreophilus*	85.79	54,738	20	0.5

If stand failure is intermittent or limited to occasional species or replications, those completing the evaluation will recommend appropriate action. In all cases, weed control will be conducted on the entire plot area. The criteria for a site to be considered successful in reclamation for the chosen well-pad will be based on site stability, seeded species, and any additional criteria outlined in the PRACWA. If areas of bare ground larger than 30 ft² exist after the 5-year evaluation, or the site is considered unstable, replanting may be required.

Shell broadcast-seeded plots, October 2005.

Shell drill-seeded plots, October 2005

Questar replicated plots, October 2006

EVALUATIONS

Shell 2006. Treatments were evaluated on July 5 and 6. At that time, a total of only 1.25 inches precipitation was recorded for the previous 8 months. Evaluation variables included a relative rating of plant vigor and stand establishment, height in inches, percentage canopy cover and/or plant counts, and photo points. The replicated plots were sampled in two different ways, depending on establishment. Plots deemed adequate in emergence were rated for estimated percentage canopy cover in a 36 ft^2 area. Plots with poor emergence received a plant count of all four rows in the 80 ft^2 area. Additional comments were noted on the presence of animal and bird life, grazing or browsing activity, weeds, and species contamination due to mechanical carry-over of seed.

In the broadcast- and hydro-seeded mixture treatments, plants were counted in 20 plots, each 1.92 ft^2. In the drill-seeded mixture treatments, plants were counted in 20 plots, each 2.69 ft^2. Plant height in inches was recorded, as well as relative ratings on vigor and stand establishment.

Shell and Questar 2007. On September 11 and 12, several teams worked to evaluate the plots. At the time of the evaluation, a total of 3.51 inches precipitation was recorded for the previous 8 months. Evaluation factors included a relative rating of plant vigor and stand establishment, height in inches, plant counts, and photo points. In the Shell replicated plots, seeded plants were counted within 1 linear row-foot at three randomly chosen locations in each of the middle two rows for a total of six, 1-foot samples per treatment plot. Plant height measurements were taken from representative plants in each sample plot. Plant vigor and relative stand establishment were visually estimated for the entire plot. Additional comments were noted on items such as the presence of animal and bird life and grazing or browsing activity.

In the Shell broadcast-, drill-, and hydro-seeded mixture treatments, plant density was determined in 10 plots, each 9.62 ft^2. A relative rating of plant vigor and stand establishment, and height in inches were recorded. In the Questar planting, all plants in each plot were counted.

RESULTS

Shell Replicated Plots. Totals of 72 different plant entries were evaluated in the replicated plots, which included 32 grasses, 24 forbs, and 16 shrubs. The 2006 data suggested that performance depended upon species (data not shown). The analysis of variance of the 2007 data (SAS, 2006) showed establishment and survival measured by the number of plants per row-foot was different among grass accessions ($p \leq 0.0001$). Grass performance data is reported in table 1. Two accessions, Sodar streambank wheatgrass and L-46 basin wildrye, established with greater numbers compared to most of the other accessions. The establishment of these two species was not significantly different than seven other accessions, which were accessions of *Elymus lanceolatus, Elymus trachycaulis,* or *Pseudoroegneria spicata*. Considering a target of 20 plants per row-foot, the plant densities of the top nine species ranged from about 13% to 22% of a full stand (USDA, 2007*a*). The height of the grasses also differed among accessions ($p \leq 0.0001$). However, the grasses with the better establishment were not always the tallest, due more to their inherent growth form. Differences among accessions in vigor ratings ($p \leq 0.0001$) and relative stand establishment ratings ($p \leq 0.0001$) were more in line with density counts than height measurements.

It is difficult to compare plot establishment between years due to the different methods of evaluation (percentage canopy cover versus density). There may be an increase in establishment of the basin wildryes and several of the wheatgrasses (slender, thickspike, and western). The bluebunch entries were much the same. A decrease was observed in bluegrass, bottlebrush squirreltail, Indian ricegrass, prairie Junegrass, and sheep fescue.

The establishment of forbs and shrubs in 2006 was very low with an average of four and two plants per plot, respectively. The best performing forbs included Maple Grove prairie flax with

18 plants per plot, silverleaf phacelia with 16 plants per plot, Appar blue flax with 14 plants per plot, and Old Works fuzzytongue penstemon with 10 plants per plot. The best performing shrubs were Wytana and Snake River Plains fourwing saltbush at seven and five plants per plot, respectively. The five sagebrush entries established an average of less than one plant per plot. Fringed sagewort was not observed on-site. The forb and shrub stands rated moderately poor to very poor, and the vigor ratings were moderate to moderately poor. The forb and shrub plants were extremely short and most were less than 1 inch in height.

On October 11, 2006, in conjunction with the installation of the Questar FEP, a short field review was conducted on the Shell plots. The Jonah area received approximately 3.5 inches in the 2006 period and 5.15 inches in the 2007 period (fig. 2). The study site is extremely droughty, and plant growth and development continued to be minimal. Species to note in the replicated plots included Rocky Mountain beeplant (an annual wildflower that was tremendously successful at completing its reproductive cycle during the establishment year), Wytana and Snake River Plains fourwing saltbush, penstemons, flax, silverleaf phacelia, and primrose. The fourwing saltbush put on considerable growth since the July evaluation.

The analysis of variance (Statistix, 2007) of the 2007 data showed a substantial decline in more than 90% of the forb entries. The best performing forbs, as reported in table 2, were Rocky Mountain beeplant, native yarrow, and several penstemons. Thirteen entries were present in the sample area, with 9 entries noted outside the plots. Plant establishment was very low compared to the actual seeding rate, with an estimated stand of 0.3 plant/ft. The average vigor and stand rating was moderately poor and poor, respectively. Height was very short and averaged 1.8 inches. Showy evening primrose and scarlet globemallow were not observed on-site.

At least one cow and an antelope were discovered inside the fenced plot for an unknown amount of time, but it was assumed to be for less than 2 days. Several grass species were grazed and browse was noted in the fourwing saltbush, winterfat, flax, penstemon, yarrow, and not surprisingly, Antelope white prairie clover. Sage-grouse and rabbits were also noted as visitors to the plots.

The analysis of variance (Statistix, 2007) of the 2007 data showed Wytana fourwing saltbush as the best performer followed by Open Range and Northern Cold Desert winterfat (table 3). Eleven of the 16 species were present in the sample area, with five species noted outside the plots. Spiny hopsage was not observed on-site. Plant establishment was very low compared to the actual seeding rate, with an average 0.1 plant/ft. The average vigor and stand ratings were moderately poor and poor, respectively. Height was very short and averaged 3.8 inches.

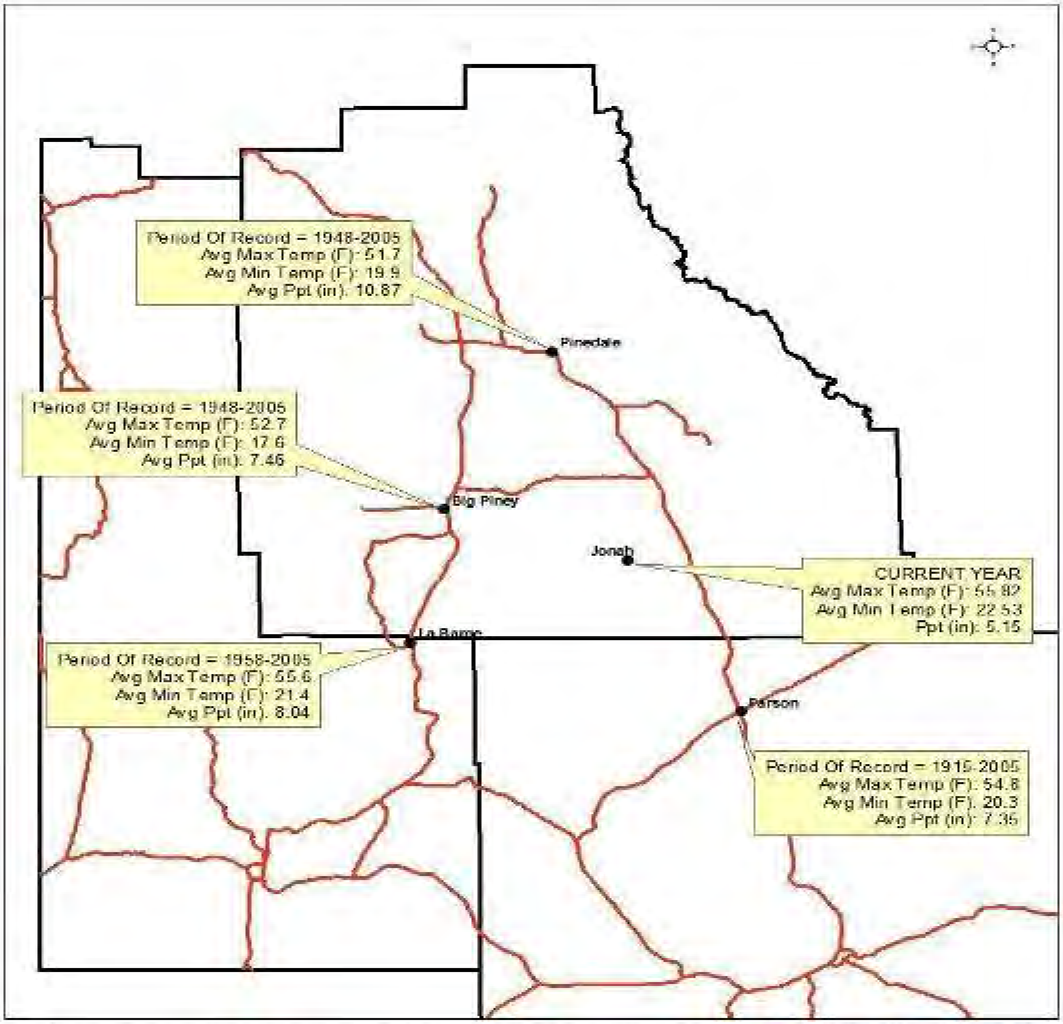


Fig. 2. Climate summaries for weather stations near the Shell and Questar Field Evaluation Plantings.

NRCS Natural Resources Conservation Service

Shell replicated plots: Copperhead slender wheatgrass in 2006 (left) and 2007 (right).

Shell replicated plots: Rocky Mountain beeplant in July 2006 and October 2007.

Shell replicated plots: fourwing saltbush in July 2006 and October 2007.

Shell Mixture Plots.

Drill-Seeded. The two seed mixtures are composed differently in species richness, relative proportion of life forms, and seeding rate. The 15-species Bridger mix is 40% grass, 33% forb, and 27% shrub, and was seeded at a rate of 10.12 lb pure-live-seeds/acre (table 4). The 10-species Shell mix is 20% grass, 40% forb, and 40% shrub, and was seeded at a rate of 5.18 lb pure-live-seeds/acre (table 5). The Shell mix was extremely fluffy due to the chaffy conditioning of the winterfat and several of the sagebrushes.

In 2006, 40% of the Bridger mix species was present in the sampled plots of the 1-acre treatment (table 7). The species, in order of most to least frequency, were 'Rimrock' Indian ricegrass and 'Rosana' western wheatgrass (25%), 'Pryor' slender wheatgrass and Wyoming big sagebrush (10%), and Wytana fourwing saltbush and silverleaf phacelia (5%). Overall vigor was moderately poor and plant height was approximately 1 inch. An additional 27% of the species mix was present outside the sample plots at very low estimates of percentage basal cover. They included 'Critana' thickspike wheatgrass, Great Northern western yarrow, Maple Grove prairie flax, and Open Range winterfat. The remaining 40% of the species in the mix was not present and included fringed sagewort, High Plains Sandberg bluegrass, scarlet globemallow, Stillwater prairie coneflower, and 'Trailhead' basin wildrye.

In 2007, there was a 50% increase in the number of Bridger mix grass species and a 50% decrease in non-grass species (table 7). Of the species in the mix, 53% were present in the sampled area. The species, in order of most to least frequency, were Pryor slender wheatgrass and Trailhead basin wildrye (50%), Rimrock Indian ricegrass and Wytana fourwing saltbush (40%), Critana thickspike wheatgrass and Rosana western wheatgrass (30%), Open Range winterfat (20%), and High Plains Sandberg bluegrass (10%). Overall vigor was moderate and plant height was approximately 4 inches.

Fringed sagewort and silverleaf phacelia were present outside the sample area. The remaining 40% of the species in the mix was not present and included Great Northern western yarrow, Maple Grove prairie flax, Stillwater prairie coneflower, scarlet globemallow, and Wyoming big sagebrush.

In 2006, in the 1-acre treatment with the Shell mix, 50% of the species was present in the sample area (table 8). The species, in order of most to least frequency, were silvery lupine (30%), Wyoming big sagebrush (25%), Sandberg bluegrass (20%), Rimrock Indian ricegrass (15%), and winterfat (5%). Overall vigor was poor and plant height was approximately 1 inch. An additional 40% of the species in the mix was accounted for outside the sampled plots at very low estimates of percentage basal cover, including fringed sagewort, Rydberg's penstemon, and native yarrow. Silvery lupine was estimated at 13% basal cover outside the sampled plots. Scarlet globemallow was not observed in the treatment area.

Shell drill-seeded plots 2007: Bridger mixture (left) and Shell mixture (right).

In 2007, in the 1-acre treatment with the Shell Mix, 60% of species in the mix was present in the sample area (table 8). The species, in order of most to least frequency, are fourwing saltbush (70%), Wyoming big sagebrush (50%), Rimrock Indian ricegrass (30%), Sandberg bluegrass and winterfat (20%), and Rydberg's penstemon (10%). The total number of plants in the treatment declined approximately 50% from the previous year. Overall vigor was moderately fair and plant height was approximately 3 inches. The remaining 40% of the species in the mix not present included fringed sagewort, native yarrow, scarlet globemallow, and silvery lupine.

There was higher plant density in the Bridger mixture plots, with 44% fewer seeds planted per acre, compared to the Shell mixture. The proportion of life forms was unchanged in the drill-seeded plots of the shrub-dominated Shell mixture, but non-grass plant density declined by more than 40%--silvery lupine (*Lupinus argenteus*) was completely absent and Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) dropped 61%.

<u>Broadcast-Seeded.</u> Establishment in the treatment was erratic due to the fluffy nature of the seed mix and uneven flow through the seeder. In 2006, 33% of the species was present in the sampled area of the 0.5-acre treatment with the Bridger seed mix (table 9). The species, in order of most to least frequency, were Rimrock Indian ricegrass (30%), Pryor slender wheatgrass (25%), Wyoming big sagebrush (15%), Critana thickspike wheatgrass (10%), and High Plains Sandberg bluegrass (5%). The overall vigor was moderate and plant height was approximately 1 inch. An additional 27% of the species in the mix was outside the sample area at very low ratings of stand establishment. These included Maple Grove prairie flax, Open Range winterfat, silverleaf phacelia, and Wytana fourwing saltbush. The species not observed were fringed sagewort, Great Northern western yarrow, scarlet globemallow, Stillwater prairie coneflower, and Trailhead basin wildrye.

Table 7. The species performance of the drill-seeded Bridger mix at the Shell Field Evaluation Planting near Pinedale, Wyoming.

Accession/Common Name	Scientific Name	Plants/acre†		% Stand		Vigor‡		Height (in)	
		2006	2007	2006	2007	2006	2007	2006	2007
Rimrock Indian ricegrass	*Achnatherum hymenoides*	4048	2723	1.9	1.3	7	5	2	3
Pryor slender wheatgrass	*Elymus trachycaulus*	1619	3630	0.7	1.7	5	6	2	4
Rosana western wheatgrass	*Pascopyrum smithii*	5668	1361	2.6	0.6	5	5	2	3
Critana thickspike wheatgrass	*Elymus lanceolatus*	0	1815	0	0.8	-	6	0	4
Trailhead basin wildrye	*Leymus cinereus*	0	3176	0	2.4	-	5	0	3
High Plains Sandberg bluegrass	*Poa secunda (P. sandbergii)*	0	454	0	0.2	-	6	0	2
9081632 silverleaf phacelia	*Phacelia hastata*	810	0	0.9	0	5	-	0.5	0
Open Range winterfat	*Krascheninnikovia lanata*	0	908	0	4.2	5	4	0	3
Wytana fourwing saltbush	*Atriplex aptera*	810	1815	3.7	8.3	5	3	1	7
Wyoming big sagebrush	*Artemisia tridentata* ssp.*wyomingensis*	1619	0	7.4	0	3	-	0.5	0
	Total:	14,574	15,881	0.85	0.93				

† Seeding rate 39 pure-live-seeds/ft^2 (10 PLS lb/acre); ‡ Rated 1-9 with 1 best.

Table 8. The species performance of the drill-seeded Shell mix at the Shell Field Evaluation Planting near Pinedale, Wyoming.

Common Name	Scientific Name	Plants/acre†		% Stand		Vigor‡		Height (in)	
		2006	2007	2006	2007	2006	2007	2006	2007
Sandberg bluegrass	*Poa seconda (P. sandbergii)*	5668	1361	0.6	0.2	5	8	1	0.5
Rimrock Indian ricegrass	*Achnatherum hymenoides*	3239	1815	2.3	1.3	5	5	3	3
Rydberg's penstemon	*Penstemon rydbergii*	0	454	0	0.2	-	5	0	0.5
silvery lupine	*Lupinus argenteus*	5668	0	43.0	0	5	-	0.5	0
winterfat	*Krascheninnikovia lanata*	810	908	1.4	1.6	5	5	3	6
fourwing saltbush	*Atriplex canescens*	0	4084	0	15.6	-	7	0	3
Wyoming big sagebrush	*Artemisia tridentata* ssp. *wyomingensis*	8097	3176	0.6	0.3	3	5	1	6
	Total:	23,482	11,798	0.8	0.4				

† Seeding rate 69 pure live seeds/ft^2 (5.2 PLS lb/acre); ‡ Rated 1-9 with 1 best.

In 2007, 73% of the species was present in the sample area of the 0.5-acre treatment with the Bridger seed mix (table 9). The species, in order of most to least frequency, were Critana thickspike wheatgrass (100%), Pryor slender wheatgrass (90%), Rimrock Indian ricegrass (70%), Wytana fourwing saltbush (60%), Wyoming big sagebrush (50%), Rosana western wheatgrass and Maple Grove prairie flax (40%), silverleaf phacelia (30%), Trailhead basin wildrye and Great Northern western yarrow (20%), and Open Range winterfat (10%). The total number of plants in this treatment was up nearly 50% from the previous year. Overall vigor was moderate and plant height was approximately 3 inches. The remaining 27% of the species in the mix not present included High Plains Sandberg bluegrass, Stillwater prairie coneflower, fringed sagewort, and scarlet globemallow.

In 2006, in the 0.42-acre treatment with the Shell seed mix, 60% of the species was present in the sample area (table 10). The species, in order of most to least frequency, were Wyoming big sagebrush (80%), Sandberg bluegrass (25%), winterfat (10%), and fourwing saltbush, Rimrock Indian ricegrass, and silvery lupine (5%). Overall vigor was moderately poor and plant height was approximately 1 inch. Native yarrow was found outside the sampled plots at a very low estimate of percentage basal cover. The remaining 30% of the species in the mix not observed were fringed sagewort, Rydberg's penstemon, and scarlet globemallow.

In 2007, in the 0.42-acre treatment with the Shell Mix, 40% of the species was present in the sample area (table 10). The species, in order of most to least frequency, were Sandberg bluegrass (90%), Wyoming big sagebrush (70%), and winterfat and fourwing saltbush (30%). Overall vigor was moderate and plant height was approximately 3 inches. The remaining 60% of the species in the mix not present included Rimrock Indian ricegrass, silvery lupine, fringed sagewort, Rydberg's penstemon, native yarrow, and scarlet globemallow.

The broadcast-seeded plots of both mixes achieved the highest plant densities, with the Bridger mix 31% greater than the Shell mix. Both of the broadcast-seeded densities were more than twice that of the drill-seeded densities. The original composition of the Bridger mix was maintained at slightly greater than 70% grass. The Shell mix broadcast plot, seeded 80% non-grass, is now composed of nearly 60% grass. The native plant community, as described in the Ecological Site Description, is most closely represented in the plot establishment of the Bridger mix.

Shell broadcast-seeded plots 2007: Bridger mixture (left) and Shell mixture (right).

Hydro-Seeded. In 2006, 33% of the species mix was present in the sample area of the 1-acre treatment with the Shell mix (table 11). The species, in order of most to least frequency, were winterfat (10%), and Sandberg bluegrass and Wyoming big sagebrush (5%). Overall vigor was average and plant height was approximately 2 inches. Fourwing saltbush, Rimrock Indian ricegrass, and silvery lupine were found outside the sampled plots at very low estimates of percentage basal cover. Fringed sagewort, Rydberg's penstemon, scarlet globemallow, and the native yarrow were not present. Due to the poor establishment, the area was hydro-seeded again in October 2006.

In 2007, 20% of the species mix was present in the 1-acre, reseeded treatment with the Shell mix (table 11). The species frequency was Rimrock Indian ricegrass (30%) and winterfat (10%). The estimated percentage stand establishment was down slightly compared to the first hydro-seeding. Overall vigor was very poor and plant height was approximately 3 inches. There were no plants of Sandberg bluegrass, Wyoming big sagebrush, fourwing saltbush, silvery lupine, fringed sagewort, Rydberg's penstemon, scarlet globemallow, and the native yarrow.

The hydro-seeding method was the least successful, and in fact, was twice considered a failure. Mixing seed directly into the slurry and applying as a one-step mulch application on a smooth slope surface, promotes seed movement and seedling desiccation due to drying and shrinking of the mulch. To restrict seed movement and promote seed-to-soil contact, a two-step approach is preferred where 1) the seed is separately mixed in a trace amount of mulch and applied directly to a roughened soil surface, followed by 2) a second application of mulch to reduce soil erosion and enhance micro-climate conditions necessary for germination and establishment (Holzworth, 2007).

Shell hydro-seeding with Shell seed mixture: December 2005 (left) and October 2007 (right).

The natural terrain of the site is rolling and the percentage slope mostly ranges from less than 1 to 8, with up to 12% slope in portions of the hydro-seeded treatment. In the steeper gradients, plots were tracked with minor rills where water moved downhill. Minor soil movement due to wind erosion was evident in small accumulations adjacent to the fence and in low lying areas.

Questar Replicated Shrub Plots. Spring monitoring in 2007 showed traces of initial emergence from Gardner's saltbush, chokecherry, curlleaf and alderleaf mountain mahogany, Prospector common snowberry, Open Range and Northern Cold Desert winterfat, Snake River fourwing saltbush, 9087673 western snowberry, and 'Maybell' antelope bitterbrush. The second accession of bitterbrush, 9087668, had a high level of emergence in all four plots. All bluebunch wheatgrass plots showed an initial level of emergence with 'Goldar' showing a slight advantage over the other entries.

Density counts taken in September indicate the ongoing drought severely impacted plant survival. Only three of the 25 shrub species (12%) were counted, as shown in table 12. Woody species were present in 13 of 116 plots (11%). There was considerable predation on the bitterbrush by rodents in addition to an aggressive Russian thistle infestation. Very few bluebunch wheatgrass could be found in the fall.

In spring 2008, the Questar site will be monitored for shrub establishment. The difficulty associated with long-term establishment of Wyoming big sagebrush may require use of a higher seeding rate (Schuman and Belden, 2002). A determination will be made whether or not to continue or replant in the near future.

Table 9. The species performance of the broadcast-seeded Bridger mix at the Shell Field Evaluation Planting near Pinedale, Wyoming.

Common Name	Scientific Name	Plants/acre†		% Stand		Vigor‡		Height (in)	
		2006	2007	2006	2007	2006	2007	2006	2007
High Plains Sandberg bluegrass	*Poa secunda (P. sandbergii)*	1134	0	0.3	0	5	-	1	0
Rimrock Indian ricegrass	*Achnatherum hymenoides*	7941	5899	1.8	1.4	7	7	1	2
Pryor slender wheatgrass	*Elymus trachycaulus*	6806	6353	1.6	1.5	5	6	3	2
Rosana western wheatgrass	*Pascopyrum smithii*	0	4991	0	1.2	-	7	0	2
Critana thickspike wheatgrass	*Elymus lanceolatus*	4538	13,613	1.0	3.1	5	7	3	4
Trailhead basin wildrye	*Leymus cinereus*	0	908	0	0.4	-	8	0	2
Great Northern western yarrow	*Achillea millefolium* var. *occidentalis*	0	908	0	0.4	-	7	0	2
Maple Grove prairie flax	*Linum lewisia*	0	1815	0	1.0	-	7	0	3
silverleaf phacelia	*Phacelia hastata*	0	1815	0	1.0	-	4	0	1
Open Range winterfat	*Kraschenninnikovia lanata*	0	454	0	1.0	-	5	0	2
Wytana fourwing saltbush	*Atriplex aptera*	0	2723	0	6.3	-	5	0	4
Wyoming big sagebrush	*Artemisia tridentata* ssp.*wyomingensis*	3403	4084	7.8	9.4	3	5	1	5
	Total:	22,822	43,563	0.7	1.3				

† Seeding rate 78 pure live seeds/ft^2 (20 PLS lb/acre); ‡ Rated 1-9 with 1 best.

Table 10. The species performance of the broadcast-seeded Shell mix at the Shell Field Evaluation Planting near Pinedale, Wyoming.

Common Name	Scientific Name	Plants/acre†		% Stand		Vigor‡		Height (in)	
		2006	2007	2006	2007	2006	2007	2006	2007
Sandberg bluegrass	*Poa secunda (P. sandbergii)*	6806	17,696	0.4	1.0	5	7	1	0.5
Rimrock Indian ricegrass	*Achnatherum hymenoides*	1134	0	0.4	0	7	-	1	0
silvery lupine	*Lupinus argenteus*	1134	0	4.3	0	5	-	1	0
fourwing saltbush	*Atriplex canescens*	1134	1815	2.2	3.5	5	4	2	3
winterfat	*Kraschenninnikovia lanata*	2269	1815	2.0	1.6	5	5	<1	5
Wyoming big sagebrush	*Artemisia tridentata* ssp. *wyomingensis*	22,688	8621	0.9	0.3	3	4	1	4
	Total:	35,165	29,948	0.6	0.5				

† Seeding rate 138 pure live seeds/ft^2 (10.4 PLS lb/acre); ‡ Rated 1-9 with 1 best.

Table 11. The species performance of the hydro-seeded Shell mix at the Shell Field Evaluation Planting near Pinedale, Wyoming.

Common Name	Genus & Species	Plants/acre†		% Stand		Vigor‡		Height (in)	
		2006	2007	2006	2007	2006	2007	2006	2007
Sandberg bluegrass	*Poa secunda (P. sandbergii)*	1134	0	0.06	0	5	-	1	0
Rimrock Indian ricegrass	*Achnatherum hymenoides*	0	3630	0	1.3	-	9	0	3
winterfat	*Kraschenninnikovia lanata*	2269	454	2	0.4	5	8	1	4
Wyoming big sagebrush	*Artemisia tridentata* ssp. *wyomingensis*	1134	0	0.05	0	3	-	3	0
	Total:	4,537	4,084	0.08	0.07				

† Seeding rate 138 pure live seeds/ft^2 (10.4 PLS lb/acre); ‡ Rated 1-9 with 1 best.

Table 12. The 2007 performance of the replicated shrub plots at the Questar Field Evaluation Planting near Pinedale, Wyoming.

Accession/Common Name	Scientific Name	Total plants/160 ft^2 plot
9087668 antelope bitterbrush	*Purshia tridentata*	75
Open Range winterfat	*Kraschenínnikovia lanata*	3
Northern Cold Desert winterfat	*Kraschenínnikovia lanata*	3
9087671 wax currant	*Ribes cereum*	1

Questar replicated plot 2007: antelope bitterbrush in May (left) and October (right).

DISCUSSION

The demand for affordable energy to fuel our nation's economy is resulting in the rapid expansion of energy exploration and extraction in high elevation sagebrush ecosystems in Wyoming. Sagebrush plant communities support mule deer, antelope, and sage-grouse, among other wildlife species (Welch, 2005). They are also important to the livestock industry. Disturbances resulting from energy exploration differ from historic disturbances of wildfire and grazing predominantly in the extent of soil disturbance, soil compaction, and loss of soil structure. Restoration of native plant communities with a diversity of grass, forb, and shrub species important to key wildlife species is relatively unrealized (Hardegree et al, 2002). The short-term results of these field experiments and trials provide information to further our ability to restore native plant communities and reduce the impact of development on sensitive wildlife species.

The Bridger mix was mostly comprised of commercially available seed and the Shell seed mixture was mostly wildland-collected. Seed costs are conservatively estimated at $125/acre for the Bridger mix and $200/lb for the Shell mix. An ongoing debate over strict use of locally indigenous material, versus seeding with widely adapted native plant materials, will ultimately be determined by seed availability and the price associated with timely revegetation of disturbed sites (Hijar, 2003; Booth and Vogel, 2006).

Environmental factors such as low precipitation, higher temperatures, and increase of weedy species, inhibit seedling establishment (Monsen et al, 2004). The native species with the highest establishment are those taking advantage of early spring moisture. Drought tolerance is the key to long-term survival in this harsh climate. The effects of mechanical site preparation and seeding techniques on disturbed sites may elevate soil erosion during the early stages of plant establishment (Pierson et al, 2007). Those factors, along with a need to determine appropriate planting techniques, should be taken into consideration during all aspects of planning for the exploration of oil and gas in southwest Wyoming.

SUMMARY

The replicated plots on the Shell site indicate accessions, currently developed, that are easily established using drill seeding under the environmental and disturbance conditions of the area. Accessions of *E. lanceolatus*, *E. trachycaulus*, *L cinereus*, and *P. spicata* demonstrated rapid establishment important in stabilizing severely disturbed soils. This is supported in the results of a similar trial conducted from 1987-2002 at Soda Lake, near Pinedale (USDA, 2008*b*). Although forb establishment was below expectations, *C. serrulata*, *A. millefolium*, *L. perenne*, *P. eatonii*, *P. eriantherus*, and *P. hastata* showed the greatest promise for providing diversity of this functional group important to wildlife habitat. Similarly, shrub establishment was disappointing with only four of 16 species important to wildlife established after two growing seasons. They were *A. aptera*, *A. canescens*, two accessions of *K. lanata*, and *A. tridentata* ssp. *tridentata.* Although establishment was below estimates of a full stand, these same species were most often encountered in the seeding mixture trials, suggesting an increased seeding rate may improve establishment.

Species performance of the drill-seeded mixture plots was substantially lower than in the broadcast-seeded mixture plots, suggesting seeding depth is an important factor for many of the small-seeded species. This is comparable to the findings of a similar trial conducted on the Express Pipeline near Greybull and Worland, Wyoming (USDA, 2002). Also, soil roughing treatments may prevent wind loss of seed from the site. Results suggest the one-step practice of hydro-seeding may not be effective and should be seriously reconsidered as the planting method of choice in the restoration of native plant communities on these sites.

The dormant-seeded planting dates in the Shell and Questar trials coincide with the Soda Lake planting dates, while the Express Pipeline test sites were spring-seeded. Future seeding trials in the Pinedale Anticline and Jonah Field should consider experimenting, depending on species, with both spring and fall planting dates.

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BURLINGTON MINE VCUP CASE HISTORY
AN ECOLOGICAL APPROACH TO MINE SITE REMEDIATION

Maureen O'Shea-Stone and Julie Ash, P.E.
Walsh Environmental Scientists and Engineers, LLC
4888 Pearl East Circle, Suite 108
Boulder, CO 80301

ABSTRACT

Remediation of the Burlington Mine was accomplished under a Voluntary Cleanup Plan (VCUP) action. The inactive mine site is located in the foothills of Boulder County, Jamestown, Colorado. In operation from 1920 to 1973, the Burlington Mine was part of the chief fluorspar-producing mining district for the western United States. Goals of the remediation were to use an ecological approach to improve water quality in downstream receiving streams, reduce surface and groundwater interaction with contaminated materials, limit the potential for future subsidence, and reduce onsite safety hazards and liability. Remedial activities consisted of consolidating acid-generating waste rock, closure of onsite adits and shafts, subsidence pit fill and mounding, realignment of an intermittent tributary, surface water runoff management, and site-wide revegetation. The VCUP design incorporated many innovative techniques that exceeded basic requirements, met multiple project goals, and accommodated the abundant physical constraints and challenges at the mine site. These included measures to address drainage issues at pit closures and unique techniques to imitate natural channel form and function. Revegetation was accomplished using soil amendments instead of topsoil augmentation. Seed mixes comprising a diverse range of native species, life forms, and longevity were developed for upland and riparian areas. Containerized shrub and tree stock was strategically planted to benefit from appropriate created habitat conditions for screening and wetland compensatory mitigation. All remediation goals were accomplished. The ecological approach resulted in naturalistic and functional, self-sustaining systems that help soften the harsh aesthetics of the former mine site and provide improved natural habitat.

INTRODUCTION

Site History

The Burlington Mine site is approximately one mile northwest of Jamestown, at the intersection of County Roads 94 and 87, in Boulder County, Colorado. The site is located on the west side of Porphyry Mountain at an elevation of about 7,300 feet and was considered part of the Jamestown Mining District, at the northeast end of the Colorado mineral belt. The district started-out as a gold-producing area, although silver, lead, and other minerals were also produced. Uranium is present in the ores from the district but does not appear to have been a major product. In later years, the district became one of the chief fluorspar producers in the western United States, of which the Burlington Mine represented the largest deposit in the district. At least eight other mines occur within a half-mile of the Burlington site.

Photo 1. View of the Burlington fluorspar mine complex, around 1940, including the mine adit, waste rock pile, residences and a hoisting tower.

Records indicate that Frank and James Warren originally patented the Burlington claim in 1920. General Chemical Corporation, later a division of Allied Chemical Corporation, began mining the Burlington fluorspar ore body in 1942 and remained a large producer for over 30 years.

Extensive development began in the early 1940s when General Chemical Company purchased the mine. Between 1943 and 1973, the mine was enlarged from a single 150-foot shaft with workings on two levels to a depth of over 1,500 feet, reportedly the deepest mine in the district, with more than 10,000 linear feet of workings on 14 levels. In about 1971, a small, open cut mine was begun on the hillside above the Balarat Hill Road and the surface structures of the mine, but was only worked for a short time. Throughout the period of ownership by General Chemical and Allied, ore from the Burlington Mine Site was shipped to Boulder for production of acid-grade fluorspar. It does not appear that milling ever occurred at the mine site.

According to a 1975 mine inspector’s report, the Burlington Mine Site was shut down in 1973. It was reported that 16 acres were reclaimed that year. In addition, buildings on site were torn down and the collar of the shaft was filled with concrete. The report stated that one-fourth acre of land was mined and two acres were used as a mine waste rock disposal area.

In 1982, Boulder County nominated the site (as part of the larger mining district) for listing as an uncontrolled hazardous waste site. The Environmental Protection Agency (EPA) performed a Preliminary Assessment of the Golden Age Mine in 1993 and an Expanded Site Inspection (ESI) in 1997. The Burlington Mine Site was included in the study area with three other local mines, the streamside, and a tailings deposit in the Jamestown town park. No notifications for hazardous substances were required. The site was found to not be eligible for listing on the National Priorities List (NPL) of Superfund sites established under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

Photo 2. Ore bin and loading structure amidst waste unvegetated waste rock pile.

Existing Conditions

At the time of the VCUP, the site was a vacant mining property, dominated by an unvegetated waste rock feature (Photo 2). Two subsidence pits and a large mine shaft opening (Photo 3) presented significant hazards and impacts to water quality. A concrete and steel ore bin and loading structure and several building foundations remained on the property. The Balarat Hill Road (County Road 82) crosses the north edge of the 11 acre site, between the main mine site and the secondary open cut mine to the north (Photo 4). The largest subsidence pit was intercepting flows in Balarat Gulch and created a direct flow path into the mine workings. Interaction with mine workings and waste rock resulted in potential water quality impacts downstream to Little James Creek (Photo 5) and ultimately to Left Hand Creek. A pond at the southern toe of the waste rock pile also drained into Balarat Gulch (Photo 6).

Photo 3. Tunnel opening in middle of waste rock pile.

Impetus for VCUP

The Voluntary Cleanup and Redevelopment Act (VCRA), effective July 1, 1994, is a program designed to foster a cooperative relationship between applicants and the Colorado Department of Public Health and the Environment (CDPHE). It is designed to solve problems to the mutual benefit of both parties, and avoid inefficient enforcement actions. Properties must not fall within the authority of other environmental enforcement programs, and the program has no enforcement authority. The owner of a property in the program may choose not to implement cleanup and no referral to any other regulatory program would occur. The program encourages voluntary cleanups of contaminated industrial and commercial properties by providing a framework for determining site-specific clean-up responsibilities and an expedited review and approval process.

REMEDIATION GOALS

Primary goals for the VCUP included:

- an ecological approach,
- improve water quality in downstream receiving streams,
- establish a naturalistic and functional, self-sustaining plant community,
- reduce surface and groundwater interaction with contaminated materials,
- limit the potential for future subsidence, and
- reduce onsite safety hazards and liability.

Remedial activities consisted of consolidating acid-generating waste rock, closure of onsite adits and shafts, subsidence pit fill and mounding, realignment of an intermittent tributary, surface water runoff management, and site-wide revegetation.

ENGINEERING ACTIONS AND RESULTS

The use of naturally functioning systems was a project goal that exceeded basic requirements. Their successful implementation at the Burlington mine site faced notable challenges to accommodate multiple project goals, as well as the abundant physical constraints at the mine site. In regards to site drainage, the use of natural systems is an important improvement over more traditional mine site remediation, which has always addressed safe conveyance of onsite water, but not necessarily how to restore natural form and function or how to use the water to maximize habitat value.

Photo 4. Secondary open cut mine.

Water Quality Improvement

The goal of water quality improvement was addressed through a combination of treatments, each of which served to reduce the interaction of surface and groundwater with the contaminated mine waste materials and underground mine workings located onsite.

Sitewide Treatments

Photo 5. Interception of Balarat Gulch by largest subsidence pit.

Activities to correct sitewide surface and groundwater interactions included surficial waste rock consolidation, subsidence pit fill and mounding, soil amendments and topdressing, and revegetation with native species. The waste rock consolidation reduced the footprint of contaminated materials onsite, which reduced the area of potential contact and interaction.

Under existing conditions, the subsidence pits were providing direct flow paths into the mine workings. Of particular concern was the pit that intercepted Balarat Gulch, an intermittent drainage that drains to Little James Creek and ultimately to Left Hand Creek (Photo 7). Backfilling this pit was the first step in eliminating the direct flow path for the gulch into the mine workings. Final grading included substantial mounding over the backfilled pits to create a minimum two percent slope. The positive slope created by the mounding discourages infiltration – and potential contact with mine workings - by promoting runoff. In anticipation of backfill settling, the area was overmounded by a minimum of four feet.

Soil amendment included an agricultural lime application to neutralize the acid generation potential of the waste rock. All areas slated for revegetation were overlaid with a native subsoil layer and dressed with compost. These topdressing layers serve two purposes: 1) they create a physical barrier to precipitation contacting the potentially acid generating materials below and 2) they provide a suitable growth medium for the revegetation effort. The physical barrier is actually a second level of protection against acid mine drainage generation since the waste rock was neutralized by the lime treatment. Revegetation helped stabilize the site and promote evapotranspiration and interception of precipitation over infiltration.

Balarat Gulch Treatments

Activities to correct the surface and groundwater interactions associated with Balarat Gulch included control of subsurface flows and construction of a diversion channel that realigned the drainage to avoid mine workings.

A projection to ground surface, created from 3-D mine mapping developed for the site, was used to identify the optimal centerline location and inverts for the diversion channel. The realignment routes flows to the east of the old subsidence areas. The diversion channel was sized to contain the 100-year storm event (plus 20 percent) within the protected main channel banks. The 100-year design reasonably protects against surface water re-accessing the mine workings by overflowing the diversion channel.

Photo 6. Mine pond at toe of waste rock pile.

The critical upper reach of the diversion channel, where the channel makes a sharp bend away from its historic path, was lined with a PVC liner to force water to stay in the channel and further reduce the potential for piping failure behind the channel's boulder wall bank protection. The two lower reaches of the diversion channel were left unlined to allow hillslope groundwater to access the new channel, rather than being forced underneath where it could potentially reach the underground mine workings.

While the diversion channel adequately rerouted surface flows in the gulch, a substantial portion of the total flow was being conveyed below the surface through the alluvium and along the bedrock contact. This subsurface flow had to be intercepted along with surface flows to successfully prevent water from reaching the mine workings. A primary alluvial water control structure, extending down to bedrock, was installed at the top of the diversion channel. Depth to bedrock was determined by a geotechnical drilling program.

Two main components comprised the alluvial control structure – a curtain drain and an impermeable liner. The curtain drain was constructed of prefabricated drainage panels with perforated PVC pipe threaded through bottom sleeves. The drain conveys the intercepted water. The impermeable lining traps the intercepted water, preventing it from bypassing the structure and forcing it into the curtain drain system.

Photo 7. Subsidence pit intercepting Balarat Gulch.

As a secondary control, a scavenger drain installed to protect the pit closures was located where it could capture any water not intercepted by the upslope primary control. The scavenger drain also captures local groundwater flowing toward the closed features.

The combination of rerouting flows, pit backfill, and subsurface water control provides solid protection against flows re-accessing the mine workings. By preventing contact with the workings, cleaner water is delivered downstream.

Erosion and Sedimentation Controls

Additional measures were implemented to control erosion and sedimentation at the site long-term. Site grading and drainage included construction of a surface water control channel network, which conveys runoff through the site in a controlled manner and prevents the formation of rills or gullies to minimize sediment entrainment. Construction best management practices (BMPs) were employed to provide interim surface protection until vegetation became fully established at the site.

The sitewide revegetation also assists with erosion and sediment control. Vegetation stabilizes the soil, decreasing erosion from stormwater runoff. Site grading followed a maximum 3H:1V slope wherever possible to assist the revegetation efforts and prevent excessive runoff velocities.

Reduction of Future Subsidence Potential

The Burlington Mine site has experienced consistent subsidence for at least 30 years. A beneficial side effect of the aforementioned water quality improvement activities is the notable reduction of future subsidence potential. The closure of shafts and subsidence areas combined with the realignment of Balarat Gulch away from the mine workings will inherently reduce the future risk of subsidence in the areas historically plagued with this problem. Similarly, by controlling and intercepting subsurface flows that would otherwise access the closed mine features, the water quality improvements mitigate the risk of future subsidence on the site.

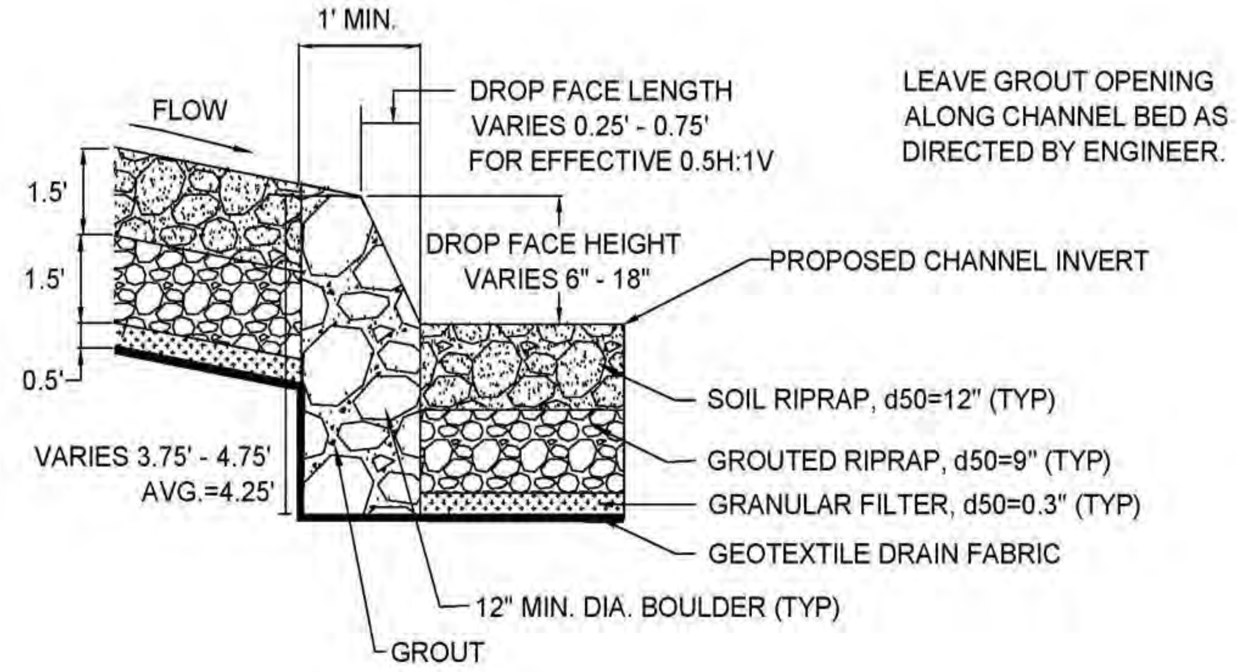
Ecological Approach

Methods for incorporating natural form and function and enhancing habitat were utilized in all feasible aspects of the remediation. The most notable features are the bed and bank treatments for the diversion channel, use of natural materials for all visible structures, waterfowl protection measures, and sitewide revegetation with native species.

Channel Bed and Bank Treatments

An innovative channel design was employed for the Balarat Gulch diversion channel. The design imitated natural channel form and function, incorporated naturalizing elements, and created aquatic and riparian habitat.

A step-pool configuration was built into the channel since this channel form is typical of high-gradient alpine streams. These systems use frequent drops to dissipate energy, as opposed to flatter gradient, valley floor systems that dissipate energy by meandering. The ranges for height and spacing of drop structures, which were used to create the step-drops, were determined based on observations and measurements of the step-drops in the reaches above and below the diversion channel. The closely spaced step-drops achieve flatter between-drop slopes and they create natural flow variability with areas of faster and slower moving water. The drop structure detail is shown below.



While the channel was designed to withstand flows in excess of the 100-year storm, a mobile bed utilizing soil and rock gradations found in the natural channel was specified as a surface treatment. The surface material is mobilized frequently by lower intensity, higher recurrence interval storms. This mobility allows natural scour and deposition cycles to occur, which can form localized pools and develop a low flow channel. The creation of deeper water prevents overly wide, shallow flow, which is a common constraint to aquatic habitat. The mobile bed treatment was underlain by a resistive grouted riprap layer to provide vertical protection against lowering of the channel invert. Channel lowering could not be allowed due to the mine workings below.

Photo 8. Balarat Gulch Diversion Channel, 2004.

Creating small notches in the tops of the drop structures further encouraged the development of a low flow channel. Notches were designed to follow a random, alternating pattern down the channel to promote low flow sinuosity. Natural materials were given preference during design of the bed and bank treatments. Concrete or grouted riprap were avoided as surface layers, favoring natural rock and boulders to provide the required surface protection.

Photos 8 and 9 show the Balarat Gulch Diversion Channel immediately following construction in 2004 and the more natural look afforded by the establishment of woody and herbaceous vegetation along the channel two years later in 2006.

The comprehensive revegetation plan, utilizing all native species, benefited the newly created channel by restoring riparian vegetation wherever possible. Native riparian shrubs and trees were planted along the lower reach of channel, where impermeable lining or exposed bedrock did not preclude their use. Restoring the riparian zone along the channel provides shading and cooling of streamflows, protective overhead cover, and terrestrial habitat. Streamside vegetation also helps to stabilize banks and functions as a detritus source for the aquatic system, forming the base of the aquatic food chain. Photo 10 shows the enhanced riparian corridor along the lower reach of Balarat Gulch.

Photo 9. Balarat Gulch Diversion Channel, 2006.

Photo 10. Lower reach of Balarat Gulch, 2006.

Waterfowl Protection

An old mine tunnel at the south end of the site has become permanently flooded and causes a constant discharge from the overlying pond. The flooded area is known as the "mine pond". Water in the pond has a low pH and heavy iron staining exists along the discharge path from the pond.

While the pond and its discharge had to be excluded from this VCUP project due to point source discharge issues, concerns for the health of waterfowl that would be tempted to land in the pond were addressed. Bird Balls™, which were recommended by the U.S. Fish and Wildlife Service, were used to cover the pond surface, preventing waterfowl from landing or residing in the pond, and removing potential contamination pathways. Photo 11 shows the Bird Balls™ covering the mine pond.

Engineering Results

The ecological approach employed for the Burlington mine site remediation resulted in more natural and functional systems that help soften the harsh aesthetics of the old mine site and improve habitat. Some of the most notable natural features at the site are the bed and bank treatments along the diversion channel. Woody and herbaceous vegetation is successfully establishing along the new channel, in the flat benches between drop structures, as intended. The

Photo 11. Bird Ball™ installation to protect waterfowl

riparian vegetation is helping to stabilize the channel under lower flow conditions and functions as a detritus source for the aquatic system, forming the base of the aquatic food chain. Restoration of the riparian corridor will ultimately provide shading and cooling of streamflows, protective overhead cover, and terrestrial habitat.

The biggest challenge associated with the Balarat Gulch diversion channel turned out to be stabilization of the extensive eastern sideslope, which had to be excavated to a 2 to 2.5H:1V sideslope. These slopes are steeper than typically desired, but were unavoidable due to the underlying mine workings. The alternative approach to maintain a 3H:1V sideslope would have dramatically increased the total disturbance area (due to the steep existing hillslope and difficulty in catching grade), to the extent that the additional loss of mature ponderosa and lodgepole pines would have been more detrimental than helpful.

Photo 12. Amendment test plot with several treatment combinations.

The steep sideslope was seeded with a native seed mix, which included native shrub seed selected specifically for optimal establishment on micro-niches within the bedrock face. The slope was then mulched and tackified prior to installation of a biodegradable, woven coconut coir erosion control fabric.

Early in the monitoring phase, problematic drainage conditions were identified along the hillslope that were exacerbating the already severe conditions and hindering revegetation. First, the excavation along the hillslope had intercepted several small drainages that were concentrating surface runoff and creating deep rills down the hillslope, under the erosion control fabric. Second, the excavation had intercepted a groundwater seep that was contributing to local instabilities. In some areas, the fabric was stretched to failure by the underlying erosion.

Rerouting flows where possible and using woody material as supplemental velocity breaks to reduce the erosive energy of flows before they accessed the hillslope stabilized the points of concentrated flow. Water from the seep was collected in a below-ground drain system and routed safely around the vulnerable hillslope to more stable, vegetated areas. This system is similar to the curtain drain employed at the top of the Balarat Gulch diversion to capture alluvial flows. Concurrent with these corrective measures, the larger rills were regraded as best possible on the steep, tall hillslope and erosion control fabric was re-installed in problem areas. These corrective measures were very successful and significant rilling has not occurred since the treatments.

Today, the sideslope shows signs of slow progress towards revegetation. Three growing seasons after construction, vegetative coverage is currently as low as five percent in some sections of the hillslope, but as high as 85 percent in other sections. Due to the severe conditions, revegetation of this hillslope is expected to take 10 to 20 years.

BIOLOGICAL ACTIONS AND RESULTS

Amendment Test Plot

The project was fortunate to have time and budget to establish a plot to test the relative merits of soil amendments (no organic amendment, topsoil, and four application rates of compost) in terms of plant germination and establishment. Waste rock was scraped from sides of the existing waste rock pile and redistributed across the top of a third-acre test site in a 12-inch lift. This material was previously tested for pH to determine lime application rates sufficient to neutralize acid-forming potential of the material. An appropriate rate of lime was applied (4 tons/ 1000 ft^2) and ripped into the upper 6 inches of waste rock across the entire test site. Compost applications were ripped into the upper 6 inches of the waste rock.

Treatments were applied to six test plots, each approximately 50 feet by 20 feet, laid out in parallel, contiguous strips, across the lime-treated waste rock site, as described below:

- Treatment 1 – Compost 1 - compost applied at rate of 30 tons/ acre, with lime.
- Treatment 2 – Compost 2 - compost applied at rate of 40 tons/ acre, with lime.
- Treatment 3 – Compost 3 - compost applied at rate of 50 tons/ acre, with lime.
- Treatment 4 – Compost 4 - compost applied at rate of 60 tons/ acre, with lime.
- Treatment 5 – Positive Control - 15 inches of subsoil + 3 inches of local topsoil.
- Treatment 6 – Negative Control - lime treatment, with no organic material.

The site was seeded with the same mix proposed for project waste rock repository. All treatments were broadcast seeded at a rate of 120 seeds/$foot^{2.}$ The site received nothing more than ambient precipitation for the entire 2003 growing season. Success parameters were measured using three replicate samples per treatment cell per sample date. Germination success was measured by counting seedlings per 25 cm^2 sample frame approximately one month after seeding. Establishment was sampled twice during the growing season. Establishment parameters measured included: 1) ocular estimation of percent cover, by life form (graminoid or forb) per 25 cm^2 sample frame, 2) height of tallest specimen per life form in each replicate quadrat, and 3) total species richness per treatment.

Photo 13. Amendment test treatment: Subsoil + 60 tons compost/acre.

As expected, the poorest performing treatment for any parameter was no subsoil with no organic amendment. The best performing treatment for germination and establishment was subsoil + 50 tons compost/acre or 60 tons compost/acre. This combination of subsoil plus compost at these rates resulted in cover estimates more than double those for the subsoil + topsoil treatment. It was therefore concluded revegetation success would be most likely achieved using a 15 inch subsoil layer, amended with commercial compost at a rate of 60 tons/ acre, over the lime amended waste rock material.

Revegetation Design Details

Revegetation addressed the waste rock repository, native, disturbed soils, and undisturbed native soils as well as the riparian corridor and other wetland mitigation areas, and an extensive and steep native rock/soil slope on the northwest side of the new channel.

Final grading was done perpendicular to new slopes. Final grade surfaces were intentionally left rough. No rock or pebble debris was removed. Upon achievement of final grade the different areas were treated as follows:

Photo 14. Amendment test treatment: no subsoil + 30 tons compost/ acre.

Waste Rock

- Waste rock was moved and consolidated into a central repository
- Agricultural lime (Effective Calcium Carbonate Equivalent [ECCE] of 87%) was applied at 30 tons/acre and ripped to a depth of 12 to 15 inches. This was allowed to cure for three months.
- Reserved subsoils were spread over the waste rock to a depth of 15 inches.
- Commercial (Type A) compost applied at a rate of 60 tons per acre, ripped into subsoil to a depth of 9 to 12 inches. All areas were broadcast seeded at a rate of 120 PLS/foot^2, using the site-specific upland seed mix detailed below. This was followed with hydromulching of all seeded areas.
- Erosion Control Fabric (ECF) was installed on the slopes greater than 2.5:1 after final grading, seeding, and mulching.

Disturbed Native Soils

- These soils were uncovered when waste rock was moved and consolidated. Agronomic tests showed these samples had considerable lower pH values than surrounding native, undisturbed soils.
- Agricultural lime applied at 5 tons/acre and ripped to a depth of 12 to 15 inches. This was allowed to cure for almost three months.
- Steepest streamside hillslope was hydroseeded at a rate of 120 PLS/foot^2. All other areas were broadcast seeded at the same rate, both areas using the site-specific upland seed mix

detailed below. This was followed with hydromulching of all seeded areas. Erosion Control Fabric (ECF) was installed on the slopes greater than 2.5:1 after final grading, seeding, and mulching.

- Upland trees and shrubs were planted following the schedule detailed below.

Wetland Mitigation Areas

- These areas were graded to final contours, and broadcast seeded at a rate of 100 PLS/foot^2, using the site-specific wetland mitigation seed mix detailed below. This was followed with hydromulching of all seeded areas.
- Riparian shrubs were planted following the schedule detailed below.

UPLAND SEED MIX				
Binomial	**Common Name**	**Form**	**Season**	**%of Mix***
Bromopsis marginatus	mountain brome 'Bromar'	bunch	C	10
Deschampsia cespitosa	tufted hairgrass 'Peru Creek'	bunch	C	10
Elymus canadensis	Canada wildrye	bunch	C	10
Elymus trachycaulus	slender wheatgrass 'San Luis'	bunch	C	10
Poa fendleriana	mutton bluegrass	bunch	C	10
Koeleria cristata	Junegrass	bunch	C	10
Poa canbyi	Canby bluegrass 'High Plains'	bunch	C	10
Aster chilensis	Pacific aster	forb	NA	3
Gaillardia aristata	blanketflower	forb	NA	2
Linum lewisii	Lewis flax	forb	NA	2
Lupinus argenteus	silver lupine	forb	NA	4
Monarda fistulosa	bee balm	forb	NA	3
Penstemon strictus	Rocky Mountain penstemon	forb	NA	3
Vicia americana	American vetch	forb	NA	4
Thermopsis rhombifolia	golden banner	forb	NA	4
Ceanothus fendleri	buckbrush	shrub	NA	1
Cercocarpus montanus	mountain mahogany	shrub	NA	1
Purshia tridentata	bitterbrush	shrub	NA	1
Ribes cereum	wax current	shrub	NA	1
Rosa woodsii	wild rose	shrub	NA	1
			Total	100

*rate of 120 pure live seed (PLS) per foot^2

WETLAND MITIGATION SEED MIX			
Binomial	**Common Name**	**Indicator Status**	**% of Mix**
Juncus balticus	Baltic rush	FACW	20
Carex nebrascensis	Nebraska sedge	OBL	30
Carex aquatilis	water sedge	OBL	20
Deschampsia cespitosa	tufted hairgrass	FACW	15
Phleum alpinum	alpine timothy	FAC	15
		Total	100

*rate of 100 pure live seed (PLS) per foot^2

RIPARIAN SHRUB SCHEDULE				
Binomial	**Common Name**	**Size**	**Spacing**	**#**
Acer glabrum	Rocky Mountain maple	# 5	5' o.c.	38
Alnus incana	thinleaf alder	# 5	5' o.c.	46
Betula occidentalis	river birch	# 5	5' o.c.	46
Lonicera involucrata	twinberry	# 5	5' o.c.	37
Prunus virginiana	chokecherry	# 5	5' o.c.	18
Ribes aureum	golden currant	# 5	5' o.c.	37
			Total	222

UPLAND TREE AND SHRUB SCHEDULE			
Binomial	**Common Name**	**Size**	**Number**
Pinus ponderosa	ponderosa pine	# 5	20
Cercocarpus montanus	mountain mahogany	# 5	30
Juniperus scopulorum	Rocky Mountain juniper	# 5	20
Padus virginiana	chokecherry	# 5	30
Physocarpus monogynus	ninebark	# 5	20
Purshia tridentata	bitterbrush	# 5	15
Ribes cereum	wax current	# 5	20
Rosa woodsii	wild rose	# 5	15
		Total	170

In addition to seeding, containerized shrub and tree stock was strategically planted to benefit from appropriate created habitat conditions for screening and wetland compensatory mitigation. Shrub and tree schedules are detailed above.

Photo 15. Sampling transect running up waste rock repository slope.

Biological Results

Revegetation has progressed as expected over the first three full growing seasons following project completion. Limited quantitative monitoring is summarized below. The following described general trends observed over the first three growing seasons following seeding and planting.

Average foliar cover was approximately 61 percent across the upland portions of the site by the end of the first growing season. By the end of the third full growing season, this value had increased to almost 65 percent.

Relative cover by native species was approximately 81 percent after the first growing season. This has been dramatically reduced to 44 percent by the end of the third growing season. This is despite the gradual reduction in the diversity of non-native species on the site (12 to 5.5) over the three years.

This is due to a relative explosion of kochia (*Bassia sieversiana*) between the second and third growing season, although it was barely present the first year. This population is now ubiquitous across the site, although the individual plants are very short (two to four inches tall).

Photo 16. Before: secondary open cut mine, January, 2004

Other than the kochia issue, weeds have been a relatively minor problem on the site. Control is being accomplished primarily by mechanical controls. A small but dense patch of prickly lettuce (*Lactuca serriola*) was continually deadheaded over the course of the first growing season, substantially reducing the seed set. Very few individuals were noted the second growing season. On-going deadheading of mullein (*Verbascum thapsus*) two or three times a year is resulting in much smaller number of individuals each subsequent growing season.

Photo 17. After: secondary open cut mine, September 2005

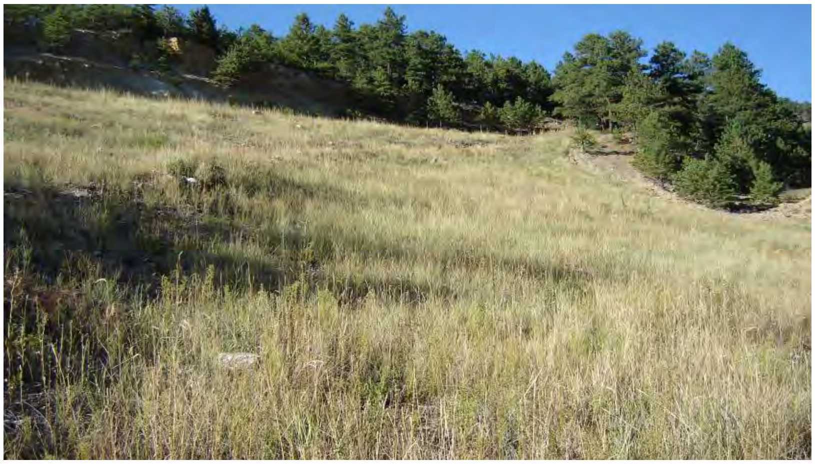


Photo 18. After: secondary open cut mine, September 2007

ANNUAL REVEGETATION MONITORING RESULTS SUMMARY				
Percent Cover	**2005**	**2006**	**2007**	**Mean**
Vegetation	61.0	61.6	64.8	62.5
Bare Ground	35.6	29.3	27.2	30.7
Rock	4.6	9.2	8.1	7.3
Relative Cover				
Native Species	80.8	40.8	43.7	55.1
Non-native Species*	19.3	20.8	21.1	14.4
Species Diversity				
Native Species	16.8	21	21.5	19.8
Non-native Species*	12	8.3	5.5	8.6
Total # Species	28.8	29.3	27.3	28.5

*includes cover by weeds

REFERENCES

Walsh, 2002. Voluntary Cleanup Plan Application, Mine Waste Rock Piles, Burlington Mine Site, Jamestown, Colorado. February 27.

RESTORATION OF SUBALPINE WETLANDS WHITE RIVER NATIONAL FOREST

David Johnson
Rea Orthner
Western Ecological Resource, Inc.
711 Walnut Street, Boulder, CO 80302

David Buscher
Buscher Soil and Environmental Consulting, Inc.
PO Box 156, Rollinsville, CO 80474

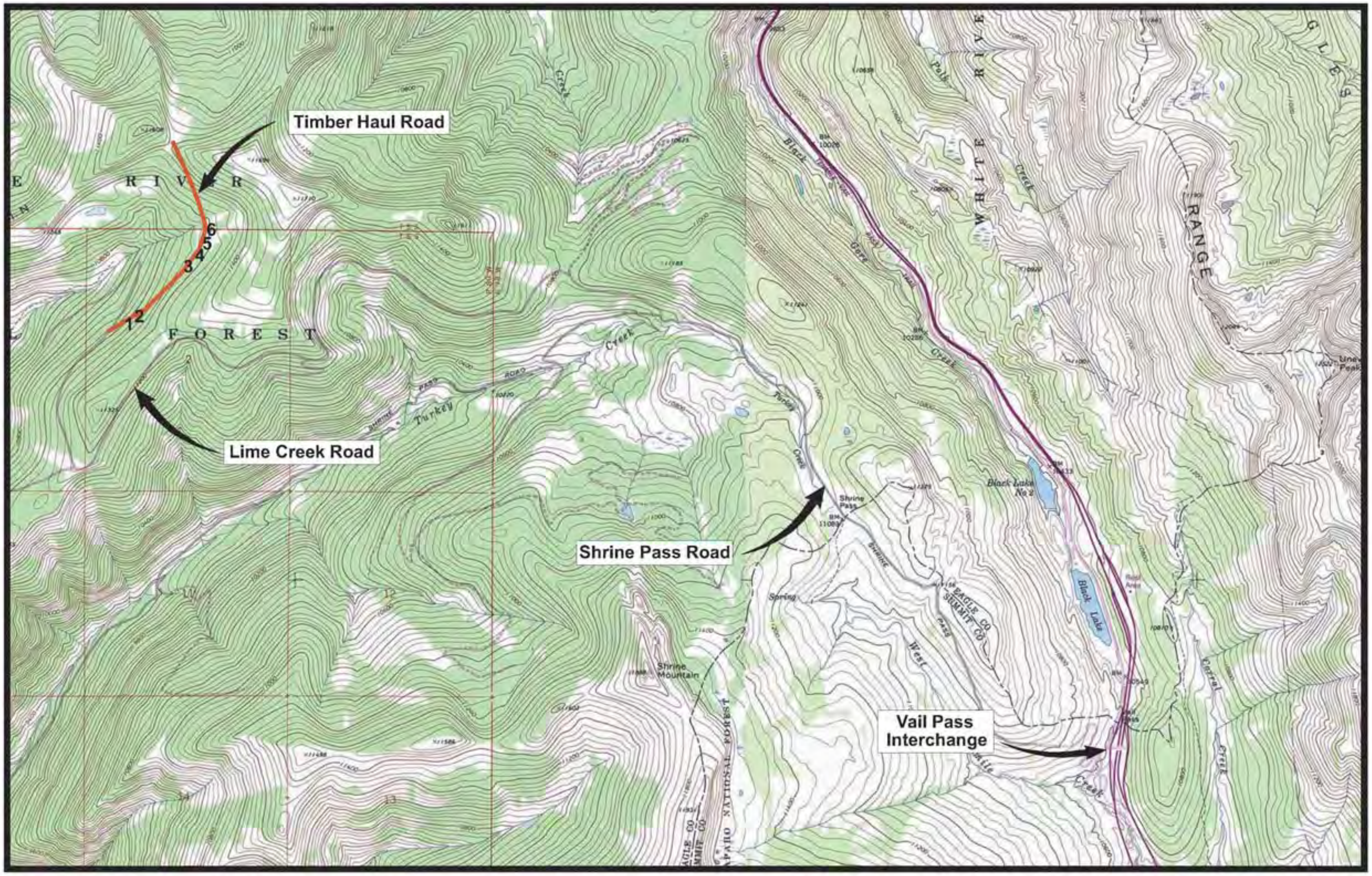
ABSTRACT

In 1998, a new timber haul road was unintentionally constructed through six wetlands. The road was located in the White River National Forest about five miles northwest of the I-70 Vail Pass Interchange at an elevation range of 10,920-11,400 feet. In September 2000, a Wetland Restoration Plan was implemented, in which the approximate original topography was restored using soil from the site, and pre-disturbance drainage and hydrologic patterns were re-established. Next, native seed collected from adjacent Reference Areas and commercial sources was broadcast and mulch was applied. In 2001, trees were transplanted to three of the restorations and plugs of native wetland sod from Reference Areas were added. For seven consecutive years, the wetland restorations were monitored, and additional seed, sod plugs, fertilizer, and mulch were applied. The vegetation cover of the wetlands and the adjacent undisturbed Reference Areas was quantitatively monitored each year by a point intercept method and the extent of the saturated soil in each wetland and the respective Reference Areas was monitored throughout the growing season. Results indicate that:

- The pre-disturbance hydrology and drainage pattern of the six wetlands was restored;
- Adding organic matter enhanced seed germination;
- Seed from adjacent wetlands and commercial sources germinated and established quickly;
- Sod plugs quickly enhanced plant cover and diversity;
- A high plant species diversity was achieved the first growing season;
- A plant cover exceeding 50% was achieved in 2-5 years;
- The total species dominance and diversity of plants in Restorations was similar to the Reference Areas;
- Subalpine wetlands likely expand and contract with climatic cycles.

INTRODUCTION

In the fall of 1998, a new road was constructed in the White River National Forest (Forest) about five miles northwest of the I-70 interchange on Vail Pass in order to remove timber harvested from the Forest (Figure 1). This one mile long road unintentionally bisected six



BASE: USGS 7.5 Minute Vial Pass, Colorado Quadrangle
Photorevised: 1987

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FIGURE 1. Location of Subalpine Wetland Restorations

Scale 1" = 3300'
Contour Interval = 40'

small wetlands on a west-northwest facing slope in subalpine forests and meadows, at an elevation range of 10,920 to 11,400 feet. As no wetland delineation was conducted prior to construction of the road, the extent of the wetland impact was determined by delineating wetlands upslope and downslope of the new road, and then connecting the upslope and downslope points. The U.S. Army Corps of Engineers reviewed and approved the wetland delineation. Figure 2 illustrates the 370 ft^2 Wetland 1 and the 619 ft^2 Wetland 2. Figure 3 illustrates the 13,818 ft^2 Wetland 3, and Figure 4 illustrates the 425 ft^2 Wetland 4 and the 1,896 ft^2 Wetland 5. Figure 5 illustrates the 13,998 ft^2 Wetland 6. Photos 1, 2 and 3 illustrate the road through the wetlands in 2000. Please note, the road segments between the impacted wetlands was also reclaimed by restoring the approximate topography and applying a native upland seed mix and mulch.

Photo 1. The Timber Haul Road as it passes through Wetland 6.

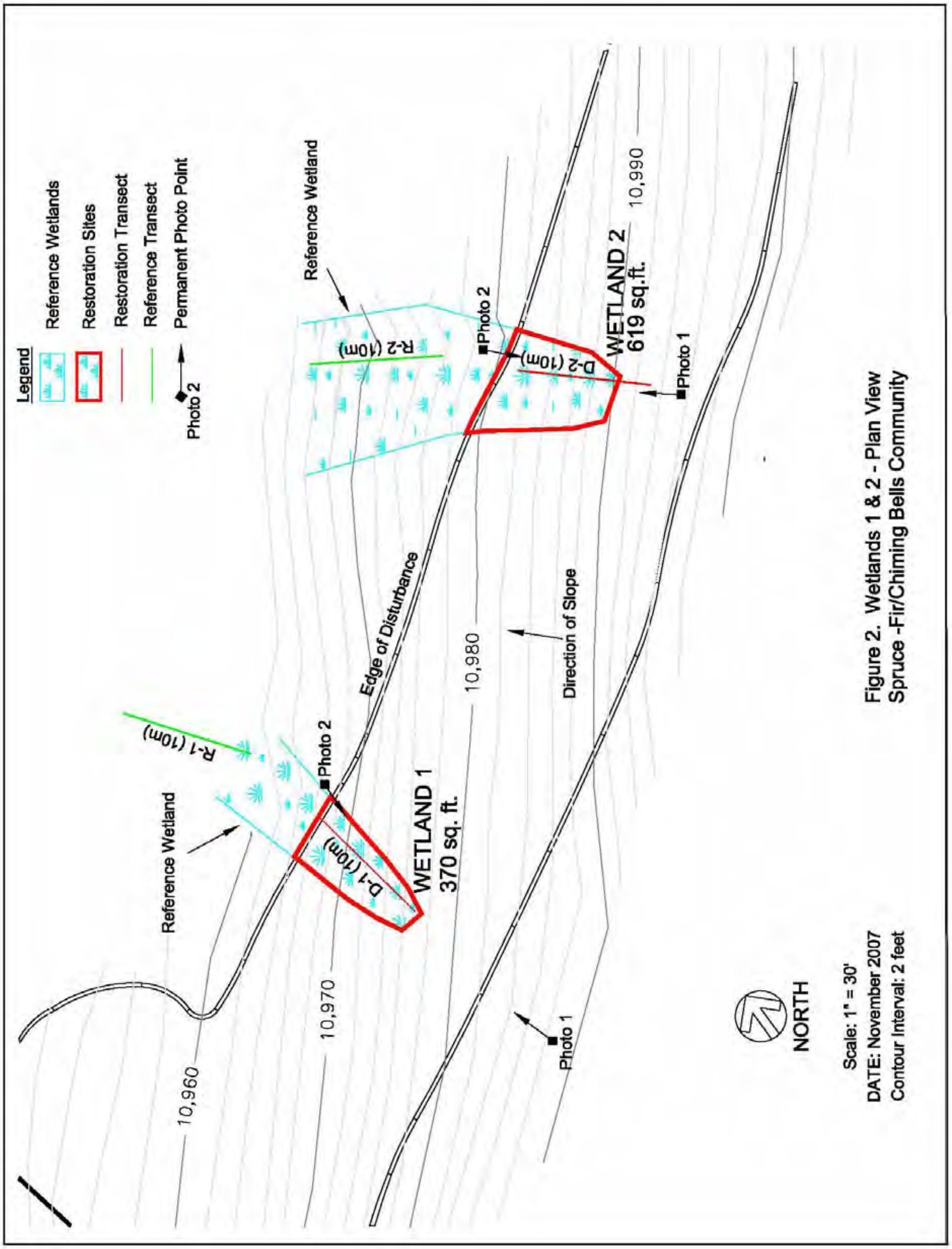


Figure 2. Wetlands 1 & 2 - Plan View
Spruce -Fir/Chiming Bells Community

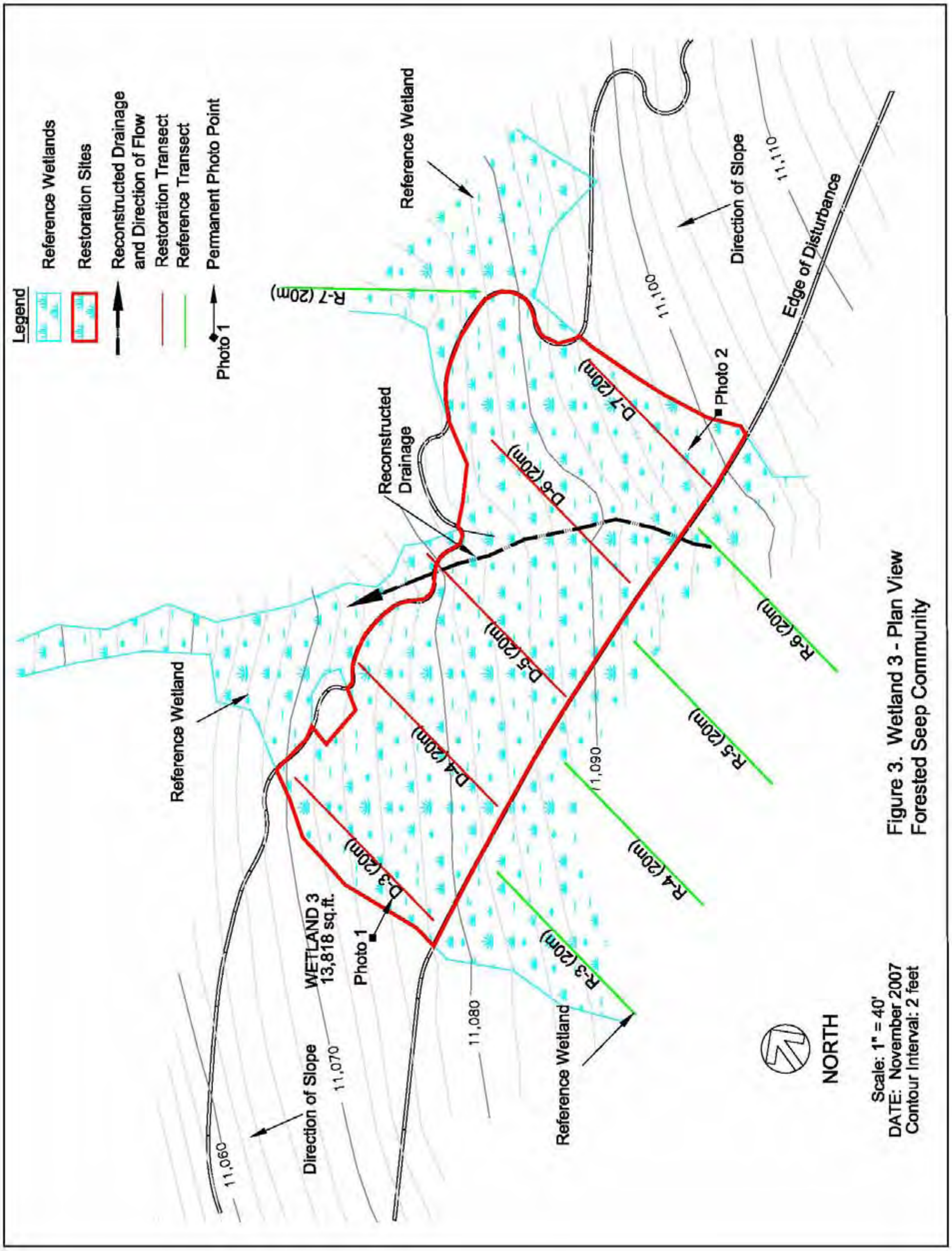


Figure 3. Wetland 3 - Plan View
Forested Seep Community

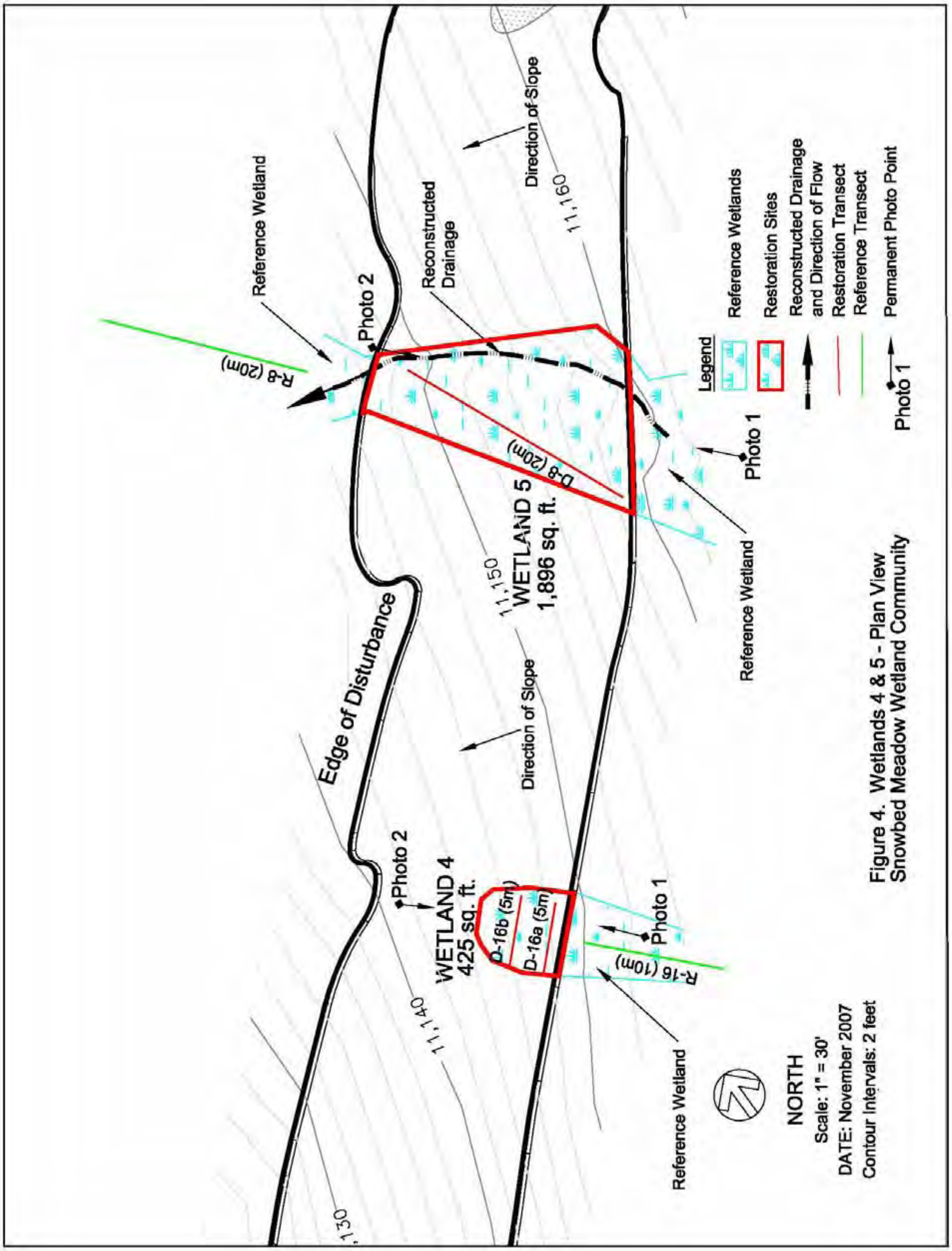


Figure 4. Wetlands 4 & 5 - Plan View
Snowbed Meadow Wetland Community

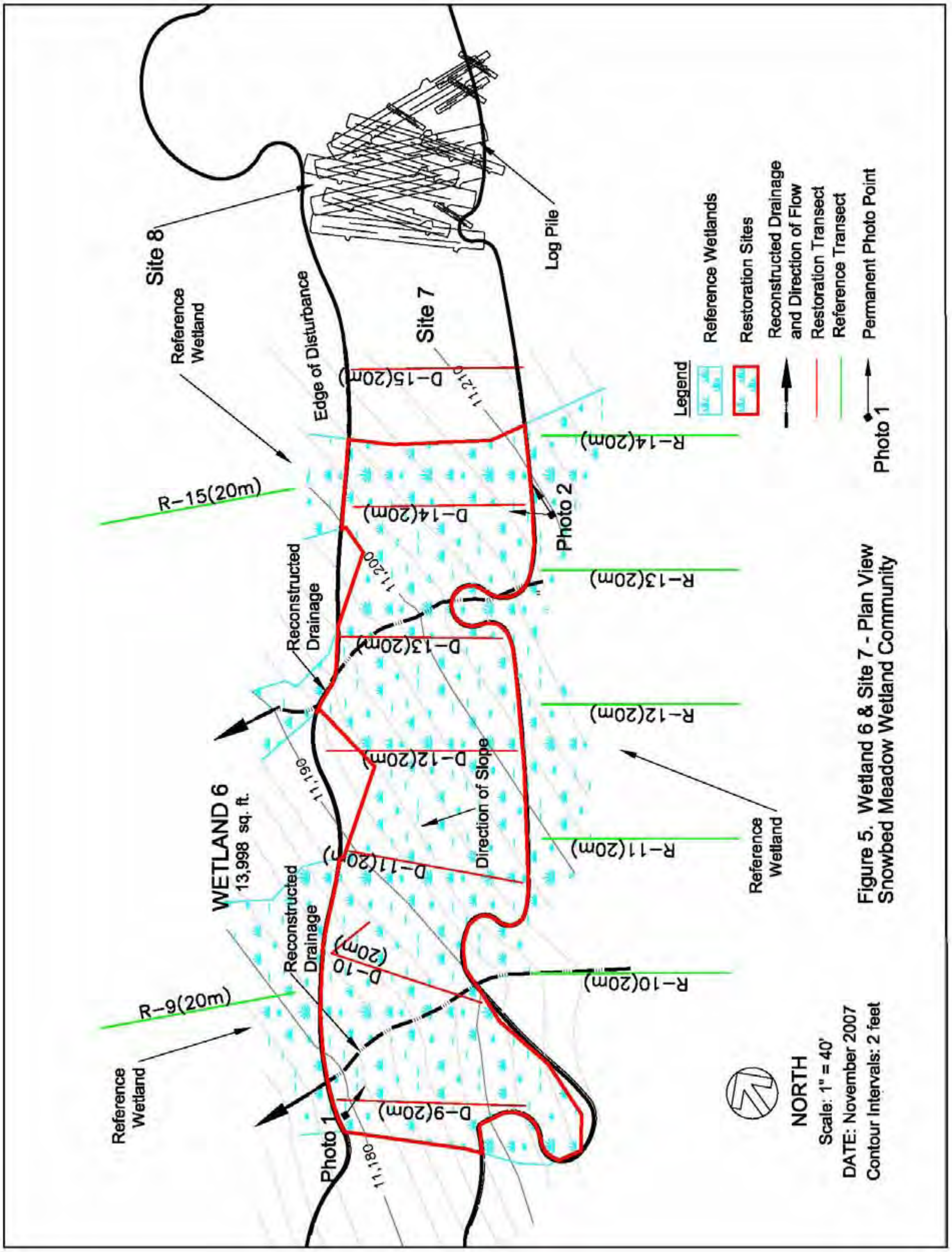


Figure 5. Wetland 6 & Site 7 - Plan View
Snowbed Meadow Wetland Community

Photo 2. Timber Haul Road in Wetland 2

Photo 3. Timber Haul Road near Wetland 3.

.

Three wetland types were impacted: Spruce-Fir/Chiming Bells (Photo 4), Forested Seep (Photo 5), and Snowbed Meadow (Photo 6) wetland communities. We developed a Restoration Plan to restore the soils, hydrology and vegetation of the impacted wetlands and to monitor the success of the Restorations. The Restoration Plan also specified criteria by which to measure the success of the restorations. Restoration commenced in September 2000, and each Restoration and the adjacent Reference Areas were qualitatively and quantitatively monitored for seven consecutive years, from 2001 to 2007.

Photo 4. Spruce-Fir/Chiming Bells Wetland Type


Photo 5. Forested Seep Wetland Type


Photo 6. Snowbed Meadow Wetland Type

RESTORATION PROCESS

Soils

The first task was to find the topsoil initially present along the road, segregate it from the subsoils, and place it on top of the re-constructed soil profile, and restore the approximate original topography and slope. A trackhoe with a 2.5 foot wide bucket was used for this work (Photo 7). A soil scientist was present during all earthwork. We were concerned that the soil compaction along the haul road might exclude root development. Therefore, soil compaction tests were conducted several days after re-establishment of the final topography, and indicated that soils in the restored wetlands were not overly compacted and were generally less compacted than adjacent undisturbed soils. Finally, to increase infiltration and restore the natural subsurface flow of water through the wetland, the road surface was ripped with a trackhoe bucket.

Photo 7. Trackhoe used for restoring wetlands.

The topsoil along the road and the adjacent Reference Areas were tested for macro and micro-nutrients and Biosol, which is composed of 70% organic material, was applied to the Restorations at the rate of 2,000 lbs/acre. A certified weed-free mulch was also applied at a rate of 2,000 lbs/acre. However, Biosol did not provide the required phosphorus, and therefore in the spring of 2001, phosphorus was applied at a rate of 10-40 lbs/acre. The soils were tested yearly for nutrients, and phosphorous was applied in several subsequent years. The application rates were based on nutrient levels of the Restorations compared to levels in the Reference Areas. In addition, sphagnum peat moss was applied to the soil surface to enhance seed germination and elevate the organic matter content of the soil. Humate was also applied to enhance the organic matter in later years.

Drainages

Three of the wetlands contained small ephemeral drainages downslope of large snow accumulation areas. These ten foot wide drainages were re-established with coarse material, then Curlex Geomat fabric and 12 inches of topsoil (Photo 8). Then the channels were rock lined to create a relatively flat surface (Photo 9).

Photo 8. Curlex Geomat fabric.

Photo 9. Reconstructed drainage.

In addition to re-establishing impacted drainages, the large drainage ditch along the uphill side of the haul road had to be filled in. We were very concerned that after re-establishment of the approximate original topography, water would continue to flow along this ditch. Therefore, clay dikes were placed at strategic intervals, the trench filled, and the soil compacted (Photo 10).

Photo 10. Clay dike in drainage ditch.

Seeding

We prepared seed mixes specific to the three wetland types, using only native wetland species present in the Reference Areas. However, only seven species were available commercially. They include two species in the Spruce-Fir/Chiming Bells, three species in the Forested Seep, and four species in the Snowbed Meadow (Table 1). Commercially available species included *Carex microptera, Deschampsia caespitosa, Achillea lanulosa, Geranium richardsonii, Ligularia amplectens,* and *Pedicularis groenlandica.* Therefore, we hand collected seed from the adjacent Reference Areas and broadcast it into the wetlands along with the commercial seed.

TABLE 1
Commercial Wetland Seed Mix 2000

Scientific Name	Common Name	Family	Wetland Status*	Bulk lbs
Spruce-Fir/Chiming Bells Community – Wetlands 1 & 2				
Perennial Forbs				
Ligularia amplectens	Showy alpine groundsel	Asteraceae	FACW	0.500
Mertensia ciliata	Chiming bells	Boraginaceae	OBL	0.125
	Total			**0.625**
Forested Seep Community – Wetland 3				
Perennial Graminoids				
Carex microptera	Smallwing sedge	Cyperaceae	FAC	2.00
Deschampsia caespitosa	Tufted hairgrass	Poaceae	FACW	3.00
Perennial Forbs				
Geranium richardsonii	Richardson's geranium	Geraniaceae	FACU	1.00
	Total			**6.00**
Snowbed Meadow Community – Wetlands 4, 5 & 6				
Perennial Graminoids				
Carex microptera	Smallwing sedge	Cyperaceae	FAC	1.00
Deschampsia caespitosa	Tufted hairgrass	Poaceae	FACW	2.00
Perennial Forbs				
Achillea lanulosa	Yarrow	Asteraceae	FACU	0.50
Pedicularis groenlandica	Elephant's head	Scrophulariaceae	OBL	2.00
	Total			**5.50**

* Wetland Status: OBL = Obligate Wetland; FACW = Facultative Wetland; FAC = Facultative; FACU = Facultative Upland; UPL = Obligate Upland; NL = Not listed on USFWS Regional Hydrophyte List

Table 2 illustrates the four graminoid and seven forbs hand collected and seeded in Wetlands 1 and 2 of the Spruce-Fir/Chiming Bells community. Table 3 illustrates the six graminoids and 16 forbs hand collected and seeded in Wetland 3 in the Forested Seep, and Table 4 illustrates the seven graminoids and 14 forbs collected and seeded in Wetlands 4, 5 and 6 of the Snowbed Meadow community in September 2000.

TABLE 2
On-site Collection Wetland Seed Mix 2000[#]
Spruce-Fir/Chiming Bells Community
Wetlands 1 & 2

Scientific Name	**Common Name**	**Family**	**Wetland Status***
Perennial Graminoids			
Carex ebenea	Ebony sedge	Cyperaceae	NL
Carex nelsonii	Nelson's sedge	Cyperaceae	OBL
Juncus drummondii	Drummond rush	Juncaceae	FACW
Luzula parviflora	Millet woodrush	Juncaceae	FAC
Perennial Forbs			
Angelica grayi	Gray's angelica	Apiaceae	NL
Arnica cordifolia	Heartleaf arnica	Asteraceae	NL
Arnica latifolia	Broadleaf arnica	Asteraceae	NL
Epilobium lactiflorum	Milkflower willowherb	Onagraceae	FACW
Ligularia amplectens	Showy alpine groundsel	Asteraceae	FACW
Mitella pentandra	Fivestamen miterwort	Saxifragaceae	FACW
Senecio triangularis	Arrowleaf groundsel	Asteraceae	OBL
Stellaria umbellata	Umbrella starwort	Alsinaceae	FAC+

About one bulk pound

* Wetland Status: OBL = Obligate Wetland; FACW = Facultative Wetland; FAC = Facultative; FACU = Facultative Upland; UPL = Obligate Upland; NL = Not listed on USFWS Regional Hydrophyte List

TABLE 3
On-site Collection Wetland Seed Mix 2000[#]
Forested Seep Community
Wetland 3

Scientific Name	**Common Name**	**Family**	**Wetland Status***
Perennial Graminoids			
Carex ebenea	Ebony sedge	Cyperaceae	NL
Carex nelsonii	Nelson's sedge	Cyperaceae	OBL
Luzula parviflora	Millet woodrush	Juncaceae	FAC
Phleum commutatum	Alpine timothy	Poaceae	FAC
Trisetum spicatum	Spiked false oat	Poaceae	FACU-
Trisetum wolfii	Wolf false oat	Poaceae	FACW-
Perennial Forbs			
Arnica mollis	Hairy arnica	Asteraceae	FAC
Arnica parryi	Parry arnica	Asteraceae	NL
Castilleja rhexifolia	Splitleaf Indian paintbrush	Scrophulariaceae	FACU
Cirsium eatonii	Eaton thistle	Asteraceae	ML
Delphinium barbeyi	Barbey's larkspur	Helleboraceae	FAC
Epilobium halleanum	Glandular willowherb	Onagraceae	FAC+
Epilobium lactiflorum	Milkflower willowherb	Onagraceae	FACW
Erigeron peregrinus ssp. callianthemus	Fleabane	Asteraceae	FACW
Ligularia amplectens	Showy alpine groundsel	Asteraceae	FACW
Mitella pentandra	Fivestamen miterwort	Saxifragaceae	FACW

Parnassia fimbriata	Grass-of-Parnassus	Parnassiaceae	OBL
Pedicularis groenlandica	Elephant's head	Scrophulariaceae	OBL
Senecio triangularis	Arrowleaf groundsel	Asteraceae	OBL
Swertia perennis	Star gentian	Gentianaceae	FACW-
Trollius albiflorus	Globeflower	Helleboraceae	OBL

[#] 1.41 total bulk pounds

* Wetland Status: OBL = Obligate Wetland; FACW = Facultative Wetland; FAC = Facultative; FACU = Facultative Upland; UPL = Obligate Upland; NL = Not listed on USFWS Regional Hydrophyte List

TABLE 4
On-site Collection Wetland Seed Mix 2000[#]
Snowbed Meadow Community
Wetlands 4, 5 & 6

Scientific Name	Common Name	Family	Wetland Status*
Perennial Graminoids			
Calamagrostis canadensis	Bluejoint reedgrass	Poaceae	OBL
Carex ebenea	Ebony sedge	Cyperaceae	NL
Juncus drummondii	Drummond rush	Juncaceae	FACW
Luzula parviflora	Millet woodrush	Juncaceae	FAC
Phleum commutatum	Alpine timothy	Poaceae	FAC
Trisetum spicatum	Spiked false oat	Poaceae	FACU-
Trisetum wolfii	Wolf false oat	Poaceae	FACW-
Perennial Forbs			
Angelica grayi	Gray's angelica	Apiaceae	NL
Arnica mollis	Hairy arnica	Asteraceae	FAC
Arnica parryi	Parry arnica	Asteraceae	NL
Aster foliaceus	Leafy bracted aster	Asteraceae	FACU
Bistorra bistortoides	American bistort	Polygonaceae	FAC
Chlorocrepis tristis ssp. gracilis	Slender hawksbeard	Asteraceae	NL
Cirsium eatonii	Eaton thistle	Asteraceae	ML
Erigeron coulteri	Coulter fleabane	Asteraceae	FACW
Erigeron peregrinus ssp. callianthemus	Fleabane	Asteraceae	FACW
Gentianopsis thermalis	Rocky Mountain fringed gentian	Gentianaceae	OBL
Ligularia amplectens	Showy alpine groundsel	Asteraceae	FACW
Pedicularis groenlandica	Elephant's head	Scrophulariaceae	OBL
Valeriana edulis	Edible valerian	Valerianaceae	FACW-
Veronica nutans	American alpine speedwell	Scrophulariaceae	FACU

[#] 0.88 bulk pounds

* Wetland Status: OBL = Obligate Wetland; FACW = Facultative Wetland; FAC = Facultative; FACU = Facultative Upland; UPL = Obligate Upland; NL = Not listed on USFWS Regional Hydrophyte List

In July 2001, the first growing season for the Wetland Restorations, native seed was again collected in the Reference Areas and broadcast into each of the wetlands (Table 5), and like the first seed collection, the mixes had a high species diversity. The mixes included 25 species for the Spruce-Fir/Chiming Bells, 33 for the Forested Seep, and 50 for the Snowbed Meadow communities. Native seed was also collected from the Reference Areas in subsequent years and broadcast into the wetlands, but on a limited basis and often for specific species, such as *Mertensia ciliata*.

TABLE 5
Second On-Site Collection Seed Mix 2001
Number of Species by Life Form

	Number of Species		
Wetland Community	**Graminoids**	**Forbs**	**Total**
Spruce-Fir/Chiming Bells	9	16	**25**
Forested Seep	9	24	**33**
Snowbed Meadow Complex	12	38	**50**

Plantings

In addition to seeding, sod plugs from the adjacent undisturbed wetlands in the Reference Areas were located in each of the six wetland restorations during the 2001 growing season, to enhance the restoration. Each plug was approximately 5-6 inches in diameter. The plugs were planted at a density of about one per 25 square feet, except in areas where the seed mix was densely germinating. A total of 733 plugs were set out in 2001 (Table 6). These plugs contained a diversity of species, including 25 for the Spruce-Fir/Chiming Bells, 50 for the Forested Seep, and 49 for the Snowbed Meadow communities. An additional 705 sod plugs were planted in the summer of 2002, the second growing season for the Restorations.

TABLE 6
Sod Plugs Per Wetland - 2001
Number by Life Form

		Number of Species		
Wetland Community	**No. Plugs**	**Graminoids**	**Forbs**	**Total**
Spruce-Fir/Chiming Bells	78	7	18	**25**
Forested Seep	200	12	38	**50**
Snowbed Meadow Complex	455	9	40	**49**
Total Plugs	**733**			

Trees were planted in the Spruce-Fir/Chiming Bells and Forested Seep Restorations, both forested wetland types, in 2000 prior to the seeding. A total of 70 trees were hand dug from the adjacent areas and planted in Wetland Restorations 1, 2 and 3. The trees averaged 28 inches in height and included *Abies lasiocarpa* and *Picea engelmannii.*

Snow

The depth of snow in each wetland was measured in April 2003 - 2007 in order to determine the conditions of the winter and the potential moisture available in spring for soil saturation and wetland plant growth. In addition, the snow was stacked upslope of the Snowbed Meadow Wetlands 4, 5 and 6 in 2003 - 2006 in order to provide additional moisture for soil saturation in the spring. Snow was not stacked in any of the quantitative transects of the Reference Areas.

MEASURING WETLAND RESTORATION SUCCESS

Reference wetlands were identified upslope and downslope of each of the six restorations in order to measure the success of each of the restorations. The Success Criteria state that each restoration must:

- Be dominated by species in the seed mixes, sod plugs and the Reference Areas
- Have a vegetation cover 95% of the Reference Areas
- Have a minimum of 15 species
- Have a weed cover no greater than 5% of the total cover
- Meet the vegetation and hydrology criteria of the 1987 U.S. Army Corps of Engineers' Wetland Delineation Manual.

MONITORING

Vegetation Monitoring

Both qualitative and quantitative techniques were used to monitor the establishment of the wetlands. In the first few years, wetlands were visited at two week intervals throughout the growing season to document plant species presence, reseed areas of low vegetative cover, look for and eradicate weeds, collect seed from wetland plants, and take photographs from fixed and other locations. With regard to quantitative monitoring, permanent transects were established in the Restorations and the adjacent Reference Areas. The number of transects in each wetland and Reference Area was related to the size of the wetland, and they were located to uniformly sample the Restoration and Reference areas. There were two transects in the Spruce-Fir/Chiming Bells Restoration and its Reference Area, five in the Forested Seep Restoration and five in its Reference Area, and eight in the Snowbed Meadow Restoration and nine in its Reference Area. A point-intercept system was used to determine plant cover, and a one meter wide belt quadrat located along each cover transect to measure species richness. Most transects were 20 meters long, and 100 points were recorded using a cover-point optical point projection device mounted on a tripod. The quantitative monitoring was completed the third week in August for Years 2001 through 2007, during which time the height of the transplanted trees was measured as well. Please note, the quantitative sampling was not conducted to any specified statistical accuracy.

Hydrology Monitoring

In April of 2003-2007, the depth of snow in each wetland was measured. In the spring, the period and volume of flow in the drainages was noted. The extent of soil saturation was mapped in each restoration throughout the growing season as measured at intervals of 4 to 14 days.

Soil

The soils of each Restoration and adjacent Reference Areas were sampled each year for organic matter content and nutrients. Additional nutrients and organic matter were applied in order to elevate levels in the Restorations to that of the Reference Areas. The soils of the Restorations were also checked for any sign of erosion.

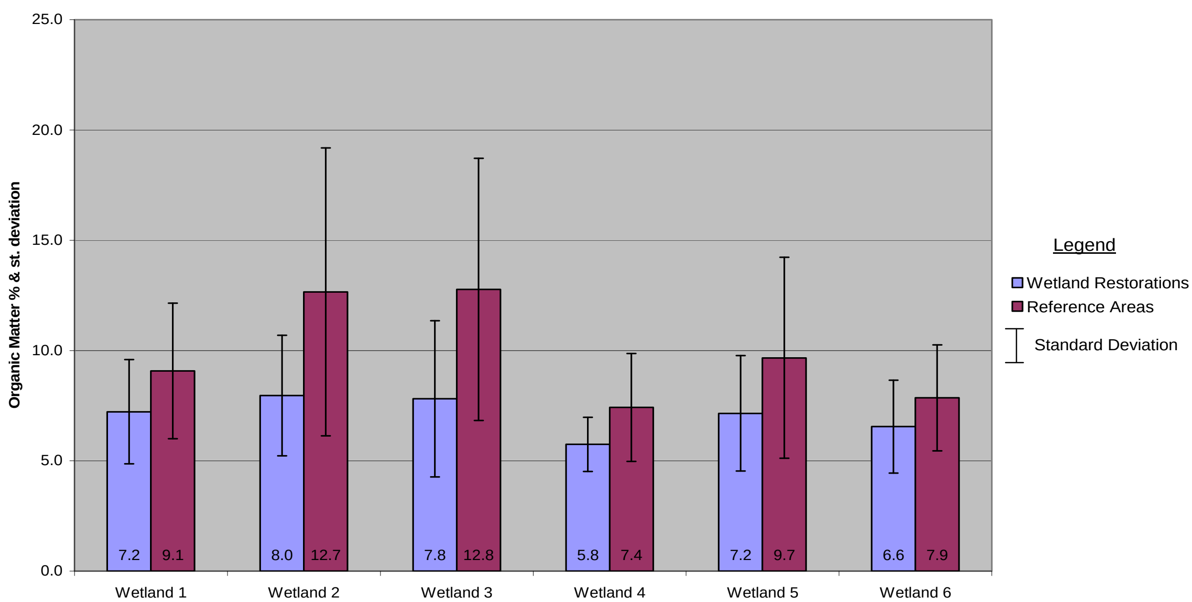
RESULTS

Soils

Organic Matter and Mulches

Straw mulch was applied immediately following wetland construction to minimize erosion. Peat moss was applied a few years later in 2003 (3-4 tons/acre) and humate, an organic-rich amendment, was applied in 2005 (500-600 lbs/acre). These amendments were applied to increase organic matter levels, retain soil moisture, reestablish soil biological activity, and enhance soil structure. Even with the addition of mulches, organic matter levels in Restoration soils were less than that of their Reference Areas. However, organic matter levels in all restored wetlands averaged over 5.5 percent in the upper 12 inches (Figure 6). There was greater variability (greater standard deviation) in organic matter levels in the Reference Areas for Wetlands 2 and 3. This represents the variability of organic matter found in these wetlands. For example, the Reference Area for Wetland 3 contains very poorly drained soils that are organic rich, and thin soils over gravelly substrate that contain significantly less organic matter.

Figure 6
Comparison of Percent Organic Matter 2000-2007
Temporary Timber Haul Road

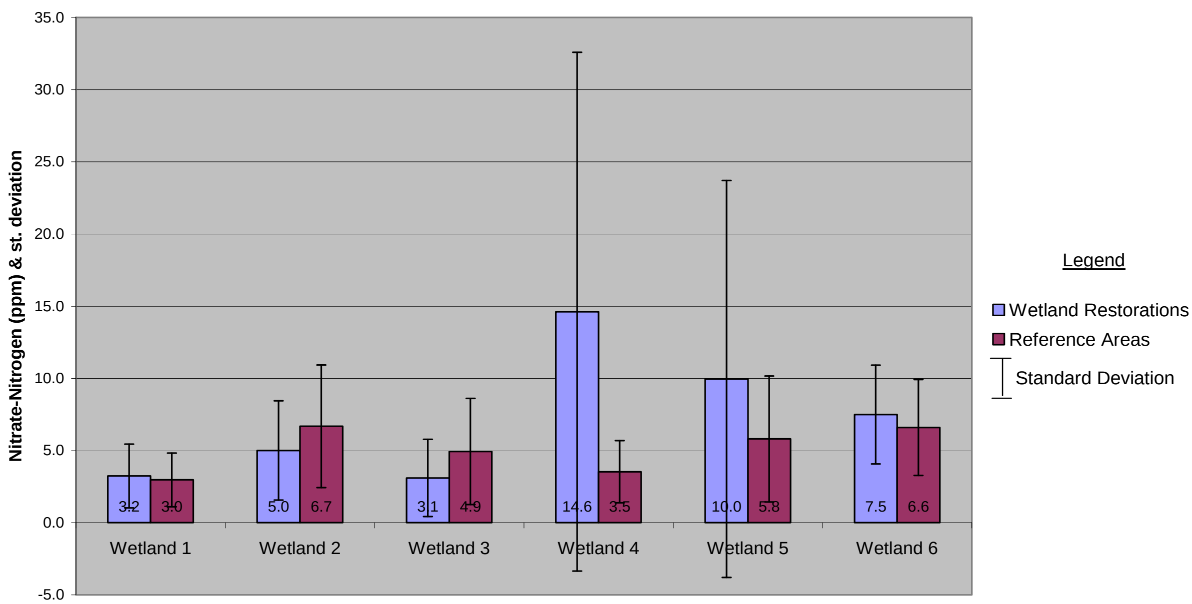


In conclusion, straw mulch minimized erosion and protected the surface from sheet erosion prior to the establishment of a vegetation cover. Peat moss retained soil moisture in the upper few inches, increased seed germination, and also added organic content to the soil.

Nutrients

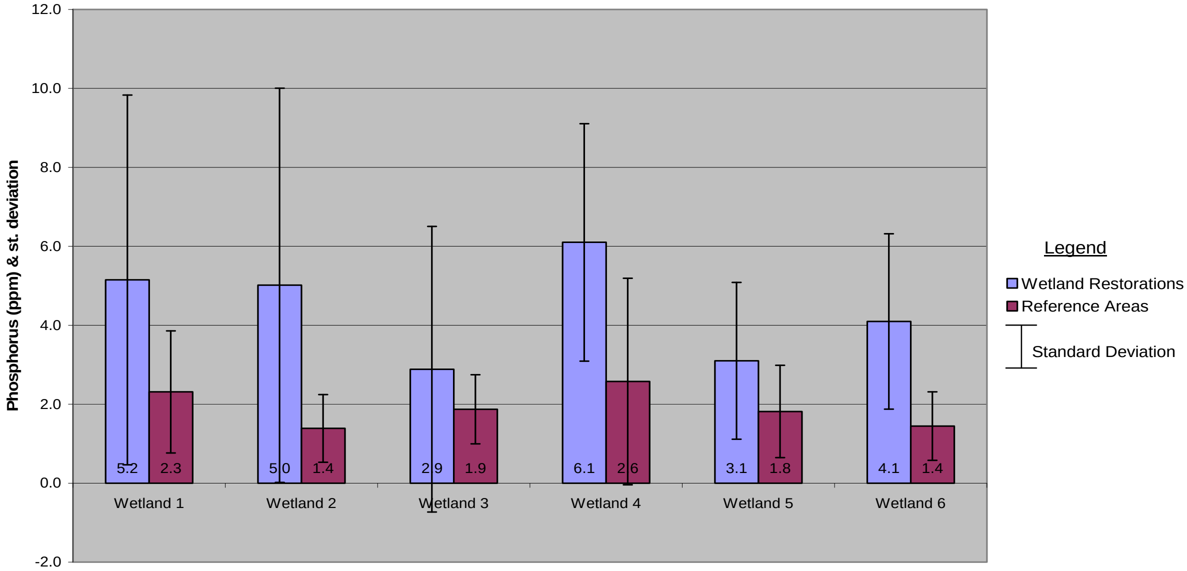
A couple of applications of organic fertilizers, including Biosol, were applied to reestablish nutrient cycling. Figure 7 shows average nitrate-nitrogen levels over eight years in the Restorations and Reference Areas. Levels are generally similar in the Restorations to their Reference Areas. There is greater nitrate-nitrogen variation in Wetlands 4 and 5, in part due to fertilizer applications and nitrogen loss due to breakdown of mulches.

Figure 7
Comparison of Nitrate-Nitrogen Levels 2000-2007
Temporary Timber Haul Road



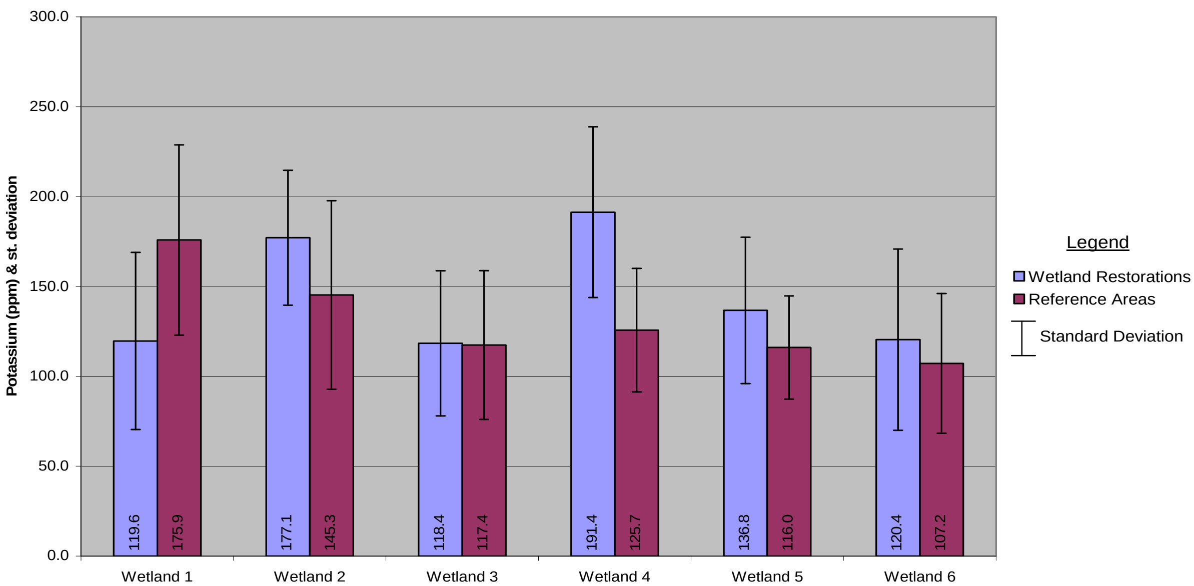
Average phosphorus levels (Figure 8) are higher in the Restorations than in the Reference Areas. In part, this is probably the result of fertilizer applications. Phosphorus is essentially an immobile nutrient and phosphorus fertilizer additions may have exceeded plant removal, and therefore, there is a buildup of phosphorus reserves.

Figure 8
Comparison of Phosphorus Levels 2000-2007
Temporary Timber Haul Road



Average potassium levels (Figure 9) in the Restorations were similar or slightly higher than in their Reference Areas. In part, this is due to fertilizer applications to the restored wetlands and possibly the result of the more clay-rich and mica-rich subsoil mixed within the upper 12 inches of the soils of the Restorations.

Figure 9
Comparison of Potassium Levels 2000-2007
Temporary Timber Haul Road



Erosion & Drainages

With the addition of mulches and the rapid establishment of vegetation, erosion was not a problem. Sheet flow was present generally in June and early July in Wetlands 3 and 6 and it was always relatively sediment free (Photo 11).

Photo 11. Sheet flow across Wetland 6, June 2007

Wetlands 3, 5 and 6 contain small ephemeral drainages that flow only during snowmelt with up to 0.3 cfs. With the addition of rocks in the constructed drainages no significant erosion occurred. Photo 12 shows a drainage in Wetland 6 immediately following restoration in 2001, and Photo 13 shows the same drainage in 2007. All drainages are intact and stable. In fact, the restored drainages are more stable than the up-gradient and down gradient connecting drainages, which were down cut in many places.

In conclusion, it is possible to minimize erosion in restored subalpine wetlands and in drainages occurring on relatively steep slopes with best management practices. With regard to the roadside ditch, surface and near surface hydrology was restored by ripping compacted road surfaces before topsoil placement to enhance infiltration, and by placing clay dikes along the road ditch to prevent preferential flow down the ditch once backfilled (Photo 10). There was no evidence of soil piping or settling along the buried ditch. We have concluded that the surface and near surface wetland hydrology was restored to the original pre-disturbance condition.

Photo 12. Restored drainage in Wetland 6, June 2001.

Photo 13. Restored drainage in Wetland 6, June 2007

Hydrology Patterns

The depth of snow in each wetland was measured in April starting in 2003 through 2007 to determine snow accumulation and the potential moisture available in spring for soil saturation.

Table 7 shows snow depths in 2003 through 2007 in each wetland. The wettest winters were 2003, 2006 and 2007. The driest winter was actually 2002, for which we have no measurement, but according to the Climax Weather Station, which is about 13 miles southeast of the project site and at a similar elevation, the winter of 2002 was drier than 2004 and 2005 winters.

TABLE 7
Snow Depth per Wetland 2003 – 2007
(Feet)

Wetland	Mid-April 2003	April 21 2004	April 20 2005	April 27 2006	April 25 2007
1	6.8	5.8 –- 7.0	5.6 - 6.5	6.3 - 7.8	7.4
2	6.8	5.8 –- 7.0	5.6 - 6.5	6.3 - 7.8	7.4
3	6.8	5.5 –- 6.9	5.9 - 6.8	6.3 - 7.9	5.8 - 7.8
4	7.3	5.4 –- 6.2	5.2 - 6.1	6.7 - 7.8	7.3 - 7.8
5	7.3	5.4 –- 6.2	5.2 - 6.1	6.7 - 7.8	7.3 - 7.8
6	7.3	5.4 –- 6.2	5.2 - 6.1	6.7 - 7.8	7.3 - 7.8

Snow stacking above Wetlands 4, 5 and 6 appeared to have little effect on the hydrology of the Restorations. In part, the volume of snow stacked was minor compared to the volume of snow on the landscape up-gradient of the Restorations. Also, in some years a significant volume of snow was lost through sublimation.

Soil saturation was measured in the upper 12 inches of soil once every four days early in the growing season in each Restoration and its Reference Area, and then once every two weeks until the end of the growing season in order to determine the extent of the wetland hydrology. Based on the length of the growing season, areas having soil saturation within the upper 12 inches for at least 4 consecutive days during the growing season were considered to have wetland hydrology. Figure 10 shows soil saturation in Wetland 3 and how it dries out throughout the 2007 growing season. The maximum extent of soil saturation was late June, which then began to dry out in early July, and by late August there were only a few small areas of saturation near seeps.

A seasonal spring would develop at the lower end of Wetland 2 in mid-June. It flowed down a poorly defined channel, provided hydrology for the lower end of the Restoration, and then dried out in a matter of days to a week. This seasonal spring may or may not have been present prior to disturbance, but if not, then the hydrology adjusted to the restored conditions. In addition, a seep developed in the reclaimed road above the north end of Wetland 6 in a depression where the original topography was not restored. It flows into Wetland 6 and provides hydrology in the north portion of the Restoration generally through July. This seep most likely was not present prior to disturbance, and therefore, the north portion of Wetland 6 would be drier than it is today without this seep.

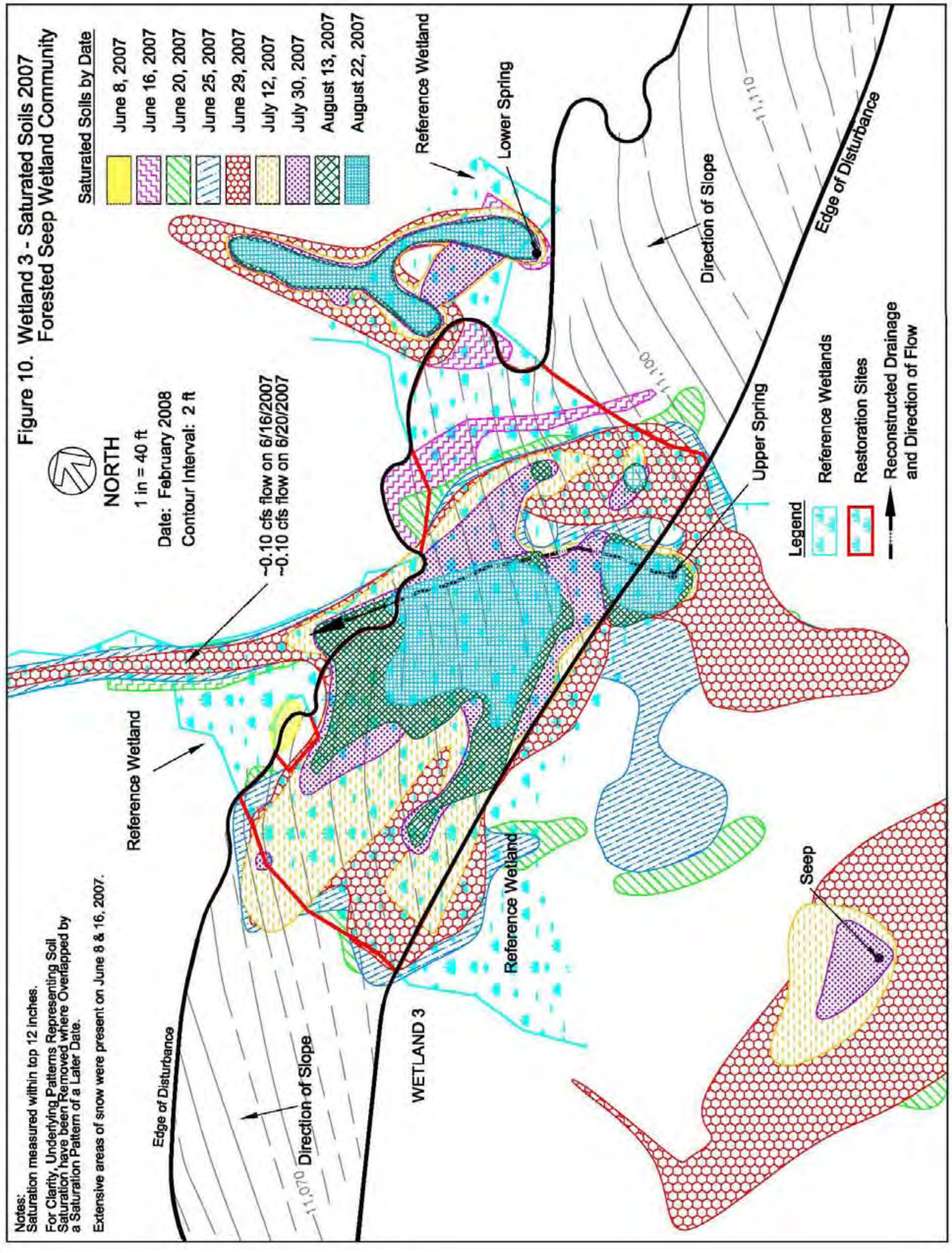


Figure 10. Wetland 3 - Saturated Soils 2007
Forested Seep Wetland Community
Saturated Soils by Date
June 8, 2007
June 16, 2007
June 20, 2007
June 25, 2007
June 29, 2007
July 12, 2007
July 30, 2007
August 13, 2007
August 22, 2007
NORTH
1 in = 40 ft
Date: February 2008
Contour Interval: 2 ft
~0.10 cfs flow on 6/16/2007
~0.10 cfs flow on 6/20/2007
Notes:
Saturation measured within top 12 inches.
For Clarity, Underlying Patterns Representing Soil Saturation have been Removed where Overlapped by a Saturation Pattern of a Later Date.
Extensive areas of snow were present on June 8 & 16, 2007.
Reference Wetland
Lower Spring
Upper Spring
Seep
Direction of Slope
Edge of Disturbance
WETLAND 3
11,070
11,100
11,110
Legend
Reference Wetlands
Restoration Sites
Reconstructed Drainage and Direction of Flow

Restored Wetland Hydrology Summary

The hydrology of the Wetland Restorations is predominately from snow melt in the form of sheet flow, near surface ground water, and seeps. Slopes of the wetlands are quite steep and range from 10 to 30 percent, so water flows relatively quickly through the wetlands. In general, the Restorations are saturated in the upper several inches (1-6 inches), the maximum extent of saturation is late June, and they begin to dry out quickly thereafter.

Figure 11 shows soil saturation in the upper 12 inches of soil for 2002, the driest winter, compared to 2006, one of the wettest winters, in the early growing season and then in the mid-growing season. Both 2002 and 2006 had similar air temperatures during the major snow melt period, May to early July, which were above the average air temperatures for those months by 2.7 to 5.5 degrees. One can see the difference snow accumulation makes on the hydrology. For the 2006 growing season, the wetter winter, soil saturation was significantly larger during both the early growing season and the mid-growing season.

Figure 12 shows a comparison of soil saturation in the upper 12 inches for 2006, a wetter winter and a warmer snow melt period, with 2007, which had a similar snow pack in late April but a cooler snow melt season. May and June temperatures in 2007 were over 2 degrees cooler than in 2006. The slower rate of snow melting and sublimation during cooler snow melt periods leads to a larger area of soil saturation during the early growing season because the hydrology is sustained for a longer period of time. By mid-growing season, however, soil saturation patterns were similar.

In conclusion, it is possible to restore wetland hydrology in reconstructed subalpine wetlands, and the total volume of snow accumulation and ambient air temperatures during snow melt control the extent of soil saturation, and hence the size of subalpine wetlands. With dry winters and warmer snow melt periods the size of subalpine wetlands decreases significantly especially during the early growing season.

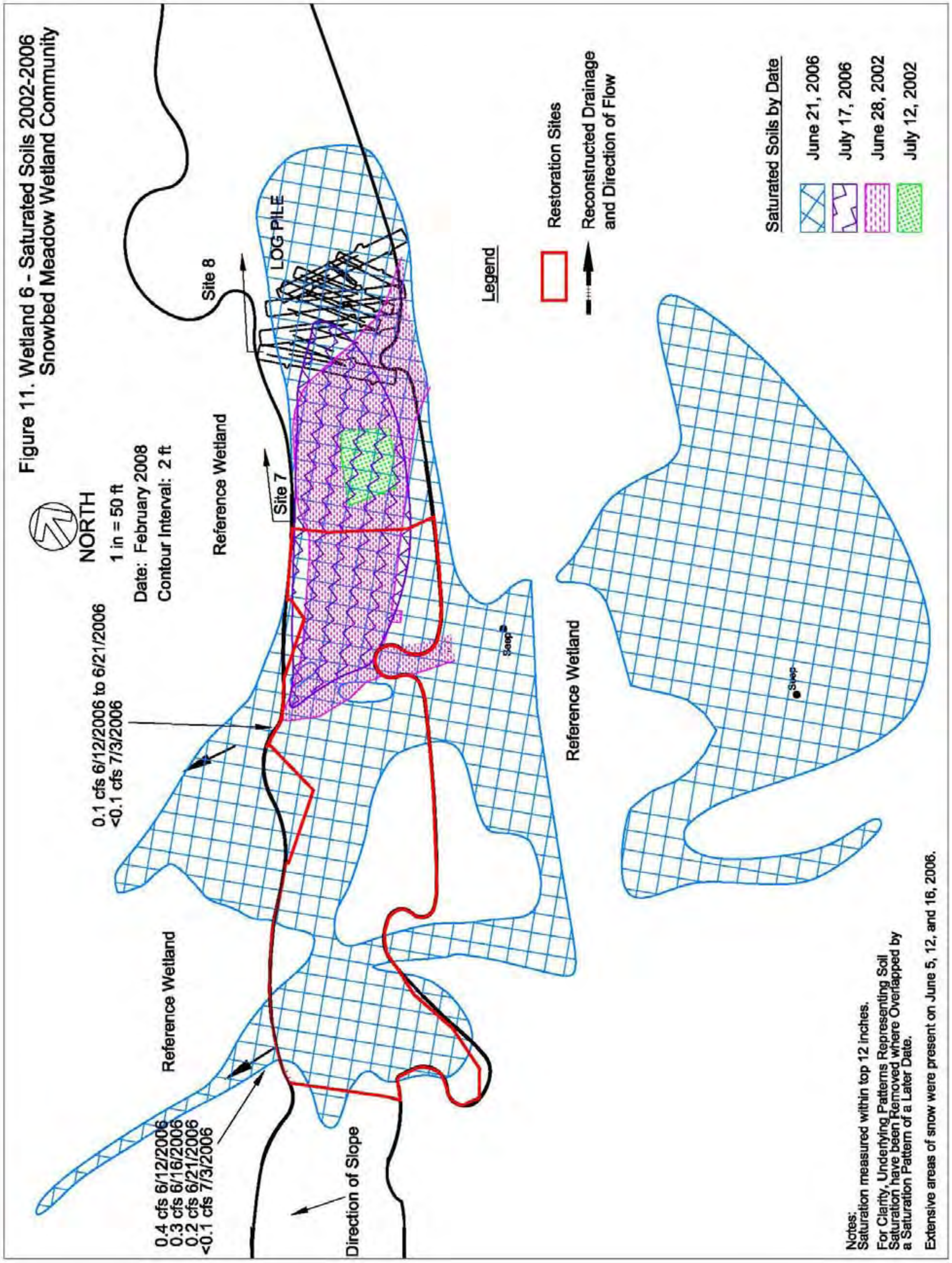


Figure 11. Wetland 6 - Saturated Soils 2002-2006
Snowbed Meadow Wetland Community
NORTH
1 in = 50 ft
Date: February 2008
Contour Interval: 2 ft
Reference Wetland
Reference Wetland
Reference Wetland
Site 7
Site 8
LOG PILE
0.1 cfs 6/12/2006 to 6/21/2006
<0.1 cfs 7/3/2006
0.4 cfs 6/12/2006
0.3 cfs 6/16/2006
0.2 cfs 6/21/2006
<0.1 cfs 7/3/2006
Direction of Slope
Seep
Seep
Legend
Restoration Sites
Reconstructed Drainage and Direction of Flow
Saturated Soils by Date
June 21, 2006
July 17, 2006
June 28, 2002
July 12, 2002
Notes:
Saturation measured within top 12 inches.
For Clarity, Underlying Patterns Representing Soil Saturation have been Removed where Overlapped by a Saturation Pattern of a Later Date.
Extensive areas of snow were present on June 5, 12, and 16, 2006.

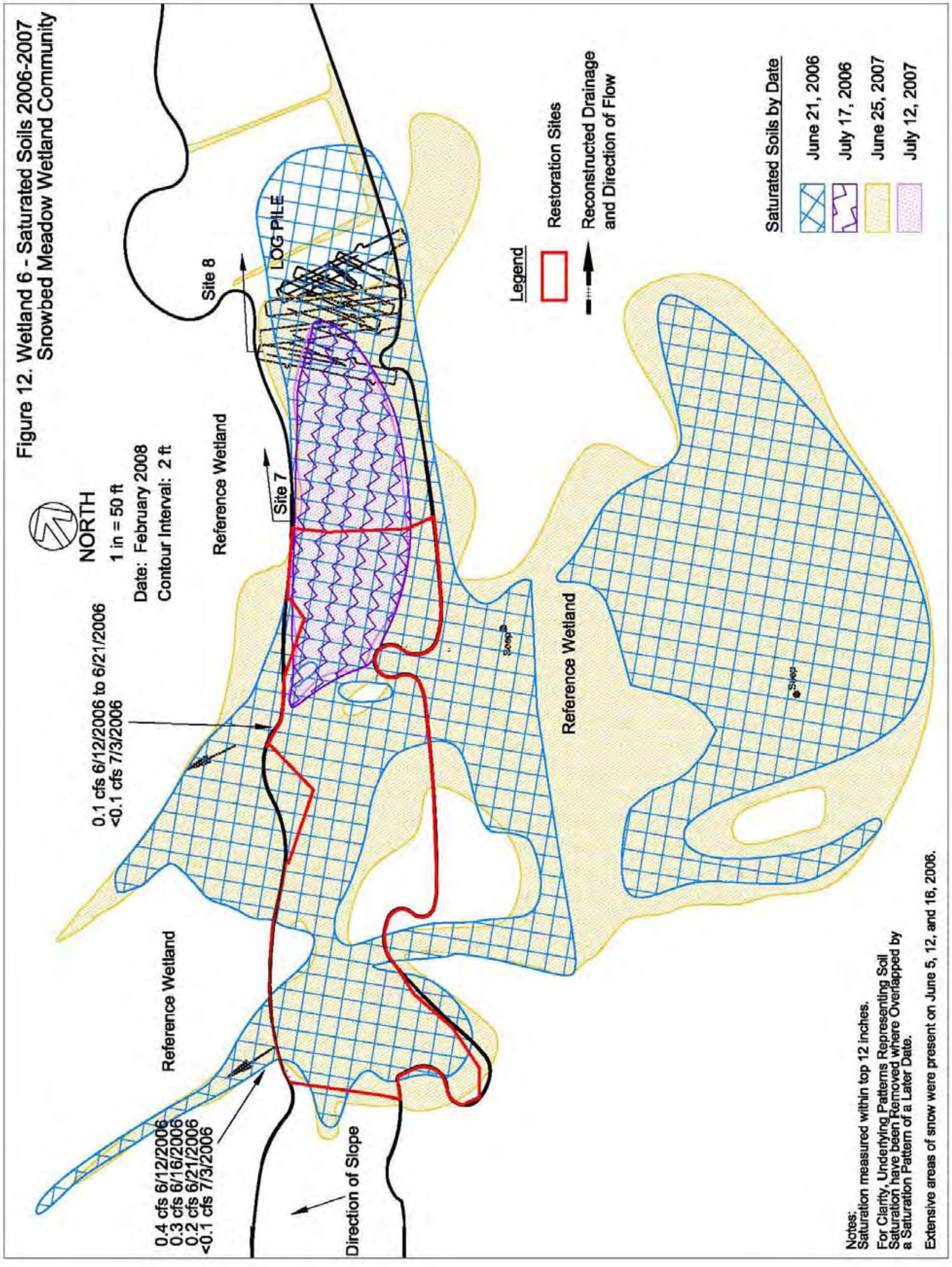


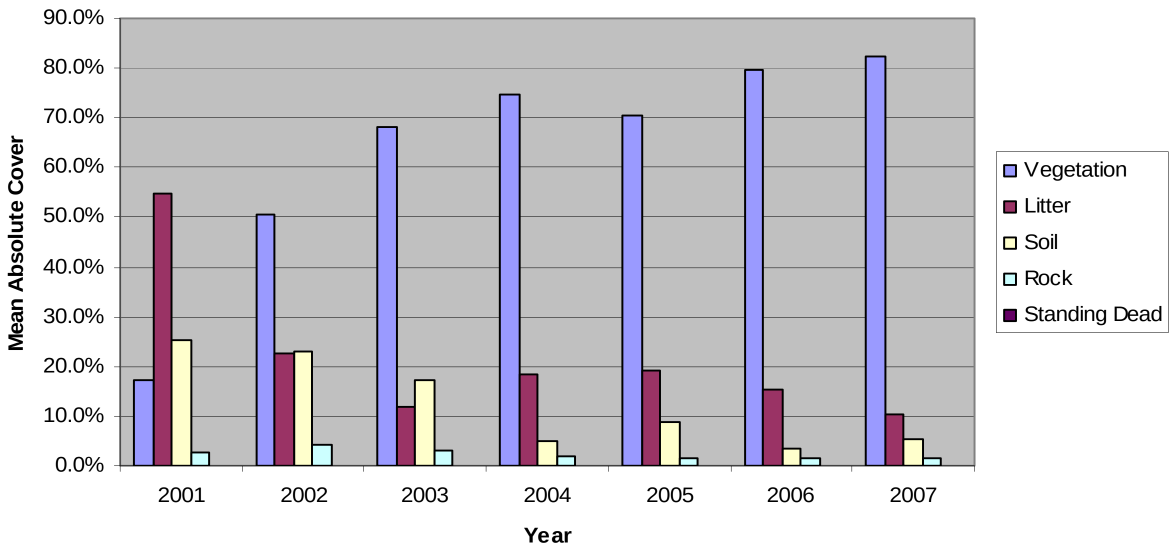
Figure 12. Wetland 6 - Saturated Soils 2006-2007
Snowbed Meadow Wetland Community

Vegetation

Absolute Cover

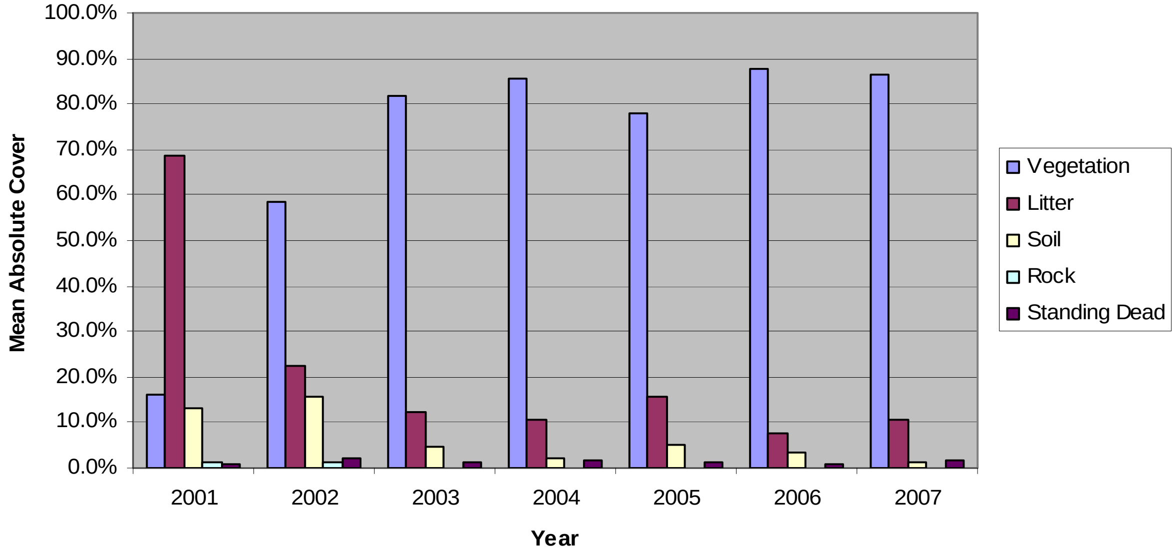
The total absolute vegetation cover increased rapidly in all three restorations, but especially in the Snowbed Meadow Restoration (Figure 13). The Snowbed Meadow Restoration had a total absolute cover of 17% in 2001, the first year of growth. The cover increased to 50% the second year, and remained near 70% or above throughout the remaining monitoring period. The cover in 2007 was 82.5%.

Figure 13
Absolute Vegetation Cover 2001 - 2007
Snowbed Meadow Wetland Restoration



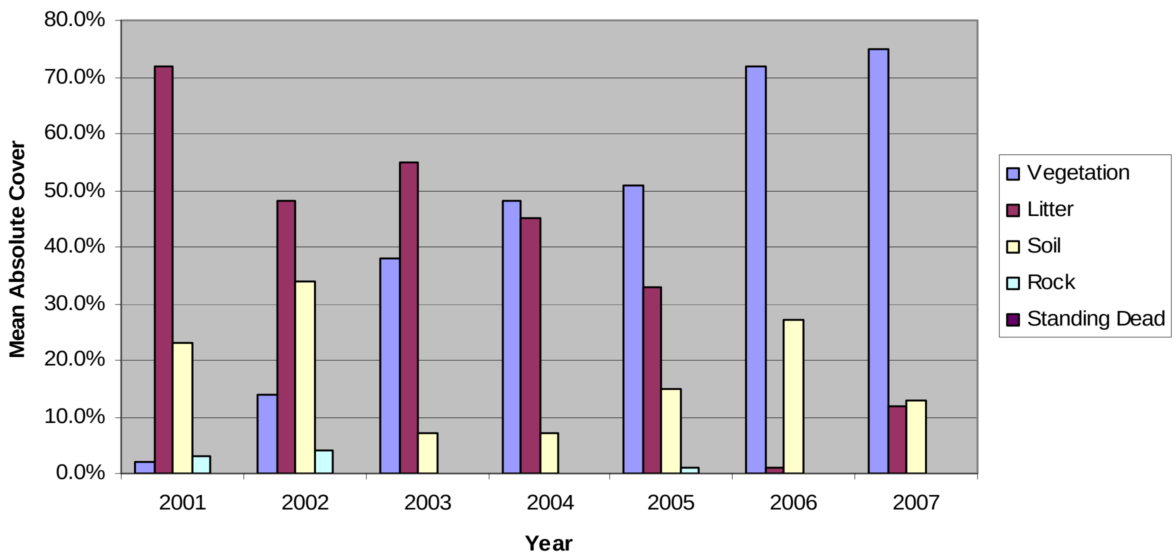
The Forested Seep only had a vegetation cover of 16% the first year following growth (Figure 14). The cover jumped to 58% the second year, surpassed 80% the third year, and then remained relatively stable.

Figure 14
Absolute Vegetation Cover 2001 - 2007
Forested Seep Wetland Restoration



The forb dominated Spruce-Fir/Chiming Bells Wetland Restoration was slowest to establish a high cover of vegetation (Figure 15). The absolute cover was 2% the first year. It increased to 12% the second year, and it was not until the sixth year that it surpassed 70%. Correspondingly, the cover of litter and soil gradually reduced as the plant cover increased.

Figure 15
Absolute Vegetation Cover 2001 - 2007
Spruce-fir/Chiming Bells Wetland Restoration



Dominant Species

Figure 16 compares the dominant species in the Spruce-Fir/Chiming Bells Restoration and adjacent Reference Area for the 7th growing season. As illustrated, *Mertensia ciliata, Ligularia amplectens, Arnica spp.,* and *Luzula parviflora* are the dominant species in these two areas. With time, we believe the cover of *Mertensia* in the Restoration will equal the cover in the Reference Area.

Figure 16
Dominant Plant Species Comparison 2007
Spruce-Fir/Chiming Bells Restoration vs. Reference Area

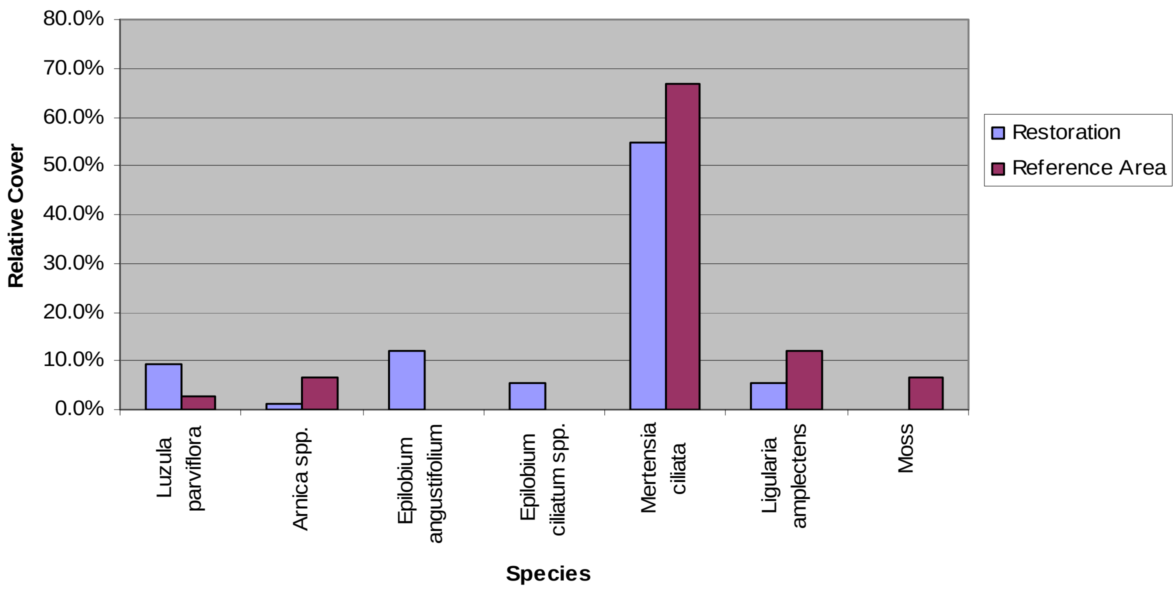


Figure 17 compares the dominance of species in the Forested Seep Restoration and that of the Reference Area for the 7th growing season. The cover of *Picea engelmannii* is much greater in the Reference Area, but in time it will increase in the Restoration as the trees grow and mature. The cover of *Deschampsia caespitosa* is far greater in the Restoration than the Reference Area. This plant has been extremely successful and has likely reduced the cover of other species. *Carex microptera* was initially thought to be present in the Reference Area and hence was seeded, and has been extremely successful as well. The other dominant species present in the Restoration, *Arnica mollis*, *Cirsium eatonii*, *Epilobium ciliatum spp.*, *Mertensia ciliata*, and *Senecio triangularis*, are also represented in the Reference Area. Species common in the Reference Area, but sparsely represented in the Restoration, include *Caltha leptosepala* and *Trollius albiflorus.*

Figure 17
Dominant Plant Species Comparison 2007
Forested Seep Restoration vs. Reference Area

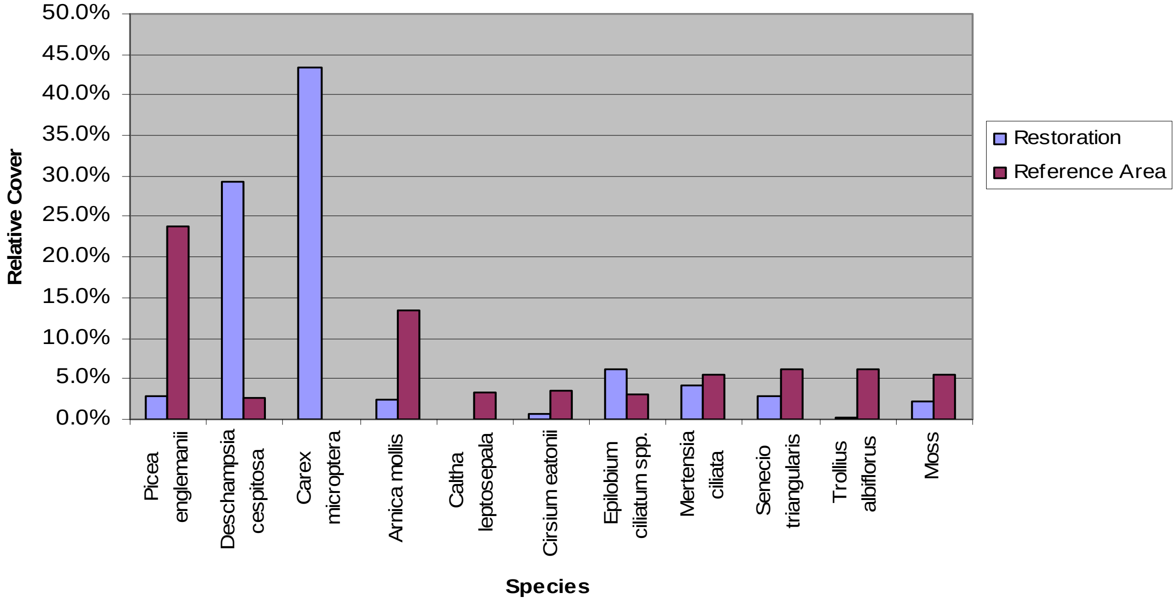
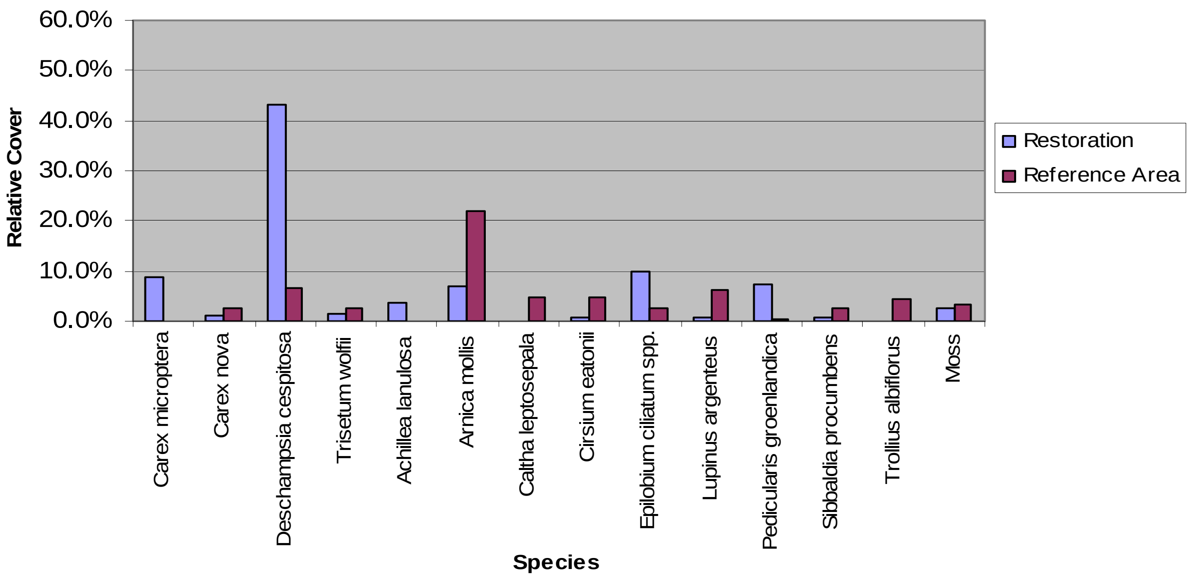


Figure 18 illustrates the same comparison for the Snowbed Meadow Restoration and its Reference Area. Again, the cover of *Deschampsia caespitosa* and *Carex microptera* in the Restoration far exceeds the cover in the Reference Area. The cover of other dominant species is in general similar, except that the Reference Area has a greater abundance of *Arnica mollis, Caltha leptosepala,* and *Trollius albiflorus,* and the Restoration has a greater cover of *Epilobium spp.* and *Pedicularis groenlandica.*

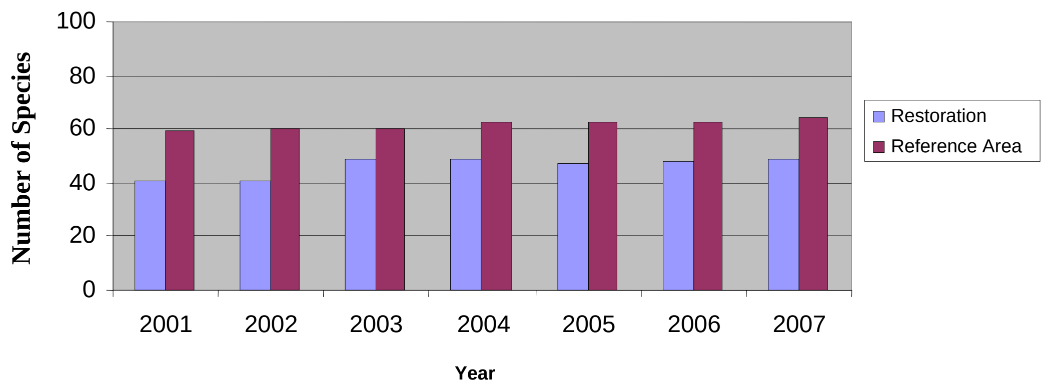
Figure 18
Dominant Plant Species Comparison 2007
Snowbed Meadow Restoration vs. Reference Area



Plant Species Diversity

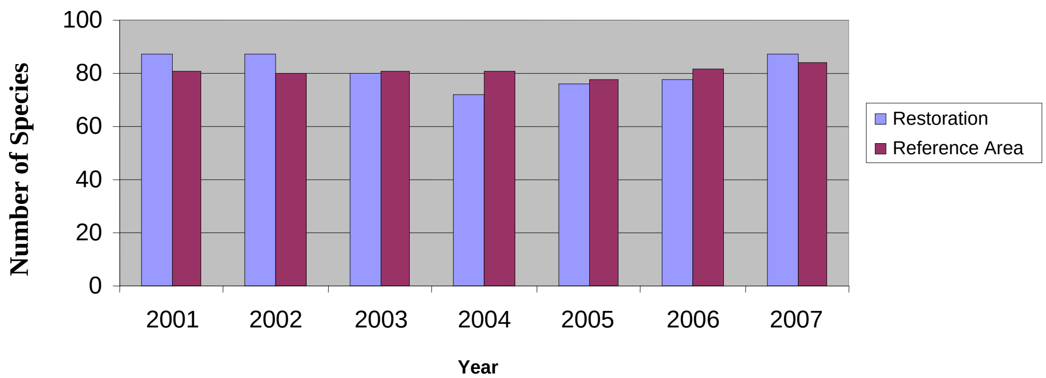
The total plant species diversity of the Spruce-Fir/Chiming Bells Restoration was 41 the first and second year, gradually increased to about 49 the third year, and remained near this level (Figure 19). The adjacent Reference Area had a high plant species diversity which ranged from 59 to 64.

Figure 19
Species Diversity
Total Number of Plants
Spruce-Fir/Chiming Bells Restoraton & Reference Area



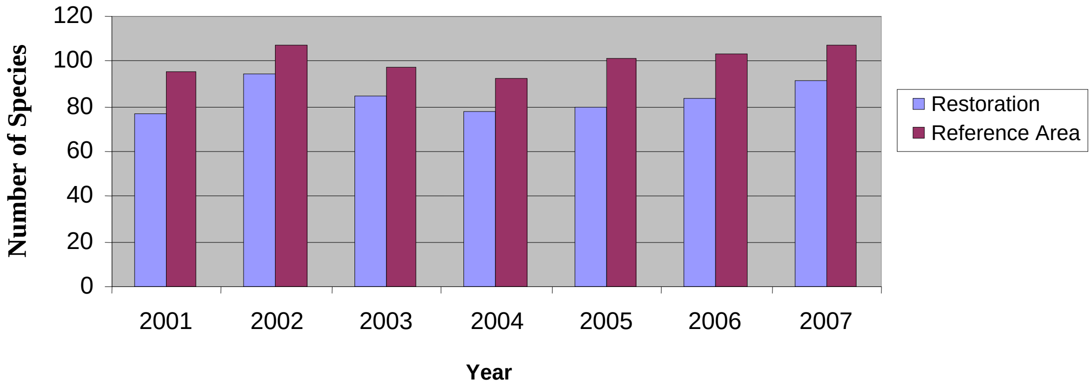
The Forested Seep Restoration had a plant species diversity of 87 for the first two growing seasons, it decreased to 72 in the fourth year, and then gradually increased to 87 in year 7, which is higher than the Reference Area (Figure 20).

Figure 20
Species Diversity
Total Number of Plants
Forested Seep Restoration & Reference Area



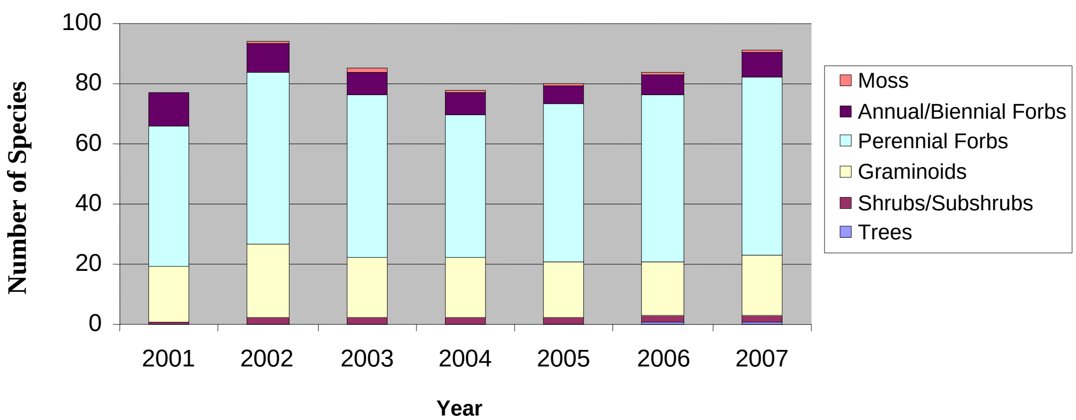
The Snowbed Meadow Restoration had a species diversity of 77 the first year (Figure 21). It increased to 94 the second year, gradually dropped to 78 the fourth year, and then increased to 91 the seventh year. The Reference Area species diversity varied from 92 to 107 over the seven years of monitoring.

Figure 21
Species Diversity
Total Number of Plants
Snowbed Meadow Restoration & Reference Area



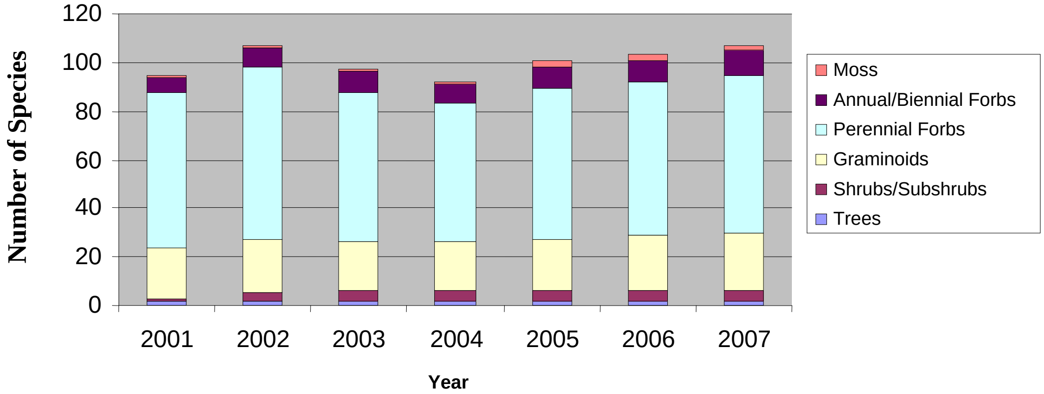
We also analyzed the species diversity by life form. Figure 22 breaks the plant species diversity down by life form for the Snowbed Meadow Restoration for the seven year monitoring period. The perennial forbs, the most abundant life form, had 47 to 59 species over this time period. Graminoids, the next most abundant life form, had 18 to 25 species. The annual/biennial forbs ranged from 6 to 11, and shrubs ranged from 1 to 2 species.

Figure 22
Plant Species Diversity by Life Form 2001-2007
Snowbed Meadow Restoration



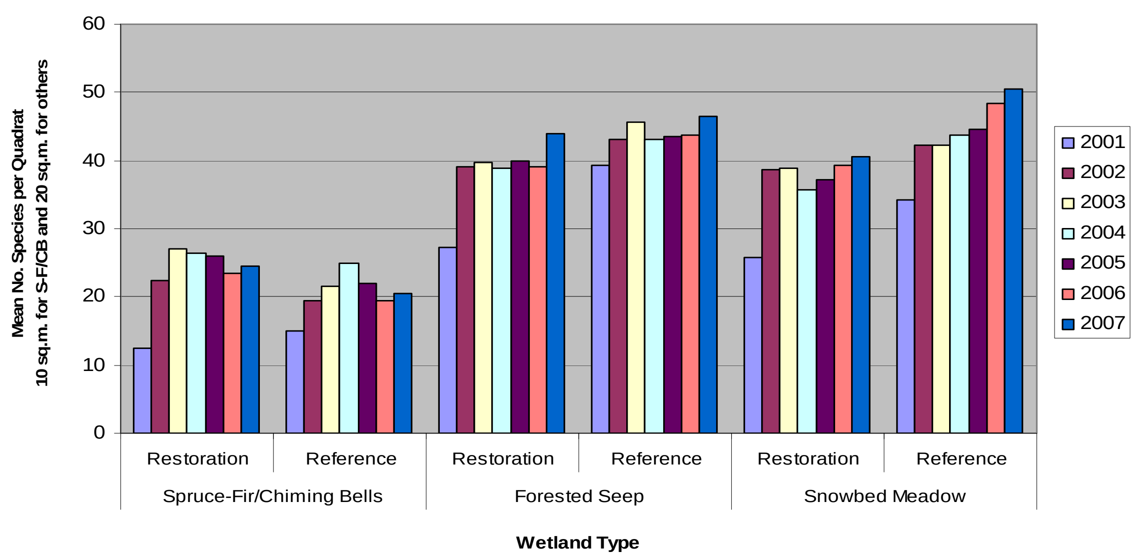
The Restoration Area is very similar to the Reference Area with regard to plant species diversity (Figure 23). Perennial forbs were dominant with 57 to 71 species, followed by graminoids with 20 to 24 species.

Figure 23
Plant Species Diversity by Life Form 2001-2007
Snowbed Meadow Reference Area



We also quantitatively determined plant species density by counting the number of species present in each quadrat, or the 2m wide by 20m long permanent belt transects located uniformly throughout the Restoration and Reference Areas. As depicted in Figure 24, the number of species is lower than the preceding figures, however Figure 24 represents a comparison of areas that are equal in size, rather than whole wetland areas. Nevertheless, the same conclusions can be made: that the restoration sites had a fairly high species density the first year and by the second year, the restoration sites were near to their corresponding Reference Areas. By the seventh year, the Spruce-Fir/Chiming Bells Restoration had a higher plant species density of 24.5 species per quadrat versus 20.5 per quadrat in its Reference Area. In the Forested Seep Restoration, species density was 44.0 species/quadrat and 46.4 species/quadrat in its Reference Area. Finally, in the Snowbed Meadow Restoration, the density was 40.6 species/quadrat in the Restoration and 50.4 in its Reference Area.

Figure 24
Species Density
Wetland Restoration & Reference Areas



We would like to point out that these wetlands are dynamic and the species within the Restorations have changed during the monitoring period. Many species could not survive in the community and were replaced by other species.

Figure 25 illustrates the number of species present in both 2002 and 2007, the number lost during this time period, and the number of new species gained for the Spruce-Fir/Chiming Bells Restoratiosn. For example, 9 perennial graminoids were present in both 2002 and 2007, 2 graminoid species were lost, and there were 3 new species of graminoids. With regard to perennial forbs, 15 species were present in 2002 and 2007, 6 were lost, and 13 were gained. Overall, 29 species were present in both years, 12 did not survive, and 20 new ones grew. The Forested Seep had 74 species present in both years, 12 did not survive, and 12 new ones grew (Figure 26). With regard to the Snowbed Meadow Restoration, 74 were constant, 19 were lost, and 16 were gained (Figure 27).

Figure 25
Species Fidelity 2002 & 2007
Lost & New
Spruce-Fir/Chiming Bells Restoration

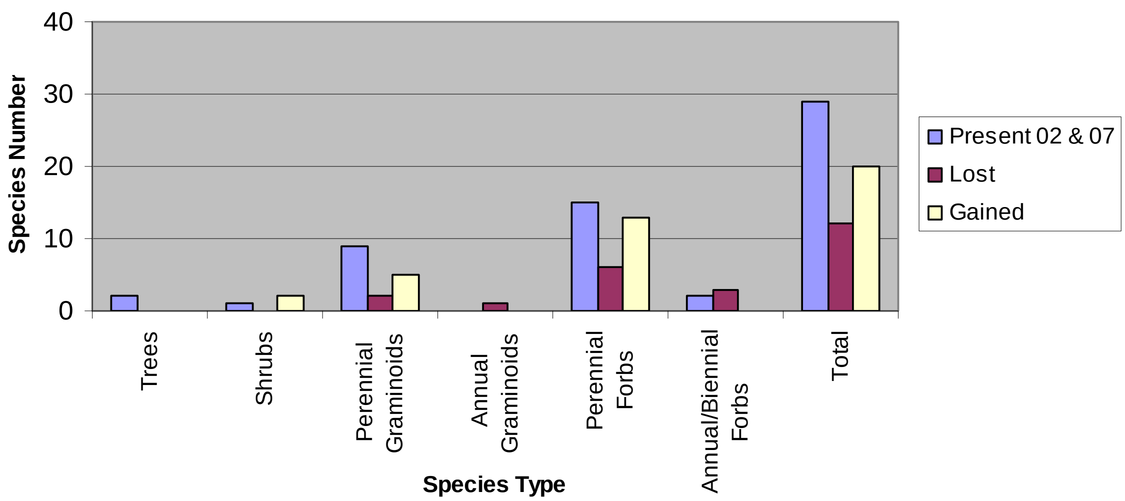


Figure 26
Species Fidelity 2002 & 2007
Lost & New
Forested Seep Restoration

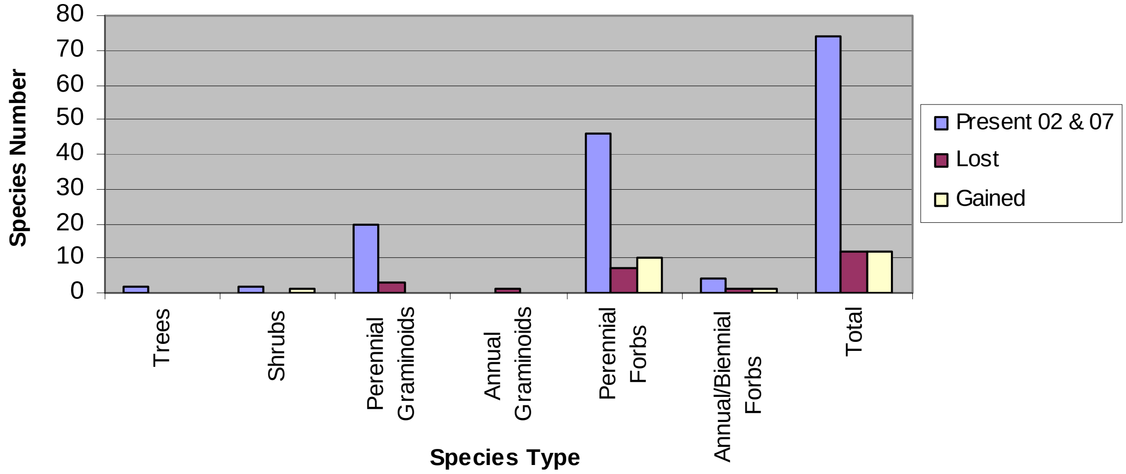
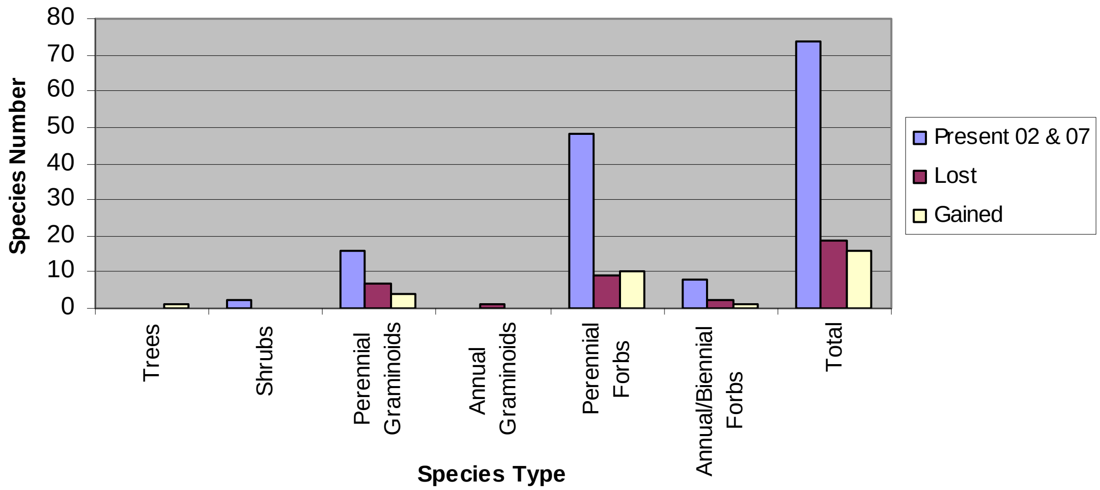


Figure 27
Species Fidelity 2002 & 2007
Lost & New
Snowbed Meadow Restoration



Trees

Tree survival and growth in Restorations 1, 2 and 3 was very good. Eleven of the 12 trees planted in Restoration 1 survived and grew an average of 18.6 inches in seven years. All 13 trees in Restoration 2 survived and grew and average of 10.0 inches in 7 years. Similarly, 39 of 45 trees planted in Restoration 3 survived and grew an average of 7.1 inches in seven years (Table 8).

TABLE 8
Tree Survivorship & Average Height

Wetland Number	Number of Trees Planted[+]	Number of Trees Alive 2007	Survivorship
1	12	11	92%
2	13	13	100%
3	45	39	87%

Wetland Number	Average Height (inches)								Increase in Height
	2000	2001	2002	2003	2004	2005	2006	2007*	
1	24.4	25.1	26.0	27.6	29.4	32.1	36.8	43.0	18.6
2	25.1	25.9	26.6	27.7	28.6	29.9	32.1	35.2	10.0
3	26.5	26.9	27.7	28.3	29.2	30.2	32.2	33.6	7.1

[+]Trees were transplanted in the fall of 2000.

*Dead trees in 2007 were excluded from height averages over all years. Two trees were excluded for Wetland 1 (No. 11 & 12, one dead and one has top stem dead), none were excluded from Wetland 2, and 6 dead trees were excluded from Wetland 3. Thus, these averages may differ slightly from those reported in previous years.

Weeds

Table 9 illustrates the 13 weed species present in the Restoration. They include three annual grasses and four annual/biennial forbs, all likely present in the straw mulch. These species in general were not difficult to control as subalpine forests are too cool for them. They were quickly eradicated from the Restoration by hand.

TABLE 9
Weeds Present in Restorations

Scientific Name	Common Name	Likely Source
Annual Grasses		
Bromus tectorum	Cheatgrass	Mulch
Hordeum vulgare	Cultivated Barley	Mulch
Triticum aestivum	Wheat	Mulch
Perennial Grasses		
Alopecurus pratense	Meadow foxtail	Mulch
Dactylis glomerata	Orchardgrass	Mulch
Phleum pratense	Timothy	Mulch
Annual/Biennial Forbs		
Anthemis cotula	Chamomile	Mulch
Capsella bursa-pastoris	Shepherd's purse	Mulch
Chorispora tenella	Purple mustard	Mulch
Descurainia sophia	Flixweed	Mulch
Perennial Forbs		
Cirsium arvense	Canada thistle	Reference Area
Taraxacum officinale	Dandelion	Reference Area
Trifolium repens	White Dutch clover	Mulch

Three perennial grasses and three perennial forbs were also present in the Restorations, and likely invaded from populations in adjacent habitats, and perhaps from the mulch as well. They were removed from the Restorations by hand, but because these plants are present in the adjacent areas, they are likely to persist in the wetland restorations at a low level.

Success of Seed Mix

Most of the seed for the wetlands was hand collected from the adjacent Reference Areas and broadcast into the Restorations. The plant species present in the Restorations resulted from both the sod plugs and the seeding. The plugs were set out at a density of 1 per 25 square feet. However, the space between the plugs was rapidly colonized by the seed. In fact, due to the dense germinating seed in the Restorations, we reduced the number of sod plugs. The seed mix was very successful. The most successful species include *Deschampsia caespitosa, Carex microptera, Pedicularis groenlandica, Epilobium spp.,* and *Arnica mollis.*

Success of Sod Plugs

The sod plugs were a very effective restoration technique. The initial sod plugs set out in 2001 had a very high species diversity. There were 25 species in the 478 plugs in the Spruce-Fir/Chiming Bells Restoration, 50 in the 200 plugs in the Forested Seep, and 49 in the 455 plugs in the Snowbed Meadow (Table 7).

Success Criteria

The six wetland restorations met all the Success Criteria after six growing seasons, and were determined to be established. Photos 14-25 illustrate the condition of the Restoration in 2001, the first season of growth, and 2007, the seventh season of growth.

Photo 14. Wetland 1 Restoration, Photo-point 1 (7/03/01).

Photo 15. Wetland 1 Restoration, near Photo-point 1 (8/8/06).

Photo 16. Wetland 2 Restoration, Photo-point 1 (7/3/01).

Photo 17. Wetland 2 Restoration, near Photo-point 1 (8/8/06).

Photo 18. Wetland 3 Restoration Area, Photo-point 2 (7/3/01).

Photo 19. Wetland 3 Restoration Area, Photo-point 2 (9/14/06).

Photo 20. Wetland 4 Restoration, Photo-point 2 (7/23/01).


Photo 21. Wetland 4 Restoration, Photo-point 2 (9/14/06).


Photo 22. Wetland 5 Restoration, Photo-point 1 (7/23/01).

Photo 23. Wetland 5 Restoration, Photo-point 1 (9/14/06).

Photo 24. Wetland 6 Restoration southwest portion, Photo-point 1 (7/3/01).

Photo 25. Wetland 6 Restoration southwest portion, Photo-point 1 (9/14/06).

CONCLUSIONS

- Subalpine wetlands can be successfully restored, often quite quickly.
- It is possible to achieve a very high plant species diversity within one to four growing seasons.
- It is possible to achieve a high plant cover within 1-3 growing seasons.
- The hydrology of subalpine wetlands can be restored.
- Use of sod plugs is a very effective way to enhance plant species diversity.
- Hand collected native seed from adjacent wetlands is also an effective method for restoring subalpine wetlands.
- Trees less than 30" in height can be successfully transplanted.
- Subalpine wetlands are dynamic and expand and contract with the available moisture.
- A deep snow pack does not necessarily translate to extensive soil saturation.
- Snow storage upslope of a Restoration had no measurable impact on the hydrology of the wetland.

Revegetation of Fluvial Mine Tailing Deposits: The Use of Five Riparian Shrub Species

Natasha Davis [1], Paul Meiman [1], Joe Brummer [2], and Jim Ippolito [3]

[1] Colorado State University, Department of Forest Rangeland & Watershed Stewardship, Fort Collins, CO 80523
[2] Colorado State University, Department of Soil and Crop Sciences, Fort Collins, CO 80523
[3] USDA-ARS-NWISRL, 3793 North 3600 East, Kimberly, ID 83341

ABSTRACT

Fluvial deposition of mine tailings has caused extensive damage to riparian ecosystems throughout the West. Willows are often used for revegetation of fluvial mine tailing deposits but some species accumulate toxic concentrations of metals in leaves and stems. A greenhouse experiment was conducted to determine the value of thinleaf alder [*Alnus incana* (L.) Moench spp. *tinuifolia* (Nutt.) Breitung], water birch (*Betula occidentalis* Hook.), red osier dogwood (*Cornus sericea* L. spp. *sericea*), and shrubby cinquefoil [*Dasiphora fruticosa* (L.) Rybd.] compared to Geyer willow (*Salix geyeriana* Andersson) for revegetation of fluvial tailing deposits along the Upper Arkansas River. Bare root shrubs were grown in tailings amended with lime and composted biosolids. Tailings were collected from three acidic and metal contaminated deposits along the Arkansas River south of Leadville, Colorado. All shrubs survived the two month experiment. Averaged across source deposits, total biomass during the experiment increased for alder, birch, dogwood, cinquefoil, and willow by 831, 689, 579, 525, and 683%, respectively. All species concentrated Pb and Zn belowground. Dogwood assimilated little Zn (44.0 mg kg^{-1}) into its leaves and stems, but showed signs of nutrient deficiency which could have been induced by metal stress. Alder and cinquefoil partitioned Pb aboveground, 30.3 and 26.1 mg kg^{-1}, respectively, which is unusual, but concentrations were below toxicity thresholds for humans and animals. All species evaluated did not exhibit greater growth when compared to Geyer willow, but the other four riparian species had metal partitioning characteristics valuable for managers planning for *in situ* restoration of mine tailing deposits.

INTRODUCTION

Ecological problems associated with abandoned mine waste affect terrestrial and aquatic ecosystems and a wide variety of organisms, including humans. Prior to federal regulations for mine waste disposal, many companies stockpiled tailings near their operations or discarded mine wastes into nearby rivers. Large flood events have eroded sediment from stockpiles, depositing highly acidic, metal-laden soils in downstream flood plains (Toevs et al. 2006, Wielinga et al. 1999, Merrington and Alloway 1994). Heavy metals from fluvially deposited acid mine waste can leach for decades to centuries after mining has stopped (Modis et al. 1998, Marcus et al. 2001). About 40%, or approximately 19,000 km, of all the waterways in the Western United States are contaminated by metals from acid mine waste (Da Rosa et al. 1997).

Extraction of metaliferous ores from the mined rock is a process that can result in acidic waste products. Mined rock often contains pyritic minerals that oxidize when exposed to oxygen in the atmosphere. Pyrite (FeS_2) loses electrons to oxygen which can then create sulfuric acid when precipitation or river water penetrates the oxidized pyrite (Reaction 1).

$$FeS_2 + 15/4O_2 + 7/2H_2O \rightarrow Fe(OH)_3 + 2H_2SO_4 \qquad \text{Reaction 1}$$

When the pH is below 4, heavy metals cannot chemically bind to soil substrates, thus increasing metal solubility. Protons are so numerous in acidic soils that they bind to most or all of the available sites on soil substrates, such as organic matter, primary and secondary minerals, as well as clays. Metals and other ions present in the bulk soil enter soil solution where they are available for plant uptake or susceptible to leaching. Arsenic (As), cadmium (Cd), copper (Cu), lead (Pb), manganese (Mn), molybdenum (Mo), nickel (Ni), and zinc (Zn) are some of the metals in tailings that cause water quality problems or can be toxic to plants, animals, or humans.

Acid mine waste is considered one of the major water pollution concerns associated with mining (Nelsen et al. 1991, Sheoran and Sheoran 2006). Tailing deposits remain acidic and metal precipitates can wash back into stream channels from reductive dissolution during seasonal flooding (Toevs et al. 2006). Once mobile, metals can be ingested by fish (Schmitt et al. 2006) and beaver (Nolet et al. 1994), and bioaccumulate in aquatic invertebrates (Cain et al. 2004).

Many strategies exist to alleviate the environmental impacts of mine tailing deposits. Contaminated soil excavation and storage is very expensive and use of this method may be limited by site accessibility. Phytoremediation may also be expensive because contaminated plants must be incinerated and new ones replanted. One much less expensive method is *in situ*, or onsite, restoration of fluvial mine tailing deposits. Woody shrubs with fibrous root systems, such as willows (*Salix* spp.), can reduce erosion by stabilizing the tailing deposits (Morgan and Rickson 1995).

Improving soil chemistry is necessary prior to revegetation. Low pH and organic matter content, and high concentrations of heavy metals make it difficult or impossible for plants and soil microbes to survive. Incorporation of a base (e.g. $CaCO_3$) raises pH and causes heavy metals to bind to the surface of clay minerals and organic matter, precipitate into solid metals, and/or reduce into less harmful metal species. The addition of organic matter increases the surface area for binding, adds nutrients (e.g. nitrogen, phosphorus, and potassium), and can inoculate the deposit with a new microbial community. Lime and organic matter are common soil amendments used in riparian areas affected by mine tailing deposits (Brown et al. 2005, Boyter 2006, Kramer et al. 2000).

Areas of deposition occur on private and public lands, creating a myriad of concerned stakeholders. Groups across the state of Colorado, for example, have formed in response to the need for restoration. The Upper Arkansas River Restoration Project (UARRP) is a stakeholder group which formed in 1995 in Leadville, Colorado. The group identified a goal of "restoring the river and associated flood plain to a healthy and sustaining condition" (URS Operating Services 1997). An 18 km stretch of the Upper Arkansas River, starting at the confluence of California Gulch, has numerous fluvial mine tailing deposits that have affected water quality and ranching. Restoration studies by the Environmental Protection Agency (EPA), Bureau of Reclamation, US Geological Survey, Colorado State University, and University of Washington have taken place along the 18 km stretch of the river following the creation of the UARRP (Walton-Day et al. 2000, Fisher 1999, Boyter 2006, Bourret 2004, Brown et al. 2005, 2007, Shanahan 2006).

Mountain (*S. monticola* Bebb.), Geyer (*S. geyeriana* Andersson), Drummond's (*S. drummondiana* Barratt ex Hooker), and planeleaf willow (*S. planifolia* Pursh var *planifolia*) have all been evaluated for their potential use in restoration efforts along the Upper Arkansas River (Fisher 1999, Boyter 2006, Bourret 2004, Shanahan 2006). Most research near Leadville by Colorado State University, concerning the restoration of contaminated sites, has focused on the use of willows. Expanding our knowledge of other riparian shrubs that can tolerate heavy metal contaminated soils will give restoration ecologists more choices to meet ecological goals.

OBJECTIVES/HYPOTHESES

Objective one was to compare survival and growth of thinleaf alder [*Alnus incana* (L.) Moench spp. *tinuifolia* (Nutt.) Breitung], water birch (*Betula occidentalis* Hook.), red osier dogwood (*Cornus sericea* L. spp. *sericea*), and shrubby cinquefoil [*Dasiphora fruticosa* (L.) Rybd.] to Geyer willow when grown in fluvial mine tailings amended with lime and composted biosolids. It was hypothesized that all species would have greater total growth as well as greater aboveground and belowground growth than Geyer willow.

Objective two was to characterize how thinleaf alder, water birch, red osier dogwood, shrubby cinquefoil, and Geyer willow partition Pb and Zn. Metal partitioning was hypothesized to vary by shrub species. It was further hypothesized that Pb would be excluded from aboveground plant parts and that thinleaf alder would exclude both metals from its aboveground parts.

LITERATURE REVIEW

The Western U.S. has a rich history of hard-rock, hydraulic, placer, and open pit mining, along with metal smelting. Before federal environmental regulations, most mining waste was uncontained in stockpiles near the mining operation or discarded in nearby streams and rivers. Regulation of pollutant discharge into U.S. water bodies and the establishment of water quality standards were initiated by The Clean Water Act of 1977. In 1980, the Comprehensive Environmental Response, Compensation, and Liability Act made mining operations liable for their release of chemical wastes. Federal control over mining activities created a focus on restoration of damaged areas, especially abandoned mining and smelting operations.

Tailings from abandoned mines can affect waterways for hundreds of years (Modis et al. 1998). Section 305(b) of the federal Clean Water Act mandates a biannual report from each U.S. state to the USEPA detailing water quality impairment information. In 2006, the Colorado Department of Minerals and Geology reported approximately 2092 km of rivers affected by inactive mining (Colorado Department of Minerals and Geology 2006). The Montana Department of Environmental Quality reported approximately 2896 km of rivers affected in their 2004 report (National Water Assessment Database 2004), while the Washington State Department of

Ecology reported nearly 161 km affected by surface mining and mine tailings in their 2000 305(b) report (Washington Department of Ecology 2000).

Colorado and Montana have extensive damage in riparian zones from fluvially deposited mine tailings. The Clark Fork River in western Montana has been affected by copper mining and smelting for over a century. High levels of Cu, Zn, and Pb are present in sediment and plant material adjacent to the river (Johns 1995). Further downstream, Soda Butte Creek in Yellowstone National Park has also been contaminated with heavy metals from the same mining and smelting. The Yellowstone site is also impacted by historic gold, silver, and copper mining wastes (Nimmo et al. 1998). Research has focused on characterizing site conditions and water quality issues.

Most of the damage near Leadville, Colorado is due to hydraulic placer and hard rock mining that occurred from the late 1800's to the mid 20th century. Mining wastes were generally not contained. Rather, they were either stockpiled or disposed of in the Arkansas River (URS Operating Services 1997). Currently, the largest ongoing impacts are to the surface water of the Arkansas River (MOUP CT 2002). Manganese, Cd, and Zn are the primary water quality concerns in the area (Walton-Day et al. 2000). Typically, fluvial mine tailing deposits vary in the depth of soil affected by acidity and heavy metals. Site characterization of the tailings along the Upper Arkansas River found that the deposits are generally less than one meter thick (MOUP CT 2002).

The use of a variety of riparian shrubs native to the Western U.S. in restoration research will expand our knowledge of species value for reclaiming heavy metal contaminated sites. Willow, birch, dogwood, and alder are common riparian shrubs that occur over a wide range of temperature and elevation gradients throughout the U.S. Cinquefoil is a woody shrub ubiquitous in the Western U.S., having ecological value in upland and riparian zones.

Willows have been used for riverbank stabilization (Morgan and Rickson 1995, Schultz et al. 1995, Pezeshki et al. 2007), improvement of soil structure (Stott 1992), and some species are known to tolerate elevated heavy metal concentrations (Cosio et al. 2006, Vandecasteele et al. 2005). While metal uptake varies by species, Pb is generally not concentrated in aboveground leaves and stems whereas Zn is often taken up by both plant roots and shoots (Vandecasteele et al. 2005, Pahlsson 1989). In a Belgium field study, *S. viminalis* L. 'Orm' accumulated an average of 18 and 3 mg kg^{-1} Pb, and 243 and 363 mg kg^{-1} Zn in roots and leaves, respectively, when grown in soil contaminated with 143 mg kg^{-1} Pb and 437 mg kg^{-1} Zn (Vervaeke et al. 2003). *Salix smithiana* Willd. c.f. *dasyclados*, *S. dasyclados* Vimm., and *S. caprea* L. concentrated 432, 591, and 471 mg kg^{-1} Zn in aboveground biomass when grown in a soil containing 279 mg kg^{-1} Zn (Fischerova et al. 2006). Geyer willow had a leaf tissue concentration of 641 mg kg^{-1} Zn in a greenhouse study using mine tailings amended with lime and composted biosolids with an initial Zn concentration of 1935 mg kg^{-1} (Bourret 2004). Willows are largely used for phytoremediation purposes because of their ability to hyperaccumulate one or more heavy metals.

Both shrub and tree life forms of birch have been used in North America (Lautenbach et al. 1995, Winterhalder 1995) as well as Russia (Kozlov 2005, Kozlov and Haukioja 1999) for restoration of smelter-damaged sites because they have a general tendency to naturally survive in unamended, heavy metal contaminated soils. *Betula pendula* Roth. and *B. pubescens* Ehrh. are pioneer species in metal contaminated areas, showing an evolved tolerance to Pb and Zn (Utriainen et al. 1997, Pahlsson 1989). European white birch (*B. pendula*) trees have shown tolerance to Zn and Pb metal contaminated soil, accumulating a maximum of 3,100 and 530 mg kg^{-1} Zn and Pb, respectively, in their leaves (Margui et al. 2007). River birch (*B. occidentalis* Hook.) grown in a greenhouse study in unamended soil that had a Pb content of 12,914 mg kg^{-1} translocated 202 mg kg^{-1} Pb aboveground (Klassen et al. 2000).

Dogwood shrubs, a common species in riparian zones, can tolerate saline soil conditions. Revegetation after strip mining for bitumen from oil sands in Alberta, Canada has included the use of red-osier dogwood (*C. sericea* L. subsp. *sericea* and *C. stolonifera* Michx.) because of its tolerance to elevated salt concentrations (Redfield et al. 2003, Renault et al. 2001).

Alders are beneficial restoration species for areas with heavy metal issues (Mertens et al. 2004, Rosselli et al. 2003). *Alnus glutinosa* L. Gaertin. grown on dredged sediment polluted with heavy metals accumulated Pb (5 mg kg^{-1}) and Zn (65 mg kg^{-1}), but not enough to be toxic (Mertens et al. 2004). *Alnus incana* used for revegetation of sediment contaminated by sewage sludge borne heavy metals also had very low leaf and stem Zn concentrations (Rosselli et al. 2003). *Alnus rubra* Bong. had similar Zn uptake regardless of whether it was planted in biosolids with low (279 mg kg^{-1}) or high (1760 mg kg^{-1}) Zn content (Gaulke et al. 2006). Alders are also beneficial because they are actinorhizal N_2-fixing shrubs that increase the availability of ammonia (NH_4^+) in soils. Symbiotic nitrogen fixing bacteria in the genus *Frankia* are responsible for this reaction (Reaction 2). *Frankia* are filamentous actinomycetes that form a symbiotic relationship with actinorhizal plants, living within globular structures attached to primary and secondary roots. The *Alnus-Frankia* relationship does not appear to be affected by high metal concentrations in soils (Gaulke et al. 2006).

$$N_{2\,(gas)} + 8H^+ \rightarrow 2NH_3 + H_2 \qquad \text{Reaction 2}$$

Shrubby cinquefoil is native to most of the U.S., occurring in all states west of the 100^{th} meridian. Erosion was reduced when heavy rainfall was simulated in riparian zones where *Potentilla gracilis* Doug ex. Hook was grown in conjunction with grasses (Pearce et al. 1998). *Potentilla fruticosa* ‘Longacre’ was found to be useful for landscaping roadsides where de-icing resulted in highly saline soils (Marosz 2004). Cinquefoil shrubs not only occur in the flood plains of streams and rivers in the Western U.S., but are also commonly found throughout the world.

MATERIALS AND METHODS

Growth Media Collection and Amendment

Tailings from three USEPA characterized sites approximately 8 km south of Leadville, Colorado, were used: FF (39°11’53.27”N 106°21’03.16”W), QO (39°07’48.93”N 106°18’44.35”W), and QN (39°07’50.14”N 106°18’47.54”W) (Figure 1). Two of the sites occurred at 2,799 m and were located on Colorado State Public land; the third site was located at 2,882 m in elevation and located on private ranch land owned by Dr. Bernard Smith. The three tailings deposits contained elevated Zn concentrations and low pH. A total of 227 L of tailings was collected from each site in November 2006. Three or four 60 cm deep holes were excavated at each site and tailings were placed in barrels for transport to Colorado State University. The top 20 cm of soil was frozen and was not collected. The tailings from each site were air dried and homogenized during December and January 2007.

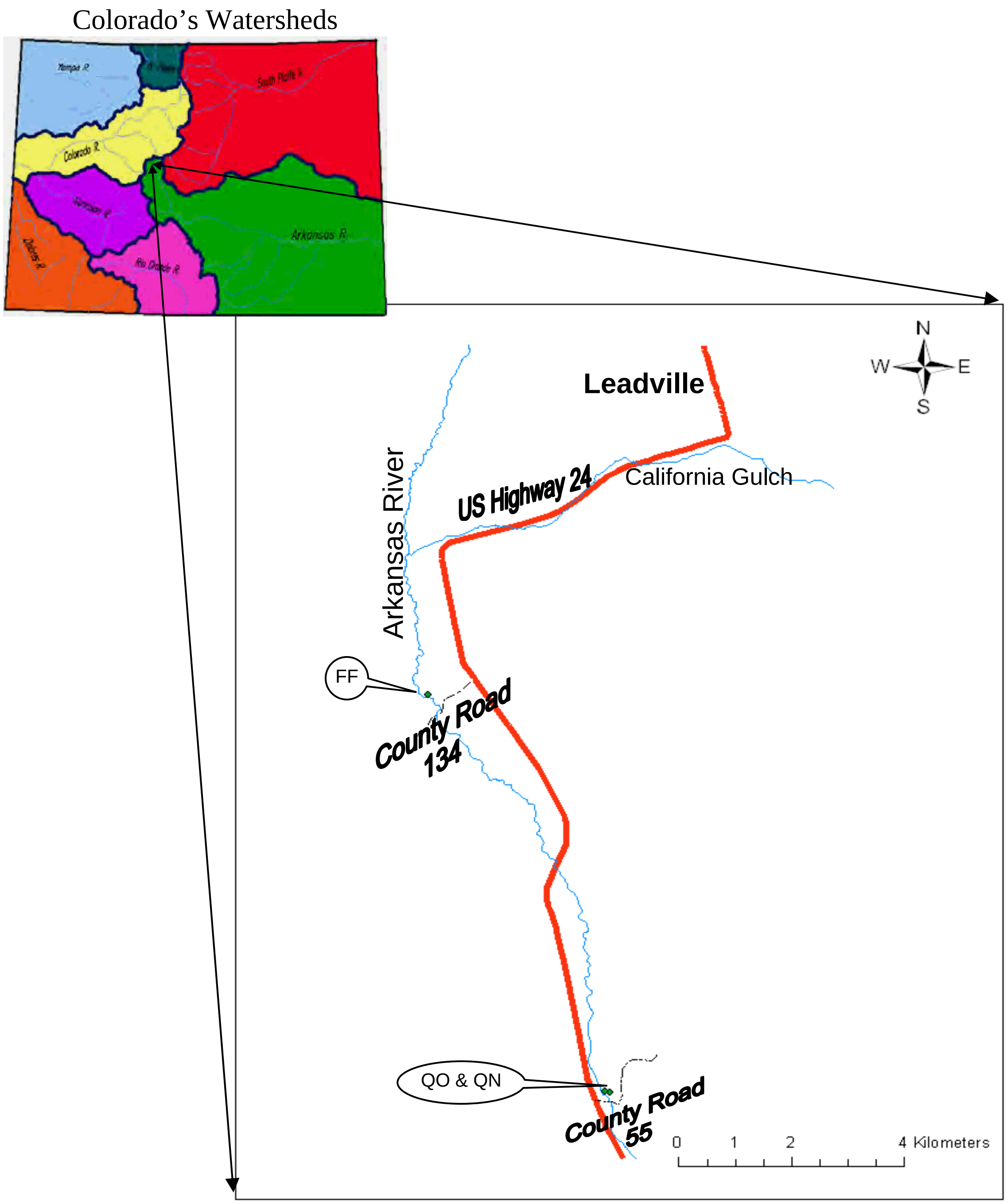


Figure 1: Map showing the location of study sites FF, QO, and QN near Leadville, Colorado.

Once tailings were homogenized within a source deposit, each was analyzed for total Cd, Cu, Pb and Zn (U.S. Environmental Protection Agency 1994) as well as bioavailable Pb and Zn (Mehlich 1984). Unamended tailings contained 1,540 to 5,250 mg kg^{-1} total Pb and 1,670 to 3,380 mg kg^{-1} total Zn. Bioavailable Pb ranged from 190 to 210 mg kg^{-1}, and bioavailable Zn ranged from 81 to 92 mg kg^{-1}.

Tailings were then amended with lime and composted biosolids in early February 2007. Lime ($CaCO_3$ powder ground to pass a 200-mesh screen) was added to raise the soil pH to 7, based on the Shoemaker-McLean Pratt (SMP) Single Buffer Method (Sims 1996; Table 1). Municipal biosolids, composted with wood chips, were added to improve soil structure, inoculate the soil with a microbial community, and supply the tailings with N, P, and K. Composted biosolids were obtained from Gunnison County, Colorado and added at the rate of 224 Mg ha^{-1} based on a previous study in the Leadville area (Brown et al. 2005). A cement mixer was used to ensure thorough mixing of amended tailings, and then the amended tailings were allowed to chemically react for an additional 14 days.

Table 1: The sites, initial tailing soil pH, and amount of lime required to raise the tailing soil pH to 7.

Site	pH	Lime Added (Mg/ha/20 cm)
FF	4.0	3.5
QO	2.0	17.2
QN	3.3	9.2

After amending, tailings from each site were analyzed for bioavailable Pb and Zn (Mehlich 1984). The lime and composted biosolids amendments reduced the soluble forms of Pb and Zn, making only 63 to 133 mg kg^{-1} Pb bioavailable, and 9 to 24 mg kg^{-1} Zn bioavailable.

Shrub Selection and Purchase

Five shrub species were chosen based on several criteria. The primary goal was to find species other than willow that would potentially grow in areas similar to those contaminated with heavy metals from fluvial deposition of mine tailings. The USDA Plants database was used to find facultative or wetland facultative shrubs native to Chaffee, Eagle, Gunnison, Lake, Park, and Summit counties in Colorado that could tolerate a pH of 4 - 5, for assurance that they would tolerate the study area growing conditions. Shrubs came from three different suppliers and were of different ages and sizes (Table 2). Thinleaf alder, red-osier dogwood, and Geyer willow were obtained from Plants of the Wild (Tekoa, WA). Water birch was obtained from Lawyer Nursery (Plains, MT). Shrubby cinquefoil was obtained from Rocky Mountain Native Plants (Rifle, CO).

The shrubs were dormant when purchased in January 2007, except shrubby cinquefoil which was leafed out. Roots of all plants were washed free of potting soil prior to being planted to ensure that the roots were in direct contact with amended tailings.

Table 2: Pre-greenhouse experiment characteristics of thinleaf alder, water birch, red osier dogwood, shrubby cinquefoil, and Geyer willow.

Species	Age (years)	Size	Seed Source
Alder	1	25 cm^3 pots	Northern Idaho
Birch	2	15-30 cm tall	Montana
Dogwood	1	25 cm^3 pots	Northern Idaho & Central Washington
Cinquefoil	1	25 cm^3 pots	Rocky Mountains
Willow	1	25 cm^3 pots	Northern Idaho

Experimental Design

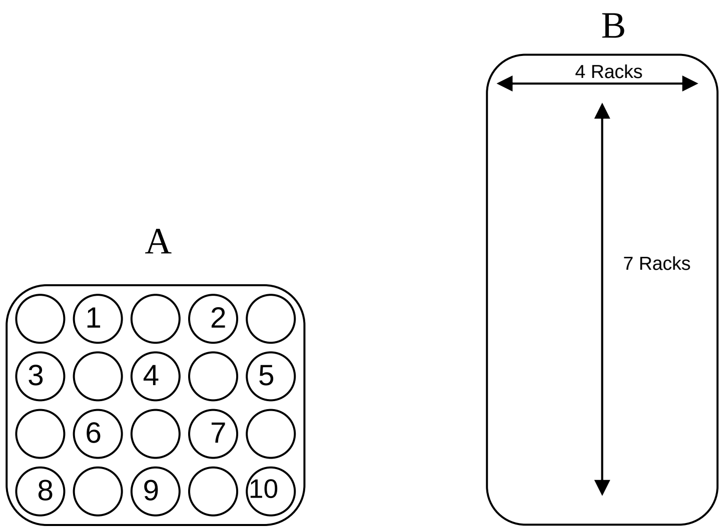


Figure 2: (A) Placement of individual plants into every other cell of a support tray. (B) Tray placement along the greenhouse bench.

Plants for this experiment were grown in the Colorado State University Plant Growth Facilities greenhouse from February 22, 2007 until April 24, 2007. The greenhouse was kept at ~25°C and the shrubs were watered with municipal water. The location of potted plants in support trays and the arrangement of support trays on the greenhouse bench were completely random. Eighteen replicates of each shrub species were planted in tailings from each of the 3 sites amended with lime and composted biosolids, for a total of 270 individual plants. Each bare root individual was planted in a 656 ml plastic pot containing amended tailings. Ten randomly chosen pots were placed in every other cell of a 20 cell support tray (Figure 2). Each support tray was randomly placed along a greenhouse bench, leaving 15 cm of open space between trays. The 27 support trays were re-randomized on the greenhouse bench twice during the study (March 15, 2007 and March 29, 2007).

Harvesting

All plants were harvested on April 24, 2007. Each plant was clipped at the soil surface to separate aboveground from belowground parts. Aboveground biomass was divided into two parts: new growth and stem (material that grew prior to the experiment). The new growth included any leaves and stems that grew during the study. This material was easily identified by the lighter stem color or pubescence. Any tailings particles present on the surface of leaves and stems were rinsed off with deionized water. Tailings were thoroughly washed away from roots using a 0.5 mm sieve and a gentle stream of water. Roots were then soaked for one minute in 0.01 M Na_2H_2-EDTA to remove cations adsorbed to the surface of the root system (Kalis et al. 2006, Slaveykova and Wilkinson 2002). Plant biomass was oven dried at 55°C for 72 hours and weighed.

Plant Metal Concentrations

Lead and Zn concentrations were estimated for new above- and below-ground growth from six randomly selected individuals from every site/amendment combination. Aboveground and belowground plant biomass was ground to pass a 1 or 2 mm screen, depending on dried plant species size. Samples of one gram or less, depending on quantity available, were digested with concentrated nitric acid and 30% hydrogen peroxide (Huang and Schulte 1985). Samples were then analyzed for Pb and Zn using inductively coupled plasma-atomic emission spectroscopy (ICP-AES) at the Plant Testing Laboratory.

Data Analysis

Initial plant size varied among the shrub species used in the study. In order to make comparisons of growth over the course of the experiment, a starting baseline biomass was determined for each of the five species at the beginning of the experiment. Eighteen individual plants of each species were selected at random from the purchased plant material for starting biomass determinations. These plants were separated at the root crown into root and stem samples. Aboveground leaves and stems with any soil particles visible on the epidermis were washed in a deionized water bath. Roots were washed free of potting soil and all plant material was oven dried and weighed as described above. Proportional aboveground growth was defined as the weight of new growth for an individual plant divided by the average baseline stem weight for that species. Proportional belowground growth was defined as ending root weight divided by the average baseline root weight for that species. Metal concentrations were expressed as mg kg^{-1} of dry weight plant material.

Raw proportional growth data and metal concentrations did not meet assumptions of normality and were log transformed for analysis. Growth and metals data were averaged across all three tailings materials in order to focus on species response rather than individual site characteristics. Differences among species for proportional aboveground and belowground growth, as well as metal concentrations, were analyzed using the Proc GLM model in SAS version 9.1 (SAS institute, 2002). Differences were examined using analysis of variance (ANOVA) at a significance level (α) of 0.05 for the experimentwise error rate, with Bonferroni's inequality used for pairwise comparrisons of the *a priori* comparisons among the 5 shrub species.

RESULTS

Growth

Species proportional growth, as compared to Geyer willow, is presented in Table 3. Aboveground growth of water birch was less than all other species. Water birch and Geyer willow exhibited the greatest belowground growth, which was significantly greater than thinleaf alder, red-osier dogwood, and shrubby cinquefoil. There was no difference among species in total growth during this experiment (p=0.23). The hypothesis that aboveground, belowground, and total proportional growth of Geyer willow would be significantly less than each of the other four species was rejected.

Table 3: Aboveground, belowground, and total growth for thinleaf alder, water birch, red osier dogwood, shrubby cinquefoil, and Geyer willow averaged across the three tailings soils. Mean ± SE Aboveground n=54, Belowground n=27, Total n=27.

	Proportional Growth (%)		
Species	Above	Below	Total
Alder	536.2 ± 65.3 a§	293.9 ± 33.0 b	831.1 ± 114.9 a
Birch	196.1 ± 14.2 b	466.7 ± 46.0 a	688.9 ± 66.5 a
Dogwood	306.9 ± 16.7 a	258.6 ± 18.4 bc	578.6 ± 39.5 a
Cinquefoil	361.0 ± 27.4 a	194.6 ± 17.0 c	525.5 ± 43.8 a
Geyer	309.1 ± 9.7 a	381.3 ± 18.1 a	682.7 ± 26.8 a

§ Within columns, lower case letters show significant differences ($p \leq 0.05$) among species for proportional growth using Bonferroni's inequality method of analysis.

Plant Metal Concentrations

Lead

Plant tissue Pb concentration results are summarized in Table 4A. Thinleaf alder and shrubby cinquefoil concentrated the most Pb in new aboveground growth over the course of the experiment. The hypothesis that Pb would be excluded from aboveground parts was rejected. Red-osier dogwood excluded more Pb belowground than Geyer willow, whereas thinleaf alder accumulated more Pb belowground.

Zinc

Plant tissue Zn concentrations are summarized in Table 4B. Red-osier dogwood had the lowest Zn concentration in aboveground new growth, significantly less than Geyer willow. Shrubby cinquefoil and thinleaf alder aboveground Zn content was also significantly lower than Geyer willow. However, birch contained comparable aboveground Zn as Geyer willow (Table 4B). The hypothesis that thinleaf alder would exclude metals from aboveground biomass was rejected. Belowground biomass Zn concentrations were greatest for thinleaf alder and least for Geyer willow. Water birch, red-osier dogwood, and shrubby cinquefoil contained belowground Zn concentrations similar to Geyer willow.

Table 4: Aboveground, belowground, and total Pb (A) and Zn (B) concentrations for alder, birch, dogwood, cinquefoil, and willow grown in lime and composted biosolids amended mine tailings soil collected near Leadville, Colorado. Mean ± SE, n=18.

A	Pb Concentration (mg kg^{-1} dry weight)		
Species	Above	Below	Total
Alder	30.3 ± 9.1 a[§]	544.1± 88.7 a	574.4 ± 97.7 a
Birch	2.5 ± 1.3 ab	367.5 ± 72.6 ab	370.0 ± 73.8 ab
Dogwood	0.6 ± 0.3 b	99.0 ± 19.2 d	99.7 ± 19.6 c
Cinquefoil	26.1 ± 7.2 a	212.8 ± 38.7 c	253.1 ± 45.8 b
Geyer	0.1 ± 0.1 b	295.5 ± 39.3 bc	295.7 ± 39.5 b

B	Zn Concentration (mg kg^{-1} dry weight)		
Species	Above	Below	Total
Alder	125.7 ± 21.8 b	471.6 ± 90.4 a	597.4 ± 112.1 a
Birch	210.9 ± 32.5 a	364.7 ± 81.5 b	575.6 ± 113.9 a
Dogwood	44.0 ± 8.3 d	250.8 ± 35.4 b	294.7 ± 43.7 b
Cinquefoil	100.8 ± 20.8 c	262.8 ± 60.0 b	363.6 ± 80.8 b
Geyer	222.8 ± 20.8 a	205.5 ± 28.6 b	427.7 ± 49.4 a

[§]Within columns, lower case letters indicate significant differences ($P \leq 0.05$) among species in metal concentration using Bonferroni's inequality method of analysis.

DISCUSSION

Growth

All five species were able to survive in the amended tailings and grew five to eight times their original weight. The four shrubs that were transplanted when dormant were able to acquire the resources needed to break dormancy and produce new growth over the course of the study. Shrubby cinquefoil was not dormant when transplanted and did show some negative responses just after transplanting. The oldest leaves became chlorotic and many were shed within the first week, but all plants recovered. The composted biosolids used contained 326 mg kg^{-1} NO_3^-, 2106 mg kg^{-1} P, and 5013 mg kg^{-1} K. Our results suggested that there was no difference in total proportional growth among the shrubs, but there were differences in where that growth occurred.

Geyer willow had not performed well in previous studies when grown in metal contaminated soils (Bourret 2004, Boyter 2006, Fisher 1999, Shanahan 2006). Previous greenhouse research showed Geyer willow plants started from cuttings collected in the Leadville area had poor growth response when using lime and composted biosolids amended tailings collected from the same area as one of our sites (Boyter 2006). Boyter (2006) found Geyer willow cuttings to have 60% less total biomass when grown in lime and biosolids amended tailings versus when grown in topsoil, with a large number of chlorotic leaves that tended to drop on the clones that survived in the amended tailings. Geyer willow plants used in our study were originally started from seed collected from Northern Idaho, were one-year old when this study began, and had 100% survival. Although some plants did show some chlorosis, they did not drop many leaves over the course of the experiment. Usually plants close to a metal contaminated site can evolve a tolerance to adverse soil conditions where plant biomass is not affected by soil toxicity (Chaney 1993, Pahlsson 1989). In the present experiment, Geyer willow seedlings had not been previously exposed to elevated heavy metal containing soils, but were resistant to biomass reduction over the course of the experiment. Thus, Geyer plants established from seed and/or the use of non-local stock can result in a greater growth response compared to the use of local cuttings.

Thinleaf alder did not show any signs of chlorosis. During the course of the study, all individuals of this species appeared healthy. Nodules were observed on roots of many thinleaf alder at the time of transplanting. Nitrogen production and nodule biomass have not been shown to be reduced by high Pb and Zn content in soil (Gaulke et al. 2006), and in the present study this symbiotic association perhaps benefited thinleaf alder. Zinc can suppress root nitrate reduction to ammonia in some plants (Pahlsson 1989), but because of *Frankia* bacteria, thinleaf alder was most likely able to acquire the ammonia it needed to synthesize plant biomass. Chlorosis, the result of a metal competing with Fe during chlorophyll synthesis, was not observed in thinleaf alder, possibly because nitrogen metabolism was not suppressed by Zn.

Aboveground growth of water birch was affected more than belowground growth. While water birch doubled in aboveground growth over the study, this growth was significantly less than the other four species. Instead, water birch concentrated its growth belowground, greater than all species except Geyer willow. Both water birch and Geyer willow belowground growth may help secure rhizosphere soil from erosion, considering their belowground growth compared to the other species. This should be researched further.

Shrubby cinquefoil aboveground growth accounted for 69% of its total proportional growth. Just after transplanting, shrubby cinquefoil showed signs of shock. The oldest leaves became chlorotic and began wilting in the first week of the study. Yet, all plants were able to recover, survive, and produce as much aboveground biomass as Geyer willow and red-osier dogwood.

Red-osier dogwood grown in consolidated tailings produced greater belowground growth than aboveground over a one year greenhouse study (Redfield et al. 2003). In the present study, above and belowground biomass were nearly equal. Aboveground biomass was similar to Geyer willow, unlike root biomass which was lower than Geyer willow.

Lead

All species concentrated Pb belowground, ranging from 84 to 99% of the total Pb uptake. When water birch was grown in the greenhouse over a 4 month period in tailings from the Pacific Mine in Utah, 90% of the Pb concentrated in roots and no signs of nutrient deficiency or toxicity were observed (Klassen et al. 2000). In our 2-month greenhouse study, 99% of the Pb accumulated by water birch was concentrated in the roots. Lead levels in the Pacific Mine tailings (30,000 to 130,000 mg kg^{-1}) were much greater than the Leadville tailings (1,540 to 5,250 mg kg^{-1}), yet water birch performed very similarly in both studies. Water birch exhibits a range of Pb tolerance implying that it is capable of some means of exclusion. By concentrating Pb belowground, water birch promotes Pb stabilization in the tailing deposits by reducing the amount of Pb within the tailings that would be susceptible to leaching. *Betula pubescens* and *B. pendula* are two species that can accumulate greater aboveground Pb concentrations (Pahlsson 1989, Utriainen et al. 1997, Margui et al. 2007) and would be better suited for phytoremediation. *Betula occidentallis* Hook. is better suited for *in situ* remediation of sites where aboveground Pb accumulation is not desired.

Thinleaf alder and shrubby cinquefoil concentrated an average of 30 and 26 mg kg^{-1} Pb, respectively, into their new growth over the study. Lead can be taken up by plant roots, but is not commonly translocated to stems and leaves (Hettiarachchi and Pierzynski 2004, Pahlsson 1989, Klassen et al. 2000). Lead can be laterally transported and accumulated aboveground when applied to bark (Lepp and Dollard 1974). Perhaps the Pb in cinquefoil and alder was not translocated from the roots, but rather absorbed from tailings splashed onto aboveground woody stems and incorporated into plant tissues prior to harvest.

Consuming vegetation containing greater than 30 mg kg^{-1} Pb is known to be toxic to cattle, sheep, pigs, horses, and rabbits (McDowell 2003). Lead is a toxic metal that can cause neurological damage to humans and pathological changes in kidneys, digestive tracts, and cardiac systems of animals (McDowell 2003). Most domestic animals can consume plants with 30 mg kg^{-1} Pb or less (McDowell 2003), the approximate concentrations we observed in thinleaf alder and shrubby cinquefoil. Thinleaf alder is a highly palatable shrub to browsing animals and cinquefoil has a medium palatability (USDA Plants Database 2007), but they would not generally comprise a significant proportion of the diet of any animal browsing along the Arkansas River.

Zinc

Soils often have total zinc concentrations between 10 and 300 mg kg^{-1} while total Zn concentrations of plants typically range from 15 to 100 mg kg^{-1} (Hagemeyer 1999). Domestic animals can tolerate a range of Zn concentrations, with the lowest tolerance at 300 mg kg^{-1} for sheep (McDowell 2003). All shrubs in this study had less than 300 mg kg^{-1} Zn in their aboveground growth. However, Zn uptake is often greater in greenhouse than field experiments due to greater greenhouse temperatures causing greater transpiration rates (Chaney 1993), and enough water supply to consistently maintain turgor pressure (Rosselli et al. 2003). All four species would likely concentrate less Zn aboveground in the field.

Thinleaf alder concentrated Zn in its new growth, but the genus *Alnus* is generally considered a heavy metal excluder. In our study, 79% of the Zn detected in alder was concentrated in the roots, which was greater than birch, cinquefoil and Geyer willow. Our results showed a similar relationship to a field study conducted in Switzerland at a high metal content sewage sludge capped landfill. In the Switzerland study, *A. incana* (L.) Moench had lower aboveground Zn concentrations than *B. pendula* and *S. viminalis* (Rosselli et al. 2003). *Alnus incana* in our experiment was consistent with other field studies where *A. glutinosa* concentrated 90% of Zn taken up in its roots (Mertens et al. 2004) and *A. rubra* concentrated 84% of Zn belowground (Gaulke et al. 2006).

General symptoms of Zn toxicity in plants include turgor loss and necrosis on older leaves (Hagemeyer 1999), water stress, wilting, and nutrient deficiency (Pahlsson 1989, Chaney 1993). Zinc can cause Fe and Mn deficiencies which then interferes with carbohydrate metabolism and translocation to growing plant parts, nitrogen metabolism, and photosynthesis (Pahlsson 1989). Only a few replicates of red-osier dogwood and water birch had necrosis on older leaves. Many of the red-osier dogwood replicates had purple spots on their leaves or a purple hue over the entire leaf, but never displayed multiple symptoms of metal stress on one individual plant. Regular spotting is indicative of cadmium and copper stress (Barcelo and Poschenrieder 1999), which was possible considering that the tailings had an average bioavailable content of 12.6 mg kg^{-1} Cu and 3.0 mg kg^{-1} Cd. The purple hue on the leaves resembled the fall coloration of this species, but the leaves were not senescing. The only leaves that died over the study were the oldest leaves due to necrosis. Red-osier dogwood showed visible signs that it suffered from some sort of metal induced nutrition deficiency.

CONCLUSION

No shrub species evaluated in this greenhouse experiment exhibited superior growth or metal uptake qualities when compared to Geyer willow. All five species could be used for *in situ* field restoration of fluvial mine tailing deposits because of their ability to exclude enough Pb and Zn as to not be toxic to wild and domestic animals. Overall metal uptake ought to be lower in the field than it was in the greenhouse study due to reduced transpiration. All five of these shrubs have shown their ability to grow when exposed to high Zn and Pb content in soils, but thinleaf alder was the only species not to exhibit any visual signs of metal induced nutrient deficiencies. Where Zn and Pb are of concern for their effect on wildlife, red-osier dogwood would be an ideal species to use because of its ability to exclude both metals from aboveground growth.

Restoring vegetative cover to fluvial mine tailing deposits using thinleaf alder, water birch, red-osier dogwood, shrubby cinquefoil, or Geyer willow is a first step to reducing heavy metal contaminated sediment erosion. Establishing these shrubs could also significantly reduce the extent of waterways reported under section 305(b) of the Clean Water Act to be effected by inactive mining. Biodiversity should be considered when planning restoration projects by using a mixture of these facultative wetland species. Stabilization of fluvial tailing deposits with shrubs should also facilitate the return of characteristic sedges, grasses, and forbs. Nutrient cycling, another ecosystem function, would also be restored, especially by the addition of N, P, K, and microbial communities from composted biosolids application. Re-creating continuity between degraded areas with adjacent riparian zones as well as upland ecosystems would also reduce exposure to animals that typically have to cross contaminated zones to access river water.

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SEDIMENTATION PREDICTION AND PREVENTION IN TRAIL CREEK HAYMAN FIRE SITE, COLORADO

Jennifer M. Patterson[1], Garth Englund[2], and George W. Annandale[1]

1. Engineering & Hydrosystems Inc. 8122 SouthPark Lane, Littleton, CO 80120
2. Douglas County 100 Third Street, # 250, Castle Rock, CO 80104

ABSTRACT

Trail Creek watershed located near Deckers, Colorado was partially burned during the Hayman Fire in June 2002. The fire resulted in increased erosion from the watershed and sediment load to the Creek. In 2005, a field investigation was conducted and sediment yield rates estimated. The goal was to determine the recovery rate of the watershed and determine when stream restoration activities would be most beneficial. Methods used included historic analysis of burn area recovery and geomorphic interpretation of the watershed. Predictions were made that the watershed was nearing recovery and that sedimentation rates should return to baseline by 2007. However the prediction was proved invalid in the spring/summer of 2007, as significant precipitation occurred and Trail Creek was completely buried. As a lessons learned, the methodology for the sediment yield predictions are presented within. Based on these new findings, a series of watershed restoration activities have been developed for the hill slopes.

INTRODUCTION

Trail Creek was one of the watersheds burned during the Hayman Fire in June 2002. In all, the Hayman Fire burned 137,760 acres including 133 homes, 1 commercial building and 466 outbuildings (Wilderness Society 2008). The cost to suppress the fire has been estimated at $39.9 million. However, the fire suppression was just the initial financial reaction to this fire. Since the fire the social, economic, and habitat impacts have continued to be realized.

Some of these impacts have been realized in the West Creek watershed and specifically the Trail Creek tributary in Douglas County (Figure 1). Increased sediment yield from the catchment is threatening to diminish the storage capacity of West Creek Reservoir, a local water supply. Douglas County along with their partners would like to prevent any reservoir sedimentation from occurring as well as maximize the impact of any reclamation activities. Therefore, a study was conducted to predict the sediment yield from the catchment and develop reclamation alternatives.

The predictive calculations are presented in detail below. The prediction was conducted in the summer of 2005 and concluded that sediment yield should return to baseline conditions in about 2007. However, the prediction was proven wrong in the spring/summer of 2007, because Trail Creek was completely buried with sediment in a series of high- and medium-intensity precipitation events. So, although the calculations present what could be considered a valid methodology, the conclusions were not accurate. The lesson learned is that precipitation is the driving factor for sediment yield.

METHODOLOGY

The prediction of sediment yield from the catchment used both a qualitative field inspection and a quantitative evaluation of historic fires. The field inspection did not include any ground measurements, but was a general geomorphic interpretation of the watershed conditions.

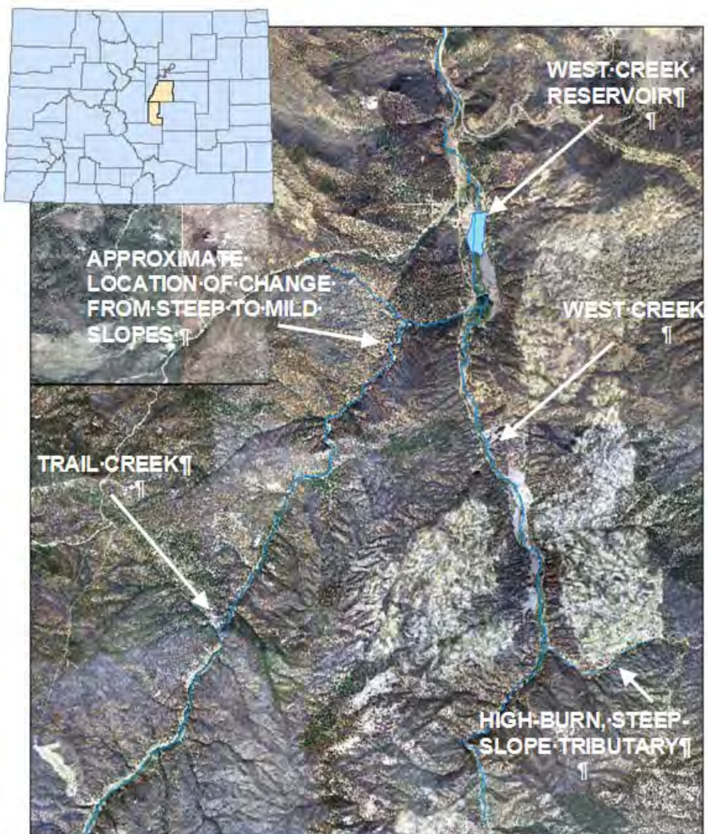

Figure 1. Site Location Map

The quantitative evaluation was primarily based on the burn severity mapping presented in Burned Area Emergency Rehabilitation (BAER) reports (Robichaud and others 2003). Pre-fire and post-fire imagery was used to visually understand the burn areas and the changes in stream and watershed characteristics as a result of the fire in 2002. Additionally, historic sediment yield data measured in previously burned areas were applied to our site using unit areas. These values were compared to site-measured data in 2002/2003 as well as baseline sediment yield data to estimate the rate of recovery.

The development of reclamation alternatives came from abundant literature review relying heavily on BAER reports. Additionally, alternatives were developed from best practices applied to river restoration.

SEDIMENT YIELD PREDICTION (2005)

The sediment yield prediction was proven to be incorrect in the spring/summer of 2007. The calculations and methodology are presented in detail, but caution must be advised when using this approach. The sediment yield is driven by precipitation, and a high-intensity precipitation event can impact not only the recovery rate, but also compromise reclamation efforts. The sensitivity of the method is associated with predicting the frequency and depth of high-intensity precipitation events. The methodology presented within is based on

Figure 2. Photo Illustrating Vegetation Recovery on Hillslopes

historically-measured sediment yield data. These data may or may not have included "as big of" a storm event as the one which occurred at this site.

Field Observations

Hill Slopes

On August 9, 2005, E&H conducted a site investigation of West Creek and Trail Creek. A primary observation was the high erosivity of the soils (Figure 2). This was confirmed by John (2002) who noted that the soils in the Hayman Fire are highly erodible when exposed to the direct impacts of rain, sheet wash, rilling, or gullying. Rills and gullies had formed in most depressions and significant downcutting was observed. Some erosion rills/gullies had eroded down to competent bedrock. This indicated that the source of sediment was diminishing, and that additional sediment would only be transported off the hillslopes if the rills/gullies widened.

Figure 3. Photo Illustrating Typical Hanging Tributary

Areas with live pine trees have duff, other areas are devoid of the organic layer. However, the active transport off the hillslopes was slowing. Vegetation was becoming established in areas that had experienced significant deposition. This implies that the deposition is not inhibiting plant growth and the rate of depositions is slowing.

Tributaries

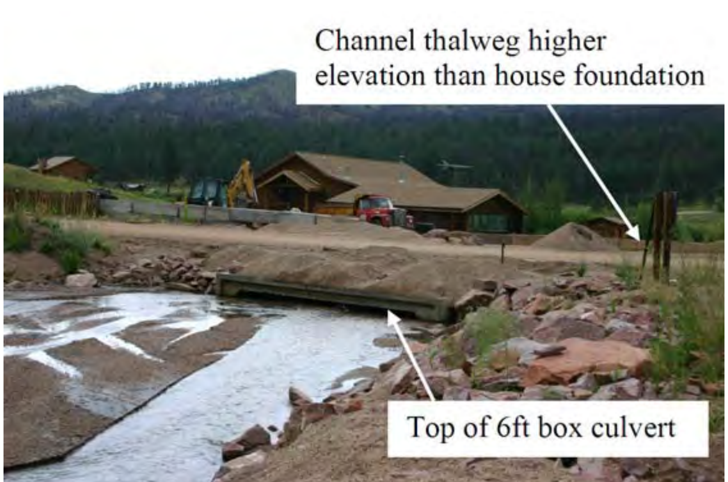

Figure 4. Photo Illustrating Sediment Deposition within Trail Creek in the Low-Slope Reach

Tributaries exhibited downcutting in the upper reaches and contributed a significant sediment load to Trail Creek. In fact, most of the tributaries were hanging relative to the local baselevel, Trail Creek. This means that degradation in these tributaries can be expected in the near future. A series of headcuts were identified in one tributary, which signifies active degradation.

Trail Creek

Within Trail Creek 2 to 4 feet of recently-deposited sediment overlies the pre-fire organic soil horizon. There was limited lateral migration during the sediment accumulation, which indicates that the volume of sediment within the valley is not as much as it potentially could have been, i.e. if the channel was carrying an abundance of sediment, a braided channel would form and cover the valley floor. A depositional reach was readily apparent and corresponded with a pre-fire change in slope. In this location, Trail Creek experienced at least 12 feet of deposition. The house at this location was constructed 8 feet above the thalweg. Currently it is located 4 feet below the thalweg. The geomorphology also reflects the amount of deposition, as Trail Creek flows up-valley before joining its mainstem, West Creek.

Geomorphic Interpretation

The interpretation of the field data suggested that the hillslopes were nearing recovery to pre-fire conditions. The understory regrowth exhibited a high density and the rills/gullies had reached competent bedrock. There was some uncertainty about the volume of sediment stored within the tributaries and the active degradation, but the amount of vegetation suggested that the tributaries were also nearing recovery. The volume of sediment deposited in the low-slope reach of Trail Creek also suggested that the most active deposition had occurred in the three years after the fire.

However, this interpretation was proved to be inaccurate. The volume of sediment stored within the tributaries was enormous (Figure 3), and the volume deposited within Trail Creek in the upper reaches was relatively insignificant (Figure 5). These two factors were overlooked due to the recovery rate of the understory and the vegetation within the tributaries. In hindsight, the potential for erosion remained due to the lack of canopy and the high erosivity of the soils.

Figure 5. Photo Illustrating Sediment Deposition within Trail Creek in High-Slope Reach

Quantitative Calculations

Research indicated that sediment yield is mainly controlled by burn intensity and vegetation recovery and to a lesser extent by slope. To assess the relative impact of these indicators, Trail Creek and West Creek were broken into three separate watersheds (Figure 6). Quantitative sediment yield estimates were made for the Upper West Creek and Trail Creek watersheds.

A database of the overall burn area for each watershed was created. Using predefined commands in ArcMap (e.g., clip, edit, intersect, etc) burn severity areas (in percentages and acres) were estimated (Figure 6). The U.S. Forest Service burn severity classifications are based primarily on overstory tree mortality (Figure 6). However, burn severity is the result of several interacting variables that are reflected to varying degrees in the overstory tree mortality (Robichaud and others 2003).

The U.S. Forest Service monitored sediment yield in the Hayman Fire burn area from 2002-2006. These monitored values were used to obtain a unit-area sediment yield from the burned areas. The unit-area numbers were applied to the Trail Creek watershed. The estimated sediment yields from Trail Creek and Upper West Creek for 2002-2005 are presented in Figure 7.

In 2002, BAER estimated that the sediment yield in high and moderate burn areas was 70 tons/acre/year. This results in an average of about 41 tons/acre/year for Trail Creek and 43 tons/acre/year for West Creek. In 2003, the Forest service estimated that this had dropped to 10 and 11 tons/acre/year for two unnamed locations in the burn area. However in 2004, the value for one of these locations actually increased. This was due to a large precipitation event, and illustrates how sensitive these values are to rain. The E&H value reported in 2005 is an estimate based on field observations and is not representative of any sampling. The Buffalo Creek value is based on 5 years of data and is presented only as a reference (Moody and Martin 2001). Baseline sediment yield ranges between 0.5 and 1 tons/acre/year.

Watershed	Total Area	Burn Area*	Watershed in Burn Area
	acres	*acres*	%
Upper West Creek	24,619	6,552	27
Trail Creek	10,669	9,427	88

*Area based on USFS Burn Area Severity Delineations.

Burn Severity	Upper West Creek		Trail Creek	
	acres	%	*acres*	%
Unburned	1,022	15.6	1,412	15.0
Low	2,181	33.3	3,638	38.6
Moderate	1,111	17.0	3,444	36.5
High	2,237	34.1	932	9.9

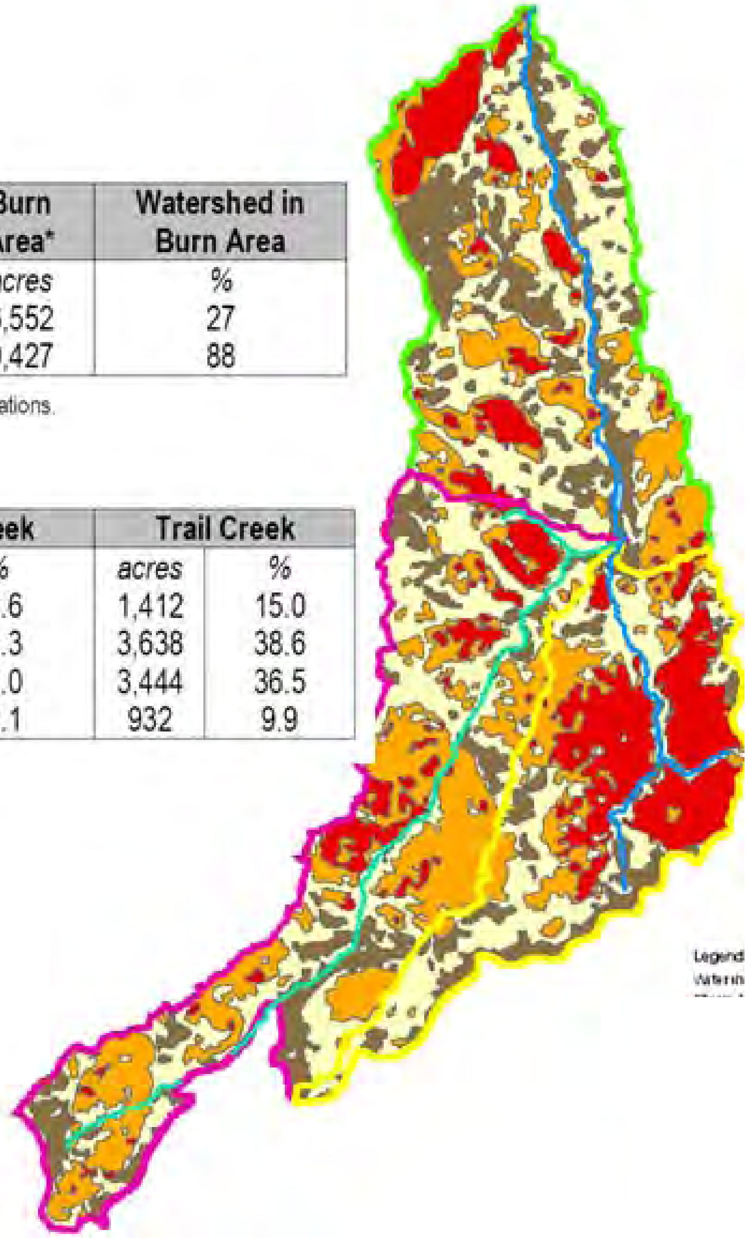

Figure 6. Burn Severity and Basin Delineations

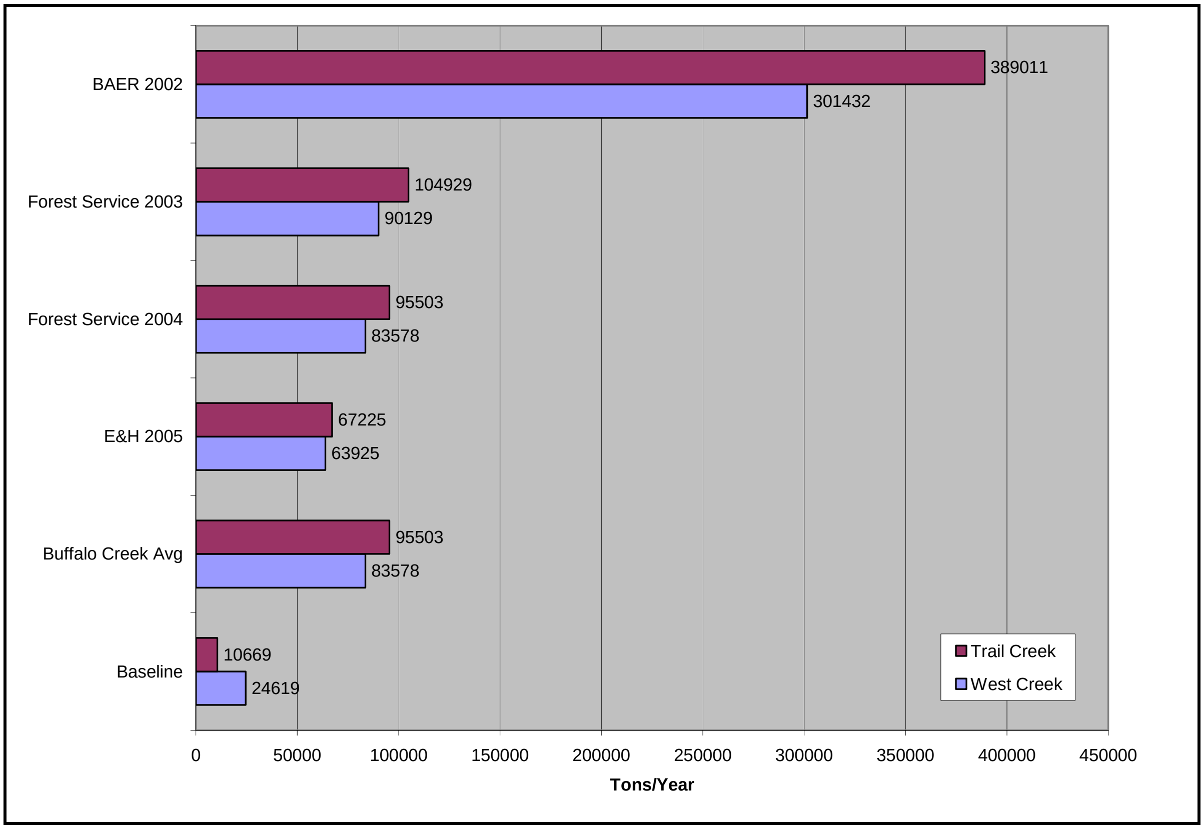

Figure 7. Calculated Sediment Yield for Upper West Creek and Trail Creek Watersheds

2005 Conclusions

Figure 7 illustrates that the sediment yield rates are

- decreasing through time,
- lower than the 5-year average for Buffalo Creek in 2005, but
- not yet to baseline conditions.

The analysis was conducted more than 3-years after the Hayman Fire. Trail Creek had only 9.9% of its burned watershed in a high burn area and the majority was in a moderate burn area. Based on previous investigations, the high burn area was estimated to have a 3-5 year recovery (Moody and Martin 2001, Benavides-Solorio 2003) and the moderate burn was estimated to have a 2-4 year recovery (Cipra and others 2003). It was concluded that the erosion rates were nearing pre-fire hillslope conditions. This was considered valid by observations made during the site investigation. The rills and gullies that formed post-fire were eroded down to bedrock in many locations, indicating a diminished sediment supply. Vegetation on the hillslopes was starting to recover in both the areas that are eroding and in areas receiving the deposition. This indicated that the sediment source on the hillslopes was returning to baseline conditions.

SEDIMENT YIELD REALITY (2007)

The conclusions made in 2005 were proven to be inaccurate by deposition events in the Trail Creek watershed during the winter/spring of 2006/2007. The rainfall patterns show large precipitation events occurred in late 2006 and 2007 (Figure 8). These precipitation events caused hillslope erosion, transport of sediment from the tributaries, and in-channel deposition (Figure 9). The culvert illustrated in Figure 4 again filled with sediment.

This conclusion was also reached by Robichaud and Wagenbrenner (2007) who stated "A previous hypothesis suggested that post-fire hydrology and erosion recover to pre-burn conditions a few years after burning. This study has clearly indicated that significant runoff and erosion are still occurring with moderate intensity rain storms four year post-fire. The length of time for full recovery remains unknown."

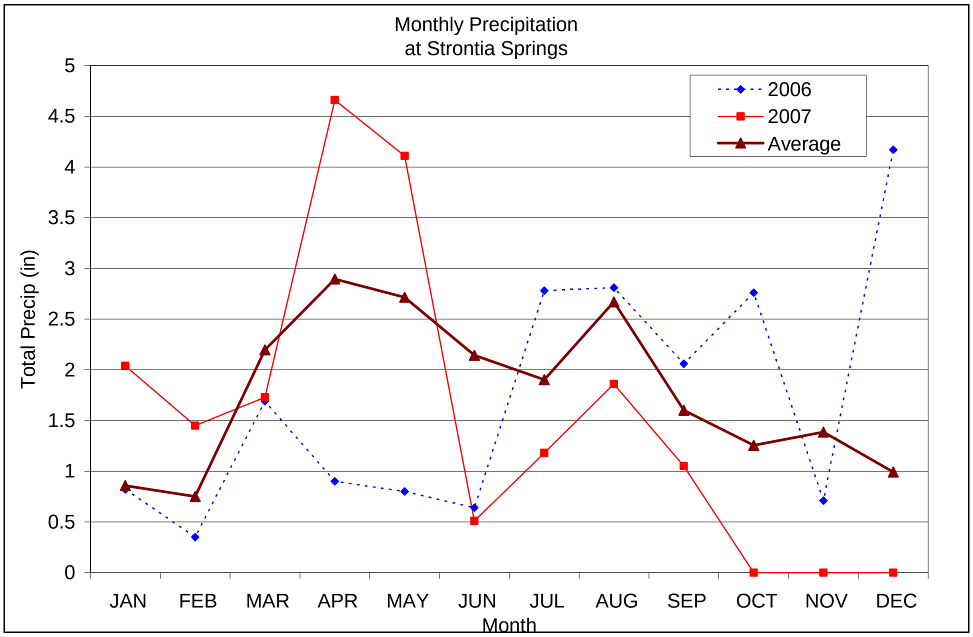

Figure 8. Monthly Precipitation Totals

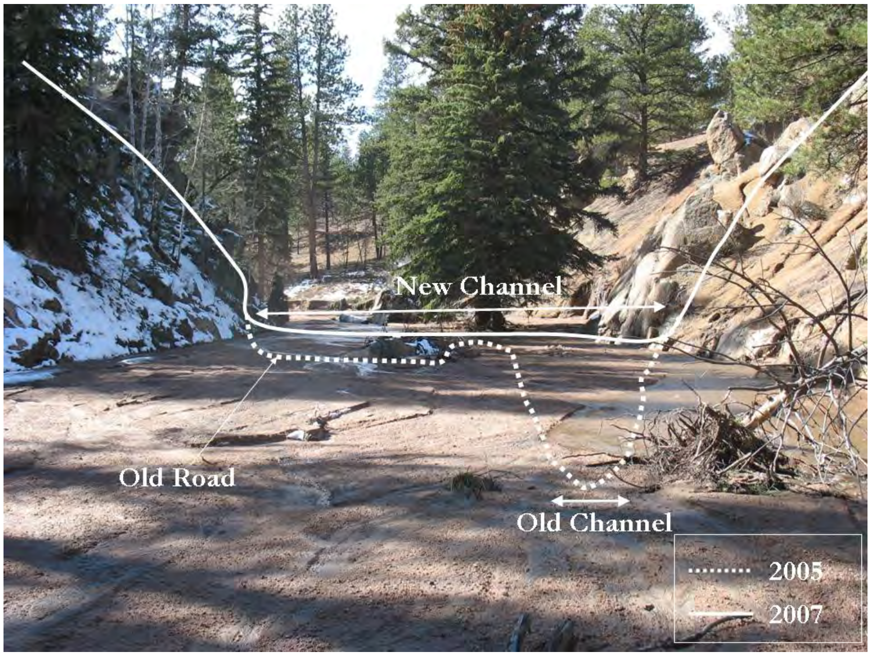

Figure 9. Schematic of 2005 and 2007 Cross Sections

RECLAMATION ALTERNATIVES

Based upon the 2007 observations, reclamation alternatives focused on hillslope erosion protection. If the conclusions in 2005 had proved to be valid, the focus would have been on the stream. However, controlling the source is paramount when addressing sediment yield issues. Initial assessments indicated that the sources (hillslopes and tributaries) were recovering to pre-fire conditions. When the excessive erosion and deposition occurred in 2007, it was determined to focus restoration efforts on the source of the sediment.

The Trail Creek watershed was divided into small (approximately 20-acre) sub-catchments to delineate high-priority hillslope restoration target areas (Figure 10). The sub-catchments were overlaid on the October 2006 aerial photographs. Each of the 408 sub-catchments was classified as low, moderate, or high-priority based on visual inspection of October 2006 aerial photographs watershed conditions. The criteria for low, moderate, and high priority selection was:

Low-priority – visible hillslope vegetated cover (60-70%) with ground vegetation recognizable as dark green and unburned trees clearly identifiable.

Moderate-priority – visible hillslope vegetated cover (40-50%) with ground vegetation recognizable as light green and some visible unburned and burned trees.

High-priority – little visible hillslope vegetated cover (20-30%) with ground vegetation recognizable as a mix of light green and brown and burned trees clearly identifiable.

The burn severity map obtained from the US Forest Service was overlaid on the priority map to further verify priority areas (Figure 10). For example, unburned or low burn severity areas should closely coincide with low-priority; moderate burn severity with moderate to high-priority; and high burn severity with high-priority. However, if BAER had conducted restoration activities, it was assumed that the burn area is not actively eroding and hence not included as a high-priority hillslope restoration target area.

Robichaud and Wagenbrenner (2007) identified that engineered wood straw was the most effective treatment method to at increase cover and reduce sediment yield. They identified that contour raking did not significantly affect the ground cover or reduce sediment yields as compared to the control plots. However, Robichaud (2007) indicated that straw mulch provided good ground cover if it was placed in areas protected from dominant winds.

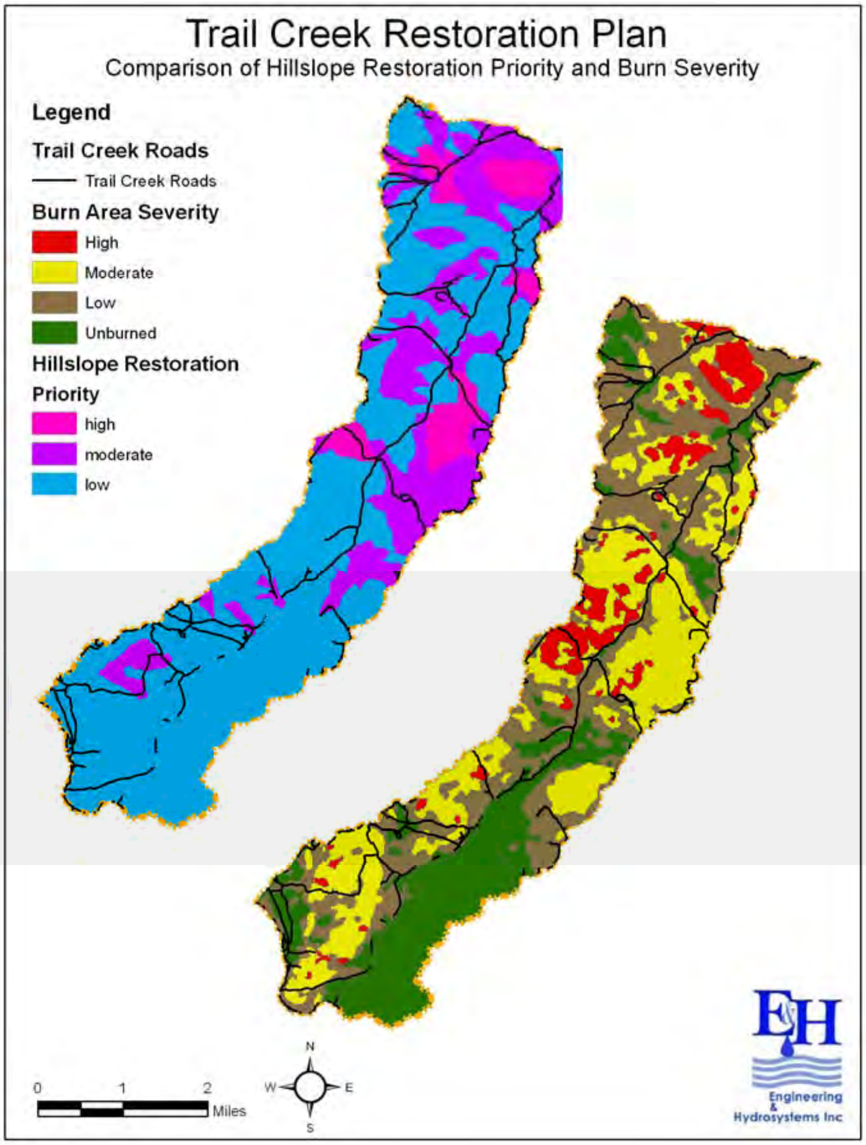

Figure 10. Hillslope Restoration Priority and Burn Severity

CONCLUSIONS

Sediment yield measurements from post-fire watersheds have historically revealed that burn severity is key for determining recovery rates. The regrowth of vegetation and subsequent increase in canopy and ground cover are necessary to achieve baseline sedimentation rates and these regrowth rates are driven by the burn severity. However, this investigation revealed that for any one year, the potential erosion depends on the rainfall patterns. This agrees with the findings from Moody and Martin (2001) work at the Buffalo Creek fire (north of the Hayman Fire) from 1996. Therefore, it is concluded that the burn severity and subsequent regrowth rates may not be the primary key to achieving baseline sediment yield, but that rainfall patterns are the driving factor.

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STAPLETON'S NORTHFIELD PONDS – LANDSCAPE ARCHITECTURE, ECOLOGY AND ENGINEERING

Jayne D. Kopperl,[1] and Doug A. Lamson[2]

[1]EDAW|AECOM, 1809 Blake Street, Suite 200, Denver, CO 80202; PH 303.595.4522; FAX 303.595.4434; email: jayne.kopperl@edaw.com

[2]Chroma Design Inc. 2805 Vassar Drive, Boulder, CO 80305; PH 303.990.2269; email: doug@chromadesigninc.com

ABSTRACT

Northfield Ponds, a 35-acre park, is part of Denver's Stapleton Redevelopment Project, as a new mixed use 'New Urbanist' community. Engineers originally conceived the site as a storm water detention and water quality facility with little enhancement beyond the typical concrete pipes and structures, erosion control, and proposed grass seeding. The proposed design opened the area to public use yet provided native plant and wetland habitat that would contribute to the area's natural resources. The facility is organized into three 'cells' for storm water management and accommodates 1600 cfs of inflowing runoff from 460 acres of commercially developed land. A river delta typology for landforms and water courses, complete with meandering braided streams and droplet shaped islands of varying sizes, were proposed for the design. Forebays and drainage structures were designed as attractive architectural elements in the landscape. The 'delta' design concept was emphasized and enhanced with the planting design of herbaceous and woody plant material native to the West's high plains. Plantings were carefully field located to follow mapped and observed groundwater contours so that plants will sustain themselves through droughts typical to the Denver area. Bioengineering practices where used on the downstream side of the forebays with the intent of spreading water across outlets to reduce the concentration of flows that would cause channelization of the run-off. Northfield Ponds is a successful example of blending the needs of storm water management with sustainable ecological goals, creating an aesthetic and useful passive park for users to observe urban wildlife.

INTRODUCTION

The Design

Northfield Ponds are part of Stapleton, Denver's former international airport. The area is one of the nation's largest urban infill projects. Stapleton has been developing as a mixed use, 'New Urbanist' community since 2001 and will house over 25,000 residents by 2020. Commercial uses within the new community include businesses that will employ up to 20,000 and a wide range of retail activities located in town centers and regional retail plazas. One such 'regional retail' facility has been constructed adjacent to the Northfields Ponds and is the reason the ponds needed to be constructed early on in the development process.

Northfield Ponds were originally conceived as a storm water detention and water quality facility with little enhancement beyond the typical concrete pipes and structures, erosion control, and grass seeding common to urban storm water treatment areas. Park Creek Metropolitan District and Forest City Development contacted EDAW in early 2004 to request a review of current storm water plans, and asked EDAW to make recommendations for developing the area as a public park. The design team began the design process by analyzing the site's surroundings and infrastructure, and they carefully examined the water resource engineer's design to fully understand the sites requirements and constraints. Pedestrian circulation routes and potential park entrances and trail connections were also mapped. The design team followed this period of inventory and analysis with a conceptual design phase, where we chose the design concept of treating the entire pond as a sort of hybrid form of river delta. The similarities between a natural high plains waterway and the ponds were obvious; the basins were wide and relatively level, designed to encourage storm water to spread out over the entire bottomland as it slowly progressed to its outlet. The patterns made by the Platte River as it winds its way across the high plains of Colorado and Nebraska seemed particularly appropriate.

Figure 1 – Aerial view of a braided river

Figure 2 – Braided River

The next step was to develop the concept so that it created a unique native plant and animal wetland habitat that would contribute to the area's natural resources and create an attractive urban destination for park users.

Northfields Ponds Park is 35 acres in size. It accommodates 1600 cfs of inflowing runoff from 460 acres of commercially developed land. The design team organized the facility into three 'cells' for storm water management. The cells or "ponds" are slightly sloping (south to north) for 1680 feet, allowing water to accumulate in a series of three open water bodies before filling up to the outlet invert elevation in the lowest pond. The release rate out is 75 cfs to nearby Sand Creek. The design team proposed a river delta typology for landforms and water courses, complete with meandering braided streams and droplet shaped islands of varying sizes. A rich palette of native trees, shrubs, forbes, and grasses enhance the wetlands.

The design team developed forebays and drainage structures as attractive architectural elements in the landscape. Sculpted concrete forms envelope the actual pipes and culverts, and invite the visitors' attention. Like giant flagstone, "Staplestone"-- large broken concrete of the former airport runways-- lined forebays, providing for maintenance access and storm water percolation.

Figure 3-7'x11' outfall structure

Figure 4-South view of grading

The design team further emphasized the delta design concept with planting design using herbaceous and woody plant material native to the West's high plains. Plantings were carefully field located to follow mapped and observed groundwater contours, so plants could sustain themselves through droughts typical to the Denver area.

Bioengineering practices were used on the downstream side of the forebays, with the intent of spreading water across outlets to reduce the concentration of flows that would otherwise cause channelization.

Figure 5-Wetland sod installed

Figure 6-Wetland sod, 2-1/2 months later

Challenges of design included variations of ground water levels during the two years of design and subsequent construction, which required field revisions to plant locations, seed mixes and planting methodologies. Soil conditions, it was also discovered to vary significantly, with much of the on-site soils composed of 88-92% sand.


U.S.P.S. SERVICE DRIVE
49TH AVENUE
QUEBEC STREET
TRENTON STREET
I-270
I-70
0 100 200 300 400
SCALE IN FEET
EDAW
May 19, 2004
Revised: December 1st, 2004
Stapleton Filing 14 Water Quality Ponds

Figure 7 – Plan view graphic rendering

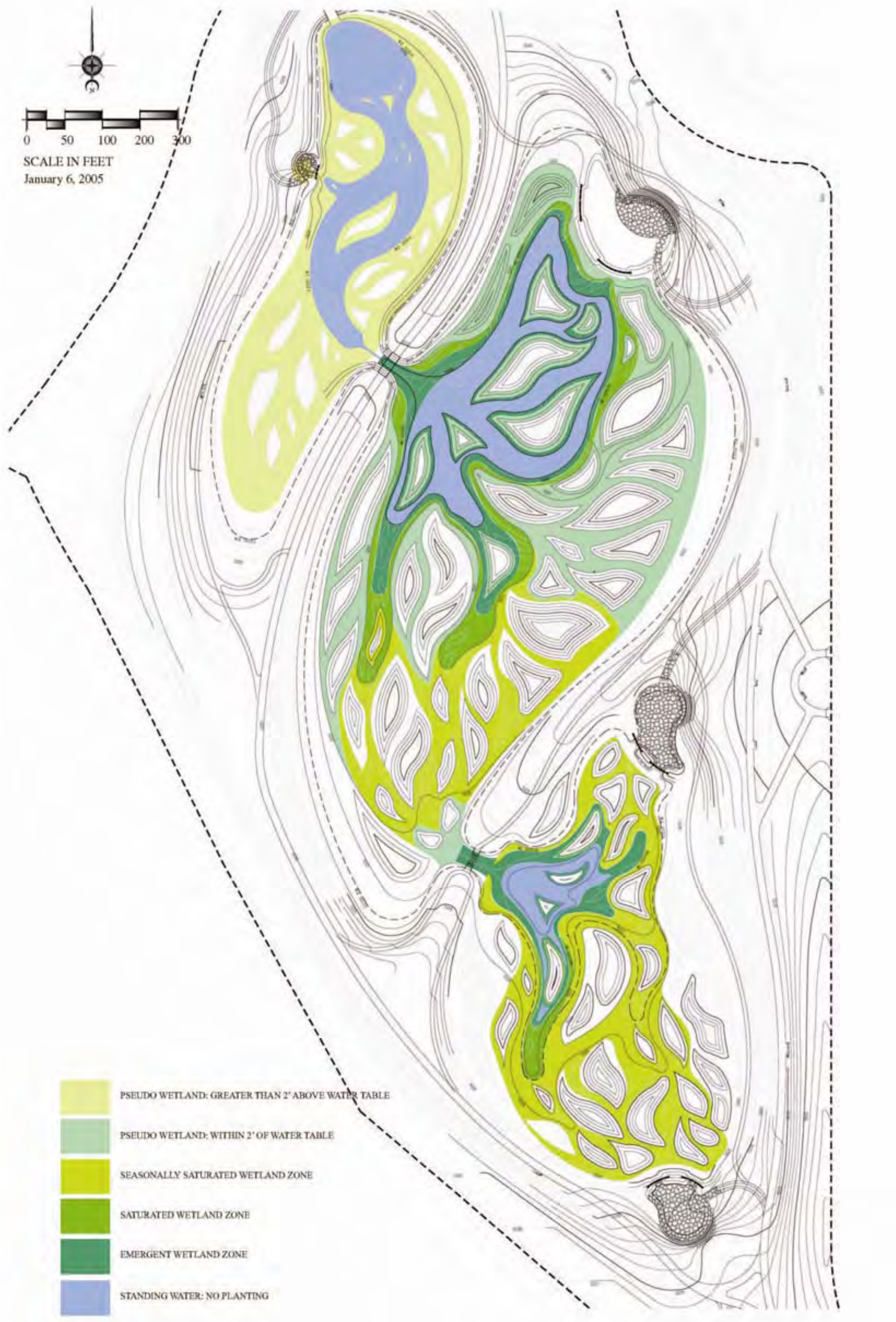

Figure 8 – Wetland planting design relative to ground water elevation

Implementation

Implementation of the proposed design depends on the existing conditions of the site. Structural analysis of the existing soils and the water table levels were known, however, further analysis for planting and seed mix design should have occurred during the planting plan development and construction documentation. Agricultural soil analysis was delayed until rough grading was complete and the selection of a landscape contractor had occurred. The planting design was developed based on ground water levels, as mapped by the project civil and hydraulic engineer. Additionally, the planting design considered the full build-out condition of the watershed contributing to the ponds, 460 acres of 75-80% impervious surface.

Rough grading began during the winter 2004 and was completed in May 2005. Concurrent with the grading operations, an 84-in storm sewer was installed at the northern edge of the project, coincident with the lowest elevation of the ground water table. The slope of the ground water, from south to north, is mimicked by the grading of the ponds and the location of the outlet. Dewatering operations occurred for the storm sewer installation for approximately 9 months.

An unanticipated event occurred on Sand Creek to the south and west of the project. An eighteen-foot drop structure failed during fall storm events, initially lowering surface water levels, but also impacting ground water levels. The drop structure was not repaired for the duration of Northfield Ponds construction period, thus further lowering the ground water table. The fact that Denver had been, and still was, experiencing a drought effectively dropped the ground water table by1.5-4 feet. This jeopardized the establishment of wetland or riparian plantings for the ponds.

Soils south of I-70 are high in clay material while soils north of I-70 are sandier. Agricultural soil analysis indicated that the site soils were 88-92% sand. Woody plant material had been procured by the landscape contractor and herbaceous material had been contracted by a wetlands nursery for delivery between June and July 2006. The planting design depended on ground water, as irrigation was highly discouraged at the sites water quality elevation by Denver's Metro Wastewater Agency. A compromise was reached, allowing four 'Big Guns': large irrigation heads with a range of approximately 120-feet, and an output of 250 gpm. These were strategically placed within the two southern ponds for planting establishment.

The combination of sandy soils and a lack of water with the inability to flood the ponds effectively posed a dilemma for the delivery of the purchased plant material. The northern pond was to have the greatest amount of open water, perched one foot above the ground water. However, the porosity of the coarse texture of the soils encouraged applied water to flow through to the groundwater rather quickly. Sedimentation fines were not in abundance from the surrounding development, as the retail component had only partially opened and the development was not complete within the watershed.

Fifteen piesometers were placed in summer, after rough grading had occurred throughout the site, to monitor ground water levels. The readings indicated that the water levels were low. Dewatering of the pipe had ceased, but it was determined that the storm sewer pipe was leaking significant volumes of water.

Conditions did not improve much through the winter and early spring; the design team discussed several options to protect the investment of material yet to be planted. Options included: (1) the installation of a cut-off wall, (2) the installation of a clay liner to impede storm water infiltration, or (3) a wait-and-see scenario, with planting occurring in the spring 2007. Each scenario had its own cost implications to the project. Meanwhile, the consultant and landscape contractor continued to research ways to keep water from vacating the site through the sandy soil.

A clay liner installation for the bottom of all three cells was cost prohibitive. Therefore an alternative was devised and tested as best as could be done in the time frame and resources available. Varying degrees of bentonite/compost/soil backfill and the cross-linked polyacrylimide polymer were added to the backfill of the trees and shrubs. The plant species used for the backfill comparisons was coyote willow (Salix exigua). Control plants had no additives; Plant A was backfilled in a standard planting detail with a 1:1 ratio of soil and bentonite. Plant B was backfilled with a 4:1 mix (2 parts compost: parts soil: 1 part bentonite), and Plant C was backfilled at 5:1 (2 compost: 3 soil: 1 bentonite). Plant D was backfilled with a 6:1 mix (2 compost: 4 soil: 1 bentonite). Plants were hand watered once or twice a week, depending on the precipitation received.

Figure 9 – Root development with 4:1 soil:bentonite mix

Figure 10– The 1:1 ratio plant, week 3

In June 2006, an additional pair of test plots was prepared, with 1" bentonite or 5 lbs/CY polymer tilled to a depth of six inches. As of June 26, these had been ongoing for approximately 14 days, with two shrubs placed in each plot. Wetland plugs were added to the soil plots after about the sixth day. The establishment of herbaceous wetland material appeared successful, but one shrub in each plot was lost and the remaining shrubs looked visibly stressed after two weeks.

The methods used for this project were by no means a controlled scientific experiment, but rather the project team's (based on collective) desperate attempt to salvage the project's plant material and provide the best possible result for the client (in consideration of the site's highly visible location).

An EDAW memo, dated June 26, 2006, described the test plot status as follows:

Hand watering of shrub and tree material in the ground continues.
Pressure grouting the leaky storm sewer pipe continues.
Groundwater readings have been trending upward, with the south and west side of the pond is closer to the design elevation for groundwater (6-8" low) and the east and north side significantly lower (18-39" low) as of the latest piesometer readings dated May 22, 2006.
Local soils testing agency had no experience or the proper testing equipment to aid in furthering our knowledge of plant materials reactions to varying densities of bentonite added to soil. Would the plant become root bound do to the immediate location of the bentonite and the ability to hold water locally or would the plant reach out beyond the confines of the mixture in search for water beyond?
The supplier of the bentonite has been requested to find any information regarding the application of bentonite for wetlands establishment beyond the use of bentonite as a liner or cut-off wall. No response to date.
The Superintendent of the landscape contractor found a scientific paper titled 'Clay Deposits for Water Management of Sandy Soils' from Saudi Arabia. This is very academic, but is in line with our needs. (Note: We did not use the results in this paper to determine our tests, but we learned that others had though of trying to retain water through the use of clay in sandy soils.)
The clay liner proposed for Cell #1 will occur in the future. Cell one will be seeded with the mid-grass seed per the specifications.
Plantings from Cell #1 will be redistributed into Cells 2 and 3.

Other thoughts outlined in the memo included:
Concerns of adding bentonite only to the wetlands areas in Cells 2 and 3 in reference to winter winds and drying conditions without the ability to apply irrigation water to keep the top layer of the soil/bentonite mixture moist have been raised. Adding bentonite will change the soil structure which is desired.
Concerns of only adding the polymer have been raised regarding the polymers ability to change the soil structure and prevent or slow the water from just passing through the soil profile after the polymer has expanded to its full potential. The polymer is only effective to a six inch depth as it is unable to expand due to the weight of the soil above.
Soil amendments were never intended to be added to the soil below the water quality level. This is due to several reasons, wetlands material does not normally need additional organic material like other woody plant species, and they need water. There was potential for too much water to be in the ponds and the amendments would float and not stay mixed in the soil. Early in the construction process of this pond we actually had water standing and were formulating dewatering techniques and options for the construction of the bridge, cut-off wall, irrigation, etc.

Conclusion

The test plots were monitored weekly until mid to late July. The results suggested the best approach would be to backfill all trees and shrubs not receiving supplemental drip irrigation with a 5:1 ratio (2 compost : 3 soil : 1 bentonite). Our visual observations of root development in the test plants, the vigor of the individual specimens, and the associated cost and warranty risk determined the selection of this 5:1 ratio. As of October/November 2006, the majority of plant material was surviving quite well. We had significant rain events that damaged the flowlines of the cells in August, but those events added fines to the soils and helped reduce the porosity of the sandy soil. Herbaceous wetland material was laid out with flags recording water surface level 4-5 days after the storm event. The true test will be how the project survives through the winter.

Figure 11-Planted wetlands

Figure 12-Upland edge

Northfields Storm April 2007

The spring storm events arrived in 2007 as expected. The ponds performed admirably considering that they had not been through an entire growing season since the completion of plant installation and seeding operations. As these photographs demonstrate the ponds filled up in a bath tub type manner as designed completely inundating the lower water quality elevations.

Figure 13-View looking south from 72”

Figure 14-View looking south from 11x7

What became quite evident is that the design of the flowlines from Cell 3 to Cell 1 became damaged due to the forces of the water wanting to move from one cell to the next. The wetland sod placed at the outlets of each of the forebays performed as expected with a few areas of erosion identified. These areas will be dissected and studied from a design, engineering and implementation perspective to determine what could be done to prevent the erosion that occurred. Flowlines were designed flat (0.03-0.04%), yet the water moves with enough velocity to register in the photos below. By their nature sandy soils move and shift easily, this makes anticipating and mitigating within the window of implementation opportunity that much more difficult.

Figure 15 - View looking north at cut-off wall between Cells 2 and 3

Figure 16 – View looking west northwest at the cut-off wall between Cells 2 and 3

Northfields 2007

A replacement walk with the landscape contractor occurred in the middle of May 2007. Of the material that was planted below the water quality level with the bentonite added to the backfill, the following table identifies the species, number and percentages that were identified to be replaced.

Species	Size	# planted	# replaced	Percentage
Alnus tenufolia	5 gal	63	6	9.5%
Amorpha fruticosa	5 gal.	192	2	1.0%
Cornus sericea 'Baileyi'	5 gal.	376	23	6.0%
Rosa woodsii	5 gal.	261	1	0.004%

Figure 17 – View looking east from Cell 2

Figure 18 – View looking east, Cell 3 wetlands

Considering the total numbers of woody trees and shrubs planted with the bentonite backfill, the success rate has been phenomenal to date. Three hundred thirty-seven (337) trees were planted, ranging from five (5) gallon *Alnus tenufolia* and *Salix amygdaloides* to 2-3 foot *Amelanchier alnifolia* and 2" caliper *Populus sargentii*. Six (6) trees, all *Alnus* were necessary to be replaced. Twenty-six (26) of the 2,342 five (5) gallon material comprised of *Amorpha fruticosa*, *Cornus sericea 'Baileyi', Rosa woodsii, Salix exigua*, and *Sheperdia aregentea* needed to be replaced. The majority being *Cornus sericea 'Baileyi'*. These numbers translate into approximately 1.8% of the trees and 1.0% of the shrubs needing to be replaced.

Herbaceous wetland material was reviewed, but not quantified for replacement. As demonstrated by the preceding photos the wetland sod and the majority of the wetland plugs are doing well. They have been inundated with significant flows during the spring and monsoonal flows of August and have established and performed well. The native grass seed cover is establishing nicely having only been through one growing season. We look forward to walking the project again in spring 2008 to see how it has survived another Colorado winter.

Figure 19 – View looking east at the access drive in the 66" forebay

Figure 20 – View looking west northwest from eastern sidewalk

Figure 21 – View looking north from within Cell #3

Figure 22 – View looking south along soft surface trail along eastern side

Northfield Ponds is a successful example of blending the needs of storm water management with sustainable ecological goals, creating an aesthetic and useful passive park for users to observe wildlife.

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Figure 2 – Oregon State University

SCIENCE-BASED APPROACH TO REVEGETATION OF THE SUMMITVILLE MINE SUPERFUND SITE: FROM GREENHOUSE SCREENING TO SITE-WIDE RECLAMATION

Julie P. Rieder[1], Mark W. Paschke[1], Edward F. Redente[1,2]
[1]Department of Forest, Rangeland, and Watershed Stewardship
Colorado State University
Fort Collins, Colorado 80523-1472
and
[2]MWH Americas, Inc.
1825 Sharp Point Drive, Suite 118
Fort Collins, CO 80525

ABSTRACT

Heap leach processing for the extraction of gold was started at the Summitville Mine in southwestern Colorado in 1985, and by 1994, the site was declared a Superfund Site. In 1995, we began a science-based approach aimed at revegetating 200 ha of highly disturbed land. Here, we describe our general approach, which included site assessment and soil testing, greenhouse pilot studies, and field test plots that culminated in site-wide revegetation efforts, and present data demonstrating the degree of revegetation success.

INTRODUCTION

Underground mining for gold began at the Summitville Mine in south-central Colorado in the 1870's, and substantial mining efforts continued until the early 1900's. Sporadic underground gold mining continued into the 1950's, followed by a brief hunt for copper in the 1970's. By the 1980's, gold mines in the western United States were experiencing a shift from underground mining practices for high quality ore to heap leaching procedures that aimed to recover precious metals from low quality ore.

In 1984, a division of the Canadian firm Galactic Resources, called the Summitville Consolidated Mining Company, Inc. (SCMCI), began open pit mining on the South Mountain at Summitville in conjunction with a heap leach recovery process to recover gold. The method involved the removal of low-grade ore from South Mountain, crushing the ore, percolating a sodium cyanide solution through the ore to leach heavy metals, and trapping the resulting metal-complexes on columns of activated carbon. Thus, heap leaching allowed the extraction and concentration of precious metals that were too diffuse in concentration to make underground mining profitable. During a period of 1984 to 1992, SCMCI mined approximately 10 million tons of low-grade ore.

The geology of the Summitville Mine contributed to the environmental problems that ensued. Natural seeps from surface water and ground water carrying metal-laden, acidic water drained from Summitville prior to mining, likely reducing the ability of Wightman Fork and the Alamosa

River to support aquatic life (Bigelow and Plumlee, 2005). Acid mine drainage increased during underground mining operations in the late 1800's and early 1900's, especially from two adits, Reynolds and Chandler, installed to access ore and drain the underground passages (Bigelow and Plumlee, 2005). The metal-laden, acidic water produced at Summitville is a consequence of the weathering of sulfide-bearing parent material. With the onset of surface mining, exposure of parent material greatly increased compared to exposure from underground mining, and metal-rich, acid-rich water began pooling on site and discharging more dramatically to Wightman Fork and the Alamosa River (Bigelow and Plumlee, 2005).

In addition to an increase in the production of metal-rich, acidic waters from exposed parent material, the cyanide solution used during the heap leach process escaped from the containment liner beneath the heap leach pad within one week of use (CDPHE 2005). Additional leaks occurred from transfer pipes, discharging cyanide directly into Wightman Fork (Bigelow and Plumlee, 2005). By 1992, SCMCI had ceased active mining, declared bankruptcy, and the U. S. Environmental Protection Agency (EPA) had taken over operations at the site and began efforts to contain and treat cyanide-contaminated, metal-laden, and acid-rich waters. In 1994, the site was declared a Superfund Site.

Since that time, efforts to contain the waste rock and contaminated water, treat the run-off before discharge to the watershed, and revegetate the site have been underway. The heap leach pad has been capped, and waste piles have been moved into the open pit mine and capped. The entire site has been graded and dikes installed to contain contaminated surface water, and divert clean water away from the site. A water treatment plant, though out dated, is in place and currently processes contaminated water before discharging to Wightman Fork. Unfortunately, the rate of water processing at this plant is inadequate during periods of above average run-off in the spring, and during these times, contaminated surface water enters Wightman Fork at levels above the Remedial Action Levels (Buckingham, 2005). Finally, 200 acres of the site has been revegetated.

Colorado State University became involved in 1995 to develop a plan for revegetating the site. Ultimately, the goals of revegetation were to provide a cost-effective, ecologically-sound revegetation approach that would result in a productive, self-sustaining plant community on waste rock and disturbed lands at the Summitville Mine, and that was capable of reducing surface water run-off and erosion, while reducing water and oxygen percolation into contaminated material buried beneath the vegetative cover. To achieve this goal, we followed a multi-step, science-based approach that included the following phases: 1) gather information from the literature and assess site conditions; 2) conduct a greenhouse and field experiment to investigate treatment combinations viable for site-wide revegetation; 3) recommend the best, site-wide treatment combination, and; 4) monitor plant recovery post-revegetation efforts. In addition to our efforts, surface water quality was monitored by the Colorado Department of Public Health and Environment (CDPHE) to assess the impact of revegetation on run-off and erosion from the Summitville Mine.

In this paper, we outline the science-based process we followed to provide the EPA and the CDPHE with a successful revegetation approach, and we present the major findings from our work to date. The Summitville Mine will continue to be monitored, and water treatment and site containment will be ongoing, into the foreseeable future.

MATERIALS AND METHODS

Site Description

The Summitville gold mine (37^{o} 25' 30" N and 106^{o} 36' 30" W) is located in the San Juan Mountains in south-central Colorado in Rio Grand County near the headwaters of the Alamosa River. Wightman Fork and Cropsy Creek receive run-off from the site, and both empty into the Alamosa River. The site sits at approximately 3,800 meters, and has a short growing season from June to September (approximately 90 days), with relatively harsh conditions for plant growth. The climate is characterized by cool temperatures (mean annual maximum temperature = 7.7 ^{o}C; mean annual minimum temperature = -5.8 ^{o}C), with the majority of precipitation falling as snow (mean annual snowfall = 1100 cm; mean annual precipitation = 115 cm) (climate data from 1957–2005, Wolf Creek Pass 1E Weather Station, Colorado, #059181). Native plant communities include willow shrubland, wet meadow, subalpine meadow, spruce-fir forest, krummholz ecotone, and alpine tundra. Sulfide-rich parent material on site is highly mineralized, and undergoes chemical weathering when exposed to oxygenated water.

Our approach to revegetation of the Summitville Mine was a multi-step, scientific-based process. The process included a series of steps including: 1) a literature review to gather information about the geology and contamination on site, as well as soil sampling across the site to assess heterogeneity of physiochemical properties; 2) a greenhouse experiment to investigate a wide array of treatment combinations to amend waste rock and facilitate plant growth; 3) a field experiment to investigate a smaller number of treatment combinations to amend waste rock and encourage development of a plant community; 4) a final recommendation for site-wide revegetation based on this collective information and expertise in revegetation of mining lands; and 5) a monitoring program to assess the outcome of revegetation efforts over time.

Literature Review and Site Assessment

Assessing the physical and chemical properties of material that may be used during revegetation efforts is essential to the prescription of successful treatment combinations. In addition, an evaluation of natural plant communities neighboring a site targeted for revegetation provides a reference community that may be used to assess revegetation success. This is especially important at Summitville because vegetation on site may be especially adapted to high metal, low pH soils found naturally at Summitville.

Literature published about the Summitville Mine was reviewed to gain a better understanding of the geology and existing conditions at the Summitville Mine. Much of this literature was produced by members of the United States Geologic Survey (USGS), EPA, and CDPHE.

Greenhouse Experiment

The greenhouse experiment was designed to test a wide array of amendments, including both inorganic and organic soil amendments, potentially useful in revegetating waste rock and disturbed sites at the Summitville Mine. The experiment was conducted at the greenhouse facility at Colorado State University from September 1995 to March 1996, and involved the shipment of 11, 55-gallon drums of soil and waste rock from the Summitville Mine. One drum contained soil from an undisturbed meadow, two drums contained topsoil that had been stockpiled at Summitville, and eight drums contained waste rock from the South Cropsy Waste Pile.

This material was then used in a large factorial greenhouse experiment with 36 treatment combinations investigating waste rock amendments. Treatments included organic matter addition (mushroom compost, sewage sludge, manure, wood chips, or none), neutralizing agent addition (agricultural grade lime, quick lime, or lime kiln dust), topsoil addition (native nonstockpiled topsoil from the meadow, stockpiled topsoil, 50:50 mix, or none), and the presence of a capillary barrier. Each treatment combination tested was replicated four times (Table 1). For each replicate, a pot approximately 15 cm wide x 45 cm tall was planted with 5, three-week-old redtop (*Agrostis gigantea* Roth) seedlings, and grown under optimal greenhouse conditions.

Table 1. Treatment combinations used in the factorial experiment in the greenhouse investigating revegetation of Summitville Mine waste rock. Each of the 36 treatment combinations were replicated four times. Adapted From Redente and Richard (1998).

	Native Topsoil					Stockpiled Topsoil					Mixed Topsoil					No Topsoil				
	M[1]	SS	MC	WW	NO	M	SS	MC	WW	NO	M	SS	MC	WW	NO	M	SS	MC	WW	NO
L[2]	0*	0	0	0	4	4	4	4	4	4	0	0	0	0	4	4	4	4	4	0
LKD	0	0	0	0	4	4	4	4	4	4	0	0	0	0	4	4	4	4	4	0
QL	0	0	0	0	4	4	4	4	4	4	0	0	0	0	4	4	4	4	4	0
NN	0	0	0	0	4	0	0	0	0	4	0	0	0	0	4	0	0	0	0	0

*Numbers of pots for that particular combination of treatments. [1]Organic matter amendments: M=manure, SS=sewage sludge, MC=mushroom compost, WW=wood waste, NO=no organic matter amendment, [2]Neutralizing agent amendment: L=lime, LKD=lime kiln dust, QL=quick lime, and NN=no neutralizer.

After four months of growth, plants were harvested and the following plant measurements were made: number of tillers, number of inflorescences, aboveground biomass, belowground biomass, rooting depth, concentration of heavy metals in above ground shoots, and percent carbon of root tissue. In addition, we tested soil and waste rock from each treatment for pH, percent organic matter, inorganic N, total N, and plant available micronutrients.

Field Experiment

Ideally, the greenhouse experiment would have been completed prior to the start of the field experiment. Unfortunately, the greenhouse experiment was contingent on the collection of soil and waste rock from the Summitville Mine. Due to late snowfalls and late snow melt, soils and waste rock could not be collected and delivered until late July 1995 and the experiment did not begin until September 1995. The field portion of the project was scheduled for installation in the late fall of 1995, and thus, results from the first three weeks of the greenhouse study were available at the onset of the installation of the field experiment in late October of 1995.

Given preliminary observations from the greenhouse study, and knowledge and experience from previous revegetation efforts on mining lands, a selection of 7 of those treatments used in the greenhouse experiment were tested under field conditions in the North Waste Dump at the Summitville Mine (Figure 1). An additional treatment combination was added to the experiment to test the benefit of ProMac®, a liquid and pellet product intended to inhibit iron-oxidizing bacteria, thereby reducing the availability of heavy metals. The field experiment was conducted under natural growing conditions and climate to investigate the performance of seeded plant species across these eight treatment combinations.

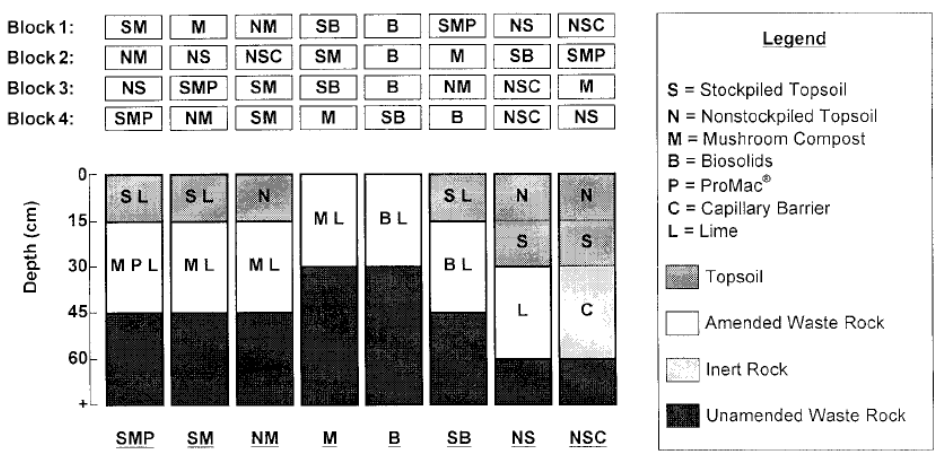

Figure 1. Experimental block design (top) and horizontal depiction of treatment applications in the field study at Summitville Mine (from Winter Sydnor and Redente, 2002; Fig. 1).

Each of the eight treatments was replicated 4 times in a completely, randomized block design (Figure 1). Plots were 10 x 20 m in size with 2 m buffers separating plots and 5 m buffers separating blocks. Factors investigated included organic matter addition (mushroom compost, sewage sludge, or none), neutralizing agent addition (agricultural grade lime or none), topsoil addition (nonstockpiled topsoil, stockpiled topsoil, 50:50 mix, or none), the presence of a capillary barrier, and the addition of ProMac®. Note, these are a subset of those tested in the greenhouse experiment, a different source of nonstockpiled topsoil was used in this field experiment, and ProMac® was a factor not tested in the greenhouse experiment. Amendments were applied, and the seed bed prepared, fertilized, seeded with a mixture of grasses and forbs, and finished with light disking and mulching.

Metrics measured included aboveground biomass (1997–1999), vegetation cover (1996–1999, 2002, 2004, 2007), rooting depth (1999), soil characteristics (1999; including pH, total organic content, inorganic carbon, plant available trace element concentrations, and total trace elements), and metal concentrations in plant tissue for Mn, Cu, Zn, Cd, and Pb (1999). When appropriate, data were analyzed with ANOVA. Additional details regarding materials and methods can be found in Winter Sydnor and Redente, 2002.

Recommendation and Site-wide Implementation

Finally, based on the results from both the greenhouse and field experiment, one treatment combination was used for site-wide revegetation of Summitville Mine. In 1999, five years after the declaration of superfund site status, site-wide reclamation began, and included re-grading of the site, creation of dikes, and general site preparation aimed at reducing overland flow, increasing infiltration of precipitation, and reducing slopes to allow establishment of vigorous plant communities.

After re-contouring, the top 30 centimeters of waste rock was amended by incorporation of agricultural grade limestone and mushroom compost. Agricultural grade limestone was added at a rate based on sampling of areas on the site, while mushroom compost was added at a rate of 40 dry tons/acre. On top of the amended waste rock, 15 cm of limed, stockpiled topsoil was added, and this amended soil seeded with a selection of grasses and forbs. Seed was collected from surrounding reference areas, and increased at the USDA Plant Materials Center in Meeker, CO. These species were selected to create a vigorous plant community in the climate and soil conditions at the Summitville Mine, and to encourage natural successional trajectories.

Monitoring

Reclamation was completed in 2000. Since that time, CSU has conducted site-wide monitoring to assess the performance of the revegetation effort. During the height of the growing season in July, transects are randomly set within polygons designated within regions of the site. These polygons delineate similar plant communities, and were created in an effort to reduce variation within transects. Along each transect, foliar vegetation cover by species is recorded. A distinction is made between rock and bare ground as these two substrates would dictate very different vegetation community potentials.

RESULTS

Literature Review and Site Assessment

Studies of the geology of the Summitville Mine area identify naturally-occurring conditions that make revegetation efforts challenging. Parent material on site is primarily sulfide-bearing rocks that chemically weather in the presence of surface water, forming acidic and metal-rich waters (Gray et al., 1994). In addition, the lack of carbonate rocks or other parent material capable of buffering the system increases the impact these sulfide-bearing rocks have on the region. The watershed immediately impacted is that of the Alamosa River, starting with Cropsy Creek and Wightman Fork that drain the surface water from Summitville, flowing into the Alamosa River, and passing through the Terrace Reservoir. In the absence of mining, this region likely supported water quality that challenged the ability of aquatic life to persist at levels found in carbonate-buffered streams and rivers (Bigelow and Plumlee, 2005). Open pit mining increased the rate of chemical weathering substantially, and further impacted surface waters downstream of the mine (Gray et al., 1994).

In addition to parent material as a source of contamination, revegetation of the Summitville Mine is challenging due to the lack of suitable substrates for plant growth and the alpine climate. Three major areas of the site required revegetation: waste dumps containing waste rock, the open mining pit, and the heap leach pad. Chemical properties of the waste rock, compared to chemical properties found in adjacent, undisturbed, native meadow soil, included low pH, low soil organic material, low nutrients, and high heavy metal concentrations that were toxic to plant growth (Table 2). Chemical properties of the substrate within the open pit mine are similar to those in waste rock piles, while chemical properties of material from the heap leach pad are complicated by the presence of cyanide compounds. Topsoil that remains on site was stockpiled during mining operations, and as a result, had low density, inactive microbial populations that would hinder establishment of vigorous plant communities (Vanderhoof, 2003). Based on these chemical properties of the waste rock and disturbed land and the condition of remaining topsoil at the Summitville Mine, establishment of vigorous vegetation without proper amendments of waste rock and disturbed land would not have been feasible.

Table 2. Comparison of chemical properties of waste rock from the Summitville Mine with soil from a neighboring undisturbed meadow. Data are from 2000 and 2001. Table adapted from Vanderhoof (2003). Plant toxicity levels from Kabata-Pendias and Pendias (1984).

Chemical Property	**Undisturbed Meadow Soil**	**Waste Rock**	**Plant Toxicity Level**
pH	5.0	2.8	
Soil Organic Matter (%)	11	1	
NH_4^+ (mg/kg)	15	12	
NO_3^- (mg/kg)	16	0	
Total Cd (mg/kg)	4	10	3–8
Total Cu (mg/kg)	24	195	60–125
Total Pb (mg/kg)	29	147	100–400
Total Zn (mg/kg)	105	175	70–400

An investigation of soil development in waste rock indicated the usefulness of particular amendments in encouraging and accelerating soil development, relative to soil processes observed in native soils. Vanderhoof (2003) investigated the effect of soil amendments on the chemical and biological properties of amended waste rock, and identified non-stockpiled topsoil and mushroom compost as two amendments most capable of reclaiming waste rock. Only the amendment of non-stockpiled topsoil, however, achieved microbial community richness compared to undisturbed sub-alpine meadow soils (Vanderhoof, 2003).

Finally, the climate of the San Juan Mountains is typical of high alpine regions with extreme temperatures, deep winter snow packs, and a short growing season of approximately 90 days. As a result, vegetation used in revegetation of the Summitville site needed to be locally adapted to the conditions generated by the parent material on site (e.g., relatively low pH of 5.0 in undisturbed subalpine meadow soils; Vanderhoof, 2003), and suited to the climate. During the assessment period, success of revegetation efforts at Summitville Mine is measured in reference to the vegetation found on undisturbed soils on site. Thus, reference sites were identified for this purpose and vegetation assessed to provide a baseline for assessing revegetation success.

Greenhouse Experiment

1. Stockpiled soil that is limed, or a mixture of stockpiled, limed topsoil with non-stockpiled, native soil, can support plant growth similar to that achieved with non-stockpiled, native soil.
2. Waste rock without topsoil, when amended with neutralizing agents and organic material, can serve as a medium for plant growth; however, this is not desirable for site-wide revegetation given the continued chemical weathering of this material when exposed directly to precipitation.
3. The presence of a capillary barrier did not improve plant growth beyond that achieved with topsoil amendments directly on top of amended waste rock.
4. Mushroom compost and manure are the most effective organic amendments compared to sewage sludge and wood chips. Wood chips were least effective in promoting plant growth.
5. Agricultural grade lime promoted plant growth by effectively neutralizing acidic waste rock, while lime kiln dust and quick lime generated strongly basic conditions and restricted plant growth.
6. Metal toxicity and metal accumulation in *Agrostis alba* from neutralized waste rock were absent or not significant.

Field Experiment

The results from the field experiment have been published in *Journal of Environmental Quality* (Winter Sydnor and Redente 2002). The results for aboveground biomass presented in Winter Sydnor and Redente (2002; Figure 2) are reproduced here, and overall results are briefly summarized.

1. Organic matter amendments, in particular mushroom compost (treatment M), improved plant growth as measured by above ground biomass. Mushroom compost was markedly better than sewage sludge (biosolids = treatment B).

2. Limed, stockpiled topsoil (treatment S) supported aboveground biomass similar to non-stockpiled topsoil (treatment N), despite the low microbial community activity of stockpiled soil.
3. Waste rock amended with agricultural grade lime and organic material (treatment M) was capable of supporting plant growth similar to waste rock covered with topsoil (treatment SM or NM).
4. The presence of a capillary barrier (treatment NSC) did not improve plant growth beyond that achieved with topsoil amendments directly on top of amended waste rock (treatments SM or NM).
5. ProMac® (treatment SMP) did not significantly improve aboveground biomass, but decreased root growth.
6. Low pH of unneutralized waste rock significantly reduced root growth.
7. Heavy metal concentrations, while often elevated, did not result in phytotoxic levels within plant tissues.

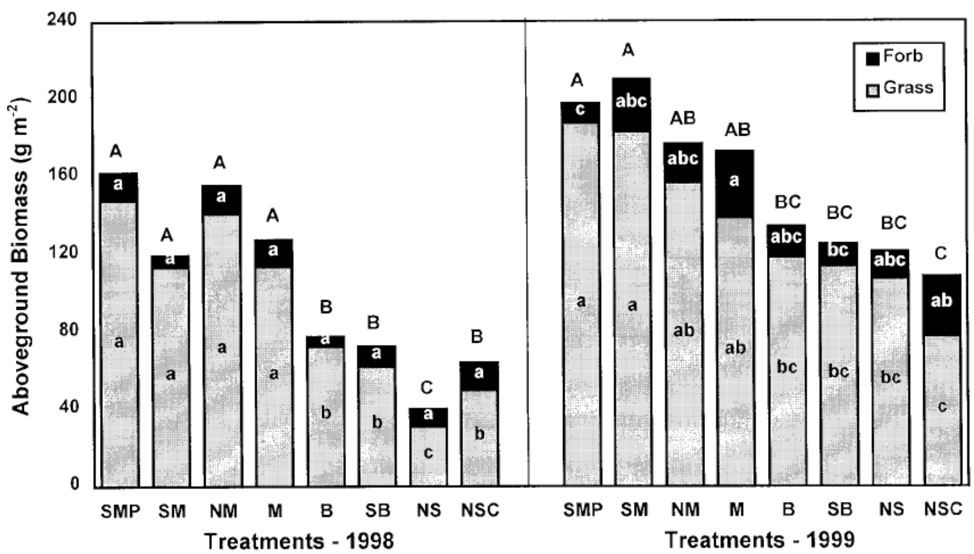

Figure 2. Aboveground biomass of forbs and grasses within the field study plots at Summitville Mine in 1998 and 1999 (from Sydnor and Redente 2002; Fig. 1). Based on least significant differences (LSD), significant differences among treatments are denoted with different letters (capitol letters for overall test within a given year, small letters for test for grasses, or for forbs, within a given year). Treatment combinations as in Figure 1.

Recommendation and Site-wide Implementation

In summary, the greenhouse and field experiments provided corroborating evidence, suggesting that stockpiled soil, non-stockpiled soil, or a mixture, in conjunction with mushroom compost organic matter amendment and agricultural lime as a neutralizing agent provided optimal plant growth for site-wide revegetation of the Summitville Mine. While amended waste rock provided plant growth similar to amended waste rock covered in topsoil, covering waste rock from mining operations with topsoil is often a required step in remediation, based on state and federal regulations (Winter Sydnor and Redente, 2002). Given the natural geologic conditions at the site, this requirement may reduce generation and off-site movement of acid-rich, metal-laden waters and sediments. Thus, based on literature reviews, site assessments of physiochemical and biological characteristics, a greenhouse experiment, and a field experiment, a site-wide revegetation formula was recommended for the Summitville Mine: waste rock was amended with agricultural grade lime and compost, and covered with a 15-cm layer of topsoil before seeding. From 1998 to 2001, site-wide revegetation efforts included the collection and increase of desirable seed, re-grading the site, applying appropriate amendments, and seeding 200 ha of highly disturbed land.

Monitoring

Since the year 2001, monitoring of the site-wide revegetation efforts, including vegetation characteristics and water quality measures have been ongoing. Monitoring will continue until the year 2010.

Vegetation cover was quite heterogeneous on the revegetated portions of Summitville Mine. In general, cover increased from 2002 to 2004, and exhibited a shift in species composition indicative of plant community succession. In 2004, short-lived perennial grass species like slender wheatgrass (*Elymus trachycaulus*) declined in percent cover, especially in those areas exposed to drier conditions and greater evapotranspiration. Areas more recently revegetated showed increases in vegetation cover by 2004. In 2007, vegetation cover data was again collected, and showed trends consistent with annual precipitation, date since revegetation efforts, and expected patterns of plant community succession.

A vigorous plant cover over mining waste rock and disturbed soil was expected to provide several ecosystem services including improved surface water quality and decreased sediment load in surface run-off. As of 2005, site-wide data collected by Summitville site managers suggested improved surface water quality post-revegetation efforts (Buckingham, 2005). More specifically, surface water samples showed a 50% reduction in total suspended solids in run-off between 1986–1994 (TSS = 47 mg/L) to 2000–2005 (TSS = 23 mg/L) (Buckingham, 2005). In addition, Cu released from the Cropsy Waste Pile was estimated at 33,000 lbs of copper per year prior to revegetation, and as of 2005, dropped to 2 pounds per year (Buckingham, 2005). While pH of surface waters has not changed significantly, significant changes in metal loading and total sediment loss from the mine site are encouraging, and suggest revegetation is achieving desired impacts (Buckingham, 2005).

CONCLUSION

In summary, the steps taken to revegetate the Summitville Mine have followed a science based approach involving site assessments, greenhouse experiments, field experiments, and finally a site-wide revegetation recommendation. Results from monitoring efforts suggest the treatment combination selected for site-wide revegetation has been successful in establishing a self-perpetuating, vigorous plant community that is reducing the off-site movement of sediment and heavy metals. Over time, continued monitoring will allow us to describe the further development of this plant community. While the use of some revegetation amendments is well studied (e.g., addition of organic material; Zvomuya et al., 2007), our science-based approach allows the identification of optimal prescriptions for revegetation that in turn provide more immediate environmental protection. Further, we suggest this approach may provide significant economic savings in the long term by avoiding failed attempts and misguided efforts that prolong revegetation efforts.

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Response of Transplanted Aspen to Drip Irrigation on Reclaimed Mine Lands

High Altitude Revegetation Workshop Presentation

by Roy A. Karo
Reclamation Manager
Peabody Energy
Seneca Mines
Hayden, CO 81639
970-276-5217

Wayne Shepperd
Frederick W. Smith
Brian Gee
Department of Forest, Rangeland, and Watershed Stewardship
Colorado State University
Fort Collins, CO 80523

Robert Musselman
USDA Forest Service
Rocky Mountain Research Station
240 West Prospect Road
Fort Collins, CO 80526

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PROJECT ABSTRACT

Successful re-establishment of aspen on surface-mined lands in the western
United States is problematic, because the species regenerates vegetatively by sprouting from parent roots in the soil which is removed in the mining process.
Previous attempts to plant aspen seedlings on reclaimed mines have failed because transplanted root sprouts or seedlings do not have an extensive root system to access water and nutrients for rapid growth. This research builds on work previously funded by the Seneca Coal Company in western Colorado to identify factors that limit the growth and survival of planted aspen. The use of supplemental irrigation to help establish planted aspen was tested; and growth and survival of three types of aspen stock on two soil types were compared. Soil and water conditions were monitored, and the effect of weed control on planting success was examined. The best combination of conditions for reproduction of aspen on reclaimed surface mined coal lands uses transplanted saplings from local sources on freshly placed soil removed from aspen stands. Growth was significantly higher when weeds were controlled around individual trees. Irrigation with non-saline water may enhance growth and survival in years with drought conditions.

PROJECT DESCRIPTION

Objectives:

1. Determine if supplemental drip irrigation will allow transplanted aspen saplings to survive and grow on reclaimed surface mined lands at a western Colorado site.

2. Quantify second and third-year growth and physiologic condition of bare-root saplings transplanted to replaced topsoil, aspen sprouting from root segments transferred with replaced topsoil, and nursery-grown potted aspen saplings planted in replaced topsoil.

3. Compare irrigation water quality and characteristics of replaced topsoil to that of water and soils in intact aspen groves located on adjacent un-mined lands.

4. Quantify the effects of mechanical weed control on growth and survival of young aspen trees.

5. Quantify root growth and development of transplanted aspen saplings, natural root sprouts, and nursery-grown potted aspen seedlings after three growing seasons.

Background:

Quaking aspen (Populus tremuloides) is the most widespread tree species in North America (Baker 1925; Preston 1976; Lieffers and others 2001), and thought to be second in worldwide range only to Eurasian aspen (Populus tremula) (Jones 1985a).

Aspen is found in most of eastern Canada and the U.S. (except the Southeast), throughout the upper Midwest and Lake States, across sub-boreal Canada and Alaska, in the Rocky Mountains from

Canada through the U.S. and into northern Mexico, and in mountain ranges paralleling the west coast from Alaska through British Columbia, Washington, Oregon, California, and Mexico's northern Baja California (Preston 1976). The species is most abundant in Canada's central provinces and the U.S. states of Colorado and Utah (Jones 1985a; Lieffers and others 2001). In much of the western U.S., aspen is a mid-elevation shade-intolerant species which is a relatively minor component of more widespread conifer forests.

Aspen is an important tree species throughout the western United States. One of the few broad-leaved hardwood trees in many western forests, it is a valuable ecological component of many landscapes, occurring in pure forests as well as growing in association with many conifer and other hardwood species. Aspen provide desirable scenic value, the diversity of plants growing under aspen supply critical wildlife habitat, valuable grazing resources, protect soils from erosion, and help maintain water quality. These features make aspen a crucial component of many Western landscapes. At the continental scale, aspen has several physiological characteristics that permit it to attain great geographic amplitude. Lieffers and others (2001) outline the following important adaptive traits of aspen:

1) Among the wide ranging genus Populus spp. (cottonwoods, poplars, aspen) aspen seems to have a very high stress tolerance. Usually high stress tolerance is associated with slow growing species and those with a limited reproduction strategy;

2) Aspen appear to rely on vegetative reproduction via root suckering more than other Populus species. These authors assert that the passing of extensive root systems between generations enhances tolerance to absorb climate stress (DesRochers and Lieffers 2001);

3) Aspen also has the ability to adapt leaf size to xeric and mesic conditions (that is, smaller leaves for drier sites). Aspen's smaller leaf size could keep the leaf surface slightly cooler allowing earlier shut down of stomata, thus tempering water stress during drought;

4) Aspen seem to tolerate cold temperature and short growing seasons better than most hardwoods (Pearson and Lawrence 1958);

5) Leaf fluttering may be an adaptive advantage in cooling leaf surfaces of many Populus species and,

6) Aspen appear to have a higher photosynthesis capability than other Populus spp. which is comparable to that of high yield poplar hybrids. Aspen photosynthesizes well in low light (for example, competitive situations) and even mature bark is capable of photosynthesis, which helps to ameliorate respiration during periods of high insolation (before spring leaf-out) (Pearson and Lawrence 1958). Photosynthesizing bark may help aspen recover from injuries and infestations (Jones and Schier 1985; Lieffers and others 2001) and may allow aspen to photosynthesize at low levels during the winter giving the tree a photosynthetic "boost" prior to leaf-out (Pearson and Lawrence 1958; Shepperd and others 2004). As leaf chlorophyll increases during the summer, bark chlorophyll decreases causing bark to become whiter (Strain 1964).

Although aspen does produce abundant crops of viable seed (McDonough 1979), it primarily reproduces vegetatively by root suckering throughout most of its western range. Occasional seedlings do establish, but seedlings require bare mineral soil and constant moisture to survive (McDonough 1979). These conditions rarely occur in many of the areas where aspen grows today. Aspen typically grows in genetically-identical groups referred to as clones. All stems in a clone sprouted from the roots of parent trees and share a common ancestor. However they do not share a common root system, as connections break down from generation to generation as new trees grow new roots.

Most aspen stands are composed of one to several clones that may persist along a continuum of successional stages, from sparsely growing individuals to apparently stable pure or near-pure groves. Although clones are often separate and distinct from one another, studies have demonstrated spatial intermingling where multiple clones are co-located (DeByle 1964; Mitton and Grant 1980; Wyman et al. 2003; Hipkins and Kitzmiller 2004).

Compared to conifers, aspen ramets – individual stems, or suckers, of the same genotype from a parent root system - are relatively short lived. This is due to succession (replacement of aspen by more shade tolerant species) and/or a typical onslaught of mortality related to stem decays and diseases from ages 80 to 100 years (Baker 1925; Hinds 1985; Potter 1998; Rogers 2002). Aspen thrive where somewhat regular and frequent disturbance promotes regeneration (DeByle and Winokur 1985). Occasionally aspen stands appear to perpetuate themselves with regular low-level regeneration in multi-layer stable stands (Mueggler 1988; Cryer and Murray 1992). Aspen in the western U.S. are longer lived than elsewhere. Healthy aspen trees can live over 300 years (Personal Comm., John Shaw, Forester, USDA Forest Service, Rocky Mountain Research Station) and attain diameters of at least 38 inches (96.5 cm) diameter at breast height (dbh), however most aspen are typically much younger and smaller. Many mature stands in Colorado are currently over 120 years of age (Shepperd 1990). Tree form varies from shrubby at upper and lower forest margins to over 100 ft (30.5 m) in height in prime locations with average heights of 50 to 60 ft (15 to 18 m) (Baker 1925).

Vegetative regeneration of aspen requires the interruption of the auxin/ cytokynin hormone balance between roots and shoots to stimulate root buds to begin growing (Schier et al. 1985). This hormonal imbalance can result from any disturbance that interrupts the flow of auxin from photosynthesizing leaves to a tree's roots. This can result from disturbances that kill the parent trees outright, such as a fire, disease, and timber harvest, or from disturbances that only temporarily defoliate the parent tree, such as a late frost, defoliating insect attack, or light herbicide application. Severing lateral roots from parent trees can also initiate suckering, as would occur when fire, burrowing animals, or other factors kill portions of a lateral root. The sucker initiating process has been referred to as interruption of apical dominance (Schier et al. 1985.).

In any case, the initiation of bud growth must also be accompanied by sufficient sunlight and warmer soil temperatures to allow the new suckers to thrive (Navratil 1991, Doucet 1989). Full sunlight to the forest floor best meets these requirements. However, young aspen suckers are susceptible to competition from other understory plants and herbivory from browsing ungulates, even if abundant suckers are present.

Having access to a well developed parental root system gives aspen sprouts a great advantage over other plants. The parent roots supply carbohydrates and access water deep in the soil profile allowing sprouts to grow rapidly, out-compete other vegetation, and withstand frequent droughty conditions in the West.

Re-establishing aspen on surface-mined lands is therefore problematic, since the parent root systems are destroyed when topsoil is removed. Planting aspen in a non-irrigated location in a Colorado study was not successful (Shepperd and Mata 2005). Transplanting greenhouse or nursery-grown aspen seedlings into the field has similar problems to those of natural seedlings, indicating that the small root mass of transplanted seedlings is insufficient to absorb enough moisture to maintain the seedlings during periods of summer drought in the wild.

In contrast, transplanting sapling-sized aspen in irrigated urban landscapes has not been a problem, because the abundant supplies of water in lawns and landscape beds enable the transplants to thrive. Although aspen is somewhat tolerant of drought conditions (Lieffers et al. 2001), irrigation could benefit growth and survival of planted aspen stock, because moisture stress negatively affects aspen response to nutrient uptake (van den Driessche et al. 2003). Water deficit stress also reduces stomatal conductance, root hydraulic conductivity, and shoot leaf water potential in aspen (Siemens and Zwiazek 2003). Irrigation has been shown to increase growth of hybrid poplar, a closely related species (Hansen 1988; Strong and Hansen 1991).

Therefore, it seems reasonable to conclude that supplemental irrigation of aspen planted on reclaimed surface-mined lands could increase initial survival and allow trees to grow sufficient root systems to ultimately survive without additional water and establish new self-regenerating clones on mined lands. Testing this hypothesis, gaining additional knowledge about different planting methods, and documenting factors that potentially limit the re-establishment of aspen is crucial to re-establishing aspen on surface-mined lands in the arid west. This research was a collaborative three-year effort, with 2005 and 2006 funding from Seneca Coal Company; and 2007 funding from Seneca Coal Company and OSM-NTTT. The US Forest Service contributed cost share funding for the project 2005-2007.

PRELIMINARY STUDIES:

A pilot study was funded by Seneca Coal Company in 2004 to examine the feasibility of using supplemental drip irrigation to establish aspen on reclaimed coal mine overburden soils. Overburden and top soils are normally stored for a number of months before landscape resurfacing and planting. The study, established on reclaimed lands owned by Seneca near Hayden, Colorado (Figure 1), examined for the 2005 and 2006 growing seasons the growth, survival, and water status of aspen trees planted on reclaimed soils during the fall of 2004.

The objective of this study initially was to examine the survival, growth, and water status of irrigated aspen transplants on two types of topsoil, placed over coal mine overburden material that had been replaced after surface mining. However, circumstances allowed us to expand the original study design to collect growth and survival data from:

1) Aspen sprouts transplanted from a nearby mine, placed in two topsoil types within a fenced area and drip irrigated at three watering levels with an un-watered control;

2) Un-watered sprouts arising from aspen root segments that had been transported into the fenced area in the two top soil types;

3) Commercially grown potted aspen seedlings that were planted in a nearby fenced area, and;

4) Natural aspen sprouts growing in an un-mined area in the vicinity that was not fenced and subject to grazing effects of ungulates on growth and survival of aspen sprouts.

Design and Methods -The initial project was a case study of the effectiveness of irrigation treatment on the survival, growth, and water status of aspen cuttings planted on a site of reclaimed land of the Seneca Coal Company II-W mine south of Hayden, Colorado. The irrigated portion of the study was designed to measure the effect of supplemental irrigation on aspen saplings that had been transplanted from a naturally regenerating un-mined site on the nearby (<3 km) Yoast mine where the original forest was being cleared in preparation for mining. Aspen saplings between 1-2 m in height were selected from this site at the end of the growing season in 2004 and pruned to leave only the uppermost branches intact.

In October, 2004, these saplings were dug using a small backhoe and immediately transplanted into augered holes that had been prepared at the fenced planting site at the II-W mine. All cuttings were presumed to be from the same genetic clone since they were collected from the same area. Trees were planted in eight blocks consisting of five rows of ten trees, (50 trees total) spaced on a 1.5 m x 1.5 m grid (Figure 2). Four blocks were placed in each of two types of topsoil that had been removed from areas being prepared for surface mining.

Roto-cleared topsoil had the original vegetation on the site chopped and mixed into the top 4 inches of topsoil prior to removal and replacement on the plantation site. Dozer cleared soils had all above-ground vegetation bladed aside for disposal prior to removal and storage before replacement on the plantation site. The dozer cleared soil used in this study had been stored for a few months, as indications of decay were present and few weeds initially grew in this soil. Both soil types were from aspen stands, contained aspen roots and were placed to a depth of approximately 1 m on the plantation site. The soils were spread by scraper in the late summer of 2003, and were final graded in May/June of 2004, prior to aspen planting in October, 2004.

Water was delivered during the 2005 growing season by drip irrigation to the transplanted aspen saplings via a computer-controlled system that timed the daily application of water through calibrated emitters. The four water treatments (high, medium, low, non-irrigated control) were randomly assigned to one of the four blocks in each of the two soil types, with all 50 trees in each block receiving the same amount of water (Figure 2). A gravity fed drip system, supplied by a 2000 gallon tank located 207 vertical feet upslope from the test site provided an adequate head to maintain water pressure greater than 60 lbs in all lines. The tank was filled by Seneca Coal Company workers as needed, generally once or twice a week. Source of water was a sedimentation pond lower in the reclaimed watershed. Drippers delivered water at 1 gallon/minute, and were

programmed to deliver water daily at 1.3, 0.6, and 0.3 gal/day/tree for the high, medium, and low irrigation levels; equivalent to 14.4, 7.2, and 3.6 inches of precipitation per month.
The non-irrigated control received no supplemental water. Irrigation treatments were applied daily during the early morning. Drippers required 4 lbs pressure for activation; the valve box and distribution lines were configured so that head pressure down stream of the valves did not exceed this value to avoid leakage between irrigation treatments. Soil moisture and temperature sensors were located in each plot and data were recorded hourly. Standard meteorological conditions were monitored at an automated weather station located at the center of the plot, and data recorded hourly included wind speed, wind direction, relative humidity, and precipitation. Hourly soil temperature, moisture content, and matrix potential were also monitored at one tree in each watering treatment. All data were recorded on a Campbell 23x data logger, which also was programmed to activate the irrigation solenoids. Power was supplied from 12 V batteries charged by a solar panel.

In addition to the watering study, growth and survival data were obtained from three other types of young aspen trees:

1) Natural sprouts that had grown from roots buried in un-irrigated areas of the roto-cleared and dozer-cleared soil adjacent to the irrigated blocks;

2) commercially-grown potted aspen seedlings that were planted in an non-irrigated fenced area approx 1 km from the irrigation study site, and;

3) Natural aspen sprouts growing in an un-mined area of the Yoast mine that had been cleared of mature aspen. None of these study sites were replicated, so the survival, growth, and water status findings are applicable only for that site; and comparability of different un-replicated treatments within the same site must be made with caution. Although the commercially-grown potted aspen trees were planted on dozer-cleared soil, it was not determined if the roots grew out of the potting mix into the dozer-cleared soil during this first year of study.

Natural sprouts were growing at random spacing, about 1 ft to 8 ft apart. Natural sprouts selected for measurement were thinned to no closer than 5 ft spacing. The potted and natural trees in all locations were from unknown genotypes, likely different from the irrigated study transplants. The natural sprouts on the roto-tilled soil were all likely from the same genotype since the soil came from the same area; but they were likely different from those on the dozer-tilled soil. Similarly, the natural sprouts on the dozer-cleared soil were possibly from the same genotype.

Data Collected

Prior to bud break, height of each tree, number of branches, disease and insect infestation, and length of terminal leader dieback was recorded for each tree. Water status and tree growth were measured periodically throughout the experiment. Physical measures of growth were height (cm), basal caliper (mm), number of basal sprouts (count), length of the terminal leader (cm), and length of each of the next three sprouts on upper portion of tree (cm). Disease and insect infestation were recorded again at the end of the growing season.

Water status, or leaf water potential, of the plants was measured on June 22, July 21, and September 20 as near to dawn as possible (½ hr predawn to ½ hr after sunup) to capture the minimum stress before rapid morning transpiration has depleted leaf moisture. One afternoon measurement was also conducted on August 18 to indicate maximum stress under high radiation loading when transpiration would be highest. Treatment, ambient temperature, time of sampling and exuding pressure level was recorded. Leaves were collected from the different treatments at random to minimize time of sampling biases.

Leaf water potential will increases as water is withheld from the plant and plant water stress increases. Water status measurements required removing one fully matured leaf randomly selected from trees in each treatment and measured for water holding capacity using a Plant Water Status Console. The leaf was removed from the plant and immediately placed in a sealed chamber with the petiole extending through a sealing hole in the chamber. A fresh slightly angled cut was made and nitrogen gas was delivered to the leaf under slowly increasing pressure until water exudes from the petiole surface. The pressure necessary for this to occur is an indication of the leaf water potential or water holding capacity of the leaf, an indication of the water stress and thus physiological stress of the plant. Different plants from each treatment were selected at each testing to minimize leaf loss from sampling. From 2-3 total measurements were made from each treatment each day of measurement. Number of measurements depended on the time necessary for each measurement, so that all measurements fall within the dawn-time window. Each day of measurements included leaves from all irrigation treatments. Size of sampled leaf was recorded as length from tip to petiole (mm), and maximum width (mm). An empirical equation was developed to relate width and length to actual leaf area.

Results (2005-2006) -The first two years of the study have provided significant results worth reporting here. Supporting data have been presented in earlier reports. The study was initially conducted to demonstrate the effectiveness of supplemental irrigation on growth and survival of transplanted cuttings; but additional experimental conditions allowed examination of additional factors. Factors examined in the experiment were: irrigation (four levels of watering), soil type (roto-cleared/fresh, dozer-cleared/stored, or undisturbed), plant type (transplanted rooted sprouts, natural sprouts, potted plants) and fencing (fenced or not fenced). Since not all treatment combinations existed and none of the treatments were replicated, statistical analyses and inferences are limited. For example, differences in growth or survival between Yoast, II-W roto-cleared soil sprouts, and II-W irrigated treatments may be due to differences in soil disturbance, genetic stock of aspen, transplant type, fencing, or microclimatic differences between sites, treatments not independently replicated for this study.

This study was considered a case study relevant only for this one location. Nevertheless, several observations were evident from the study that might be helpful for future aspen management and to identify areas for additional research.

I. Irrigation treatment - For this experiment rainfall was plentiful and not typical for the first two years during the study and soil moisture was relatively high even in un-irrigated plots, as indicated by soil moisture matrix potential values and low leaf water potential data for all treatments. This prevented a good examination of the irrigation treatment effects. Aspen growth and survival did not appear to be dependent on, or in some cases consistent with, irrigation treatment, suggesting that soil moisture from the frequent rain events was sufficient even in the non-irrigated plots. The supposition of adequate moisture available to all trees is further evident in that there appeared to be no relationship between irrigation treatment and average leaf area, total leader growth, terminal leader growth, stem diameter growth or caliper, or survival (data previously shown in earlier reports). Growth of second, third, and fourth lateral branches appeared to be similar for all treatments, but are reflected in total growth. Pre-dawn leaf water potential levels also indicate moisture stress was generally less than 8 bars (0.8 mPa) pressure, and did not appear to be related to irrigation treatments during the years when these measurements were taken.

II. Transplant type -The aspen saplings used in the irrigation study that were transplanted from the Yoast site exhibited considerably more injury and had considerably more disease infections than natural sprouts arising from buried root segments or potted plant. Transplant shock was evident only the first year. Leaf area growth, leader growth, stem diameter growth, and survival were considerably less with these plants than with natural sprouts or potted plants during the first year of the study, but the transplanted trees grew well the second and third year of the study (depending on treatment). Potted plants survival was 100% and growth on these trees appeared better than transplanted cuttings the first year. Growth of the transplants was better than potted plants in subsequent years.

III. Soil type –Roto-cleared soil provided sufficient natural sprouting to provide an adequate stand of aspen trees, and these trees appeared to grow better and survival appeared higher than adjacent transplanted trees growing in the same soil in the first two years of the study. Dozer-cleared soil which had been temporarily stored, had considerably lower numbers of natural sprouts than roto-cleared soil, and stocking was sparse (data not shown). Natural sprouts appeared to have greater total leaf area and greater stem diameter growth on roto-cleared soil than dozer-cleared soil, but terminal leader growth appeared similar on both soil types (data presented in earlier reports). Natural root sprouts had no lateral branches. Leaves also appeared to be larger on these trees (data not shown). Nevertheless, these trees apparently experienced somewhat greater pre-dawn water stress in July and September than trees in the irrigated treatments, including the irrigated controls with no water added. The data suggest that pre-dawn water stress levels as high as 14 bars, and afternoon water stress levels as high as 20-25 bars, were not of sufficiently high levels to cause enough stress to reduce survival or growth of these trees. Soil moisture stress appeared to be less with transplanted sprouts in the irrigation experiment, including the un-irrigated controls, than with natural root sprouts or potted plants. It is interesting to note that leaves appeared smaller and terminal growth appeared less on these apparent less-stressed transplanted trees, suggesting that growth of root sprouts, potted plants, and natural sprouts was not limited by the apparent higher moisture stress levels they experienced. Maximum leaf water potentials at mid-afternoon found stress levels of about 25 bars or less, levels that appeared unrelated to treatment, or to growth and survival.

The growth data suggest that roto-cleared soil could have provided additional nutrients or other benefits, perhaps mycorhizae, for tree growth. Weed growth appeared greater on roto-cleared soil than dozer-cleared soil (data not shown).

IV. Fencing -Fencing is necessary to obtain an adequate stand of aspen, regardless of the sources of the trees. The unfenced Yoast site had severe damage from ungulates, including breakage of stems, browsing, and rubbing damage. Most trees at this site had some form of injury. Yet, growth and survival of these trees was good, suggesting that the undisturbed soil presence of an extensive parent root system is ideal for growth of aspen. Nevertheless, fencing of these trees is recommended to produce an adequate stand of mature aspen.

CONCLUSIONS (2005-2006):

I. Growth and survival did not appear to be related to irrigation treatment, likely a consequence of the high rainfall during the 2005 and 2006 growing seasons.

II. Best growth appeared to be on natural root segment sprouts on roto-cleared soil for the first year. Transplanted trees grew well after the first year's transplant shock.

III. Transplanted sprouts showed considerable transplant injury their first year, regardless of irrigation treatment in this relatively wet. Growth and survival was relatively low and diseases were higher in transplant cutting plots compared to natural sprouts and potted plants. Recovery of surviving transplant trees was good and growth was good the second year.

IV. Potted aspen from nursery stock planted on dozer-cleared soil grew well and had high survival the first year.

V. Fencing is necessary to protect small aspen trees from browsing injury.

EXPERIMENTAL PROCEDURES/METHODOLOGIES FOR 2007

Study Design:

Based on the important finding for 2005-2006 summarized above, several new questions regarding aspen growth and survival on reclaimed lands arose, and follow-up research was conducted using the same II-W Mine plots where the 2005-2006 study was conduced. Our intention was to utilize the existing study design and sampling regime to collect third year survival and growth data from trees sampled in 2005-2006. OSM funding was used for data collection during 2007 and for data analysis and preparation of the final report. Details of operation of the irrigation system, types of planted aspen studied and sampling procedures remained as previously described. Deviations and additions to the original study design are described below.

Irrigation Treatments:

Based on findings from 2005 and the higher than normal rainfall, irrigation treatments were applied differently during the 2006 and 2007 growing seasons. Treatments were applied at 0.0, 0.15, 0.3, or 0.6 gallons each day of treatment, one-half the rate applied in 2005. Irrigation treatments were to be continued throughout the growing season. Because of evidence of saline condition of the irrigation water supply during 2005 - 2006, clean potable water from a
Hayden, CO, hydrant was used to irrigate the trees in 2007.

Growth of transplanted rooted sprouts in the second and third year: Some of the transplanted aspen in the irrigation plots had apparent dead tops after the first year. It was expected that some of these could grow back from root sprouts. We examined survival and re-growth of these trees that died back from injury or disease the first year. It was expected that surviving plants would do well in the second year following first year transplant shock. Survival and growth in the third year would enhance long term survival. Growth and survival of natural sprouts and potted plants were also examined in the third year to provide an indication of possible long-term survival.

Differences in soils:

There were rather dramatic differences between the two soil types for many of the attributes measured in 2005. As such, it was important that differences between the two soil treatments be fully described. Soil samples from the two treatments were collected and analyzed for organic matter and nutrient content, water holding capacity, chemical, and physical properties. Since the soils were mixed and soil horizons present in normal soils were missing, integrated samples were collected through the entire surface soil profile, approximately 0.75 to 1 m depth. Soils were analyzed for soil texture and fertility (organic matter, pH, N, P, K, CEC). Bulk soil samples were periodically collected and oven-dried for soil moisture determination.

Given the growth differences observed on the two soil types in 2005, it was important to quantify how the replaced soil differs from natural soils on the Seneca II-W Mine. Samples of undisturbed soil were collected under aspen stands in undisturbed areas of the mine and subjected to the same analysis described above. In addition, differences in soil conditions between reclaimed soils in the study area and those under nearby undisturbed aspen clones were quantified by comparing physical and nutrient characteristics of soil samples from both the normal and augmented reclaimed soils to those of the natural soils. Sampling of the soils under nearby native undisturbed aspen stands were extended to the same depth investigated in the reclaimed soils on the study plot. Effects of reclamation on soil moisture regimes were investigated by monitoring soil moisture during the growing season in undisturbed clones to that of un-irrigated portions of the study site.

Discussions with Seneca Coal Company document that the roto-cleared soils had been moved directly from its original site to the plot site; while the dozer-cleared soil placed at the experimental site was from a soil storage site where it had been stored for several months. The difference in response of aspen tree growth between the two soils types was expected to be primarily due to storage rather than to method of tree removal. Stored soils were observed to be anaerobic.

Water Chemistry:

White salt deposits were observed around some of the irrigated treatments in 2005, particularly those trees receiving the high irrigation treatment, leading to the question of whether these salts were leached from the re-deposited topsoil, or were present in the irrigation water. The soil chemistry tests conducted included a salinity analysis. Soils analyses confirmed that the soils with the highest rate of irrigation were indeed saline, likely the result of irrigation with saline water. Only clean water was used to irrigate the trees during 2007 to avoid further decline and to see if the trees irrigated with saline water could recover. Root zone soil samples were also submitted to the soils testing laboratory for determination of saturated paste extract conductivity.

Root growth:

Aspen is a relatively short-lived disease and injury susceptible tree that relies on periodic re-sprouting from lateral roots to maintain its presence on a site (Shepperd 2005). Therefore, the development and lateral extension of new roots is critical for the ultimate survival and re-establishment of any aspen planted on mined lands. We quantified new root development since planting by excavating randomly selected surviving plants during 2007, washing soil from the roots to quantify total root biomass and new root growth. Trees were chosen from each of the different irrigation, soil, and transplant treatments studied. Soil was carefully loosened and roots exposed by washing soil away with a high pressure water jet. Once roots were exposed, the spread of any lateral roots away from the planting site was measured as distance from the tree base and as total length of each root. Root masses were separated by size class and total below-ground biomass dry weight was measured. It is particularly crucial to see if roots have extended beyond the planting hole for transplants or beyond the potting mix for potted aspen. This root extension is necessary for survival of the trees and the ultimate re-establishment of natural aspen clones. Roots must also reach a large enough size, and be close enough to the surface, for suckering.

Physiological status:

Monitoring of leaf water potential during 2005, a wet growing season, indicated that varying irrigation treatment did not affect leaf water stress condition of the plants. However, additional physiological conditions of the plant that affect growth and survival were unknown. Other physiological conditions, such as stomatal conductance, photosynthesis, and respiration, may show response to drought prior to indication by plant water status; or at the least indicate which trees are stressed and not likely to survive. Therefore, we collected limited additional physiological measurements of the transplants under each irrigation treatment, including photosynthesis, respiration, and transpiration. This would allow a better evaluation of the physiological stress conditions occurring under specific irrigation treatments; and the physiological conditions favorable for survival.

Competing vegetation:

Invasive annual weeds including tumbleweeds and thistles were common in the plantations in 2005 and 2006, as well as numerous native herbaceous species. We controlled competing vegetation in the irrigation and root-sprout treatments by repeatedly hoeing and cutting all weeds growing around study trees. Landscape fabric placed around potted trees when they were planted prevented weeds from growing next to those trees. The aggressive nature of weeds suggests that vegetative competition may be important in survival and growth of aspen trees. The inability of easily controlling competing vegetation with herbicides around broad-leaved species like aspen presents additional constraints.

We investigated this question by continuing to mechanically control competing vegetation around trees in half of each irrigation and soil treatment. Treatments in the fenced plantation area were divided into sections to be weeded and sections not weeded. The two weeding treatments were superimposed on the existing study design; and growth, physiological parameters, and survival were compared as in other treatments. Soil samples were collected from each treatment for moisture content analysis.

EXPERIMENTAL RESULTS

Aspen growth and survival on reclaimed lands was successful under certain conditions. The experiment was conducted 2005-2007 on the II-W Mine plots, Seneca Coal Company, near Hayden, CO (Figure 1). This report examined third year growth and survival of these trees.

Growth by irrigation treatments and plant type:

Saline water inhibited the growth of aspen on high and medium irrigation treatment plots the first and second year of the study. These trees were still smaller in the third year but their annual growth had nearly recovered to that of low and control irrigation treatments (Figure 3). Growth of the low irrigation and control (no irrigation) treatment trees was higher than that for the high and medium irrigation treatments suggesting that the reduced growth from the saline water used for irrigation in the first and second years of the experiment was still evident in the third year of treatment. Nevertheless, growth of these trees was still greater than that for the natural sprouts and potted trees. None of the trees that had died in previous years re-sprouted from residual roots in 2007. Since growth of aspen was good with the low and no irrigation treatments, it is evident that there was sufficient natural rainfall during the three years of the study for the trees to survive without irrigation. It is possible that growth under the high irrigation treatment could have been higher than the lower irrigation treatments had clean water been used. The benefit of clean water irrigation of newly planted trees under more normal, low rainfall conditions could not be determined in this experiment since low rainfall and drought conditions did not occur during the study.

Growth of the transplanted trees was generally good during the third year of treatment and surpassed that of the natural sprouts and potted trees (Figure 3). Survival was similar for all transplants and natural sprouted trees (50-57%), but was considerably higher for potted plants (80%). Growth and survival of the potted trees was excellent the first year of the study, but after three years growth of the potted trees remained relatively stagnant and these trees were considerably smaller than the transplanted trees. Growth of natural sprouts was also less than transplants after three years.

Differences in soils:

There were rather dramatic differences between the two soil types for many of the attributes measured in the experiment, particularly growth (Figure 4). Soil samples from the two soil types were collected and analyzed for organic matter and nutrient content, water holding capacity, chemical, and physical properties. Because the soils were somewhat mixed prior to placement and no soil profile existed, sampling at 1 foot increments was not conducted. Samples analyzed were taken from the entire topsoil depth placed at the site, about 1 m deep. Preliminary data indicate that neither soil type was toxic, except for high electric conductivity in high irrigation treatments for 2006. Nutrient content such as nitrogen did not seem to be related to soil type, and appeared to not be the limiting factor in tree growth.

Fresh roto-cleared soils provided adequate sprouting of aspen from residual aspen roots in the topsoil. Limited sprouting occurred from the stored dozer cleared soils. The data suggest that moving fresh soil to reclaimed land could allow for sufficient sprouting of aspen from residual roots without planting. While survival was not significantly different on the roto-cleared (53%) and dozer-cleared (52.5%) soils, average growth on dozer-cleared soils (18.9 cm) was only about two-thirds of that on the roto-cleared soils (29.4 cm).

Dozer cleared soil had higher moisture content, suggesting either less ability of the trees to extract the moisture since they were smaller, and/or the dozer cleared soils had better soil moisture holding capacity and/or was less well drained. Visual observations suggested that the dozer cleared soil was more compact and poorly drained as evidenced by water ponding in a soil pit at the site. Roto-cleared soil generally had less moisture available for trees (Figures 5-7). The soil moisture seemed to have no relationship to amount of irrigation, but was somewhat related to biomass; with larger trees and greater amount of weed growth on the roto-cleared soils related to lower soil moisture. Soil moisture was higher at 30-40 cm depth in the soil than at the surface (Figures 8-9).

The lower soil moisture content on the roto-cleared soil was perhaps because of the better drainage and greater plant biomass removing water from the soil. Water in this soil was likely less tightly held since this soil was considerably less compact. All these conditions apparently favored growth of aspen trees.

Water Chemistry:

Data from 2006 confirmed that local pond water used for irrigation was saline. Non-saline potable water from a Hayden, CO, hydrant was used to irrigate the trees in 2007. Carryover of effects of saline irrigation water for 2005-2006 was evident in lower growth of aspen in the high and medium irrigation treatments compared to the low and control treatments.

Physiological status:

Initial analyses indicate that soil type and weed competition affected rate of photosynthesis and respiration. Highest rates of photosynthesis seemed to be in the weeded plots on roto-cleared soils, suggesting that these conditions are best for aspen growth and survival. Plant top and root growth on these plants would seem to verify that finding. Plant water status measurements indicated that when these tests were conducted during the 2007 growing season (June 28 and August 1) the plants were not water stressed, with pre-dawn leaf water potential pressures not exceeding 10 bars and most often less than 5 bars (Figures 10-11).

Root growth:

Root growth of transplants was best in weeded plots on roto-cleared soil and lateral roots extended far from the base of the original tree (Figures 12). They were of sufficient size (4 mm or more) where suckering could begin, but many were too deep (15 cm or deeper), a result of the deep planting of the transplanted trees. Trees in other treatments are surviving and roots are extending out, but it will take additional years for most to obtain sufficient size at depths necessary for suckering. In any case, suckers are more likely to appear after injury or death of parent trees when apical dominance is inhibited. Roots growing from the potted trees were mostly confined to the potting hole. This was also true for some of the transplants on dozer-cleared soil, perhaps a result of the high density and compaction of this dozer cleared and stored soil.

Depth of the roots systems for the transplanted aspen ranged from about 15 to 40 cm, with transplants in the roto-cleared soil planted somewhat deeper than those on the dozer cleared soil. These depths are too deep to allow effective suckering. Even though roto-cleared trees were planted somewhat deeper than dozer-cleared trees, growth was better on the roto-cleared trees. It is expected that trees planted deep will take longer to produce roots at a depth conducive to suckering, but those deep planted trees that survived are now producing shallower roots. Lateral root systems were already developing on most of the transplanted trees, and roots were observed near the surface several meters from the base of some trees suggesting that these trees were becoming well established. Apical dominance of the rapidly growing transplanted trees likely prevented suckering of these lateral roots. It is expected that enough root system has developed that further irrigation of these trees is not necessary.

Competing vegetation:

Weeds were an important competitor for soil moisture in the planted aspen plots. Soil moisture was higher in the weeded plots, suggesting more soil moisture available for tree growth in these plots (Figure 4). Weeding was particularly important for survival of natural sprouts occurring from residual aspen roots in the replaced topsoil. Trees growing on weeded plots grew considerably better and had higher rates of survival. Of 34 natural sprouted trees initially marked for study on the roto-tilled fresh soil in year 1, half were weeded and half un-weeded in years 2 and 3. All of the weeded trees survived into year 3 while only 4 of the un-weeded trees survived the first three years of the experiment. Of the 21 natural sprouts on the dozer-cleared stored soil, 8 of the 11 weeded trees but only 2 of the 10 non-weeded trees survived after 3 years. Most of the vegetative competition consisted of annual herbs, perennial grasses, and weed species. Weed present were primarily various thistle species. Shading was not a factor, since the trees were larger and growing above the competing vegetation canopy. The soil moisture data suggest competition between surface vegetation and trees for a limited amount of available water.

CONCLUSIONS

Irrigation:

Best growth and survival was with low or no irrigation, but salinity of irrigation water in the first two years of the experiment reduced growth of trees receiving high and medium amounts of irrigation. Reclaimed soils were not saline, but salinity levels were high enough in irrigation water from local ponds to reduce growth of aspen. Care must be taken to provide low saline water when irrigating planted aspen trees on reclaimed lands. Low level irrigation and no irrigation growth and survival were similar, suggesting that enough rainfall and soil moisture occurred for the years this experiment so that irrigation was not necessary. It is expected but not tested in this experiment, that supplemental irrigation with clean water may have increased growth and survival above non-irrigated trees. It is expected that all surviving trees now have developed enough root system after three years that further irrigation is not needed.

Plant source:

Transplanted trees from local sources grew best once established. Most natural suckers did not survive without weeding. Potted plant had a high rate of survival, but growth was lower then for transplants and natural sprouts. Roots of potted aspen general stayed in the augured potting hole. This also occurred for a few of the transplanted trees in the more compact stored dozer cleared soil on the irrigation treatment plots, the same soil type where this occurred for the potted plants.

Soil type:

Best growth and survival occurred on roto-cleared (fresh) soil compared to dozer cleared (stored) soil. More natural sprouts from residual root segments were evident in roto-cleared soil. It is expected that higher number of natural sprouts was due to the shorter length of soil storage and the soil characteristics rather than the clearing method. The dozer cleared soil appeared to be more compacted and was less well drained than the roto-cleared soil, and it is expected that these physical characteristics were more important to tree growth than the method of clearing. Also, storage effects on the soil were likely more important than method of clearing.

Weed control:

The best growth of aspen was with trees that were weeded. This was likely related to lower water stress of the trees, since weeds competed with the trees for the limited water supply. This was particularly apparent on the roto-cleared soils where weed competition was high.

Root growth:

Similar to top growth, root growth was greater in weeded plots compared to non-weeded plots on the roto-cleared soil. Effect of weeding on root growth of dozer cleared soils was less evident, likely since weed competition was considerably less and growth was less on the dozer cleared soils. Roots in most treatments were of sufficient size but too deep to support suckering. Nevertheless, sucker initiation was likely inhibited by apical dominance of the growing trees. Lateral root extension was progressing, but was considerably slower in the un-weeded plots and on the dozer cleared soils. The upward growth of roots toward the soil surface that was observed indicates that care should be taken in future plantings to plant trees only to a depth of the original root collar.

OVERALL RECOMMENDATION

Best conditions for reproduction of aspen on reclaimed surface mined coal lands is by using transplanted saplings from local sources on freshly placed soil removed from aspen stands. Care should be taken to avoid compaction of the replaced soil. Transplanted trees should be planted no deeper than the original root collar, and weeds should be controlled around individual trees. Irrigation with non-saline water might enhance growth and survival in years with drought conditions.

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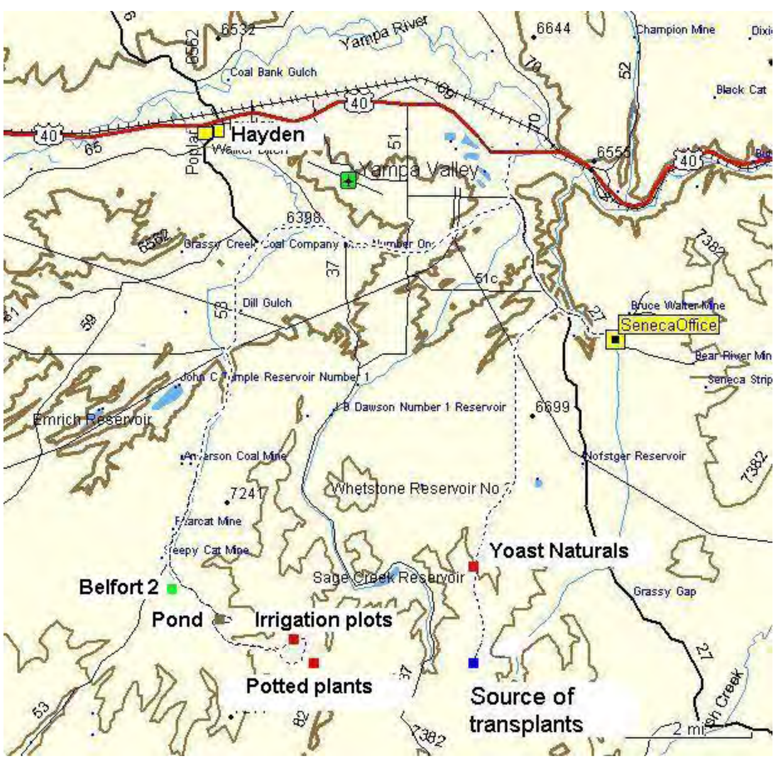

Figure 1. Map of experimental plot location, Seneca Coal Mine, Hayden, CO.

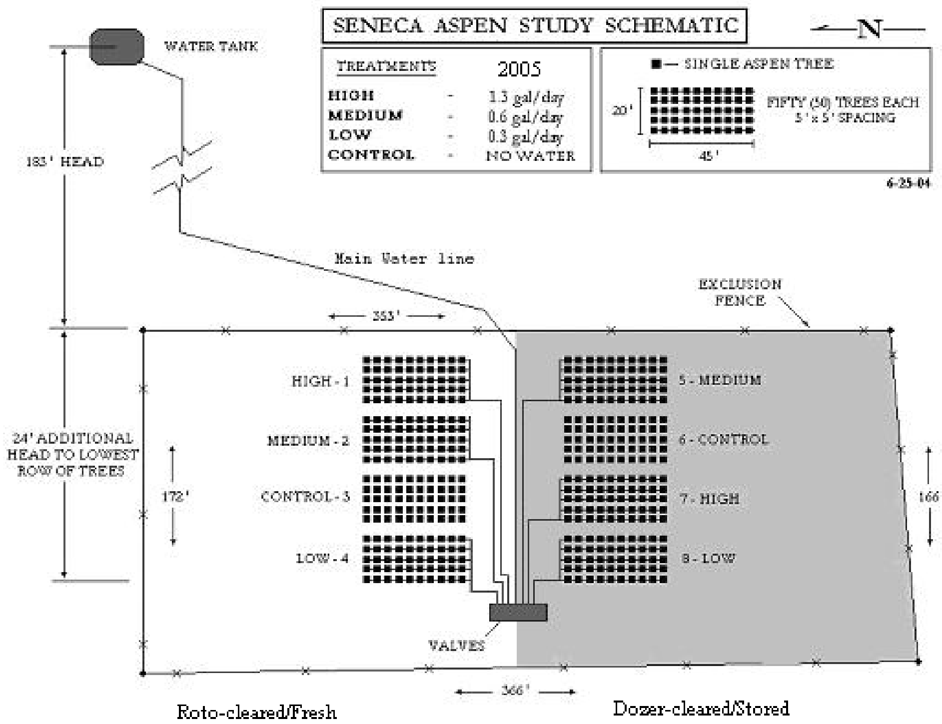

Figure 2. Experimental design for aspen reclamation project, Seneca Coal Mine, Hayden, CO.

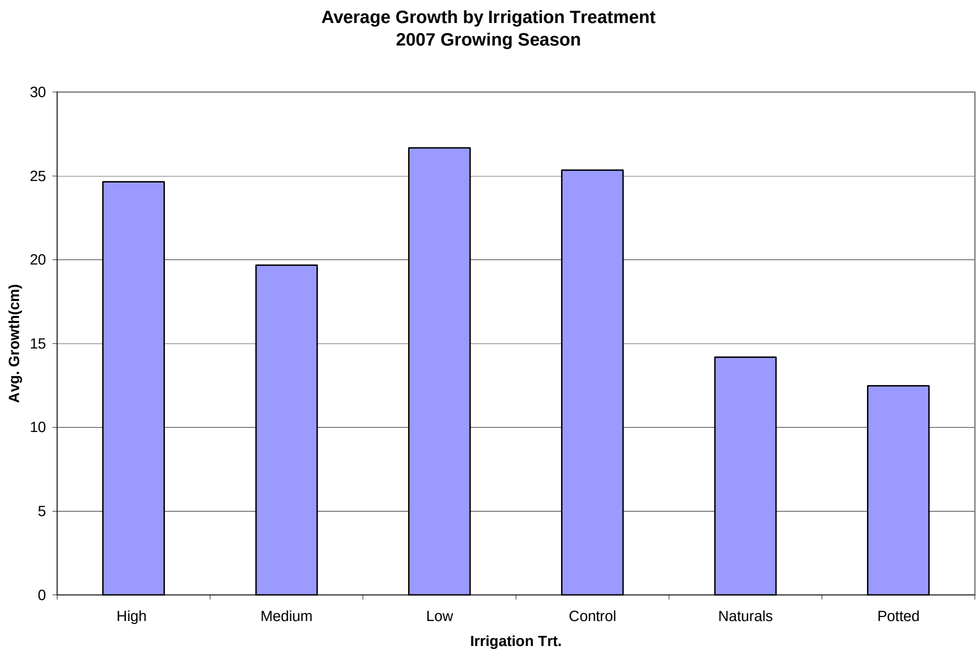

Figure 3. Average growth, cm, by irrigation treatment. Controls, naturals and potted trees were not irrigated.

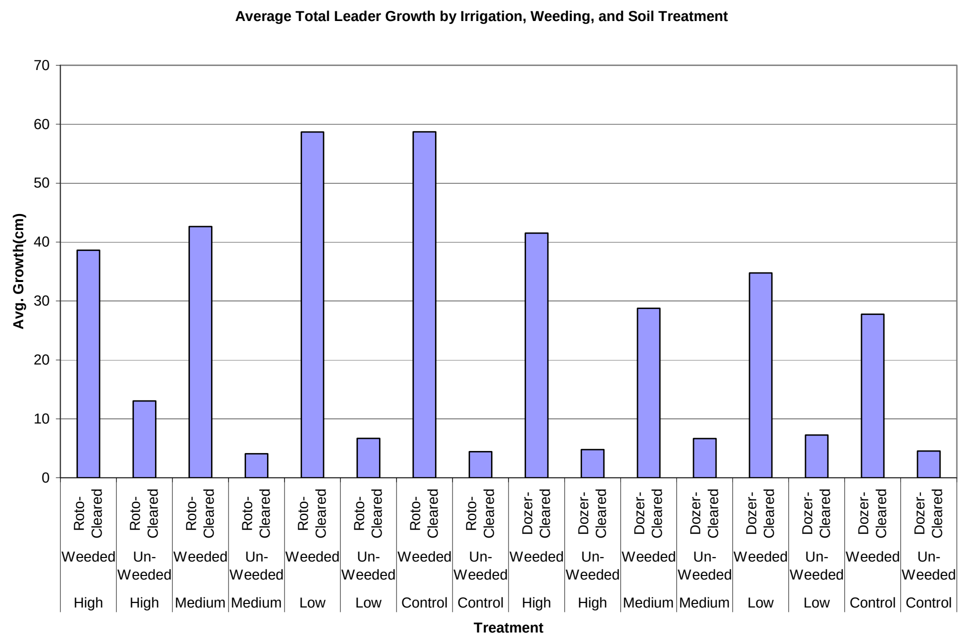

Figure 4. Average growth in cm by irrigation, weeding, and soil type.

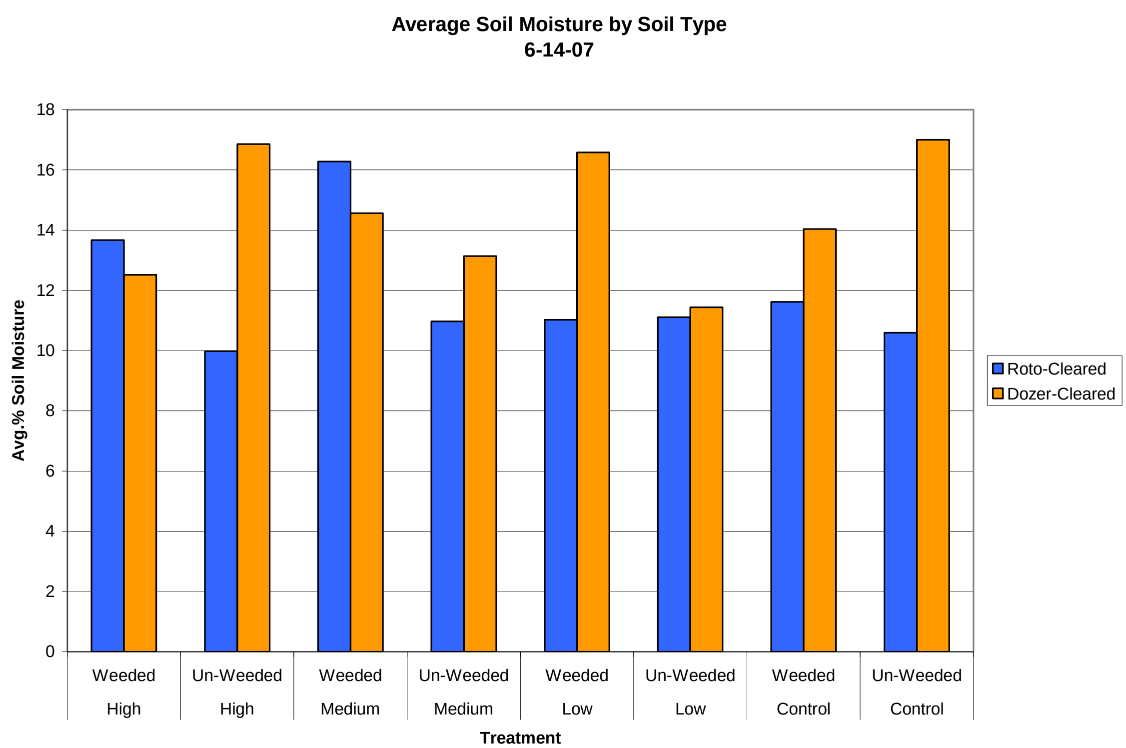

Figure 5. Average soil moisture by soil type and weeding treatment, June 14, 2007.

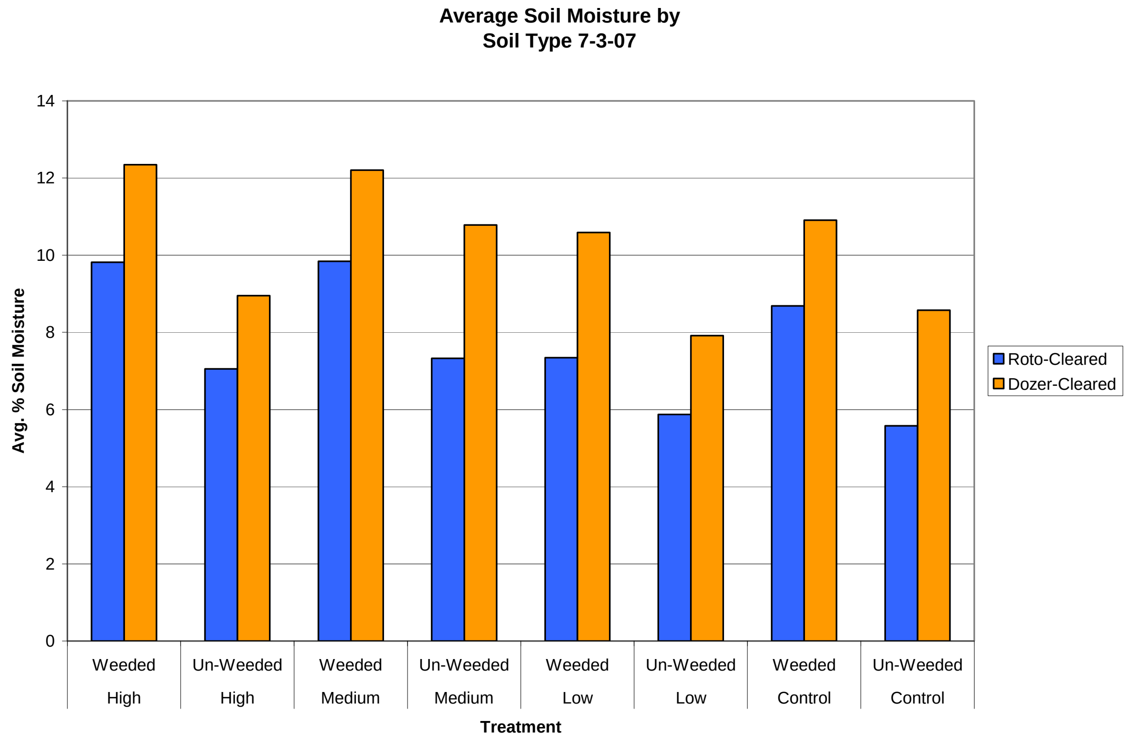

Figure 6. Average soil moisture by soil type and weeding treatment, July 3, 2007.

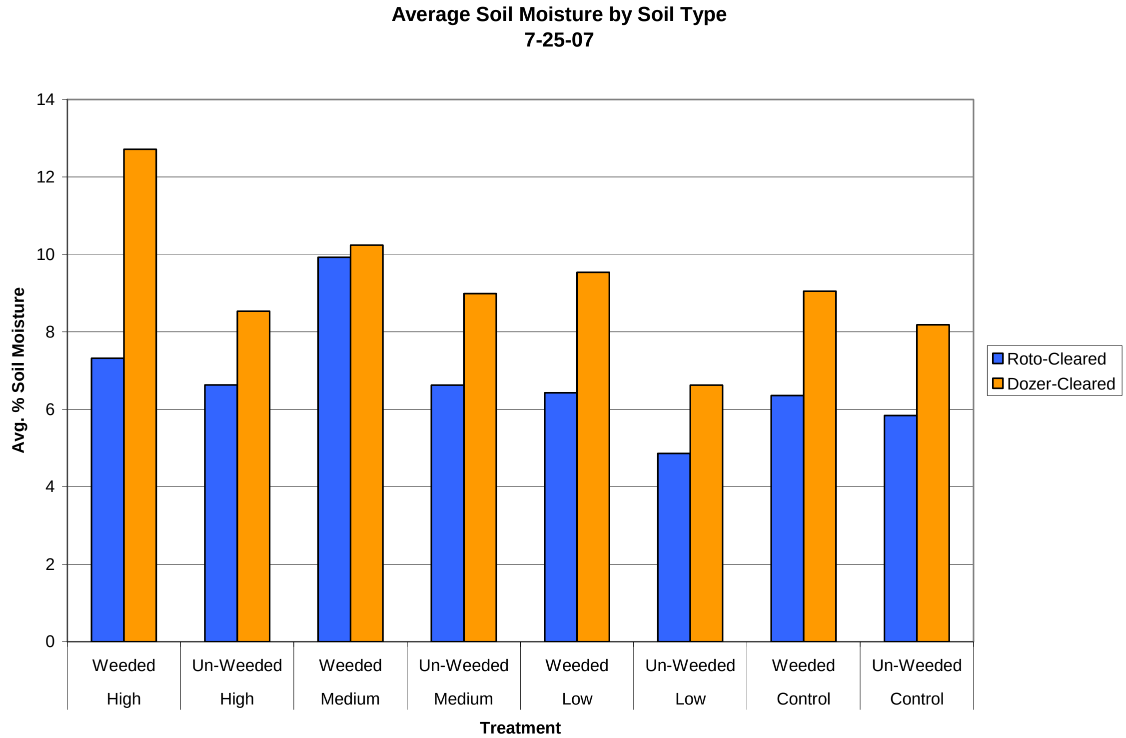

Figure 7. Average soil moisture by soil type and weeding treatment, July 25, 2007.

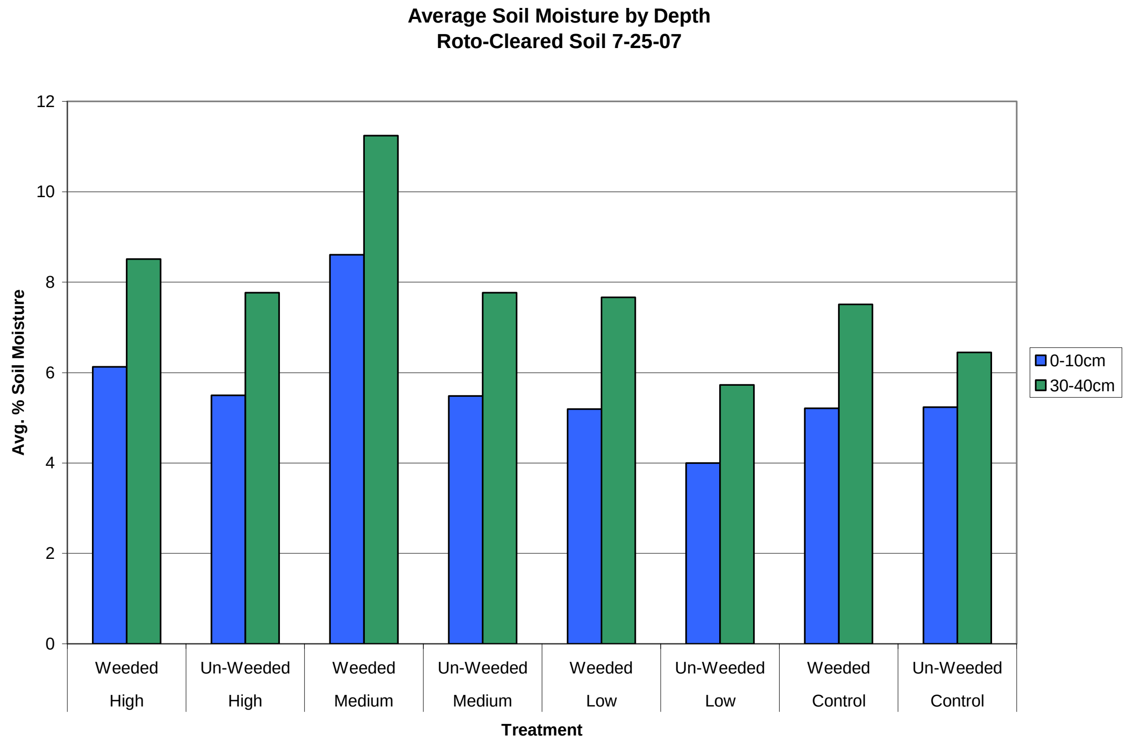

Figure 8. Average % soil moisture by depth, roto-cleared soil.

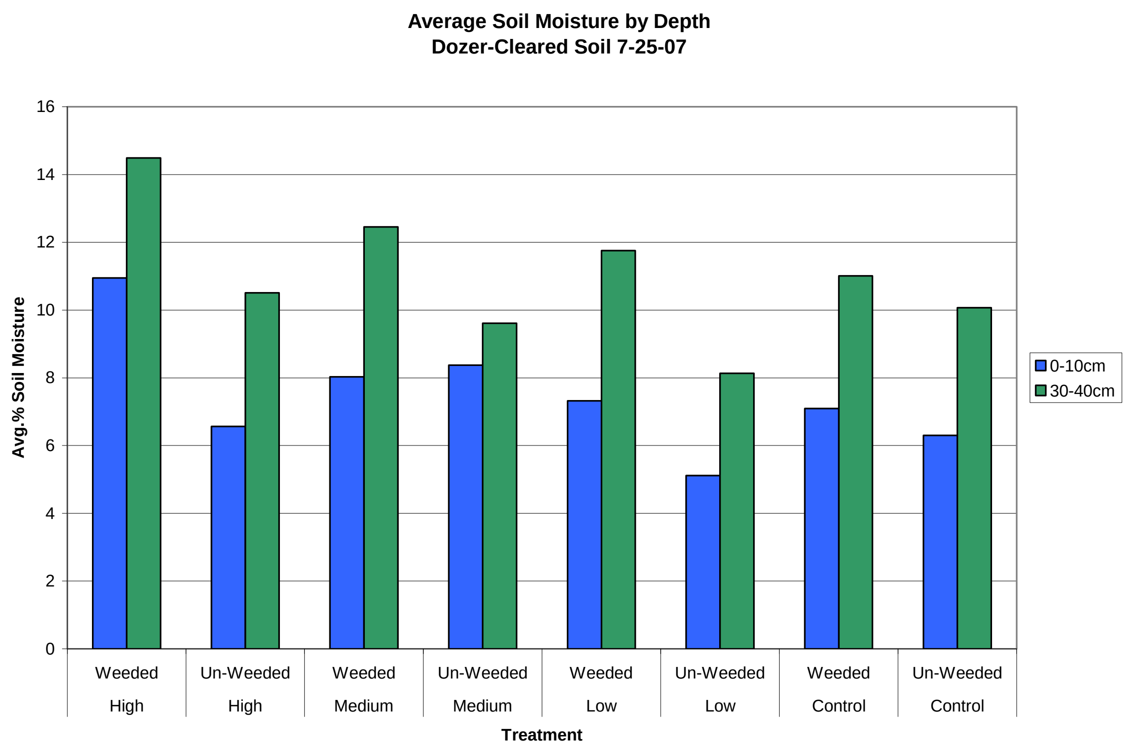

Figure 9. Average % soil moisture by depth, dozer cleared soil.

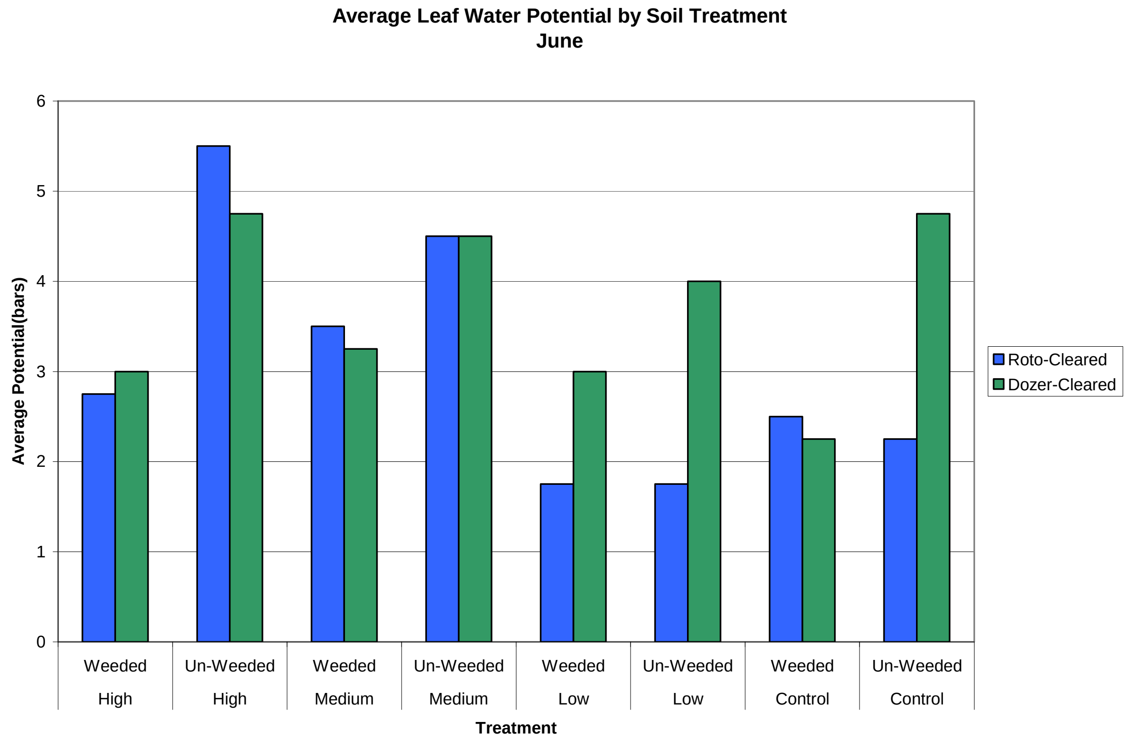

Figure 10. Average pre-dawn leaf water potential, June 28, 2007.

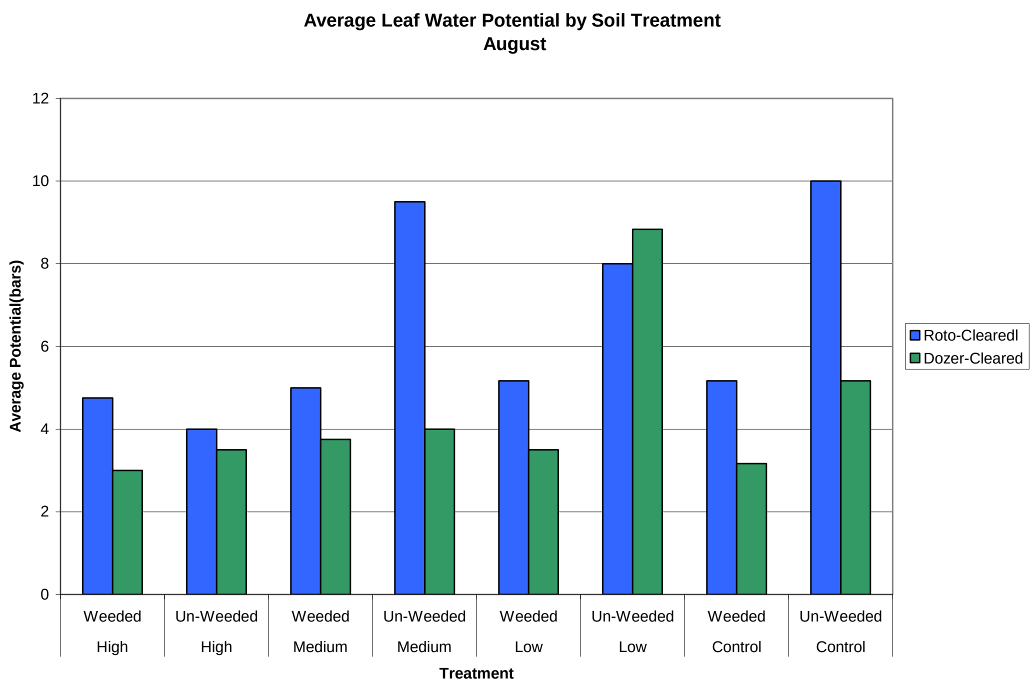

Figure 11. Average pre-dawn leaf water potential, August 2007.

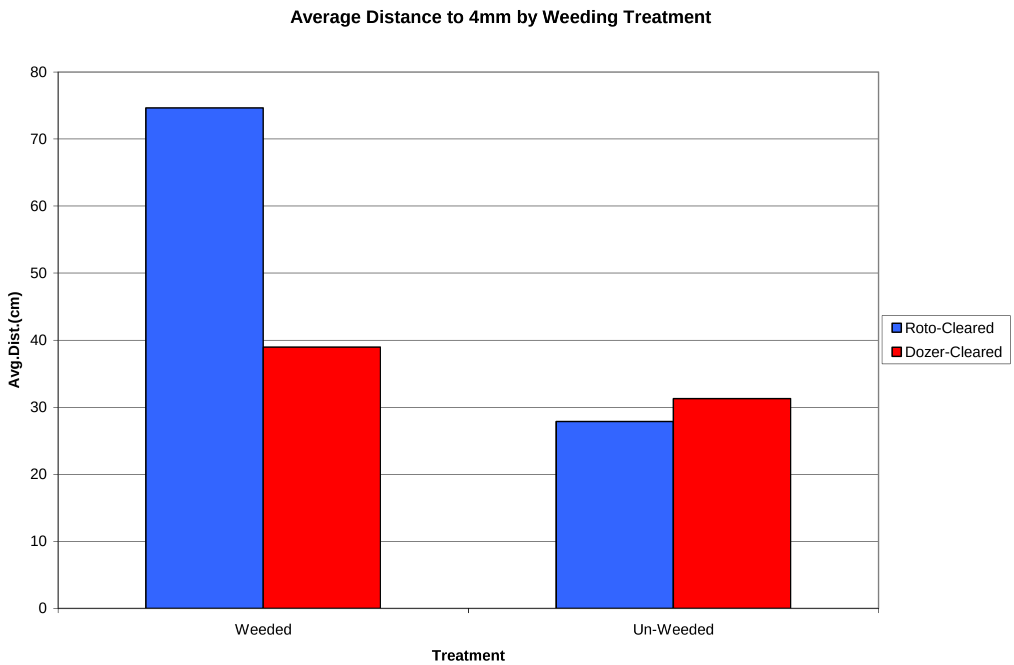

Figure 12. Average distance in cm of root extension from base of tree to 4 mm root diameter.

Aspen in study area at Seneca 2W.JPG

aspen study area Seneca 2W minesite 07.JPG

Black bear on Seneca 2W minesite.JPG

Drip irrigation system at aspen study Seneca
2W.JPG

mule deer on the reclaimed land Seneca.JPG

Reclaimed land at Seneca planted 1978.JPG

roots of transplanted aspen Seneca 2W.JPG

Roy Karo with 4 year old aspens on reclaimed land at Seneca 2W.JPG

Service berry on reclaimed land Seneca.JPG

WHEN THE GRASS STOOD STIRRUP-HIGH

Dave Bradford
Rangeland Management Specialist
USDA Forest Service, Paonia Ranger District
Paonia, Colorado

ABSTRACT

There are numerous stories of North America, as it existed before European settlement. These stories often describe a virtual Garden of Eden. It has become conventional wisdom in popular American culture that European immigrants had a profoundly destructive impact on the North American landscape and that the indigenous peoples lived in perfect harmony with the land. These popular perceptions are often carried into discussions on natural resource management. How accurate are these legends? Are they based on accurate, historical facts or are they based on speculative, often erroneous assumptions? One such story concerns the salt deserts of western Colorado. These desert areas are known locally as the “adobies.” The tradition is that these areas once supported “stirrup-high” grasslands. Is there historical documentation to support the claim of stirrup-high grass?

I reviewed over 150 different publications from over a dozen institutions including local, state and national libraries and museums that contained information on the Uncompahgre Basin and the North Fork Valley. This journey into the past culminated in the discovery of over 300 historic landscape photographs, taken from 1883 through 1916. These photographs came from a variety of sources - the U.S. Geological Survey, the U.S. Forest Service, the National Archives, the Denver Public Library - Western History Collection, local historical societies and individuals.

There is considerable historic documentation that we natural resource managers often ignore. The early European and American explorers, the American military and the early American scientific surveys left a trove of information on environmental conditions of the areas they explored. I suggest that studying this information can help us view the land with better understanding as well as appreciation. The historic documents and photographs I have located are providing factual baseline information on environmental conditions and the historic range of variability for many of the landscapes in western Colorado.

Evaluation of Gully Erosion Control and Restoration Techniques in the North Crystal Creek Basin, Pikes Peak

Eric Billmeyer
Associate Director, Rocky Mountain Field Institute
Colorado Springs, CO 80904

Wendi Clouse
Department of Geography and Environmental Studies
University of Colorado at Colorado Springs
Colorado Springs, CO 80907

ABSTRACT

Adequately addressing gullies created by stormwater runoff originating from high mountain roads and the resultant sedimentation of connected streams and wetlands has been a challenge for land managers across Colorado due to the impacted areas often being located in difficult to reach terrain. Remote streams and wetlands on Pikes Peak can be included among those most affected. Basins located on Pikes Peak have received an unusually excessive amount of sediment, up to eleven times the estimated natural erosion rate, due to uncontrolled runoff conveyed through erosion gullies emanating from the Pikes Peak Highway. Within the North Crystal Creek Basin on Pikes Peak, discharge of stormwater off the highway onto unprotected slopes has resulted in the development of thirteen long, deeply incised gullies located in difficult terrain. While loose rock check dams have been found to be an effective gully control prescription, the amount of material needed for construction usually requires access by heavy machinery. However, many gullies, including those on Pikes Peak, are inaccessible to heavy machinery for mitigation work and building access roads to the gullies is neither desirable nor feasible. The use of a Rock Tram system is presented as an alternate method to the use of heavy machinery to construct loose rock check dams in difficult to reach areas. Methods and initial results of the erosion control prescriptions and vegetation techniques used to stabilize a 120 m long gully emanating from the Pikes Peak Highway in the North Crystal Creek Basin are presented as a case study.

INTRODUCTION

Colorado's high sub-alpine and alpine regions have long been an attractive draw for those wishing to exploit these areas for their mineral deposits, wildlife, or scenic beauty. The result has been over 100 years of road construction within some of the most environmentally sensitive lands within the state. Many roads were constructed with little or no thought as to how stormwater would affect adjacent watersheds. Culverts, if any at all, were often placed in inappropriate locations and protection of the slope beyond the out fall was extremely rare. The legacy of many of Colorado's mountain roads is a degraded landscape characterized by gully scars and sediment laden streams. Pikes Peak (4,302 m), renowned as America's Mountain, is an extreme example of how the presence of an automobile route in combination with poor stormwater management can severely degrade a watershed.

Dominating the skyline just west of Colorado Springs, CO, Pikes Peak is one of the principal landmarks in the western United States and provided inspiration for the song "America the Beautiful." The summit of Pikes Peak is accessible by the 19 mile long Pikes Peak Highway Toll Road. Constructed in 1915, the Pikes Peak Highway now supports over 300,000 visitors a year helping to establish Pikes Peak as the second most visited mountain in the world after Japan's Mount Fuji. In addition to being a major tourist draw, Pikes Peak is also one of the most important natural areas in the region. The mountain provides critical habitat for a wide range of native flora and fauna including populations of the federally listed threatened Colorado greenback cutthroat trout and the Pikes Peak Watershed is the principal local source of water for the communities of Colorado Springs and Manitou Springs.

The Pikes Peak Highway has long been a center of controversy. Beginning as early as 1952, nearly a dozen reports and studies from several organizations and agencies have confirmed the environmental degradation caused by the road upon the surrounding landscape and the Pikes Peak Watershed. All of the reports agreed that the environmental impacts from the Pikes Peak Highway are a direct consequence of the highway being maintained as an unpaved road and that the lack of proper water control structures are a principal factor behind the degradation. The discharge of stormwater runoff from the highway unto unprotected slopes has resulted in the creation of over 120 gullies within the watershed, facilitating the transport of road material and radically increasing natural erosion rates (RMFI, 2003). Many of the gullies are over a quarter mile long, have developed on extremely steep terrain, and are located in difficult to reach areas.

In 1998 the Sierra Club filed suit in US District Court against the City of Colorado Springs and the USDA Forest Service alleging violations of the Clean Water Act in the management of the Pikes Peak Highway. In 2000, the Court ruled in favor of the Sierra Club and instructed the City of Colorado Springs and the Forest Service to address the erosion and sedimentation problems of the highway and to bring the road into compliance with the provisions of the Clean Water Act. The court set a timeline of 10 years for these improvements to be made and since that time approximately 4 miles of unpaved road has been surfaced with asphalt and erosion control structures put into place.

As the paving of the Pikes Peak Highway progresses, remediation and restoration of areas within the watershed impacted by almost 100 years of uncontrolled runoff is being undertaken by the Rocky Mountain Field Institute. Addressing the numerous gullies and reducing their impact to streams and wetlands within the watershed is a primary goal of the *Pikes Peak Watershed Restoration Project*. Loose rock check dams have been found to be an effective gully control prescription but due to the amount of material needed for construction access by heavy machinery is required (Heede, 1976). However, many gullies, including those on Pikes Peak, are inaccessible to heavy machinery for mitigation work and building access roads to the gullies is neither desirable nor feasible. The use of a Rock Tram system is presented as an alternate method to the use of heavy machinery to construct loose rock check dams in difficult to reach areas. The initial results of the effectiveness of the erosion control prescriptions and vegetation techniques used to stabilize a 120 m long gully emanating from the Pikes Peak Highway in the North Crystal Creek Basin are also presented.

METHODS

Site Description

The North Crystal Creek Basin abuts the Pikes Peak Highway between mile markers 7 and 10 at an average elevation of 3000 m. Within the basin is North Crystal Creek, a small tributary stream to Crystal Creek, the main natural source of water flowing into Crystal Reservoir within the Pikes Peak Watershed. This reservoir is a primary source of drinking water for the City of Colorado Springs.

Within the North Crystal Creek Basin, discharge of stormwater off the Pikes Peak Highway onto unprotected slopes has resulted in the development of thirteen deeply incised gullies. These gullies are highly unstable with active undercutting of the bankslopes occurring. Exposure of tree roots from the undercut banks has resulted in the death of a substantial amount of local trees in the vicinity of the gullies. Extensive alluvial deposits have also formed at the gully outlets, spreading into the North Crystal Creek channel. The North Crystal Creek Basin was identified as a priority for completing paving and erosion control on the Pikes Peak Highway. Work completed in 2005 resulted in all culverts discharging stormwater from the highway into the North Crystal Creek Basin being either removed or closed.

The project gully is approximately 112 m in length. The natural drainage area for this gully is estimated to be 7.77 acres (3.14 ha). Previous runoff has resulted in an incised channel that averages 1.5 m deep and 3 m wide through most of its length with an average channel gradient of 12 percent.

Loose Rock Check Dams

Loose rock check dams have long been recognized as an effective way to provide gully control. Heede (1976) studied and quantified the effectiveness of several types of rock check dams along Colorado's Front Range and the National Resource Conservation Service has been using check dams for gully control for decades. Loose rock check dams are easy to construct but can require a substantial amount of material depending upon the area and length of the gully to be controlled. General practice usually involves using heavy machinery to move the material into place. Due to the inaccessible nature of the gullies on Pikes Peak an alternate method to transport material to the project site was needed. The Rocky Mountain Field Institute has had good success in gully control and remediation in remote, difficult to access alpine areas using a Rock Tram system to transport large amounts of rock material to build check dams and retaining walls. This method involves setting up a tram tower at the material source and a second tower near the work site. The tram at the material source must be located above the work site. In general, a flat area of about 4 m^2 is required to provide enough space for the tram tower to be constructed. A rope pulley system is then rigged between the two towers that allow rock material to be transported through the air from the source pile to the work site. The system can be used to transport up to .10 cubic meters (approximately 250 to 350lbs) of rock material in a large bucket or individual rocks up to 400lbs in a sling each trip (Figure 1 and 2). Distances of up to 120 m can be covered depending upon the steepness of the slope with steeper slopes allowing for longer distances.

Figure 1 and 2. Example of Rock Tram with bucket and rock sling

The system has many advantages over the use of heavy machinery. It is easily transportable and can be set up on extremely steep slopes, which is actually desirable due to the rope slack in the system which can cause the rock bucket or sling to drag on the ground if the slope is not steep enough. The system does not require any access roads to be constructed as generally the top tower will be placed on or near the existing road above the gully to be treated. The system allows material to be transported quickly and without disturbing the landscape under which the material is being carried. The main disadvantage to the system is that it is very labor intensive, requiring at least three persons to operate the top tram and load material from the source pile, and at least two persons to dump the material and ready the bucket or sling to be transported back to the top tram. Individuals wanting specific information on setting up the Rock Tram system should contact the Rocky Mountain Field Institute directly.

The Rock Tram system was applied in the construction of 12 loose rock check dams within the project gully in the North Crystal Creek Basin. Position of the check dams was determined using the standard calculation;

$$D = (100 \times H) \div Z$$

where

D = Distance between structures
H = Height of proposed structure
Z = Percent grade of channel (Fifield, 2000)

Dams were constructed according to specifics outlined by Heede (1976) and Fifield (2000). Approximately 46 cubic meters (62 tons) of granite rock 3” to 36” in diameter was utilized to construct the rock check dams. Sizes of the check dams ranged from 1.6 cubic meters to 23.7 cubic meters and averaged 1 meter high. The rock tram was utilized to transport the rock 24 m from the staging area off the Pikes Peak Highway down into the gully (Figure 3 and 4). From there a team of 11 workers filled painters’ buckets with 40 to 50 pounds of rock and hand carried the material to the dam site (Figure 5 and 6).

Figure 3 and 4. Examples of unloading the bucket from the tram set up.

Figure 5 and 6. Examples of building the check dams.

Cross-section baseline measurements were recorded for each rock check dam after completion in 2006 and a second survey was completed in June of 2007 using a CST/berger LM700 Laser Level**.** Cross-sections were located 250 cm upstream from the check dams' center line and were delineated by rebar pins. Cross-section measurements will continue to be taken annually for the next two years to record changes in channel elevation and bank slope. Presence of the check dams should stabilize channel banks with the banks showing a gradual decline in the steepness of their slope. A gradual infilling of the channel behind the dam is also expected allowing vegetation to take root and further stabilize the channel.

Vegetation Prescriptions

In addition to the installation of the rock check dams, a variety of vegetation prescriptions were used to asses their ability to increase vegetation within the gully channel. Twelve monitoring plots (5 m x 3 m) were established; each upstream of a check dam to measure changes in the percentage of vegetation cover. Four plots were located in the upper portion of the gully, four in the middle, and four in the lower section. Each site within a section had one of the following four prescription(s) used:

- Seeding, soil amendment, erosion control matting, and bank shaping
- Seeding, soil amendment, and erosion control matting
- Seeding and soil amendment
- Seeding only

Breakdown of the plots was as follows:

	Plot treatment
Plot/Dam #	Closest to highway
Upper Section	
12	Seeding and soil amendment
11	Seeding, soil amendment, erosion control matting, and bank shaping
10	Seeding, soil amendment, and erosion control matting
9	Seeding only
Middle Section	
8	Seeding, soil amendment, and erosion control matting
7	Seeding only
6	Seeding, soil amendment, erosion control matting, and bank shaping
5	Seeding and soil amendment
Lower Section	
4	Seeding, soil amendment, erosion control matting, and bank shaping
3	Seeding only
2	Seeding and soil amendment
1	Seeding, soil amendment, and erosion control matting

Table 1. Plot Treatment Description

The seed mix used within each plot was comprised of the following:

Species/ Common Name/ PLS lbs-acre/ % of Seed Mix
Elymus Canadensis/ Canada Wildrye / 9.00 / 48.6
Festuca arizonica / Arizona Fescue/ 6.00/ 32.4
Trisetum spicatum/ Spike Trisetum / 3.00 / 16.2
Achillea millefolium/ Common Yarrow / 0.10 / 0.5
Chrysopsis villosa / Golden Aster/ 0.20/ 1.1
Penstemon virgatus/ Palmer's Penstemon / 0.20/ 1.1

The soil amendment used was commercially available Biosol. The erosion control matting applied consisted of certified 100% California Straw and Coir, with 2 natural biodegradable nets.

As Bonham (1989) states, measuring an increase in vegetation cover from monitoring plots is useful for monitoring plant responses to various vegetation treatments. To establish percent cover for the plot, six transects were randomly placed along the 3 m (300 cm) length of the side of the plot running parallel to the gully bank. A random number generator was used to choose the locations. Cover was then measured using the line intercept method as described by Elzinga et al., (1998). Samples from the six transects were aggregated and a percent cover for the entire plot was calculated. Each transect was also broken down into left bank, channel, and right bank and samples from the six transects were aggregated and a percent cover for the each subsection was calculated. A table was then developed to compare the different prescriptions used within each plot and to note any differences in vegetation responses to gully morphology. Two control plots were also established in a nearby gully to assess natural changes in vegetation cover and compare to the treated sites in the project gully.

RESULTS

Check Dam Analysis

Twelve loose rock check dams were successfully constructed in an erosion gully located in difficult terrain with limited access using a Rock Tram system and hand crews (Figure 7 and 8).


Figure 7 and 8. Examples of finished check dams.

This method proved to be an efficient means to transport large quantities of rock without the use of heavy machinery. As stated previously, the rock tram can transport .10 cubic meters (approximately 250 to 350 pounds) of rock in a large bucket or rock sling per trip. An average of 8 minutes was used loading, lowering, unloading, and pulling the bucket or sling back to the tram station. All twelve dams were completed within 10 days by an eleven person crew. Each dam required 69.5 person hours to construct at a cost of $1,628.

Table 2. Loose Rock Check Dam Cost Summary

Cost Summary for Installation of Loose Rock Check Dams	
Labor*	834 hrs x $18.75 ($15,637)
Equipment	$1,318
Materials	$2,576
Total cost	$19,531
Total cost each structure	69.5 hrs $1,628

*Labor cost per hour is based upon the volunteer rate as approved by the Colorado State Trails Program.

WinXSPRO v3.0 Channel Cross Section Analyzer software was utilized to quantify changes in gully morphology upstream of the dam sites (USDA, 2005). Initial evaluation of the cross-sectional area measurements found that 10 of the 12 dam sites had some deposition accruing behind the structure as intended. Two of the sites increased in cross-sectional area indicating continued erosion of the gully channel.

Table 3. Comparison of Cross-section Area Change Per Dam

Cross-section area change for dam sites

Dam	2006 Area (sq m)	2007 Area (sq m)	Difference (sq m)
1	1.82	1.57	-0.25
2	2.76	1.96	-0.80
3	1.51	1.21	-0.30
4	0.23	0.20	-0.03
5	0.59	0.49	-0.10
6	0.33	0.30	-0.03
7	1.86	1.62	-0.24
8	1.61	1.29	-0.32
9	1.32	2.67	1.35
10	2.37	2.26	-0.11
11	2.96	3.19	0.23
12	2.75	2.64	-0.11

Vegetation analysis

New vegetation growth within the plots was primarily Festuca arizonica (85% of plants observed), with limited plants of Elymus Canadensis and Trisetum spicatum present. The remaining three species were completely absent from all plots except for two plants each of Achillea millefolium and Chryopsis villosa found in plot #11.

Analysis of the vegetation plots showed an expected substantial increase in percent cover of vegetation within the gully channel after treatments were applied in 2006. Percent cover increased from 0% to an average of 37% for all plots combined. In comparison, the two control plots showed a combined increase in percent cover within the gully channel from 0% to 4% during the same time. Of the four treatments, the two that included applying seed, soil amendment, and erosion control matting had the greatest increase in percent cover in the gully channels increasing from 0% to 48% and from 0% to 42% for the treatment also including bank shaping. The application of seed only also proved to be successful if somewhat less so than the other treatments. Percent cover within the gully channel increased from 0% to an average of 27% for plots treated with seed. When looking at changes of cover for the left and right banks, only the treatment consisting of applying seed, soil amendment, erosion control matting, and bank shaping had an increase in percent cover for both banks. All other treatments showed a decrease in percent cover for either the left bank or right bank and an increase in cover for the opposite bank.

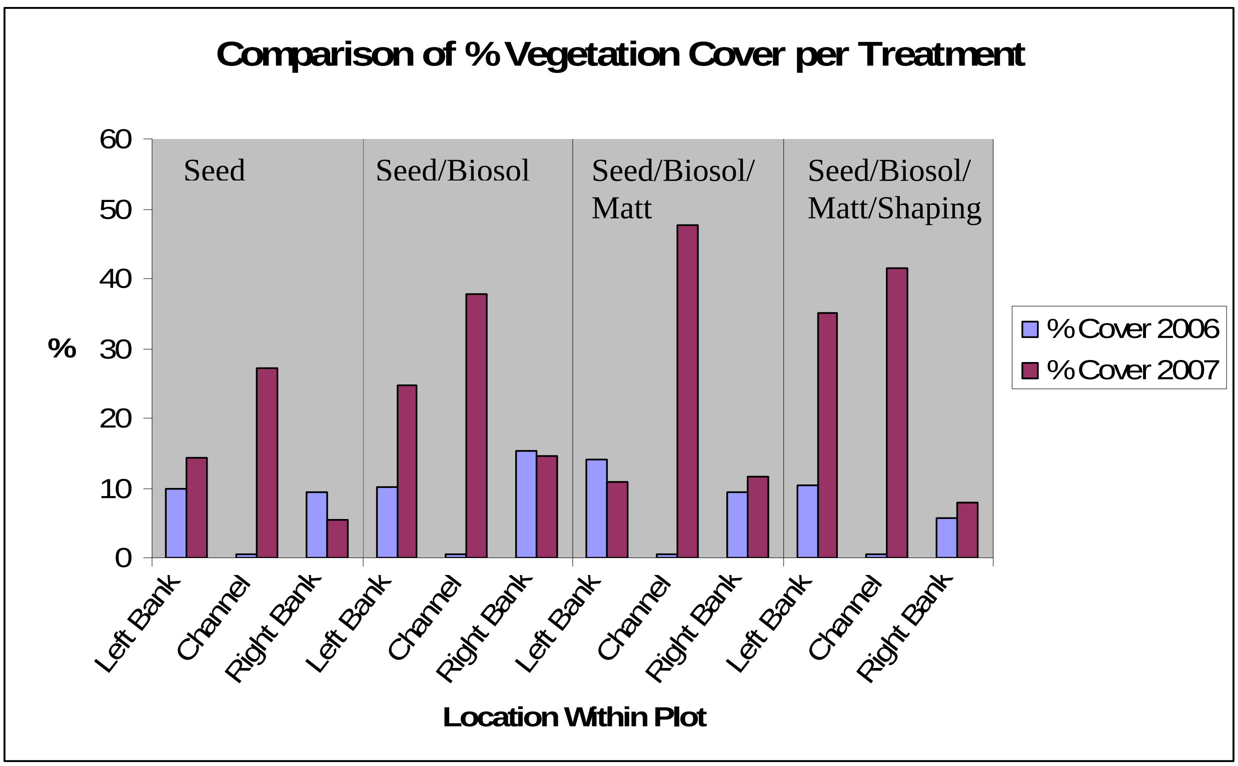

Figure 9. Comparison of % Vegetation Cover by Treatment Type and Gully Morphology.

CONCLUSION

This project has shown that rock check dams can be successfully installed in hard to reach, limited access areas off of mountain roads using a Rock Tram system. While labor intensive to apply, these costs can be substantially reduced through the use of volunteers or Youth Corps teams to complete construction. In gullies disconnected from stormwater discharge, vegetation can quickly be established within the gully channel to help further stabilize soils and reduce erosion. Monitoring of the channel morphology and vegetation growth will continue for the next two years to better quantify initial results presented here.

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ESTABLISHING NATIVE PLANTS ON ABANDONED FARMLAND

Cynthia S. Brown[1], Claire DeLeo[2], Richard Lancaster[1]

[1] Bioagricultural Sciences and Pest Management
1177 Campus Delivery
Colorado State University
Fort Collins, CO 80523-1177

[2] Boulder County Parks and Open Space
5201 St. Vrain Road
Longmont, CO 80503

ABSTRACT

Many land managers are faced with the challenge of establishing diverse, stable, native plant communities on former agricultural lands, and there is a growing need for methods that effectively accomplish this goal. We (1) evaluated the abundance of native species planted in different proportions and compositions during the first two years after seeding; and (2) examined factors associated with establishment and growth of seeded species including non-seeded species cover, soil nitrogen (N) and carbon (C) levels, and light availability. Non-seeded species, which included native and non-native species, had much greater cover than seeded species in both years. Slender wheatgrass and western wheatgrass were the most abundant seeded grasses; fourwing saltbush was the most abundant seeded broadleaf species. Very few seeded forbs were observed, regardless of their representation in the seed mixtures. Generally, the cover of the most abundant seeded grasses and forbs reflected the proportion seeded in the first year, but this pattern weakened over time. After two years, cover of seeded species decreased with increasing non-seeded species cover, suggesting negative competitive effects. Cover of non-seeded species was negatively correlated with soil percent C, while cover of seeded species was positively correlated with this variable. The cover of non-seeded and seeded species and their performance in seeding mixtures varied across the study area. Species richness, and cover of bareground and non-seeded species decreased as light interception by the plant canopy and cover of litter and seeded species increased over time, documenting the successional development of the plant community.

INTRODUCTION

Colorado grasslands have been heavily impacted by agriculture. Re-establishing stable, productive and invasion resistant plant communities on lands that were once farmed is a huge challenge. It is possible to restore native, perennial vegetation to disturbed areas in arid regions (Bugg et al., 1997; Brown and Bugg, 2001), but many questions remain about which approaches are most effective. The establishment of native shrubs from seed can prove to be especially difficult and the ideal proportion of grasses, forbs and shrubs to include in seed mixtures for optimal establishment of diverse plant communities is not well known. In the work presented here, we evaluated techniques for establishing diverse, stable native plant communities on former agricultural lands.

Weedy and invasive plants are a common cause of failure of restoration seedings (Wilson et al. 2004). These plants compete with seeded species for nutrients, water and light, which can reduce their survival and growth. Areas that have been cultivated are often high in resources due to historical fertilization and removal of vegetation, conditions that favor growth of weedy species (D'Antonio and Meyerson 2002). Early successional species flourish after resource-releasing disturbance (Burke and Grime, 19965; Huenneke et al., 1990), whereas perennial species are often less able to convert available nutrients into biomass as quickly due to slower growth rates (e.g. Claassen and Marler, 1998). However, shade from non-seeded species may reduce water stress of newly established seedlings in arid environments, thus, increasing survival. Despite this, as time goes on, the net effect of weedy species on seeded species is likely to be negative.

We quantified the abundance of native species planted in different proportions and compositions during the first and second years after seeding, and evaluated factors associated with success and failure of native plant establishment including abundance and identity of non-seeded plant species, soil nitrogen (N) and carbon (C) and light availability.

We tested the following hypotheses: (1) Abundance of seeded grasses, herbaceous forbs and shrubs will reflect their proportions in the seed mixtures. Alternatively, the abundance of seeded species may differ from their proportional representation in the seed mixtures; (2) Success of seeded species will be positively associated with (a) reduced non-seeded species abundance, (b) lower soil N and greater soil C (i.e. conditions that will not favor fast-growing, weedy species) and (c) reduced light availability, which may reduce water stress. Alternatively, success of seeded species may be unrelated to these factors or show a different relationship than we expect.

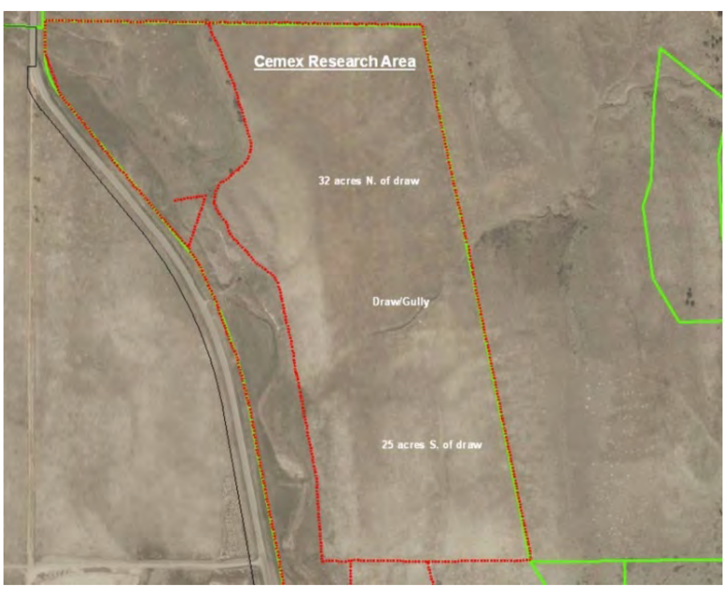

Figure 1. The CEMEX Research Site is located south of the Boulder County Parks and Open Space Rabbit Mountain Open Space parking area, and east of the county road. It is outlined in red.

METHODS

Study Site

The experimental plots are located in the CEMEX Research Site shown in Figure 1.
The site was planted with milo or grain sorghum (*Sorghum bicolor*) the year prior to initiation of the experiment.

Experimental Design

The experiment is a complete randomized block design with four seed mixture treatments (Figure 2). Seeding rates and composition were recommended by Boulder County Parks and Open Space (BCPOS) (Claire DeLeo personal communication) and the mixtures were seeded 1 – 3 February 2006 by BCPOS personnel using a Truax FLX816 seed drill (10.5 ft wide with 16 rows, 8 inches apart) (Truax, Inc., New Hope, Minnesota).

Seed Mixtures

The total seeding density was 50 kg pure live seed/ha for each of the four seed mixtures. The proportions of grass species remained constant with respect to each other in all four mixtures. The forb and shrub species also were included in constant proportion with respect to each other. However, the relative proportion of grasses to forbs and shrubs varied among the mixtures. Mix 1 included half grasses and half forbs and shrubs. Mix 2 included 75% grasses and 25% forbs and shrubs. Mix 3 included 66% grasses and 33% forbs and shrubs. Mix 4 included only grasses. The grasses included in each of the seed mixes were side oats grama (*Bouteloua curtipendula*), blue grama (*Bouteloua gracilis*), buffalo grass (*Buchloe dactyloides*), slender wheatgrass (*Elymus trachycaulus*), prairie junegrass (*Koeleria macrantha*), western wheatgrass (*Pascopyrum smithii*) (1 cultivar, 1 native), Indian ricegrass (*Oryzopsis hymenoides*), little bluestem (*Schizachyrium scoparium*), and green needlegrass (*Stipa viridula*). The shrub species included in the mixes were prairie sage (*Artemisia lucoviciana*), fringed sage (*Artemisia frigida*), fourwing saltbush (*Atriplex canescens*), and rubber rabbitbrush (*Chrysothamnus nauseosus*). The herbaceous forb species included in the mixes were purple prairie clover (*Dalea purpurea*), blanketflower (*Gaillardia aristata*), yellow coneflower (*Ratibida columnifera*), and globemallow (*Sphaeralcea spp*).

Sampling Methods

Seeded and non-seeded plant abundance

We established four sampling plots within each treatment plot. Each sampling plot was 6 m x 6 m and located in the center of the 12 m wide treatment plot (Figure 2). Corners of the sampling plots were marked with rebar wrapped in brightly colored flagging tape to facilitate relocation. The corners were marked with colored flags prior to field operations to avoid damaging equipment and shins. The sampling plots at either end of the treatment plots were at least 30 m from the treatment plot end. The remaining two sampling areas were located equidistant from each other and the two end sampling plots. This plot placement ensured that we sampled the variation present throughout the treatment plots.

Four 0.5 m^2 sampling subplots were located within each sampling plot, one at each corner of the plot (Figure 3), and the mean of these was used in the statistical analysis. One corner of each subplot corresponded with the corner of the sampling plot, thus, were marked with rebar. These subplot locations will be re-sampled over time. We counted the individual seedlings of seeded species and estimated the percent aerial cover of all species occurring in each 0.5 m^2 subplot. Presence of species within the 36 m^2 plots that did not occur within the 0.5 m^2 subplots was recorded in order to assess diversity at the larger scale. Correct identification of seedlings of seeded species was facilitated by examining seedlings grown in pots in the greenhouse at Colorado State University (CSU) and in the monocultures.

Sampling was done 19 July through 1 August 2006 and was repeated 6 July through 23 July 2007 for Blocks I - V, and 12 and 13 August 2007 for Block VI.

Soil N and C

Between 7 and 18 July 2006 one soil sample 0 – 15 cm deep and 2 cm in diameter was collected at the four corners of each sampling plot, as indicated by the red circles in Figure 3, and the samples from each sampling plot were pooled. Total soil C and N were determined for each sample using the LECO CHN1000 (LECO Corporation, St. Joseph, MI, USA) in the Natural Resources Ecology Laboratory facility at CSU.

Light interception

The reduction of light availability at the soil surface by plant canopy was measured using a light ceptometer (AccuPar LP-80, Decagon Devices, Inc., Pullman, WA, USA) 13 and 17 July 2006 and again 11 through 15 July 2007. One measurement was made in the middle of each 0.5 m^2 subplot, as indicated in Figure 3, and the mean of the four measurements was used as plot level light interception.

Species richness

The number of species present in each 6 m by 6 m plot was counted.

Statistical Analysis

Abundances of seeded and non-seeded plants, cover of litter and bare ground, and percent C and N were analyzed using analysis of variance models (SAS version 9.1 and JMP version 5.0.5.1, SAS Institute, Inc., Cary, NC) that included block, seed mixture and their interaction. For 2006 data, when raw data were ill-conditioned, results of analyses on raw data were similar to those of log transformed data, thus, results from analysis of the former are reported. The same was true for 2007 data with the following exceptions. Seeded species data were ln + 1 transformed, and fourwing saltbush data were ln + 0.1 transformed for analyses.

Simple linear regression was used to evaluate the performance of seeded species with respect to abundance of species that were not seeded (non-seeded species), cover of litter (log transformed for 2006 data) and bare ground, light interception (log transformed for 2006 data), and soil C and N. Student's t or Tukey's least significant differences were employed for mean separations. Statistical significance was set at $\alpha = 0.05$.

Figure 2. Experimental design and layout.

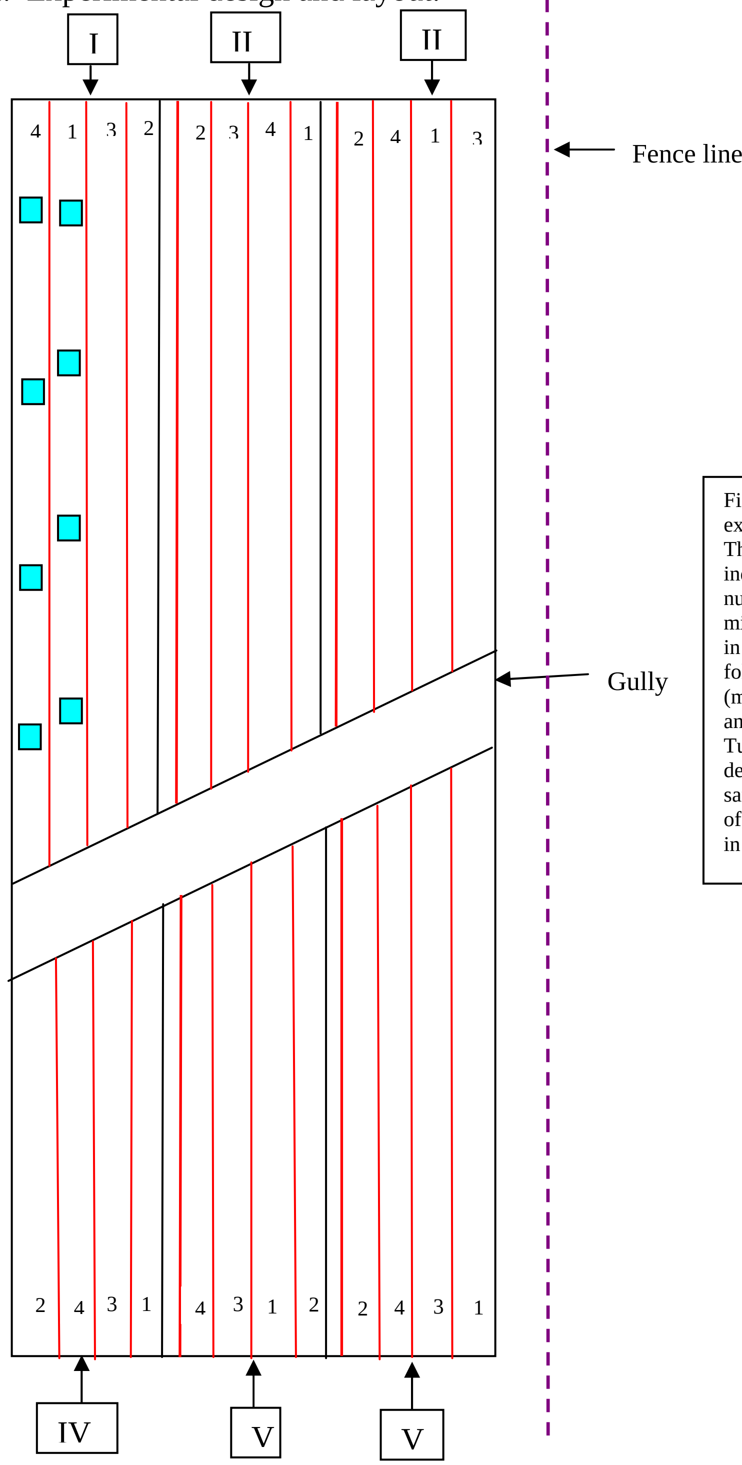

Figure 2. Diagram of experimental layout. The six blocks are indicated by roman numerals. Seed mixtures are planted in 12 m wide strips as follows: 1 (mix 1), 2 (mix 2), 3 (mix 3), and 4 (grasses only). Turquoise squares denote 6 m x 6 m sampling areas, four of which are included in each treatment plot.

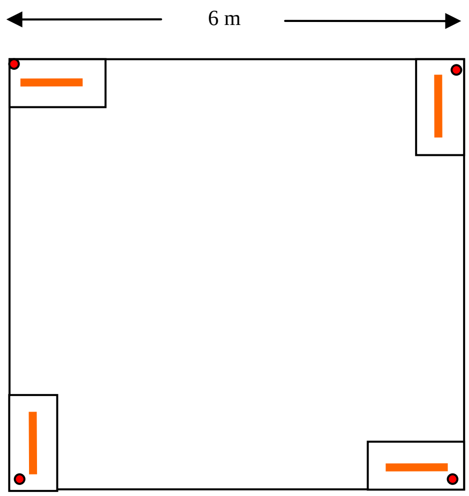

Figure 3. Sampling area layout. 0.5 m^2 subplots (0.5 x 1.0 m) were placed at the corners of the 6 m x 6 m plots. Soil samples were taken at the locations indicated by the red circles for total N and C measurements. Light interception was measured in the center of each 0.5 m^2 subplot, as indicated by the orange bar. Plant species were monitored within the 36 m^2 area.

RESULTS

Seeded Species

Species encountered during sampling and abbreviations for their names used throughout the following figures are listed in Table 1. The cover of seeded species (Figure 4) was highly correlated with density of seeded species (Figure 5) in 2006 and 2007 ($P < 0.0001$, $R^2 = 0.81$ and $P < 0.0001$, $R^2 = 0.73$, respectively), thus, only analyses of cover are presented. Cover of seeded species was much lower than non-seeded species in both years, and doubled in 2007 (Figure 6). There was no correlation between the abundance of seeded and non-seeded species in 2006 ($P = 0.59$, $R^2 = 0.003$), and a negative correlation in 2007 ($P < 0.0001$, $R^2 = 0.45$, coefficient = -0.28). There was a tendency for cover of seeded species to be lower in plots with high litter in 2006 (Figure 6a, $P = 0.08$, $R^2 = 0.03$)), a relationship that became stronger in 2007 (Figure 6b, $P = 0.01$, $R^2 = 0.07$). There was no relationship between cover of seeded species and bare ground in 2006 (Figure 6a, $P = 0.10$, $R^2 = 0.03$), and a negative relationship in 2007 (Figure 6b, $P = 0.0002$, $R^2 = 0.14$).

Table 1. Species names and abbreviations. Non-seeded species in bold are native to Colorado.

Common name	Variety	Scientific Name	Code
Seeded Species			
Fringed sage		*Artemisia frigida*	ARTFRI
Prairie sage		*Artemisia ludoviciana*	ARTLUD
Fourwing saltbush		*Atriplex canescens*	ATRCAN
Sideoats grama	"Vaughn"	*Bouteloua curtipendula*	BOUCUR
Blue grama	Native	*Bouteloua gracilis*	BOUGRA
Buffalograss	"Texoka"	*Buchloe dactyloides*	BUCDAC
Rubber rabbitbrush		*Chrysothamnus nauseosus*	CHRNAU
Purple prairie clover, Kanab		*Dalea purpurea*	DALPUR
Slender wheatgrass	"San Luis"	*Elymus trachycaulus*	ELYTRA
Blanketflower		*Gaillardia aristata*	GAIARS
Junegrass	Native	*Koeleria macrantha*	KOEMAC
Indian ricegrass	"Rimrock"	*Oryzopsis hymenoides*	ORYHYM
Western wheatgrass	"Arriba"	*Pascopyrum smithii*	PASSMA

Western wheatgrass	“Native”	*Pascopyrum smithii*	PASSMN
Yellow coneflower		*Ratibida columnifera*	RATCOL
Little bluestem	"Camper"	*Schizachyrium scoparium*	SCHSCO
Globemallow		*Sphaeralcea spp*	SPHSP
Green needlegrass	"Lodorm"	*Stipa viridula*	STIVIR
Non-seeded Species			
prostrate pigweed		*Amaranthus blitoides*	AMABLI
redroot pigweed		*Amarathus retroflexus*	AMARET
prickly poppy		***Argemone polyanthemos***	**ARGPOL**
wild oat		*Avena fatua*	AVAFAT
field brome		*Bromus arvensis*	BROARV
cheatgrass		*Bromus tectorum*	BROTEC
littlepod false flax		*Camelina microcarpa*	CAMMIC
musk thistle		*Carduus nutans*	CARNUT
prostrate or spotted spurge		*Chamaesyce maculata*	CHAMAC
creeping spurge		*Chamaesyce serpens*	CHASER
common lambsquarters		*Chenopodium album*	CHEALB
		Chenopodium berlandieri	CHEBER
		Chenopodium sp1	CHESP1
Canada thistle		*Cirsium arvense*	CIRARV
poison hemlock		*Conium maculatum*	CONMAC
hare's ear mustard		*Conringia orientalis*	CONORI
field bindweed		*Convolvulus arvensis*	CONARV
hounds tongue		*Cynoglossum officinale*	CYNOFF
flixweed		*Descurainia sophia*	DEXSOP
toothed spurge		*Euphorbia dentata*	POIDEN
snow-on-the-mountain		***Euphorbia marginata***	**EUPMAR**
beeblossom		***Gaura L.***	**GAU**
annual sunflower		***Helianthus annuus***	**HELANN**
foxtail barley		*Hordeum jubatum*	HORJUB
kochia		*Kochia scoparia*	KOCSCO
prickly lettuce		*Lactuca serriola*	LACSER
western sticktight		***Lappula occidentalis***	**LAPOCC**
pineappleweed		*Matricaria matricarioides*	MATMAT
alfalfa		*Medicago sativa*	MEDSAT
		Nutalia nuda	NUTNUD
witchgrass		*Panicium capillare*	PANCAP
Virginia ground cherry		*Physalis virginiana*	PHYVIR
devils shoe string		*Polygonum arenastrum*	POLARE
wild buckwheat		*Polygonum convolvulus*	POLCON
		Polygonum ramosissimum	POLRAM
slimflower scurf pea		***Psoralidium tenuiflorum***	**PSOTEN**
wild rose		***Rosa* sp.**	**ROSMUL**
Russian thistle		*Salsola iberica*	SALIBE
lanceleaf sage		***Salvia reflexa***	**SALREF**
butterweed, golden ragwort		*Senecio sp.1*	SENSP1
tumble mustard		*Sisymbrium altissimum*	SISALT
buffalobur		*Solanum rostratum*	SOLROS
cut-leaved		*Solanum triflorum*	SOLTRI

nightshade		
spiny sowthistle	*Sonchus asper*	SONASP
sand drop seed	***Sporobolus cryptandrus***	**SPOCRI**
white heath aster	***Symphyotrichum ericoides***	**SYMERI**
salsify sp	*Tragopogon sp1*	TRASP1
salsify sp	*Tragopogon sp2*	TRASP2
cow cockle	*Vaccaria pyramidata*	VACPYR
common mullein	*Verbascum thapsus*	VERTHA
prostrate vervain	***Verbena bracheata***	**VERBRA**
crownbeard, crow pen daisy	***Ximenesia encelioides***	**XIMENC**

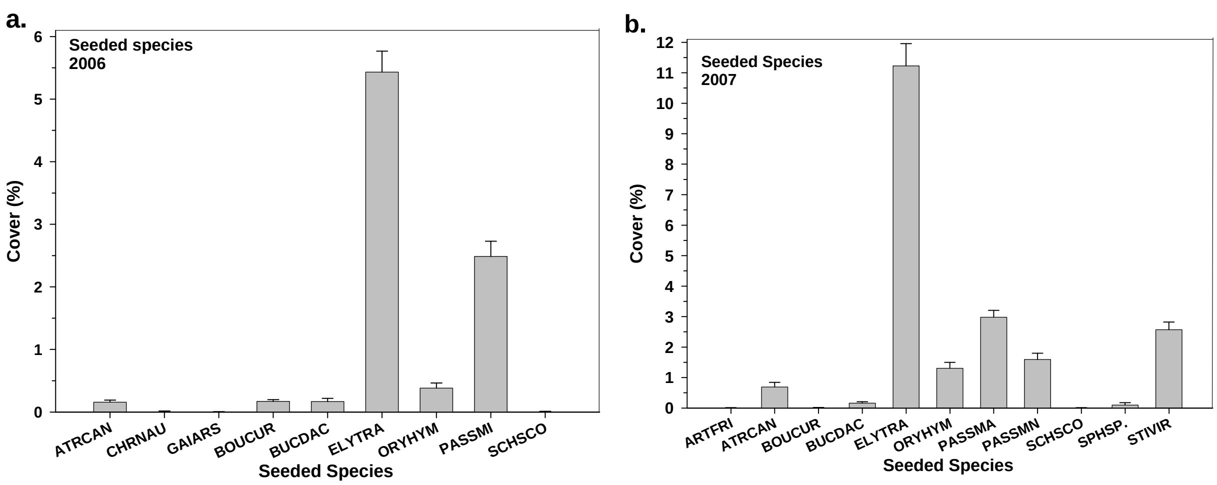

Figure 4. Mean cover of seeded species (± one standard error of the mean) for (a) 2006 and (b) 2007. Species are fourwing saltbush (*Atriplex canescens,* ATRCAN), fringed sage (*Artemisia frigid*, ARTFRI), sideoats grama (*Bouteloua curtipendula*, BOUCUR), buffalo grass (*Buchloe dactyloides*, BUCDAC), slender wheatgrass (*Elymus trachycaulus*, ELYTRA), indian ricegrass (*Oryzopsis hymenoides*, ORYHYM), western wheatgrass “Arriba” (*Pascopyrum smitthii* Arriba”, PASSMA), western wheatgrass “native” (*P. smithii* “Native”, PASSMN), scarlet globemallow (*Sphaeralcea coccinea*, SPHCOC) and green needlegrass (*Stipa viridula*, STIVIR). Globemallow and green needlegrass were present in 2007, but not 2006, while blanket flower was present in 2006, but not 2007. In 2006, we were unable to distinguish between the two western wheatgrass accessions, thus these species were combined into PASSMI. Bars are mean ± one standard error of the mean. *Note*: All 96 plots were included in these mean calculations.

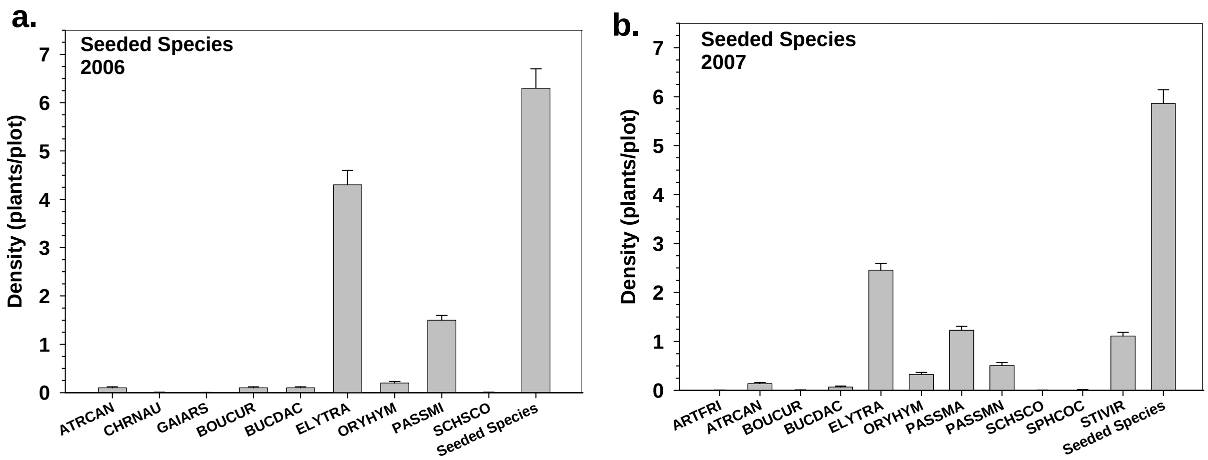

Figure 5. Mean density of seeded species (± one standard error of the mean) for (a) 2006 and (b) 2007. Species are fourwing saltbush (*Atriplex canescens*, ATRCAN), fringed sage (*Artemisia frigid,* ARTFRI), sideoats grama (*Bouteloua curtipendula*, BOUCUR), buffalo grass (*Buchloe dactyloides*, BUCDAC), slender wheatgrass (*Elymus trachycaulus*, ELYTRA), indian ricegrass (*Oryzopsis hymenoides*, ORYHYM), western wheatgrass "Arriba" (*Pascopyrum smitthia* "Arriba", PASSMA), western wheatgrass "native" (*P. smithii* "Native", PASSMN), scarlet globemallow (*Sphaeralcea coccinea*, SPHCOC) and green needlegrass (*Stipa viridula*, STIVIR). Scarlet globemallow green needlegrass were present in 2007, but not 2006, while blanket flower was present in 2006, but not 2007. In 2006, we were unable to distinguish between the two western wheatgrass accessions, thus we combined both into PASSMI. Bars are mean ± one standard error of the mean. *Note*: All 96 plots were included in these mean calculations.

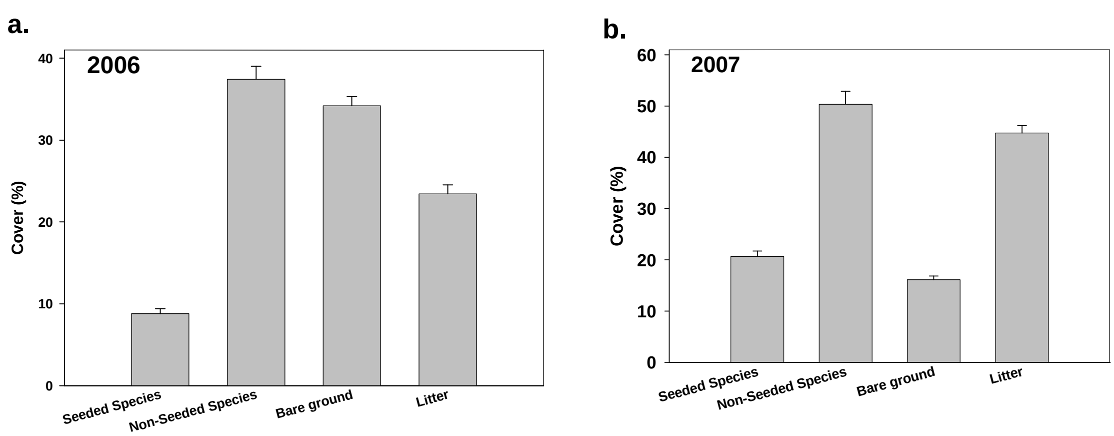

Figure 6. Mean cover of seeded species, non-seeded species, litter and bare ground in (a) 2006 and (b) 2007. Bars are mean ± one standard error of the mean. *Note*: All 96 plots were included in these mean calculations.

In 2006 and 2007 the cover of seeded species in each of the seed mixture treatments depended on location in the field (significant Block x Seed Mixture interaction, Table 2, Figure 7). In 2006, seeded species in Mix 1 (50% grass) had higher cover than other seed mixtures in Block V, but had much lower cover than other mixtures in Blocks I, II, III and VI. Low cover in Blocks I and II can be attributed to seeder malfunction. Cover of seeded species in each of the seed mixtures also depended on field location in 2007 (Table 2b, Figure 8a). Plots from Blocks I and II, Mix 1 were not included in the analyses because the grass box of the seeder malfunctioned when they were being planted.

Table 2a. ANOVA table for seeded species in 2006 (α=0.05). *Note:* Data were not transformed prior to analysis.

Factor	df	Seeded species		BOUCUR		BUCDAC		ELYTRA		ORYHYM		PASSMI	
		F	*P*	F	*P*	F	*P*	F	*P*	F	*P*	F	*P*
Block	5	5.9	0.0001	4.4	0.001	3.2	0.01	2.85	0.02	1.37	0.24	5.63	0.0002
Seed Mixture	3	19.5	<0.0001	0.37	0.78	4.15	0.009	17.42	<0.0001	0.88	0.46	12.98	<0.0001
Block x Seed Mixture	15	4.4	<0.0001	1.60	0.10	1.76	0.06	3.41	0.0002	0.86	0.60	2.34	0.009

Table 2b. ANOVA table for seeded species in 2007 (α=0.05). *Note:* Data were natural log + 1 transformed prior to analysis.

Factor	df	Seeded species		BUCDAC		ELYTRA		ORYHYM		PASSMA		PASSMN		STIVIR	
		F	*P*	F	*P*	F	*P*	F	*P*	F	*P*	F	*P*	F	*P*
Block	5	8.79	<0.0001	6.89	0.0004	10.21	<0.0001	1.61	0.20	1.73	0.17	1.77	0.16	3.59	0.02
Seed Mix	3	0.11	0.89	0.12	0.89	0.42	0.66	1.93	0.15	0.23	0.80	1.14	0.32	0.90	0.41
Block x Seed Mix	15	2.79	0.003	1.26	0.26	1.92	0.04	1.45	0.16	1.68	0.08	1.26	0.26	2.45	0.009

Seven of the ten grass species planted were observed at least once in 2006, and nine in 2007. The grasses comprised the majority of the seeded species cover (Figure 4a and b). In 2006, cover of the most successful seeded grasses (slender wheatgrass and western wheatgrass) in each of the seed mixture treatments depended on location (Table 2, Figure 7b and c). In Mix 2 (75% grass) and Mix 4 (100% grass) they had lower cover when located in Blocks IV and V than when located in Blocks II and III. These species had very low cover in Mix 1 when located in Blocks I and II, which can be attributed to mechanical malfunction of the seeder that resulted in lower grass seeding rates in Blocks I, II, and 10 feet of Block III, but their cover in this mixture was similar in Blocks III, IV, V and VI. In 2007, performance of slender wheatgrass and green needlegrass in each of the seed mixture treatments depended on field location (Table 2b, Figure 8b and c).

Averaging across seed mixture treatments, cover of sideoats grama and buffalograss were affected by location (i.e. significant Block effect) in 2006 (Table 2a, Figure 9a). Sideoats grama had greater cover in Block VI than other blocks, while buffalo grass had greater cover in Block II than other blocks. In 2007, only buffalo grass cover was related to field location (Table 2b, Figure 10a). Its cover was greater in Block VI than Blocks III, IV and V, which were greater than Blocks I and II, the latter having the lowest cover of all. Sideoats grama occurred in only one plot in 2007. In 2006, cover of buffalo grass in Mix 4 (100% grass) was similar to Mix 3 (66% grass) and greater than Mixes 1 (50% grass) and 2 (75% grass) (Table 2a, Figure 11).

Indian ricegrass occurred in 40 subplots in 2006 and 102 subplots in 2007, but no relationship between location (i.e. Block) and seed mixture treatment could be detected in either year (Table 2a and b). Western wheatgrass "Arriba" and "Native" occurred in 250 and 129 sub-plots, respectively, in 2007, but no relationship between location and seed mixture treatment could be detected (Table 2b). Little bluestem was observed in only three plots in 2006 and one plot in 2007, thus effects of location and seed mixture treatments are not biologically meaningful.

Two of the four shrub species and one of the four forb species were observed in 2006 (Figure 4a). In that year, fourwing saltbush was present in 28 plots, while rubber rabbitbrush and blanketflower were present in only one plot each. Blanket flower was not present in 2007, but globemallow was detected for the first time. No meaningful statistical analyses could be conducted on the latter three species due to low frequency. In 2006, cover of fourwing saltbush was greater in Blocks II and III than the other blocks (Figure 10a). It was not seeded in Mix 4 (100% grass), thus, its cover was greater in the three seed mixtures in which it was included in 2006 (Figure 11). In 2007, the pattern was less clear in that Mix 3 (66% grass) and Mix 2 (75% grass) had greater cover of fourwing saltbush than Mix 4 (100% grass) (Figure 12). Cover of fourwing saltbush in Mix 1 (50% grass) was probably not different from Mix 2 and Mix 3, but mean separation tests were not estimable due to missing data for this treatment in Block I.

Non-Seeded Species

Twenty nine non-seeded species were found in the sampling plots in 2006 (Table 1, Figure 13), and 21 non-seeded species were found in 2007 (Table 1, Figure 14). Cover of non-seeded species differed among locations (Blocks), but not among seed mixture treatments in 2006 (Table 3a, Figure 9b). Block III had greater non-seeded species cover than any other block. Non-seeded cover in Block IV was lower than Block I and V, but not different from Blocks II and VI. In 2007, the cover of non-seeded species in different blocks depended on seed mix (significant Block x Seed Mixture interaction, Table 3b, Figure 15a). Cover of non-seeded species appeared to be greatest for Mixes 2, 3 and 4 in Block VI. Mix 1 had greater cover of non-seeded species than the other seed mixture treatments only in Block V.

Twelve of the non-seeded species were native (Table 1), but occurred in such small amounts that we were not able to statistically analyze their abundances. Four non-seeded species had average cover greater than one percent in 2006 and six species in 2007; analyses will focus on them (Figure 13a, 14a). Field bindweed was the most abundant non-seeded species in 2006 and 2007. Cover of field bindweed in 2006 was greater in Block I and III than any other blocks and greater in Block II than Blocks IV, V and VI (Table 3a, Figure 16). Cover of field bindweed in blocks depended on seed mixture treatment (i.e. significant Block x Seed Mixture interaction, Table 3b, Figure 15b) in 2007. Russian thistle was an abundant non-seeded species in both 2006 and 2007. The cover of Russian thistle was greater in Blocks V and VI than any other blocks and was similar in Blocks II and IV in 2006 (Table 3a). Blocks I and III had Russian thistle cover similar to Block II, but less than Block IV (Table 3a, Figure 16). In 2007 its cover in blocks depended on seed mixture treatment (i.e. significant Block x Seed Mixture interaction, Table 3b, Figure 15c).

Kochia had cover of less than 1% in 2006 (Figure 13b) and it was detected in only 13 of the 96 plots, although it dominated the vegetation in parts of the field. In 2007, it was detected in 63 plots and its cover was just over 1% (Figure 14a). Its cover did not differ among blocks or seed mixture treatments this year (Table 3b). Prickly lettuce occurred in both years, but had cover greater than 1% only in 2007 (Figure 14a). In that year, its cover depended on location (i.e. Block) (Table 3b, Figure 17a) and was lowest in Block VI. Its cover was also affected by seed mixture treatment (Table 3b) and it was more abundant in Mix 3 than Mix 4 (Figure 18).

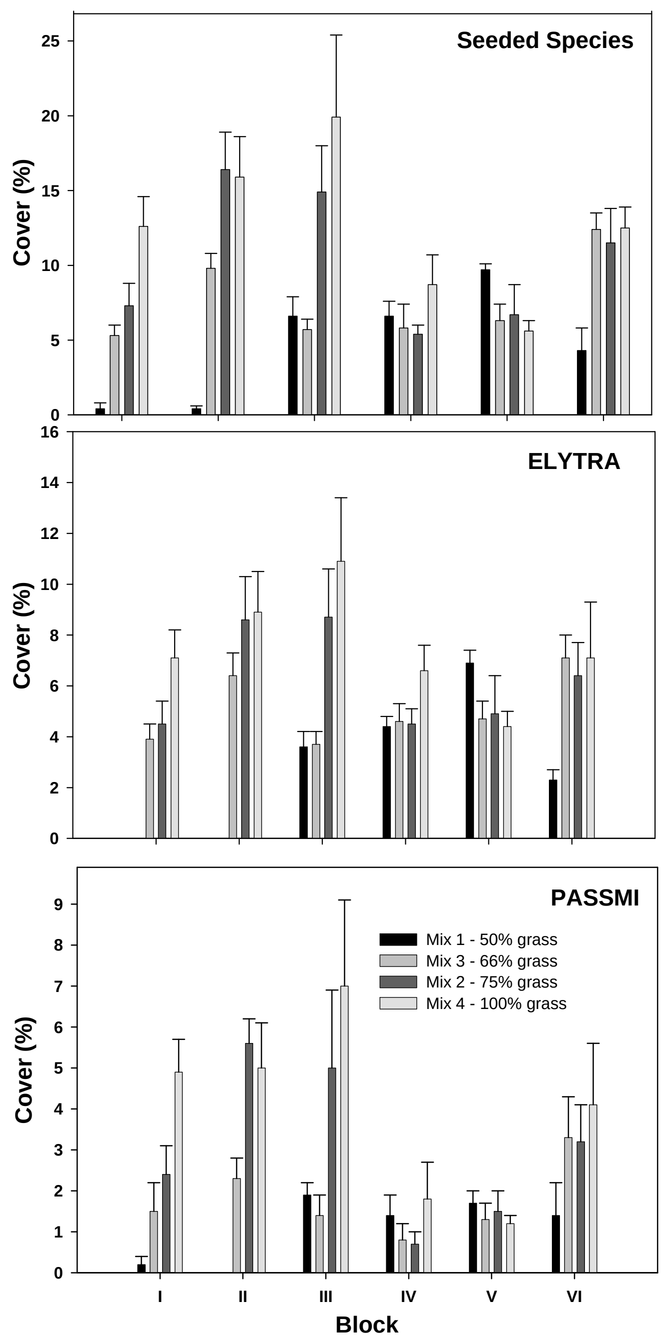

Figure 7**.** Cover of seeded species with significant Block x Seed Mixture interaction in ANOVA in 2006: (a) all seeded species, (b) *Elymus trachycaulus* (ELYTRA), and (c) *Pascopyrum smithii* (PASSMI) (bars are mean ± one standard error of the mean). *Note:* Block I and II, Seed Mix 1 were omitted due to seeder malfunction.

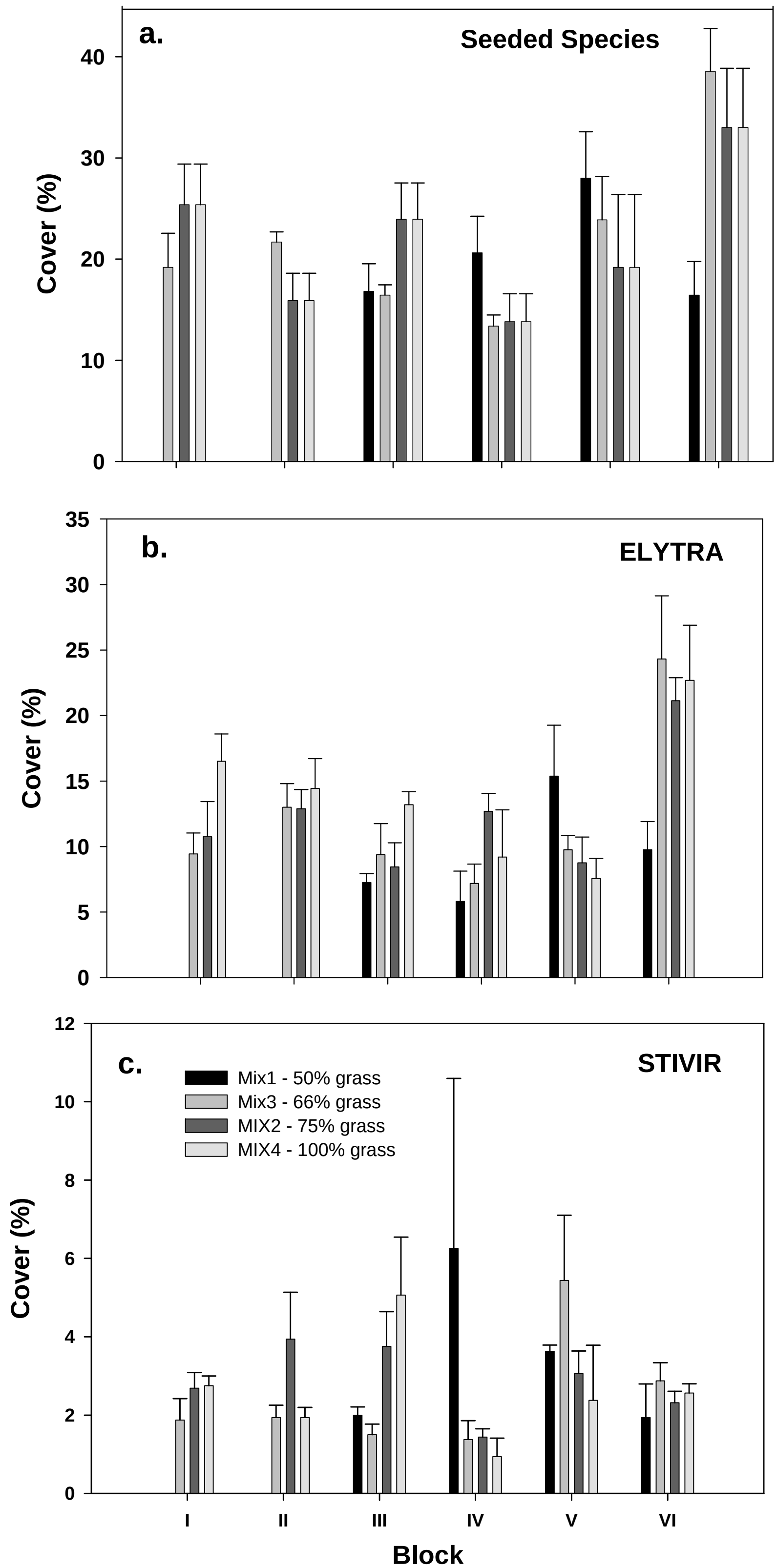

Figure 8. Cover of seeded species with significant Block x Seed Mixture interaction in ANOVA in 2007: (a) all seeded species, (b) *Elymus trachycaulus* (ELYTRA), and (c) *Stipa viridula* (STIVIR) (bars are mean ± one standard error of the mean). *Note:* Block I and II, Mix 1 were omitted due to seeder malfunction.

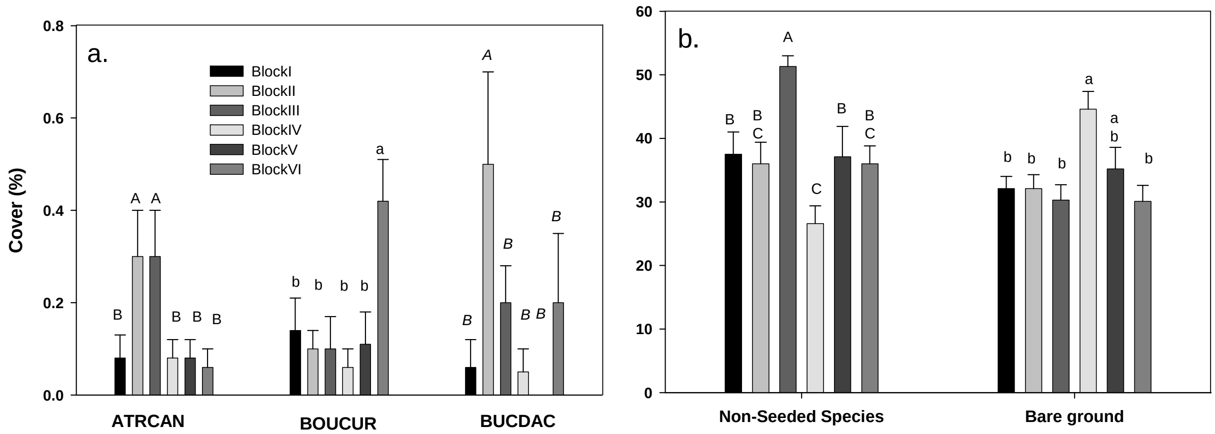

Figure 9. Cover of (a) seeded species and (b) non-seeded species and other factors with significant Block effects in ANOVA in 2006 (bars are mean ± one standard error of the mean). Means with different letters are significantly different at α = 0.05.

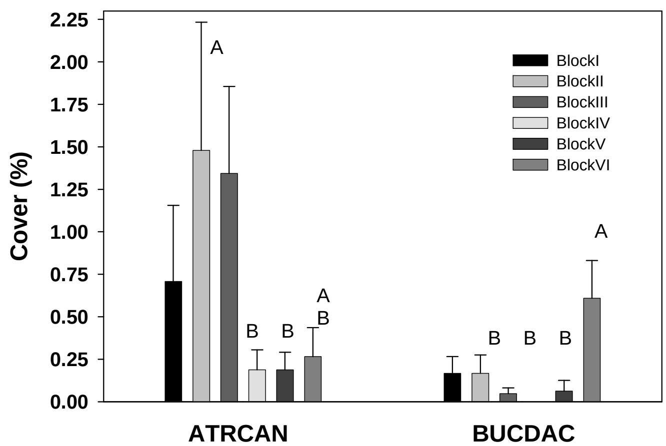

Figure 10. Cover of seeded species by block in 2007(bars are mean ± one standard error of the mean). Means with different letters are significantly different at α = 0.05.

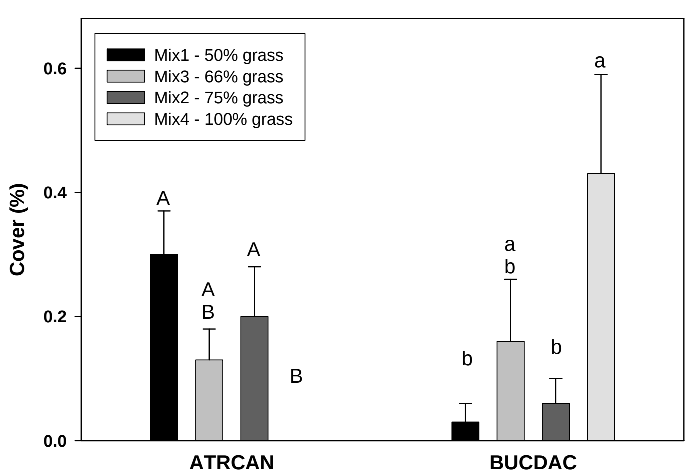

Figure 11. Cover of seeded species with significant seed mixture effects in ANOVA in 2006 (bars are mean ± one standard error of the mean). Means with different letters are significantly different at α = 0.05.

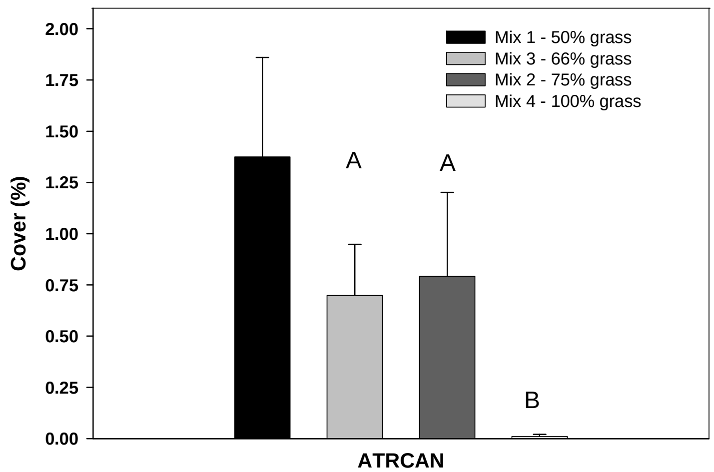

Figure 12. Cover of fourwing saltbush, the only seeded species with significant seed mixture effects in ANOVA in 2007. Means with different letters are significantly different at α = 0.05. Mean separation was not estimable for Seed Mixture 1 due to missing data.

Table 3a. ANOVA table for most abundant non-seeded species in 2006 (α=0.05).

Factor	df	Non-Seeded		CHESP1		CONARV		SALIBE		SOLTRI	
		F	*P*	F	*P*	F	*P*	F	*P*	F	*P*
Block	5	4.93	0.0006	14.76	<0.0001	24.11	<0.0001	10.99	<0.0001	5.76	0.0002
Seed Mixture	3	1.78	0.16	1.34	0.27	2.37	0.08	1.41	0.25	1.43	0.24
Block x Seed Mixture	15	0.69	0.78	2.04	0.02	1.08	0.039	0.39	0.98	0.91	0.56

Table 3b. ANOVA table for most abundant non-seeded species in 2007 (α=0.05).

Factor	df	Non-Seeded		CONARV		CONORI		LACSER		KOCSCO		SALIBE		SISALT	
		F	*P*	F	*P*	F	*P*	F	*P*	F	*P*	F	*P*	F	*P*
Block	5	0.93	0.43	11.47	<0.0001	0.84	0.48	5.06	0.003	1.04	0.38	14.48	<0.0001	3.51	0.02
Seed Mixture	3	15.12	<0.0001	0.97	0.38	0.68	0.51	5.64	0.005	1.37	0.26	4.08	0.02	2.19	0.12
Block x Seed Mixture	15	3.67	0.0002	2.71	0.004	0.87	0.59	1.17	0.32	1.71	0.08	6.32	<0.0001	1.01	0.45

Some non-seeded species were detected only in 2006. The cover of *Chenopodium* sp. in different seed mixture treatments depended on location (i.e. Block) that year (Table 3, Figure 19). The cover of this species in Block III was greater than in any other block and it was concentrated on the east side of the block. The cover of cut-leaved nightshade, which also only occurred in 2006, increased progressively from Block I to Block VI (Table 3, Figure 16).

Some non-seeded species were detected only in 2007. One of these species, hare's ear, had cover greater than 1% in 2007, but was unaffected by location or seed mixture treatments (Table 3b). Tumble mustard also occurred only in 2007. Its cover was greater in Blocks I and II, although mean separation tests could not be conducted due to missing data.

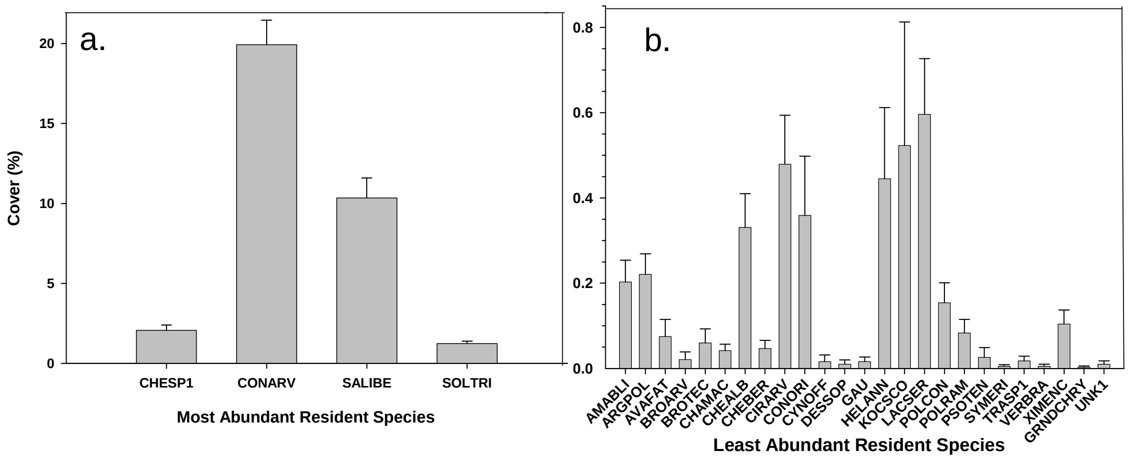

Figure 13. Mean cover in 2006 of (a) most abundant and (b) least abundant non-seeded species ± one standard error of the mean. *Note:* Block I and II, Seed mix 1 were omitted due to seeder malfunction.

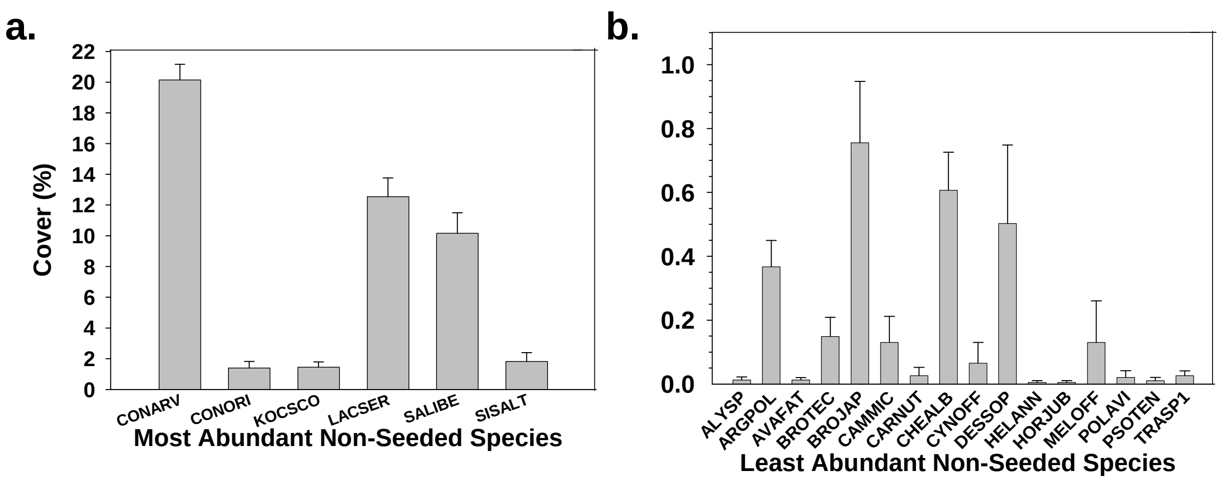

Figure 14. Mean cover in 2007 of (a) most abundant and (b) least abundant non-seeded species ± one standard error of the mean (bars are mean ± one standard error of the mean).

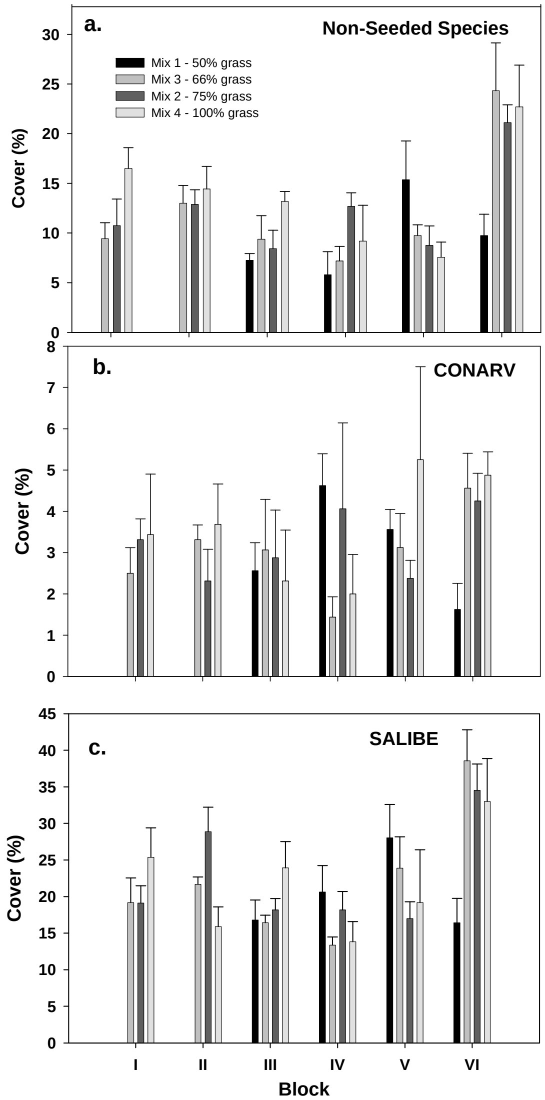

Figure 15. Cover of (a) non-seeded species, and (b) field bindweed and (c) Russian thistle (two abundant non-seeded species) by block and seed mixture in 2007 (bars are mean ± one standard error of the mean).

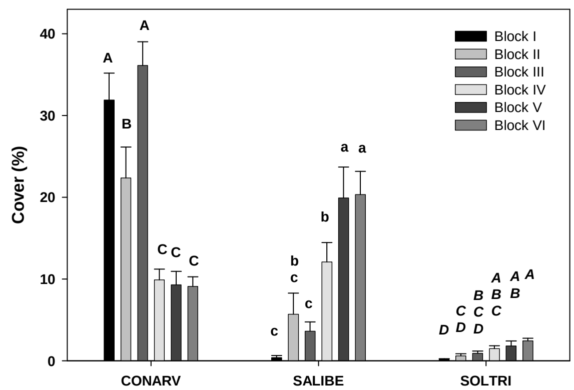

Figure 16. Cover of abundant non-seeded species by block in 2006. Bars are mean ± one standard error of the mean. Means with different letters are significantly different at α = 0.05.

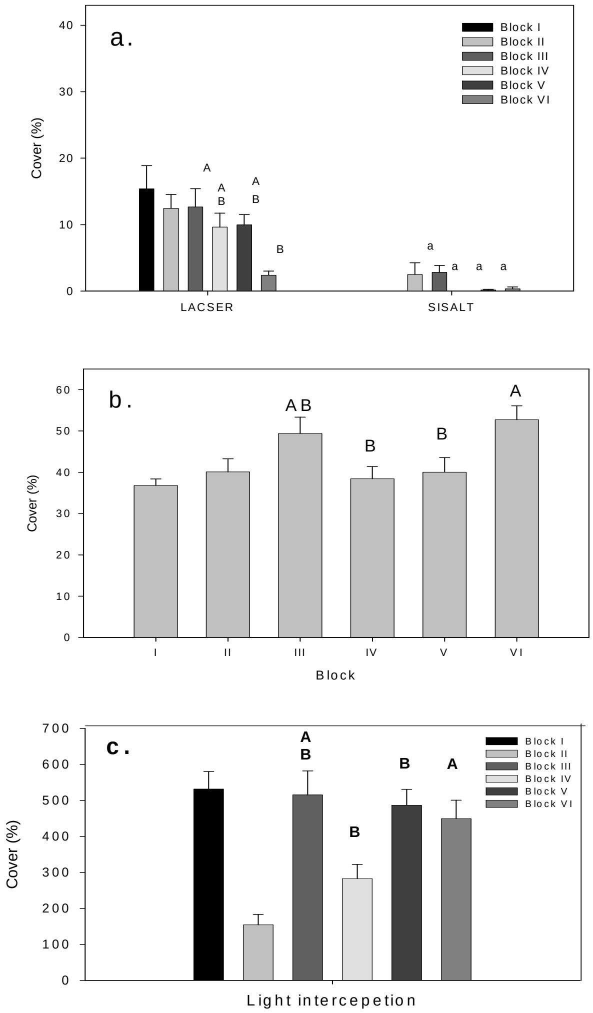

Figure 17. Cover of (a) non-seeded species, (b) litter, and (c) light interception by block for 2007. Bars are mean ± one standard error of the mean. Means with different letters are significantly different at $\alpha = 0.05$. Mean separation tests were not estimable for Blocks I and II due to missing data.

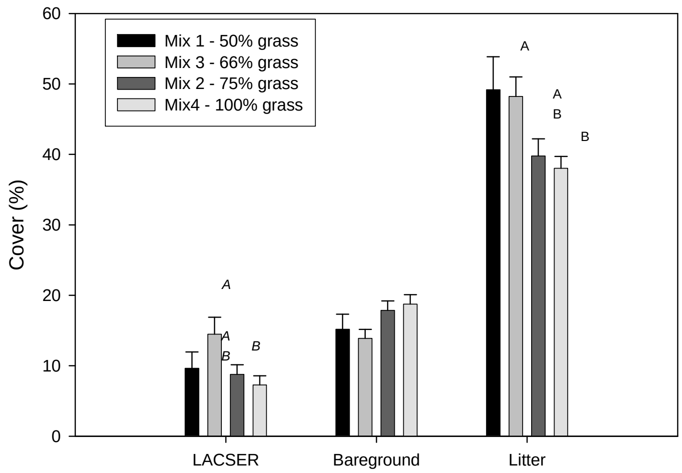

Figure 18. Cover of prickly lettuce (LACSER), bareground and litter by seed mixture for 2007. Means with different letters are significantly different at α = 0.05. Mean separation tests were not estimable for Mix 1 due to missing data.

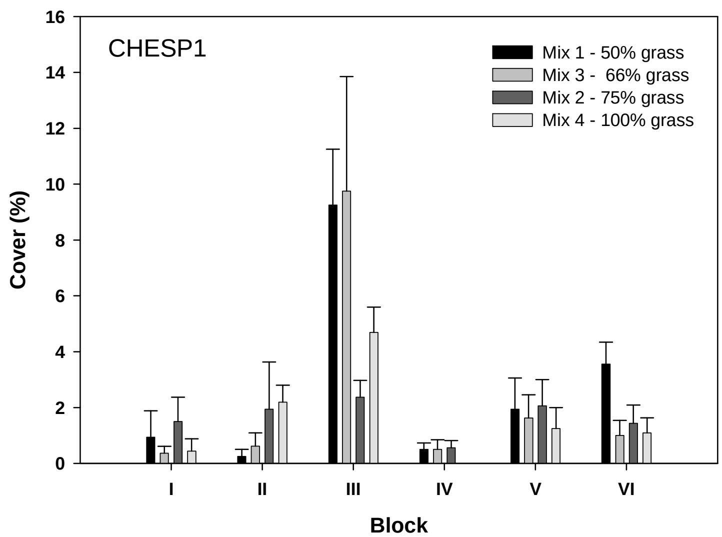

Figure 19. Cover of *Chenopodium* sp. by block and seed mixture in 2006 (bars are mean ± one standard error of the mean).

Abiotic Factors

We detected no effects of location (i.e. Block) and seed mixture treatment on cover of litter and light interception by the plant canopy in 2006 (Table 4a). In 2007, light interception was greater in Blocks V and VI than Block IV. Although mean separation tests were not estimable due to missing data, the light interception was lowest in Block II (Figure17c). In 2007, cover of litter was greater in Block VI than Blocks IV and V, (and probably greater than in Blocks I and II, although mean separations were not estimable), but not different than Block III (Table 4b, Figure 17b). In 2007, cover of litter was greater in Mix 3 than Seed Mixture 4 (Table 4b, Figure 18). In 2006, cover of bare ground in Block IV was similar to Block V, but higher than Blocks I, II, III, and VI (Table 4a, Figure 9b). These differences were not seen in 2007. Instead, cover of bare ground differed among seed mixture treatments, but mean separation tests were inconclusive due to missing data (Table 4b, Figure 18).

We detected no differences in percent nitrogen (N) among blocks or seed mixes (Table 4a). Percent carbon (C) differed among blocks (Table 4a, Figure 20).

Table 4a. ANOVA for abiotic factors in 2006 (n=96 for light interception, litter and bareground, n=88 for soil %C and %N) α=0.05.

Factor	df	Light Interception		Litter		Bare ground		Soil % C		Soil % N	
		F	*P*	F	*P*	F	*P*	F	*P*	F	*P*
Block	5	1.0	0.4	2.2	0.1	4.4	0.002	32.15	<0.0001	1.66	0.18
Seed Mixture	3	2.0	0.1	2.0	0.13	0.2	0.9	0.73	0.49	1.64	0.20
Block x Seed Mixture	15	0.7	0.7	1.4	0.2	0.6	0.8	0.22	1.0	0.38	0.97

Table 4b. ANOVA for abiotic factors in 2007 (n=88) α=0.05.

Factor	df	Light Interception		Litter		Bare ground	
		F	*P*	F	*P*	F	*P*
Block	5	7.87	0.001	6.00	0.001	1.45	0.24
Seed Mixture	3	0.81	0.37	5.46	0.006	3.57	0.03
Block x Seed Mixture	15	1.74	0.08	1.61	0.10	0.93	0.53

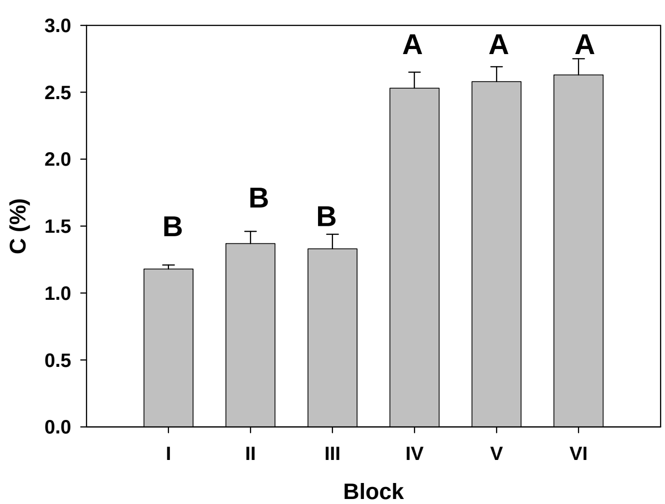

Figure 20. Soil percent carbon in experimental blocks in 2006. Means with different letters are significantly different at α = 0.05. Bars are mean ± one standard error of the mean.

In 2006, percent C was correlated with cover of non-seeded species, but percent N was not and neither percent C nor percent N were correlated with cover of seeded species (Table 5a, Figure 21). There was no relationship between cover of seeded species and bare ground and litter in 2006, whereas non-seeded species were negatively associated with both factors (Table 5a). In 2007, percent C was positively correlated with seeded species cover and negatively correlated with non-seeded species cover. Nitrogen continued to be unrelated to cover of either seeded or non-seeded species. Seeded species were positively correlated and non-seeded species were negatively correlated with bareground. Seeded species were negatively correlated and non-seeded species were positively correlated with litter (Table 5b).

Table 5a. Statistics for simple linear regression of seeded and non-seeded species cover on percent C and N in 2006 (α=0.05).

Factor	Soil % Carbon			Soil % Nitrogen			Bareground			Litter		
	Coeff.	*P*	R^2	Coeff.	*P*	R^2	Coeff.	*P*	R^2	Coeff.	*P*	R^2
Seeded species cover	-0.60	0.45	0.01	-99.90	0.07	0.03	-0.10	0.07	0.03	-0.10	0.06	0.04
Non-seeded species cover	-5.4	0.01	0.07	-27.13	0.86	0.0003	-0.91	<0.0001	0.41	-0.78	<0.0001	0.30

Table 5b. Statistics for simple linear regression of seeded and non-seeded species cover on percent C and N in 2007 (α=0.05).

Factor	Soil % Carbon			Soil % Nitrogen			Bareground			Litter		
	Coeff.	*P*	R^2	Coeff.	*P*	R^2	Coeff.	*P*	R^2	Coeff.	*P*	R^2
Seeded species cover	3.61	0.009	0.07	73.68	0.46	0.006	0.56	0.0002	0.14	-0.19	0.01	0.07
Non-seeded species cover	-10.48	0.001	0.10	277.88	0.25	0.01	-2.03	<0.0001	0.32	0.79	<0.0001	0.21

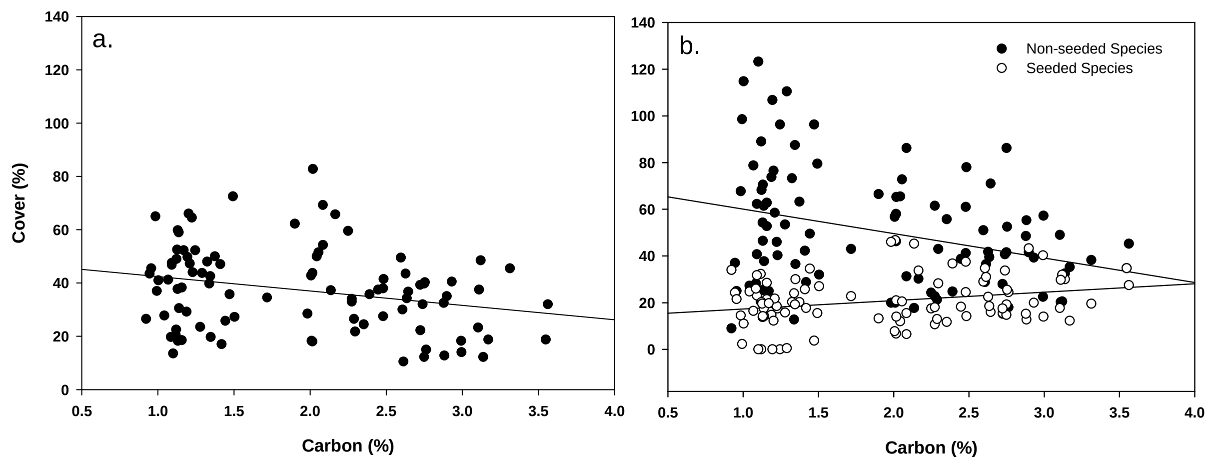

Figure 21. Simple linear regression of (a) non-seeded species cover in 2006 and (b) non-seeded and seeded species in 2007 on soil percent C.

Species Richness

In 2006 the species richness of the seeded species in each seed mixture depended on location in the field (i.e. significant Block by Seed Mixture effect) (Table 6a). In 2007 species richness of seeded species in each seed mixture depended on location (Table 6b).

Table 6a. ANOVA table for species richness in 2006.

Factor	df	Total Species Richness		Seeded		Non-Seeded	
		F	*P*	F	*P*	F	*P*
Block	5	2.57	0.03	6.33	<0.0001	2.62	0.03
Seed Mixture	3	1.19	0.32	6.41	0.0007	0.00	0.10
Block x Seed Mixture	15	1.62	0.09	3.85	<0.0001	0.52	0.92

Table 6b. ANOVA table for species richness in 2007.

Factor	df	Total Species Richness		Seeded		Non-Seeded	
		F	*P*	F	*P*	F	*P*
Block	5	5.93	0.0001	3.15	0.013	8.70	<0.0001
Seed Mixture	3	7.46	0.0002	6.13	0.0009	4.52	0.01
Block x Seed Mixture	15	2.49	0.0052	4.33	<0.0001	1.83	0.047

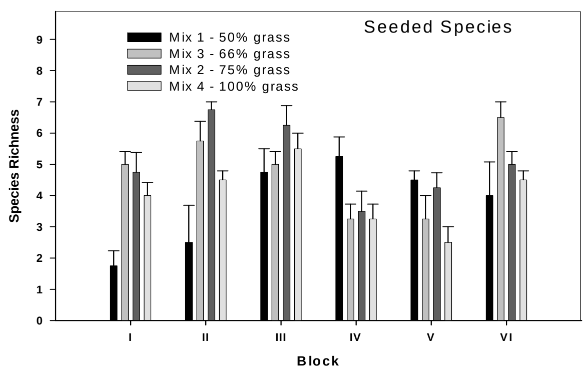

Figure 22. Species richness of seeded species by block and seed mixture in 2006. Bars are mean ± one standard error of the mean.

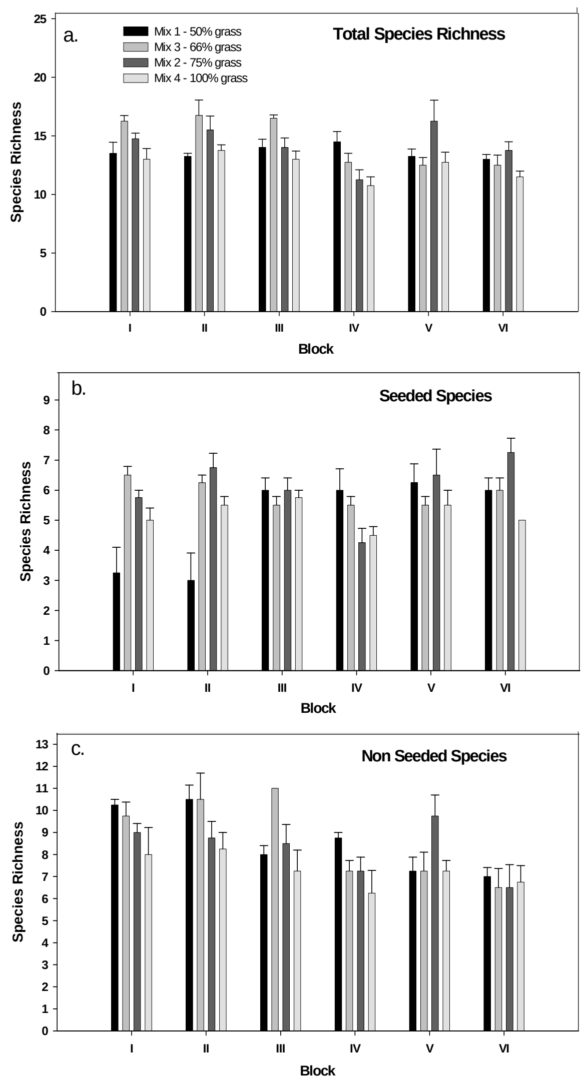

Figure 23. (a) Total species richness, (b) species richness of seeded species and (c) species richness of non-seeded species in 2007 by block and seed mixture. Bars are mean ± one standard error of the mean.

DISCUSSION

The cover of seeded species doubled in the second year after seeding. Our hypothesis that the abundance of seeded grasses, herbaceous forbs and shrubs would reflect their proportions in the seed mixtures was generally supported in the first year, although cover of forbs and shrubs was very low. Seeding proportion and density effects were observed in the first year after seeding for prairie plantings on agricultural lands in the Central Valley of California, but these differences were not apparent in subsequent years (Brown 1998). This same pattern appears to be emerging at this site as well.

We hypothesized that success of seeded species would be positively associated with low non-seeded species abundance if they competed with seeded species for resources, or positively associated with greater non-seeded species abundance if shading helped reduce water stress of seeded species seedlings. In the first year, non-seeded vegetation neither helped nor hindered the establishment and growth of seeded species. However, in the second year, there was a strong negative correlation between seeded and non-seeded species cover. This suggests that the non-seeded species may be having a negative effect on the seeded species in the second year of establishment through competition.

We detected no relationship between the abiotic factors measured and establishment of seeded species in the first year after seeding. However, cover of non-seeded species decreased with increased soil percent C, bareground and litter. The decreased bareground with increased non-seeded species cover is a necessary reciprocal relationship. However, the decreased non-seeded species cover with increased litter may suggest suppression of germination. The patterns changed in the second year, when light interception by the canopy and cover of litter differed by location, and litter differed among seed mixture treatments. Soil percent N continued to be unrelated to seeded or non-seeded species cover. However soil percent C was strongly associated with seeded and non-seeded species cover, but in opposite directions. Non-seeded species continued to be negatively related to percent C, however, in the second year percent C was positively associated with cover of seeded species.

The reciprocal relationship between percent soil C and seeded and non-seeded species is of particular interest. Although higher C levels are usually associated with greater fertility, they may indicate lower N availability at our study site. Addition of labile C sources reduces N availability and favors late succesional species over weedy annuals (McLendon and Redente, 1992; Paschke et al., 2000). Soil N did not differ across the site, thus, this measure of fertility does not appear to explain the observed differences. However, we did not measure available N, but rather measured total N, which includes forms of N that are immediately available to plants and those that will become available over weeks or months. The negative association between non-seeded species and soil C and the positive association between seeded species and soil C at our site may be indirectly due to lower N availability, mediated by microbial immobilization of N. The differences among blocks in soil C may be a legacy effect of the cultivation history of the site. This would seem to be supported by the fact that the site consists of only one soil type (USDA NRCS Web Soil Survey 2007). It is important to determine whether the characteristics of the soils (e.g. soil C), which favor seeded species and disfavor non-seeded species, can be enhanced with management. We believe this is important to study further.

In the second year of the study, we began to see plant community effects on and responses to abiotic factors, which may be indirectly influenced by the developing plant community. Differences in species composition among treatments will lead to different inputs into ecosystem processes. Over time, we expect to see differences in ecosystem functions such as nutrient and water cycles. The performance of seeded species also seemed to be greatly affected by where in the field they were planted in both years.

Management Implications

Increasing proportional representation of species in seed mixtures can lead to greater establishment in the first year after seeding. Location in the field influenced success of seeded species and learning more about the features and history of the different areas will assist in making the best species selections. In particular, the reasons for the underlying differences in soil C should be identified to determine whether this characteristic can be manipulated through management activities to favor desired species. It appears that seeding diverse mixtures of species can maximize the likelihood that seed of species adapted to the different microenvironments will be planted in appropriate microsites, resulting in good establishment overall.

CONCLUSION

The establishment of seeded species on this site has been successful, but seeded broadleaf species remain a small component. Many of the species that have not been apparent initially may become established in later years. This is especially likely for forb and shrub species, which can have long-lived seed and high levels of dormancy. For the future, the project will provide the opportunity for long term research, testing establishment and management methods including, but not limited to: (1) staged revegetation and restoration approaches by introducing forbs after native grass establishment, enabling the use of broadleaf-specific herbicides until then (Brown and Bugg 2001), (2) comparison of efficacy of seeding vs. transplanting shrubs in sequential introduction, (3) testing methods of weed control and resource manipulation to facilitate the establishment of a diverse native plant community, (4) studying ability of native plants to compete with weedy species and the impact that weedy species have on native species (Dukes 2001), and (5) assessing the soil seed bank to evaluate the relative abundance of seeded forbs, which are a highly desired part of the plant community, but remain less common in the aboveground plant community than grasses.

ACKNOWLEDGEMENTS

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REVEGETATION OF THE ROCKY FLATS SITE, COLORADO

Jody K. Nelson

Professional Environmental Group/S.M. Stoller Corporation
Rocky Flats Site
11025 Dover Street, Suite 1000
Westminster, CO 80021

ABSTRACT

At the U.S. Department of Energy's (DOE's) Rocky Flats Site (Site), a former nuclear weapons component manufacturing plant near Golden, Colorado, approximately 650 acres were revegetated as part of the cleanup and closure activities. Numerous issues and challenges were addressed during the revegetation activities at the Site. These included deciding on revegetation and restoration goals; addressing poor substrate issues and soil compaction problems; use of soil amendments and topsoil; seed selection issues; timing and location of revegetation projects relative to continuing closure activities; inconsistencies between revegetation contractors; inexperienced project oversight; problems with weed control and erosion control; and lack of revegetation specifications in closure contracts. Consultation with regulatory agencies and mitigation was required for unavoidable disturbances to Preble's meadow jumping mouse habitat (a federally listed species) and wetlands. Resolution of these issues and the lessons learned during the pre- and post-closure revegetation activities at the Site are discussed. Establishment of vegetation has been good at most locations, given the variable environmental conditions present during the first two years. At several locations where roadbase was the substrate after Site closure, additional soil amendments were added, and the areas were reseeded to improve the chances of revegetation success.

INTRODUCTION

The U.S. Department of Energy's (DOE's) Rocky Flats Site (Site) was established in 1951 as part of the United States' nationwide nuclear weapons complex to manufacture nuclear weapons components. The Site is located between Boulder and Golden, Colorado, along the mountain front, approximately 16 miles northwest of downtown Denver. During the height of operations, over 6,000 employees worked at the Site, and an industrial site occupying over 400 acres was present (Figure 1). The Site had its own water treatment facility, sewage treatment plant, steam plant, electrical substations, and dozens of administrative and production buildings used to support Site operations.

In 1992 weapons production halted, and the Site mission changed to include environmental investigations, cleanup, and site closure. In October 2005, DOE and its contractor completed an accelerated 10-year, $7 billion cleanup of chemical and radiological contamination left from nearly 50 years of production. The cleanup required the decommissioning, decontamination, demolition, and removal of more than 800 structures; removal of more than 500,000 cubic meters of low-level radioactive waste; and remediation of more than 360 potentially contaminated environmental sites. As a result of cleanup operations, approximately

650 acres of land were disturbed and in need of revegetation. This paper discusses some of the experiences, challenges, solutions, and lessons learned related to the revegetation activities at the Rocky Flats Site.

Figure 1. Aerial photograph of Rocky Flats (2001), looking toward the northwest

VEGETATION

At an elevation of approximately 6,000 feet, the Site contains a unique ecotonal mixture of mountain and prairie plant species resulting from the topography of the area and its proximity to the mountain front. The native plant communities at the Site include the xeric tallgrass prairie, mesic mixed grass prairie, shrublands, wetlands, and Great Plains riparian woodland communities. The spatial distribution of the plant communities is largely determined by the hydrology and soil types at the Site. The xeric tallgrass prairie is present on the pediment tops (upper flat surfaces extending from the mountain front) and ridgetops primarily on the western side of the Site, although smaller pockets occur on the eastern side. The pediment tops are underlain by the Flatirons very cobbly, sandy loam soil type (SCS 1980), which has developed from the Rocky Flats Alluvium. The xeric tallgrass prairie community dominates this soil type and is characterized by native graminoid species such as big bluestem (*Andropogon gerardii*), little bluestem (*Andropogon scoparius*), needle and thread (*Stipa comata*), mountain muhly (*Muhlenbergia montana*), and forbs like Porter’s aster (*Aster porteri*) and blazing star (*Liatrus punctata*).

The mesic mixed grassland community dominates the hillsides at the Site. Denver-Kutch-Midway clay loams form the complex of soil types on the hillsides where species such as western wheatgrass (*Agropyron smithii*), blue grama (*Bouteloua gracilis*), side-oats grama

(*Bouteloua curtipendula*), green needle grass (*Stipa viridula*), and Kentucky bluegrass (*Poa pratensis*) are common. At locations where more moisture is available, particularly on the hillsides and in the drainage bottoms, shrubland communities, wetlands, and Great Plains riparian woodland communities predominate. The underlying geology influences the locations of the more hydric communities at the Site. Where the Rocky Flats Alluvium meets the underlying bedrock, seeps form on the hillsides at locations where water daylights, and large hillside seep wetlands occur at these locations. These wetlands are dominated by various species of sedges (*Carex* sp.), rushes (*Juncus* sp.), cattails (*Typha* sp.), and various forb species. On the hillsides above the seep lines and wetlands, shrublands occur in long narrow bands. The shrublands are dominated by chokecherry (*Prunus virginia*), hawthorne (*Crataegus erythropoda*), and American plum (*Prunus americana*). In the valley bottoms along the intermittent streams, plains cottonwood (*Populus deltoides*), peach leaf willow (*Salix amygdaloides*), coyote willow (*Salix exigua*), and wild indigo (*Amorpha fruticosa*) predominate.

An understanding of the ecology and species composition of these plant communities at the Site was used in the development of the revegetation plan for the Site and for mitigation activities discussed below.

GOALS

In general, the goals of the Site revegetation efforts could be placed into three broad categories:

1. Reestablish vegetation on the disturbed areas to prevent soil erosion and help meet surface water quality standards at the Site. Reestablish plant communities using dominant native species found on the surrounding undisturbed landscape.
2. Reestablish Preble's mouse habitat in mitigation areas to offset disturbances and losses from cleanup activities.
3. Reestablish and create new wetlands as mitigation to offset disturbances and losses from cleanup activities.

REVEGETATION CHALLENGES AND SOLUTIONS

As with any revegetation project, numerous factors and variables can affect the end result—an established stand of desirable vegetation. Some of these are controllable, such as the choice of seed mix best suited to the conditions, and other factors, such as climate, are not. Economics, site policies, and project management can also play a role, and decisions are often based on factors other than ecological and biological considerations. Revegetation efforts at the Rocky Flats Site were no exception. Table 1 identifies some of the issues and concerns that were addressed during planning and implementing revegetation activities. These are further discussed along with the solutions and resolutions in the following paragraphs.

Table 1. Revegetation Issues and Challenges

Issue/Challenge	Concern
Revegetation versus restoration	What is the goal?
Poor substrate conditions	Highly altered soils and fill materials with lots of rock , asphalt, and roadbase.
Soil compaction	Highly compacted soils beneath buildings, roads, and parking lots. Deep ripping limited by site constraints.
Soil amendments	Cost prohibitive for scale needed.
Topsoil addition	Cost prohibitive for scale needed. Availability? Weed problems?
Seed	Local genotypes versus commercially purchased seed. Graminoids and forbs?
Seeding	Broadcast versus drilling. Drilling almost impossible at most locations due to rocky ground surface. Issues with broadcasting consistency.
Timing of revegetation efforts	Project was schedule driven; not based on ecological considerations.
Isolated, project-by-project revegetation versus larger-scale "regional" site revegetation	Small revegetation efforts were conducted at the conclusion of each project. Problem: areas were continually redisturbed by adjacent projects. Increased costs. Patchwork quilt of different efforts versus large areas at one time after many projects are completed.
Irrigation	Not available as an option.
Weeds	Conduct weed control.
Erosion controls	Various methods used over large-scale areas. Some worked much better than others. Problems with straw mulch.
Project management and oversight	Revegetation projects managed by non-revegetation/ecology specialists. Problems: lack of consistency across large areas.
Contractual issues	Lack of revegetation specifics in closure contract.

One of the initial issues was whether the revegetation efforts were going to be a revegetation project or a restoration project (i.e., were we going to try to reestablish a native prairie like the undisturbed surrounding grasslands?). In the process of developing the revegetation plan for the Site, various stakeholders brought up this issue in discussions. After much discussion it was decided that it would be impractical to have restoration as the goal because (1) the goal would not likely be achievable, since no true restoration of a native prairie has ever been demonstrated anywhere else, (2) seed is not available for many of the species found on the surrounding native prairies, (3) the time frame required for such an effort would be decades, at a minimum, and (4) contractual obligations between DOE and the operating contractor had no such requirements and would prove problematic. Therefore, the term and concept of revegetation was settled on. It was determined that the revegetation efforts would consist of seeding the dominant native graminoid species found on the surrounding prairies along with a few early successional native species. The goal would be to establish a native perennial cover of vegetation. The use of nonnative graminoid species such as smooth brome (*Bromus inermis*), intermediate wheatgrass (*Agropyron intermedium*), and similar species would not be allowed. This would not preclude the possibility of interseeding native forbs and other grasses at a later time to increase the species richness and diversity of the reclaimed areas and thus make them similar to the surrounding grasslands.

Soil conditions and seedbed preparation were recognized as a potential problem during planning. Most of the former Industrial Area at the Site where production activities took place was a developed "city." Hundreds of buildings, roads and parking areas, utility infrastructure, and other disturbances had highly altered or completely removed the original soils, and what was left in many cases was not the best for trying to reestablish native vegetation. At many locations only roadbase was present after the asphalt or concrete had been stripped off. Where more "native" soils existed, the rocky, cobbly nature of the Rocky Flats Alluvium was further exposed by ripping, which brought many of the rocks to the surface. At these locations soil compaction was often a problem. At other locations, fill or borrow material was brought from both on-site and off-site borrow sources and placed over buried infrastructure that would remain in place; the fill was also used for covers on the two landfills at the Site. At the landfills, the borrow material was largely subsurface material that was excavated and spread as surface material. While generally less compacted than the old road and parking areas, the fill material was often rocky or clayey and was not always the best seedbed material.

Several options were considered as potential means to prepare a suitable seedbed. Deep ripping was proposed to relieve compaction and mix in some of the less suitable surface materials (like roadbase) into the subsurface. While ripping to 3 feet or more would have been desirable, Site constraints limited actual ripping depths to 1–2 feet because of concerns about remaining buried uncontaminated infrastructure (wiring, cables, pipes, etc.) that had been left in place. The solution was to rip or scarify the surface as deeply as possible, given the site constraints. The 1–2 foot ripping and scarification helped to relieve soil compaction in the upper surface and, in most cases, prepared a suitably loose substrate to seed into and allow for root establishment. Although this process did not mix the less suitable surface materials into the subsurface as much as we would have liked, the mixing was accomplished as well as possible given the Site constraints.

Addition of soil amendments and topsoil was considered as an option to improve soil conditions. Soil test results from several locations suggested there was no need to add amendments such as organic matter or fertilizers at most locations. One trial that was conducted early in the process after the first few small buildings were removed involved bringing in topsoil to improve the quality of the seedbed substrate. The areas were ripped, and a topsoil layer (up to several inches in depth) was spread evenly across the areas and seeded (Figure 2). One of the major concerns with using topsoil was that whatever species were growing on it prior to being stripped off would ultimately be the species that would establish, regardless of what was seeded. In large part that proved true where the topsoil was used. Most of the seeded species did not establish or, if they did, were soon outcompeted by the weeds or other undesirable nonnative grasses that had been growing in the pasture from which the soil topsoil was taken. Had there been an opportunity to

Figure 2. Topsoil trial at the former Building 111 revegetation location.

evaluate the preexisting vegetation growing on the topsoil, this could have been avoided by not using topsoil from that location. However, because no evaluation was done, a stand of undesirable nonnative grasses established along with a few plants of yellow starthistle (*Centaurea solstitialis*)—an A-list state noxious weed in Colorado. As a result, topsoil, unless it could be evaluated beforehand, was not used again at the Site. Given the scale of the revegetation (650 acres), topsoil and other soil amendments also became cost prohibitive and were not used during the Site closure revegetation efforts.

The use of local genotype graminoid seed rather than commercially available seed was also considered and discussed in various stakeholder meetings. From a practical standpoint this was largely dismissed because there was no way to collect and grow out the quantities of graminoid seed needed to revegetate the Site in the time frame required. One idea that did come out of this discussion, however, was the use of volunteers to collect native seed from surrounding grasslands. The native seed could then be added to the commercial seed being spread to incorporate some local genotypes into the mix. This was done and continues to be done by a dedicated group of volunteers who collect native seed two or three times a year and provide it to the Site for use in revegetation efforts.

Another seed mix issue was the use of forbs in the seed mixes. Selected forbs were initially included in some of the early seed mixes. This was discontinued, however, after weed control activities required to help establish the seeded graminoid species were detrimental to the forbs that had been seeded and that had begun to establish. Therefore, it was decided that until the native perennial grasses had become well established there would be no seeding of forbs. This resulted in cost savings, and it was decided that desirable forbs could be interseeded at a later date, as needed. The use of volunteer-collected forb seed may be employed as the native grasses get established.

The timing and location of revegetation efforts was another concern during closure operations. The revegetation plan had initially specified spring and fall planting windows. However, schedule and milestone requirements did not account for seeding windows, and to meet milestones for project completion and to close out project contracts, it was desirable to complete revegetation activities as soon as possible. Given the economic and schedule constraints, the eventual solution was to allow seeding and revegetation activities to take place as soon as the final land configuration was completed for each project. The goal was to get each project area into final closure status as soon as possible after project activities were completed. One of the problems that arose as a result of this decision was that many of the earlier-completed revegetation projects were like small islands in a sea of remaining structures. As closure activities began in adjacent areas, many of these earlier-completed revegetation areas were destroyed by the new activities because of the need for space to work with heavy equipment. Thus, what began as a decision to complete final revegetation activities in a patchwork fashion (to meet schedule and milestones as projects were completed) became less cost effective and less practical as many areas were reseeded multiple times. Eventually, as smaller areas were completed they were either seeded with a temporary seed mix or protected with erosion controls until larger areas that would not require redisturbance were ready for final revegetation. Thus, the process evolved over time and changed to allow seeding to take place any time of year. While this approach did not follow the traditional revegetation paradigm, it does not seem to have affected the resulting stands of vegetation at most locations. In fact, several locations seeded outside the original fall/spring planting windows have done better than those planted within the time frames.

Irrigation was not an option for the revegetation at the Site because DOE had no water rights, and purchasing water for irrigation would be costly. So revegetation efforts have relied solely on natural precipitation (about 15.5 inches annually). Final closure revegetation efforts at the Site were completed in fall 2005. Throughout the winter of 2005–2006 and into much of 2006, precipitation was below normal. Thus, germination and vegetation establishment were less than expected during the first full growing season. In winter 2006–2007, abundant snowfall and normal spring precipitation in 2007 provided the moisture needed for many of the seeded species to begin to establish. After two growing seasons, a good initial stand of vegetation is present across much of the Site, although it was somewhat limited during the first growing season because of the lack of precipitation.

Weed control is crucial in establishing seeded species in the semiarid conditions at the Site. Without weed control, various noxious weeds and other undesirable weedy species have the potential to outcompete the seeded species during their initial establishment period. During revegetation activities, administrative controls were in place at the Site to limit importation of noxious and other undesirable seed as much as possible. Purchased seed was required to be free of noxious weed seed according to Colorado state regulations. Certain species of exotic, aggressive graminoid species (e.g., smooth brome or intermediate wheatgrass) were prohibited from use at the Site. Straw or hay used for mulch or use in straw bales or wattles for erosion control had to be certified weed free. Washing or cleaning equipment prior to bringing it on site or taking it off site was recommended but not enforced because of the impracticality of implementing it on the scale necessary during closure operations.

Some of the common weed species that have been problematic in the revegetation areas at the Site include diffuse knapweed (*Centaurea diffusa*), Russian thistle (*Salsola iberica*), kochia (*Kochia scoparia*), devil's shoestring (*Polygonum arenastrum*), filaree (*Erodium cicutarium*), wild lettuce (*Lactuca serriola*), and yellow sweet clover (*Melilotus officinalis*). Given the Site conditions, kochia, Russian thistle, devil's shoestring, and filaree are the typical, problematic, first-year weed species that compete with natives. Typically, herbicide is not applied during the first growing season in order to give the grasses a better chance to establish and to attain sufficient size that the herbicide will not stunt their growth. If weed control is needed in the first year, mechanical control (mowing, weed whacking) is the option of choice. Most of the first-year weedy species tend to disappear on their own after the first season once the perennial grasses begin to establish and provide competition. In the second year, there is typically a flush of yellow sweet clover along with some diffuse knapweed (the latter depends on location). At some locations, yellow sweet clover can become so large and dense that it shades out and outcompetes the grasses. In the second year, an herbicide application of Milestone (aminopyrilid at a 7 ounces/acre application rate) is often used to reduce the competition from the yellow sweet clover and other undesirable forb species and give the grasses an opportunity to become well established. Mowing may be used again during the second year at some locations, depending on the condition of the establishing grasses and the size and abundance of the weedy species. If Milestone has been applied during the second year, it typically has enough residual effect that the grasses continue to establish well during the third year with little competition from the weedy species. All this presumes that the grasses receive good precipitation.

Erosion controls are an essential part of a good revegetation project. With no vegetation on the soil surface to protect it, appropriate erosion controls are needed to protect the soil from wind and water erosion, help to establish desirable seedlings, and to meet storm water control requirements. At the Site, an additional requirement is to remain in compliance with surface water quality standards set by the U.S. Environmental Protection Agency (EPA) and Colorado Department of Public Health and Environment for the Site. Several erosion control techniques were used effectively during closure operations. Wattles and straw bales were more effective than silt fences for controlling runoff because of the high maintenance requirements for the silt fencing. High winds common at the Site during winter months (exceeding 80 miles per hour) often shred the silt fence or knock it over, making maintenance a continual problem. Erosion control blankets were used extensively on hillside locations where steep slopes needed protection. Biodegradable erosion control blankets with a straw or coconut matrix center and permanent reinforcement mats were used for different projects, depending on the project-specific requirements (Figures 3 and 4). These have functioned well, not only as protection for the soil, but also as a mulch, trapping moisture and heat, which has helped the perennial grasses to

Figure 3. Temporary erosion blankets (and wattles on far hillside) used to protect soil and prevent erosion on the hillslopes at the Site.

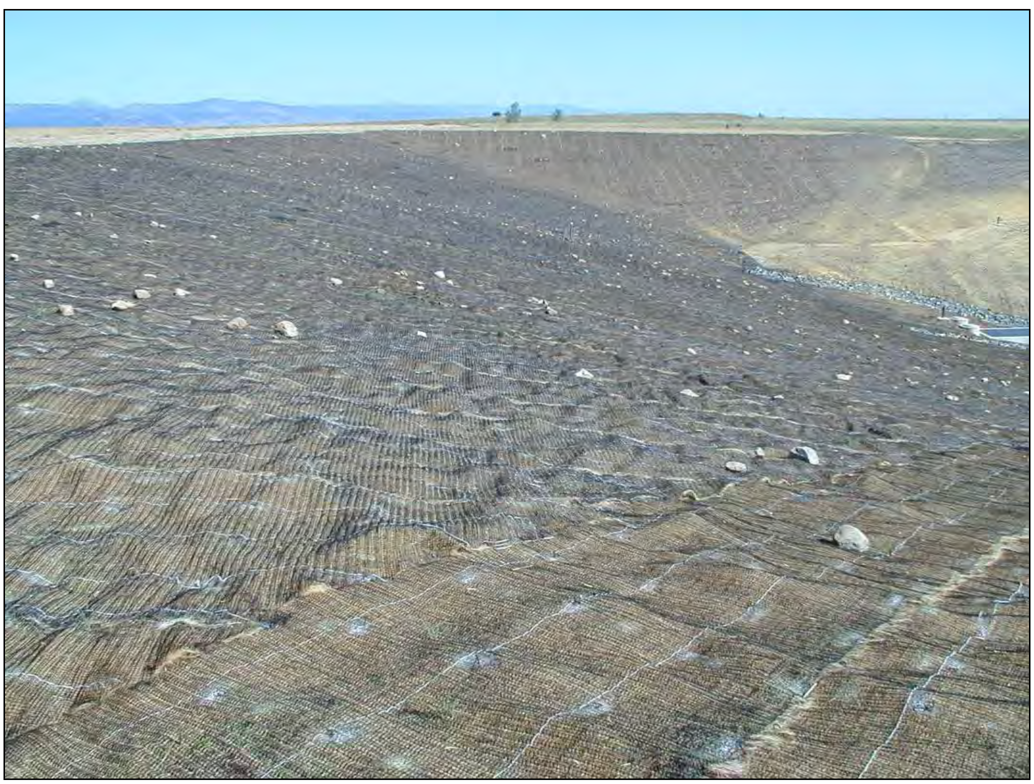

Figure 4. Permanent erosion control blankets on the steep face of the Present Landfill.

germinate and establish. The biggest problem at the Site with the erosion blanket controls is the difficulty of staking them to the ground, given the very rocky, cobbly nature of the soil. Being securely anchored to the ground is critical for erosion blankets; the high winds at the Site would otherwise tear the blankets loose. At some locations, rocks and cobbles have been used instead of stakes to hold the mats on the ground and have worked quite well.

Crimped straw was used in the later stages of revegetation at the Site on the upper flat pediment surfaces. The application rate for straw was approximately 1.5 tons/acre. The use of crimped straw at the Site presented several difficulties. The length of the unbroken straw stems was generally too short for effective crimping at many locations. The use of hay mulches, which typically have a longer stem length, was considered; however, concerns regarding the species composition of these “native” hay mulches precluded their use. The possible introduction of exotic pasture grasses was a major concern, and bringing exclusively “native” hay from long distances in the large volumes that were required became cost prohibitive. In addition, the rocky, cobbly soils were not conducive to crimping in general.

During the first winter after closure (2005–2006), the high winds that typically occur at the Site in the winter months (50–100 mile-per-hour winds are not uncommon) blew most of the crimped straw away, stripping this protection from the exposed upper mesas and depositing several inches to several feet of straw on some downwind hillslopes and lower areas (Figure 5). The lack of protection on the upper areas allowed the already drought-limited soil moisture to be further

Figure 5. Windblown straw deposited in a drainage inhibiting plant germination.

reduced by the winds, adding to the stresses on vegetation establishment. In the lower areas where the straw was deposited in deep piles there has been little or no vegetation establishment two years later, because the straw is too deep to allow for germination of the seed in the ground. Another problem with crimped straw was the abundance of volunteer wheat that grew the first and second years from the seedheads present in the straw. The wheat crop further limited establishment of the seeded species by competing for resources such as nutrients and water. In general, the use of crimped straw is no longer considered a viable option at the Site.

One of the most effective erosion control products used at the Site has been flexible growth media compounds such as Flexterra. This biodegradable product provides excellent erosion control with low maintenance while acting as a mulch that helps with the vegetation establishment (Figure 6). Where vehicle access is possible for the large hydromulch trucks used to apply the material, the cost is less per acre for installation and maintenance than erosion blankets, and it has worked well at holding the soil in place while the perennial grasses establish. It has been used on both flat (3,000 pounds/acre) and hillslope (3,300–3,500 pounds/acre) surfaces at the Site with good success.

Figure 6. Flexterra application on a hillslope at the Site.

Project oversight of the revegetation activities by project managers unfamiliar with revegetation processes and results created several problems of its own. A revegetation plan had been prepared and written for the Site with the idea that it would provide a cookbook approach for projects to follow. Some flexibility was built into the plan to allow for variation in project completion schedules, environmental conditions, substrate differences, and application methods. However, it is apparent now, more than two years after the initial revegetation efforts, that more stringent requirements and oversight of revegetation activities by revegetation and ecology specialists, combined with approval or sign-off steps could have helped eliminate some of the problems we now face.

Seeding operations was one area where this has become apparent. Although the revegetation plan allowed for either drill seeding or broadcast seeding, drill seeding was almost impossible at the Site without destroying a seed drill, given the rocky, cobbly nature of the soils. As a result, nearly all the areas were broadcast seeded. The methods used to broadcast the seed ranged from hand broadcasting on foot and mechanical broadcasting using mounted or pull-behind equipment, to hand broadcasting out the sides of small ATV "mules" while driving around the areas. It is apparent at some locations that the operators (particularly of the hand-broadcasting methods) were not very skilled at keeping track of where they were or had been, since two years later vegetation is coming up at several locations in patches or rows, with unseeded areas often alternating or occurring nearby. As a result, additional reseeding has been required in these areas. At other locations, in an overzealous effort to avoid soil erosion, erosion controls (straw with flexible growth media sprayed on top to hold it in place) were placed so heavily that they prevented vegetation establishment altogether. In another case, newly installed willow stakes were pulled out of the ground so that erosion blankets could be installed across the bottom of a created wetland, and the willow stakes were then reinstalled through the blanket, tearing the new roots off. In each case, although intentions were good, better project oversight by personnel familiar with the application methods and results of proper revegetation activities could have largely prevented these issues.

Finally, it is important to include revegetation information and language in the contractual agreements for future DOE site closure operations. Contractual agreements with the closure contractors at sites where revegetation is required should specifically address the issues of soil quality and soil compaction. More stringent requirements and oversight of initial pre-closure revegetation activities with approval or signoff steps throughout the revegetation process could help eliminate problems that will not show up until a few years later. The choice of erosion controls should be considered and specifically addressed in contractual agreements. Post-closure reseeding and revegetation should also be considered and planned for in budgeting exercises for out-years, since not all efforts will succeed. If the closure contract does not sufficiently address revegetation issues, it should be expected that more intensive revegetation efforts will need to be planned and budgeted for several years after closure.

PREBLE'S MOUSE HABITAT AND WETLAND MITIGATION

Cleanup operations at several locations had to address two regulatory issues that had revegetation components: Preble's meadow jumping mouse (Preble's mouse; *Zapus hudsonius preblei*) and wetland issues. The Preble's mouse, a federally listed threatened species under the Endangered Species Act, lives in the drainages at the Site. Disturbances to Preble's mouse habitat had to be addressed through a consultative process with the U.S. Fish and Wildlife Service (USFWS) prior to the start of work. In addition, at several cleanup locations disturbances to wetlands were unavoidable, and discussions and consultations with EPA and the U.S. Army Corps of Engineers (USACOE) were held to address wetland impacts. In dealing with the Preble's mouse or wetlands issues, some of the greatest challenges in working with projects were (1) educating project managers about the issues, (2) getting them to incorporate the time frame needed to get permits and approvals into their work schedule—to prevent delays later on, (3) getting a final plan that could be provided to the regulators for approval (on some projects the plan was constantly changing), and (4) keeping the projects in accordance with specific requirements of the permits and approvals once they started. Involving the regulatory agencies from the beginning helped to address certain early issues and helped with the educational process for project management.

A Programmatic Biological Assessment (PBA) and other separate project-specific Biological Assessments (BAs) were written and approved by the USFWS to address the potential impacts to the Preble's mouse habitat resulting from cleanup and ongoing operations at the Site. The PBA and BAs addressed mitigation, reestablishment of Preble's mouse habitat at disturbed areas, and monitoring. General revegetation guidelines and monitoring and success criteria were discussed in the PBA. Nationwide and individual Section 404 permits were used to address wetland issues and mitigation. In addition, a wetland mitigation monitoring and management plan was also written to assist with the mitigation activities.

Because the Preble's mouse lives primarily along the streams at the Site, the two types of mitigation areas often overlapped or were the same, since the wetland mitigation areas were also typically along the streams. During final land configuration activities, stream drainages in the former Industrial Area were reconfigured to resemble pre-Site conditions as much as possible (given engineering limitations). Preble's mouse mitigation areas were designed to restore or create riparian vegetation found along the undisturbed streams and the surrounding upland grasslands at the Site. Several larger wetland mitigation areas were designed to replace smaller more isolated wetlands that were disturbed or destroyed by cleanup activities. Several created and restored wetlands were engineered and re-created in the different drainages at the Site (Figure 7). These areas were seeded with native wetland species of sedges, rushes, bulrushes, and grasses and also had coyote willow, peach-leaf willow, and plains cottonwood stakes installed along their perimeters to accelerate reestablishment of the woody component of the plant communities. The surrounding upland areas were seeded with the common native graminoid species typical of the native hillside grassland communities at the Site. After two growing seasons, the wetland areas are developing well, and both the herbaceous and woody species are thriving at most locations. The adage "if water is present it will grow" has certainly held true for the stream and wetland mitigation areas. At the upland mitigation areas, establishment has been similar to that of the surrounding uplands where a lack of precipitation initially limited growth during 2006. However, the additional precipitation received in 2007 has helped reverse that trend, and good establishment of the native species was observed in 2007.

MONITORING

Vegetation monitoring is conducted in both the general revegetation areas and the Preble's mouse and wetland mitigation areas. Both qualitative and quantitative monitoring methodologies are used. Qualitative monitoring consists of general revegetation observations, weed assessments, and photopoint monitoring. Quantitative monitoring uses both quadrats and transects to measure species richness, frequency, and vegetation cover. Counts are typically made of woody plant survival also. These data are then used to compare the establishment of the vegetation to success criteria specific to different locations and their appropriate regulatory drivers. Data summaries are prepared annually, interpreted, and documented in annual reports submitted to the appropriate regulatory agencies.

Figure 7. Functional Channel 4 mitigation wetland in South Walnut Creek.

POST-CLOSURE REVEGETATION ACTIVITIES

In general, after the first two growing seasons, the overall vegetation establishment has been quite good across the Site. However, certain areas have needed additional work. These generally fall into one of two categories: areas that received either no seed or very little seed during the initial seeding efforts and areas with extremely poor soil conditions (i.e., roadbase) where roads, parking areas, and some building footprints were once located. At the locations where little seed was apparently sown, additional interseeding was conducted. Where extremely poor soil conditions existed, additional soil amendments were added, and those areas were reworked to improve the chances for successful establishment of vegetation. At those locations, compost (40 tons/acre) was spread on the surface, and the areas were ripped 1–2 feet deep. Then Biosol (1,000 pounds/acre) and a mycorrhizal inoculant (60 pounds/acre) were applied and disced into the surface soils. The areas were then seeded with a native seed mix, and a flexible growth medium (Flexterra, 3,000 pounds/acre) was applied as the erosion control.

LESSONS LEARNED

The following list identifies many of the lessons learned during the revegetation activities conducted at the Site.

- Identify the goal of the revegetation project up front—revegetation or restoration. Get agreement among the various stakeholders as to what the goal is and why. Agreement as to what seed mix species to include and not to include (i.e., exotic graminoid species) is valuable also.
- Evaluate soil conditions and compaction issues up front and identify specific locations or problem areas that will need amendments to enhance chances for successful revegetation. Conduct soil sampling and soil testing to determine what (if anything) needs to be done at different locations. Doing so up front will save costs in the long-term by not having to remobilize equipment and pay for increased revegetation costs in the future.
- Work with project managers during the planning stages to address regulatory issues and to educate them on what will be required to get their project done and on schedule. Include the regulators early on in the process.
- Make sure field project oversight is being done by revegetation and ecology specialists who are knowledgeable and have practical experience in revegetation and erosion control planning, installation, and implementation.
- Use sign-off or approval logs as needed during fieldwork to ensure that different tasks are performed according to specifications.
- Make sure that equipment is appropriate for the task and is functioning properly. Make sure that operators are skilled and diligent in performing their tasks.
- DOE site closure contracts must have revegetation specifics incorporated into them. Items to address should include goals of revegetation efforts, seedbed preparation issues (soil conditions, soil testing, use of soil amendments), soil compaction, seed selection, use of appropriate equipment to do the work, weed control, erosion control, monitoring, success criteria, and reseeding for failed efforts.

Although many lessons have been learned and continue to be learned through the revegetation efforts at the Site, and while the projects did not always follow a textbook approach, a good stand of vegetation has begun to establish at most locations. Figure 8 shows an aerial view of the Site as of June 2007. Time will tell which species of plants will ultimately dominate the plant communities at the Site.

LITERATURE CITED

SCS. 1980. Soil survey of Golden Area, Colorado. U.S. Department of Agriculture, Soil Conservation Service.


Figure 8. Aerial photograph of Rocky Flats (June 2007), looking toward the northwest.

Design and Construction of the Shell Trenches Alternative RCRA Cover at Rocky Mountain Arsenal, Commerce City, Colorado

Carl Mackey

Principal Environmental Specialist
URS Washington Division
Rocky Mountain Arsenal Project
Remediation Venture Office
P.O. Box 1717
Commerce City, CO 80037
303-286-4825
carl.mackey@wgint.com

ABSTRACT:

Rocky Mountain Arsenal is a hazardous waste site located in Commerce City, Colorado. The Record of Decision for the site was signed in 1996 and required design and construction of approximately 500 acres of alternative design vegetative RCRA landfill covers. The first of these alternative vegetative landfill covers to be designed and constructed is the Shell Disposal Trenches cover. The approval process for the alternative design included modeling, construction of demonstration covers, and refinement of the demonstrated design by a team of regulatory agency and industry engineers and scientists. The final design was constructed during spring/summer 2007. A number of lysimeters are included in the cover for measurement of percolation after the native plant community has established. The case study will discuss details of the design, illustrate the construction and provide current status of the project.

INTRODUCTION

Industrial History

Rocky Mountain Arsenal National Wildlife Refuge (RMA) is a former U.S. Army facility located in Commerce City, Adams County, Colorado eight miles northeast of the Denver city center. The RMA is approximately 25 square miles (~16,000 acres) and is surrounded by residential and commercial development, or land being developed for those uses (Figure 1).

In 1942, the U.S. Army (Army) purchased the site and constructed facilities to manufacture chemical weapons for use in World War II. Following the war, the Army continued to use the site, but also leased some of the facilities to private companies for the manufacture of agricultural chemicals. Shell Oil Company (Shell) became the ultimate lessee and manufactured primarily chlorinated pesticides. All manufacturing activities at the site had ceased by 1982 (Ebasco et al. 1994).

Common industrial waste disposal methods used during those years resulted in contamination of structures, soil, surface water, sediment and ground water (EPA 1996).

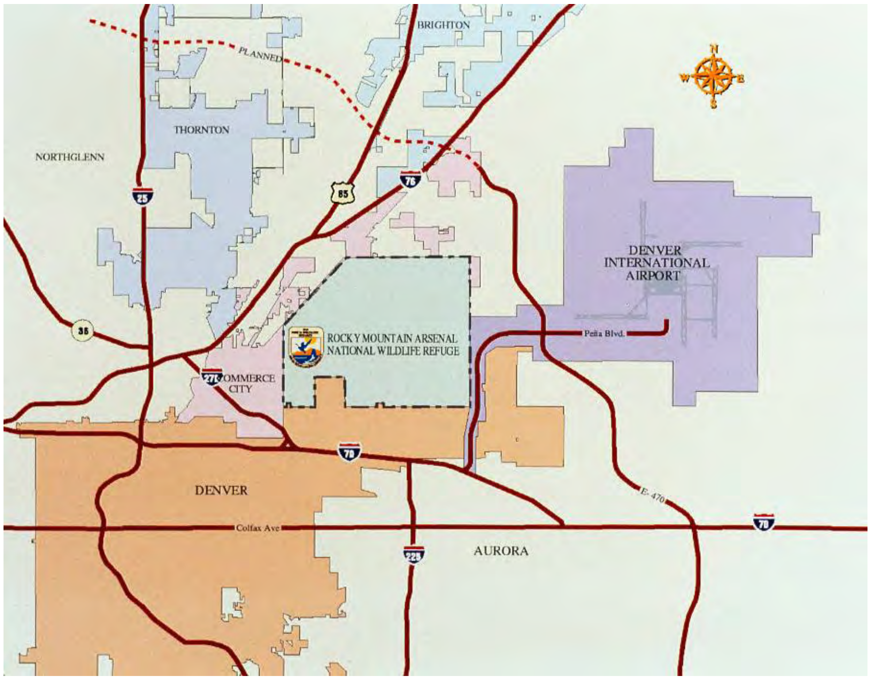

Figure 1. Regional location of Rocky Mountain Arsenal National Wildlife Refuge

To a lesser extent, contamination also occurred via demilitarization activities, routine agricultural operations, and accidental spills and releases (Ebasco et al. 1994). Due to these releases of hazardous waste and the resulting environmental impacts, in 1984 Army began investigating site contamination in accordance the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) of 1980. The site was placed on the National Priority List (NPL) in 1987.

In 1996, the Record of Decision (ROD) presented the selected remedial action for RMA part of which included construction of Alternative RCRA Soil Covers for selected contaminated areas. The Army, Shell, and the U.S. Fish and Wildlife Service (FWS) formed the Remediation Venture Office (RVO) partnership to manage the site cleanup and restoration activities.

Ecological Setting

Located on the plains but near the foothills of the Rocky Mountains, RMA provides the setting for flora and fauna that is regionally scarce due to population growth and development of Denver and the surrounding cities. Although the central zone of RMA has been impacted, a large buffer zone surrounding the manufacturing and waste disposal core has remained un-effected by hazardous substances or the disturbance associated with manufacturing activity. The buffer zone has been used by a wide variety of wildlife species, and native vegetation has also flourished in this area (Hoffecker, 2001).

RMA landscape and climate can support the variety of species associated with short and mid-grass prairie vegetation associations. However, much of the site has been disturbed or planted to non-native grassland. Some remnant sites occur and provide a basis for restoration of prairie for approximately 10,000 acres of RMA. Past and ongoing restoration activities are using appropriate native species, with the goal of returning the area to its pre-development state as much as reasonably possible. Alternative RCRA Cover areas are included in this restoration effort (U.S. Fish and Wildlife Service, 1999).

ALTERNATIVE RCRA COVER DESIGN AND CONSTRUCTION

Prescribed Design

Traditional or prescribed RCRA landfills are composite cover designs that reduce the migration of hazardous substances into the environment, as well as the potential for direct exposure by minimizing infiltration through the contaminated material and isolation of the contaminated medium through containment. The traditional composite cover consists of multiple layers that include a compacted clay layer covered with a flexible-membrane liner and a soil/vegetation layer to minimize erosion. Additional layers may also be part of the design. These include a biota-intrusion barrier, drainage layers (course material and geotextile) and geogrid for stability. The covers are constructed with sufficient slope to prevent ponding of precipitation on the cover (Figure 2).

The goal of the prescribed design is to isolate waste and minimize percolation to groundwater. The design uses artificial barriers such as compacted clay and synthetic layers. The result is generally an engineered landscape with low habitat value. In addition, the design may not be appropriate for arid and semi-arid climates where clay layers can dry and crack.

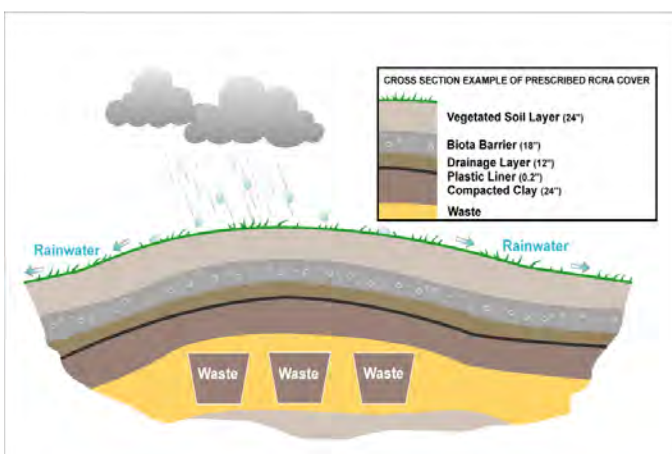

Figure 2. Prescribed RCRA Cover Design.

Alternative Design (RCRA Equivalent Cover)

Two standards included in the ROD most critical to the alternative RCRA cover design at RMA are that infiltration would not be greater than the range of infiltration that would pass through an EPA prescribed RCRA cover, and that the alternative design would be field demonstrated to achieve regulator approved percolation limits (i.e. 1.3 mm per year after establishment of seeded vegetation). The RCRA-Equivalent Cover Demonstration Project was successful in meeting both the infiltration and percolation criterion (Kiel, et al, 1998). Based on this accomplishment, some of the demonstration cover features were incorporated into the full-scale design while others were subject to further review and evaluation (Remediation Venture Office, in preparation).

The goal of the alternative design was the same as for the prescriptive design, i.e. to isolate waste and minimize percolation to groundwater. The method to achieve the goal differed. Instead of the artificial compacted clay and synthetic layers used in the prescriptive design, the alternative design relies on sufficient soil thickness (sponge) and a self-sustaining plant community (pump) to contain and transpire the predicted maximum annual precipitation (ITRC, 2003). In addition, the alternative design provides the opportunity for an improved blending of a landfill into the landscape and the prospect of improved habitat (Figure 3).

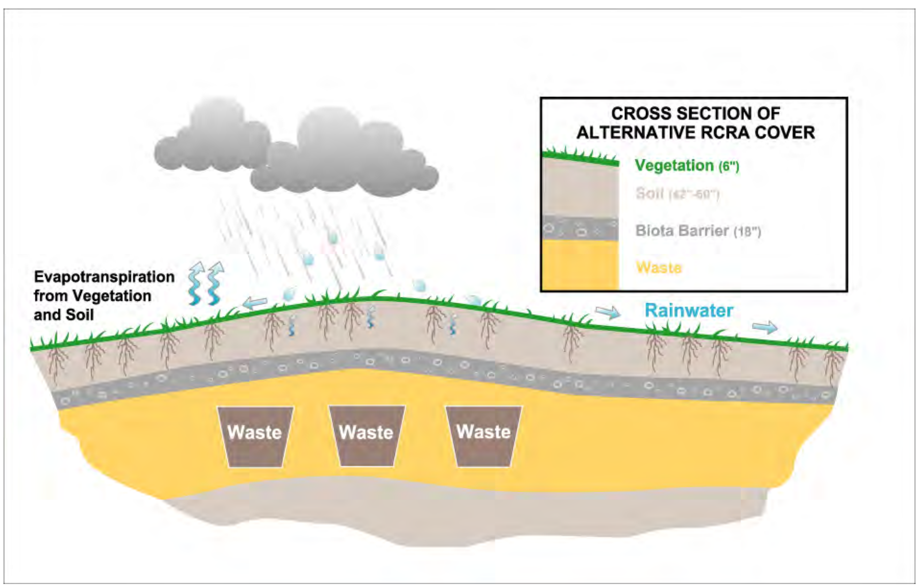

Figure 3. Alternative RCRA Cover Design.

Alternative cover designs at RMA also include a biota barrier layer composed of 18 inches of crushed concrete salvaged from the runway demolition at former Stapleton International Airport. The gradation for the biota barrier material was for sizes that would minimize between cobble open spaces and ranged from about 3/8 inch to 12 inches.

Texture

An acceptable zone (AZ) for soil texture was developed that identifies soil textures that, when compacted to within a prescribed density range, have predicted percolation performance that meets the ROD standard. The computer model UNSAT-H was used to compare the predicted percolation performance of potential borrow soils of various textures, compacted to various densities. The basis of comparison was the depth to which 1.3 mm of percolation was predicted by UNSAT-H to penetrate into a 48-inch soil cover with actual precipitation data that had been shown to be particularly severe with regard to its tendency to produce deep percolation. Other input parameters for UNSAT-H were derived from local plant community data.

Agronomic property constraints were also considered for developing the AZ. Soil with greater than a 40% clay fraction was excluded, as was material with a greater than 60% fraction of silt. These soil types were disqualified based on the difficulty of establishing a diversity of native grasses under the physical conditions that exist when this material is placed, i.e. low soil moisture availability, high erosion potential, high surface cracking potential, etc. (Tetra Tech FW, Inc., 2005)

The AZ determined is illustrated in the standard soil texture triangle in Figure 4.

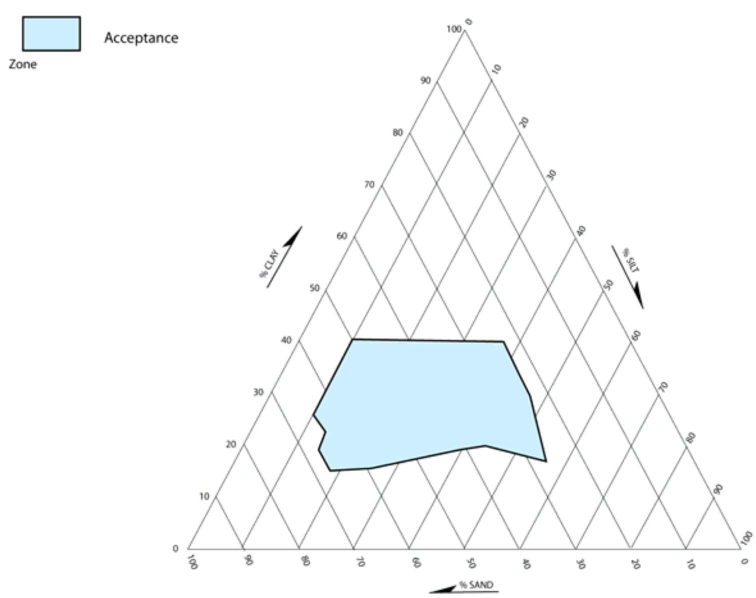

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Figure 4. Borrow Soil Texture Acceptable Zone

Other Agronomic Considerations for Acceptable Borrow Soil

In addition to the textural constraints, other agronomic properties of soil material were considered to identify acceptable soil. Percent calcium carbonate was limited to less than 15% for any borrow source and with the goal of less than 10% in the placed cover surface. Ph was also restricted to within the range of 6.0-8.4. Other fertility considerations were addressed by the addition of composted manure as described below.

Density

Several literature and field investigations were conducted to arrive at a soil placement density specification. Placement and post vegetation establishment in-situ densities for the demonstration plots were considered. The Growth Limiting Bulk Density (GLBD) (Daddow and Warrington, 1983) for the AZ soil was calculated. In-situ densities for native grass stands were measured. For construction, soil placement density was specified to be in the range of 75-85% of standard proctor. This range is lower than the GLBD, higher than the density of placed material in the demonstration plots, but more practical to construct (Tetra Tech FW, Inc., 2005).

Cover Soil Layer Depth

Several factors were considered to determine the depth of the cover soil layer for the Alternative RCRA Covers. UNSAT-H predictions suggested that two to three feet of AZ soil would be sufficient to store annual precipitation in most years. Since the design included a biota barrier layer composed of crushed concrete with gradation of material from less than 3/8 inch to 12 inches, the depth of soil freezing was considered so that the biota barrier material did not heave to the soil surface over time. The general depth of frost for the area is about 36 inches. A conservative soil cover thickness with regard to soil freezing was specified at 42 inches. There were also 42-inch demonstration covers which passed the percolation criteria during the test year. A long-term erosion loss was calculated and an additional six inches of soil material was included for a total cover thickness of 48 inches. This depth of soil will not only absorb annual precipitation for all but the very wettest years, but it will also sufficiently contain the rooting depth for the native grasses established on the covers (Tetra Tech EC, Inc., 2007).

Fertility

The Alternative RCRA Covers at RMA will be constructed with subsoil borrow which is nearly devoid of organic matter and plant available nitrogen. Other major plant nutrients are generally adequate.

To alleviate nutrient deficiencies in the borrow soil, composted manure will be tilled into the surface 8-12 inches of the cover. The target organic matter (OM) composition in the constructed surface is one percent, which is the normal organic matter composition for most of the well-developed native soils at RMA (Walsh, 1988). This value can be achieved by incorporating approximately 20 dry tons per acre of OM into the soil. To achieve this rate, batches of composted manure are analyzed for percent OM and moisture content. These values are then used to calculate the rate of application to achieve the 20 dry tons of OM per acre.

Seeded Species Mix

A number of factors were considered when developing the seed mix for the Alternative Covers at RMA. The plant communities established on the covers needed to be self-sustaining and provide reasonable habitat for prairie wildlife since the covers are located on a National Wildlife Refuge. To these ends, only plant species native to the region were included. Plant transpiration is an important component of the alternative design. After precipitation is stored in the soil surface (sponge) it must be returned to the atmosphere via evaporation and transpiration. Plants with rooting characteristics that would be able to "pump" soil moisture from the entire thickness of the cover back into the atmosphere were required. For this objective, grass species that would develop deep, fibrous root systems were selected. In order to maximize the seasonal duration of transpiration, both cool and warm season grass species were selected. Taller grass species with comparably larger leaf area index were also selected to maximize potential transpiration. Tall grasses may also act as a deterrent to colonization of the covers by prairie dogs. Grazing and burrowing activity by these animals could jeopardize the integrity of the cover design. Bunch grasses were included for structural diversity that would provide improved habitat. Rhizomatous species were selected for soil stabilization. Drought tolerance was also a long-term consideration. To address this concern, a low percentage of highly drought tolerant species (i.e. blue grama [*Bouteloua gracilis*] and buffalo grass [*Buchloe dactyloides*] were included. There was a small potential for pockets of higher pH soils to occur in the covers. To address this concern, *Alkali sacaton*, a high pH/salt tolerant species was included. The final seed mix is presented in Table 1.

TABLE 1. ALTERNATIVE RCRA COVER NATIVE GRASS SPECIES MIX				
Scientific Name	**Common Name**	**Variety**	**lbs PLS/Acre**	**%**
Buchloe dactyloides	Buffalo Grass	Cody	0.7	2.5
Buchloe dactyloides	Buffalo Grass	Native*	0.7	2.5
Bouteloua gracilis	Blue Grama	Alma	0.05	2.5
Bouteloua gracilis	Blue Grama	Birds eye, Bad River or Native*	0.05	2.5
Panicum virgatum	Switchgrass	Nebraska 28	0.4	10
Bouteloua curtipendula	Side-oats Grama	Vaughn	0.8	10
Sporobolus airoides	Alkali Sacaton	Salado	0.02	2.5
Sporobolus cryptandrus	Sand Dropseed	Native*	0.01	2.5
Schizachrium scoparium	Little Bluestem	Pastura	0.6	10
Pascopyrum smithii	Western Wheatgrass	Arriba	4.2	30
Stipa comata	Needle-and-thread	Native	0.7	5
Elymus trachycaulus	Slender Wheatgrass	Pryor or Revenue	1.0	10
Elymus lanceolatus ssp lanceolatus	Thickspike Wheatgrass	Critana	0.5	5
Koeleria cristata	Prairie Junegrass	Native	0.02	2.5
Elymus elymoides	Bottlebrush Squirreltail	Native	0.02	2.5
		Grass Species Total	**9.77**	**100**
Grass species: “Native” (*) seed varieties shall be from appropriate climatic region. Sources for native seed variety shall be subject to inspection and concurrence by the Contractor before Subcontractor is authorized to proceed with seeding.				

Noxious and other weed species, as well as shrubs and other deep tap rooting species were specifically excluded from occurring on the covers. It is anticipated that herbicide use will be required in the initial plant establishment years, therefore, forb species were not included in the mix.

After seeding, native grass hay mulch was spread and crimped into the cover areas to stabilize soils during vegetation establishment.

Irrigation

Unpredictable interruptions to construction schedules, as well as vagaries in precipitation distribution engender the reliance upon irrigation for establishment of the seeded plant communities. Seeded areas are irrigated for the initial growing season. The irrigation strategy includes frequent, but short duration irrigation initially to stimulate germination, followed by less frequent, but longer duration irrigation to stimulate deeper root growth, and a gradual reduction in both frequency and duration to harden plants for winter survival. A total of 6 inches of supplemental water was specified to be applied during June, July, and August regardless of natural precipitation amounts.

Shell Disposal Trenches Alternative RCRA Cover Construction Schedule

The Shell Disposal Trenches Alternative RCRA Cover (Shell Cover) was the first alternative cover to be constructed at RMA. At 20 acres, this was the smallest of the six alternative covers to be constructed that total about 450 acres. Construction of the Shell Cover experienced many weather related delays, as well as design changes during initial construction activity that also caused delay in the schedule.

The sub-grade for the Shell Cover was completed during 2005. Construction of the Shell Cover was initiated at the end of September in 2006 with placement of the biota barrier layer. Cover soil placement began on March 5th and was completed on June 18, 2007. Soil amendment incorporation was completed the following day, and seeding occurred from June 20-23, 2007, well beyond the seeding window dates initially specified. A modified irrigation schedule began on July 2 and supplemental water was applied until September 15th. A total of 12.25 inches of irrigation water was applied during the two and a half months of irrigation activity. This is more than twice the rate initially specified. The increased rate was justified due to the late seeding date and the hot, dry weather conditions that prevailed during the months after seeding.

Results

Quality Assurance and Quality Control data indicated that all aspects of the specifications for soil texture, placement density, soil amendment incorporation, seeding and the modified irrigation schedule were achieved.

The percolation criterion (1.3 mm/year) does not apply until the vegetation is characterized by an established plant community (after the 5th growing season). However, initial percolation data indicate that the cover system is performing as designed.

Because of the late seeding date there was concern regarding establishment of seeded species. However, the vegetation assessment conducted at the end of September, 2007 indicated that a diversity of seeded species had germinated and established during the irrigation period. Total live cover averaged an exceedingly high 74% with total ground cover averaging 89%. The irrigation applied seemed to be successful insuring vegetation establishment (Figure 5). Weedy species occurred and, although not considerable, will likely require control in subsequent growing seasons (Tetra Tech EC, Inc., 2008).

Figure 5. Shell Trenches Alternative RCRA Cover at Rocky Mountain Arsenal National Wildlife Refuge, September 27, 2007

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HIGH ALTITUDE NATIVE RESTORATION AT THE WINTER PARK RESORT

Denise Arthur, Ph.D.
ESCO Associates Inc
5360 Manhattan Circle, Suite 200
Boulder, Colorado 80303

and

Michael Ricketts
Recreation Forester
Arapahoe Roosevelt National Forest
Sulfur Ranger District
9 Ten Mile Drive
P.O. Box 10
Granby, Colorado 80446

ABSTRACT

Re-establishment of vegetation at high altitude is a difficult process. Seed germination, seedling growth, and establishment of plant communities are extremely slow and difficult due to the extreme limitations of the environment. Winter Park Resort near Winter Park, Colorado built two new ski lifts in 2006 and 2007. Both projects were at high altitude, with the highest point of the lifts at 11,500 feet and 12,000 feet, respectively. To greatly accelerate plant establishment and development, and to perpetuate plant communities maximizing representation of local genomes, re-establishment of pre-existing plants was undertaken. Plant material in rocky soil was salvaged by hand, and in areas with lower rock densities, plant material was salvaged by machine. The ski area is on Forest Service leased land which therefore required Forest Service input and over-sight. The projects were carefully planned and implemented. The success of the projects can be attributed to the simultaneous salvage of topsoil and plant material by machine, as well as hand salvage of intact plant material in areas inaccessible to the machine. Details critical to success included 1)Retention of large and small rocks for reinsertion into the reconfigured sites to maximize blending with intact adjacent habitat. 2) Careful hand placement of all the plant material as represented by results from 2006 that showed very high survival. The area restored in 2007 will be monitored for success in 2008. Another key to the success of the project was the constant oversight by Winter Park personnel, Winter Park's consultant, and the Forest Service.

INTRODUCTION

Winter Park Resort, near Winter Park, Colorado built new ski lifts in 2006 and 2007. Winter Park Resort is located in Grand County, 70 miles northwest of Denver Colorado. The Resort operates on approximately 3,630 acres of the Arapahoe National Forest on the south side of the Fraser River Valley. The Eagle Wind lift was built in 2006. The majority of the disturbance for this lift was from a utility line and two ¼ acre disturbances at the top and bottom of the lift. The utility line was 2700 feet long requiring a trench which traversed several ecotones and extended from a concession area (Lunch Rock) at 11,200 feet elevation to the top of the lift terminal at 11,500 feet. The Panoramic lift built in 2007 is a 6-passenger detachable lift which required the removal of old lift towers and installation of new lift towers, in addition to the construction of a large top terminal at nearly 12,000feet elevation. The unload zone of the Panoramic lift is about 1 acre of disturbance. The ski area has been planning several projects since 2001 - including the above listed projects.

Forest Service managers recommended Winter Park Resort hire a Restoration Ecologist to plan and over-see the work, so that the restoration of the disturbed areas would be state-of-the-art. Winter Park Resort Director of Planning and Development, Doug Laraby, supported the recommendation and agreed to contract a consultant in 2006 and 2007. Winter Park's Bob Dart, the project manager in 2007, also supported the close over-site by a Restoration Ecologist. As a result, two restoration plans were developed by ESCO Associates (one for each project) and approved by the Forest Service. The Restoration Ecologist, Denise Arthur, was intimately involved during all phases of the project: site lay-out, plant salvage, topsoil salvage, subsoil storage, topsoil replacement and final re-planting. Several Forest Service specialists were also involved in the project early in the planning process, including Forest Service Project Lead, Mike Ricketts who was often on site over-seeing all aspects of the project and was vital to its success.

GENERAL RESTORATION INFORMATION

Reestablishment of vegetation at high altitude (11,500 - 12,000 feet) delays seed germination, and seedling establishment. The maturation of plants and the on-going development of the plant communities of even modest dimensions are processes that are excruciatingly slow due to the extreme limitations of the environment. To ameliorate slow plant community development, we salvaged and replaced intact plant material, not only to perpetuate adapted genetic plant communities, but also to preserve much of the root and shoot development that would otherwise take MANY years to (re)develop. Plant salvage of the intact material will also retain much of the original plant community diversity. In general, there are no commercial nursery sources of the variety of plant species that grow at these altitudes.

The maintenance and timing of the replacement of the salvaged plant material is a crucial decision. Generally the shorter the length of time the salvaged material is in storage, the better the survivability. An important maintenance activity, which allowed storage of salvaged plant sod, was watering.

Another consideration during the construction was the peripheral disturbance outside the actual construction area. This includes storage of topsoil and rocks, plant material storage, and equipment access and storage. Limitations on outside disturbance were set prior to the project implementation.

Restoration Goals

1. Plan and implement the project such that it follows an ecologically sound sequence and process
2. Visually ameliorate the top terminals to blend with natural topography and vegetation
3. Accelerate successional processes
4. Maintain genetic integrity and species composition of the plant community
5. Balance constructability with ecological considerations/recovery potential
6. Limit peripheral disturbance
7. Control invasive weeds

Disturbance Zone

Eagle Wind Lift

The main disturbance on the Eagle Wind Lift was the 2,700 foot long utility line trench and the top terminal unload area. The trench was 3-4 feet deep and 3-7 feet wide depending on excavated rock. The utility line route ascends from the Lunch Rock area and proceeds up through several ecotonal vegetation types. The first type is Engelmann spruce forest within a vegetation matrix dominated by broom huckleberry, along with species with an affinity for moderate snow-accumulation such as timber oatgrass (*Danthonia intermedia*). As the climb steepens, the route is "leeward" in nature and the number of scattered wind-dwarfed krummholz increases as the Englemann spruce decreases. The route continues through more east-facing areas that even in the middle of June had some accumulated snow in 2006. From the end of krummholz to the summit, the last reach of the utility path passes through what might be termed an alpine turf community. Although the turf is not continuous, the sedges and grasses such as spike trisetum (*Trisetum spicatum*) indicated a zone of very modest snow cover that is bare well into the fall and then opens early in the spring. The top terminal at 11,500 feet is fellfield plant community with little snow accumulation and distinctive cushion plant dominated rock matrix plant community. The chairlift towers descend from the top terminal taking a different route than the utility line through fellfield but then quickly descends through a short section of krummholz and into the majority of Engelmann spruce forest. The bottom terminal is on the edge of a lush creek corridor ending near a wetland area surrounded by large spruce trees.

Photo: Before disturbance utility line path, transects multiple ecotones, including fellfield above.

On both sides of the trench disturbance materials were separated into four distinct groups, topsoil, restoration rock, subsoil, and plant material. The top terminal and unload area of the project was a cut and fill operation.

Panoramic Lift

The Panoramic lift's main disturbance was the unload areas at the top and bottom terminals. The top terminal is at 12,000 feet, and as with the Eagle Wind, the top terminal was a cut-and-fill area configured to allow skiers to off-load and exit the lift area. The bottom terminal area at 10,300 feet elevation was also a cut-and-fill operation. However, plant material and topsoil were more accessible by machine and more easily removed and replaced using conventional methods. The restored top terminal was sloped as close to 3:1 as possible to enhance vegetation growth and blending with the natural topography. One portion of the restoration at the front of the top terminal, opposite the unload area, was quite steep (approximately 1:1 to 1.5:1) The fellfield plant community within the disturbance area at the top terminal consists of a matrix of rock and cushion plant dominated community. As such, it represents the most difficult end of the recovery –potential spectrum for alpine tundra. Soils in fellfield are only 4-8 inches thick but vitally important to the existence of the cushion plants that manage to establish and survive.


Photo: Panoramic lift before disturbance

Construction sequence for both lifts and the utility line

The general construction sequence was to first hand salvage as much plant material as possible between rocks in the krummholz and fellfield areas as soon as possible in the spring. Hand salvage was accomplished starting in early July on the Eagle Wind and at the end of May for the Panoramic lift. Starting on the Panoramic lift in late May was slightly too early as the crews had to work around the accumulated snow drifts and some frozen ground. A mid-June start for the Panoramic lift would have been better.

 

Photo: Panoramic Lift plant salvage late May

During the hand plant salvage phase, a number of small surface rocks were also salvaged and placed with the plant material in a separate stock pile. Later these surface rocks were replaced and set by hand during the plant replacement phase, to ensure the disturbed site would blend with the surrounding undisturbed area.

Once the hand salvaged plant material and small rocks were removed, the topsoil was stripped and the large surface rocks were salvaged with equipment. Topsoil on the lower portions of the Eagle Wind utility line was salvaged with equipment because the area had less rock and the majority of the topsoil and plant material could be salvaged together.

Once all the surface components were salvaged, the subsoil and subsurface rocks were removed and stockpiled or used in the cut and fill process.

Once disturbed areas were re-contoured with subsoil, large surface rocks were counter-sunk into the disturbed areas at approximate natural plant-sheltering heights. The large rocks enhance erosion control, improve the natural aesthetics and blend with the native undisturbed adjacent areas. Rock placement was carefully performed so lichen faces established on the rock were favorably placed and the rock densities and configurations were matched to the surrounding rock configurations. Attention to detail in placing rock with the lichen side up, proper counter sinking height, direction of the rock into the subsoil, and numbers of rocks left on the surface, was necessary to establish proper open niches for plant material replacement and for blending with the surrounding habitat. This required close oversight by the onsite Ecologist during this phase in particular.

Photo: Eagle Wind rock placement with clam bucket and spider hoe. (Right) Panoramic lift rock placement with excavator with a bucket thumb

After the subsoil re-contouring and large rock placement, the topsoil was replaced as a matrix between the large rocks over the entire disturbed site. After completion of the topsoil replacement, the hand-salvaged plant material was carefully hand-reset (described below). The salvaged small loose rocks were also set in between the plant material by hand at this time.

Stockpiling and Geotextile

On the Eagle Wind project, all salvaged and removed material was stockpiled outside the disturbed area on geotextile material. The Eagle Wind utility line construction had several stock piles of material placed along side the trench or adjacent to the top terminal disturbance. Placement of materials on the geotextile outside the disturbance included hand and machine salvaged plant material, topsoil, subsoil, and rocks. On the Panoramic project all the plant material was placed outside the disturbance on geotextile, however the topsoil and rocks were placed mainly within the disturbance area and construction was attempted in phases. While this seemed like a good idea at first, it did not turn out to be practical because the materials including topsoil had to be moved multiple times during the operation.

During the Eagle Wind construction all the topsoil and subsoil was placed on polypropylene geotextile. It was thought that the material could be attached to the equipment and lifted to place the last of the materials into the trench or the last veneer of topsoil on the surface. As it turned out, the material was not strong enough to sustain the weight of the soil. It ripped and dumped the soil onto undisturbed portions of the area. It was crucial that the subsoil, or for that matter the topsoil, did not bury the intact plant material. Several attempts were made to modify how the geotextile was lifted, but to no avail. The last of the subsoil and topsoil had to be hand shoveled into piles and picked up by the machine, or hand shoveled directly into the trench.

Trench backfilling proceeded carefully to ensure that the final backfill grade was lower to accommodate topsoil and plant material. At one point during the subsoil placement the contractor was required to remove subsoil because not enough room had been left for the topsoil and plant material. The subsoil was also compacted either by the spider hoe bucket or the spider hoe wheels to assure no piping occurred. The final grade after topsoil placement matched the undisturbed elevations on either side of the trench.

To avoid the need for excessive hand work on the Panoramic project, heavier geotextile (4 mil) was ordered. Unfortunately the geotextile was still not heavy enough gauge to lift the soil with equipment. Another way to handle excess soil was devised for the Panoramic tower holes located above treeline. Large 2 cubic yard soil bags were used to store the subsoil and topsoil for later placement.

Photo: Soil bags used above treeline. Limited loose soil on undisturbed ground. (Right) One soil bag was removed by Maruka rubber tracked dump truck the others were removed by helicopter

The soil bags worked well and the material did not contaminate the intact plant material surrounding the tower holes. The "block footer" construction method used on six lift towers above timberline resulted in excess soil material.   The helicopter was able to lift the soil bags and place the material where fill was needed on other areas of the project. The only downside to the soil bags is that it took slightly longer to stockpile the material since it can not simply be flung into a pile but had to be carefully placed in the open soil bag. However, this was offset by the fact that no hand work was required for material replacement. The best bags were those that could be opened by a string on the bottom of the bag. If soil bags had been used on the Eagle Wind lift, a lot of time and labor could have been saved. Filling the trench would not have been such a slow and tedious process, trying to keep the geotextile from breaking. In the end much of the subsoil and topsoil had to be raked and piled and placed directly into the trench by hand. The trench backfill could have been simply to lift the soil bag over the trench with the spider hoe and then have someone pull the cord that opens the bottom of the bag. The soil bags could hold 2 cubic yards at approximately 2500 lbs. as measured by the helicopter scale.

On the Panoramic project there included the use of a rock hammer to cut the top terminal unload area back to the survey depth. It should be noted that whenever an area is excavated down to bedrock it will need to be over-excavated.   It is important to provide sufficient room for mineral soil replacement to sustain plant material over time.

Plant Salvage and Replacement

As mentioned, the hand plant salvage phase of the project occurred in early July for the Eagle Wind and late May on the Panoramic projects. A variety of tools were brought to the project site, however the best tool for the job was a standard spade tipped shovel. The point of the shovel was forced into the soil 6 to 8 inches in a circular fashion between rocks then the plant "plugs" with intact soil were pried upward. The sod pieces in some cases were as large as 2 feet wide. The goal was to take plugs as large as possible to maintain the integrity of the root system.


Photo: Eagle Wind (11,500') plant salvage large sections. Placed on geotextile outside disturbance

All the plants were stockpiled outside the disturbance zone on rolled out pieces of geotextile. The geotextile was porous so the intact plants below would have access to air and water. The plants were set on the geotextile tightly so that the edges of the pieces were against each other to keep the roots from being exposed. On the Panoramic project some sections of the hand salvage process were aided by the use of a rubber tracked bobcat. The bobcat followed predetermined paths to where the hand salvage was taking place. The plant material was set onto a tray specifically designed for the project by Winter Park employees. The tray is lined with geotextile fabric. Once the tray was full of plants, the bobcat was driven outside the disturbance area. The plants were removed by sliding the geotextile off the tray.


Photo: Panoramic lift (12,000), hand plant salvage placed on tray, picked up by bobcat and set outside disturbance area. Plant material is covered in jute mat.

The plants were watered the day they were removed from the ground and then watered two to four times a week thereafter depending upon precipitation. Water availability was logistically difficult at the top of both terminals. For the Eagle Wind project most of the water was brought in by helicopter in large tanks and set in strategic locations to facilitate watering plants along the trench by gravity. In some cases the tanks were filled with water brought up by a low ground pressure vehicle called a Terratrac AEBI. For the Panoramic project water was brought in tanks with a pump utilizing the old Timberline chair lift which remained operational throughout most of the project. Watering was carefully performed by Winter Park and ESCO personnel. A large heavy high pressure spray was not used but rather a slow soaking stream. Jute mat was draped over the plants to protect them from desiccating winds and sun intensity.

Photo: Water tanks and pump on the Panoramic lift. (Right) Soaking watering spray

The plants were not replaced as soon as we would have liked. Watering the plants allowed extended storage time and the plants did quite well. One could see blooming flowers rising through the jute mat. The Panoramic project plants were replaced by the end of September, the Eagle Wind plant replacement was completed by mid October. This translates to 4 months plant storage for the Panoramic and 3 ½ months for the Eagle Wind.

Photo: High altitude plants flowering through jute mat during storage

The plant material was carefully set making sure to counter sink the roots of the sod pieces so that the tops of the plants did not extend above the height of surrounding rock more than the original condition. Soil was firmly packed around the edges of the replaced sod pieces. The placed sod left no roots exposed and the soil was sufficiently packed down so the surrounding soil would not wash away during precipitation events. Any topsoil left on the geotextile after plant replacement was used on the restored area to set the native sod pieces, or to thicken the topsoil where needed.


Photo: Panoramic Lift completed hand set plant material and rocks

Sensitive Plants

The Forest Service flagged *Draba exunguiculata*, a Forest Service sensitive plant, two years prior to the construction of the Panoramic Lift. The flags were set close to the individual plants, but not directly next to them, making them difficult to locate. The alpine mustard is miniscule and a couple of other mustard species look very similar. When plant salvage began the plants were not blooming and therefore it was impossible to tell which plants were the sensitive ones. The entire area where sensitive plant flags were placed was sectioned off and all salvaged plants within that area were carefully set in a specific "stockpile" area. The idea was to plant the sensitive mustard plants in an area with similar snow load and wind scour. The plants were then salvaged June 23, when they were actually blooming which is key to identifying them properly. Once the plants were found among the salvaged plants, four appropriate areas were flagged off so the Forest Service could monitor the replaced populations. Care was taken to place the plants in some what sheltered places. After planting, tiny white gravel was spread on the surface to match the surrounding conditions.

Photo: Planting salvaged sensitive plant *Draba exunguiculata*. (Right) Completed planting of sensitive plant (near tip of shovel) .

Seeding

The intent of seeding was to provide additional vegetation within the bare areas among the

Species	Common Name	Variety	% of mix*	PLS / ac.**	1000 PLS / sq.ft.
Trisetum spicatum	Spike Trisetum	VNS	50	1.52	0.04
Festuca brachyphylla	Alpine Fescue	VNS	15	0.35	0.01
Phleum alpinum	Alpine Timothy	VNS	10	0.34	0.01
Deschampsia cespitosa	Tufted Hairgrass	Peru Creek Cent. or So. Rky	10	0.12	0.00
Poa alpina	Alpine Bluegrass	Mtn Source	15	0.46	0.01
		TOTAL	100	2.79	0.06

lightly disturbed areas, and/or between the replanted plugs. It is hoped that the original disturbed plants will recover and reassert their former dominance. The Forest Service had some concerns about the genetic make-up of the seed coming from commercial sources, so one species sown on the Eagle Wind lift was left out. In preparation for the Panoramic Lift, seed was contracted for hand collection from Western Native Seed in 2006. In addition to this hand collected seed, ESCO collected seed from some of the high altitude adjacent *Deschampsia* dominated meadows. The *Deschampsia* was collected by mowing the grass right after the seed heads had matured and collecting the clippings with the seed. This essentially ended up like meadow mulch.

Photo: Mowing seed collection method adjacent to the Panoramic lift disturbance.

The seed and *Deschampsia* mulch was broadcast by hand onto a newly raked, decompacted surface. Once sown, the seed/mulch was immediately raked into the surface. Raking was sufficiently deep to result in loose enough soil, ready to accept broadcast seed; but not overly deep to rip out the roots and root crowns of the existing plants or planted plugs. In steep areas on both lifts, jute mat was installed, such that the overlap was oriented for water run off and then overlapped again for wind exposure (downwind rows lapped under the upwind row). A trench was dug at a minimum of 6 inches deep for anchoring the uphill edge of the jute mat, and staked down inside the trench. Biodegradable stakes (no less than 6 inches) were used in the lapped sections at a minimum of 18 inch intervals. In addition to stakes, rocks were placed as directed to anchor the jute matting.

Photo: Jute mat installation Panoramic lift. (Right) Jute mat installation Eagle Wind lift

An important lesson learned was that all helicopter work should be complete before seeding is performed. On the Panoramic lift a very large helicopter (Sky Crane) was used to set the towers. This helicopter had a great deal more prop wash than anticipated and a large cloud of topsoil and potential seed bed was raised. It had to be re-worked and reseeded.

Photo: Do not seed when there is still helicopter work yet to be performed!

Topsoil and Rock Salvage/Subsoil Removal

After removing plant material by hand, surface rocks and topsoil was salvaged separately from the subsoil. The same geotextile fabric was placed on intact plant material outside the disturbance zone. Rocks and topsoil were placed on the fabric to be used in the final restoration. Once the topsoil and rocks were placed in storage, the subsoil was removed and, if necessary, separately set on geotextile outside the disturbance; otherwise the subsoil remained within the disturbance zone during the cut and fill operations.



Photo: Welded bar for topsoil salvage spider hoe machine plant and topsoil salvage together

Access

Access to the Eagle Wind was overland. The equipment trips were limited to reduce disturbance. In order to access the site with tools and equipment, ATV use was allowed All other access was on foot. All construction vehicle operators were emphatically instructed on the importance of slow, careful ATV traverse, without spinning wheels, and in the case of tracked machinery (MANTES crane) absolutely minimal track setting and pivoting. The crane path to the top terminal was laid out in advance to reduce disturbance to fragile vegetation and wetlands and to make a clear straight path to the top without pivoting the grousers on the crane. A consistent ATV path was not outlined, rather the idea was to disperse use every time the ATVs were driven up to limit concentrated compaction and disturbance. The drive up was complicated with large rocks, a wetland area, and steep slopes. These obstacles ended up limiting the number of paths available and the ATVs began to take certain routes over and over which ended up creating several visual paths up the mountain. It was also difficult to control the ATV operators. In retrospect it would have been better to choose one path that everyone would travel and then it could be properly managed and restored.

Photo: Four paw ATV operator in training. (Left) Eagle Wind during trench grade restoration, faint ATV trails forming to left of the trench

The main access to the Panoramic top terminal was by using the old Timberline lift that unloaded in nearly the same spot as the new lift. The Timberline lift was used for construction personnel and small equipment access all summer in 2007 before it was decommissioned. Some ATV access was required for emergency egress, i.e. lightning, in case of injury, and for getting certain materials to the top terminal. The limited ATV access for the Panoramic project utilized an existing trail route laid out in advance by the Forest Service. The disturbance associated with access by ATVs was decompacted and seeded. Initial equipment including two trackhoes and a skid steer were driven to the top terminal earlier in the summer over snow and driven down from the top terminal over pre-designated routes. All vegetation disturbed by equipment access was decompacted and seeded.

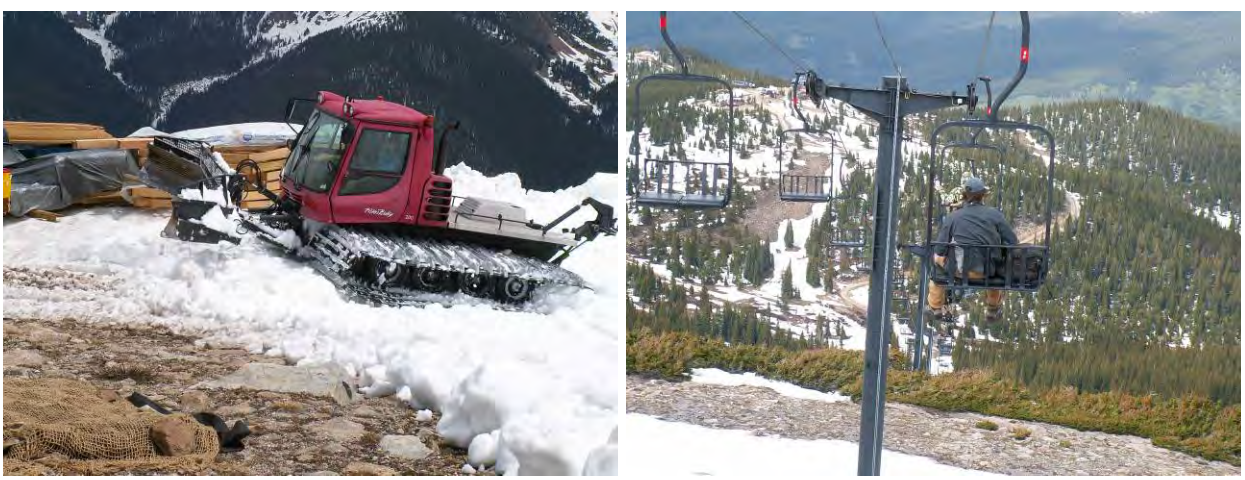

Photo: Panoramic lift equipment access by snow road created by snowcats, personnel access by chairlift

Equipment

Mostly low ground pressure equipment was utilized. Most equipment was tracked for the Panoramic lift. For instance, two excavators (330 &220) were used and they both had lower profile grousers (street grousers) to reduce vegetation damage to the fellfeld plant community when mobilizing off the site. The excavators had several adaptations for the cut and fill including a bucket with a thumb for moving and setting rocks, a rock breaker to excavate through bedrock, and a welded smooth bar across teeth of the bucket for topsoil removal. Other equipment for both the projects included spider hoes, Maruka rubber tracked dump truck, a rubber tracked skid steer, snowcat, ATVs and an AEBI vehicle.

Photo: Maruka rubber tracked dump truck and spider hoe used on the Eagle Wind lift.

LESSONS LEARNED

1. Transplanted vegetation salvaged from the disturbed site has great success.
2. Make sure all helicopter work is completed before seeding due to prop wash.
3. Consistent oversight by a qualified ecologist, Winter Park personnel and the Forest Service was important for success.
4. Detailed restoration work is critical. Including, salvage and placement of plant material, topsoil and rock.
5. Even at high altitude there is ample topsoil to salvage.
6. The geotextile material worked well for plant storage but was not strong enough to sustain the weight of soil. It ripped and dumped the soil onto undisturbed portions of the area. It was crucial that this material not bury the intact plant material. Several attempts were made to modify how the geotextile was lifted, but to no avail. Much of the subsoil and topsoil had to be hand shoveled into piles and picked up by the machine or hand shoveled directly into the trench
7. Soil bags worked well to store and remove soil from the site without disturbing intact habitat. The use of the soil bags likely saved money since the soil materials did not have to be handled by hand. The best bags were those that could be opened by a cord on the bottom of the bag.
8. A Late May start for the 11,000 to 12,000 feet was too early the crews had to work around the accumulated snow drifts and frozen ground. A mid-June start is better.
9. Topsoil and rocks were placed within the disturbance area on the Panoramic Lift and construction was attempted in phases. While this seemed to be a good idea initially, it did

not turn out to be practical because it was hard to manage the materials without moving them. For instance, topsoil had to be moved multiple times during the operation.

10. During the Eagle Wind construction obstacles ended up limiting the number of paths available to ATVs. ATVs traffic began to repeatedly take certain routes due to the maneuvering difficulty and obstacles (e.g. wetland) which ended up creating several visual paths up the mountain. It was also difficult to control the ATV operators. In retrospect it would have been better to choose <u>one</u> path that everyone would travel and then manage and restore at the end o the project.
11. Maruka rubber tracked dump truck was very efficient at moving materials and did little damage to the intact plant community.

CONCLUSIONS

The Winter Park high altitude projects have been a success as of the summer of 2007. There is qualitative information for the Eagle Wind lift restoration that estimates that 98 percent of the vegetation plugs on the Eagle Wind greened up and were well established in the first year after restoration. . (No follow up can be performed on the Panoramic lift until summer of 2008). The intact plant restoration was far superior to the areas that were seeded on the Eagle Wind in terms of cover and production. Some of the seeded grasses did germinate but they were extremely small and fragile in the first growing season. It is obvious that it will take years for the grass foliage to develop into a plant community that would be appropriate for erosion control and would blend with the surrounding habitat.

Photo: Planted plug and germinating native grass (right) planted at the same time after one growing season.

The Eagle Wind Utility trench restoration was already starting to blend well with the adjacent habitat. At the top of the lift the trench is difficult to find in the photo below. The undisturbed *vaccinium* that was intact <u>under</u> the geotextile, died back, but was slowly re-establishing from intact root sources. As the *vaccinium* recovers it and other species will establish in the interspaces between plant plugs. The hope is within the next two years, the trench disturbance will not be visible from Lunch Rock.

Photo: Utility trench disturbance 1st year blending completely at the upper portion and well in the center of photo

The use of intact plant material was the best way to perform the restoration on a project of this scale. It took a team of committed people to make the project work. Any project is only as good as its team of people that perform the work and Winter Park and the Forest Service put together a great team.

MT. GOLIATH REVEGETATON PROJECT
AT THE
DOS CHAPPEL NATURE CENTER

Mark Fusco
Senior Horticulturist
Denver Botanic Gardens
909 York St
Denver, Colorado80214

Denise Arthur Ph.D.
ESCO Associates Inc.
5360 Manhattan Circle, Suite 200
Boulder, Colorado 80303

ABSTRACT

The presentation and paper will take the audience through the process of revegetating a disturbed natural site around the Dos Chappel Nature Center. The paper will discuss the construction of a naturalistic rock garden, and the process of revegetating the rock garden from seed collected at Mt. Evans. Construction and slope revegetation around a new parking lot will be discussed and contrasted with the revegetation of the garden area. Over 58 species of plants have been planted on the site thus far. A projected goal of an additional 50 species will be added over the next 5 years. The paper will focus on garden design, seed collection, plant propagation and construction of the highest alpine rock garden in North America.

INTRODUCTION

Mt. Goliath forms the Northern shoulder of the Mt. Evans massif, with a peak of 12,100'. The peak is located just above tree line. Descending from this point one finds a variety of alpine plant communities. Above tree line Fellfields; Crevice, Talus and Scree communities, and dry meadow communities form a mosaic of niches in which indicator species thrive. Moving down the mountain these same communities mix with the krumholz, giving way to the subalpine forest of brislecone pines and engelman spruce below. At 11'500 feet and slightly North East of the peak, the forest breaks along a windswept ridge. At this elevation a willow carr, and now the Dos Chappell Nature Center, punctuate the natural area. This, a popular stopping point along highway 14 (the road to Mt. Evans) has undergone a number of iterations leading to its' present state. The area surrounding the Dos Chappel Nature Center is the site of the Mt Goliath Revegetation Project at the Dos Chapel Nature Center.

Site History

Denver Botanic Gardens has had a long standing relationship with the United States Forest Service at Mt. Goliath. In 1967 the M.Walter Pesman Trail was constructed on Mt. Goliath by the USFS. This trail was named for the Landscape Architect/ Botanist and long standing board member of Denver Botanic Gardens (DBG). The trail was designed with two access points (trail heads) along highway 14; one close to the summit and the second just below tree line at 11,500' where the Nature Center is now located. This allowed visitors to start at the top in the alpine tundra and descend into the krummholz and sub-alpine forest of ancient bristlecone pines. Denver Botanic Garden and the United States Forest Service agreed to share the maintenance responsibilities for the new trail. DBG also began to offer guided wildflower hikes in 1968. The guided hikes are still offered today, starting in June and ending in August.

By the 1990's parts of the trail were in need of repair, especially the last 200 yards near the lower trailhead. This section of trail had devolved in to a series of muddy social trails meandering through the willow carr. In addition, the area around the parking lot had been used to park C-Dot heavy equipment and was devoid of vegetation.

Plans were laid in 1995 the USFS and DBG to fix the trail and create a small rock garden at the lower trailhead. The Garden Club of Denver donated the money to construct the garden and the USFS, with assistance from Volunteer for Outdoor Colorado, reconstructed the trail in 1996. DBG employed a Czech rock garden designer named Zdenik Zovlanik to create the new rock garden. Zovlanik, with the help of DBG volunteers and USFS employees, constructed a rock garden complete with a perennial stream running through the middle in two weeks. Plants were relocated from the trail and were then worked directly into the new rock garden by volunteers, and they successfully established. The rock garden transformed the compacted and unvegetated area into a habitat more suitable for the new transplants. The rocks provided crevices for plants like *Silene acaulis* and *Heuchera bracteata* and wind breaks for a few seedling conifers. This new garden also helped generate a renewed interest in the site from DBG, USFS and Volunteers for Outdoor Colorado (VOC). Having an alpine satellite was a great achievement for DBG, making them the first North American Botanic Garden to have such an amenity. Alpine satellite gardens are common among European botanic gardens and DBG now had the opportunity to create, curate and maintain their own alpine site. It was decided that this site would differ from European alpine gardens and utilize only native species, found growing naturally on Mt. Goliath.

THE NATURE CENTER

In 1996 the USFS's requested that VOC help reconstruct the lower portion of the trail and add crusher fine paths around the small rock garden. Dos Chappel, director of VOC, in 1998 had a renewed interest in the project and led the charge to raise money to build a nature center on the site.

During the summers of 1998 to 2000 the garden was replete with transplants and a few nursery bought native plants. The criteria for the greenhouse grown plants was that they had to be grown from a wild collected Colorado seed source. (Note: Later this policy was changed and we soon started using only plants that were grown from wild collected seed from Mt. Evans and Mt. Goliath.)

Funding for the nature center was available in 2000 but it took two years to create a site plan for the building. In 2002 building construction was underway and the building was completed in 2003. DBG decided to extend the existing rock garden and build more rock gardens surrounding the nature center. Incorporated into the design was a plan to construct and plant the garden to represent six different alpine and sub alpine plant communities (dry meadow; wet meadow; crevice, talus, and scree; fellfield, krumholz, and bristlecone forest). This provided the opportunity to offer interpretation inside and outside the nature center about the specific plant communities.

Dos Chappell (VOC) passed away in 2003 and the building now commemorates Dos and his great contribution to VOC and the state of Colorado. Denver Botanic Gardens began preparing the site to construct the Alpine Rock Garden now the Dos Chappel Nature Center.

ALPINE ROCK GARDEN CONSTRUCTION

Soil and Rock Placement

Over 120 yards of soil was transported to the site from an existing C-Dot borrow pit located at just over 10,000 feet high along highway 103 for the alpine rock garden. The soil consisted primarily of decomposed granite and was a close match to the soil at the existing site. The soil was placed along the east side of the nature center according to the landscape plan. Eighty tons of boulders and rocks were also delivered to the site from the Central City Byway Project. Once unloaded all boulders weighing over 1.5 tons were craned into place with a 70 ton crane. The balance of the rocks and boulders were placed with skid steers and by hand. In all more than 10 DBG employees and interns assisted with rock placement. The rock placement for the garden was completed in 5 weeks. The garden plant communities included, fellfield, crevice, talus and scree area, krumholz, bristlecone pine forest, dry meadow. In addition, a drainage ditch was converted to a wet meadow/streamside garden. The rock work in each garden area was constructed to match natural rock formations from the corresponding plant communities.

Plant Propagation

In preparation for planting the rock garden on the east side of the Dos Chappell; Nature Center seed was hand collected from Mt. Goliath in 2003. More than 20 different species were collected with an emphasis placed on grasses and sedges. The wild collected seed was placed in seed pots, covered with plastic and placed outside shaded from the winter sun in the winter of 2003-2004. Cold stratification is necessary to initiate germination of many high altitude and native species. The seed pots were then placed in a warm mist house which keeps the plants at 80- 90 degrees F and 80 percent humidity. After germination they were moved to a cold green house at 45-55 degrees F and grown until a healthy root is established. At this point each small plant is divided from the crowded seed pots and moved into an individual plant cell. The plants were grown in both 2"1/4" cells and 2" tubes. Grasses and sedges were transferred to tubes and forbs were planted in the shorter wider cells. Both the tubes and the cells were a flat with 32 plants.. The flats were then taken back to the cool green house for continued growth. In April the flats were transferred outside to the nursery and grown under shade cloth. The grasses and sedges were quite easy to grow, but many of the forbs proved to be much more challenging. Most species in Asteracea like *Erigeron peregrinus, E. simplex, E. pinnatasectus, Solidago radiata* and *Artemesia campestris* were fairly easy to grow to a size conducive to planting. Their germination rates were fairly consistent from year to year. Other plants were quite variable. One year *Silene acaulis, Heuchera bracteata* and *Eriogonum flavum v. xanthum* germinated and proliferated while other years success was low, probably due to seed viability. *Phacelia sericea* and *Hymenoxys grandiflora* germinated quite well, but proved difficult to grow to a plantable size. It may have been better to sown these in situ. *Minuartia obtusiloba* was difficult to propagate and grow out even in years where larger quantity of seed was collected. *Castelleja rhexifolia, C. puberula*, and *C. minuata* were all relatively easy to germinate, but were also difficult to grow to a plantable size. The best success was with *C. puberula* which isn't surprising. One of the most abundant plants found on the tundra, *Geum rossii*, was difficult to germinate and grow, much like *Cirsium scopularum*. It was challenging to collect seed on *Eritrichium aretioides, Primula angustifolia*, and *Trifolium nanum*. The little seed we did collect never germinated. Both *Penstemon whippleanus*, and *P. virens* germinated easily if collected at the right time. The elk, deer, and marmots seemed to know, to the day, when to graze the most ripened seed. The birds picked the *Pinus aristata* seeds clean but left the *Picea engelmanii* which was fairly easy to grow.

Plant Installation

In July 2004 volunteers and employees began to install the flats of plants grown at DBG. Well over 200 flats of plants were installed into the garden. Indicator species were planted into their respective plant communities. For example cushion plants like *Phlox condensata, Paronychia pulvinata*, and *Silene acaulis* were planted into the fellfield garden. The spaces between tightly placed boulders in the crevice, talus and scree garden communities were planted with *Huechera bracteata, Polemonium viscosum, Trisetum spicatum*, and *Eriogonum flavum var. xanthum.* Grasses, sedges and three different species of Erigerons made up the dry meadow plant community. The wet meadow received all of the *Pedicularis parryii, Castilleja rhexifolia, Rhodiola integrifolia*, and willow cuttings. The krummholz and bristlecone pine forest proved to be the most challenging. We had a local nursery, Laporte avenue nursery, grow Engelman spruce from seedlings and we grafted 100 bristlecone pine cuttings onto standards in our green houses. Of those only 5 survived and are now planted in the Bristlecone pine garden and the krumholz garden. It is important to note that as the plants were installed they were watered well for the first two weeks and then at least once a week throughout September.

By the last week in September the all of the rock work and plants were installed. More seed was collected at this time to be propagated in the DBG green houses. Each year better results were achieved and more propagated flats were available. We also increased the number of flats we produced by dividing the grasses and sedges into more cells. These plants were then ready for the final phase of the revegetation and garden construction process.

PARKING LOT CONSTRUCTION

Throughout the process the parking expansion and parking lot slope revegetation plans were unresolved. By the end of 2005 the USFS developed a new parking expansion plan. The plan was to add 10 additional parking places to the small parking area. The new plans required hundreds of yards of fill to be brought in to construct the additional parking spaces. The USFS to put the parking lot project out to bid and had a signed contract in 2006. The pavement from the original parking area was removed in June, but the contractor didn't return to the site until late August which at this altitude does not leave much time to complete the project. Per USFS specification rock crusher fines were hauled in as fill. The fill was pushed down the slope and compacted with a sheep's foot compactor. Well over 200 yards of crusher fines were hauled up to Mt. Goliath, dumped and compacted. By mid September the crusher fines were in place and the sidewalk, which ran around the outer perimeter of the parking lot, was poured. A week later the road was closed due to weather and the remainder of the work would have to be completed in 2007.

In the winter of 2006 employees from DBG and from USFS had accessed the site on foot and noticed that the crusher fines were quickly eroding. The silt fence that was set up at the bottom of the slope was mostly covered and the crusher fines were eroding over the fence and washing into the natural area. The USFS and DBG had made the agreement that the USFS would administer the parking lot construction and DBG would revegetate the area around the parking lot. The USFS hired the consultants ESCO Associates to assess the situation with DBG. ESCO Associates walked to the site and had many concerns. The erosion was out of hand and how the site was left would be impossible to revegetate properly. Some slopes were left at the angle of repose and others were at a 1:1 slope. In addition the crusher fine material was sent in for soil analysis and it was determined that there were very few fines in the soil and generally no plant nutrients, or organic matter. Crusher fines were not a suitable planting media for revegetation. The general plan by ESCO Associates and DBG was to reduce the slope angle to as close to 3:1 as possible by trucking in suitable soil from another site and add large rocks for slope stability. However, in the spring of 2007 all parties were concerned about the continued erosion of the slopes, and additional upward piping of water from within the parking pad itself. The USFS engineers determined that the crusher fines weren't compacted properly and parking lot could fail all together if a different material was not used for the parking pad itself. The USFS made the decision to start over. All past work on the parking lot was torn out and hauled away.

DBG and ESCO Associates searched for a soil source that could be used to create the parking pad and could also be revegetated on the side slopes. A source of material was found on a construction site near Evergreen. The source material was similar in texture to the soil onsite. DBG and ESCO Assoc. provided continuos project over sight, working directly with the contractor to ensure that the grade construction would be conducive to revegetation and would be aesthetically pleasing. Over 400 yards of the soil was transported to the site. The material was placed in 2 foot lifts and compacted. The last two feet of material was left with only light compaction by approximately two passes with a tracked piece of equipment. It is important to leave at least two feet of loose material so plant roots can extend deep enough to tap water and nutrient source at depth. The tow of the slope had to be extended out into an undisturbed area to reduce the angle of the slope. This required more fill dirt and created a much larger revegetation area but was necessary to construct a site that could establish vegetation which ultimately provides long term erosion control and aesthetic value. A narrow portion at the lower part of the disturbance zone was a willow carr. As the willows were removed for the construction many cuttings were set into a small pile of soil. The willows were watered twice a week and eventually rooted and were placed in the final slope of the project.

DBG and ESCO Associates requested that the USFS provide large rocks for slope stability and so the area would better blend with the surrounding habitat. Large rocks also provide sheltered sites for certain alpine species. DBG and ESCO Associates wanted the slope to integrate into the surrounding landscape so all parties worked together in the field to create undulations and small ridges that mimicked the surrounding landscape. Rocks were also placed in a way that would mimic the natural geology of the area. In two months time over 90 tons of boulders were placed. The parking lot was out sloped and there was some issues with water concentrating on the restored slopes. The outer edge of the parking lot was armored, to create a bioswale, with hand placed rocks to slow the flow of water. In addition, large and small rocks were placed in concentrated erosion areas.

After all of the rocks were in place the hand collected seed from Mt Golitah was sown onto the slopes by volunteers at a rate of approximately 100 seeds per square foot. A high seeding rate was required because the material was not checked for viability, as it was simply collected and mildly mulched then applied. After the seed was applied it was raked into the surface with a hard tined rake. Jute mat was installed directly after seeding. A six inch trench was dug at the top of the slope and the jute mat was pined and buried into the trench. The matting was unrolled down the slope, and the edges were overlapped by 6” and staked with biodegradable stakes every 12 – 18 inches foot. The jute matting was cut out around the large rocks and staked for extra security. Wattles were secured in areas where there were more washouts.

After the jute matting was completed 300 grown out flats of plants were installed, including 85 seedling Engelmann spruces, grasses, sedges and forbs. The grasses and sedges plugs were planted in strategic locations to fill washouts and reduce erosion.

The final revegetated area around the parking lot added to the aesthetic value of the interpretive gardens and provided long term erosion control for the parking lot.

Interpretation

The ultimate use for the site was to provide an interpretive center to educate people about the unique high altitude plant communities which reside in the area**.**
In the winter of 2004/2005 the USFS and DBG hired an interpretation company Exhibit Design Associates (EDA). In a collaborative effort DBG, EDA and the USFS developed an interpretive master plan with funds secured by DBG through securing a grant from Senic Byways. The interpretive exhibits and signs were installed in late 2005, with the finishing touches finalized in early 2006. One can visit the Dos Chappell Nature Center from Memorial weekend in late May through the first accumulation of snow in late August to late September.

PROMOTING PLANT DIVERSITY WITH LOW BROADCAST SEEDING RATES APPLIED TO AMENDED OVERBURDEN MINESOILS AT A LIMESTONE QUARRY IN TIJERAS, NEW MEXICO

Robin Bay, Wayne Erickson, and Ken Carlson

Habitat Management, Inc.
Englewood, CO 80112

ABSTRACT

Four soil amendment treatments, three broadcast seeding rates, and transplanting of woody species were evaluated to determine the best strategy to enhance reclamation efforts at GCC Rio Grande, Inc's Tijeras Cement Plant and Limestone Quarry located in Tijeras, New Mexico. Redbed materials were used in lieu of salvaged topsoil for soil growth medium reconstruction at the site. Earthwork construction was completed in the summer of 2003 and plots were seeded and planted in November 2003. We collected baseline data on transplants and seed germination in Spring 2004, and monitored success of test plots in the Fall of 2004, 2005, and 2006. In this paper we highlight trends in cover, transplant survival, species composition, diversity, growth, and community health observed over three growing seasons. Increases in vegetation cover, desirable species, shrub densities and/or species diversity have been achieved through the application of these different treatment combinations, although no single treatment yields the best outcome for all of these parameters. .However, as a whole, the test plots have established a diverse, effective and permanent vegetation cover, capable of self-regeneration.

INTRODUCTION

GCC Rio Grande, Inc's ("GCC") Permit No. BE001RE required the development and implementation of a reclamation test plot study at its Tijeras Cement Plant and Limestone Quarry located in Tijeras, New Mexico. The study was approved by the New Mexico Mining and Minerals Division ("MMD") on November 20, 2002. Construction of the test plots began in May 2003 and planting was completed in November 2003. The goal of the study is to identify and evaluate specific methods and practices having the potential to enhance reclamation efforts on redbed materials used in lieu of salvaged topsoil for soil growth medium reconstruction at the quarry. Specifically, the test plots investigate two primary variables (soil amendments and seeding density) that can be controlled during the reclamation process. These variables have the potential to significantly affect vegetation stand characteristics within the reclaimed area.

Past studies have shown that soil amendments such as mulch, compost, and sewage sludge have the potential to increase organic carbon, total nitrogen, and moisture availability, and decrease erosion potential, when applied to mine spoil materials (Chambers et al. 1994, Cogger 2005, Moreno-Peñaranda et al. 2004). Zvomuya et al. (2007) compared compost and hay mulch incorporated into soils on reclaimed natural gas wellsites. They found both carbon and nitrogen to be more stable when derived from compost, but no difference was found in final organic carbon between treatments. Nitrogen content increased with increasing hay application, but was unaffected by compost application rate. Moreno-Peñaranda et al. (2004) showed that sewage sludge increased biomass and cover after 5 years over non-amended soils; however, species richness was lower and fewer legumes were present. Organic amendments are often thought to increase weedy species abundance, but this can be managed if care is taken in selecting the material sources.

Seed mix species selection and application rate can also play a significant role in the character of the final reclaimed community. Species selected need to be appropriate to the site and climate, but considering their competition roles is also important (Jefferson 2004). Competition for water, nutrients, and other resources will affect the structure and diversity of the community. Reclamation efforts often utilize high seeding rates (100 – 300 PLS/sq. ft.) to ensure adequate cover quickly. While this increases costs slightly, if several individuals die, the overall effect on cover is minimal. However, the community will often be dominated by the more competitive species in the mix with minimal diversity and little room for natural colonization of other species. This can potentially lessen the threat of weedy invaders, but again, decreases diversity. In this study, we evaluate several low rates for broadcast seeding (5 – 20 PLS / sq. ft.) with the hypothesis that adequate cover can still be achieved with decreased competition leading to greater diversity (both from the seed mix and outside colonizers) and heartier individuals.

This paper documents the trends in cover, transplant survival, species composition, diversity, growth, and plant health observed after three growing seasons with four soil amendments and three low rate seeding treatments.

METHODS

Site Description

The GCC Limestone Quarry is located east of Albuquerque and south of I-40 in Tijeras, New Mexico. It is New Mexico's only cement manufacturer and has been in operation since the early 1950's. The test plot site is located between 6,390 and 6,525 feet elevation with a generally north aspect. Slopes on the test plots range between 5% and 30%. Gradient terraces provide drainage control and minimize the potential for impacts on the vegetation test plots associated with surface water runon from adjacent slopes. The site was backfilled and graded to approximate post-mining contours prior to placement of soil reconstruction materials. Redbed materials, located between two limestone members in active quarry areas, were excavated and hauled to the test plot site for use as a plant growth medium. Redbed materials were graded to final contour with a minimum of two feet of depth.

Test Plot Design

Four soil amendments, three broadcast seed rates, and a transplanted treatment were applied in a randomized strip plot design (Figure 1) with three replicates for a sample size of 48. Soil amendment treatments included: composted horse manure wastes applied at two rates of 20 and 30 tons of dry organic matter per acre, native hay mulch applied at a rate of two tons per acre, and an untreated control. All plots were seeded at rates of 5, 10, or 20 pure live seeds (PLS) per square foot. The test plots were seeded with a variety of native grass, forb, and shrub species as well as two desirable introduced species (Table 15). These different life forms germinate and mature on different timescales, with their populations responding differently to ecologic and climatic variation. In addition to seeding, 12 plots that received 20 PLS also received a total of 60 transplants of 12 woody species planted in a matrix for easier monitoring. Transplanted species included: *Juniperus monosperma* (oneseed juniper); *Cercocarpus montanus* (mountain mahogany); *Rhus trilobata* (skunkbush sumac); *Krascheninnikovia lanata* (winterfat); *Pinus ponderosa* (ponderosa pine); *P. edulis* (pinyon pine); *Rosa woodsii* (Woods' rose); *Ericameria nauseos*a (rubber rabbitbrush); *Quercus gambelii* (Gambel oak); *Chrysothamnus viscidiflorus* (yellow rabbitbrush); *Purshia mexicana* (Mexican cliffrose); and *P. tridentata* (antelope bitterbrush)

To insure the validity of the strip plot design (Miliken & Johnson 1984), treatments were randomly assigned to the rows (soil amendments/treatments) and columns (broadcast seeding densities) within each study plot replication (Figure 1). Because the treatment combinations were randomly assigned to rows and columns to facilitate soil amendment applications, rather than each individual test plot as in a

Figure 1: Tijeras Limestone Quarry Vegetation Test Plots Location and Layout

completely randomized design, special care was taken to properly test for main effects and interactions among treatment factors.

Test Plot Monitoring

Vegetation test plots were monitored following applicable MMD monitoring guidelines and standards to the extent this was appropriate and possible. Monitoring in 2004 included abiotic and biotic observations of seedling germination, seedling establishment, and transplant survival and growth. In 2005 and 2006, we monitored vegetation and total ground cover, shrub density, and transplant survival and growth. We also recorded qualitative observations of species dominance, community health (e.g. weed and pest presence, nutrient and water stress, and grazing), and erosion issues each year along with photo documentation of each plot.

Vegetation Cover

Each test plot was subdivided into five monitoring transect panels. A five-foot buffer zone was provided around the perimeter of each test plot to minimize edge effect from adjacent treatments. The five transect panels were oriented lengthwise across the hill. The panels are approximately 13 feet wide and 40 feet long. Sample start point locations were randomly located within each of the five sample panels using a fixed one-foot interval grid on an x and y axis.

Line-transect point-intercept methods were used to collect ground cover data from the vegetation communities in all five panels of each test plot. Cover measurements were taken from point-intercepts at ten centimeter intervals along a ten-meter transect using a laser bar point frame, for a total of 100 intercepts per transect. When the line-transect intersected a panel boundary, it was redirected into the panel at a 90˚ angle. Each point-intercept represents 1/5 of 1% toward total cover measurements. Cover measurements recorded “first-hit” point-intercepts by live foliar vegetation species, litter, rock or bare ground. Litter included all dead organic material. Rock fragments were recorded when equal to or greater than two millimeters in size. First-hit data were tabulated to evaluate total ground cover and vegetation cover. Total ground and vegetation cover measurements are expressed in percentages for each test plot.

Woody Plant Density

We evaluated woody plant density using ten-meter square belt transects (1 m width X 10 m length) established at a one-meter distance from the right side of the line transect used for cover sampling. When necessary, adjustments to the belt transect location over the line-transect were made to avoid overlapping measurements. We recorded each woody plant rooted within the belt transect by species. Woody plants with multiple stems from a specific crown were recorded as one individual.

Transplant Survival

We recorded baseline height and basal diameter measurements of woody transplants in April 2004, and all subsequent growth values were based on these measurements. Shrub height was measured from root crown to apex of the main stem, or longest branch in the case of multi-stemmed shrubs. Crown area was measured on each shrub species with two perpendicular measurements collected on north/south and east/west ordinates.

Statistical Analysis

The test plot full-factorial design had an adequate sample size (48) to test for differences in seeding rates, organic amendment procedures, and their interactions. Statistical analyses were performed using SPSS 15.0 statistical software (SPSS, Inc. 2006) and SYSTAT 11 statistical software (Systat Software, Inc. 2004). Unless otherwise noted, statistical significance was determined at $p < 0.05$.

We used two-way analysis of variance (ANOVA) to test for seeding rate and organic amendment main effects and interactions on total ground cover, total vegetated cover, total species diversity, cover and diversity by growth form, and woody density (Milliken and Johnson 1984). Woody densities were converted to stems / sq. ft. prior to analyses. The Tukey Honestly Significant Difference (HSD) correction was used to control maximum family-wise error rate (MFER) at ≤ 0.01.

Due to the small sample size (n=3), ANOVA tests were not appropriate for measuring transplant success in the 20 PLS + Transplants test plots. Rather, a binomial dataset with the number of trials (woody plants transplanted) and number of successes (woody plants alive) was tabulated to infer the percentage of transplants that were alive. We used the ellipsoid volume, calculated from horizontal and vertical axis width measurements, to determine trends in survival and growth.

Climate

The Quarry is located in a transitional zone between mountain shrub and semi-arid coniferous forest ecosystems, and is surrounded by steep foothills and rocky outcrops. Historic annual precipitation for the Tijeras region averages 16.4 inches (1971 – 2000, Western Regional Climate Center 2007) with the majority falling in July through October. The weather station at the Quarry has recorded precipitation since 1996 (Table 1). 2006 was a very unusual year with below average rainfall in January through April and above average rainfall in June – October (Figure 2).

Year	Annual Precipitation (in.)
1996	12.18
1997	14.25
1998	16.94
1999	14.85
2000	15.73
2001	9.05
2002	8.09
2003	10.06
2004	13.63
2005	14.12
2006	**19.89**
1996 – 2006 Mean	13.53
1971 – 2000 Mean	16.4

Table 1: Annual Precipitation – Tijeras Weather Station

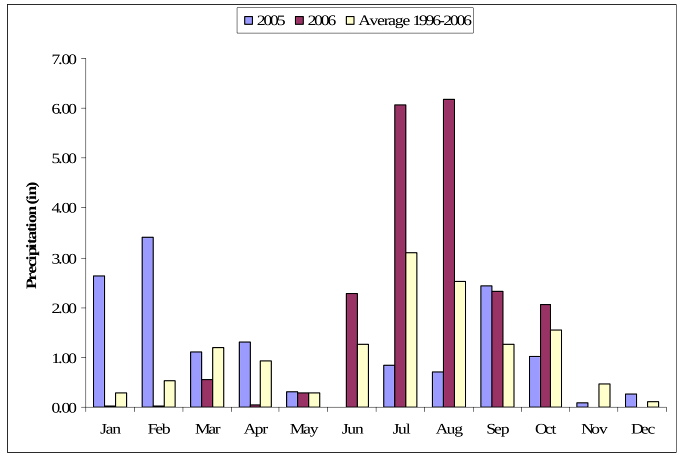

Figure 2: Average monthly precipitation for 2005, 2006, and the 10 years preceding

RESULTS

Vegetation Cover

Vegetation cover is used to evaluate the overall soil productivity, and the ability of the reclamation treatments to foster a diverse, stable, persistent community. We also performed analyses of desirable (native species and planted introduced species) versus undesirable species to gauge which treatments are establishing a diverse and desirable community.

Total ground cover counts included all litter, rock (≥2 mm), grass, forbs and woody plants. Mean total ground cover ranged from 62.7% to 83% (Table 2), but there were no significant relationships between total cover, seeding density, and organic amendment treatments. While not statistically significant (p=0.068), mean total ground cover was greatest (78.6%) in plots seeded with 10 PLS and lowest (69.3%) in plots seeded with 20 PLS + Transplants. The total ground cover also increased significantly from 48.5% in 2005 to 73.7% in 2006 (p≤0.0001).

Table 2: Total ground cover (%) by treatment

	Soil Amendments					
Seeding Density	*Untreated control*	*2 tons native hay*	*20 tons compost*	*30 tons compost*	**2006 Mean**	**2005 Mean**
5 PLS	62.7	83.0	74.7	73.5	73.5	50.23
10 PLS	78.9	82.2	78.3	74.9	78.6	50.03
20 PLS	73.1	76.3	75.2	69.0	73.4	47.03
20 PLS + Transplants	69.9	71.4	69.2	66.8	69.3	45.07
2006 Mean	71.2	78.2	74.4	71.1		
2005 Mean	42.27	57.80	45.73	46.57		

Mean vegetative cover ranged from 44.5% to 71.0% (Table 3) with an average of 56.7% across all plots. There was a significant main effect for soil amendment (p=0.001) such that plots treated with 2 tons native hay mulch (66.0%) had significantly higher vegetative cover than all other plots. Desirable cover did not differ significantly between treatments (p=0.938). There was also a main effect for seeding density (p=0.024), in which mean vegetative cover was significantly higher with 10 PLS (61.8%) than 20 PLS + Transplants (51.0%). However, when looking specifically at desirable cover ($p \leq 0.0001$), it was higher at 20 PLS + Transplants (28.0%), 20 PLS (30.7%), and 10 PLS (24.8%) than at 5 PLS (17.3%). The total vegetative cover also increased significantly from 30.2% in 2005 to 56.6% in 2006 ($p \leq 0.0001$).

Table 3: Total vegetative cover (%) by treatment

	Soil Amendments					
Seeding Density	*Untreated control*	*2 tons native hay*	*20 tons compost*	*30 tons compost*	**2006 Mean**	**2005 Mean**
5 PLS	44.5	71.0	51.5	56.5	55.9	32.18
10 PLS	61.0	67.9	59.5	58.7	61.8	**32.28**
20 PLS	54.5	66.7	57.7	53.0	58.0	29.98
20 PLS + Transplants	48.3	58.3	48.5	48.8	51.0	24.62
2006 Mean	52.1	**66.0**	54.3	54.2		
2005 Mean	30.12	28.62	30.40	29.93		

Mean grass cover ranged from 3.4% in untreated plots planted with 10 PLS to 17.1% in plots treated with 2 tons native hay mulch and 5 PLS (Table 4). There was a significant main effect for soil amendment ($p \leq 0.0001$) such that mean grass cover with 2 tons native hay (16.4%) was significantly higher than with any other amendment (Table 4). Mean grass cover was also significantly greater in 2006 than it was in 2005, across all treatments (p=0.001).

Table 4: Grass cover (%) by treatment

	Soil Amendments					
Seeding Density	*Untreated control*	*2 tons native hay*	*20 tons compost*	*30 tons compost*	**2006 Mean**	**2005 Mean**
5 PLS	4.4	17.1	4.5	4.7	7.7	6.72
10 PLS	3.4	17.0	8.8	6.7	9.0	5.38
20 PLS	8.5	16.5	8.7	5.5	9.8	3.73
20 PLS + Transplants	8.5	15.1	9.3	10.3	10.8	4.75
2006 Mean	6.2	**16.4**	7.9	6.8		
2005 Mean	1.53	12.92	2.62	3.52		

Relative cover of grasses across all treatments averaged 16.45% and native grasses made up an average of 81% of total grass cover. Native grass cover was significantly greater in plots seeded at higher seed rates (p=0.008). Three native perennial grasses (*Achnatherum hymenoides* or Indian ricegrass, *Bouteloua curtipendula* or sideoats grama, and *Pascopyrum smithii* or Western wheatgrass) and one introduced perennial grass (*Festuca arvernensis* or field fescue) each contributed over 1% of average absolute cover across treatments (Table 5). While the native species were present in the majority of plots across all treatments, the field fescue was primarily present in plots treated with 2 tons native hay (p=0.001), where it contributed an average of 8.4% absolute cover.

Mean forb cover ranged from 25.9% in plots treated with 30 tons organic amendment and 20 PLS + Transplants to 50.1% in plots treated with 2 tons native hay mulch and 5 PLS (Table 6). There was a significant main effect for soil amendment (p=0.006), such that mean forb cover for 2 tons native hay mulch (44.1%), was significantly higher than 30 tons compost (34.2%) and 20 tons compost (36.4%). Desirable forb cover, however, was significantly higher (p=0.015) with 20 tons compost (10.6%) than untreated plots (7.28%, Figure 3). There was also a significant main effect for seeding density (p≤0.0001), in which mean forb cover for 5 PLS and 10 PLS was significantly greater than 20 PLS + Transplants. However, while not significant at the 95% confidence level (p=0.053), desirable forb cover was greater with 20 PLS (10.6%) than with 5 PLS (7.2%, Figure 3).

Table 5: Dominant species (>1% average absolute cover) cover and frequency

Genus	Species	Common name	Average Absolute Cover (%)	Average Relative Cover (%)	Frequency (%)
Graminoid: Perennial Undesirable					
Festuca	*arvernensis*	field fescue	2.2	3.9	44
Graminoid: Perennial Desirable					
Achnatherum	*hymenoides*	Indian ricegrass	2.0	3.5	90
Bouteloua	*curtipendula*	sideoats grama	1.0	1.8	90
Pascopyrum	*smithii*	western wheatgrass	2.6	4.6	92
Forbs: Annual & Biennial Undesirable					
Kochia	*scoparia*	kochia	6.9	12.2	90
Melilotus	*officinalis*	sweetclover	**14.9**	**26.4**	94
Salsola	*paulsenii*	Russian thistle	5.6	9.8	**100**
Forbs: Perennial Desirable					
Astragalus	*cicer*	cicer milkvetch	3.4	6.1	96
Onobrychis	*viciifolia*	sainfoin	1.3	2.3	85
Shrubs: Desirable					
Atriplex	*canescens*	four-wing saltbush	5.3	9.3	**100**
Chrysothamnus	*viscidiflorus*	yellow rabbitbrush	2.7	4.7	98

Table 6: Forb cover (%) by treatment

	Soil Amendments					
Seeding Density	*Untreated control*	*2 tons native hay*	*20 tons compost*	*30 tons compost*	**2006 Mean**	**2005 Mean**
5 PLS	36.0	50.1	38.9	42.7	**41.9**	22.25
10 PLS	46.1	44.9	40.1	38.2	**42.3**	23.37
20 PLS	35.3	42.2	34.3	30.1	35.5	20.63
20 PLS + Transplants	28.4	39.2	28.3	25.9	30.5	15.33
2006 Mean	36.5	**44.1**	35.4	34.2		
2005 Mean	25.80	11.70	22.88	21.20		

While forb cover was greater in 2006 than it was in 2005 across all treatments, there was a significant interaction between year and organic amendment (p=0.031). In 2005 forb cover was lowest in plots with 2 tons of native hay, but in 2006 these plots had the highest average forb cover (Figure 4).

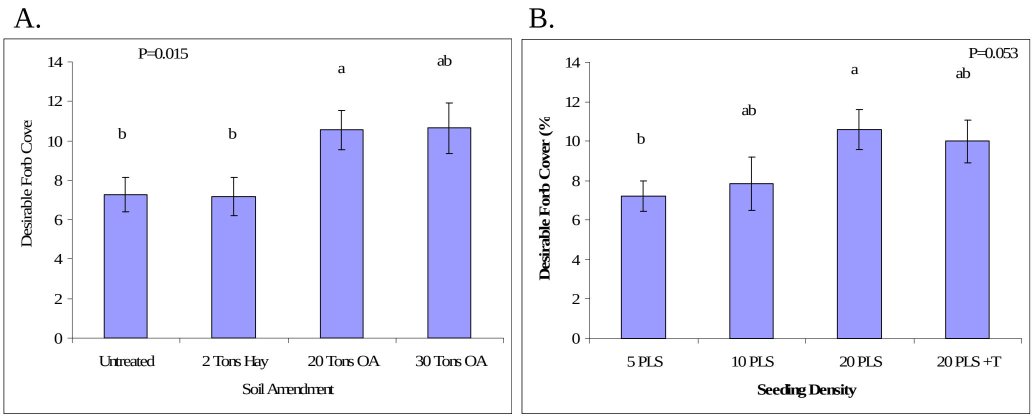

Figure 3: Mean desirable forb cover (+ 1 SE) by (A) organic amendment and (B) seeding density

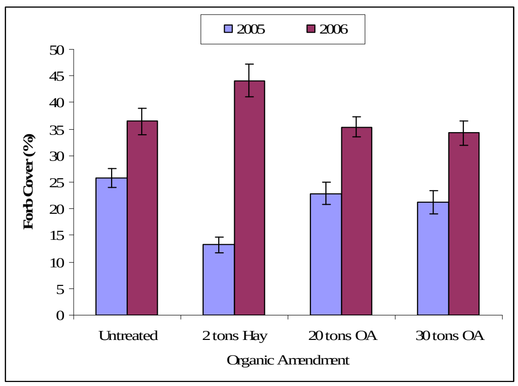

Figure 4: Mean forb cover (+ 1 SE) interaction between organic amendment and year

Relative cover of forbs across all treatments averaged 66.29%, but desirable forbs only made up an average of 24% of forb cover. Three introduced, undesirable forbs (*Melilotus officianalis* or sweet clover, *Kochia scoparia* or kochia, and *Salsola paulsenii* or Russian thistle) dominated the sites, each contributing over 1% of average absolute cover across treatments and a combined average of 48.4% of relative cover (Table 5). These three species were each analyzed for main effects of seeding and organic amendment. Sweetclover cover was significantly lower in plots treated with 30 tons organic amendment than any other treatment (p=0.001), Russian thistle was significantly lower with 30 tons organic amendment than untreated plots (p=0.002), and kochia cover was significantly greater in plots with 30 tons organic amendment ($p \leq 0.0001$, Figure 5). Sweetclover was also significantly lower in plots seeded with 20 PLS + Transplants than in plots seeded with 10 PLS (p=0.012).

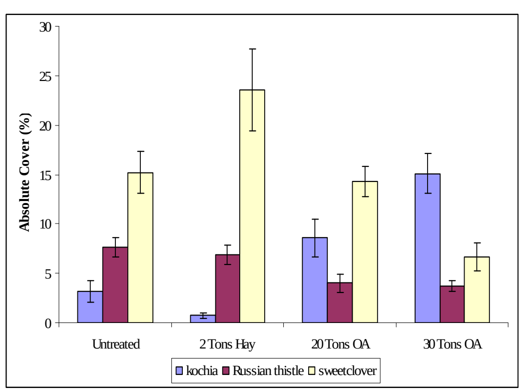

Figure 5: Mean cover (+ 1 SE) of kochia, Russian thistle, and sweetclover by organic amendment

Mean woody cover ranged from 4.1% in both untreated plots with 5 PLS and plots treated with 2 tons native hay mulch and 20 PLS + Transplants to 17.3% in plots treated with 30 tons organic amendment and 20 PLS (Table 7). There was a significant main effect for soil amendment (p=0.003) such that plots treated with 2 tons native hay mulch (5.5%) had significantly lower woody cover than plots treated with 20 (11.0%) or 30 (13.2%) tons organic amendment. There was also a main effect for seeding density (p=0.019) in which mean woody cover was significantly higher with 20 PLS (12.7%) than 5 PLS (6.25%). Woody cover also increased significantly from 4.2% in 2005 to 9.8% in 2006 ($p \leq 0.0001$).

Table 7: Woody cover (%) by treatment

	Soil Amendments					
Seeding Density	*Untreated control*	*2 tons native hay*	*20 tons compost*	*30 tons compost*	**2006 Mean**	**2005 Mean**
5 PLS	4.1	3.9	8.0	9.0	6.3	3.22
10 PLS	11.5	6.1	10.6	13.7	10.5	3.53
20 PLS	10.7	8.0	14.7	17.3	**12.7**	5.62
20 PLS + Transplants	11.4	4.1	10.8	12.6	9.7	4.53
2006 Mean	9.4	5.5	**11.0**	**13.2**		
2005 Mean	2.78	4.00	4.90	5.22		

Relative cover of woody species across all treatments averaged 17.3%. Only one introduced subshrub (*Marrubium vulgare* or horehound) was present, contributing less than 1% to cover, and native species made up an average of 98% of total woody cover. Two native shrubs (*Atriplex canescens* or four-wing saltbush and *Chrysothamus viscidiflorus* or yellow rabbitbrush) each contributed more than 1% to absolute cover (Table 5).

Species Diversity

Mean total graminoid diversity ranged from four to seven species (Table 8) with an average of 80% native species. There was a significant main effect for soil amendment (p=0.004) such that plots treated with 2 tons native hay mulch (6.7 species) had significantly higher overall grass diversity than untreated plots (4.8 species) and plots treated with 20 tons organic amendment (5.2 species). There was also a main effect for seeding density. Both overall grass diversity (p=0.024) and native grass diversity (p=0.002) were greater in plots seeded with 20 PLS and 20 PLS + Transplants than in plots seeded with 5 PLS (Figure 6).

Table 8: Grass species diversity by treatment

	Soil Amendments					
Seeding Density	*Untreated control*	*2 tons native hay*	*20 tons compost*	*30 tons compost*	**2006 Mean**	**2005 Mean**
5 PLS	4.3	5.3	4.0	4.7	4.6	3.3
10 PLS	4.3	7.3	5.7	4.3	5.4	2.4
20 PLS	5.3	7.0	5.0	6.7	**6.0**	3.2
20 PLS + Transplants	5.0	7.0	6.0	6.0	**6.0**	3.6
2006 Mean	4.8	**6.7**	5.2	5.4		
2005 Mean	2.3	2.9	3.5	3.8		

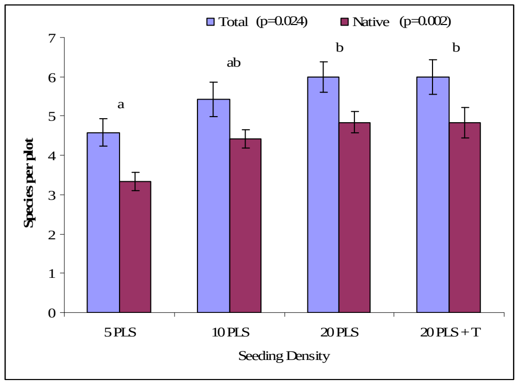

Figure 6: Mean total and native grass diversity (+ 1 SE) by seeding density

While graminoid diversity increased significantly overall from 3.1 species in 2005 to 5.5 species 2006 ($p \leq 0.0001$), there was a significant interaction between organic amendment and year ($p=0.013$). In 2005 graminoid diversity was greatest in plots with 30 tons of organic amendment; however, in 2006 graminoid diversity was greatest in plots with 2 tons native hay mulch amendment (Figure 7).

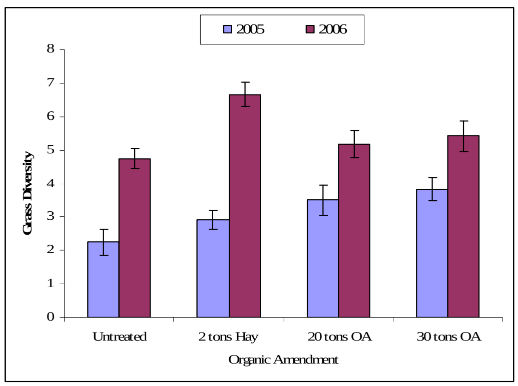

Figure 7: Mean graminoid diversity (+ 1 SE) organic amendment and year interaction

Mean total forb diversity ranged from 8.3 to 12.7 species, but on average only 63% were desirable species. There were no significant relationships between seeding density, organic amendment and forb diversity or desirable forb diversity. Forb diversity did increase significantly from 5.8 species in 2005 to 11.3 species in 2006 ($p \leq 0.0001$).

Woody species diversity ranged from 3.0 to 6.3 species per plot (Table 9). Only one of the 16 woody plant species observed along cover transects, was undesirable. While not statistically significant ($p=0.081$), mean woody plant diversity was greatest (5.7 species) in plots seeded with 20 PLS + Transplants (likely due to the additionally transplanted species) and lowest (4.2 species) in plots seeded with 5 PLS. Mean woody diversity also increased significantly from 2.5 species 2005 to 4.9 species in 2006 ($p \leq 0.0001$).

Total diversity ranged from 18.7 species in plots seeded at 10 PLS with no organic amendment to 26.0 species in plots treated with 20 tons organic amendment and seeded with 20 PLS (Table 10). There was a significant main effect for seeding density ($p=0.034$), such that plots seeded with 20 PLS had significantly greater species diversity (23.2 species) than plots seeded at 5 PLS (19.3 species, Table 10). Total desirable diversity was also significantly greater in plots seeded with 20 PLS and 20 PLS + Transplants than plots seeded at 5 PLS. There was no main effect for organic amendment.

Table 9: Woody Diversity by treatment

Seeding Density	*Soil Amendments* Untreated control	2 tons native hay	20 tons compost	30 tons compost	2006 Mean	2005 Mean
5 PLS	4.0	3.0	5.0	5.0	4.3	2.4
10 PLS	5.0	4.7	4.7	5.3	4.9	2.3
20 PLS	4.7	4.7	4.7	4.7	4.7	2.6
20 PLS + Transplants	6.3	5.7	5.7	5.0	5.7	2.6
2006 Mean	5.0	4.5	5.0	5.0		
2005 Mean	2.1	2.3	3.1	2.5		

Table 10: Total Diversity by treatment

Seeding Density	*Soil Amendments* Untreated control	2 tons native hay	20 tons compost	30 tons compost	2006 Mean
5 PLS	19.0	18.0	19.3	21.0	19.3
10 PLS	18.7	23.0	23.7	19.3	21.2
20 PLS	22.7	26.0	20.3	23.7	**23.2**
20 PLS + Transplants	19.7	24.7	23.7	23.7	22.9
2006 Mean	20.0	22.9	21.8	21.9	

While not statistically significant (p=0.097), there was an interesting interaction effect on total desirable diversity. Plots treated with 5 PLS were less diverse than all other seeding densities for all soil amendments except 30 tons organic amendment. However, with 30 tons organic amendment, 5 PLS was more diverse than 10 PLS and the same as 20 PLS and 20 PLS + Transplants.

Woody Species Density

Woody species density ranged from 0.65 stems/m^2 in plots seeded at 5 PLS with 20 tons organic amendment to 1.81 stems/m^2 in plots treated with 30 tons organic amendment and seeded with 20 PLS (Table 11). There was a significant main effect for seeding density ($p\leq0.0001$) in which woody density mean with 20 PLS (1.63 stems/m^2) and 20 PLS + Transplants (1.58 stems/m^2) was significantly higher than with 5 PLS (0.77 stems/m^2 or 3,116 stems/acre) and 10 PLS (0.96 stems/m^2 or 3,871 stems/acre, Table 11). There was also a main effect for organic amendment such that woody density was significantly lower with 2 tons native hay mulch (1.02 stems/m^2) than in untreated plots (1.38 stems/m^2) and plots treated with 20 tons organic amendment (1.37 stems/m^2). Total woody density increased significantly from 0.87 stems/m^2 (3,516 stems/acre) overall in 2005 to 1.23 stems/m^2 (4,988 stems/acre) in 2006 ($p\leq0.0001$). This is an increase of almost 1,500 stems/acre.

Table 11: Woody density (per m2) by treatment

Seeding Density	*Soil Amendments* Untreated control	2 tons native hay	20 tons compost	30 tons compost	2006 Mean	2005 Mean
5 PLS	0.81	0.65	0.84	0.79	0.77	0.81
10 PLS	1.14	0.79	1.15	0.75	0.96	0.81
20 PLS	1.77	1.30	1.81	1.63	1.63	0.81
20 PLS + Transplants	1.80	1.35	1.67	1.49	1.58	0.81
2006 Mean	**1.38**	1.02	**1.37**	1.16		
2005 Mean	0.61	1.09	0.97	0.81		

The most common woody species observed in shrub transects was *Atriplex canescens* (four-wing saltbush), which comprised 42.3% of all observations and was present in all 48 plots. *Krascheninnikovia lanata* (winterfat) comprised 27.8% of observations and was present in all but one plot. *Chrysothamnus viscidiflorus* (yellow rabbitbrush) made up 20.8% of observations, being present in all but two plots. *Ericameria nauseosa* (green rabbitbrush) and *Purshia tridentata* (antelope bitterbrush) were each present in 77% of plots, but contributed less than 5% of observations. *Heliomeris multiflora* (showy goldeneye), *Rosa woodsii* (Woods' rose), *Rhus trilobata* (skunkbrush sumac), *Juniperus monosperma* (oneseed juniper), *Artemesia frigida* (prairie sagewort), and *A. ludoviciana* (white sagebrush) each comprised 1% or less.

Transplant Growth & Survival

Transplant growth and survival data presented here represent the total change since April 2004. Overall these data suggest that untreated test plots yield the greatest transplant growth (3,230.2 in^3) and survival (65.0%), while 30 tons organic amendment plots yield the least with 1,510.14 in^3 change in volume and 38.3% survival (Table 12). Across all organic amendment treatments *Cercocarpus montanus* (CEMO, mountain mahogany) exhibited the greatest survival (80.0%), but with the lowest volumetric growth (133.62 in^3) among shrub species (Table 13). Mountain mahogany also exhibited the greatest amount of grazing with 38.3% of individuals, this likely led to its negative height growth (-4.34 in). *Chrysothamnus viscidiflorus* (CHVI8, yellow rabbitbrush) and *Ericameria nauseosa* (ERNA10, rubber rabbitbrush) exhibited the greatest volumetric growth (4,553.42 in^3 and 4,193.61 $in^{3,}$ respectively) and had very high survival rates (73.3% and 76.7%, respectively, Table 13). The two pine species, *Pinus edulis* (PIED, pinyon pine) and *Pinus ponderosa* (PIPO, ponderosa pine) experienced the greatest mortality overall with only 13.3% and 21.7% survival respectively (Table 13).

Table 12: Woody Transplant Survival and Growth (April 2004 – Sept 2006)

	Untreated		**2 Tons Native Hay**		**20 Tons Organic Amendment**		**30 Tons Organic Amendment**	
Species	**Volume (in^3)**	**Survival (%)**	**Volume (in^3)**	**Survival (%)**	**Volume (in^3)**	**Survival (%)**	**Volume (in^3)**	**Survival (%)**
CEMO2	248.7	93.0	127.4	60.0	263.7	100.0	-217.0	66.7
CHVI8	5609.0	66.7	3602.7	80.0	6479.0	73.3	2705.3	73.3
ERNA10	5238.8	86.7	4312.3	66.7	4749.7	86.7	1993.3	66.7
JUMO		53.3		66.7		60.0		33.3
KRLA2	1980.5	86.7	2471.3	73.3	1305.6	80.0	1267.2	46.7
PIED		13.3		13.3		20.0		6.7
PIPO		40.0		26.7		13.3		6.7
PUME	2528.8	66.7	727.6	26.7	1563.2	53.3	1416.3	33.3
PUTR2	2054.9	33.3	-10.3	20.0	658.2	33.3	198.2	6.7
QUGA		53.3		13.3		40.0		26.7
RHTR	3603.5	86.7	1263.6	80.0	3062.9	66.7	1783.7	46.7
ROWO	4305.4	100.0	812.8	60.0	1069.0	53.3	1632.9	46.7
Average	3230.2	65.0	2000.6	48.9	2531.9	56.7	1510.1	38.3

Table 13: Average species size, growth and survival across treatments

	2006		2004 - 2006			
Species	**Average Height (in)**	**Average Volume (in3)**	**Height Growth (in)**	**Volume Growth (in3)**	**Survival (%)**	**Grazed (%)**
CEMO2	17.79	943.70	-4.34	133.62	80.0	38.3
CHVI8	18.55	4567.48	17.30	4553.42	73.3	13.3
ERNA10	18.32	4222.44	15.57	4193.61	76.7	10.0
JUMO	12.75		7.07		53.3	1.7
KRLA2	16.33	1809.13	14.87	1801.58	71.7	5.0
PIED	7.53		-0.34		13.3	6.7
PIPO	6.21		2.58		21.7	11.7
PUME	17.59	2001.75	10.34	1769.82	45.0	3.3
PUTR2	10.75	1144.45	3.79	980.90	23.3	6.7
QUGA	4.06		1.08		33.3	13.3
RHTR	17.28	2644.02	7.34	2502.94	70.0	11.7
ROWO	15.24	2559.46	5.27	2355.85	65.0	16.7

Soil Erosion

Rill soil movement was lowest (22.3 tons/acre) in plots treated with 20 tons compost and 5 PLS. By far the greatest soil movement (155.7 tons/acre) was observed in plots treated with 2 tons native hay mulch and 20 PLS + Transplants (Table 14). However, due to very high variances within and among treatments, no significant differences were found between treatments. There was a strong trend (p=0.054) for plots seeded at 10 PLS to have less soil movement than those treated with 20 PLS + Transplants.

Table 14: Soil movement (tons/acre) by treatment

	Soil Amendments				
Seeding Density	*Untreated control*	*2 tons native hay*	*20 tons compost*	*30 tons compost*	**2006 Mean**
5 PLS	41.1	92.7	22.3	40.3	49.1
10 PLS	24.2	49.7	28.9	40.6	35.9
20 PLS	36.9	56.9	34.1	56.8	46.2
20 PLS + Transplants	103.2	**155.7**	38.2	56.9	**88.5**
2006 Mean	51.4	**88.8**	30.9	48.7	

Another interesting trend was that soil movement decreased from the top to the bottom of the slope (p=0.001, Figure 8). This suggests that vegetation covers and soil amendments may be successfully diminishing soil movement across plots. Further supporting this hypothesis is the result that net soil movement (bottom rill volume minus top rill volume) across each plot was negative on average.

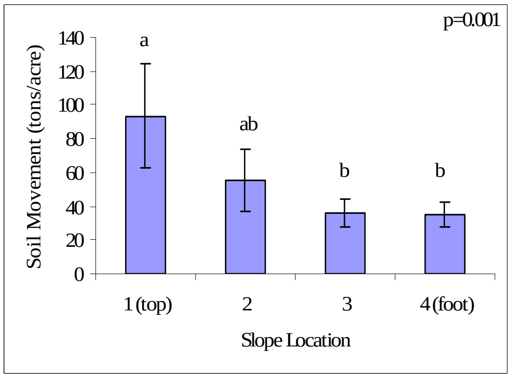

Figure 8: Mean soil loss (tons/acre + 1 SE) by slope location

DISCUSSION

The data presented here strongly suggest that reclamation on redbed alternate topsoil materials can be very successful. These data represent only three growing seasons at the Tijeras test plots, and it is still likely too early to reject any particular treatment or combination of treatments. However, it is already possible to discern some differences between the various seeding and organic amendment treatments that were employed.

Vegetation Cover

Forb cover was greater in plots seeded at lower densities and lowest in the plots with 20 PLS + Transplants. Because test plot vegetation is well established after three growing seasons, vegetative cover is primarily a result of plants' ability to efficiently gain and use resources. In those plots seeded at higher rates, and especially those with transplants as well as seeding, competition was greater in the first few years of establishment. .Those individuals who survived were likely stunted compared to those individuals subjected to less competition during establishment.

Total vegetative cover exhibited the same trend as forb cover, likely because forbs dominated cover overall. However, grasses and woody plant species did not follow this trend. Woody plant cover was actually the opposite with greater cover in plots seeded at 20 PLS and lower cover at 5 PLS. Woody species tend to grow more slowly than forbs and grasses, and because of this are less effective competitors in initial stages of community development. In 2004, all life forms had greater cover in plots with higher seeding densities. While the grasses and forbs have begun to reach later stages of community succession, the slower growing woody species are still becoming established and have not yet reached the stage where they can compete with other life forms for resources.

Grass, forb, and total vegetative cover was greater in plots treated with 2 tons native hay than other treatments, while woody cover was greater with 20 or 30 tons organic amendment. This same trend was observed in 2005 for grasses and woody species; however, forbs exhibited the same trend as woody species. In 2005, plots treated with 2 tons native hay mulch were 43% grasses, 44% forbs, and 13% woody species, while in 2006 these plots were 24% grasses, 66% forbs, and 8% woody species. This change in forb cover is likely driven by the increase in sweetclover from 7.4% cover in 2 tons native hay mulch plots in 2005 to 23.6% cover in 2006. The three dominant invasive forbs (sweetclover, kochia, and Russian thistle) combined increased from 11.4% to 31.1% absolute cover.

Qualitative observations taken in 2005 suggest that sweetclover, while not as prevalent as in 2006, was much taller. In 2006, late summer precipitation was well above average while spring precipitation was below average. The opposite was true for 2005 when spring precipitation was above average and summer precipitation was below average. Anecdotal evidence suggests the sweetclover flourishes in New Mexico when the late summer and winter precipitation is above average. Thus, it is likely that sweetclover was able to take advantage of the above average rainfall whenever it occurred, with later rainfall leading to greater density and earlier rainfall leading to greater size.

Species Diversity

Total grass, native grass, total desirable species, and total species diversity increased with increasing seed rate. While not statistically significant, this trend occurred for woody plant species as well. At very low seed rates, if mortality is high then diversity will be more greatly affected than at higher seed rates. While this was generally true, there was an interesting trend in plots with 30 tons organic amendment, such that those seeded with 5 PLS were not different from 20 PLS and were greater than 10 PLS. This suggests that greater amounts of organic amendment help to balance out the effects of different seeding rates. This will be an interesting trend to investigate in future years. Across all seeding and amendment treatments diversity has increased every year.

Woody Density

As with woody cover, woody density was significantly greater with higher seeding densities. As stated above, these plots had lower vegetation cover overall and specifically lower forb cover, which allowed the slower growing woody species to more effectively compete for resources in 2006. Woody species density and diversity have continually increased over time. In 2005, 50% of density observations were four-wing saltbush, 34% were yellow rabbitbrush, and 8% were winterfat; while these species still dominated in 2006, their relative dominance began to even out with an especially marked increase in yellow rabbitbrush.

Desirable Species

As already mentioned, 6 of the 11 dominant species were introduced; however, 2 of these introduced species (*Astragalus cicer* or cicer milkvetch and *Onobrychis viciifolia* or sainfoin) were included in the seed mix and are considered desirable. Only 15 of 73 species (20.5%) observed along cover transects were undesirable; however, 55.5% of the total vegetative cover was comprised of undesirable species.

While total cover was greater at lower seed rates, desirable cover was greater at high seed rates. At lower seed rates there was less competition from seeded species which could have allowed fast growing, introduced species to gain more of a foothold initially. The percent of grass, forb, and total vegetation cover that was desirable increased in every combination of treatments between 2005 and 2006. This increase was similar for all treatments; however, while in all other treatments this occurred due to an increase across all life forms, in the native hay mulch plots the increase was almost completely driven by an increase in the percent of grass cover that was native. In 2005, the introduced, undesirable grass *Festuca arvernensis* (field fescue) comprised 11.2% of absolute cover (35.9% relative cover) in these plots, but in 2006 it dropped to 8.4% of absolute cover (12.7% relative cover). The plots treated with native hay mulch were the only plots with a substantial amount of field fescue, and these promising results suggest that this species is likely to become less dominant over time.

In 2006, forbs dominated the majority of plots (37.6% average cover and 66.3% average relative cover) and only an average of 24% of that forb cover was desirable. This has almost doubled from 2005 (15%). While it is still much lower than in 2004 (54%), it is still potentially of concern. The weedy species (kochia, sweet clover, and Russian thistle) were able to take advantage of the increased late-season precipitation in 2006. In a healthy, developing community we would expect the percentage of kochia, sweet clover, and Russian thistle to decrease over time and will continue to monitor this closely over the next several years.

Transplant Survival

Transplants on test plots that were not treated with organic amendment experienced the greatest volumetric growth and maintained the highest survival rates in 2006, and those plots with 30 tons organic amendment exhibited the lowest growth and survival. This trend holds true for every year, and survival of transplants in plots with 30 tons organic amendment decrease faster than other treatments over time. Invasive forb species (sweetclover, kochia, and Russian thistle) were more prevalent every year in plots with organic amendments, and while their dominance diminished slightly in 2006, kochia was still signifiancly more abundant in plots with 20 and 30 tons organic amendment than other treatments. Transplanted individuals that were stressed from competition, grazing, and water and nutrient stress in these plots may have been weakened over previous years and finally depleted their stored resources in 2006.

Of the 12 species transplanted, 6 shrubs (*Cercocarpus montanus*, *Chrysothamnus viscidiflorus*, *Ericameria nauseos*a, *Krascheninnikovia lanata*, *Rhus trilobata*, and *Rosa woodsii*) and 1 tree (*Juniperus monosperma*) had over 50% survival after three growing seasons, while 3 trees (*Pinus edulis*, *P. ponderosa*, and *Quercus gambelii*) and 2 shrubs (*Purshia Mexicana* and *P. tridentata*) had poor survival. The oak, cliffrose, and bitterbrush are all very palatable for both grazing and browsing by deer and rabbits, which may have led to their poor survival; however, the winterfat is generally as palatable and it had a very high survival rate. Bitterbrush and cliffrose also established well from seed and bitterbrush was present in 77% of plots.

Seeded Species Establishment

When determining whether or not a reclamation effort is successful, it is important to consider the performance of the species seeded, as well as the vegetative cover, diversity, and transplant survival. For each seeded species, each plant life form, and the seed mixture, an establishment rating was calculated by dividing the average absolute cover by the percent contribution to the seed mix.

The establishment rating for this seed mixture based on cover monitoring data was only 22% (Table 15). Of the 26 species used, only four currently have establishment ratings over 50% (*Atriplex canescens*, *Astragalus cicer*, *Chrysothamnus viscidiflorus*, and *Pascopyrum smithii*), 15 more established at a rate of less than 50%, and 7 were not present in the cover observations. All four of the top performing species are quite drought tolerant and are commonly used in arid lands seed mixtures. The first two growing seasons, when these seeds were germinating and establishing, received below average precipitation, which may have hampered the establishment of less tolerant species.

Nine of the seeded species had establishment greater than 20% and at this time show the most promise for use in future reclamation efforts at Tijeras (Table 15 in bold). Of these species, 3 are grasses, 3 are forbs and 3 are shrubs; 2 are introduced and 7 are native. A diverse community can benefit from all present species, even those present in only trace amounts. While the overall establishment rating for this seed mix was low, the fact that 23 of the 26 species were found at the site suggests that the species chosen were appropriate for the site. Some species rarely observed in point-intercept data, may yet be important place holders in the vegetation community when climatic conditions are unusual or herbivore pressure is high. In future years, an effort will be made to determine if those species not encountered in the plots are in fact present in trace quantities on the slope. Additionally, future monitoring, as this site continues to develop, will help to shed light on the roles of all of the planted species.

Table 15: Seeded species average performance and establishment ratings

Species	**Common Name**	**Absolute Cover (%)**	**Relative Cover (%)**	**Seed Mix (%PLS)**	**Rating**
Grasses					
Achnatherum hymenoides	**Indian ricegrass**	**1.96**	**3.46**	**5**	**39%**
Andropogon hallii	sand bluestem	0.10	0.17	5	2%
Bouteloua curtipendula	**sideoats grama: Butte**	**1.02**	**1.79**	**5**	**20%**
Bouteloua gracilis	blue grama: S Native	0.09	0.15	5	2%
Pascopyrum smithii	**western wheatgrass: arriba**	**2.63**	**4.63**	**5**	**53%**
Pleuraphis jamesii	James's galleta	0.13	0.23	5	3%
Pseudoroegneria spicata	bluebunch wheatgrass: Secar	0.55	0.97	5	11%
Sporobolus cryptandrus	sand dropseed	0	0	5	0%
Stipa neomexicana	New Mexican feathergrass	0	0	5	0%
Grass Total		6.38	11.23	45	14%
Forbs					
Achillea millifolium	western yarrow	0.37	0.65	3.5	11%
Astragalus cicer	**cicer milkvetch: lutana CT**	**3.43**	**6.05**	**3.5**	**98%**
Gaillardia aristata	Indian blanket flower	0.15	0.27	3.5	4%
Linum lewisii	Lewis (Blue) flax	0.004	0.01	3.5	0%
Lupinus argenteus	silver mountain lupine	0	0	3.5	0%
***Onobrychis* viciifolia**	**sainfoin: eski**	**1.32**	**2.32**	**3.5**	**38%**
Penstemon angustifolia	narrow-leaf penstemon	0.42	0.74	3.5	12%
Ratibida columnifera	**coneflower**	**0.89**	**4.57**	**3.5**	**25%**
Sphaeralcea coccinea	scarlet globemallow	0	0	3	0%
Forb Total		6.584	14.61	31	21%
Shrubs					
Atriplex canescens	**four-wing saltbush**	**5.26**	**9.28**	**3**	**175%**
Cercocarpus montanus	mountain mahogany	0	0	3	0%
Chrysothamnus viscidiflorus	**yellow rabbitbrush: Douglas**	**2.66**	**4.7**	**3**	**89%**
Ericameria nauseosus	rubber rabbitbrush	0.38	0.67	3	13%
Kraschenninikovia lanata	**winterfat**	**0.72**	**1.27**	**3**	**24%**
Purshia mexicana	New Mexico cliffrose	0.004	0.01	3	0%
Purshia tridentata	antelope bitterbrush	0.14	0.25	3	5%
Rosa woodsii	Wood's rose	0.03	0.06	3	1%
Shrub Total		9.194	16.24	24	38%
Seed Mixture Total		22.158	42.08	100	22%

CONCLUSION

After three years, all combinations of seeding and amendment treatments have effectively established plant communities on alternate topsoil materials. Additionally, vegetative cover and diversity increased from 2005 (due in part to record precipitation in 2006) demonstrating that the reclamation has and will continue to develop dramatically over the next few years, regardless of treatment. Determining which of these treatments is the best at establishing and maintaining desirable plant communities will depend on the criteria used to define reclamation success.

Of the four seeding densities used, 5 PLS or 10 PLS yielded the greatest total vegetation cover, ground cover, and forb cover, while 20 PLS and 20 PLS + Transplants yielded the greatest woody plant density; grass and woody cover; desirable forb, grass, woody, and total cover; and all measures of diversity. In analyzing the organic amendments, it appears that 2 tons native hay yielded the greatest woody density; total, grass, and forb cover; and total, grass, forb, and woody diversity. However, 20 tons organic amendment yielded the highest desirable grass, forb, and woody cover along with high total woody cover and forb diversity.

Ideally, statistical analyses would have shown interaction effects between seeding densities and organic amendments to show which combination was the most effective. In lieu of significant differences, trends can still be determined by looking at which combination of treatments yielded the highest mean for any given success parameter. Those combinations that yielded the greatest mean for the most parameters were 20 PLS with 30 tons organic amendment, and 5 PLS with 2 tons native hay mulch. Five other treatment combinations also produced the greatest mean for three parameters each. If we only look at those parameters that pertain to desirable species development, plots with 20 PLS with 30 tons organic amendment, and plots with 20 PLS with no soil amendment appear to yield the greatest mean for the most parameters.

These preliminary results illustrate the importance of identifying and prioritizing reclamation goals prior to evaluating treatments, as the most effective treatment for one outcome may not be the best for another outcome. If the goal is ground cover to minimize soil loss, then a low seed rate with 2 tons native hay mulch would be best. However, if desirable species cover is more important, then 20 PLS with a 30 tons organic amendment would be best. Finally, woody density and total diversity appear best achieved with 20 PLS and 2 tons native hay mulch.

Future monitoring in Year 5 will serve to better define how seed density and organic amendment treatments affect reclaimed plant community development within the test plots.. After three growing seasons, all treatments have yielded diverse, effective, and permanent vegetation cover that is currently experiencing dramatic growth and development. All of the practices used on the test plots are adequately supporting development of vegetation communities that are stable and are developing plant species diversity capable of supporting the post-mining land use of wildlife habitat.

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RESTORING SAGE GROUSE HABITAT IN THE PINEDALE ANTICLINE GAS FIELD, WY: SHELL/BLM REVEGETATION PILOT PROJECT

Richard S. Carr, III[1] , H. James Sewell[2], Aimee Davison[3], John Steinbacher[4]
[1]C-M Environmental Group, Inc.
62 Beaver Run Road, Pinedale, WY 82941
[2]Shell Exploration & Production Company
4582 South Ulster Street Parkway, Suite #500, Denver, CO 80237
[3]Shell Rocky Mountain Production Company, LLC
205 S. Entertainment Lane, Pinedale, WY. 82941
[4]Summit Associates, LLC
529 E.Sunnyridge Ct., Boise, ID 83702

ABSTRACT

In the fall of 2004, Shell Rocky Mountain Production Company (Shell) initiated the "Shell/BLM Pinedale Anticline Revegetation Pilot Project" in cooperation with the Pinedale, Wyoming BLM Field Office. The objective of the voluntary project has been to reintroduce native plant species supportive of sage grouse and ungulate habitat to numerous interim reclaimed drill locations over the full length of the Pinedale Anticline gas field. A number of variables are being examined in the project, including the use of a habitat blend seed mix that reduces the emphasis on grasses, seeding techniques, the use of organic soil amendments and biostimulants, the effectiveness of over-seeding the habitat seed mix into previously established grass-dominated reclaims and the effectiveness of fencing on seeded locations. The project is ongoing; monitoring data and observations are presented here for the first locations seeded in 2004. Observations to date indicate the establishment of sage shrubs was successful on both hydroseeded and drill-seeded locations. The de-emphasis of grasses is evident in the data, but differences between those locations with more successful grass-shrub-forb establishment that received soil amendments and those that did not is unclear, due in part to varying local and regional precipitation regimes of individual sites over the three years since seeding. Drill-seeding of a more shrub-forb dominated habitat mix into previous grass-dominated reclaims has shown only limited success in a few overseed locations. Livestock fencing of reclaimed sites during the first several growing seasons appears critical to reestablishing a healthy, sustainable native plant community.

INTRODUCTION

One of the more controversial issues involved with the current natural gas exploration and development play in the Green River basin of western Wyoming is the destruction of the native sage-grassland ecosystem and, in particular, sage grouse and ungulate habitat. Until recently, accepted and required revegetation practices for drilling pit closures and interim reclamation of production pads on BLM lands have included the seeding of grasses, forbs and shrubs that are often not conducive to accelerated restoration of the native habitat. This has resulted in the occurrence of scattered acres throughout the region that are grass-dominated, surrounded by older, mature sage-dominated rangelands. These disturbances will remain highly visible for many years, and healthy sage communities may be prolonged for better than a quarter century.

In the fall of 2004, Shell Rocky Mountain Production Company (Shell) initiated the "Shell/BLM Pinedale Anticline Revegetation Pilot Project" in conjunction with the Pinedale, Wyoming BLM Field Office. The objective of the voluntary project has been to reintroduce native plant species supportive of sage-grouse and ungulate habitat to numerous interim reclaimed drill locations over the full length of the Pinedale Anticline gas field (Figures 1 and 2). Utilizing native habitat seed mixes that provide for more native forbs and shrubs, and reducing the percentage of grass species from the levels currently used for interim reclamation, should reduce the time required to re-establish natural habitats disturbed during natural gas development. Handled appropriately, this should benefit sage-grouse.

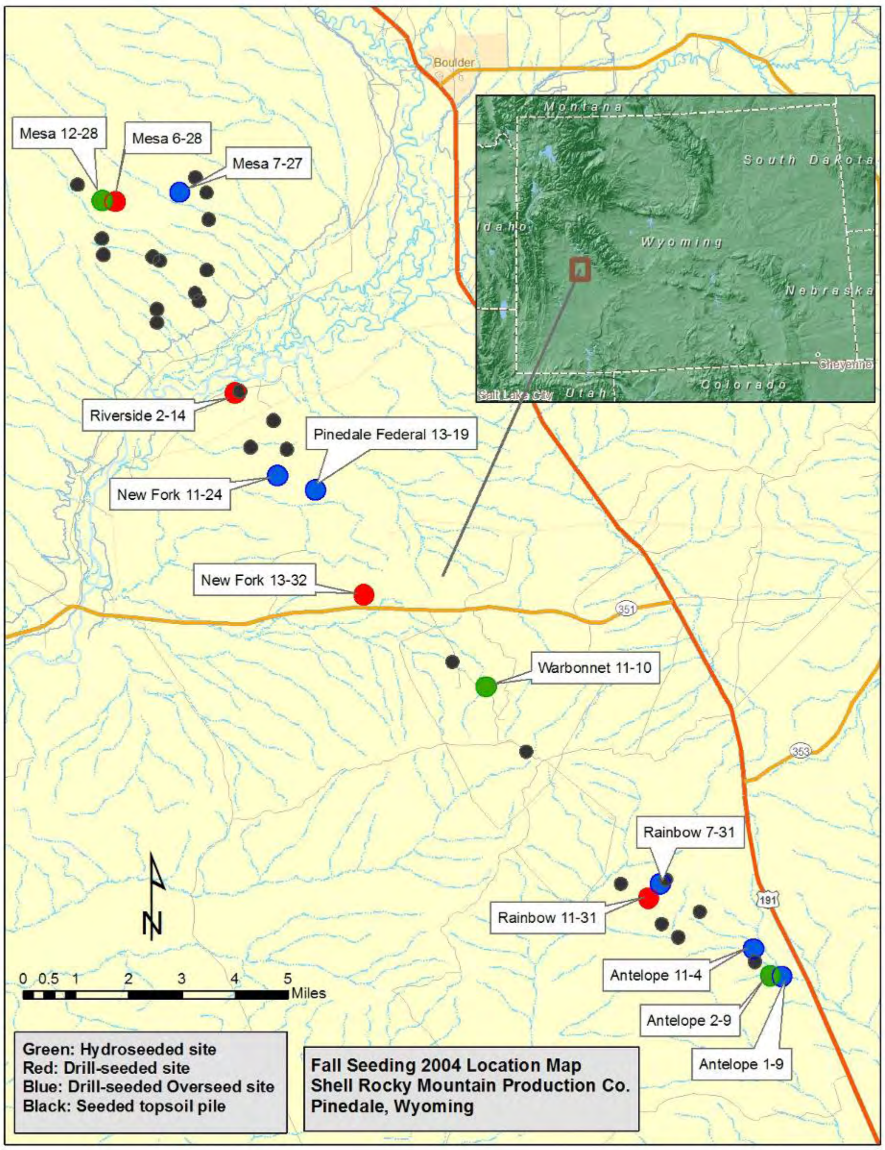

Figure 1. Location map showing seeded location names as referred to in the text.

A number of variables are being examined in the project, including the testing of:

- a new "Habitat Blend" seed mix that reduces the emphasis on grasses and is based in large measure on native plant species found in the adjacent undisturbed habitat which are critical for food and cover for sage grouse and native ungulates;
- site- or area-specific soil amendments to jump-start soil conditions favorable for the growth and establishment of native species;
- seeding techniques – range drill and hydroseeding
- the effectiveness of fencing on seeded locations to protect against cattle grazing during the first few seasons of new plant growth;
- the effectiveness of over-seeding the "Habitat Blend" into previously established grass-dominated seeded locations;
- topsoil pile seeding – seeding with grasses that would provide temporary forage, reduce weed infestation and keep soil mycorrhizal conditions favorable for accelerated re-establishment of native habitat during reclamation.

A separate part of the pilot project was to test the cost-effectiveness of hydroseeding fill/cut slopes of existing drill pads to reduce erosion.

The project is ongoing, with annual spring/summer monitoring of seeded locations and new interim closures being seeded during the late fall of each year. Three growing seasons have now passed since the first locations were seeded in 2004. This paper presents the results of our monitoring and observations for these 2004 sites only; locations seeded in 2005-2007 are not discussed here, nor are the seeding of fill/cut slopes or topsoil piles – these will be presented in a future venue, when more data are available.

Figure 2. View of the southern end of the Pinedale Anticline gas field, looking toward the northwest. Marked locations: A – Antelope 2-9; B – Antelope 11-4; C – Rainbow area. 10/26/07 photo.

BACKGROUND

The Shell revegetation efforts addressed the challenges of growing Wyoming Big Sage plant community species in a high-altitude, semi-arid environment noted for unreliable rain and a precariously short growing season. The focus on Wyoming big sagebrush (mainly *Artemisia tridentata ssp. wyomingensis)* plant communities underscores their comparative wide range of distribution across the Pinedale Anticline, and their greater importance to sage grouse than many other taxa. Scientific literature indicates that sage grouse are highly dependant on Artemisia (sage) for all life processes across their entire range. Central to the revegetation philosophy pursued was the understanding that these native plant species require specific physical and organic conditions in the soil for germination, and that a functional microbial community in the soil must be established for the plants to be self-sustaining.

Soil Ecology and Microbial Activity

In general, the organic content of a soil is a direct indicator of its fertility, ability to support microbial populations, retention of mineral nutrients, and water retention potential. Relatively small amounts of organic matter may provide the amount of moisture retention needed to germinate seeds and sustain young seedlings until root systems are able to extract water from a larger volume of soil. As organic matter is incorporated into the soil, it also provides food for a community of soil organisms that constitute the soil-microbial community. This community of burrowing animals, worms, arthropods, bacteria, protozoa and fungi provides for functional balance in the soil, thus the soil ecology terminology – the microbial community (Davies and Ghabbour, 1998).

The roles microbes play in water and nutrient movement are particularly critical for ecosystems with soils of relatively poor nutrient status, such as those typical of the semi-arid American west and the Pinedale Anticline in particular. More specifically, the soil microbes referred to as mycorrhizal fungi are known to be efficient at extracting nutrients from both mineral and organic sources, enabling plants to thrive in habitats that are considered poor in nutrients (Ghabbour and Davies, 2001; Swift and Spark, 2001).

Vesicular-arbuscular mycorrhizal fungi - there are as many as 2000 different species - are important in natural ecosystems, living in symbiotic relationship with 95% of the dominant shrub, forb, grass and tree species on the American west sage-steppe. These relationships are characterized by bi-directional movement of nutrients where carbohydrate-carbon flows to the fungus and inorganic nutrients move to the plant, thereby providing a critical linkage between the plant root and soil. The soil surface contact area covered by the fungus for nutrient and water absorption is many times greater than that possible by the plant roots alone, thus expanding and extending the plant’s nutrient and water uptake potential. As much as 96% of the root length can be colonized by mycorrhizal fungi. As a result, mycorrhizal plants are often more competitive and better able to tolerate environmental stresses than are non-mycorrhizal plants, leading to improved plant growth and reproduction (Andrade et al, 1998; Wicklow-Howard, 1989, 1984).

Soil Microbes and Land Disturbance Effects

One of the most successful land management methods for aiding revegetation on disturbed sites has been the retention of topsoil and its critical organic matter in order to re-establish the microbial soil community. Concurrent reclamation techniques redistribute stockpiled topsoil to re-establish mycorrhizae and related soil biota, followed by reseeding the desired native species. Even the addition of relatively small amounts of topsoil (two to three inches in depth) to a site results in improved microbial foundation and subsequent establishment of indigenous grass, shrub and forb species - species superior for erosion control and stabilization.

If no topsoil, or poor topsoil, is returned to a disturbed site, concentrated organic materials typically must be introduced to the soil so that plant life may be reestablished. Disturbed soils generally have low microbial diversity, and are relatively sterile and poorly colonized with indigenous microbial populations. The importation of naturally-occurring humic substances that function hormonally to stimulate and accelerate the growth of enzymes and soil microbes, particularly fungi, dramatically enhances the success of native plant seeding. Humic acid, humic fractions and specific humic substances such as fultic acid and ulmic acid activate the development of soil microbes, improve the physical properties of soils, and aid in water retention (Stahl and Christensen, 1982).

PILOT PROJECT WORK

A total of seven newly-reclaimed and six previously reclaimed locations, spanning approximately 20 miles (NW to SE) of the Pinedale Anticline gas field, were seeded in the fall of 2004 (Figure 1). Of the seven newly-reclaimed sites, three were hydroseeded, two were drill seeded with no soil amendments added, one was drill seeded with soil amendments added, and one was drill seeded and split into two sections - one half with, and one half without, soil amendments. Three of the previously reclaimed locations ("Overseed sites") had organic amendments applied when overseeded, and two were fenced.

SOILS AND ORGANIC SOIL AMENDMENTS

Soils

Table 1 shows soil analysis data for the seeded locations. Prior to pit closures, topsoil piles were sampled for most of the 2004 sites; the table shows data for samples taken after vegetation was established as well as soil samples from adjacent offsite areas for comparison. Even with topsoil replaced, soil chemical conditions on reclaimed sites are not always predictable prior to closure.

Organic Soil Amendments

Recommendations for organic soil amendments and biostimulants based on the available soil data at the time were made for each specific location with poor soil conditions, but a decision was made in 2004 to limit the organic amendment blends to three "regional" blends, based on similarities of the soil data between certain locations (Table 2). More site-specific blends were used in subsequent fall seeding programs (not presented here).

The soil amendments were supplied by Quattro Environmental, Inc., of San Diego, CA. These included the various mineral components listed in Table 2 and the custom organic materials known as Fertil-Fibers NutriMulch™ (Fertil-Fibers), humic shale and Kiwi Power Organic Soil Treatment™ (Kiwi Power). These nutrients and biostimulants are used to activate the development of soil microbes, improve the physical properties of soils and aid in water retention, thereby encouraging native plant growth and establishment, especially on disturbed sites.

The mineral amendments, Fertil-Fibers and humic shale were blended together in the form of pellets and were supplied in 50 lb bags. For hydroseeding, the appropriate pellet blend was loaded into the seeder tank along with water, Kiwi Power and a "tackifier" to hold the mixture on the soil surface and to help retain moisture. Finally, the seed mix was added to the tank just before spraying. Gypsum, where needed (Warbonnet 11-10 only), was sprayed as a separate application pass prior to applying the growing and holding mediums. A Simonsen fertilizer spreader was used to apply the soil amendments in dry pellet form on drill seeded locations. Following pellet application, Kiwi Power was sprayed over the sites with a hydroseeder.

Table 1. Soil analyses for Shell locations seeded in 2004.

SOIL ANALYSES
SHELL LOCATIONS SEEDED FALL 2004

Sample Location	Antelope 2-9 pre-closure topsoil pile	Ant 2-9 post-closure reclaim composite	Ant 2-9 offsite	Warbonnet 11-10 pre-closure topsoil pile	Warbonnet 11-10 pre-closure clay-rich spoil pile	Warbonnet 11-10 post-closure reclaim composite	Warbonnet 11-10 offsite - upper part of location	Warbonnet 11-10 offsite - lower part of location	Mesa 12-28 pre-closure topsoil pile	Mesa 12-28 post-closure reclaim composite - east side of location	Mesa 12-28 post-closure reclaim composite - south & west side of location	Mesa 12-28 offsite	Rainbow 11-31 post-closure composite	Rainbow 11-31 offsite	New Fork 13-32 post-closure reclaim composite - "A" area	New Fork 13-32 post-closure reclaim composite - "B" area	New Fork 13-32 offsite	Riverside 2-14 post-closure reclaim composite	Riverside 2-14 offsite	Mesa 6-28 post-closure reclaim composite	Mesa 6-28 offsite	Antelope 1-9 post-closure reclaim composite	Antelope 11-4 post-closure reclaim composite
Sample Type	Topsoil	Reclaim	Offsite	Topsoil	Subsoil	Reclaim	Offsite	Offsite	Topsoil	Reclaim	Reclaim	Offsite	Reclaim	Offsite	Reclaim	Reclaim	Offsite	Reclaim	Offsite	Reclaim	Offsite	Reclaim	Reclaim
Sample Date	May-04	Sep-05	Sep-05	May-04	May-04	Sep-05	Sep-05	Sep-05	May-04	Sep-05	Sep-05	Sep-05	Sep-05	Sep-05	Sep-05	Sep-05	Sep-05	Sep-05	Sep-05	Sep-05	Sep-05	May-04	May-04
% Organic Matter	1.3	1.3	1.5	0.7	0.4	1.2	1.0	0.8	1.8	1.8	2.5	2.2	1.1	1.3	1.5	1.7	1.7	1.0	1.1	2.3	2.1	0.9	1.3
Nitrate N ppm	40.0	13.0	2.0	9.0	2.0	11.0	2.0	2.0	26.0	16.0	28.0	3.0	4.0	1.0	21.0	16.0	3.0	3.0	1.0	31.0	3.0	3.0	6.0
Phosphorus ppm	40	15	5	13	15	10	6	5	7	11	23	15	6	7	32	22	12	15	10	29	17	11	30
Potassium ppm	290	252	182	110	181	214	197	147	223	249	386	314	184	147	280	350	284	175	189	285	256	201	275
Magnesium ppm	245	375	406	220	195	422	202	238	362	533	379	409	365	398	552	526	415	261	195	403	572	330	363
Calcium ppm	1586	3137	2329	2032	3669	4745	6793	2131	4201	4278	5178	3613	2393	2208	4952	4867	3847	2100	1346	5090	4825	1702	2921
Sulfur ppm	4.0	10.0	7.0	9.0	255.0	84.0	988.0	10.0	10.0	79.0	14.0	9.0	8.0	5.0	22.0	17.0	8.0	10.0	6.0	30.0	12.0	4.0	10.0
Zinc ppm	0.8	0.7	0.4	0.5	0.4	0.8	0.5	0.3	0.5	0.9	1.0	0.8	0.4	0.3	0.9	0.6	0.6	0.6	0.4	1.3	0.7	0.5	1.1
Manganese ppm	4.0	3.5	1.2	1.1	1.1	1.9	0.9	0.9	1.8	4.4	4.3	2.2	1.5	1.4	7.5	6.7	1.7	2.1	2.0	5.9	1.9	1.8	1.9
Copper ppm	1.3	1.2	0.9	0.7	1.1	1.0	0.6	0.6	1.3	1.1	1.3	1.1	0.9	1.0	1.3	1.3	1.1	0.9	1.1	1.1	1.1	1.0	1.2
Iron ppm	22.2	14.8	12.1	10.0	6.2	9.0	7.3	5.0	8.9	6.9	8.3	9.6	8.9	10.4	6.1	8.6	5.8	10.0	12.4	6.4	8.0	16.3	15.8
Boron ppm	0.5	1.2	1.0	0.5	0.9	1.4	2.1	1.1	0.7	2.4	2.0	1.2	1.1	0.8	2.0	1.7	1.3	0.9	0.9	1.8	1.5	0.5	0.6
Soil pH	6.8	7.9	7.3	6.0	7.1	8.2	7.8	8.4	7.3	7.9	7.9	7.6	8.0	7.2	8.2	8.0	7.8	8.0	7.3	7.7	7.8	8.6	6.4
Excess Carbonate*	5	10	10		5	15	15	15	10.0	15.0	10.0	10.0	10	5	15.0	10.0	10	10.0	5.0	15.0	10.0	10	
Soluble Salts mmhos/cm	0.33	0.4	0.2	0.42	2.03	1.1	3.7	0.4	0.44	0.7	0.5	0.3	0.3	0.3	0.8	0.7	0.3	0.2	0.2	0.6	0.4	0.20	0.32
Sodium ppm	15	83	23	292	1477	687	579	270	21	162	17	21	77	66	363	290	38	41	10	51	36	38	70
Total CEC	10.8	19.8	15.6	13.5	26.9	30.8	38.7	14.2	24.7	27.2	30.1	22.4	15.8	15.0	31.7	30.9	23.6	13.3	8.9	29.8	29.7	11.9	18.6
Ca/Mg	6.5	8.4	5.7	9.2	18.8	11.2	33.6	9.0	11.6	8.0	13.7	8.8	6.6	5.5	9.0	9.3	9.3	8.0	6.9	12.6	8.4	5.2	8.0
CEC Ca/Mg	3.9	5.0	3.4	5.6	11.2	6.8	20.0	5.4	7.0	4.8	8.2	5.3	3.9	3.3	5.4	5.5	5.6	4.8	4.1	7.6	5.1	3.1	4.8
% Sand		61.2	69.2			59.2	65.2	73.2		53.2	47.2	41.2	67.2	61.2	37.2	39.2	45.2	77.2	79.2	47.2	39.2		
% Silt		23.6	17.6			19.6	19.6	15.6		27.6	35.6	41.6	21.6	21.6	39.6	37.6	50.8	18.8	18.8	46.8	52.8		
% Clay		15.2	13.2			21.2	15.2	11.2		19.2	17.2	17.2	11.2	17.2	23.2	23.2	4.0	4.0	2.0	6.0	8.0		
Soil Texture		SANDY LOAM	SANDY LOAM			SANDY CLAY LOAM	SANDY LOAM	SANDY LOAM		SANDY LOAM	LOAM	LOAM	SANDY LOAM	SANDY LOAM	LOAM	LOAM	SILT LOAM	LOAMY SAND	LOAMY SAND	SANDY LOAM	SILT LOAM		
Bulk Density	1.54	1.53	1.52	1.49	1.35	1.46	1.47	1.57	1.19	1.37	1.32	1.30	1.62	1.57	1.31	1.37	1.39	1.59	1.71	1.31	1.34	1.42	1.50
Conversion Factor	2.3	2.3	2.3	2.3	2.0	2.2	2.2	2.4	1.8	2.1	2.0	2.0	2.5	2.4	2.0	2.1	2.1	2.4	2.6	2.0	2.0	2.2	2.3

*** Excess Carbonate: 5 = VL, 10 = L, 15 = M**

Soil analyses by MDS Harris, Lincoln, NE

Table 2. Soil amendment blends used in the 2004 fall seeding. "A" – Antelope area (also used in the New Fork area); "W" – Warbonnet area; "M" – Mesa area.

SOIL AMENDMENT BLENDS - 2004 FALL SEEDING

	"A" amendment blend used in 2004	"W" amendment blend used in 2004	"M" amendment blend used in 2004
Fertil-Fiber tons/acre	1	2	1
Humic Shale lb/acre	500	500	500
Gypsum lb/acre		6000	
Urea lb/acre	10	15	
P2O5 lb/acre	20	20	25
MgO lb/acre		15	
Elemental Sulfur lb/acre	15		
Zinc lb/acre	2	4.3	2
Mn lb/acre	2.0	1.0	
Agricultural Lime lb/acre	300		
Boron lb/acre	1		
Kiwi Power gals/acre	5	5	5
Cliffhanger Tack lbs/acre	150	150	150

SEED MIX

The seed blend selected for use at the Shell sites was developed in cooperation with Nancy Shaw at the Rocky Mountain Research Station and was based partly on research by Connelly and Braun (1997). Work by Shaw, DeBolt, and Rosentreter, as described in *Sage-Grouse Habit Restoration Symposium Proceedings* was central to seed blend planning as well (Shaw et al, 2005). Plant succession approaches to plant community restoration were explored, emphasizing early seral stage native species. Research by Crawford on the importance of herbaceous vegetation to female sage-grouse during the repercussive period was also of particular value (Crawford, 1997).

The BLM's recommended general seed mixture guidelines for use in the Pinedale Anticline project area (and generally followed prior to this pilot project by Shell and other companies) call for 4.0 PLS lbs/acre each of Thickspike Wheatgrass (Critana), Western Wheatgrass and Indian Ricegrass; 2.0 PLS lbs/acre of Winterfat; and 1.0 PLS lbs/acre each of Bitterbrush, Fourwing Saltbush and Scarlet Globemallow for a total of 17 PLS lbs/acre (BLM, 2000).

The Shell locations reclaimed prior to 2004 and over-seeded as part of this pilot project were originally seeded following these guidelines, but generally without bitterbrush and often without winterfat, which was difficult to seed using the conventional grass drills.

The 2004 Shell Habitat seed mix used in this project is shown in Table 3. Species diversity in the selected seeding blends was carefully considered, incorporating requirements and concerns of the BLM and other agencies. Native seed species were selected based on their desirability for reestablishing a healthy mycorrhizal soil biological community and restoring sage grouse habitat. Wind River Seed, of Manderson, Wyoming, provided the source-identified native seed, and selected available species that were best suited for the difficult Pinedale Anticline growing environment.

Table 3. Sage Habitat mix used in Shell/BLM pilot project, 2004 fall seeding.

Shell Recommended Sage Habitat Mix					
Species	#/Acre	Seeds/Ft2	% Seeds	Justification[1]	Native
WY Big Sagebrush	0.50	28.70	41.50	Provides excellent habitat for sage grouse and winter browse for big game	Yes
Winterfat	1.00	1.30	1.88	Good winter forage value for wildlife and stock	Yes
Four-winged Saltbush	0.50	0.60	0.86	Valuable browse in winter for big game, attracts insects	Yes
Fringed Sagewort	0.05	5.21	7.53	Transitional food for juvenile sage-grouse	Yes
Sandberg Bluegrass	1.00	21.24	30.71	Good for cattle, fair for sheep, deer and pronghorn in spring, early summer	Yes
Indian Ricegrass, Rimrock	1.00	3.24	4.68	Good winter forage value for wildlife and cattle, drought tolerant	Yes
Yarrow, white N. American	0.05	3.18	4.60	Sage-grouse food, adapted to a wide range of soils at disturbed sites, attracts insects	Yes
Lupine, Robinson L. polyphyllus	1.00	0.30	0.43	Sage-grouse food source and habitat for insects for grouse, adds soil nitrogen	Yes
Penstemon Procerus	0.05	5.05	7.30	Forage value fair for mule deer	Yes
Globemallow, Scarlet	0.03	0.34	0.50	Excellent forage value for deer and pronghorn	Yes
	5.18	69.15	100.00		

[1] References:
1) *North American Range Plants* , Stubbendieck, Hatch, Butterfield, 5th Edition
2) *Grasses of Wyoming* , Hallsten, Skinner, Beetle, 3rd Edition
3) *Weeds of the Wes* t, Western Society of Weed Science, 9th Edition
4) *Draft Pinedale Anticline EIS / ROD* , BLM, 1999
5) USDA Plant Guide Web Site

SEEDING

Hydroseeded Locations

Three interim reclaim locations spanning the length of the Pinedale Anticline gas field were chosen for hydroseeding with Shell Habitat seed mix at 5.2 lbs PLS/acre, using a Finn 1000 gallon hydroseeder. Locations (listed from north to south, see Figure 1) are:

Mesa 12-28 – 6.2 acres, elevation 2,264 meters (7,427 ft), seeded October 5, 2004 (Figure 3). The site is flat and set on the top of one of the "Mesa" ridges. All seed and organic amendments were mixed in the hydroseeder and applied in a single pass (Blend "M", see Table 2). Within one week of seeding, hard rains caused flooding of the seeded areas east of the pad, which then froze for much of the winter. This probably attributed to a poorer showing there than elsewhere on the site. The location was fenced in the spring of 2005.

Figure 3. Hydroseeding Mesa 12-28 site 10/5/04.

Warbonnet 11-10 – 5.0 acres, elevation 2,203 meters (7,228 ft), seeded October 5, 2004 (Figure 4). This site is located on the bentonite shales along a bluff known as the "Blue Rim" and has a generally southwest-facing slope. Soil amendment requirements for this location were considerable, due to the poor soil conditions of the reclaimed site (Blend "W", see Table 2). Multiple passes were required to apply the amendments and seed mix. The seed was added to the load containing the Fertil-Fibers, humic shale and Kiwi Power. The site was fenced in late fall of 2004.

Figure 4. Hydroseeding Warbonnet 11-10 site 10/5/04.

Antelope 2-9 – 5.0 acres, elevation 2,187 meters (7,175 ft), seeded October 4, 2004 (Figure 5). The site has a north-facing slope aspect. All seed and organic amendments were mixed in the hydroseeder and applied in a single application (Blend "A", see Table 2). Soil bed was somewhat soft during application. The site was fenced in late fall 2004.

Figure 5. Hydroseeding Antelope 2-9 site 10/4/04.

Drill Seeded Locations

Four newly-reclaimed locations were drill seeded with a Truax Rough Rider range drill, obtained through the Vale, Oregon BLM office. Shell Habitat seed mix was divided by seed size and soil depth requirements into the three seed boxes (see Table 3) and applied at a rate of approximately 5-7 lbs PLS/acre (as close as the Truax drill would calibrate without the use of rice hulls). Organic soil amendments, when used, were applied using a Simonsen fertilizer spreader. Kiwi Power, when used, was sprayed over the amended area at a rate of 1000 gallons water and 5 gallons Kiwi Power per acre. Locations (listed from north to south, see Figure 1) are:

Figure 6. Drill seeding Mesa 6-28 site with a Truax Rough Rider range drill. 11/4/04

Mesa 6-28 – 6.5 acres, elevation 2,263 meters (7,425 ft), seeded November 4, 2004 (Figure 6). The site is flat, and is located adjacent to the hydroseeded location Mesa 12-28 on the top of one of the "Mesa" ridges. Organic soil amendments and Kiwi Power were applied to the site. Half of the site was fenced in the spring of 2005. The earthmovers were leaving the site as the Truax drill seeder arrived, thus the newly spread topsoil was extremely dry and powdery; many surface seeds were unfortunately buried in this topsoil fluff.

Figure 7. Drill seeding Riverside 2-14 site with a Truax Rough Rider range drill. 11/2/04

Riverside 2-14 – 2.0 acres, elevation 2,105 meters (6,907 ft), seeded November 2, 2004 (Figure 7). No organic soil amendments were applied. The site was not fenced.

New Fork 13-32 – 2.5 acres, elevation 2,150 meters (7,054 ft), seeded November 3, 2004 (Figure 8). The location has generally a north-facing slope aspect. The soils on the reclaim here have a fairly high clay content (Table 1). Organic amendments (Blend "A", see Table 2) and Kiwi

Figure 8. Spreading organic amendment pellets on New Fork 13-32. 11/3/04

Power were applied to approximately half of the site. The site was fenced, but the fence was not constructed until late spring of 2005, after cattle had done considerable damage – particularly to the amended area.

Rainbow 11-31 – 4.0 acres, elevation 2,237 meters (7,339 ft), seeded October 6, 2004 (Figure 9). The site has generally a southwest-facing slope aspect. This was the first location seeded with the Truax drill. The seeding rate at first appeared to be a little heavy, so was cut back slightly to approximately 5-7 lbs PLS/acre during seeding on this site. No organic soil amendments were applied. The site was fenced in spring 2005.

Figure 9. Drill seeding Rainbow 11-31 with a Truax Rough Rider range drill. 10/6/04

Overseed Locations

Six locations that had been seeded prior to 2004 with the recommended grass-dominated BLM mix were over-seeded with the Shell Habitat seed mix at a rate of approximately 5-7 lbs PLS/acre, using a Truax Rough Rider range drill. Organic amendments, when used, were applied using a Simonsen fertilizer spreader. Kiwi Power, when used, was sprayed over the amended area at a rate of 1000 gallons water and 5 gallons Kiwi Power per acre. The objective of over-seeding was to test the feasibility of increasing the shrub/forb component and establishing sage grouse habitat in these areas.

Mesa 7-27 – 4.0 acres, elevation 2,190 meters (7,184 ft), originally seeded with a modified BLM-recommended mix in 2003, Overseeded on November 4, 2004 (Figure 10). It was thick with weed cover (netseed lambsquarter and Russian thistle dominant) when seeded. No organic amendments were applied. The location was not fenced.

Figure 10. Drill seeding Mesa 7-27 with a Truax Rough Rider range drill. 11/4/04

Figure 11. Weeds at New Fork 11-24 locction when seeded. 11/3/04

New Fork 11-24 – 3.1 acres, elevation 2,129 meters (6,985 ft), originally seeded with a modified BLM-recommended mix in 2003, Overseeded on November 3, 2004 (Figure 11). Organic amendments (Blend "A" – see Table 2) and Kiwi Power were applied. Approximately half the site was fenced in late spring 2005.

Pinedale Federal 13-19 – 2.7 acres, elevation 2,133 meters (6,998 ft), originally seeded with a modified BLM-recommended mix in 2003 containing beeplant, Overseeded on November 2, 2004 (Figure 12). A significant part of this site was thick with weed cover (Russian thistle and halogeton) when overseeded. No organic amendments were applied. The location was not fenced.

Figure 12. Drill seeding Pinedale Federal 13-19 with a Truax Rough Rider range drill. 11/2/04

Rainbow 7-31 – 3.1 acres, elevation 2,241 meters (7,351 ft), originally seeded with a modified BLM-recommended mix in 2003, Overseeded on October 6, 2004. (Figure 13). No organic amendments were applied. The location was fenced in late spring 2005.

Figure 13. Truax drill rows in older grasses at Rainbow 7-31. 10/6/04.

Antelope 11-4 – 3.0 acres, elevation 2,193 meters (7,196 ft), originally seeded with a modified BLM-recommended mix in 2003, Overseeded on October 6, 2004 (Figure 14). Organic soil amendments (Blend "A", see Table 2) and Kiwi Power were applied. The location was not fenced.

Figure 14. Spreading organic amendment pellets in the rain on Antelope 11-4. 10/20/04

Figure 15. Antelope 1-9 prior to overseeding. October, 2004

Antelope 1-9 – 3.0 acres, elevation 2,184 meters (7,167 ft), originally seeded with a modified BLM-recommended mix in 2002, Overseeded on October 7, 2004 (Figure 15). No organic soil amendments were applied. The site was fenced in late spring 2005, but after cattle had been through. Cattle managed to get through a fence opening again in early 2006, but little damage was noted.

MONITORING

The locations seeded in 2004 were monitored for plant emergence and growth progress annually from 2005 to 2007. Due to fluctuations in precipitation in each of these three years, the timing of monitoring varied from one year to the next (Figure 16). Monitoring transects and plant counts were carried out in late July/early August in 2005, in late June into mid-July in 2006, and in the latter half of May in 2007, but casual observations were made throughout the growing season each year.

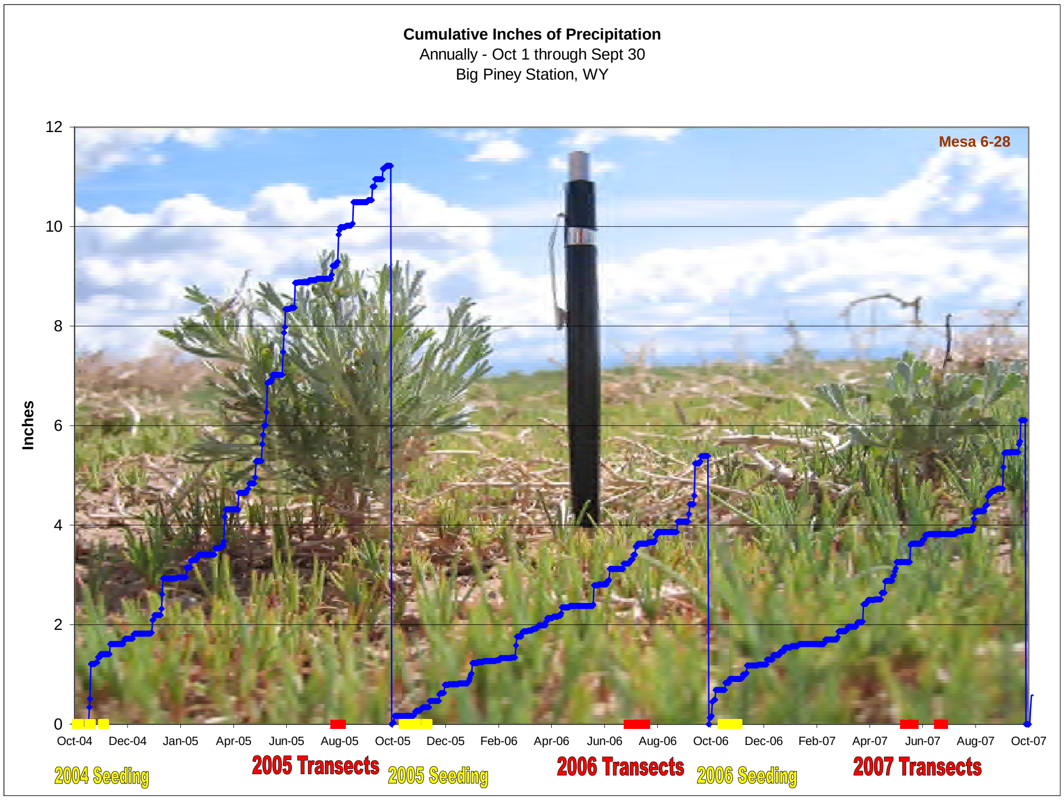

Figure 16. Precipitation data chart, also showing timing of seeding and monitoring transects.

Monitoring Methods

For the 2005 work, transects consisted of 200 foot lines set out randomly on the three hydroseeded locations, but set diagonally to the seed rows on the drill-seeded sites. Other than casual observations, the Overseed locations were not monitored in 2005, since the small seedlings were too difficult to spot in the grasses. The following observations were recorded for the Seeded locations:

1. 200 foot line transects – Percent shrub canopy was measured along the line, tallied by shrub species.

2. Quadrants – 50 cm x 50 cm quadrants were used, 20 per transect line, placed evenly along the length of the transect line (every 10 ft). The quadrants were used for:

- Species % Composition – dry mass weight of vegetation was estimated in each quadrant, and ranked as 1, 2 or 3 (70%, 20% or 10%). A single species would be ranked as 1,2,3; four or more species would be ranked 1,2, or 3 for the three species with the highest estimated dry weight mass, and the remaining species would be noted with an "x" on the field sheets, but would not be used in the "% Composition" calculation. The rankings were tallied by species, by multiplying the "1" rankings times 7, the "2" rankings times 2 and the "3" rankings times 1, and each ranking tally was totaled. The "% composition" was then calculated from these totals, by species. Weeds were lumped together as "undesirable forbs". Table 4 shows the % species composition results for the 2005 transects.
- Relative Basal Ground Cover Point Intercept – the leading outside corner of each quadrant was used as a point intercept, with grass, forb, shrub, bare ground, etc. being noted at each point intercept. *Note that these data are based on only 20 points.*
- Sage plant height – the height of the sage seedling nearest to the leading outside corner of each quadrant (the point intercept corner) within a five foot radius was measured. Absence of sage seedlings was noted, but the average height measurements calculated from all 20 quadrant points was based on sage seedlings actually present and measured.
- The presence and type of animal scat in each quadrant was also noted.

3. Permanent photoplots (1m x 1m) were established on the seeded locations for annual comparisons, with photos taken of the plot frame and all four points of the compass.

The 2006 monitoring was similar to 2005, but with the addition of a belt transect for species density and diversity information. All species of interest were counted by species in a continuous belt transect for the length of the line; counts were divided into 20% lengths of the line (0-40ft, 40-80ft, 80-120ft, 120-160ft, 160-200ft) to help determine evenness of distribution. For the Overseed locations only shrubs and forbs were counted. Species density was calculated in number of plants per square meter for all belt transects.

In 2007 – the third growing season for the 2004 seeded locations – a change was made in the monitoring methods. Twin 10-point frames (constructed and manned by Aster Canyon Consulting, Pinedale, Wyoming) were used for relative basal ground cover, providing 2000 point intercepts per 200 foot transect. Transects were staked out on both the Onsite seeded areas and an adjacent Offsite "reference" area for each location. Additional Onsite transects were laid out on partially-fenced locations to include fenced versus non-fenced areas. Belt transects were continued, but only shrubs were counted on the Offsites and shrubs and forbs counted on the Onsites. As with the previous two years, percent canopy cover was measured along the line transects, and nearest shrub heights were measured at 20 points along the lines (within a 5 foot radius), using the 10 foot markers. An attempt was made early on to measure new shrub growth, but lack of growth due to the early season timing of the monitoring as well as grazing by cattle and antelope rendered this attempt somewhat fruitless. Similar onsite-offsite data was collected on both the 2004 Seeded locations and the 2004 Overseed (grass) locations.

Quadrants were not used in the 2007 monitoring work, other than for scale in transect photos. Dry weight mass estimates and percent composition calculations were discontinued.

Table 4. Percent Composition estimates - 2005 transect quadrants.

2005 Transect Name:	Antelope 2-9 Hydroseeded	Mesa 12-28 A Hydroseeded	Mesa 12-28 B Hydroseeded	Mesa 12-28 C Hydroseeded	Warbonnet 11-10 A Hydroseeded	Warbonnet 11-10 B Hydroseeded	Mesa 6-28 A Truax (amendments added)	Mesa 6-28 B Truax (amendments added)	New Fork 13-32 A Truax (amendments added)	New Fork 13-32 B Truax (no amendments)	Rainbow 11-31 Truax (no amendments)	Riverside 2-14 Truax (no amendments)
Species	**% Composition**											
Undesirable forbs	70.6	50.5	54.0	66.3	50.0	51.0	84.5	90.5	90.0	77.0	52.1	63.5
Wyoming Big Sage	10.6	8.5	1.5	12.6	7.5	9.5	0.5		1.6	9.5	12.1	13.5
Winter Fat	1.7				3.5	1.0		2.0	3.2	1.5		0.5
Four-wing saltbush										0.5	0.5	
Fringed sage												
Yarrow	3.9	0.0	0.5		0.0	1.0	1.0		1.6		0.0	2.0
Penstemon	0.6	0.0					1.5					
Lupine	5.6										0.5	
Sandberg Bluegrass	1.1	1.0	0.0	0.5	0.0		5.5	0.5	3.2	2.0	21.6	0.5
Ricegrass	6.1	1.5		5.8			2.0	0.5	0.5	4.0	10.5	4.5
Rabbitbrush					0.5							
Alyssum				0.0	37.5	34.5	0.5	1.0				13.0
Unknown mustard					0.5	3.0		2.0				
Clover	0.0											
Aster								0.5				
Unknown forbs		36.0	41.5	12.1	0.5	0.0	4.5	3.0		3.5	2.6	2.5
Bottlebrush Squirreltail		2.0	1.5	0.5								
Green Foxtail		0.5	1.0	1.1								
Unknown grass				1.1						2.0		
	100.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.1	100.0	99.9	100.0
	(orange)	Seeded species; globemallow was also observed on several locations, but was never identified in transects.										
	(yellow)	Hydroseeded Location										

Monitoring Results and Observations

Single transects per site may not provide a rigorous scientific study of the success or failure of each variable, but do give – along with visual observations throughout the growing season – a qualitative assessment of progress. Timing of the project initiation was fortuitous; the 2004-2005 precipitation season in the Pinedale Anticline region of Wyoming was one of the best in many years (Figure 16). Thus, no site seeded in 2004 on this project fared poorly, particularly with respect to sage shrubs. The exception was Mesa 6-28, which had poor soil seedbed conditions at the time of seeding, but even this site has some fairly healthy shrubs and forbs. The two subsequent seasons have not been as good. Substantially different precipitation in the three growing seasons since seeding has complicated the interpretation of monitoring data. Nonetheless, what follows is a brief listing of some of the project variables and observations of transect data and visual inspections.

The 2007 transects were completed in mid- to late May, which proved to be a little early for many forbs, therefore the quantitative data for forbs is somewhat suspect; more forbs were noted in the 2005 and 2006 transects (albeit by different method) than in 2007, despite the dry year in 2006. Notes on casual visual observations taken in mid-June, 2005 indicate many of the seeded species were starting to emerge on all seeded locations (Table 5). Various results of the monitoring observations and data are shown below in Tables 6 through 8 and Figure 17.

Table 5. Notes on casual observations of plant emergence, June 15-17, 2005.

Observations - June 15-17, 2005

HYDROSEEDED	Antelope 2-9 Area A	Antelope 2-9 Area B	Antelope 2-9 Area C	Antelope 2-9 Area D	Warbonnet 11-10D Area A	Warbonnet 11-10D Area B	Mesa 12-28
Species							
Winterfat					S	A	
Yarrow, white N. American		A	S	A	A	A	S
Penstemon Procerus							
WY Big Sagebrush	A	A	A	A	A	A	A
Fringed Sagewort							
Indian Ricegrass, Rimrock	R	S	S		S	A	
Four-winged Saltbush	A	A	A	A	A	S	A
Globemallow, Scarlet							
Sandberg Bluegrass	A	A	A	R	S	A	A
Lupine, Robinson L. polyphyllus	S	A	A	R	S		S

Relatively: A = Abundant; S = Sparse; R = Rare

Observations - June 15-17, 2005

	New Seed Locations													
TRUAX DRILL-SEEDED	Rainbow 11-31 Area A	Rainbow 11-31 Area B	Rainbow 11-31 Area C	New Fork 13-32 Area A	New Fork 13-32 Area B	Riverside 2-14	Mesa 6-28 Area A	Mesa 6-28 Area B	Mesa 6-28 Area C	Mesa 6-28 Area D	Mesa 6-28 Area E	Mesa 6-28 Area F	Mesa 6-28 Area G	Mesa 6-28 Area H
Species - Surface														
Winterfat				A	A	A				R	S	A	A	A
Yarrow, white N. American	A	S	A	A	A	A	A		A		A	A	S	A
Penstemon Procerus														
WY Big Sagebrush	A	A	A	A	A	A	A		A	S	A	A	A	A
Fringed Sagewort														
Species - 1/4" depth														
Globemallow, Scarlet														
Sandberg Bluegrass	A	A	A	A	A	A	A					A	S	S
Species - 1" depth														
Indian Ricegrass, Rimrock	A	A	A	S	A	A	A	R			R		S	A
Four-winged Saltbush	A	A	A	A	A	A	S	S	A	A	S			A
Lupine, Robinson L. polyphyllus	A	A	A	A	A	A		R			S		R	S

Relatively: A = Abundant; S = Sparse; R = Rare

Table 6. Occurrence of Seeded Species in Transects and/or Observed - 2005 to 2007.

Seeded Species - Occurence in Transects and Observed - 2005-2007

2004 Seeded Locations	Sage			Winterfat			4 Wing SB			Fringed Sage			Yarrow		
Pad Locations	2005	2006	2007	2005	2006	2007	2005	2006	2007	2005	2006	2007	2005	2006	2007
Mesa 12-28	x	x	x	x	x		x	x	x				x	x	
Mesa 6-28	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Riverside 2-14	x	x	x	x	x	x	x	x					x	x	x
New Fork 13-32	x	x	x	x	x	x	x	x	x				x	x	x
Warbonnet 11-10	x	x	x	x	x	x		x	x				x	x	x
Rainbow 11-31	x	x	x		x	x	x	x	x		x	x	x	x	x
Antelope 2-9	x	x	x	x	x			x					x	x	x
Overseed Locations															
Mesa 7-27		x	x		x	x		x						x	
Pinedale Fed. 13-19		x	x		x	x								x	x
New Fork 11-24		x	x		x	x								x	
Rainbow 7-31		x	x					x	x						
Antelope 11-4		x	x		x			x						x	
Antelope 1-9		x	x		x			x	x					x	

2004 Seeded Locations	Lupine			Penstemon			Globemallow			Sandberg BG			Indian Ricegrass		
Pad Locations	2005	2006	2007	2005	2006	2007	2005	2006	2007	2005	2006	2007	2005	2006	2007
Mesa 12-28		x		x	x					x	x	x	x	x	x
Mesa 6-28		x		x				x		x	x	x	x	x	
Riverside 2-14		x			x			x	x	x	x	x	x	x	
New Fork 13-32	x			x						x	x	x	x	x	
Warbonnet 11-10										x	x	x		x	x
Rainbow 11-31	x	x			x					x	x	x	x	x	x
Antelope 2-9	x			x						x	x	x	x	x	x
Overseed Locations															
Mesa 7-27												x			
Pinedale Fed. 13-19												x			x
New Fork 11-24												x			
Rainbow 7-31															x
Antelope 11-4												x			
Antelope 1-9								x				x			x

Red = Hydroseeded

Table 7. Average sage shrubs heights, shrub density and percent shrub canopy cover transect data for 2005 to 2007.

Transect lengths 200ft, 60m or 100m			WY Big Sage - Measured Plant Heights Average height in cm; Sample size (n); *Std. Dev.*				Shrub Density Data from Belt Transects Plants/m^2 (3 ft belt) All shrubs			Sage shrubs only			Percent Canopy Cover (Shrubs) Line Transect Data (%)			
Seeded Location Transects	Fenced		2005	2006	2007	2007 Offsite	2006	2007	2007 Offsite	2006	2007	2007 Offsite	2005	2006	2007	2007 Offsite
Antelope 2-9	y		6.1 (18) *1.73*	6.5 (20) *1.86*	6.4 (16) *2.28*	31 (20) *11*	1.42	0.74	3.57	1.40	0.72	2.80	0.46	0.94	0.69	16.10
Rainbow 11-31	y		3.7 (20) *1.00*	8.5 (20) *3.01*	7.1 (20) *1.39*	24 (20) *9.2*	4.99	4.82	3.35	4.83	4.66	2.64	0.69	2.71	6.32	30.70
Warbonnet 11-10 A	y		6.5 (20) *2.74*	8.1 (20) *3.11*	7.4 (20) *2.07*	25 (20) *13*	6.42	9.80	2.97	6.24	9.62	1.06	1.28	2.94	4.80	7.90
Warbonnet 11-10 B	y		9.0 (20) *3.14*	8.1 (20) *2.79*	11.0 (20) *3.91*		7.22	8.99		7.05	8.81		0.92	3.73	8.35	
New Fork 13-32 A	y	A	6.4 (20) *1.95*	10.6* (39) *4.56*	11.1 (20) *3.01*	20 (20) *6.9*	1.62*	1.18	3.82	1.24*	0.84	2.64	0.11	1.12*	0.60	18.40
New Fork 13-32 B	y		5.8 (20) *1.97*	5.6 (20) 3.09	8.7 (20) *4.33*		2.55	2.10		2.48	2.03		0.67	1.26	0.65	
Riverside 2-14			3.7 (20) *1.24*	3.9 (20) *2.10*	4.8 (20) *0.87*	16 (20) *7.0*	6.40	6.02	2.73	4.66	5.67	2.44	0.90	1.00	1.45	18.15
Mesa 6-28 A	y	M	6.4 (13) *0.35*	4.3** (19) *2.22*	6.8 (13) *2.89*		0.72	2.39		0.68	2.13		0.10	0.00	0.25	
Mesa 6-28 B		M	7.5 (8) *2.74*	5.2** (16) *3.10*	6.3 (19) *1.94*		1.87	6.48		1.58	5.60		0.00	0.11	0.75	
Mesa 12-28 A	y		7.0 (15) *2.94*	10.7 (18) *2.33*		19 (20) *8.3*	0.95		3.36	0.93		2.96	0.75	0.72		28.75
Mesa 12-28 B	y		9.6 (18) *3.10*	11.7 (15) *2.37*			0.59			0.57			0.26	0.71		
Mesa 12-28 C	y		9.3 (19) *3.76*	13.1* (38) *3.42*	11.7 (20) *3.99*		1.51*	2.23		1.46*	2.21		2.05	2.37*	3.30	
Overseeded Location Transects																
Antelope 1-9	y			2.7 (19) *1.17*	5.1 (14) *3.25*	31 (20) *10.9*	1.72	0.22	3.57	1.45	0.20	2.80		0.74	0.24	16.10
Antelope 11-4		A		3.2 (17) *1.30*	3.6 (7) *1.13*	27 (20) *9.3*	0.71	0.05	2.62	0.55	0.05	2.26		0.18	0.00	20.52
Rainbow 7-31	y			2.0 (9) *0.66*	3.0 (14) *0.91*	25 (20) *7.7*	0.98	0.89	2.84	0.18	0.40	2.39		4.20	1.70	26.80
Pinedale Federal 13-19		A		4.0 (8) *1.51*	4.2 (10) *1.23*	13 (20) *4.7*	0.29	0.31	4.34	0.27	0.29	3.80		0.12	0.00	16.55
New Fork 11-24 A	y	A		3.0 (16) *1.72*	5.3 (16) *1.46*		0.31	0.24		0.28	0.38			0.00	0.05	
New Fork 11-24 B		A		3.3 (15) *1.49*	5.4 (17) *2.29*	14 (20) *4.2*	0.69	0.60	3.78	0.67	0.56	3.28		0.02	0.10	17.45
New Fork 11-24 C		A			4.7 (19) *1.38*			1.56			1.52				0.17	
Mesa 7-27				2.2 (8) *1.20*	3.5 (17) *1.23*	14 (20) *13*	0.49	0.58	3.42	0.28	0.54	2.89		0.00	0.00	4.25

* Average of 2 transects ** Re-seeded 2005; counts include new seedlings

Hydroseeded location - 2004 (included organic soil amendments)

No transects

A/M Organic soil amendments applied in dry pellet form - 2004; A="A" blend; B="B" blend

Table 8. 2007 Point Intercept Relative Basal Ground Cover Data shown as percent (10-point frames; 2000 points per transect) for Onsite and Offsite transects in 2007. Data for most shrubs, forbs and grasses.

2007 TRANSECT DATA

2004 Seeded Locations

2000 pt intercept (10-pt frames) data Basal Ground Cover Onsite and Offsite Transects	Antelope 2-9-07 (Onsite)	**Antelope 2-9-07-OS Offsite**	Rainbow 11-31-07 (Onsite)	**Rainbow 11-31-07-OS Offsite**	Warbonnet 11-10-07 A (Onsite)	Warbonnet 11-10-07 B (Onsite)	**Warbonnet 11-10-07-OS Offsite**	New Fork 13-32-07 A (Onsite)	New Fork 13-32-07 B (Onsite)	**New Fork 13-32-07-OS Offsite**	Riverside 2-14-07 (Onsite)	**Riverside 2-14-07-OS Offsite**	Mesa 6-28-07 A (Onsite)	Mesa 6-28-07 B (Onsite)	**Mesa 12-28-07-OS Offsite**	Mesa 12-28-07 (Onsite)
	(hydroseeded)				(hydroseeded)	(hydroseeded)		A					A	A		(hydroseeded)
Bare Ground	78.6	70	85.3	74.7	81	76.9	73.4	76.3	85.1	76.8	86.4	77	73.6	64.3	68.5	69.2
Litter	7.2	20.4	6.6	17.8	6.1	7.7	16.7	8.3	4.5	13	2.6	14	18.9	22.4	21.3	9.1
Woody Litter	0.5	2.5	0.8	1.6	0.5	1.8	1.9	0.9	0.4	2	0.5	1.5	0.1	0.5	2.4	1.2
Rock	0.3	0.1	0.1								0.1		0.4		0.1	0.6
Shrub	0.1	1.5	0.7	1.9	1.4	1.4	1.3	0.4	0.4	1.4	0.8	1.9	0.3	0.5	1.8	0.4
Forb		1.5	0.3	1.7	8.4	5.7	1.7	0.1	1.5	1	1.9	0.9	0.4	1.3	2.9	0.3
Grass	0.2	2.9	2.5	2.5	0.1	0.3	5.2	0.2	0.4	6.1	0.4	5.1	0.4	0.5	3.5	0.6
Weed	13.5		3.9		2.7	6.7	0.1	14.1	7.9		7.6		6.1	10.9		19.1
Shrubs & selected forbs and grasses																
Wyoming Big Sagebrush - *Artemisia tridentata ssp. wyomingensis*	0.1	1.6	0.6	1.7	1.4	1.3	0.9	0.2	0.4	1.2	0.6	1.4	0.2	0.3	1.3	0.4
Winterfat - *Krascheninnikovia lanata*										0.2						
Fourwing Saltbush - *Atriplex canescens*																
Yellow Rabbitbrush - *Chrysothamnus viscidiflorus*		0.4		0.1			0.4					0.2			0.1	
Cushion Buckwheat - *Eriogonum ovalifolium*				0.1											0.2	
Spoonleaf Buckwheat (?) - *Eriogonum spathulatum*							0.2									
Phlox - *Phlox pulvinata*				0.3			0.6			0.5		0.8			1.8	
Phlox - *Phlox multiflora*				0.7			0.2			0.1					0.2	
Alyssum - *Alyssum simplex*		0.1			8.3	5.6	0.7		0.8		1.8	0.1	0.1	1.0		
Goldenweed - *Happlopappus acaulis (Stenotus acaulis)*		0.1		0.2						0.1					0.7	
Clover - *Trifolium gymnocarpon*										0.3						0.3
Western Yarrow - *Achillea millefolium*			0.2		0.1	0.1					0.1			0.2		
Indian Ricegrass - *Achnatherum hymenoides*		0.7	0.6		0.1	0.1	2.0					1.1			0.4	0.1
Sandberg Bluegrass - *Poa secunda*		1.5	1.9	1.6		0.2	1.1	0.2	0.1	4.5	0.4	2.2	0.4	0.5	1.2	0.2
Western Wheatgrass - *Pascopyrum smithii*	0.2									1.6						
Thickspike Wheatgrass - *Elymus lanceolatus*		1.7		0.8			2.1		0.3			1.7			1.3	
Idaho Fescue - *Festuca idahoensis*		0.3														
Bottlebrush Squirreltail - *Elymus elymoides*		0.3	0.1	0.1								0.1			0.6	0.2
Needleandthread - *Hesperostipa comata*																0.1
Halogeton - *Halogeton glomeratus*	12.6		3.5		1.4	1.4	0.1	3.5	3.6		6.7					18.6
Russian Thistle - *Salsola iberica*	0.9		0.4		0.2	0.1		5.2	4.1		0.9		4.3	9.8		0.1
Netseed Lambsquarter - *Chenopodium album*						0.4							1.7	1.1		0.2

(yellow) Hydroseeded location - 2004

A Amendments applied - 2004

Table 8 (continued). 2007 Point Intercept Relative Basal Ground Cover Data shown in percent (10-point frames; 2000 points per transect) for Onsite and Offsite transects in 2007. Data for most shrubs, forbs and grasses.

2007 TRANSECT DATA

2004 Over-Seeded Locations

2000 pt intercept (10-pt frames) data Basal Ground Cover Onsite and Offsite Transects	Antelope 1-9-07 (Onsite)	**Antelope 2-9-07-OS Offsite**	Antelope 11-4-07 (Onsite)	**Antelope 11-4-07-OS Offsite**	Rainbow 7-31-07 (Onsite)	**Rainbow 7-31-07-OS Offsite**	Pinedale Federal 13-19-07 (Onsite)	**Pinedale Federal 13-19-07-OS Offsite**	New Fork 11-24-07 A	New Fork 11-24-07 B	New Fork 11-24-07 C	**New Fork 11-24-07-OS Offsite**	Mesa 7-27-07 (Onsite)	**Mesa 7-27-07-OS Offsite**
			A				A		A	A	A			
Bare Ground	78.8	70	76.2	74.5	63.5	76.1	84.6	73.1	80.9	82.8	81.8	71.1	71.9	78.5
Litter	12	20.4	14.6	14.7	26.4	12.7	8.9	14.6	10.8	8.9	9.1	17.4	20.9	13.5
Woody Litter	0.6	2.5	1.1	2.9	1.5	1.7	1	2.7	0.4	0.4	0.3	3.9	1.1	0.9
Rock		0.1				0.2							1.3	0.5
Shrub	0.3	1.5		1.8	0.2	1.1	0.1	1.6		0.1	0.3	1.3		1.2
Forb	0.1	1.5	1.1	2.9	0.1	3.4	0.2	1.8	0.1		0.1	2.2		3.2
Grass	8.4	2.9	6.4	3.6	8.5	5.3	5.5	6.5	7.2	6.2	6	4.6	4.9	2.6
Weed	0.1		0.9						0.9	2.0	2.8			
Shrubs & selected forbs and grasses														
Wyoming Big Sagebrush - *Artemisia tridentata ssp. wyomingensis*	0.1	1.6		1.5		1.1	0.1	1.3		0.1	0.2	1.2		0.7
Winterfat - *Krascheninnikovia lanata*												0.1		
Fourwing Saltbush - *Atriplex canescens*														0.1
Yellow Rabbitbrush - *Chrysothamnus viscidiflorus*		0.4		0.3				0.3						
Cushion Buckwheat - *Eriogonum ovalifolium*				1.0										
Spoonleaf Buckwheat (?) - *Eriogonum spathulatum*														
Phlox - *Phlox pulvinata*				1.9										
Phlox - *Phlox multiflora*					0.1									
Alyssum - *Alyssum simplex*	0.1	0.1	1.0											
Goldenweed - *Happlopappus acaulis (Stenotus acaulis)*		0.1		0.1										
Clover - *Trifolium gymnocarpon*				0.1					0.1		0.1			
Western Yarrow - *Achillea millefolium*							0.1							
Indian Ricegrass - *Achnatherum hymenoides*	0.7	0.7		0.1	0.3		0.1							
Sandberg Bluegrass - *Poa secunda*	0.2	1.5	0.4	1.6			0.4		0.2	0.5	0.6		0.6	
Western Wheatgrass - *Pascopyrum smithii*	4.1		3.1		4.2		2.4		3	3	2.2		1.5	
Thickspike Wheatgrass - *Elymus lanceolatus*	0.5	1.7	2.9	0.8	3.6		2.6		4	2.7	3.2		2.8	
Idaho Fescue - *Festuca idahoensis*		0.3												
Bottlebrush Squirreltail - *Elymus elymoides*	0.1	0.3		0.1										
Needleandthread - *Hesperostipa comata*					0.4									
Halogeton - *Halogeton glomeratus*			0.8						0.6					
Russian Thistle - *Salsola iberica*	0.1		0.1						0.3	1.9	2.8			
Netseed Lambsquarter - *Chenopodium album*														

(shaded)	Hydroseeded location - 2004
A	Amendments applied - 2004

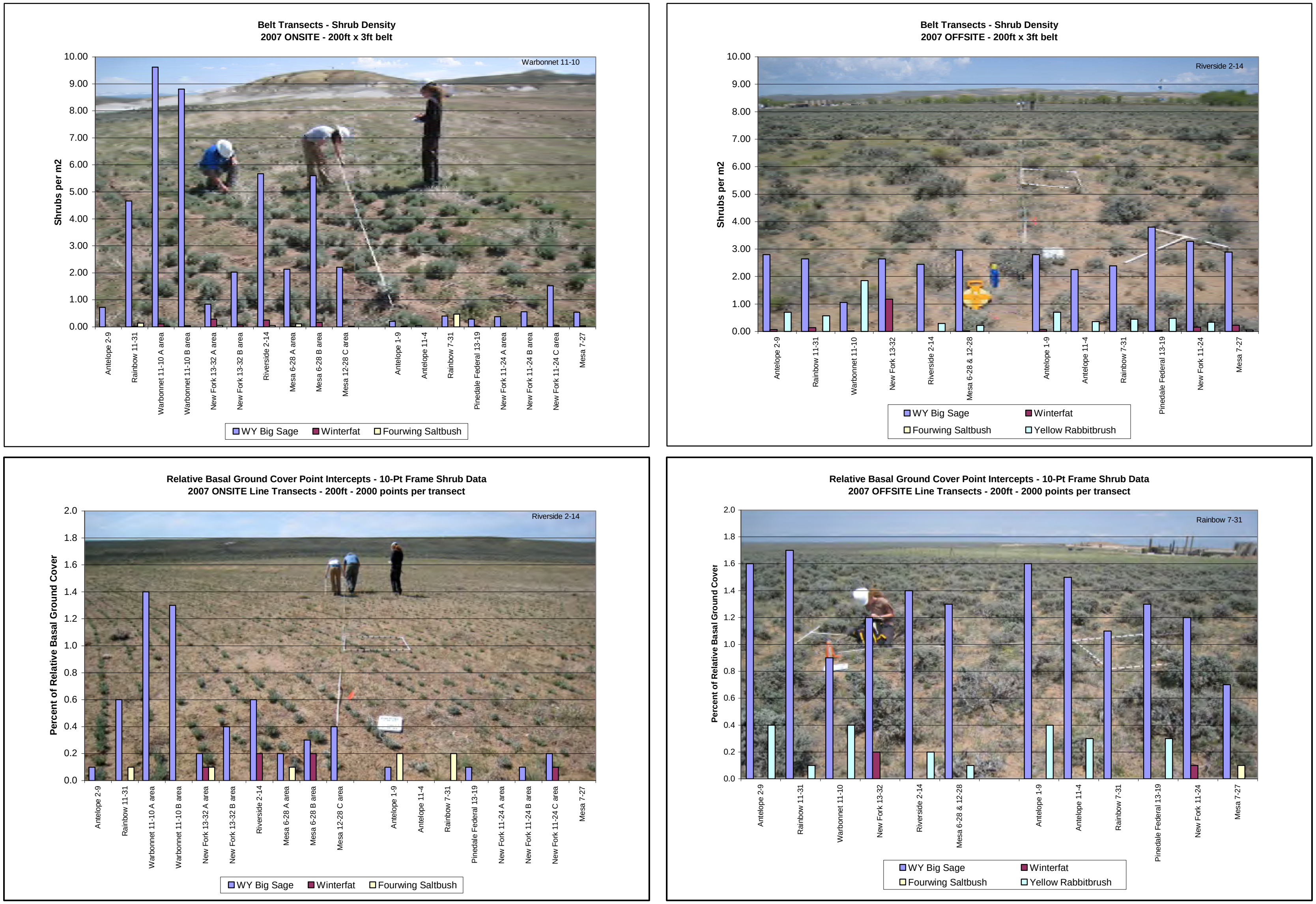

Figure 17. Comparison bar charts of transect data from the 2007 transects. Top charts show shrubs/m^2 for Onsite (left) and Offsite (right) transects; bottom charts show percent relative basal ground cover data for shrubs for Onsite (left) and Offsite (right) transects. Background photos are marked with transect locations.

Two seeded locations stand out as unusual successes, both in the data and on visual inspection: Rainbow 11-31 (drill-seeded location with no amendments added – good soils), and Mesa 12-28 (hydroseeded location with amendments). These two locations are discussed first; comments on the remaining eleven Seeded locations follow.

Rainbow 11-31 (drill-seeded, no amendments, fenced for livestock) – Observations in mid-June, 2005, indicated relatively abundant emerging sage, fourwing saltbush, yarrow, lupine, Indian ricegrass and Sandberg bluegrass. Herbaceous predation took a toll on the forb population, particularly the large lupines seen that first season (Figure 18). Table 7 shows measured sage height, shrub density and percent shrub canopy cover for the years 2005 through 2007.

Figure 18. RAINBOW 11-31. Blooming lupines and yarrows with Indian Ricegrass and sages (and weeds). Photos taken 7/27/05 (left) & 7/25/05 (right).

Despite the droughty year in 2005-06 and browsing by antelope, shrub height increased significantly. Density of shrubs per square meter as counted in the belt transects in 2006 and 2007 is higher than the adjacent offsite shrub density. Relative basal ground cover data (10-point frames) in 2007 shows non-weed vegetation constitutes 3.5% of the relative basal ground cover, consisting of:

- 20% shrubs – 86% sage, 14% fourwing saltbush
- 9% forbs – 67% yarrow, 33% Virginia bluebells (not in seed mix)
- 71% grasses – 76% Sandberg bluegrass, 24% Indian ricegrass, 4% bottlebrush squirreltail

Offsite transect - 6.1% of the relative basal ground cover is vegetation, consisting of:

- 31% shrubs – 90% sage, 5% rabbitbrush, 5% prickly pear cactus
- 28% forbs – 59% phlox species, 24% unidentified forb, 12% goldenweed, 6% buckwheat species
- 41% grasses - 64% Sandberg bluegrass, 32% thickspike wheatgrass and 4% bottlebrush squirreltail.

Figure 19 shows yearly photoplot comparisons of the Rainbow 11-31 location, and Figure 20 shows views of the location in 2006 and 2007.

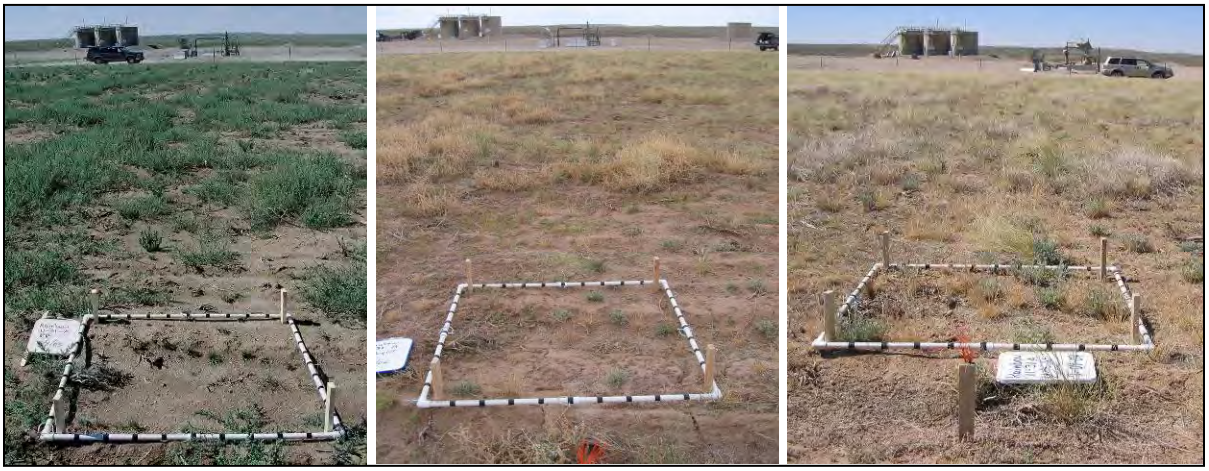

Figure 19. Photoplot A – RAINBOW 11-31 location. View to south; one meter square frame. Photos taken (left to right): 8/4/05, 7/5/06, and 7/9/07, respectively. Seeded 10/6/04; native plants in view include Wyoming Big Sage, Sandberg bluegrass, Indian Ricegrass, Fourwing Saltbush, Western Yarrow.

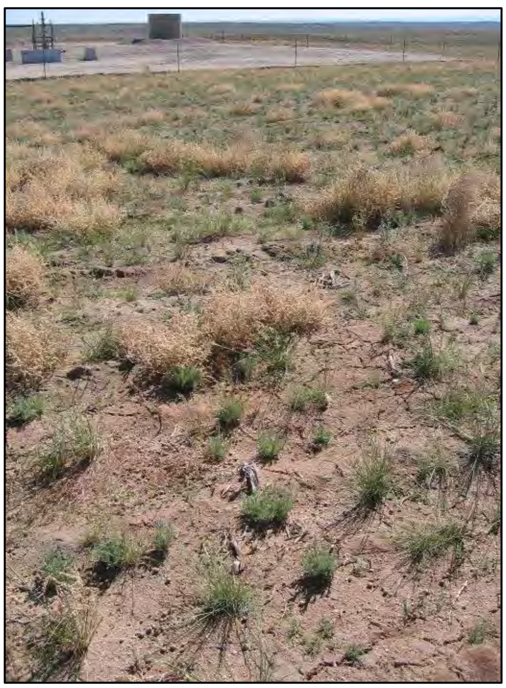

Figure 20. RAINBOW 11-31. Wyoming Big Sage, Indian Ricegrass, Sandberg bluegrass, Fourwing Saltbush, Western Yarrow. Photos taken 6/5/06 (left) and 7/9/07 (right).

Mesa 12-28 (hydroseeded with "M" amendments; fenced for livestock) – Observations in mid-June, 2005 show relatively abundant emerging sage, fourwing saltbush and Sandberg bluegrass, with lesser amounts of yarrow and lupine (Table 5 and Figure 21). Fencing had not yet been constructed at this time; some ungulate traffic was observed, but with minor resulting damage. The transects labeled "A" and "B" were taken on the east side of the location, where flooding and freezing occurred shortly after seeding in 2004. Though sage density was less here than in the area that was not affected by flooding (transect "C"), sage height increased from 2005 to 2006. Transects were discontinued in this area in 2007 due to plans for a pad expansion in that direction. Visual estimations, however, indicate the seeded species vegetation has increased significantly since 2006.

As seen in Table 7, the Mesa 12-28 C transect area showed an increase in sage height from 2005 to 2006, then a slight decrease in 2007, which probably reflects the effects of browsing and the earlier seasonal timing of the transects in 2007. Sage density data as counted in the belt transect show sage density alone is close to 75% of the adjacent Offsite sage density. Percent canopy cover increased from 2% in 2005 to 3.3% in 2007.

Figure 21. MESA 12-28. Wyoming Big Sage seedlings. Photos taken 6/15/05. See also Figures 20 & 21, taken near the same site on this location.

The total non-weed vegetation makes up 1.3% of the relative basal ground cover as measured in the 2007 transect (10-point frame – Table 8) consisting of:

- 31% shrubs – 100% sage (fourwing saltbush also noted in the belt transect)
- 23% forbs – 100% clover
- 46% grasses – 33% Sandberg bluegrass, 33% bottlebrush squirreltail (not in seed mix), 17% Indian ricegrass, 17% needleandthread (not in seed mix)

Offsite transect - 8.2% of the relative basal cover was vegetation, consisting of:

- 22% shrubs - 72% sage, 22% prickly pear cactus, 6% rabbitbrush
- 35% forbs – 69% phlox species, 24% goldenweed, 7% buckwheat species
- 43% grasses – 37% thickspike wheatgrass, 34% Sandberg bluegrass, 17% bottlebrush squirreltail, 11% Indian ricegrass

Figure 22 shows sages and bunchgrasses on the site in late May, 2007. The sages on this site were producing seed in September, 2007 (Figure 23). Though not seen in the transects, yarrow is fairly common, and aster, lupine and penstemon have been found on the site – particularly during the wetter 2005 summer. The other two hydroseeded locations were successful in producing sages and varying amounts of yarrow and grasses, but not in the same abundance as on Mesa 12-28.

Antelope 2-9 (hydroseeded with "A" amendments; fenced for livestock) - Species noted as emerging in different areas of Antelope 2-9 in mid-June, 2005 included relatively abundant sage, fourwing saltbush and Sandberg bluegrass and varying amounts of yarrow, lupine and ricegrass. No winterfat, penstemon, fringed sage or scarlet globemallow were noted at this time. Winterfat, lupine and penstemon did appear later in the season, but in minor amounts. The average sage height as measured in 2005 did not increase significantly over the next two years. However, the site is heavily grazed by antelope; sages and yarrows protected by Russian thistle on one area of

Figure 22. MESA 12-28. Wyoming Big Sage, Fourwing Saltbush and bunch grasses. 5/29/07 photo.

Figure 23. MESA 12-28. Wyoming Big Sage in seed - same location as Figures 20 & 21. 9/14/07 photo.

the property grew considerably during that time. Sage density data from the belt transects and percent shrub canopy cover show a significant decrease from 2006 to 2007, but
this could reflect the irregular distribution of the shrubs on site (thus error of single-transect method), since no evidence of shrub mortality was noted.

Figure 24. ANTELOPE 2-9. Sage grouse scat and sages. 5/15/07 photo.

The total non-weed vegetation makes up only 0.3% of the relative basal ground cover as measured in the 2007 transect (10-point frame – Table 8). This consists of:

- 33% shrubs – 100% sage
- 0% forbs
- 67% grasses – 100% western wheatgrass (not in seed mix)

This is somewhat in contrast with earlier transects (2005 and 2006), as well as with visual observations during the 2007 transect work on the site; yarrow, Sandberg bluegrass and Indian ricegrass occur in varying amounts across the location. Sage grouse scat was noted in numerous spots on the seeded location (Figure 24).

Offsite transect - 8.7% of the relative basal ground cover is vegetation, consisting of:

- 23% shrubs - 80% sage, 20% rabbitbrush
- 25% forbs – 55% buckwheat species, 36% phlox species, 4.5% alyssum, 4.5% goldenweed
- 52% grasses - 38% thickspike wheatgrass, 33% Sandberg bluegrass, 16% Indian ricegrass, 6.7% Idaho fescue and 6.7% bottlebrush squirreltail

Figure 25. WARBONNET 11-10. Wyoming Big Sage shrubs. 7/12/06 photo.

Warbonnet 11-10 (hydroseeded with "W" amendments, fenced for livestock) – Bentonite clay bed outcrops occur near the upper edge of the property. For monitoring purposes, the location was divided into an upper "A" area and a lower "B" area; the upper A area slopes generally SW about 5-7 degrees. The lower B area is on flatter ground, with about a 2 degree slope; Basin Big Sage shrubs line a drainage just off the lower edge of the property in the B area, some of which exceed 2 meters in height. The mid-June 2005 observations noted relatively abundant emergence of sage and yarrow, with varying amounts of winterfat, fourwing saltbush, Sandberg bluegrass, Indian ricegrass and lupine (Table 5). These same species, minus lupine, were noted either in transects or otherwise observed on the location in 2007 (Table 6). Measured average sage height data from the belt transects for 2005 through 2007 show some difference between sage heights in the two transect locations, with the heights in the flatter B area generally greater than on the slope. This location is heavily used by antelope and sage grouse scat has been observed on the upper slopes in the seeded area. The average sage density on this location is the highest of any seeded location at approximately 9 sage shrubs counted per square meter; percent shrub canopy cover is likewise higher. Distribution of the shrubs is somewhat patchy, however. Relative basal ground cover data (average of A and B transects) from the 10-point frame transects indicates non-weed vegetation makes up about 7-9% of the relative basal ground cover, consisting of:

16% shrubs – 96% sage, 4% rabbitbrush
81% forbs – 98% alyssum, 2% yarrow
2.5% grasses – 66% Indian ricegrass, 34% Sandberg bluegrass

Offsite transect – 8.3% of the relative basal ground cover is vegetation, consisting of:

16% shrubs - 69% sage, 31% rabbitbrush
20% forbs – 47% phlox species, 41% alyssum, 12% buckwheat species
63% grasses - 40% thickspike wheatgrass, 38% Indian ricegrass, 21% Sandberg bluegrass

A minor amount (1%) of the relative vegetative basal ground cover in the Offsite transect is halogeton. Sage shrub density as counted in the belt transect is about 1.1 sage shrubs per square meter, which is considerably less than the sages on the seeded location (Table 7).

New Fork 13-32 (drill-seeded; "blend A" organic soil amendment pellets applied dry to approximately one-half of the location; fenced for livestock) – The fence was not installed until after cattle had done considerable damage to the site in the wet spring of 2005. The location was divided into A (amendments applied) and B (no amendments applied) areas. Despite the cattle damage, casual observations in mid-June 1005 showed relatively abundant sage, winterfat, fourwing saltbush, yarrow, lupine, Sandberg bluegrass and varying amounts of Indian ricegrass emerging on both areas. Except for lupine, all of these species were noted either in transects or in visual observations in 2007. Transects were run on both the A and B areas in all three years, as well as on an adjacent Offsite "reference area" in 2007. A duplicate transect on the A area was run in 2006. Average measured sage heights, shrub density and percent shrub canopy are

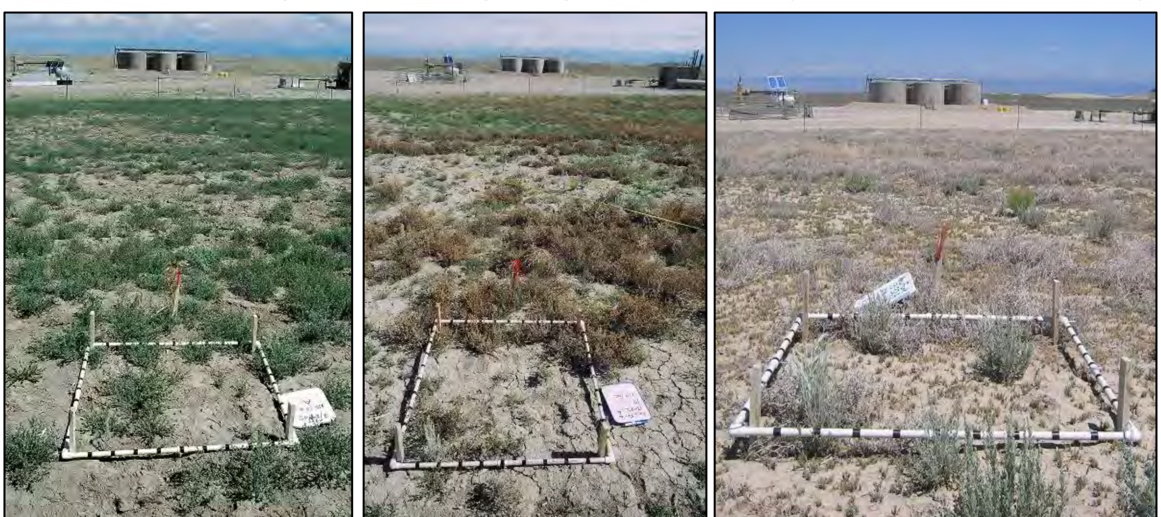

Figure 26. NEW FORK 13-32. Photoplot New Fork 13-32 A. Photos taken (left to right): 7/25/05, 7/12/06 and 7/9/07. View to north. One meter square frame. Larger green shrubs in 2007 photo are Wyoming Big Sage and Winterfat, with some Fourwing Saltbush. Increasing effects of dry years are evident in 2006 and 2007 photos.

shown in Table 7. Area A transects indicate a lower density of sages, but an average measured sage height that is higher than area B. Although it is tempting to attribute this to the effects of the added amendments, this more likely reflects a slightly lower browsing rate of the sages by antelope; the A area adjoins an access road to another location that could be a deterrent to antelope spending as much time on that area of the location as on area B. Percent shrub canopy cover as measured in the line transects were about the same on both the A and B areas. The relative basal ground cover transects (10-point frames) indicate non-weed vegetation accounts for only 0.7% of the relative basal cover in the A area, and 2.3% in the B area:

Figure 27. NEW FORK 13-32. Winterfat shrubs. 8/8/07 photo.

Onsite transect A – 0.7% of the relative basal ground cover is non-weed vegetation, consisting of:

- 57% shrubs – 50% sage, 25% winterfat, 25% fourwing saltbush
- 14% forbs – 100% unidentified forb
- 29% grasses – 100% Sandberg bluegrass

Onsite transect B – 2.3% of the relative basal ground cover is non-weed vegetation, consisting of:

- 17% shrubs – 100% sage
- 65% forbs – 53% alyssum, 40% unidentified forb, 7% mustard
- 17% grasses – 75% thickspike wheatgrass (not in seed mix), 25% Sandberg bluegrass

These percents are skewed somewhat by the presence of alyssum and thickspike wheatgrass on the B area. There was an old strip of relatively little-disturbed ground in the reclaim on the B area side that contained the wheatgrass and it is difficult to align a transect without running over part of it. The wheatgrass also appears to be moving into the rest of the seeded area on the B side. Only sage was encountered on the B transect, but healthy winterfat shrubs are scattered across the B area (Figure 27). This part of the Pinedale Anticline field has a noticeably higher proportion of winterfat shrubs than elsewhere in this project area, as seen in the Offsite relative basal ground cover transect data.

Offsite transect - 8.5% of the relative basal ground cover is vegetation, consisting of:

- 16% shrubs - 86% sage, 14% winterfat
- 12% forbs - 60% phlox, 30% clover, 10% goldenweed
- 72% grasses - 74% Sandberg bluegrass, 26% thickspike wheatgrass

Within about 50 meters of the Offsite transect is a "winterfat circle" – a roughly circular area of about 10 meters in diameter containing nearly all winterfat as small, stubby shrubs.

Riverside 2-14 (drill-seeded; no amendments applied; not fenced) – This is a small, flat location near the New Fork River. Mid-June, 2005 observations showed relatively abundant emergences of all seeded species except fringed sage, penstemon and scarlet globemallow (Table 5). Rare penstemon was noted in 2006 and minor amounts of globemallow appeared on this location in 2006 and were blooming in May, 2007. The shrubs, forbs and grasses here are browsed heavily by cattle, antelope and possibly deer, as reflected in the average measured shrub heights (Table 7). Density of sages are high, more than twice the Offsite sage density as measured in the transects. The data indicate a slow growth in both average height and density. Percent shrub canopy cover (1.45%) also shows a steady increase. See Figure 17 for photos of this site.

Onsite transect - 3.1% of the relative basal ground cover is non-weed vegetation, consisting of:
- 26% shrubs - 75% sage, 25% winterfat
- 61% forbs - 95% alyssum; 5% yarrow
- 13% grasses – 100% Sandberg bluegrass

Indian ricegrass also occurs, but was not intersected in the transect (Table 6).

Offsite transect - 7.9% of the relative basal ground cover is vegetation, consisting of:
- 24% shrubs - 74% sage, 16% prickly pear cactus; 10% rabbitbrush
- 11% forbs - 89% phlox species, 11% alyssum
- 65% grass - 43% Sandberg bluegrass, 33% thickspike wheatgrass, 22% Indian ricegrass, 2% bottlebrush squirreltail

Mesa 6-28 (drill-seeded; "M" organic amendments applied in dry pellet form; half the location fenced for livestock) – This location is immediately to the east of the Mesa 12-28 (hydroseeded) location. The same Offsite reference transect was used for both locations. Mid-June, 2005 observations noted the emergence of sage, winterfat, fourwing saltbush, yarrow, lupine, Sandberg bluegrass and Indian ricegrass in only sporadic amounts and in scattered locations (Table 5). Sage and yarrow were the most common. However, by the end of 2007, all seeded species had been observed on the location, though not in every year (Table 6) – including many healthy fringed sages (Figure 28). Transects were run both inside (A) and outside (B) the fenced area in all three years. Frequency of occurrence of shrubs in the 2005 quadrants was low. The location was re-seeded in the fall of 2005 with the same seed mix, using a Truax Rough Rider range drill again, but no more amendments were applied. Average sage heights of those shrubs that were found in the 2005 transects were similar to sages on the adjacent Mesa 12-28 (area A – see Table 7). 2006 average sage heights reflect the addition of new seedlings since only the nearest sage shrub to the quadrant reference point was measured. 2007 average heights indicate the sages are now more uniform in size. Sage densities reflect a similar trend, as does the percent shrub canopy cover.

Figure 28. MESA 6-28. Fringed Sagewort. 7/1/06 photo.

Onsite transect A (inside fence) - 1.1% of the relative basal ground cover is non-weed vegetation, consisting of:
- 27% shrubs - 67% sage, 33% fourwing saltbush

- 36% forbs – 75% mustard, 25% alyssum
- 36% grasses – 100% Sandberg bluegrass

Onsite transect B (outside fence) – 2.3% of the relative basal ground cover is non-weed vegetation, consisting of:

- 22% shrubs – 60% sage, 40% winterfat
- 57% forbs – 77% alyssum, 15% yarrow, 8% mustard
- 22% grasses – 100% Sandberg bluegrass

Overseed Locations

Both measured sage heights and shrub density show an increase from 2006 (first monitoring observations) to 2007 (Table 7). Percent shrub canopy cover is erratic, reflecting grazing and seasonal timing of the transects.

Antelope 1-9 - fenced, but not before cattle grazed in early summer 2005. In the 2007 Onsite transect, 8.8% of the relative basal ground cover (10-point frame data – Table 8) was non-weed vegetation, consisting of:

- 3.4% shrubs – 33% sage, 67% fourwing saltbush
- 1.1% forbs – all alyssum
- 95% grass – 49% western wheatgrass, 39% thickspike wheatgrass and other unidentified wheatgrass, 8% Indian ricegrass, 2% Sandberg bluegrass, 1% bottlebrush squirreltail

The Offsite transect (same as for Seeded location Antelope 2-9) showed vegetation makes up 8.7% of the relative basal ground cover, consisting of:

- 23% shrubs – 80% sage, 20% rabbitbrush
- 25% forbs – 55% buckwheat species, 36% phlox species, 4.5% alyssum, 4.5% goldenweed
- 52% grasses – 38% thickspike wheatgrass, 33% Sandberg bluegrass, 16% Indian ricegrass, 6.7% Idaho fescue, 6.7% bottlebrush squirreltail

Antelope 11-4 – not fenced. In the 2007 Onsite transect, 7.5% of the relative basal ground cover (10-point frame data – Table 8) was non-weed vegetation, consisting of:

- 0% shrubs
- 14.7% forbs – 91% alyssum, 9% forget-me-not
- 85% grasses – 48% western wheatgrass, 45% thickspike, 6% Sandberg bluegrass, 5% bottlebrush squirreltail

Offsite transect – In the 2007 Onsite transect, 8.3% of the relative basal ground cover was vegetation, consisting of:

- 22% shrubs – 83% sage, 17% rabbitbrush
- 35% forbs – 86% phlox species, 7% buckwheat species, 3% clover, 3% milkvetch
- 43% grasses – 53% Sandberg bluegrass, 36% thickspike wheatgrass, 11% bottlebrush squirreltail

Rainbow 7-31 –fenced. In the 2007 Onsite transect, 8.8% of the relative basal ground cover (Table 8) was non-weed vegetation, consisting of:

- 2.3% shrubs – 100% fourwing saltbush

1.1% forbs – 100% phlox species

97% grasses – 49% western wheatgrass, 42% thickspike wheatgrass, 5% bottlebrush squirreltail, 4% Indian ricegrass

Offsite transect – 9.8% of the relative basal ground cover was vegetation, consisting of:

11% shrubs – 100% sage

35% forbs – 73% phlox species, 12% buckwheat species, 9% goldenweed, 3% alyssum, 3% mustard species

54% grasses – 55% Sandberg bluegrass, 24% Idaho fescue, 9% bottlebrush squirreltail, 8% thickspike wheatgrass, 4% needleandthread

Pinedale Federal 13-19 – not fenced; heavily overgrazed every summer. In the 2007 Onsite transect, 5.8% of the relative basal ground cover was non-weed vegetation, consisting of:

1.7% shrubs – 100% sage

3.4% forbs – 50% yarrow, 50% sweetpea

95% grasses – 47% thickspike wheatgrass, 44% western wheatgrass, 7% Sandberg bluegrass, 2% Indian ricegrass

Offsite transect – 9.9% of the relative basal ground cover was vegetation, consisting of:

16% shrubs – 81% sage, 19% rabbitbrush

18% forbs – 61% phlox species, 22% buckwheat species, 17% clover

66% grasses – 52% Sandberg bluegrass, 32% thickspike wheatgrass, 14% Idaho fescue, 2% bottlebrush squirreltail

New Fork 11-24 - partially fenced.

Transect A (inside fence) – 7.3% of the relative basal ground cover was non-weed vegetation, consisting of:

0% shrubs

1.4% forbs – 100% clover

99% grasses – 56% thickspike wheatgrass, 42% western wheatgrass, 3% Sandberg bluegrass

Transect B (outside fence east of pad) – 6.3% of the relative basal ground cover was non-weed vegetation, consisting of:

1.6% shrubs – 100% sage

0% forbs

98% grasses – 48% western wheatgrass, 44% thickspike wheatgrass, 8% Sandberg bluegrass

Transect C (outside fence south of pad) – 6.4% of the relative basal ground cover was non-weed vegetation, consisting of:

4.7% shrubs – 67% sage, 33% winterfat

1.6% forbs – 100% clover

94% grasses – 53% thickspike wheatgrass, 37% western wheatgrass, 10% Sandberg bluegrass

Offsite transect – 8.1% of the relative basal ground cover was vegetation, consisting of:

16% shrubs – 92% sage, 8% winterfat

27% forbs – 54% phlox species, 23% buckwheat species, 9% clover, 9% biscuitroot, 4% fleabane

57% grasses – 46% Sandberg bluegrass, 30% thickspike wheatgrass, 11% Idaho fescue, 7% Indian ricegrass, 6% bottlebrush squirreltail

Mesa 7-27 - not fenced. In the 2007 Onsite transect, 4.9% of the relative basal ground cover was non-weed vegetation, consisting of:

NO shrubs or forbs

100% grasses – 57% thickspike wheatgrass, 31% western wheatgrass, 12% Sandberg bluegrass

Offsite transect – 7.0% of the relative basal ground cover was vegetation, consisting of:

17% shrubs – 58% sage, 33% prickly pear cactus, 8% fourwing saltbush

46% forbs – 59% phlox species, 31% buckwheat species, 3% goldenweed, 3% clover, 3% biscuitroot

37% grasses – 62% Sandberg bluegrass, 31% thickspike wheatgrass, 4% Indian ricegrass, 4% bottlebrush squirreltail

SUMMARY

The data present a snapshot of a work in progress. Control of any one variable in the revegetation efforts is difficult at best and the huge variable of precipitation has affected all seeding results to date. However, examination of the variables guiding this pilot project have shown:

1. The Shell Habitat seed mix has been successful in restoring significant sage stands to the sites. Sage is the important ingredient of the natural habitat, but other shrubs also show some initial success. The paucity of forbs in general will likely be corrected with even one fair to good precipitation season. Onsite/Offsite comparisons of seeded sites have shown the need to increase slightly the grass content of our seed mix. However, through pellet counts (not reported here), it has been shown that these reclaimed areas have provided food and cover for large ungulates, Sage Grouse, rabbits and small rodents.
2. The effectiveness of soil amendments is not clear at this point in the project; however, successful sites seeded without amendments had somewhat superior soil conditions to begin with. It is also unlikely that at least one of the hydroseeded sites with poor soils (Warbonnet 11-10) would have had any sage shrub establishment without the application of mineral and organic soil amendments. We will continue to monitor individual amendment vs. no amendment sites in our assessment of this variable.
3. While there may be conditions where hydroseeding is necessary, the Truax Rough Rider range drill is currently our preferred method of seeding in the project area. Its ability to place seeds at varying depths in the soil is especially desirable. However, this project has proven that with proper site preparation, the use of amendments and (again) good precipitation, hydroseeding can be quite successful.
4. Fencing of sites, at least for the first few growing seasons, has made a difference in native plant establishment, particularly in areas more heavily grazed.
5. Overseeding the habitat blend seed mix into previously seeded grass-dominated sites has shown limited initial success. The shrub-forb grass diversity in the Offsites that is crucial to a healthy native sage grouse habitat is improving; however, these sites will continue to be grass-dominated for many years.

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VISUAL RESOURCE CONSIDERATIONS IN THE RECLAMATION EQUATION

John McCarty
Bureau of Land Management
1849 C Street NW (L.S. 302)
Washington, DC 20240

Tom Lahti
Bureau of Land Management
Wyoming State Office
PO Box 1828
Cheyenne WY, 82003

Kate Schwarzler
Otak, Inc.
36 North 4th Street
Carbondale, CO 81623

ABSTRACT

Federally administered Public Lands are experiencing unprecedented development and use pressures from energy development, transmission and transportation corridors recreation activity, livestock grazing, and other mineral development activities. Compounding pressures, conflicts and controversial public perspectives regarding how these lands should be managed are driving public dialogue. While countless issues fuel the public debate, most public opinion is formulated through visual observation of the multiple-use activities and their associated impacts. This “What you see is what you get” phenomenon has become the basis for formulating the public’s opinion of reclamation success.

The Bureau of Land Management (BLM) administers public lands under a multiple-use management policy mandated by the Federal Land Management Policy and Management Act of, 1976, (FLPMA). The FLPMA mandates BLM to manage, protect, and preserve the visual resources on the Public Lands. The BLM Visual Resource Management program provides policy and guidance for managing visual resources while accommodating multiple uses of the public lands.

The BLM Wyoming State Office is finalizing a new reclamation policy that will guide reclamation planning and establish criteria for evaluating reclamation success beyond “growing grass”. The Policy will mandate consideration of additional reclamation goals, including: visual impact mitigation, surface and subsurface stabilization, weed control, etc. This policy will help establish new reclamation standards which other states may wish to follow.

INTRODUCTION

Visual resources refer to the physical objects (man-made and natural, moving and stationary) and features (e.g., landforms, vegetation and water bodies) that are visible on the landscape (BLM, 1984). These resources contribute to the scenic or visual quality of the landscape. Landscape disturbance and subsequent reclamation activities generally result in long term changes to the landscape. These changes are both ecological and physiological in nature and consequently generate modification in the visual environment. Visual impacts of our scenery resources is commonly thought of as a subjective impact driven by unquantifiable and often emotional responses by the general public or individual observers. The BLM Visual Resource Management (VRM) program is designed to facilitate an objective management process and supports a systematic evaluation of proposed activities that result in landscape modifications.

Our purpose in the delivery of this paper is to introduce the BLM’s VRM system in order to heighten awareness and integrate its use in project and/or subsequent reclamation planning and implementation.

The paper is divided into three sections with the first covering national VRM policy and procedures; second addresses the BLM's Wyoming State Office's new draft policy on reclamation standards and how it factors in visual resources; and the third provides four case studies in VRM application.

NATIONAL VRM POLICY OVERVIEW

The development of VRM is an outgrowth of the US National Environmental Policy Act (NEPA) of 1969 mandating the analysis of aesthetic effects of federally funded projects (Sheppard, 2001). Legislative reference to the "aesthetic environment" was motivated by public reaction to past land management practices associated surface mining activities, transportation facility expansion, roadway corridor management, industrial contributions to water pollution (Randall, 1965) and the clear-cutting controversy on public forest lands (Sheppard, 2001). NEPA led to subsequent land management legislative action and policies that instituted VRM programs within federal land management agencies. VRM established the visual environment as a "resource" value that could be systematically mapped and included in land management decision-making with equal consideration to other multiple use resource allocations (Smardon, 1986).

The challenges in public land management are compounding with population growth in the western United States. Communities have grown closer to the once-remote BLM administered lands. More than 4,100 communities, with a combined population of 22.2 million people, now live within 25 mi (40 km) of BLM administered lands. Western population growth has led to increased recreation activities on the public landscape, such as OHV use, hunting, fishing, equestrian, hiking, and camping (Cownover and Dawson-Powell, 2003).

As human presence and recreation activities increase on the public landscape, so do the sensitivities toward other uses and their respective physical modification of that landscape. Additional factors contributing to increased activity on the public landscape include:

- consumer-based demand driving the need for increased natural resource development;
- expansion and development of new Rights-of-Ways for accommodating America's growing transportation, energy and communication networks;
- environmental incentives for developing renewable energy resources (solar, wind and geothermal).

At the same time, the public has an expectation for sustaining the health and diversity of biological resources, and preserving the integrity of landscape ecology and the associated historic, cultural and visual qualities of the physical setting. Change is inevitable in both the natural and built environments. How we administer change is of critical importance and serves as an opportunity to visually integrate multiple use into land management.

The BLM administers approximately 258 million acres (107 million hectares) and operates under the enabling legislation of the *Federal Land Policy and Management Act of 1976* (FLPMA) mandating that these public lands be managed under a multiple use policy. The various uses include energy and minerals; timber; forage; recreation; wild horse and burro herds; fish and wildlife habitat; wilderness areas; and archaeological, paleontological, and historical sites. The BLM also administers mineral leasing and oversees mineral operations over all Federal mineral estate underlying other state, private, or Federally-administered land, and manages most mineral operations on Indian lands (BLM, 2008).

Visual resources are a part of the BLM's list of resources that fall under the multiple use management policy, and are administered under the BLM's VRM program. The VRM program is guided by the policy outlined in the Visual Resource Management Manual 8400 and implemented in accordance with the procedures set forth in the Scenery Inventory Handbook 8410 and Contrast Rating Handbook 8431. Other manuals that also play a role in management of visual resources include the BLM Land Use Planning Handbook H-1601-1, BLM NEPA Handbook H-1901-1.

The majority of the following information is paraphrased from the BLM Visual Resource Management manual and handbooks, which are all available on the BLM website at www.blm.gov.

The BLM also has training courses on this subject matter and is available, on a limited basis, to the professional consultants, contractors and industry personnel.

Bureau of Land Management Visual Resource Management Policy

The Bureau has a basic stewardship responsibility to identify and protect visual values on public lands and is a shared responsibility by all resource programs. The BLM's underpinning principles for the VRM policy is set forth within the Visual Resource Management Manual and includes the following seven policy parameters. The BLM shall:

1. Prepare and maintain an inventory of visual values on all public lands.
2. Develop visual management objectives (classes) through the Resource Management Planning (RMP) process for all Bureau lands.
3. Establish interim visual management objectives until the RMP is finalized.
4. Provide visual management standards for the design and development of future projects.
5. Incorporate visual design considerations into all surface disturbing projects early in the planning and design stages.
6. Use the contrast rating process as a visual design tool in project design development and as a project assessment tool during environmental review.
7. Ensure that project monitoring efforts include timely and thorough compliance evaluations to ensure that visual management provisions are effectively carried out through all phases of development.

The VRM policy establishes the framework for practicing context sensitive site design by incorporating visual design skills and considerations into all project proposals. Having members of the planning team that are adequately versed in applying visual design considerations with site planning will help industry and the BLM meet their public policy commitments and expectations.

How the BLM Implements the VRM Policy

Guidance on implementing the VRM policies is described in two BLM Handbooks H-8410-1 Visual Resource Inventory and H-8431-1 Visual Resource Contrast Rating. The system is designed to remove subjectivity from the process, and is based on physical characteristics of the landscape. Visual resource management system is divided into three stages of management as shown in Figure 1:

- Inventory of scenery resources
- Establishing Visual Resource Management Classifications
- Impact assessment and evaluation of proposed project activities

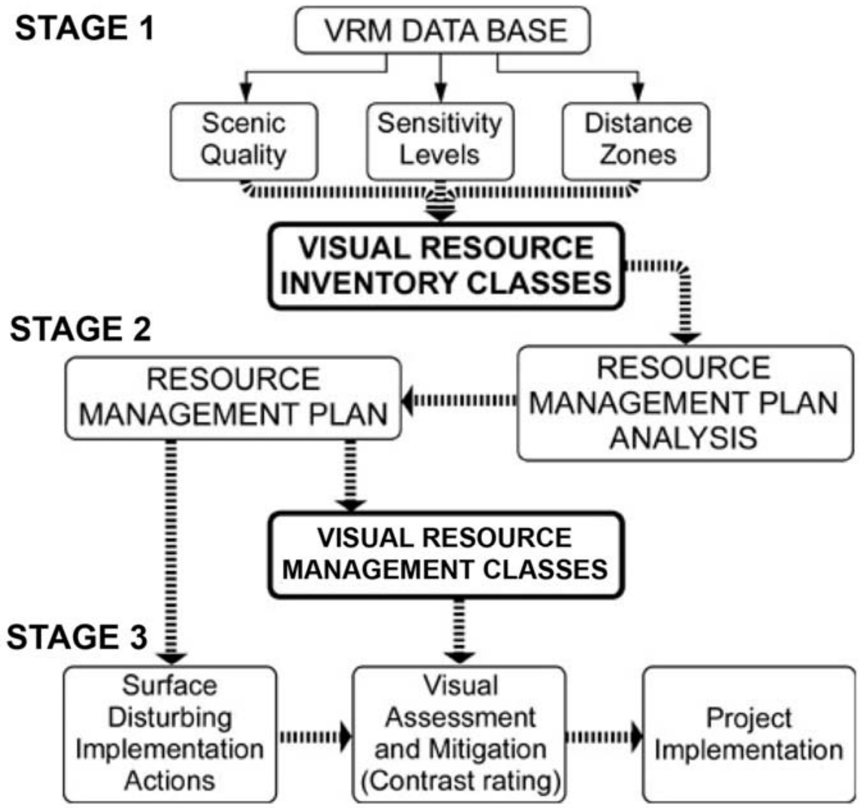

Figure 1: VRM Process Diagram

Scenery Resource Inventory

The inventory stage includes identifying the visual resources of an area and assigning inventory classes. The visual appeal of a tract of land is rated based on measurement criteria established in the BLM Handbook H-8410-1 Visual Resource Inventory.

The three step inventory process outlined in the handbook includes:

- Scenic quality evaluation – determining the scenery quality through evaluation of the visual appeal of the landscape characteristics. Public lands are rated as an A, B, or C with "A" considered high quality and "C" being of less quality. Seven factors are considered when evaluating scenic quality: landform, vegetation, water, color, adjacent scenery, scarcity, and cultural modifications, which are delineated into Scenic Quality Rating Units. Factors are ranked on a comparative basis with similar features within the physiographic province. Important premises of the evaluation are:
    - All public lands have scenic value, but areas with the most variety and most harmonious composition have the greatest scenic value.
    - Evaluation of scenic quality is relative to the natural landscape.
- Sensitivity Analysis - Measuring the public's concern for the scenic quality takes into account the types of users, amount of use, public interest, adjacent land uses, special area designations

(wilderness, wild and scenic, Areas of Critical Environmental Concern, scenic byways, etc.). Sensitivity is assigned and delineated on a map as high, medium, or low level.

- Distance Zones - Landscapes are subdivided and mapped into 3 distanced zones based on visibility from travel routes (highways, roads, trails, rivers, etc.), and observation points (campgrounds, scenic overlooks/interpretative areas, visitor centers, etc.).
  - Foreground-Middleground (fm) zone - includes areas seen from highways, trails, rivers, or other viewing locations which are less than 3 to 5 miles away.
  - Background (bg) zone - beyond the foreground-middleground zone out to approximately 15 miles.
  - Seldom-seen (ss) zone – Areas not seen as foreground-middleground or background (i.e., hidden from view).

Scenic Inventory Management Classifications - The three sets of data are overlaid for a comparative analysis deriving Scenic Inventory Management Classifications I through IV. The classifications are not assigned management criteria, but simply combine the three sets of criteria to into a decision matrix that illustrates the measured qualities of the visual environment, as shown in Figure 2.

Visual Senstivity Levels

		High			Medium			Low
Special Areas		I	I	I	I	I	I	I
Scenic Quality	**A**	II	II	II	II	II	II	II
	B	II	III	III* / IV*	III	IV	IV	IV
	C	III	IV	IV	IV	IV	IV	IV
		f/m	**b**	**s/s**	**f/m**	**b**	**s/s**	**s/s**
		DISTANCE ZONES						

Figure 2: VRM Scenery Inventory Management Classification Matrix

There is an important distinction between Class I and the other three classes II through IV. Class I is an assigned through an independent procedure for areas where a management decision is made outside of the inventory process to maintain a natural landscape. This decision may or may not consider scenic quality and sensitivity. Class I areas may include national wilderness areas, the wild section of national wild and scenic rivers, and other congressionally and administratively designated areas where a decision has been made to preserve a natural landscape.

Classes II, III, and IV are assigned based on a combination of scenic quality, sensitivity level, and distance zones. Class II is considered the highest valued scenery with Class IV being of lowest value. The inventory classes are informational in nature and provide the basis for considering visual values in the Resource Management Planning (RMP) process. They do not establish management direction and should not be used as a basis for constraining or limiting surface disturbing activities.

Assigning Visual Resource Management Classes

Resource Management Plan (RMP) establishes how the public lands will be used and resources allocated for different purposes. The RMPs are developed and managed from BLM Field Offices. The results of the visual resource inventory classifications are considered along with the other resource allocations throughout the RMP process. Visual resources are then assigned management classifications I, II, III or IV which reflect the visual resource values of a given area along with the other permissible resource activities. VRM Classes have the following established objectives:

- **Class I Objective:** To preserve the existing character of the landscape. The level of change to the characteristic landscape should be very low and must not attract attention
- **Class II Objective:** To retain the existing character of the landscape. The level of change to the characteristic landscape should be low
- **Class III Objective:** To partially retain the existing character of the landscape. The level of change to the characteristic landscape should be moderate.
- **Class IV Objective:** To provide for management activities which require major modification of the existing character of the landscape. The level of change to the characteristic landscape can be high.

Project/Activity Planning and the Visual Impact Mitigation Plan

Scenery inventory and VRM management class designations assigned during the RMP process sets the stage to analyze the acceptable level of a given activity's impact on the visual environment. The project and activity analysis step is where the project proponents encounter VRM policy and practices. The following discussion covers the VRM analysis procedures and considerations. The Case Studies section at the end of the paper (3rd section) illustrates project examples.

All post RMP resource activities and development actions that involve surface disturbing activity are required to consider the importance of the:

- visual resources values,
- impacts on these values, and
- meeting the stated VRM objectives through proper and early planning and design.

Visual Resource impacts associated with activities are measured through a Contrast Rating Analysis, which evaluates the level of contrast anticipated from a surface disturbing activity. Methods for measuring contrast is defined in the BLM Handbook H-8431-1, Visual Resource Contrast Rating and involves comparing the project features with the major features in the existing landscape using the basic design elements of form, line, color, and texture. The analysis serves as a basis for further design and/or mitigation to resolve visual impacts. BLM managers review project plans for effective reductions in visual impacts and decide whether to accept, deny, or further mitigate project proposals.

The steps involved with contrast rating analysis include:

1. Obtaining a project description. Identify VRM objectives found in the RMP.
2. Select Key Observation Points (KOP's) that represent the critical viewpoints to conduct the contrast rating. KOPS are commonly traveled routes, recreation sites, trails, residential areas, etc.
3. Prepare visual simulations that help visually portray the project in its proposed location.

4. Complete the contrast rating form from key observation point(s) using Bureau Form 8400-4 - Visual Contrast Rating Worksheet.

The degree of contrast is measured through evaluating the changes between the proposed and existing conditions. The setting is broken down into basic landscape features (landform, water, vegetation and structures) and the basic visual elements (form, line, color, and texture). Assessing how the form, line, color, and texture of the proposed activity interrupts, contrasts or harmonizes with that of the natural or cultural landscape setting determines the degree of contrast.

Understanding the degree of contrast is the outcome of the Contrast Rating Form and is qualified in the following terms:

None	The element contrast is not visible or perceived
Weak	The element contrast can be seen but does not attract attention.
Moderate	The element contrast begins to attract attention and begins to dominate the characteristic landscape.
Strong	The element contrast demands attention, will not be overlooked, and is dominant in the landscape.

The four degrees of contrast (none, weak, moderate, and strong) generally corresponds to the VRM class I, II, III, and IV objectives, respectively.

There are 10 other factors that are considered when evaluating visual impact which include:

- Distance,
- horizontal and vertical angle of observation of the viewer to the project,
- length of time the project is in view,
- relative size or scale of the project as compared to its surroundings,
- season of use and the physical conditions that exist during the heaviest or most critical visitor use season,
- natural light conditions,
- reclamation recovery time necessary for successful VRM objective compliance (grasses, shrubs, tree establishment beyond the purpose of erosion control, but in terms of visual values),
- spatial relationship within a landscape,
- atmospheric conditions,
- motion from the project.

Visual Impact Mitigation Plan

Bringing a project into VRM compliance typically requires developing mitigation plan. The term mitigation implies the need for developing measures to offset impacts associated with the proposed action. With respect to visual resources, the need to develop mitigation requirements implies that the original planning did not account for the landscape setting and its inherent visual values. Our goal is to encourage early consideration of VRM in the planning process and avoid the need for tacking on additional mitigation at the end.

In order to help facilitate good design practices, the BLM has developed a list of VRM best management practices (BMP). This list is divided into subjects regarding landform adjustment, vegetative manipulation and facility treatment. In acknowledging room for improvement and expansion of ideas, we encourage open communication and sharing of strategies and successes between permit planners, industry representatives and BLM personnel that continually upgrades the list of BMPs.

The Case Study section of the paper provides an in-depth discussion on VRM BMPs.

Overall project and site planning need to consider all other multiple resource values. Early consideration of visual values will help facilitate a full understanding of all surface related alterations providing for proper impact analysis when conducting an Environmental Assessment (EA). A project planning team should include other resource disciplines to help evaluate impacts, conflicts, and develop opportunities for other resource improvements.

Monitoring and Compliance

The Visual Impact Mitigation Plan needs to include a section on a monitoring strategy to ensure that the project is constructed according to the plans and mitigation requirements.

- Sets conditions and terms for implementation and how it will be monitored.
- Clarifies performance standards for the applicant and their operators.
- Identifies how compliance will be quantified and measured.
- Outlines corrective actions to be taken when a site is out of compliance.
- Establishes a clear understanding of expectations and a road map to successful compliance.

There is no cookbook approach to compliance monitoring. The compliance strategy is dependent on the collective design/ BMP elements of the project's VRM plan.

BUREAU OF LAND MANAGEMENT WYOMING RECLAMATION POLICY

The State of Wyoming, as with many other western states, is experiencing an elevated amount of resource development on federal lands. Along with the elevated activity comes public concern over potential compromise to the quality of environment. The Wyoming BLM has drafted new policy that establishes standards for the reclamation of all surface disturbing activities. The draft policy essentially requires reclamation to achieve re-establishment of a fully functioning natural ecosystem not only physically and biologically, but also visually.

Successful reclamation efforts are critical in maintaining an effective multiple use land management program. Nearly all authorizations for surface disturbing actions are based upon the assumptions that an area can and ultimately will be successfully reclaimed. We recognize reclamation of approved activities is often a multi-step approach which includes short-term stabilization and long-term reclamation. Early in the process, Bureau of Land Management (BLM) will explain to those seeking approval to conduct surface disturbing activities on Public Lands to include reclamation planning as part of their permit application.

The level of reclamation success is becoming an increasing concern with new disturbances occurring in areas that are topographically or ecologically more challenging. Most landscapes can be reclaimed using established reclamation methods. However, under extreme conditions, innovative techniques beyond traditional practices must be developed to deal with these "tougher conditions." The landscapes identified as having Low Reclamation Potential (LRP) are characterized by highly erosive soils, soils with severe physical or chemical limitations, extremely steep slopes, or areas having severely limiting precipitation rates. The LRP areas may require site specific reclamation standards and practices not specifically addressed in the Wyoming Reclamation Policy. Each Field Office shall delineate their LRP's and develop a unique set of reclamation standards for those areas within the framework of the policy.

The Wyoming BLM Reclamation Policy applies to all surface disturbing activities. These activities include all Federal actions authorized, conducted, or funded by the BLM, and disturb vegetation and the mineral /soil resources on the public lands (both the surface and subsurface estate). This policy is intended to be compatible with other BLM program objectives.

A reclamation plan will be required for all surface disturbing activities. The level of detail for the reclamation plan will need to reflect: the complexity of the project, the environmental concerns generated during project review, and the reclamation potential for the site. These plans will also need to incorporate any program or regulatory specific requirements for reclamation. The reclamation plan will address short term stabilization (Interim Reclamation) and facilitate long term reclamation. The draft reclamation plan requirements are described below. Each standard will need to be addressed in the reclamation plan along with a detailed description of the techniques needed to meet the reclamation standards. Reclamation plans will also require the BLM's concurrence for approval. Note that the Visual Standard is addressed in item number 8.

Reclamation Goals

1. The primary goal for reclamation is to facilitate eventual ecosystem reconstruction by returning the land to a safe, stable, and proper functioning condition. A condition that meets the resource objectives prescribed in the land use plan.
2. The short-term (interim) reclamation goal is to immediately stabilize disturbed areas and to provide the necessary conditions to achieve our long term goal.

Reclamation Standards

The following Reclamation Standards apply to all surface disturbing activities, including BLM initiated activities and must be addressed in each reclamation plan. These standards also must be met prior to release of the bond and/or the reclamation liability. In cases where they differ from other required program standards, those program standards apply.

1. Manage all waste materials:
    - Segregate all waste materials from the subsoil and topsoil.
    - Waste materials can be buried on site, if authorized. Buried material must be covered with a minimum of five feet of soil or to meet specific program standards consistent with State and other Federal regulations.
    - All waste materials transported and disposed of off-site, must be placed in an authorized disposal facility in accordance with all local, State and Federal requirements.
2. Ensure subsurface integrity, surface stability, and eliminate ground and surface water contamination.
    - All drill holes and other small openings shall be properly plugged and, where water is present, sealed from the bottom to top of water-bearing formation.

- All open shafts, underground workings, and other openings shall be stabilized, properly back filled, capped, and/or restricted from entry.
- Backfill to prevent surface subsidence, slumping, or downward movement of surface soil materials.
- Install storm water controls.
- Prevent contamination of surface and ground waters.

3. Re-establish slope stability and desired topographic diversity.
   - Reconstruct the landscape to approximate the original contour and topographic diversity.
   - Eliminate soil movement, mass wasting, or head cutting on disturbed slopes.
   - Remove all highwalls, steep cut slopes, and depressions
4. Reconstruct and stabilize water courses and drainage features.
   - Reconstruct drainage basins to have similar features found in nearby properly functioning basins, including: basin relief ratios, valley gradients, sinuosity, and drainage densities for all reclaimed basins.
   - Reconstruct drainages to have similar hydraulic characteristics found in properly functioning drainages, including: flow depth, water surface top width, cross-section area of flow, water surface slope, mean channel velocity, desired vegetation, and channel roughness.
   - Where necessary, use appropriate armor to protect newly created slopes and/or dissipate the energy from water flow.
   - A post reclamation impoundment must meet water quality and quantity standards and be a justifiable post-disturbance beneficial use.
5. Maintain the biological, chemical, and physical integrity of the topsoil resource.
   - Salvage all topsoil based on site specific soil analysis.
   - Where possible, integrate stored topsoil into the existing production landscape.
   - Stabilize all stored and disturbed topsoil from water and wind erosion, within 30 days of disturbance.
   - Seed topsoil stored beyond one growing season with desired vegetation.
   - Identify topsoil storage with appropriate signage.
6. Prepare site for revegetation.
   - Minimize surface soil movement by applying soil stabilizing controls (erosion control matting, mulching, hydroseeding, surface roughening).
   - Reduce soil/subsoil compaction to the anticipated root depth of the desired plant species.
   - Redistribute the topsoil to planned pre-disturbance depth.

- Provide surface and subsurface physical, chemical, and biological properties to support the long term establishment and viability of the desired plant community.

7. Establish a desired self-perpetuating native plant community.

   - Establish species composition, diversity, and total ground cover for the desired plant community.
   - Select genetically appropriate native plant materials based on the site characteristics and ecological setting.
   - Select non-native plants only as an interim, non-persistent alternative to native plant materials.
   - Ensure the non-natives will not hybridize, displace, offer long-term competition to the endemic plants, and are designed to aid in the re-establishment of native plant communities.

8. Reestablish visual composition and characteristics.

   - The reclaimed landscape shall possess similar visual composition and characteristics of the adjacent undisturbed area in order to not result in a change in the Scenic Quality Rating of the area.
   - Ensure the overall location, landform scale, shape, color, and orientation of major landscape features blends into the adjacent area and meets the needs of the planned post disturbance land use.

9. Prevent introduction, establishment, and spread of invasive plant species.

   - Develop an invasive species management plan.
   - Inventory invasive plant infestations before ground disturbing activities begin.
   - Prevent the introduction of invasive species.
   - Control and manage infestations.
   - Reestablish native plant species in areas impacted by invasive species.

10. Develop and implement a reclamation monitoring protocol.

    - Conduct compliance and effectiveness monitoring in accordance with the approved reclamation plan.
    - Evaluate monitoring data for compliance with reclamation plan.
    - Document and report monitoring data and recommend revised reclamation strategies.
    - Implement revised reclamation strategies as needed.
    - Repeat the process of monitoring, evaluating, documenting/reporting, and implementing, until reclamation goals are achieved.

Low Reclamation Potential Areas (LRP)

There are areas (e.g., alkali flats, badlands, dunes, rock outcrops) where reclamation may be more difficult than in traditional landscapes. LRP areas are characterized by highly erosive soils, Sites having physical, biological, and/or chemical limitations, low precipitation rates, or areas which have characteristics that make traditional reclamation practices impractical or unfeasible.

Because reclamation in LRP areas is more difficult, LRP areas should be avoided. However, if areas of LRP have been previously leased or permitted, additional bonding may be required. Alternatives to development in LRPs should be carefully analyzed using information from the reclamation plan and documented in the NEPA process.

LRP areas should be identified by the Field Offices and considered early in the land use planning, revision, or amendment process. Management prescriptions, including reclamation strategies for LRP areas, should be part of Resource Management Plans.

CASE STUDIES

Four project case studies are presented to demonstrate VRM applications at the activity/project level (the third stage of the BLM's VRM program):

1. La Plata County's proactive approach to dealing with oil and gas VRM mitigation applications on private lands. This section provides more detailed explanation of using VRM elements to visually mitigate the contrasts with the landscape characteristics.
2. Kanda natural gas pipeline crosses through two states and multiple field office jurisdictions. Linear corridors providing for resource conveyance is one of the larger challenges in VRM mitigation.
3. Town of Basalt – how VRM can be applied on a local level where a local government is dependent on federally administered lands to provide critical domestic water service to an expanding population.
4. Multiple color application pattern development and field testing for enhanced visual concealment of structural facilities – what's coming down the line.

VISUAL MITIGATION GUIDELINES FOR OIL AND GAS FACILITIES IN LA PLATA COUNTY, COLORADO CASE STUDY

La Plata County covers approximately 1,690 square miles (1,081,616 acres). The northern portion is mainly comprised of U.S.D.A. Forest Service (USFS) land in the San Juan National Forest; the central portion contains the majority of the county's private lands and the southern portion is occupied by sections of the Southern Ute Reservation. Public land comprises 444,678 acres of the county's total area. La Plata County government regulates the approximately 636,938 acres of private lands residing within its boundaries.

As oil and gas activity in La Plata County continues to increase, so does the awareness of the associated visual impacts. The La Plata County Land Use Code requires that a visual mitigation plan be part of all new minor and major facility development. The code also recommends visual mitigation techniques that can be utilized on a site-specific basis.

As a proactive measure, the County created a guidance document to aid landowners, operators, agents, planners, and other stakeholders in making educated decisions on which combination of BMPs would be the most effective to mitigate the visual impacts associated with oil and gas facilities that are located on private lands within La Plata County and subject to county development code and regulations.

It is important to note that one of the guiding principles of the document is that the proper siting of facilities from the beginning of the planning process will often reduce or solve visual mitigation issues.

Landscape Characteristics

The eye's viewing field is made up of negative and positive space. The eye is trained to recognize and focus upon the positive space first, which is usually the most dominant feature of the landscape. Dominance is generally created by a sharp contrast in one or more of the four basic landscape characteristics: form, line, color, or texture. Dominance creates a visual anomaly—an object with elements of color, form, line, or texture that differ from the surrounding landscape. When the eye detects such an anomaly, the brain immediately begins trying to identify it as a known object. The most effective visual mitigation will address these characteristics collectively.

Form

Form is the figure of an object or the collective mass of similar objects. Visual contrasts in form result when the figure of an introduced or altered object is significantly different from existing figures in the landscape. For example, if figures in the existing landscape consist primarily of low vegetation with hills in the background and storage tanks are introduced into the landscape, the form of the tanks creates a sharp visual contrast to the vegetation and landform.

Line

Line is the edge where dissimilar forms, colors, or textures meet. Visual contrasts in line result when the existing landscape edges are altered by introduced forms, colors, and textures that are apparently non-native to the existing landscape, causing interruption or augmentation to the existing lines. Using the storage tank example mentioned above, the hard edges of the tank are dissimilar to the soft, irregular edges of the landscape.

Color

Color is the reflection of visually perceptible light from objects. Visual contrasts in color arise when introduced or altered objects in the landscape reflect color in patterns or wavelengths that are dissimilar to what is found in the native landscape. For example, the clear-cutting of trees for installation of a pipeline creates a color contrast between forested and clear-cut areas.

Seasonal Variations

The changing of seasons will have an effect on some visual mitigation measures. Deciduous vegetation such as grasses, chokecherry, aspen, cottonwood, Gambel oak, three-leaf sumac, and serviceberry will change colors and most will drop their leaves. Snow may pile up on horizontal surfaces, such as the tops of tanks. It is best to plan for the season with the greatest number of viewers.

Texture

Texture is the pattern created by the forms of different colors. The forms of color do not appear as individual objects, but are part of the overall scene. For example, the forms of color in the foreground vegetation create a different texture than the background and the hills. Together, these textures create a pattern that is distinct to this type of landscape. Visual contrasts in texture arise when the introduced or altered features of the landscape have dissimilar pattern grain, density, direction, or irregularity. Seasonal variations will also affect texture, as discussed above.

Observation Variables

Specific viewer variables have an effect on how a facility is observed.

Distance

The viewer's distance from an object affects how the object is seen, and which element of form, line, color, or texture is most dominant. The further away an observer is from the object, the more the characteristic of texture begins to fade into forms of color.

Viewing angle

The angle of view also needs to be considered. The vertical angle and the horizontal angle from which a viewer observes the facilities determine which characteristics of the facility are most dominant, and will aid in defining which mitigation techniques will be the most effective. Some angles will be more sensitive than others.

Motion, speed, and length of time in view

Motion and speed affect the viewer's perception of a facility in the landscape. If the viewer is in motion it means that the facility can potentially be seen from multiple distances and angles as the viewer travels past. All views should be taken into consideration when planning for visual mitigation. If the facility itself is in motion (a pumpjack, for example), more attention will be drawn to it, especially its active parts.

When the viewer is in motion, the length of time a facility is in view may be greatly diminished. The effects of speed, the period of viewing time, and the angle of view should be considered when deciding on effective visual mitigation techniques.

Best Management Practices

A BMP is an action approved by law or policy, generally representing the preferred way to achieve a desired result.

BMPs for visual mitigation described in La Plata's guidance document include sightline interruption and repetition of form, line, color, and texture in the surrounding environment. Both of these BMPs provide several techniques that can be used alone or in combination to address differences in landscape characteristics, facility types, and locations.

Use of appropriate BMPs may also provide other benefits in addition to visual mitigation, such as noise reduction and erosion / noxious weed control. The majority of sites will require a combination of techniques for effective visual mitigation.

Sightline Interruption BMPs

One of the simplest visual mitigation methods is to interrupt the sightline from the viewer to the object. This may be achieved using both man-made and natural elements. Proper location of proposed facilities in the initial design phases can save significant time and effort during the visual mitigation process. Following is a list of sightline interruption techniques that were detailed in the guidance document for La Plata County:

- Proper Facility Location
- Layout and Choice of Equipment
- Preservation of Vegetation
- Naturalized Vegetation
- Naturalized Berms
- Using Structures for Sightline Interruption

Repetition of Surrounding Landscape BMPs

Repetition and continuation of the surrounding landscape characteristics is another method to use towards achieving visual mitigation. Facilities become visually apparent when they disrupt the natural form, color, pattern, and line of the adjacent landscape. Repetition of the elements found in the adjacent landscape will help prevent the view from identifying the facility as an intrusion on the landscape. The following is a list of techniques for repetition of surrounding landscape characteristics that were addressed in the guidance document.

- Preservation of vegetation
- Naturalized cut-and-fill slopes, berms, and contour manipulation
- Thinning and feathering of existing vegetation
- Naturalized vegetation
- Color and texture manipulation
- Lithic Mulch
- Bare ground treatment

A combination of these techniques and the Sightline Interruption techniques is likely to be the most effective solution in the majority of cases.

Selection Visual Mitigation BMPs

Selecting the most effective BMPs for visual mitigation requires an on-site evaluation of each proposed project. A flowchart and worksheets were created to assist users of the guidance document to defining the issues, variables, landscape and land use affecting the project. The worksheets also help with selecting and prioritizing the appropriate BMPs.

Implementing Visual Mitigation BMPs

The implementation of BMPs is a collaborative and adaptive process. A preconstruction meeting should be arranged in advance of implementing the visual mitigation program, and periodic progress monitoring should be scheduled. Construction inspection and adaptive management during the implementation process will be necessary to achieve the visual mitigation objectives.

KANDA LATERAL AND MAINLINE EXPANSION PROJECT CASE STUDY

This next example is a pipeline project that crosses two states and involves multiple field offices. Wyoming Interstate Company, Ltd. (WIC) is expanding its natural gas pipeline capacity between Uintah County, Utah and Sweetwater County, Wyoming. The proposed natural gas pipeline, known and the Kanda Lateral and Mainline Expansion Project, would interconnect with existing Questar Corporation (Questar) and WIC natural gas pipeline systems. The pipeline would terminate at the proposed Kanda Interconnect/Meter Station in Sweetwater County, between the cities of Green River and Rock Springs, Wyoming. Along the route, the pipeline would interconnect with two existing interstate pipelines, and the new Norwest Interconnect/Meter Station and the existing Clay Basin Interconnect/Meter Station in northeastern Utah.

Near the Utah/Wyoming state line, the proposed right-of-way (ROW) parallels existing pipelines through the Greater Red Creek Area of Critical Environmental Concern (ACEC), in an area administered by the BLM Rock Springs Field Office (RSFO). Visual issues, as well as potential impacts to other natural resources in that locale are of high concern.

Mitigation of Visual Impacts and Planting Supplemental Revegetation Species

Mitigating impacts to visual resources and supplementing the revegetation efforts with additional plant species are primary concerns for the Red Creek Portion of the Greater Red Creek ACEC. The potential for visual impacts has been acknowledged and efforts to minimize them were made during the project planning process. Incorporating selected additional plant species and planting techniques will not only benefit visual aspects of the project, but will also provide additional plant diversity and wildlife habitat.

The Red Creek portion of the Greater Red Creek ACEC is classified as a BLM Visual Resource Management (VRM) Class II in the current Green River Resource Area Management Plan. The objective of this class is to retain the existing character of the landscape. The level of change to the characteristic landscape should be low. Management activities may be seen, but should not attract the attention of the causal observer. Any changes must repeat the basic elements of form, line, color, and texture found in the predominant natural features of the characteristic landscape (BLM, 1986).

Mitigation Plan

To help assure the successful mitigation of the Kanda lateral and mainline expansion through the Red Creek Portion of the Greater Red Creek ACEC, a site-specific mitigation plan was created. Mitigation monitoring points were chosen at locations which represent prominent views seen from Key Observation Points. These mitigation monitoring points are to be used over the life of the project to review the success of the mitigation plan. WIC will monitor and maintain the visual impact mitigation measures for a 5-year period after the initial restoration effort. Over this period, WIC will interact with the BLM to ensure that mitigation measures remain intact as necessary and that vegetation establishment is proceeding appropriately.

The following techniques were identified in the mitigation plan as measures that would effectively provide visual mitigation along the disturbed pipeline corridor:

Organic Clearings

- Organic clearings will be used to expand the linear vegetation edge resulting from construction activity within the construction corridor. Create an irregular, undulating form that mimics the clearings that occur naturally in the surrounding environment.
- Clearing is defined as removal of upright vegetation only. Root structures will be left intact to minimize erosion.
- Organic clearing will not be used in wetland areas, washes, or on steep side slopes due to erosion concerns. The contractor will have the option to decide whether organic clearing is practical, subject to field conditions.
- The existing vegetation along the edges of the organic clearing will be thinned and feathered.
- Areas designated to be cleared can be used during construction to store spoil or vegetation for transplanting.

Thinning and Feathering

- Existing trees and/or shrubs that remain adjacent to areas where vegetation has been cleared will be thinned and feathered to open up the linear edge of the existing stand and emulate the undulating, less-dense edge texture found in nature.
- To achieve a natural-looking edge, every other tree or shrub adjacent to the edge of construction disturbance will be removed, transitioning to the removal of every third tree or shrub while moving outward from the edge of disturbance.
- Heavy equipment such as a hydro-ax may be used when conditions allow; hand-clearing with chain saws may be required in some areas.
- Trees and shrubs to be removed during thinning and feathering may be used for transplanting.
- Use of thinning and feathering will be limited on steep side slopes due to field conditions.

Preservation of Existing Vegetation

- Islands of existing vegetation will be preserved in the pipeline right-of-way. These islands will have organic forms and mimic the appearance of naturally occurring vegetation islands.
- Portions of the project area contain steep slopes. Depending on work space available and safety requirements, preservation areas may need to shift.
- Preserved vegetation may not be within 35 feet of the pipeline trench.
- The edges of preserved vegetation islands will be thinned and feathered to mimic the edge texture of the surrounding natural environment.

Transplants

- Vegetation from areas that are to be cleared or thinned, either for construction or visual mitigation, is to be transplanted into areas that were disturbed and cleared in the construction corridor. Appropriate-sized plants may also be purchased if necessary.
- Vegetation that will be cleared as part of construction shall be stockpiled and used for transplanting in the reclamation phase.
- The transplants are to be planted in clusters that emulate the natural vegetation cluster patterns. Vegetation is to be planted within a depression surrounding the root-ball to collect water. Even if the vegetation does not survive, it will provide the vertical texture seen in the surrounding environment.

Roughened Slope and Mountain Mahogany

- Soil surface will be returned to a roughened state, mimicking the texture of the surrounding hillside and creating microclimate pockets to encourage successful revegetation.
- Mountain Mahogany will be planted in the depressions of the roughened slope. Quantities and locations will be determined on-site in accordance with the BLM.

Escarpment Reconstruction

- The stone shelf of the escarpment will be reconstructed to continue the linear form found in the surrounding environment.
- Rock shall be removed and stockpiled before construction and used to rebuild the escarpment edge.

Planting Native Vegetation

- The following types of vegetation will be planted, with quantities and locations determined on-site in accordance with the BLM.
  - Utah Juniper tubelings (may not be within 10 feet of the trench)
  - Wyoming Big Sagebrush
  - Mountain Mahogany
  - Willow tubelings (to be planted in washes and wetland areas)

In addition to the specific mitigation measure outline above, the following general conditions were also applied to the project:

- This is a conceptual plan and is representative of the techniques that will actually be applied during pipeline construction. Adjustments may be made where necessary to ensure safe working conditions and constructability. Visual mitigation plans are to be reviewed in the field before implementation.

- Re-established native grasses in the recommended seed mixes will mirror the color and form of the herbaceous species present in the undisturbed areas adjacent to the construction corridor. In addition:
  - Forb species content will be amplified in the seed mix and planted throughout the area (additional forb species can be planted at rates of 0.25 to 0.50 pounds of pure live seed per acre) to enhance habitat for small wildlife species, further reduce runoff, and improve soil infiltration.
  - Scarlet globemallow and arrowleaf balsamroot will be planted in efforts to enhance sage-grouse habitat.
  - White sagebrush and/or fringed sagebrush, as forbs or sub-shrubs, may be planted to form dense rootmats, which work well with perennial grasses and benefit sage-grouse.
  - Utah sweetvetch or northern sweetvetch will also be planted to provide wildlife value and increase nitrogen content in the soil.
  - Modifications to the standard Reclamation Plan also will involve planting Utah juniper tubelings, and seeding and/or planting containerized adapted sagebrush species (Wyoming big sagebrush), Willow species in riparian areas, and Mountain Mahogany up the Escarpment. This will help blend the proposed right-of-way disturbance with areas where juniper woodlands or shrublands were visually dominant prior to construction.
- Juniper and over-mature sagebrush stands have proven to inhibit the growth of grasses and forbs, which are far more effective at controlling runoff and erosion. In fact, several BLM districts in the Intermountain West are undertaking programs to reduce historic juniper woodland expansion and over-mature sagebrush stands. Given that the BLM established the ACEC on the basis of erosion and sedimentation, this enhanced reclamation program (which includes clearing, thinning, transplants, reseeding, and plantings) will balance the visual resource management goals with wildlife management and erosion control and stabilization objectives.
- All areas are to have a finished grade that emulates the existing contours prior to construction and will flow naturally into the surrounding environment.

BASALT WATER TANK VISUAL MITIGATION CASE STUDY

Visual mitigation can also be applied at a local level. The Town of Basalt, Colorado is in the process of proposing an additional water tank to increase their capacity for water storage. They have identified two sites as potential locations for the proposed facility, one on private property and the other on Bureau of Land Management (BLM) property. Visual issues are a concern for both the Town of Basalt and the BLM. Even if the tank location is placed on private property, the town wants to address visual issues and has decided to analyze and compare the two proposed tank sites to see which site has the most potential to be visually mitigated.

The BLM lands where the tank is being proposed hold a VRM Class designation of II. VRM Class II lands are to retain the existing character of the landscape. Any changes should repeat the form, line, color and texture found in the surrounding natural elements and the activities should not attract the attention of the casual observer (BLM manual H-8410-1-Visual Resource Inventory).

In addition to the BLM and Town concerns for visual impact, the proposed locations for the water tank are located in Pitkin County which places a large emphasis on maintaining its scenic quality throughout its Master Plan and Land Use Codes. The hillsides where the proposed action is to be located fall under the Pitkin County Scenic View Protection overlay, due to their proximity to Highway 82. This overlay designates areas where preservation of county character is critical and careful attention to the visible impacts of proposed development is important. The Scenic View Protection overlay works to maintain natural ridgeline silhouettes, ensure new development is designed to complement the natural features of the landscape, reduce visual damage and maintain a rural atmosphere. (Pitkin County Land Use Code, 2006, 7-20-120: Scenic View Protection).

Proposed Actions

The Town of Basalt is proposing the construction of a one million gallon water tank that would be 72 feet in diameter and 32 feet high. The location of the tank would require cut and fill to create a level and stable surface for placement.

There is also an existing road that would be enhanced for site access. In addition, a water pipeline would be buried along the uphill side of the road. Road improvement and pipeline installation would require disturbance up to 20' wide, after construction the road would be reclaimed back to a two track. There are up to two drainage crossing which would require cut and fill slopes and the installation of a culvert or bridge in order to access the BLM site.

Key Observation Points

The proposed action will be visible from various locations in the valley. Two Key Observation Points (KOPs) were chosen to represent the two major viewing angles from which the proposed action will be seen. The KOP's will be used to evaluate how the proposed actions may visually affect the area and what visual mitigation measure may be needed.

KOP 1 – Westbound lane of Highway 82 represents the viewer traveling along the transportation corridor on the valley floor. The viewer would be at an inferior position to the proposed action and traveling at highway speeds, with intermittent views of the hillsides to the south. The viewer along KOP 1 would be at an average of 0.5 miles away from the proposed actions, placing the proposed actions in the visual foreground.

KOP 2 – Located along Promontory Lane representing a view from the residential units along the north hillsides of the valley. The viewer would be at an equivalent or superior elevation to the proposed action, with a generally stationary panoramic view of the hillsides to the south. The viewer at KOP 2 would be at an average of one mile away from the proposed actions, placing the proposed actions in the visual foreground.

Mitigation Measures

Grading plans for both sites were provided by an engineering firm showing the proposed improvements without mitigation. Three dimensional models were created of the two proposed plans in order to gain an understanding of what mitigation techniques could best be applied to the site. Once the most effective mitigation techniques were determined, photo simulations were created of both plans showing the mitigation techniques applied to the site. Further analysis was then conducted to determine if the mitigation techniques were effective, and adjustments were made as necessary.

Standard mitigation measures applied to the two sites included:

Access Road/Pipeline Installation

- All road surface enhancements will be constructed using native material and will not be constructed utilizing a material of lighter color then the current site conditions.
- Spoils from road/pipeline construction will not be side cast.
- The access road/pipeline route will be limited to a disturbance width no greater than 16', with the allowable disturbance width being reduced further in visually sensitive areas.

- Upon construction completion, the access road will be reclaimed to a two track road. Top soil will be spread on the road surface, filling in the spaces between the gravel and then a seed mix will be applied. The seed mix will contain species found in the native areas adjacent to the site and appropriate species selection will be coordinated with a plant specialist.
- Where the access road crosses the major drainage, cut slopes will be retained using rock walls. The stone used to construct the walls will be a dark brown/grey color or stained to achieve such a color.
- Care must be taken to preserve the coniferous vegetation down slope from cut/fill required to cross the large drainage with the access road because the vegetation will provide some screening for the required cut/fill slopes.

Tank Location

- Cut slopes will be limited utilizing rock or gabion retaining walls in locations where steep slopes require a larger disturbance area to meet grade. (Vertical walls will be used to reduce the need to disturb more horizontal surface to match the grade.)
  - Retaining walls will be constructed of a dark grey/brown stone material to emulate the darker/shadow colors found in the surrounding landscape. If, after installation, the color of the wall material is too light for the landscape, it will be stained a darker color to emulate the shades of shadow seen in the adjacent, upright vegetation. If gabion walls are used, the mesh used to construct gabion walls will not be reflective.
- All cut and fill slopes will have undulating contours which emulate the slopes seen in the adjacent landscape. Constructed slopes will meet existing grades with a similar slope to eliminate the line created at the edge where two different grades meet.
- Upright vegetation adjacent to the areas disturbed during construction will be thinned and given an undulating edge which emulates the organic, transitional edges of adjacent upright vegetation.
- Vegetation should not be cleared in areas where fill slopes/berms will be created; it will be preserved and fill distributed on top. This allows the tops of existing vegetation to protrude through the surface of the fill slope and provide additional texture and screening even if the vegetation does not survive.
- Woody debris and stone material generated during construction will be saved and placed on the disturbed ground surfaces to provide color and texture and to also create microclimates, encouraging vegetation growth.
- All disturbed surfaces will be revegetated with the species found in the adjacent landscape.
- The tank will be painted with a dark/grey green color, determined in the landscape, repeating the color found in the shadows of the landscape.
- For the BLM location, a berm will be constructed to the north of the proposed tank location and will emulate the contours of the surrounding environment and meet existing grades at a natural slope. The top of the berm will near the elevation of 6896’, therefore intercepting the view of the bottom 24’ of the tank. When the berm is revegetated and the vertical vegetation begins to mature, the remaining 8’ of the tank in view should be intercepted.

Implementation and Establishment

In order to ensure a successful project, a mitigation plan needs to identify how the mitigation measures will be implemented and established throughout the construction process. The implementation of the

Visual Mitigation Alternatives needs to be a collaborative and adaptive process. A preconstruction meeting should be arranged in advance of implementing the visual mitigation program with periodic progress monitoring. Construction inspection and adaptive management during the mitigation implementation is imperative to achieve maximum results.

Prior to construction a complete road construction plan needs to be developed. At a minimum it should include the existing contours, construction requirements, limits of disturbance, and reclamation plan.

During Construction

When the tank location and access road are being constructed, some of the Visual Mitigation tasks may also be completed. As the vegetation is being cleared for the tank location, the crew may also start thinning and feathering the adjacent vegetation. Hand saw techniques will be utilized and care taken to leave a 6” stump and to not disturb the root structure of the vegetation.

When excavation begins for the tank location, the topsoil is to be salvaged. Stripping of topsoil must be monitored to strip the O and A1 horizon of the native soil. Topsoil stripping needs to be stockpiled in shallow piles to preserve topsoil quality.

- 3 foot pile is ideal for preserving the life of the soil.
- 5 foot pile is acceptable.

All woody and lithic material generated during construction will be saved and placed on the finished grades during reclamation. Topsoil needs to be placed back on the reclaimed slopes and berm immediately upon completion.

Grading and Reclamation

Once the tank has been constructed, the disturbed tank site can begin to be reclaimed. The cut and fill slopes can be graded back to slopes matching the natural grade with contouring and undulations to emulate the surrounding terrain. While grading, collection pools can be established to collect stormwater run-off, integrating them into the landscape to look like natural undulations.

The access road will also be reduced back to a two track. Top soil will be spread on the road surface, filling in the spaces between the gravel and then a seed mix will be applied. The seed mix needs to contain species found in the native areas adjacent to the site and appropriate species selection will be coordinated with a plant specialist.

Revegetation can begin once the finished grades are established. Revegetation includes the replacement of topsoil, lithic mulch/roughened slope as well as seeding with the preferred seed mix. Tubling or containerized plants will also be used along the top of the berm. Stock will be planted in depressions, monitored and watered, and protected with animal fencing until it is established (which may take multiple years).

In addition to benefiting visual mitigation, the quick establishment of revegetation is important for storm water control. The stabilization of the topsoil to reduce erosion is crucial in retaining the valuable topsoil on site.

Maintenance and Monitoring

After construction is complete it is important to establish a maintenance and monitoring program to assure long term results and to help decrease the impact to other natural resources. For example, removal of undesirable species before they become established and crowd out the desirable species is needed in order to encourage the growth of the advantageous species. Also, revegetated areas need to be enclosed with a fence to keep livestock and wildlife impact minimal until revegetation is established.

In addition, it is important to have a way to monitor the project for VRM compliance. Visual compliance can be evaluated by comparing the form, line, color and texture characteristics represented in the report’s photo simulation to that is observed from the selected KOP. Observed site conditions should be photo documented.

Monitoring should include an interim assessment of compliance (approximately every six months), with an estimated level of success projected out to the end of a selected monitoring period. If determined early in the monitoring period that objectives are not being met, then adaptive measures would be mutually agreed upon between the Town of Basalt and the regulating agency.

ENVIRONMENTAL COLOR AND CAMOUFLAGE MITIGATION FIELD TEST

Visual mitigation techniques are continuously changing as we are able to analyze, monitor, and learn from existing mitigation plans that have been implemented. In addition, new technology is also allowing for the advancement and study of new methods for mitigation. One such project, being led by the BLM, is in the beginning stages of studying potential camouflage techniques.

Project Objectives and Strategy

This project will field-evaluate the theories and methods of multiple color applications as described in the Draft Field Guide for the Use of Color to Mitigate Visual Impacts. When complete, this effort will have nationwide applications within multiple federal agencies and state and local governments. This project is broken into two tasks:

Task 1: Evaluate a single camouflage pattern on two different tanks and evaluate proposed methods of applying camouflage treatment. The two types of multiple color applications being field tested are:

- 3M vinyl adhesive appliqué, and
- Masked/stenciled painting.

The evaluation will determine the suitability of this technology and application methods to serve as a visual mitigation Best Management Practice for oil and gas development.

Task 2: Develop a narrow set of standard camouflage patterns (texture and color) that effectively mitigate visibility of select facilities within a ¼ mile to 1 mile distance range in multiple landscape settings. A narrow range of suitable patterns (1-3) will be developed that work in multiple settings rather than having one pattern per setting.

The information and images documented from the field exercises will be used in training sessions demonstrating the effectiveness, pros, cons, and opportunities for this technology. The anticipated audience will be BLM personnel, other federal agencies, local governments, special interests, consulting contractors, industry proponents and vendors educating on the what, why, how, methods, costs, pros, and cons of this technology.

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MOUNTAIN PINE BEETLE AND SPRUCE BEETLE OUTBREAKS: CHANGING OUR HIGH ELEVATION FORESTS OF COLORADO

Sheryl Costello
Entomologist, USDA Forest Service
Forest Health Protection
Lakewood Service Center
740 Simms St., Golden, CO 80401

Mountain pine beetle, *Dendroctonus ponderosae*, and spruce beetle, *Dendroctonus rufipennis*, are two of the most important mortality agents in Colorado forests. These beetles are native insects that typically exist at background population levels, infesting only stressed or injured trees. Under the right conditions, population levels can build up to the current outbreak levels. Mountain pine beetle is currently impacting almost ½ of the lodgepole pine cover type in Colorado and is also affecting limber and ponderosa pines. Large outbreaks of spruce beetle are affecting Engelmann Spruce in Southern Colorado. In 2007 alone, surveys attributed 5.2 million dead lodgepole pine trees on 970,000 acres in Colorado to mountain pine beetles. Spruce beetles were estimated to have caused the death of 300,000 spruce trees on 98,000 acres. Due to the large-scale of these outbreaks, the landscape is and will continue be dramatically affected. Post-outbreak forests undergo several changes, including the eventual accumulation of dead trees on the forest floor and subsequent regeneration of the stand. Finally, these outbreaks show no signs of diminishing until most all of the suitable host trees have been killed in an area.

This presentation gives an overview of the biology of these beetles, forests affected in Colorado, outbreak dynamics and future changes.

Cooperation: The Key to Success—*The History of the Southfork Weed Management Area in Park County, Wyoming*

Bob Parsons, Supervisor

Park County Weed and Pest Control District (Wyoming)
PO Box 626
Powell, WY 82435

ABSTRACT

Weeds do not recognize political boundaries or private fences, but for years government agencies and private landowners have treated noxious weeds based on land ownership. After the 1988 Yellowstone fires, many land managers decided to look at the spread of noxious weeds in the same manner they had witnessed with the spread of fire. In the spring of 1989, representatives from federal agencies, states, local government and the private sector came together to establish a concept of weed control that was based on weed infestations and topography rather than land ownership.

Since the distribution of the *Guidelines For Coordinated Management of Noxious Weeds In the Greater Yellowstone Area* (1990) and the *Guidelines for Coordinated Management of Noxious Weeds: Development of Weed Management Areas* (2002), Park County Weed and Pest Control District in northwest Wyoming has formally implemented three Cooperative Weed Management Areas (CWMA) and has laid the groundwork for two more. By using a true integrated weed management program of chemical, biological, and mechanical controls, along with education and restoration, many severe weed infestations have been reduced to a manageable level.

INTRODUCTION

Between July 15 and September 11 of 1988, there were 248 fires in the Greater Yellowstone Area and over 1.2 million acres (about 36%) burned or scorched. More than 25,000 firefighters (as many as 9000 at one time) attacked Yellowstone fires in 1988, at a total cost of about $120 million. In the aftermath, about 665 miles of hand-cut fireline and 137 miles of bulldozer lines, including 32 miles in the park, needed some rehabilitation, along with the remnants of fire camps and helicopter-landing spots. Before all the fires were completely extinguished, bids went out from federal agencies for native grass and forage seed to start the restoration of disturbed lands. In many cases, the specifications were very general in their descriptions of requested species and in most cases no reference was made to the “other weed seeds” that would not be allowed. The potential for a massive planting of noxious weeds was practically inevitable.

The History of Weed Management Areas

Recognizing the Potential Crisis

Local weed control agencies in the Greater Yellowstone Area (GYA) ecosystem recognized the possibility of new infestations of noxious weed being introduced by the planting of poor quality seed. State weed coordinators from Wyoming, Montana and Idaho discussed what steps could be taken to reduce the chance of this happening. It was generally agreed that the problem centered on the fact that there were no guidelines which addressed noxious and exotic weeds on a multi-jurisdictional basis. In the winter of 1988, a meeting was held in Cody, Wyoming to bring together federal land managers, state departments of agriculture, and local governmental agencies involved in weed control. From that meeting came the plans for an ad hoc committee to establish guidelines that would address the concerns of the group.

The committee consisted of Jim Free with the U.S. Forest Service; Barbra Mullin, Montana State Weed Coordinator; Hank McNeel, Weed Specialist with the Bureau of Land Management; Bob Parsons, Supervisor of the Park County Weed and Pest District; James Sweaney, Forestry Supervisor for Yellowstone National Park; and Loal Vance, Idaho State Weed Coordinator. This committee met over the next year and in the spring of 1990 published the *Guidelines For Coordinated Management of Noxious Weeds In the Greater Yellowstone Area*. The value of these guidelines is greatly enhanced by the fact that they had been approved with a MOU signed by the Governors of three states, three Regional Foresters, three State Directors of the Bureau of Land Management, and the Regional Director of the National Park Service.

The Cooperative Concept is Given Structure

The *"Guidelines..."* addressed most of the operations associated with noxious weed control as had been carried out for many years by county weed control districts and various governmental agencies. These operations included sections on awareness, education, prevention, inventory, integrated weed management, monitoring, evaluation, and reporting. All these sections were supported by an extensive appendix of supporting material.

The primary benefit of the document seemed to center around the section, "Purpose & Organization of Weed Management Areas." As public land managers began to implement the guidelines, many saw the value of an organized committee of interested parties in providing on the ground application of noxious weed control. The basic concept of a weed management area (WMA) was "…replaces jurisdictional boundaries that are barriers to weed management programs in favor of natural or more logical boundaries that facilitate weed management and control."

Weed control projects in the past had been stymied by "the blame game" and "finger pointing" types of accusations. Because funding for weed control programs had often been centered on ownership boundaries, it seemed important to determine where the weed had originated and whose was at fault for the infestation. The concept of a WMA nullified the need to determine the culprit responsible for the initial introduction of the infestation since all agencies and individuals within the area would share in the cost of control. (It was still recognized as important to determine the method of introduction for educational purposes to prevent the likelihood of similar incidences.)

The concept of a WMA was to establish the boundaries of the infestation and its potential spread then use that information to determine the boundaries of the WMA. These natural barriers are usually associated with hydrographic divides or vegetational zones. Once the area has been defined, an inventory of land ownership is conducted to determine potential cooperators and land managers for the organizational structure of the WMA.

The "*Guidelines...*" also included suggestions on how to establish a steering committee, assessing the extent of the infestation, and writing a WMA plan. These suggestions were supported by examples included in the Appendix.

Guidelines are Expanded Beyond the Greater Yellowstone Area (GYA)

Because of the popularity of the WMA concept fueled by the reported successes, many requests were made for copies of the *Guidelines For Coordinated Management of Noxious Weeds In the Greater Yellowstone Area*. As this document was distributed over a continuing larger area, requests where made for a more generalized document that was not so specific to the GYA. In 2002 the ad hoc committee was reestablished to modify the document to include the majority of the western states. For the most part, only minor changes were made. Two major changes were defining grazing as a biological control method and the addition of a section related to weed management for burned areas. The added section addressed the subject of revegetation more completely than the previous document.

As the success of WMA's became more eminent, other agencies and individuals began publishing documents more suited to their region or state. One of the more notable was the CWMA Cookbook from the Idaho Noxious Weed Coordinating Committee in 2003. This was one of the first documents to coin the phrase, *Coordinated* Weed Management Area. Because this title emphasizes the idea of coordination, it seems to have become the more common terminology over the past few years.

Putting the Concept into Practice

Background

Prior to 1970, Wyoming's Park County Weed and Pest Control District had identified a small infestation of Dalmatian toadflax about 47 miles west of Cody, Wyoming. The infestation was sparsely spread over about 180 acres of Shoshone National Forest (USFS) land near the junction of Cabin Creek and the Southfork of the Shoshone River.

Because the infestations were insignificant compared to other weed problems, they were not prioritized in USFS management plans. When the federal government reduced funding available for weed management programs, the USFS did not have the resources to keep Dalmatian toadflax control at the forefront of Shoshone National Forest land management programs.

Within three years of this decision, Dalmatian toadflax spread to cover a 2,000 acre area of national forestland and nearby private properties. The expansive infestation posed a growing threat to bighorn sheep grazing in the area. As it flourished, Dalmatian toadflax began to replace native plants, which provide important nutritional food sources for bighorn sheep and other grazing wildlife in the Shoshone River valley.

Topography and Demographics

The Southfork of the Shoshone River is one of the two major tributaries of the Shoshone River. It is located in Park County, Wyoming in the northwestern section of the State of Wyoming. Over 95% of the Southfork drainage is public lands managed by the Shoshone National Forest. It has long been winter grazing range for bighorn sheep and elk in the Absaroka mountain range.

Because of its beauty and isolation from the general public, many of the large ranches in the valley have been purchased by non-resident landowners for summer vacation spots. Although there are still cattle ranches in the area, much of the land is used for private enjoyment and recreation. Many of the private landowners have little experience with the noxious weeds found in the mountain states of Wyoming. Very few recognized Dalmatian toadflax as an aggressive invasive species and considered it a pretty mountain flower. The need for education was obviously paramount.

Selecting the Steering Committee

Both sets of "*Guidelines...*" and the *CWMA Cookbook* suggest a basic organizational structure that begins with the forming of a steering committee made up of interested and committed individuals. In the Fall of 1992, the Park County Weed and Pest Control District (PCWP) and the Wapiti District of the Shoshone National Forest (USFS) agreed to begin the process of forming a weed management area based on the GYA guidelines. The original committee consisted of representatives from PCWP, USFS, the Cody Conservation District (CCD), and the University of Wyoming Cooperative Extension Service (UWCES).

The committee discussed the need for a WMA and mutually agreed that it would be the best way to promote weed control in that area. It was decided that the management area would be called the "Southfork Weed Management Area" (SFWMA) and would encompass all lands within the drainage of the South Fork of the Shoshone River from its headwaters to the Buffalo Bill Reservoir west of Cody, Wyoming. *(Figure 1)* The purpose would be primarily for the control of Dalmatian toadflax but other weeds would be addressed when appropriate.

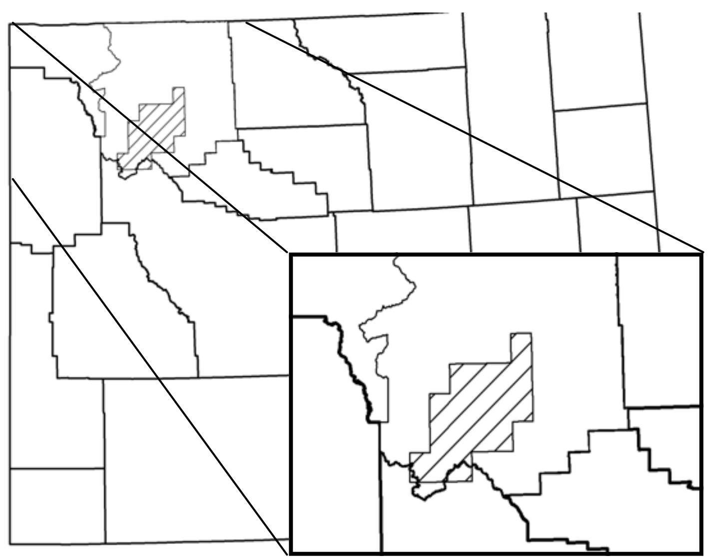

Figure 1
Location of the Southfork Weed Management Area

Forming the Weed Management Area Coordinating Committee

In the Winter of 1992-93, the steering committee contacted the local newspapers for an interview about the formation of a WMA. In addition, an advertisement was placed notifying interested persons of a meeting to address questions. The meeting was attended by the steering committee, the State Weed and Pest Coordinator from the Wyoming Department of Agriculture (WDA), and representatives from the Wyoming Game and Fish (WGF), the Bureau of Land Management (BLM) and the Bureau of Reclamation (BOR). There were also about fourteen private landowners or managers from within the WMA.

Major points of discussion and concern were:

- Why do we need to control Dalmatian toadflax when it is such a pretty flower?
- Are you going to use herbicides to control the weeds?
- What other vegetation is going to be killed with the use of herbicides?
- How are the herbicides going to affect wildlife and livestock?
- Are herbicides going to be used to control weeds along the river bank?
- Are there any biological control agents available?
- Will hand pulling the weeds get rid of them?
- Will all landowners be forced to control the toadflax even if they don't want to?
- Who is going to pay for the program?

At the conclusion of the meeting, a request for volunteers to form a coordinating committee was made. The general consensus was that each governmental land management agency would have a representative on the committee. Most of the private landowners felt that their concerns would be addressed by the PCWP and one or two private landowners could serve to ensure their private property rights were recognized.

By the conclusion of the public meeting, the general feeling of the crowd was positive. There were a few attendees that were totally opposed to the concept and vowed to contest not only the WMA but any efforts of the PCWP to try and force them to control noxious weeds on their lands or adjacent public lands. It was agreed that PCWP staff would approach these individuals on a personal basis to explain the Wyoming Weed and Pest Act and the Park County Weed and Pest District-wide Quarantine.

Activities of the Coordinating Committee

The SFWMA Coordinating Committee started meeting in the Spring of 1993 to establish goals and objectives for the organization *(Appendix A)*. The long term goal was simple**—Reduce the level of infestation within the Southfork Weed Management Area.**

The short term goals were:

- Contain Dalmatian toadflax within current boundaries
- Inventory and map the current boundaries of Dalmatian toadflax
- Determine effective Dalmatian toadflax control methods
- Develop awareness and educate the public about the Dalmatian toadflax problem

The committee agreed that one of the first activities had to be the mapping and inventorying of the infestation. Assignments were given to land management agencies to have the entire WMA mapped by the Fall of 1994. This lofty goal was completed with the unexpected help of a grant from DOW AgroSciences to help fund the hiring of a private contractor to map the privately owned lands within the WMA.

Hiring a WMA Coordinator

In Park County, the PCWP staff is, by statute, responsible for coordinating an effective weed and pest management program within the county. It became very clear that the existing staff was not going to be able to devote the time necessary to ensure the success of the WMA. In an effort to address this problem, the SFWMA coordinating committee contracted with individuals to coordinate programs within the WMA. These individuals are financed through grants and other funding obtained by the SFWMA coordinating committee. They compliment the activities of the PCWP staff and are probably the single most important aspect of the success of the SFWMA.

Obtaining Financial Support

Although funding had been available for the ongoing noxious weed program within what was now the SFWMA, more financial support was needed to expand the work identified by the coordination committee. Both short term and long term monetary support methods were sought.

Short Term Support

- DOW AgroSciences provided funding to hire a commercial contractor to survey and map the private lands within the SFWMA. ($5,000)
- The Cody Conservation District obtained a grant from the Wyoming Association of Conservation Districts to purchase bio-agents from USDA-APHIS/AR in Bozeman, MT. ($7,500)
- Both the local chapter and the national chapter of the Foundation for North American Wild Sheep (FNAWS) supported the SFWMA with grants for biological control and revegetation for Big Horn Sheep winter range. ($10,000)
- The SFWMA applied for and received three Pulling Together Initiative (PTI) grants from the National Fish and Wildlife Foundation (NFWF). This was a precedent setting accomplishment since it was the first time that three PTI grants had been awarded to the same project. ($150,000)
- The WMA also received two grants from the Wyoming Wildlife and Natural Resources and have currently applied for a third one. A large portion of this grant is designated to the SFWMA. ($150,000)
- The PCWP has directed a portion of their annual funding from the USFS State and Private Forestry grant to the SFWMA. (Approximately $30,000 per year)
- The BLM provided funds for an education information sign to be place along the highway which accesses the WMA. ($1,200)

Long Term Support

- Because of the commitment of adjacent landowners and land managers of public lands to support the WMA, the Shoshone Forest increased its USFS budget for weed control directed to the SFWMA. This had resulted in increased support of around $50,000 per year.
- The PCWP Board of Directors has agreed to provide a 100 percent cost share on all herbicides used on private lands for the control of Dalmatian toadflax within the SFWMA. The PCWP also is responsible for the cost of weed control along all county roads and state highways within the WMA. The total cost to the PCWP within the WMA is approximately $35,000 per year.
- Private landowners within the WMA have provided financial support either in the form of cash donations or in-kind services. Although this varies each year dependent upon the size of the donation or amount of work done on private lands, it is estimated that this results in over $20,000 per year in cash and services.
- The BLM has increased its budget for noxious weed control on public lands to help support programs within the WMA. In addition, they have provided extensive support in housing mapping and inventory information on their GIS system. We estimate a value of over $15,000 per year for this service.

Implementing the Integrated Weed Management Plan

It was agreed from the implementation of the SFWMA that weed control in the project area would include all methods of a true integrated pest management (IPM) program. Much of the success of this WMA is associated with the fact that allowing cooperators the option of various control methods has neutralized many of the concerns of herbicide control. Over the years, even the most determined chemical and biological control opponent has come to recognize that the proper use of herbicides and biological control is necessary for long term control of Dalmatian toadflax.

Awareness/Education

Because many of the private landowners within the WMA were not trying to make a living from agriculture or ranching on their lands, they did not recognize the negative effect of this invasive weed on the natural ecology of this ecosystem. Education became paramount in assuring the success of the WMA.

One of the most varied groups within the SFWMA was the Upper Southfork Landowners Association. This group meets annually in the early fall as this is the only time that many of the private landowners are in residence in Wyoming. Representatives from the PCWP and the CCD have been able to make presentations to this group over the years. This one-on-one contact has been invaluable in educating landowners of the threat that noxious weed infestations have on the financial value of their investment as well as the negative impacts to the ecosystem.

The SFWMA is home of one of the largest bighorn sheep winter ranges in Wyoming. Because of the threat of Dalmatian toadflax infestations to the survival of this big game species, the Foundation for North American Wild Sheep (FNAWS) asked for the WMA to provide an educational program for their members during their annual meeting in Cody, Wyoming. For three consecutive years, the SFWMA arranged a weed tour and hands-on educational program for FNAWS and local residents. The program included the presentation of information about toadflax and also provided attendees to experience hand pulling of Dalmatian toadflax infestations.

The USFS and the BLM provided funds to sponsor interns from Student Conservation Association (SCA) to develop a public relations and education publication to be used by future SCA interns in the Rocky Mountain area. These individuals worked very closely with the SFWMA to educate individuals and promote noxious weed control programs.

The SFWMA arranged to have a sign posted at the head of the South Fork Valley with information about Dalmatian toadflax and the potential of it spreading to other areas. The sign was provided by the Worland District BLM office. The Park County Commissioners agreed to use the county road and bridge department to install the sign along the highway.

Chemical Control

Chemical control of Dalmatian toadflax has been a major part of the weed control program in Park County for many years. Application has always been hand spraying of products such as picloram, 2,4-D, dicamba, metsulfuron, and imazapic. Although this is the most efficient method of controlling toadflax, it is still just another tool in the IPM control program.

Biological Control

Extensive work has been done by the University of Wyoming and the USDA/APHIS/ARS to establish biological control agents to control Dalmatian toadflax within the SFWMA. Agents that have been introduced into the area include: *Brachypterolus pulicarius*, *Calophasia lunula*, *Gymnetron linariae*, *Gymnetron antirrhini*, and *Mecinus janthinus*. Of these insects the two most affective have been the *B. pulicarius* and the *M. janthinus.* However, the *M. janthinus* has been difficult to establish in some areas because browsing bighorn sheep continue to eat the stems where the over-wintering agents are found. It is still the belief of the SFWMA that over the long term, biological control will be the tool that reduces Dalmatian toadflax to an acceptable level of infestation.

Mechanical Control

Dalmatian toadflax is one of the few noxious weeds that can be effectively controlled with hand pulling. Many local landowners within the WMA have developed extensive control programs centered on the mechanical removal of Dalmatian toadflax. Landowners are encouraged to use hand pulling of isolated plants or new infestations as an effective control method. However, it has not proven to be effective on a large scale because of the cost of labor and the inability to continually eliminate new growth during the entire growing season.

The shallow volcanic soils found within the WMA prevent the use of mechanical farm equipment such as discing or plowing. Most of the lands are rangeland and therefore the use of mechanical equipment is not a viable alternative. Mowing in mountain meadows has been used to reduce seed formation, but because of the short growing season, the loss of forage makes mowing impractical.

The use of fire for control is also a very limited alternative. Areas where wildfire or even prescribed burns have removed the desirable vegetation, the density of the infestation of Dalmatian toadflax has increased dramatically. Even if fire did give some level of control, most areas do not have enough understory to carry the fire.

Revegetation

The use of competitive grasses and forage has long been a preferred method of control of Dalmatian toadflax. Extensive experiments have been conducted within the SFWMA to establish both native and non-native vegetation to reduce the density of Dalmatian toadflax. Some of the plots within the WMA have been successfully reseeded using broadcasting and working the seed in with light harrowing. Heli-seeding has also resulted in the establishment of competitive grasses and forbs in some of the burn areas. However, because the SFWMA is normally has a relatively dry climate and has been in a drought cycle for at least eight of the last ten years, some revegetation projects have met with very limited success.

Prevention and Early Detection

It is the general belief that prevention and early detection has been the most successful tool in controlling the spread of Dalmatian toadflax both inside and outside the SFWMA boundaries. The contention that the effectiveness of prevention cannot be measured does not change the fact that common sense tells us that the lack of introduction will reduce the overall level of infestation.

Much of the control efforts within the SFWMA are dependent upon the concept of prevention and early detection. All the educational programs of the SFWMA contain components that emphasize the importance of purchasing weed free forage products for use on private lands. In addition, the USFS and the BLM require that all forage brought onto public lands be certified weed free forage or grain. PCWP has a district-wide quarantine which requires that all farm products be inspected and released prior to movement within the county. This program has been strongly promoted within the SFWMA as well as around the rest of the county.

The SFWMA coordinators, PCWP staff, and UWCES agents all include weed identification in their educational classes. This helps ensure that local residents not only recognize noxious weeds when they encounter them, but also recognize the importance of controlling small infestations before they have a chance to spread. Many small infestations of Dalmatian toadflax have been reported by individuals using public lands within the WMA for recreational purposes.

Acquiring Partners

As stated in the title, cooperation is truly the key to the success of the SFWMA. The diversity of individuals and governmental agencies who have contributed in various ways has served as an example for other WMA's in both Park County and neighboring counties and states. Here is a partial list of cooperators.

- Park County Weed and Pest Control District, Park County, WY
- Shoshone Forest, US Forest Service, Cody, WY
- Cody Conservation District, Cody, WY
- University of Wyoming, Laramie, WY
- Private Landowners within the Southfork Weed Management Area, Cody, WY
- Upper Southfork Homeowners Association, Southfork of Shoshone River, WY
- Wyoming Game and Fish, Cody, WY
- Bureau of Land Management, Worland & Cody, WY
- Natural Resources and Conservation Service, Cody, WY
- USDA-APHIS-PPQ, Bozeman Biocontrol Station, Bozeman, MT
- Wyoming Department of Agriculture, Cheyenne, WY
- BASF, Laramie, WY
- DOW AgroSciences, Billings, MT
- Center for Invasive Plant Management, Bozeman, MT
- Foundation for North American Wild Sheep, Cody, WY
- Rocky Mountain Elk Foundation, Missoula, MT

The list could be much more extensive if we were to list each individual landowner that provided in-kind services both in labor and use of their land for research. Also not listed are the organizations and foundations that provided financial support in the form of grants and technical services. Without these people and many others, the SFWMA would not have been as successful as it has.

Evaluating the Results

The success of the SFWMA can be measured in many ways. The most obvious benchmark is whether or not the infestation of Dalmatian has been reduced over the last thirteen years. This has been documented quantitatively by continued monitoring and inventorying. Although isolated plants are still found in the same proximity of the original infestations, the density is reported to be at 20% of what it was in 1996. Many of the local residents have also commented about the reduction of Dalmatian toadflax within the WMA. Education programs, signs posted at trailheads and weed control at access points to the backcountry have reduced the potential of infestations in wilderness areas and adjacent public lands.

Another measure of success is the fact that no other infestations of Dalmatian toadflax have been established since the formation of the SFWMA. Although isolated plants and new small patches have been reported, rapid response from the PCWP and other governmental agencies has prevented establishment of permanent infestations.

The success of forming a weed management area has been duplicated many times over since the introduction of the concept in the *Guidelines For Coordinated Management of Noxious Weeds In the Greater Yellowstone Area* and the *Guidelines for Coordinated Management of Noxious Weeds: Development of Weed Management Areas*. In Park County there have been two more equally successful WMA's started over the past thirteen years, and two more areas have been designated as future areas for organization. The favorable reaction to the WMA concept has resulted in formal recognition of the term in many state and federal legislative acts and policies. Today, few people involved in weed management are ignorant of the WMA concept and the importance it plays in successful control of large infestations of noxious weeds.

Appendix A

Southfork Weed Management Area
Goals and Management Plan

Introduction:
The Southfork drainage in Park County is currently experiencing a serious infestation of Dalmatian toadflax. Due to the extent of the infestation and the diverse land ownerships, it was decided that a cooperative effort is needed to address this problem. The following groups have agreed to form the Southfork Weed Management Area, to allow personnel and resources to be pooled.

Park County Weed and Pest, P.O. Box 626, Powell, WY 82435 754-4521
Cody Conservation Districts, 808 Meadow Lane, Suite A, Cody, WY 82414 587-3251
UW Cooperative Extension Service-Park County, P.O. Box 3099, Cody, WY 82414 587-2204, ext. 248
Wyoming Game and Fish Department, 2820 State Hwy 120, Cody, WY 82414 527-7125
Soil Conservation Service, 808 Meadow Lane, Suite A, Cody, WY 82414 587-3251
Bureau of Land Management, P.O. Box 119, Worland, WY 82401 347-9871
United States Forest Service, P.O. Box 2140, Cody, WY 82414 527-6241

Weed Management Area boundaries:
The drainage of the Southfork of the Shoshone River from its headwaters to Buffalo Bill Reservoir.

Land Ownership and Use:
The Weed Management Area is made up of land owned by private citizens, the Bureau of Land Management, the US Forest Service, the Bureau of Reclamation and the State of Wyoming.

The land is used for grazing, crop production, recreation, mining and wildlife. It includes wildlife winter range, irrigated agriculture and upland rangeland. Certain land entities, such as wilderness areas and selected landowners, provide special restrictions which need to be addressed.

Weed Management Area goals:

Long -Term goal:

Reduce the level of infestation within Southfork Weed Management Area.

Short – Term goal:

1) Contain Dalmatian toadflax within current boundaries.
2) Inventory and map the current boundaries of Dalmatian toadflax.
3) Determine effective Dalmatian toadflax control methods.
4) Develop awareness and educate the public about the Dalmatian toadflax problem.

Background information:

The river and its tributaries are a major limiting factor. The water and rocky soils provide physical barriers to control. They also limit the chemical options which are available for use in Dalmatian toadflax control programs. Another factor which needs to be taken into account is that the area provides important winter range for a variety of big game animals. The inventory process will identify additional areas with special restrictions. Those restrictions will be addressed when the program actions are planned.

To our knowledge the only threatened or endangered species which may be in the area are the Grizzly Bear, Peregrine Falcon and the Bald Eagle. There are no plants in the area which have been proposed for listing.

Range site descriptions and soil types will be considered on a site by site basis as needed for proposed control actions. Archaeological sites and other cultural sites will also be addressed individually when necessitated be proposed actions. Surveys for cultural and archaeological sites and endangered and threatened species, as well as other factors which may be required, prior to all major treatment projects.

There are an abundance of resources available to address weed problems. The University of Wyoming, Soil Conservation Service, Weed and Pest Control District, Bureau of Land Management, US Forest Service, Wyoming Game and Fish Department, as well as other groups and individuals, have expertise and personnel. Many of these same groups have funds which may be made available. Park County Weed and Pest has the mechanism in place to handle funding coordination and accounting.

Planned activities:

Inventory and Mapping:

The Southfork Weed Management Area will have a mapped inventory of Dalmatian toadflax by fall of 1994. The area and those responsible are:

Areas	Responsible Persons
Wilderness Areas	US Forest Service
Private and State Lands	Cody Conservation District and Soil Conservation Service

National Forest Land (other than Wilderness)	Game and Fish, US Forest Service and Weed and Pest

Park County Weed and Pest will fill in the gaps. They will map Dalmatian toadflax in their normal area of operations. Inventory and mapping progress will be evaluated at the end of 1993. A plan will then be made to ensure all areas are mapped by Fall 1994. The mapping will be consolidated by the Bureau of Land Management. All inventory and mapping will follow BLM guidelines.

Education:

The general public, including permittees, outfitters and surrounding landowners need to be educated about Dalmatian toadflax. Signs, posters and brochures are three ways to accomplish the education. Weed and Pest will coordinate the signs, posters and brochures.

Control Research:

Herbicide Trails: The Extension Service will put out herbicide test plots during the Summer and Fall of 1993.

Biological Release: The Extension Service will work with Bob Lavigne on a biological control agent.

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VEGETATIONAL FUTURE OF COLORADO MOUNTAIN VEGETATION – RECOVERY FOLLOWING AN EPISODE OF HEAVY INFESTATION BY TREES

David L. Buckner
ESCO Associates Inc. P.O. Box 18775
Boulder, CO 80308

ABSTRACT

Mountain vistas covered by trees are popularly accepted as the most desirable and "natural" condition for mountain forests of Central Colorado landscapes. Yet when the canopy cover by trees reaches a state of near total closure over vast reaches, the expression of the biodiversity of vascular plants in the ecosystems involved is strongly suppressed. Shading, heavy needle litter layers, shortened and cooled growing seasons, and direct root competition for moisture and nutrients are active in the diminished growth of non-tree species. Agents of change in the form of fires or insect epidemics that kill trees operate to restore conditions suitable to the reinstated growth of species of smaller stature ("understory" plants). Aside from vascular plant diversity/abundance, open and patchy environments are supportive of many vertebrate and invertebrate animal species whose habitat requirements are not met in closed canopy forest. Historic and pre-historic evidence supports the proposition that landscapes, including those of the mountains, have passed through, tolerated, and may reasonably require episodes of extensive environmental change, especially including the periodic demise of heavy tree cover. Public perception of the well-being of western forest lands needs to incorporate an appreciation of the existence of adaptation to, and even dependence on, environmental change in long-term maintenance of biodiversity on these landscapes.

INTRODUCTION

The objective of this presentation/essay is to encourage an alternative view to the changes associated with massive losses of forest trees to insect infestation that are on-going in mountainous Colorado. In particular, the biological features associated with much-reduced tree cover are explored.

It is doubtless true that extended vistas of red/dead-colored lodgepole pine in the central portions of Colorado in 2006 and 2007 are troubling not only to the thousands of visitors who come expecting green forests, but also to the Summit and Grand County residents who have settled into life amidst the once verdant canopies of pine. Death of vast numbers of trees evinces more or less universal feelings of loss and the news of such events inevitably is cast in the context of environmental degradation. Although human affinity for trees has waned and waxed through history, the present list of positive attributes associated with trees is long: for example, shade in summer, wind protection all year round, soil stabilization, wildlife habitat, and of course most recently the concept that they constitute carbon storage modules.

Positive images of trees and forests fit comfortably into the current common (and appropriate) perception of the "rightness" of conservation. This was not always so. Neither the positive embrace of the trees/forests image nor the concept of conservation are of great antiquity in our culture. The intact forest primeval of Europe and Eastern North America was indeed regarded by most writings of the time as foreboding -- dark and full of potential for misadventure. Remember that the forest primeval at both these sites was at the time of human arrival comprised of a large component of truly very large trees -- especially compared to the second-, if not third- or fourth-growth forests that presently prevail in eastern North America and Europe.

Trees have formed literally and figuratively a central structure on which the trappings of civilization have been hung (see the excellent book by John Perlin 1989). Use of timber resources for structural materials and fuelwood extensively diminished forest cover in many parts of the European (and Middle Eastern) world during the history of western civilizations (Perlin 1989). Slowly and only recently (see contributions of John Evelyn, Court of English King Charles II 1664) did a conservation ethic germinate and slowly establish. As a practical matter that ethic has spread most extensively in cultural environments where its existence impedes the actual survival of the fewest people. Hence wealthier societies such as our own have adopted it most widely. In very recent times, cutural phenomena such as Smokey the Bear and Bambi (the Disney children's' movie) have contributed to the common perception of forests as important and valuable natural features.

Suffice it to say that forest conservation has, at the present time, achieved prominence worldwide. When the handsome, fragrant, and green, trees that visually and aesthetically define many western mountain landscapes meet sudden demise, it is consistent with human nature to feel that some sort of eternal natural order has been disrupted. But from the view point of natural history, the implications of the presence or absence of trees is complex.

TREES AS STRATEGIES

First we should examine the ecological nature of trees. Trees and other woody plants are thin veneers of living tissue stretched thin over a skeleton of (mostly non-living) wood, slowly accumulated as each year of growth proceeds. This structure allows a single individual plant to place its light interception apparatus (leaves) "first in line" to receive direct sunlight over a much larger area than can be managed by individual plants beginning each year from seed (annual species) or even those perennials that start anew each season from a buds borne at or below ground level. Being "first in line" to receive sunlight is important for maximizing sequestration of input energy that can be used during a long life and to maximize reproductive effort. This approach is one "strategy" that living things may possess to advance the likelihood of their continued existence. The overarching leaf canopy of a tree is usually matched by a similar underground extension of roots, and by the influence of fallen leaves or needles on the ground surface below.

WESTERN FORESTS VERSUS EASTERN FORESTS

Environments of much of the western U.S. including Colorado are continental – that is high and comparatively dry (Bassman et al. 2003). The high precipitation that accompanies forests of the eastern U.S. (and Europe) is not matched here, though the highest elevation (subalpine) forest are typically provided with somewhat higher moisture input, mostly during winter as snow. For purposes of the remainder of this discussion, attention will be directed to forests of zones below subalpine, except as specifically noted. Besides increased exposure to moisture stress, plants occupying the mountain and plateau environments of Colorado are more vulnerable to recurring fire than would be the case in moister landscapes. The recurrence of fire in western landscapes has been extensively investigated and documented (Weaver 1951, Arno 1980, Gruel 1985, Veblen 1986a,b). Fire recurrence intervals as low as 5 yrs in the lower elevation forests and woodlands have been documented (Peet 1988). Given the dryness and susceptibility to fire, Colorado mountain environments have often been dominated by herbaceous species and stump-sprouting woody plants. When afforded protection from fire as has been the case since early in the 20th century, tree cover can displace the herbaceous cover. This displacement is especially likely when that herbaceous cover has been weakened by improvidently high intensities of grazing by domestic livestock, as occurred especially during the late 19th and early 20th centuries over large areas . As a result, herbaceous cover in open areas that could have carried fires and competed with tree seedlings for moisture was greatly diminished (Peet 1988).

At middle elevations in mountainous areas, precipitation is sufficient to support tree growth and when provided with protection from fire (a more extensive phenomenon in these dry environments) tree growth can coalesce into continuous cover, at least temporarily. But trees are not the only well-adapted lifeform here. Smaller woody plants (shrubs, subshrubs) as well as perennial herbs (forbs and grasses/ grass-likes) are also variously positioned by their ecological adaptations to survival under dry conditions. Grasses especially are possessed of the ability to go beyond mere survival and actually dominate landscapes to the same degree that trees (once established) can and do worldwide by virtue of their bulk (see above). Hence many western mountain lands can enter, and persist in, a grass-dominated condition for short, medium and even long periods. Beyond the capacity of grasses to tolerate recurring fire, their sheer competitive strength can greatly slow or exclude tree reproduction for long periods. Many of the Colorado mid-elevation mountain environments that are presently so heavily occupied by tree cover have in the past been occupied for long periods by mixtures of grasses, shrubs, forbs and scattered trees.

ENVIRONMENTAL EFFECTS OF TREE OUTBREAKS

The title of this section is facetious, yet from the standpoint of non-tree lifeforms, the present dense cover of trees on many sites <u>can</u> be regarded as "an outbreak." Where closed or nearly closed conifer canopy is present, needle litter along with reduced light intensity (Moir 1966, Anderson et al. 1968) has profound influence on the ground surface. Organic acids leached from needles can adjust soil pH downward and aside from any direct sensitivities to soil pH that ground layer species may have, indirect effects of more acid conditions may add to the limitations on suitability of the site for other plant species. Of course the very direct effects of the physical layer of needle accumulation on keeping the mineral soil surface dark and cool are also part of cause of the easily observable sparseness of understory plants beneath closed conifer forest canopies in Colorado forests.

Colorado lodgepole pine forests as of 2008 are those experiencing the most widespread devastation by insects. These forests are well known, one might even say, notorious for low understory plant diversity. A typical lodgepole pine forest stand with closed or nearly closed canopy will have in addition to the trees, an extensive carpet of needle litter with scattered Canada buffaloberry (*Shepherdia canadensis*) and occasionally common juniper (*Juniperus communis*) and /or Scouler willow (*Salix scouleriana*). Herbaceous plants are often totally absent, though very scattered elk sedge (*Carex geyeri*), goldenweed (*Oreochrysum parryi*), or (at higher elevation) broom huckleberry (*Vaccinium scoparium*) may be present. These shade-tolerant species are important reference points in the classifications of lodgepole pine habitat types (see for example Hess and Alexander 1986) and although other plant species are variably present, that presence is almost always very limited in abundance.

Forest habitat types of Colorado and other environments of the western U.S. have been discussed as to their permanence before. The status of particular forest types as “climax” or “successional” has been frequently and oft-times inconclusively debated over many years (Clements 1910, Mason 1915, Moir 1969). Whether or not a particular species is persistent and self-replacing under climatic uniformity is irrelevant to the issue here. Either way, the long life of trees and their large size do mean that the influence they wield on these ecosystems is heavy.

From the standpoint of plant species diversity, the presence of a heavy tree cover is a mixed blessing (Peet 1978). The deep shading and heavy needle litter input definitely diminish the extent of cover by understory plant species, especially on the poorer soils. When at least small openings are included in the stand, the continued minimal presence of various species may be facilitated. However, if in addition to species richness of understory species, the abundance of those species is considered, the development of heavy forest cover is an overall net negative influence on vascular plant species diversity. Tree-covered sites, in the absence of fire or other agents of massive disturbance, can linger in a more or less similar configuration for long periods, attracting the appellation “climax.” But from a “species / lifeform diversity” point of view, a condition with few trees may be far more desirable. One of the striking aspects of most burned forest sites within the first three to five years is the diversity and abundance of species whose presence was extremely limited or even (apparently) non-existent in the pre-fire vegetation.

In the years immediately following death of forest trees killed by mountain pine beetle, direct sunlight will reach the ground, but the ground will have heavy needle litter still in place. Incidence of direct sunlight on the ground surface, increased early season warmth, cessation of input of fresh needle litter, and increased soil moisture due to reduced canopy interception will occur. These changes will allow, over a period of years, the (re)development of plant species that have been abundant between outbreaks of tree growth but which had been minimized under the heavy tree canopy.

EFFECTS ON ANIMALS

Both vertebrate and invertebrate animals will experience changed conditions with the demise of the live tree cover. To the extent that newly invigorated herbaceous and shrubby plant species provide food and cover for certain animal species, they will find that the upsurge in abundance of lower stature plants allows them to exist in greater number (see e.g. Villa-Castillo and Wagner 2002). Standing dead trees will continue to provide structure for invertebrates (e.g. secondary beetles, spiders, carpenter ants) and the vertebrates that seek them as food (e.g. downy and three-toed woodpeckers).

A PROBLEM OF PERCEPTION

Public perception of the well-being of western forest lands needs to incorporate an appreciation of the existence of adaptation to, and dependence on, environmental change in long-term maintenance of biodiversity on these landscapes. This need to incorporate an understanding of the dynamic nature of vegetation (and of other ecosystem components including climate and animals) is equally as important to the decision-making / opinion-forming public as it is to scientists charged with conducting meaningful and useful inquiries into the status of natural systems.

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THE APPLICATION OF ECOLOGICAL PRINCIPLES TO ACCELERATE RECLAMATION OF WELL PAD SITES

Joshua D. Eldridge[1] and Edward F. Redente[1,2]

[1]Colorado State University
Department of Forest, Rangeland and Watershed Stewardship
Fort Collins, CO 80523

and

[2]MWH, Inc.
1825 Sharp Point Drive, Suite 118
Fort Collins, CO 80525

ABSTRACT

Western Colorado is experiencing a boom in natural gas development. The problem is the arid ecosystems of this area have difficulty recovering from the disturbance. The purpose of this study is to improve reclamation techniques of natural gas well pads on the Western Slope of Colorado to enable the establishment of viable native plant populations. The study examines the effects and interactions of seedbed preparation, soil amendments, seed mixtures, and seeding methods. The experiment was conducted in pinyon-juniper and sagebrush-greasewood plant communities on five natural gas well pads near Parachute, Colorado. Plant cover data were collected to access the effectiveness of 16 different treatment combinations. The data was analyzed by using a generalized linear mixed model. After one year of plant growth, the data show that the use of native annuals in seed mixtures improves the cover of native seeded species and helps reduce the cover of non-native plant species. The combination of using native annuals in the seed mix, wood chips as a soil amendment, and rough tillage by creating micro-catchments, significantly increased native seeded species cover and reduced non-native species cover when compared to a seed mix with only perennial species, no wood chip amendment, and smooth tillage treatments. These reclamation techniques are intended to repair damaged ecological processes and help guide the trajectory of natural plant succession toward a more desired plant community.

INTRODUCTION

Natural gas exploration and extraction has experienced a flurry of development in Western Colorado in recent years. This increase in natural gas extraction impacts the plant communities and wildlife habitats in these areas. The construction activities associated with well pads, access roads, and pipeline right-of-ways remove existing vegetation and fragments wildlife habitat. The Colorado Oil and Gas Conservation Commission requires that natural gas pads on private and state land be reclaimed within 3-12 months after drilling operations have ceased and that the vegetation composition consist of species that are consistent with the surrounding plant community (COGCC, 2006). The Bureau of Land Management (BLM) regulates its public lands in much the same way (WORG, 2006). These guidelines were established to mitigate the impacts of the oil and gas development on the natural environment, including air and water resources.

Natural gas development creates disturbances that will require the reclamation of both physical and biological processes. The creation of well pads for natural gas extraction involves the removal of the existing vegetation cover and the leveling of the landscape on approximately two acres. Activities related to drilling result in soil compaction and the introduction of drilling related chemicals to the sites. In Garfield County in Western Colorado, most of the areas around the well pads have large amounts of introduced and noxious weeds like cheatgrass (*Anisantha tectorum (L.) Nevski)*. The interaction of disturbance and weedy species produces an environment where successful reclamation is more challenging. The objective of this research is to identify successful reclamation strategies for natural gas development on the Western Slope of Colorado.

The process of degradation on arid rangelands can be described by four steps: the first is a change in the age structure of plant populations, the second is a decrease in rangeland diversity and productivity, the third is the reduction of perennial plant cover and finally, vegetation is completely lost, erosion is accelerated, and the soil is salinized (Milton et al. 1994). As an area regresses into the later stages of this model, it requires more energy inputs for recovery to occur. Once an area regresses to step three it is unlikely that natural recovery can occur unless the physical environment is improved before animal and plant assemblages can be restored. The physical environment must be improved by controlling erosion, increasing water infiltration, improving water holding capacity of the soil, protecting the soil surface from temperature extremes, ameliorating salinization, and creating microsites suitable for the establishment of perennial plants (Milton et al. 1994). Modifying the physical environment will help support a successional trajectory towards the desired plant community.

Successful land reclamation following well pad creation is needed to repair damaged ecological processes and to revegetate disturbed areas to reestablish lost ecological services. Often times this is done simply by seeding with perennial species; an approach that is often unsuccessful. There is a new paradigm that is receiving attention among reclamation practitioners that treats the causes of plant invasion, establishes plant communities that can resist invasion, and maintains proper ecosystem function. This new paradigm is based on the growing knowledge of plant succession and community assembly and is referred to as successional management or assisted succession (Cox and Anderson 2004; Sheley and Krueger-Mangold 2003; Krueger-Mangold et al. 2006).

Successional management is based on the concept that restoration must be founded on ecological principles that are universal and not just site specific prescriptions (Sheley and Krueger-Mangold 2003). The objective of successional management is to understand and manipulate the factors that modify successional processes to favor desired species. Ultimately, the goal is to direct existing plant communities containing undesirable species toward a more desirable plant community (Sheley and Krueger-Mangold 2003). Successional management is linked to three causes of succession: site availability, species availability, and species performance (Pickett et al. 1987; Cox and Anderson 2004). These causes can be divided into two levels: the processes and components associated with each cause and then the factors that can modify each of the causes of succession.

The processes and components are: disturbance, dispersal, propagule supply, available resources, ecophysiology, life history, stress, and interference (Sheley and Krueger-Mangold 2003; Krueger-Mangold et al. 2006). The modifying factors of the causes of succession are varied and cover a broad range of subjects. Examples include: size and severity of disturbance, dispersal mechanisms and landscape features, land use, climate, soil resources, competition, and herbivory (Sheley and Krueger-Mangold 2003; Krueger-Mangold et al. 2006). The following text describes the ecological processes and the modifying factors that this research has focused. The ecological processes are seed dispersal, resource supply, environmental stress, and interference. The modifying factors are seedbed preparation, soil impoverishment, seed mixtures, and cover crops.

Seed Dispersal and Seedbed Preparation

Seedbed preparation is a critical component to successful reclamation and relates to site and species availability. It not only creates a more favorable growing medium, but it can be modified to create safe-sites for seedling establishment. It is through the use of different seedbed preparation techniques that land managers can modify sites to improve the effectiveness of trapping and retaining seeds (Chambers 2000). In addition to trapping seeds, seedbeds with depressions on the soil surface capture and retain moisture and provide more favorable soil surface temperatures than a smooth soil surface (Chambers 2000; Call and Roundy 1991). Proper seedbed preparation can improve hydrologic cycles, seed retention, and seedling establishment and can also increase niche availability and species performance (Call and Roundy 1991; Chambers 2000; Cox and Anderson 2004).

Resource Supply and Soil Impoverishment

The amount of available resources in the soil can have a significant influence on the species that become established. Weeds are typically adapted to disturbance, initiate growth early, grow rapidly, produce abundant seed, and allocate little carbon (C) to root exudates or maintenance of the microbial community in the rhizosphere (Paschke et al. 2000; Blumenthal et al. 2003). This strategy relies upon high soil resources being available. Therefore weeds compete well in high nitrogen (N) environments and are less competitive in low N environments (Blumenthal et al. 2003). This has led to many studies where C amendments have been used to reduce the amount of available N in the soil with the purpose to impede weed invasion or survival and increase the rate of succession in old-field and rangeland systems (Paschke et al. 2000; Blumenthal et al. 2003; Herron et al. 2001; Baer et al. 2004; Reever Morghan and Seastedt 1999). These studies demonstrate that the addition of C lowers available N and creates an advantage for late-seral native species because they are adapted to surviving in low nutrient environments (Paschke et al. 2000; Blumenthal et al. 2003; Herron et al. 2001; Baer et al. 2004). While agricultural systems may add N fertilizer to increase crop yield, in natural systems high levels of available N usually benefit the annual weedy species more than the desired perennial species.

Environmental Stress and Species-Rich Seed Mixtures

Environmental conditions can vary from site to site and year to year. This creates stress on established and invading plants. Using a species-rich seed mixture that includes different functional guilds is likely to have ample emergence and prevent invasive species of the same functional guild (Fargione et al. 2003; Sheley and Half 2006; Pokorny et al. 2005). The niche trade off model predicts that resident species will most strongly inhibit establishment and growth of species that are similar to them (Fargione et al. 2003). Therefore, the more functional guilds included in the seed mix or plant community, the less likely it is to be invaded by plants of the same functional guilds. In addition, seed mixes that have high species richness are more likely to have at least one or two species that have germination requirements that meet the current site conditions (Sheley and Half 2006). There is also evidence that would suggest that species mixtures with high functional diversity use available resources more completely, thus decreasing invasion potential because of less available resources (Pokorny et al. 2005; Pyke and Archer 1991).

Interference and Cover Crops

The use of cover crops has a long history in agriculture (Hartwig and Ammon 2002), but only in recent times has it been discussed for use in the reclamation of wildlands (Pyke and Archer 1991). Cover crops help reduce erosion, provide organic matter, and interfere with invasive species by occupying resources (Hartwig and Ammon 2002). Pyke and Archer (1991) suggest using legumes for cover crops because they can help establish a viable N cycle. It should be noted that legumes do not usually fix abundant amounts of N to the point where it would facilitate invasive species establishment (Hartwig and Ammon 2002). One purpose for cover crops in restoration is to occupy space until desired species can become established

Site Description

Parachute (39°27’07”N 108°03’08”W) is located on the western slope of Colorado in the Grand Valley at an elevation of 1551 m above sea level. The town of Parachute sits in the valley bottom near the confluence of Parachute Creek and the Colorado River. The Roan cliffs and Battlement Mesa highlight the surrounding area, which extend 900 m above the valley floor. Based on the data available from the Rifle, CO weather station (NCDC Coop # 057031), this area receives approximately 300 mm of precipitation a year with an even distribution of precipitation throughout the year when averaged over decades (WRCC, 2007). However, the month to month variability is very high when examining data from any single year.

The plant community in the valley bottom has largely been converted to cropland, but what native plant community remains is a sagebrush-greasewood dominated system. The sagebrush-greasewood community type transitions into a pinyon pine-juniper community as elevation increases, followed by a mixed mountain shrub community near the top of the plateau. The pinyon-juniper and sagebrush-greasewood plant communities are the community types where our research is located.

There are five well pad locations for this study. Three are in the sagebrush-greasewood community and two in the pinyon-juniper community. The well pads vary in size from 0.47 ha to 0.78 ha. They also vary in elevation from 1609 m to 1789 m. The well pads are located in three different gas fields: two in the West Rulison field, two in the Parachute field, and one in the Grand Valley field. The distance across these fields is approximately 19 km.

METHODS

This research attempts to integrate the aforementioned ecological processes and modifying factors into techniques that can be applied to the reclamation of natural gas well pads. The study of reclamation should not be separated into the different stages of reclamation, i.e. seedbed preparation, soil amendments, seeding method, etc., because in practice these are all performed together for the purpose of successful revegetation. We are interested in how the different practices of reclamation interact and affect the final outcome. Therefore, we compare four reclamation practices: tillage, soil amendments, seed mixes, and seeding method. Each of these independent variables has two different treatment levels. These treatments are described below.

A randomized block split-split plot design was used to test the interactions of the independent variables. This was used to allow a balanced design that is practical in application and can isolate variability across well pads. This research uses a 2 x 2 x 2 x 2 design that results in 16 different treatment combinations. There are three replicates for each treatment at each well pad. Therefore, each well pad has 48 sub-plots for a total of 240 sub-plots across all five well pads. Each of the 16 treatments has 15 total replicates. The sub-plot dimensions are 6 x 12m. There are eight sub-plots to a whole plot, making the whole plot dimensions 25 x 27m. This includes a one meter buffer strip between the sub-plots. Fertilization and mulching were applied across all plots. The following describes the four independent variables that make up the 16 different treatment combinations.

Tillage Treatments

There are two tillage treatments that are being tested in this experiment, one that has a rough soil surface with micro-catchments and one that is a smooth soil surface. There are four micro-catchments in each sub-plot, one every 18 m^2. The soil surface in between the micro-catchments is rougher than the smooth soil treatment. The orientation of the micro-catchments is perpendicular to the prevailing wind direction on flat surfaces and perpendicular to the slope on steeper surfaces. The final dimensions of the catchments are approximately 183 cm long x 91 cm wide x 25 cm deep. This does not include the pile of soil that is placed on the windward or downhill side of the catchments. The purpose of micro-catchments is to improve water capture and provide more safe sites for seedlings. The smooth soil surface had as little surface relief as possible before seeding. The purpose of these two treatments is to compare the effects of different seedbed preparation methods and how soil surface roughness might affect seedling establishment in this semi-arid region.

Soil Amendments

There are two soil amendment treatments for this experiment: wood chips versus no wood chips. An application rate equal to 90 Mg of wood chips per hectare was applied to half of the sub-plots on all well pads. The wood chips were incorporated into the top 15 cm of the soil. The incorporation of the wood chips is intended to improve infiltration, increase soil moisture capacity, and increase the organic matter content of the soil.

Seeding Methods

The seeding method treatments consist of two different broadcast methods. These methods include island broadcasting and traditional broadcasting. Island broadcasting is a method that separates the forb and shrub species from the grass species in the seed mix. The forbs and shrubs are then broadcast in vegetative islands with the interspaces seeded with grasses. On the rough tillage plots the forb and shrub mix was broadcast over and around the micro-catchments. On the smooth tillage plots the shrub and forb mix was broadcast in approximately the same spatial locations as the micro-catchments. This is designed to more closely mimic the surrounding landscape structure and possibly give shrubs and forbs a better chance for survival since competition with grasses is reduced. The traditional broadcast method had all plant life forms combined in one seed mix and broadcast homogenously over the entire plot.

Seed Mixes

There are two different seed mixes tested in this experiment, one seed mix contains only native perennials and the other contains native perennials and annuals. Traditionally, reclamation seed mixes have included only perennial species. However, the use of native annuals may be able to compete better against the exotic annual weeds that are problematic in this area.

Data Collection

Plant cover was collected in July 2007. Plant cover was estimated using the point intercept method along line-transects. Data collection included live cover by species, bare ground, litter, or rock. We estimated aerial cover for these plots, so any plant part from current year's growth that intercepted the line was recorded as an intercept. From the data, we calculated total percent cover, percent cover of desired species and invasive species, species richness and frequency, among others. Plant cover data were also collected from the surrounding undisturbed area for comparison against the treatment combinations. A series of random coordinates were generated for three 100 m line-transects at each well pad location. The data from the undisturbed areas was analyzed with the same methods as the data from the treatment sub-plots.

Data Analysis

All data that was not bare ground, rock or litter was grouped into four classes: native seeded, native volunteers, non-natives, and non-native noxious. These classes were then added together to create a fifth class of total plant cover. The distributions and variances of the data for the five dependent variables (native seeded, native volunteers, non-natives, non-native noxious, and total seeded cover) were not normally distributed nor did they have homogenous variances. No transformation corrected the distribution or variances. In order to account for the non-normal distributions and unequal variances of data, a generalized linear mixed model, known as GLIMMIX, was used in the statistical software SAS (SAS Institute 2006). This procedure functions as a hybrid of a generalized linear model and a mixed model allowing us to fit statistical models to data with unequal variances and non-normal distributions.

There are four independent variables and five dependent variables for this analysis. The independent variables each have two levels: tillage treatment is separated by rough and smooth seedbed treatment; soil amendment treatment is separated by the presence of wood chips or the lack of wood chips; seed mix is separated by annual plus perennial species seed mix and only perennial species seed mix; and seeding method is distinguished by broadcast seeding or island broadcast seeding. The dependent variables are: native seeded, native volunteers, non-natives, non-native noxious, and total seeded cover. Each of the dependent variables was analyzed to determine which of the independent variables or interaction of variables had significant effects.

RESULTS and DISCUSSION

Native Seeded Cover

Across all treatments native seeded cover averaged 3.9 percent with a standard deviation of 5.3 and ranged from 0 to 31 percent. The native seeded cover consists of all the species that were seeded on the plots. The most successful shrub, forb, and grass species were: fourwing saltbush (*Atriplex canescens*), Rocky Mountain bee plant (*Cleome serrulata*), and western wheatgrass (*Pascopyrum smithii var. Ariba*). There were two independent variables that had significant effects on the native seeded cover. These are the seed mix and the three-way interaction of tillage, wood chips, and seed mix.

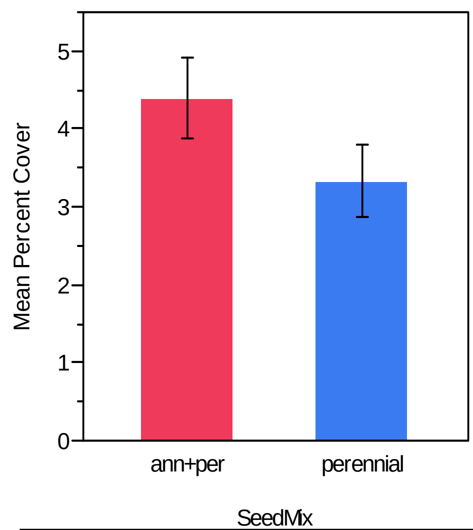

Figure 1. The effect of seed mix on native seeded cover (mean ± 1 SE).

Figure 1 shows the mean native seeded cover and the effect that the annual plus perennial seed mix has on the native seeded cover when compared to the perennial seed mix. The use of native annuals improved the mean native seeded cover. This is the single one-way interaction that appears to be significant after one growing season.

Newman and Redente (2001) found seed mixture to be the only single main effect when comparing multiple reclamation cultural practices in northwest Colorado over the long-term. They also determined that the initial reclamation practice influences the plant community development over time. In regards to the low percent cover of the native seeded species, Doerr et al. (1983) found that it takes native species 4 to 5 growing seasons before they reach their production potential on semi-arid sites.

Figure 2 shows the three-way interaction between tillage, wood chips and seed mix. In this figure it appears that the rough tillage increases the mean native seeded cover, however this did not prove to be statistically significant. Although, within the rough treatment the annual seed mix produced a consistent and significant pattern, in which the mean native seeded cover was higher than the perennial seed mix. This pattern is also seen when examining the no-wood chip treatments.

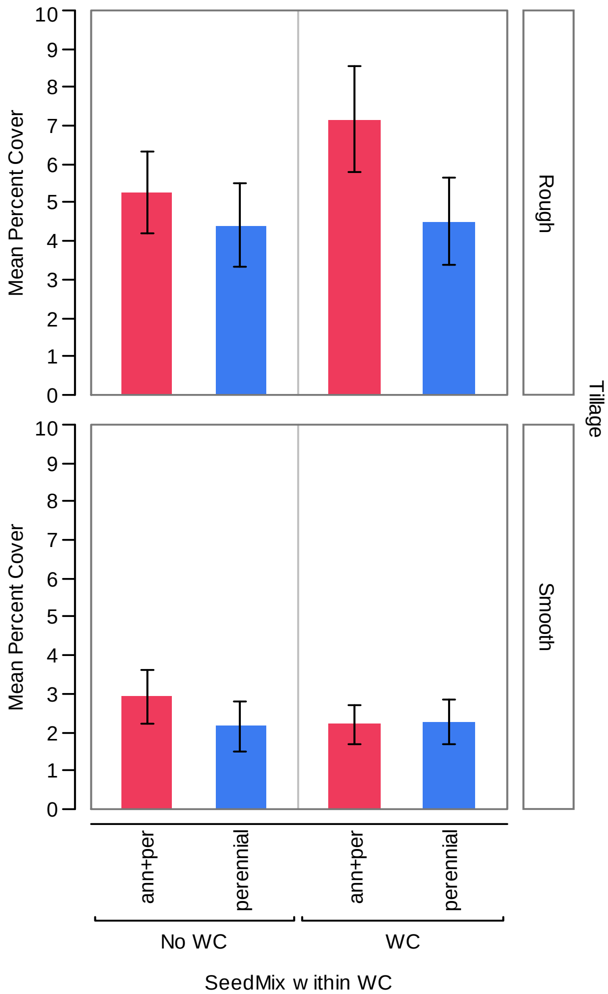

Figure 2. The effects of seed mix, wood chips and tillage on native seeded cover (mean ± 1 SE).

The rough tillage likely maintained better moisture conditions and provided more safe sites for seed germination (Smith and Capelle 1992) than the smooth soil surface (Winkle et al.1991). The addition of wood chips and the subsequent change in nutrient availability do not appear to negatively affect the native seeded species (Eschen et al. 2007). This will hopefully allow more native late seral species to become established over time since the reduction of N does not greatly reduce the native seeded species. The use of annual species increased native seeded cover in all treatment combinations except the smooth tillage and wood chip combination. This is most likely due to the disadvantages that the smooth soil surface has for seedling establishment. The annual and perennial seed mix with rough tillage and wood chips showed the most significant growth of native species.

Non-Native Cover

Across all treatments, non-native cover averaged 24.5 percent with a standard deviation of 23.8 and ranged from 0 to 78 percent. Non-native cover consists of all non-native plant species that are not noxious weeds. The three most prevalent species were: Russian thistle (*Salsola iberica L.*), common wheat ((*Triticum aestivum L.*) from the mulch), and lambsquarter (*Chenopodium album L.*). There was one two-way and one three-way interaction within this dependent variable that had significant effects. The interaction of wood chips and seed mix showed a significant decrease on non-native species. The three-way interaction of wood chips, seed mix and tillage also showed a significant decrease in non-native species. Because of the similarities of these two main effects only the three-way interaction will be discussed.

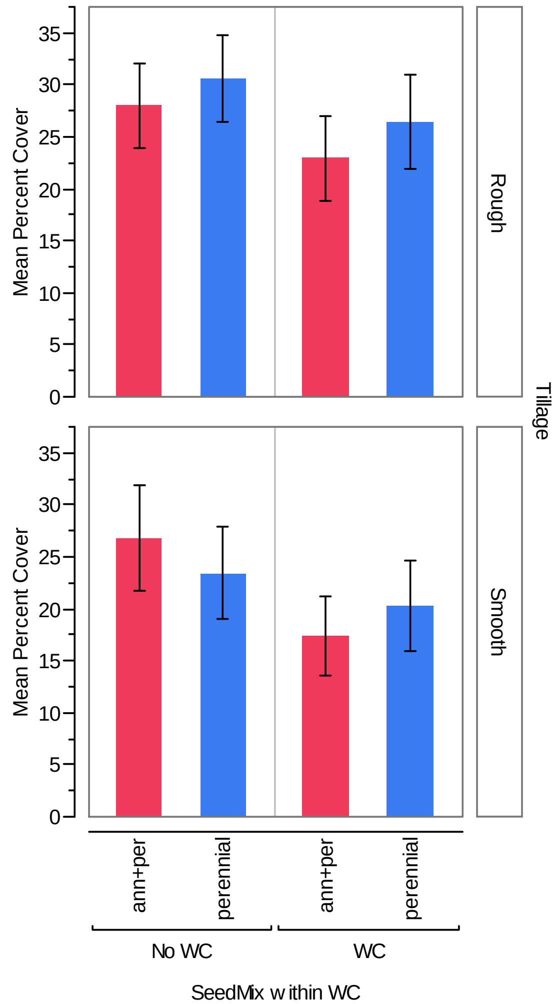

Figure 3. The effects of Seed mix, wood chips, and tillage on non-native plant cover (mean ± 1 SE).

Figure 3 shows the non-native plant response to the interaction between tillage, wood chips and seed mix. The annual seed mix decreases the mean non-native plant cover when compared to the perennial seed mix. The only place this pattern does not appear is in the no-wood chip, smooth tillage treatment combination. Once again the rough tillage treatment increases plant cover when compared to the smooth tillage treatment. The addition of wood chips also appears to decrease the mean non-native plant cover compared to the no-wood chip plots, but this treatment alone was not significant. The two-way interaction of seed mix and wood chips is apparently driving this three-way interaction.

It was expected that the addition of wood chips would result in reduced plant growth (Blumenthal et al. 2003). This result is also expected because the most abundant non-native species was Russian thistle and Redente et al. (1992) found that Russian thistle was significantly reduced at low levels of available N. The annual and perennial seed mix showed a greater reduction of non-natives than the perennial species seed mix. The most abundant natives and non-natives were annual forbs. This supports the niche tradeoff model that predicts that resident species will most strongly inhibit the establishment and growth of species similar to them (Fargione et al. 2003). The interaction between wood chips and native annuals appears to be favoring native species by reducing non-native plant growth and by interfering with non-native annual forb establishment.

Non-Native Noxious Cover

Across all treatments, non-native noxious plant cover averaged 0.2 percent cover with a standard deviation of 0.55 and ranged from 0 to 4 percent. The category for non-native noxious consists of non-native plant species that are on the Colorado state noxious weeds list. There were four plants that comprised this category. They are cheatgrass (*Anisantha tectorum (L.) Nevski),* halogeton *(Halogeton glomeratus (Bieb.) C.A. Mey.),* redstem storkbill *(Erodium cicutarium (L.) L'Hér.),* and field bindweed (*Convolvulus arvensis L.)* There were no treatment effects that made a significant difference on noxious weed presence. This is a result of the very low occurrence of noxious weeds on the plots.

Total Plant Cover

Across all treatments total plant cover averaged 30.2 percent cover with a standard deviation of 24.4 and ranged from 0 to 83 percent. Total plant cover consists of all of the previous cover classes, including native volunteers. There is just one significant interaction presented in this cover class. It is the three-way interaction between tillage, wood chips, and seed mix.

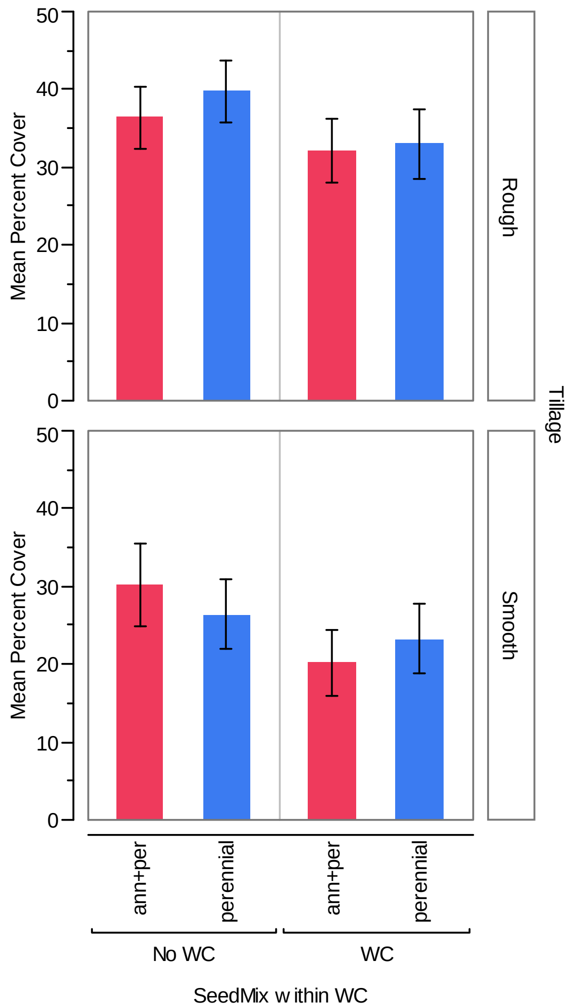

Figure 4. The effect of tillage, wood chips, and seed mix on total plant cover (mean ± 1 SE).

Figure 4 shows how the combination of tillage, wood chips and seed mix affects total plant cover. In this graph, the rough tillage treatment has a higher total cover than the smooth tillage treatment. The rough tillage treatment also appears to diminish the effect of the wood chips in reducing plant cover. The smooth tillage treatment has lower total plant cover and there is a more obvious effect of wood chips in reducing plant cover. With the smooth tillage treatment, the annual plus perennial seed mix increased total plant cover when there are no wood chips used, but decreased total cover with wood chips.

This pattern closely mimics the response of non-native plants with this treatment combination. In other words, the annual plus perennial seed mix, when used in combination with rough tillage and wood chips, significantly reduced non-native species. This response carries over to the total plant cover. This treatment combination was significant for the native seeded species and non-native species and Figure 4 shows the combined effect of those cover classes. This treatment combination resulted in higher plant cover for the natives and lower plant cover for the non-natives.

The key component of Figure 4 is the reduction of non-natives and the increase of natives when the annual and perennial seed mix, wood chips and rough tillage are used. The wood chips affect the nutrient availability which reduces the non-natives, namely Russian thistle (Blumenthal et al. 2003; Redente et al. 1992). The native annuals also appear to interfere with the non-natives because the non-native cover is reduced when the annual plus perennial seed mix is used (Fargione et al. 2003). Over time the increased cover of the native annuals will hopefully facilitate the establishment and production of perennial species by providing shading from the extreme temperatures that occur during the growing season (Francisco et al. 2005). The effect of rough tillage appears to benefit all plants regardless of nativity. This form of tillage may be necessary to improve the plant cover on well pads, but other cultural practices, i.e. C source addition and native annuals in seed mixtures may be necessary to limit the establishment of non-native species.

The effect of both wood chips and tillage is apparent in the previous graphs but they were not significant as a single main effect. This is most likely a result of the experimental design. In order to efficiently install the plots, the tillage and wood chip treatments were split whole plots rather than random sub-plots. This reduced the statistical power for these treatments.

SUMMARY

After only one growing season it is difficult to draw many conclusions or recommendations for changing reclamation strategies. It will take several more years to determine if the treatment effects that we are seeing are still effective when given more time. Newman and Redente (2001) found that initial reclamation practices can have a long-term influence on plant community development over time. So if these trends remain constant over the next growing season it may be possible that over time we will create an autogenic, native plant community that will meet state and federal reclamation requirements and improve the landscape in the gas fields of the Western Slope of Colorado.

At this point in time, this research shows that the use of native annuals in seed mixes has potential benefit in improving reclamation success. The use of native annuals significantly increased the native seeded cover and decreased non-native plant establishment. One could infer that the native annuals are interfering with the establishment of the non-native annual species. By using species that interfere with the non-natives there is potential that the native perennials can become established and eventually replace the native annuals and return to the desired plant community.

The incorporation of wood chips into the rooting zone also seemed to work to the favor of the native seeded species. The wood chip addition should increase the C:N ratio in the soil, thus affecting nutrient availability. This benefited native species as evidenced by a nine percent increase in plant cover when wood chips were added. All other plant cover classes decreased in the presence of wood chips. The secondary benefits of the wood chips (e.g.. increased organic matter, improved infiltration rates, and increase water holding capacity of the soil) should begin to show in subsequent years as the plants begin to increase in biomass. These improved soil qualities will create more favorable growing conditions for the plants that are able to become established. Aboveground biomass will be collected during the second growing season and will reveal if wood chip addition is influencing plant growth as anticipated.

The rough tillage treatment was the final treatment that appeared to have a positive impact on plant cover. This tillage practice increased cover for all plant classes compared to the smooth tillage treatment. The creation of the micro-catchments provided more safe sites for seedlings and provided some shade to reduce temperature extremes. The catchment basins also captured more moisture and organic matter than the smooth soil surface. The creation of the micro-catchments was not difficult and this practice may prove to be the most beneficial treatment in improving plant cover in our study.

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BIOSOLIDS USE FOR RECLAIMING FLUVIAL MINE TAILINGS

C.L. Freeman[1], J.A. Ippolito[2], M.E. Stromberger[1], K.A. Barbarick[1], and E.F. Redente[3,4]

[1]Department of Soil and Crop Sciences
C-127 Plant Sciences Building
Colorado State University
Fort Collins, CO 80523-1170

[2]USDA-ARS Northwest Irrigation and Soils Research Laboratory
3793 N. 3600 E.
Kimberly, ID 83341

[3]Department of Forest, Rangeland and Watershed Stewardship
Colorado State University
Fort Collins, CO 80523-1472

[4]MWH Americas, Inc.
1825 Sharp Point Drive, Suite 118
Fort Collins, CO 80525

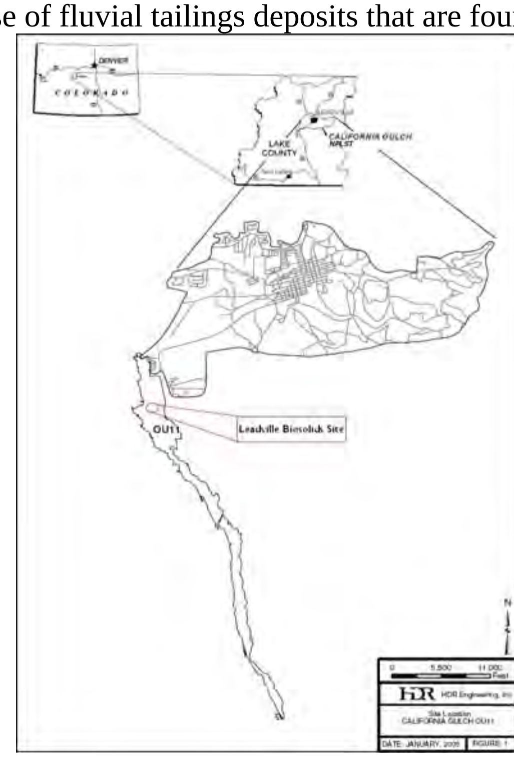
ABSTRACT

This study was conducted to determine the effect of biosolids and lime on reclamation of a heavily contaminated metal site. Within the Superfund area near Leadville, CO, biosolids and lime were amended (1998) to a 1 ha site at rates of 240 Mg ha^{-1} each. In 2006, soil samples were collected on a 10 m x 10 m grid to a depth of 30 cm across the site. Basic soil analysis included pH, EC, total C and N, inorganic and organic C, and NO_3-N and NH_4-N. A sequential fractionation for metal contaminants of concern (Cd, Cr, Fe, Pb, Mn, and Zn) identified associations with: 1) soluble/exchangeable; 2) specifically sorbed/weakly bound; 3) non-crystalline Fe/Mn oxides; 4) crystalline Fe/Mn oxides and organically complexed; 5) residual organic; and 6) residual inorganic phases. Sequential extraction data was cross correlated with basic soil analysis. Basic soil analysis were affected by both lime and biosolids applications. Cadmium was found primarily in mobile phases, Cu, Fe, Pb, and Mn in more resistant phases, and Zn distributed equally among all soil fractions. Metals were negatively correlated with basic soil analysis. The greatest mobile-phase metal concentrations were observed at the site's south end. This may have been due to a lack of uniformly applied or incorporated biosolids, or not enough lime applied to raise soil pH and complex metals in more immobile phases. If mobile phases were present over the entire site prior to reclamation, then a positive phase shift has occurred towards more immobile metal phases following reclamation.

INTRODUCTION

The Rocky Mountains in Colorado have a mining legacy ranging from gold to uranium. Several mines are still in operation today, yet most mines have been shut down or abandoned. The Colorado gold rush began in 1859 and during its history produced 45 million ounces of gold (Colorado Geological Survey, 2005). Silver was accidentally discovered in Leadville, CO while panning for gold. When recognized as silver ore, this find opened the prospect for other minerals to be mined in Leadville, including zinc and lead.

As a consequence of wide spread mining and smelting prior to regulation, extensive contamination has occurred in this region. A major area of contamination drains from California Gulch just east of Leadville, CO. Great quantities of wastes were released into this tributary in the form of metal sulfides, resulting in reaction between sulfides and the atmosphere, producing sulfuric acid. The primary source of this acid mine drainage originates from the Yak Tunnel, which is connected to 17 mines (U.S. Environmental Protection Agency, 2007a) just east of Leadville. Aside from acid drainage, the water contains elevated concentrations of dissolved metals such as iron, lead, zinc, manganese, and cadmium (U.S. Environmental Protection Agency, 2007a). The entire affected area spans 43 ha^2 (U.S. Environmental Protection Agency, 2007b) and includes Leadville, CO. This area was placed on the National Priorities List (NPL) of Superfund sites (the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)) in September 1983 and cleanup continues to this day. In 1994, the EPA divided the site into 11 geographically-based areas called operable units (U.S. Environmental Protection Agency Region 8, 2005). The Arkansas flood plain, or operable unit 11, has been included in the Superfund project because of fluvial tailings deposits that are found along the river.



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In an initial site assessment, Levy et al. (1992) found excessive total soil concentrations of copper, cadmium, iron, lead, manganese, and zinc within operable unit 11. Total metal concentrations ranged from 14 to 1200 mg Cu kg^{-1}, 3 to 110 mg Cd kg^{-1}, 16500 to 45200 mg Fe kg^{-1}, 46 to 49000 mg Pb kg^{-1}, 1740 to 8760 mg Mn kg^{-1}, and 44 to 12100 mg Zn kg^{-1}. Soil metal fractionation determined water extractable, exchangeable, organically bound, and oxide-bound. Cadmium, Pb, and Zn were all primarily found in the oxide fraction, while Cu was predominantly associated with the organic fraction (Levy et al., 1992). Metal transport, and subsequent environmental contamination within this system, occurred primarily as alluvial deposition.

Damaging mining effects on soil, either from direct mining deposits or indirect alluvial or aeolian deposition, have been observed over decades and centuries. Acidic mine drainage can decrease soil pH, solubilize metal contaminants, and potentially increase forage metal uptake. Soil factors that contribute the greatest extent in terms of metal bioavailability are pH, organic matter, clay content, surface charge density, soil solution composition, redox potential, rhizosphere interactions (Naidu et al., 2003), competition among metals, carbonates, chloride ions, and accumulation in plants (Adriano, 2001). Metal ions transported within mine drainage can rapidly interact with soil mineral and organic phases to form quasi-equilibrium with soil solution metal ions (Naidu et al., 2003), thus controlling metal solubility.

Among factors that influence metal availability, pH is the most widely utilized to improve the understanding of metal availability. Soil pH can be viewed as the master driver of all the other factors because it can affect the surface charge of layer silicate clays, OM, and oxides of Fe and Al (Adriano, 2001). It also influences precipitation-dissolution reactions, redox reactions, mobility and leaching, dispersion of colloids, and the eventual bioavailability of the metal ions (Adriano, 2001). As pH increases, a decrease in the mobility of cationic trace elements occurs, due primarily to the aforementioned soil reactions. Adriano et al. (2004) stated that the effect of pH values >6 in lowering free metal ion activities in soils can be attributed to the increase in pH-dependent surface charge on Fe, Al, and Mn oxides, chelation by organic matter, or precipitation of metal hydroxides. Metals can form both inorganic and organic complexes. With an increase in pH, the carboxyl, phenolic, alcoholic, and carbonyl functional groups in soil organic matter dissociate, thus increasing the affinity of ligand ions for metal cations (Adriano et al., 2004). Immobilization of metals predominantly occurs during precipitation in alkaline soils and in the presence of anions, especially when metal ion concentrations are high (Adriano, 2001).

Soil is one of the most important natural resources, and thus remediating mine land sites for ecosystem sustainability is essential. The soils natural “cleaning” action is primarily controlled by metal physico-chemical reactions with soil components carrying surface charge, and by soil microbial biochemical transformations (Bolan et al., 1999; Adriano, 2001; Bolan and Duraisamy, 2003). Remediation can be performed *ex-situ* or *in-situ*. *Ex-situ* remediation is carried out by contaminated soil extraction/removal with subsequent on- or off-site treatment.
Ex-situ treatment options consist of land treatment, thermal treatment, asphalt incorporation, solidification/stabilization, chemical extraction, and excavation (Sparks, 2003). *In-situ* remediation occurs on-site to stabilize contaminants, can be considered a more natural clean-up process, and in most cases is significantly less expensive than *ex-situ* remediation options. *In-situ* treatment options include volatilization, biodegradation, phytoremediation, leaching, vitrification, isolation, and passive remediation (Sparks, 2003).

Most *in-situ* techniques require amendments to help promote contaminant degradation/stabilization. Typical amendments, applied alone or in combination, include lime, manure, and fertilizers (nitrogen, phosphate, etc). Amendments accelerate natural processes such as metal sorption, precipitation, and other complexation reactions to reduce trace element mobility and bioavailability (Bolan and Duraisamy, 2003; Hartley et al., 2004; Pérez de Mora et al., 2005). Amendments can also enhance microbial activity, colonization and development of plant communities, essentially restarting soil nutrient cycling (Madejon et al., 2006).

Recently, biosolids or composted biosolids have become a more frequently used amendment complimenting the *in-situ* remediation process. Lime, in conjunction with biosolids, has been used to reduce the total acidity of acidic mine spoils and thus raise the pH at which the soil is buffered. Due to this pH increase, liming will increase the negative charge on oxides, clays, and organic matter effectively reducing the mobility of trace elements (Adriano, 2001). When limestone is used, supplied carbonate consumes excess protons from soil solution and exchange sites, thus raising pH. Essington (2004) also noted that protons consumed in the initial dissolution of $CaCO_3$ can be released during precipitation of exchangeable Al as gibbsite, and thus there is no net consumption of H^+. The initial buffering effect could be attributed to other metal contaminants when individual metal pH thresholds are met and solid phase precipitation begins.

Pérez de Mora et al. (2005) found composted biosolids application, at a rate of 100 Mg ha^{-1} on a fresh basis at 20-25% moisture content, to a heavy metal contaminated site was effective in significantly reducing metal solubility. This decrease in metal solubility was potentially the result of the organic amendment increasing soil organic matter content, enhancing soil fertility, structure, and water retention (Madejon et al., 2006). Composted biosolids was also effective in buffering soil pH (Pérez de Mora et al., 2005; Madejon et al., 2006), with buffering capacity controlled by non-humic and humic substance functional groups.

The Upper Arkansas River near Leadville, Colorado has been heavily affected by historic mining operations. Mine wastes were generally stockpiled or dumped directly into the river, resulting in fluvial mine tailings depositions along a 22-km stretch (Brown et al., 2005). These deposits are now considered for cleanup under the USEPA CERCLA National Priorities List. In 1998, Brown et al. (2005) incorporated municipal biosolids and agricultural limestone into the surface of alluvial mine tailings found within the Leadville, Colorado CERCLA area to restore ecosystem function. The research site provided an opportunity to study the long-term amendment effects on soil reclamation of fluvial mine tailings. The objective of this study was to identify and relate soil and plant spatial variability across the Leadville, CO site to reclamation success.

MATERIALS AND METHODS

The experimental site was located on the Smith ranch south of Leadville, Colorado, associated along the Arkansas flood plain in the California Gulch Superfund Site. In the summer of 1998, biosolids and lime were both applied at rates of 224 Mg ha^{-1} on a dry weight basis. Materials were mixed on a volume basis using a front-end loader before application (Brown et al., 2005). The amendments were surface-applied using a rear throw spreader with floatation tires and incorporated with a ripper to a depth of approximately 20 cm (Brown et al., 2005). Biosolids and lime were supplied from the Denver Metro Wastewater Facility and Calco Limestone Products (Salida, CO), respectively. The biosolids were anaerobically digested with a solids content of approximately 17% and met Class B criteria for pathogen reduction (Brown et al., 2005; USEPA, 1993).

During the fall of 2006 the site was grid-soil-sampled using 10 m x 10 m sampling coordinates (Fig. 1). South, West, and North sampling boundaries roughly followed the Arkansas River; the East boundary followed a North-South fence-line. Soils were collected to a depth of 30 cm at each grid point; a total of eighty eight soil cores were obtained. The two prominent soils on site were the Rosane loam 1-5% slopes and Newfork gravelly sandy loam, 1-3% slopes (USDA NRCS, 2007). All samples were placed in a cooler and transported to Colorado State University for analysis.

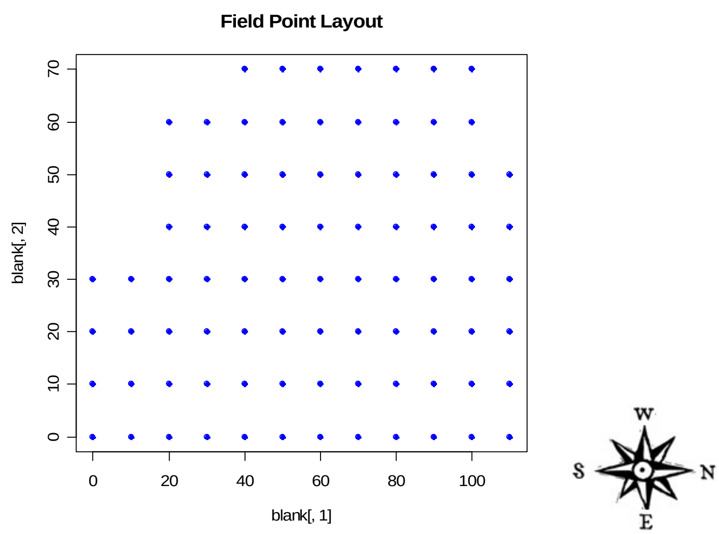

Figure 1. Field Grid-Point Sampling Lay-out.

Soil samples were immediately air-dried and ground to pass a 2mm sieve. Basic soil analysis consisted of pH and electrical conductivity (EC) measured using a saturated paste extract, total C and N determined using a LECO-1000 CHN auto-analyzer, inorganic C measured using a modified pressure-calcimeter method, NO_3-N and NH_4-N concentrations on 2 *M* KCl extracts, and organic C and N determined by subtracting inorganic C and N content from total C and N concentrations.

Most studies pertaining to soil heavy metal contamination focus on plant-available or total extractable metals. However, these studies are lacking a fundamental understanding of the potential transformations and ultimate fate of metals in the soil environment. To assess metal fate following reclamation, a six-step metal fractionation separated soils as follows: 1) soluble and exchangeable; 2) specifically sorbed and weakly bound; 3) non-crystalline Fe and Mn oxides (i.e. amorphous phases); 4) crystalline Fe/Mn oxides; 5) residual organic; and 6) residual inorganic (Sloan et al., 1997). The extraction scheme essentially utilizes increasingly harsher extractants to differentiate metal pools. Following each extraction step, all samples were centrifuged, the supernatant filtered through a 0.45μm membrane, and then analyzed using inductively coupled plasma-atomic emission spectroscopy.

Data were statistically analyzed using R version 2.5.0 (The R Foundation for Statistical Computing, 2007). Spatial autocorrelation and cross correlation statistics were used to characterize the site. Moran's I was employed for spatial autocorrelation, which provides a P-Value and a Moran's I number for both normal and randomization assumptions. Randomization was utilized since the data was assumed to not be normally distributed due to grid sampling. To be significantly spatially correlated we considered the two-sided p-value to be ≤ 0.1, while Moran's I identified either a positive or negative correlation with distance from sampling location. Contour maps were created using datasets that were significantly correlated, to show an overall trend surface across the site. Contour maps underestimate variability do to interpolation of the original data values. Bimoran's I was used for spatial cross correlation statistics between soil metals and basic soil characteristics, which provides a P-Value and a Moran's I number under the randomization assumption only. To be significantly spatially correlated we considered the two-sided p-value to be ≤ 0.1, while Moran's I identified either a positive or negative correlation with distance from sampling location.

RESULTS AND DISCUSSIONS

Spatial Autocorrelation

Basic Soil Characteristics

The pH contour map (Fig 2 (a)) illustrated the greatest pH through the middle of the site with lowest concentrations on the south. This could be a function of lime application. Electrical conductivity and inorganic nitrogen contour maps (Fig 2 (b) and (c)) showed greater conductivity and concentration on the north/east side of the site. This could also be a function of the lime application. Organic nitrogen and organic carbon contour maps (Fig 2 (d) and (f)) were variable across the site, potentially a function of biosolids application.

Cadmium

All six sequential extraction steps for cadmium had two-sided p-values of <0.10. Soluble and exchangeable, specifically sorbed/weakly bound, non-crystalline Fe/Mn oxides, crystalline Fe/Mn oxides & organically complexed, and residual organic all contained greater Cd concentrations on the site's southern portion (Fig 3 (a), (b), (c), (d), and (e)). Residual inorganic Cd (Fig 3 (f)) was opposite, with the greatest concentrations in north side soils. Overall, the greatest Cd concentrations were found in steps 1 and 2, or the soluble/exchangeable and specifically sorbed/weakly bound phases, phases which are plant available and potentially mobile in the soil. If these two relatively mobile phases were present in greater concentrations over the entire site prior to reclamation, then a positive phase shift has occurred towards more immobile Cd phases. Li et al. (2001) noted an increase in Cd sorption with increasing biosolids application, and upon removal of the soil organic phase, Cd sorption persisted. The authors attributed adsorption to the inorganic fraction provided by biosolids. Hettiarachchi et al. (2003) further showed reduced soil Cd adsorption by removing both the organic C and Fe/Mn fractions. Thus, the addition of biosolids containing appreciable quantities of Fe and Mn oxides could promote Cd sorption in a relatively immobile phase. Ippolito et al. (2007) noted biosolids applied at a site in Colorado contained elevated Fe concentrations due to waste stream $Fe_2(SO_4)_3$ addition for reducing digester H_2S production. Overall, the greater concentrations of mobile Cd phases observed at the south end of the site may have been due to a lack of uniformly applied or incorporated biosolids, or not enough biosolids/lime applied to raise soil pH and complex excess Cd in Fe/Mn oxide phases.

Copper

All six steps for copper had two-sided p-values of <0.10. Soluble/exchangeable Cu concentration was greater on the site's south/west side (Fig 4 (a)). Specifically sorbed/weakly bound, non-crystalline Fe/Mn oxides, and crystalline Fe/Mn oxides/organically complexed Cu concentrations were greatest on the south and north sides (Fig (b), (c), and (d)). Residual organic and inorganic Cu concentrations were greater on the north side (Fig (e) and (f)). Greatest Cu concentrations were observed in the organically complexed and residual organic forms, a potential function of biosolids application. Adriano (1986) stated that applied or deposited Cu will persist in soil because it is strongly complexed or sorbed by OM, oxides of Fe/Mn, and clay minerals. Relative to phases dominating Cu complexation, Fe/Mn oxides and OM are the most important Cu complexing soil constituents (Jenne, 1977; McLaren et al., 1981). The bulk of the bioavailable soil Cu resides in the organically bound fraction (McLaren and Crawford, 1973). Behel et al. (1983) found that up to 80% of the total amount of Cu occurs in fulvic-metal complexes. Copper forms stable complexes with humic and fulvic acids (Stevenson and Fitch, 1981). The complexing ability is due to their high oxygen-containing functional groups such as carboxyl, phenolic hydroxyl, and carbonyls of various types (Schnitzer, 1969; Stevenson, 1972). Overall, the greater concentrations of mobile Cu phases observed at the south end of the site may have been due to a lack of uniformly applied or incorporated biosolids, or not enough biosolids/lime applied to raise soil pH and complex excess Cu in Fe/Mn oxide phases. However, if mobile phases were present in greater quantities over the entire site prior to reclamation, then a positive phase shift has occurred towards more immobile Cd phases following reclamation.

Iron

All but the soluble/exchangeable phase (Fig 5 (a)) had two-sided p-values of <0.10. Specifically sorbed/weakly bound, non-crystalline Fe/Mn oxides, and crystalline Fe/Mn oxides/organically complexed Fe concentrations were elevated on the site's south side (Fig 5 (b), (c), and (d)). The residual organically bound Fe concentration was greater on both north and south sides (Fig 5 (e)). Residual inorganic Fe concentration was greatest on the site's north side (Fig 5 (f)). The greatest Fe concentrations were found in crystalline Fe/Mn oxide & organically complexed, residual organic, and residual inorganic phases. As with Cd and Cu, elevated Fe concentrations in mobile phases on the south side of the site may have been due to a lack of uniformly applied or incorporated biosolids, or not enough biosolids/lime applied to raise soil pH and complex excess Fe in relatively immobile phases. However, if mobile phases were present in greater concentrations over the entire site prior to reclamation, then a positive phase shift has occurred towards more immobile Cd phases associated with reclamation.

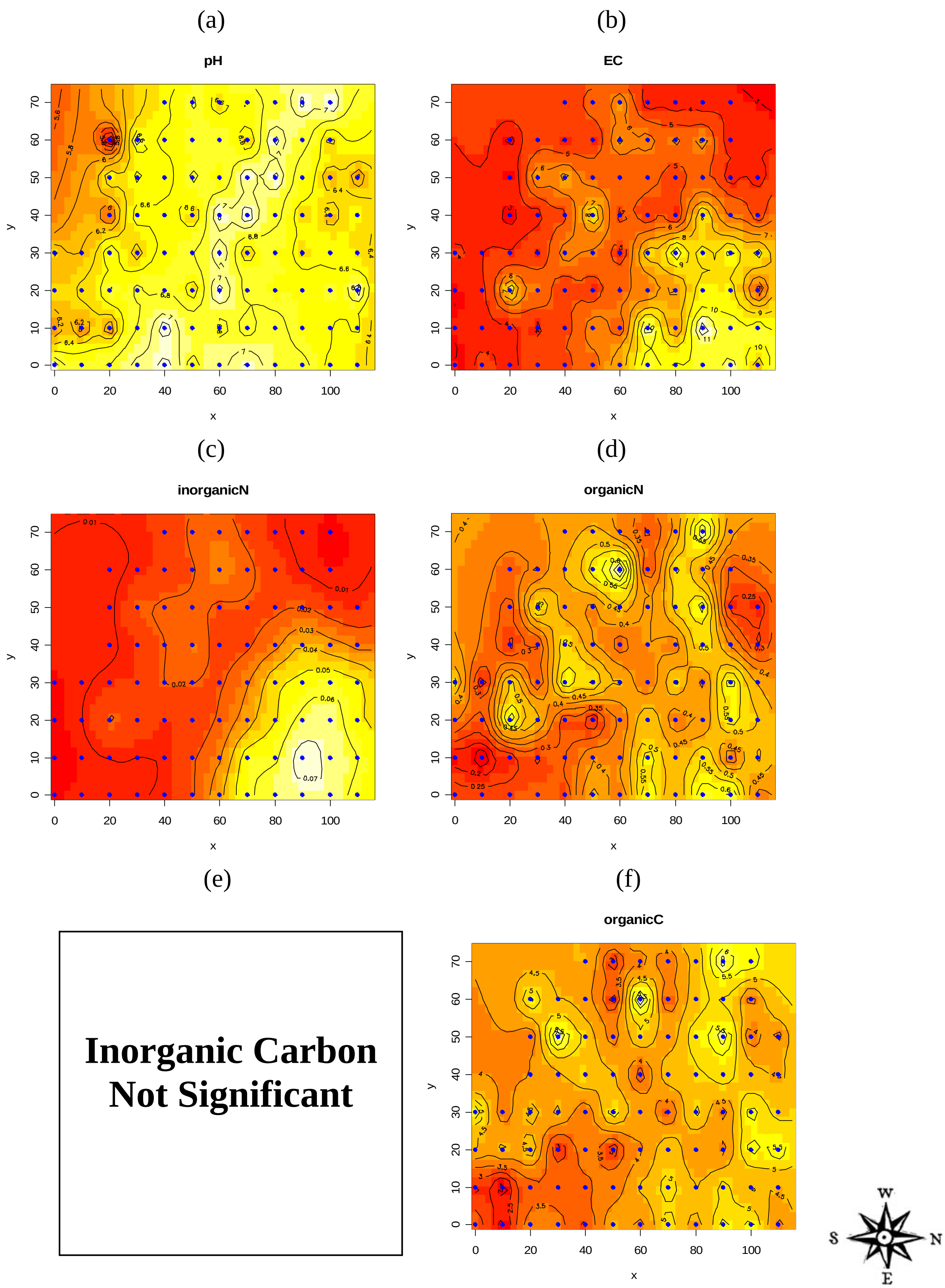

Fig 2: Basic soil characteristics: (a) pH, (b) electrical conductivity, (c) inorganic nitrogen, (d) organic nitrogen, (e) inorganic carbon, and (f) organic carbon. Darker colors (e.g. red) = relatively low concentration. Lighter colors (e.g. white) = relatively high concentration.

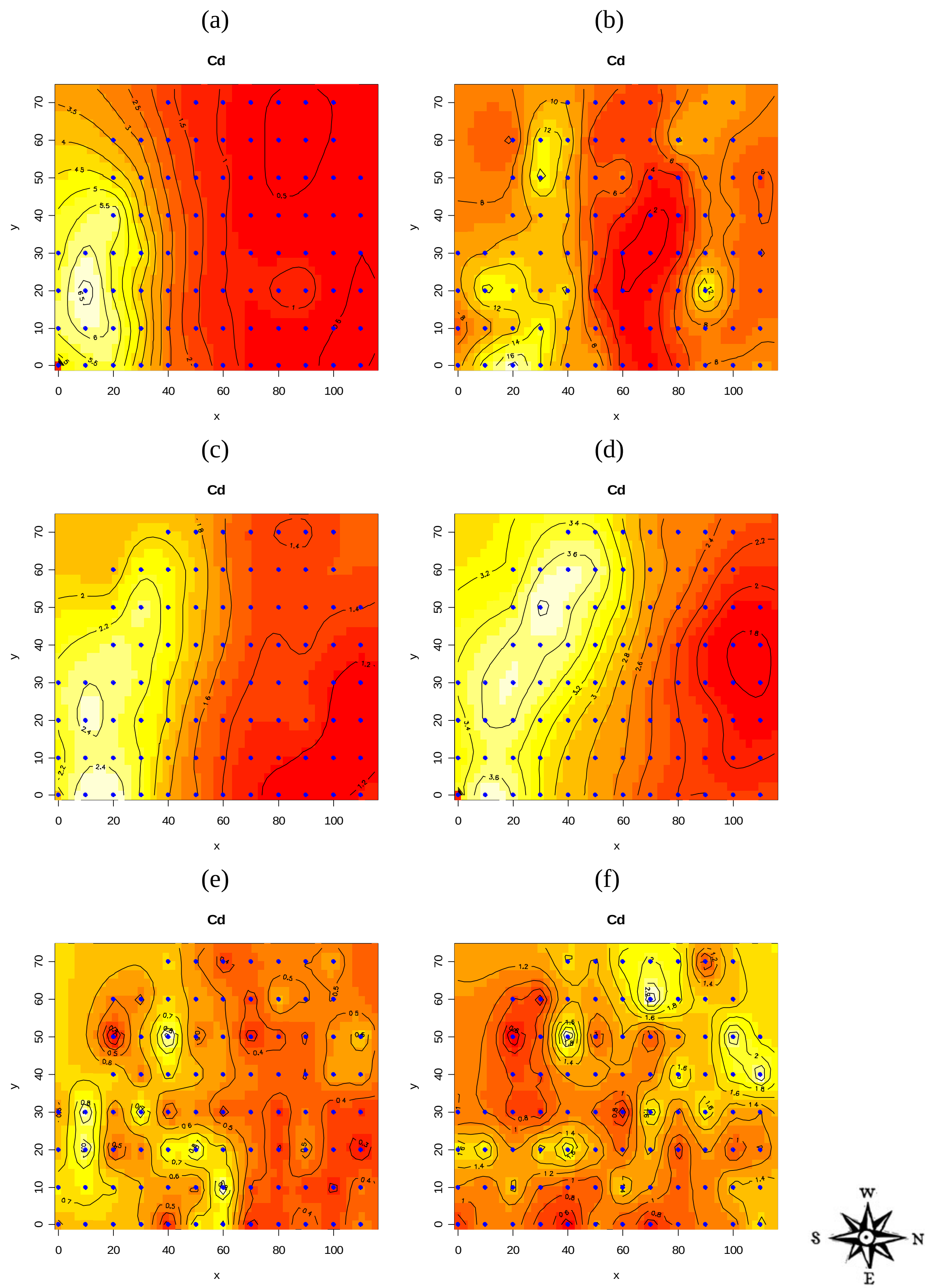

Fig 3: Cadmium associated with: (a) soluble and exchangeable, (b) specifically sorbed/weakly bound, (c) non-crystalline Fe/Mn oxides, (d) crystalline Fe/Mn oxides & organically complexed, (e) residual organic, and (f) residual inorganic phases. Darker colors (e.g. red) = relatively low concentration. Lighter colors (e.g. white) = relatively high concentration.

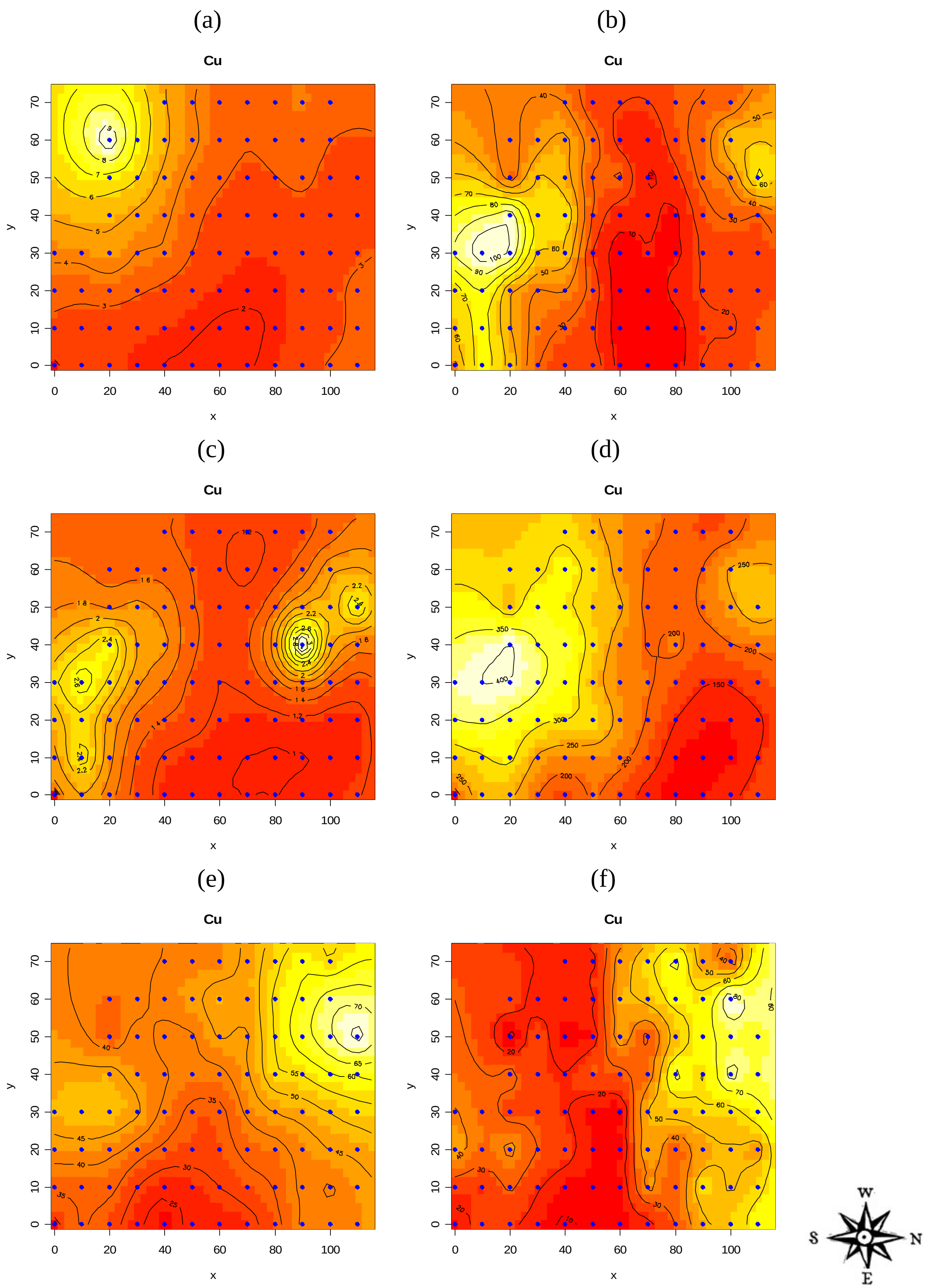

Fig 4: Copper associated with: (a) soluble and exchangeable, (b) specifically sorbed/weakly bound, (c) non-crystalline Fe/Mn oxides, (d) crystalline Fe/Mn oxides & organically complexed, (e) residual organic, and (f) residual inorganic phases. Darker colors (e.g. red) = relatively low concentration. Lighter colors (e.g. white) = relatively high concentration.

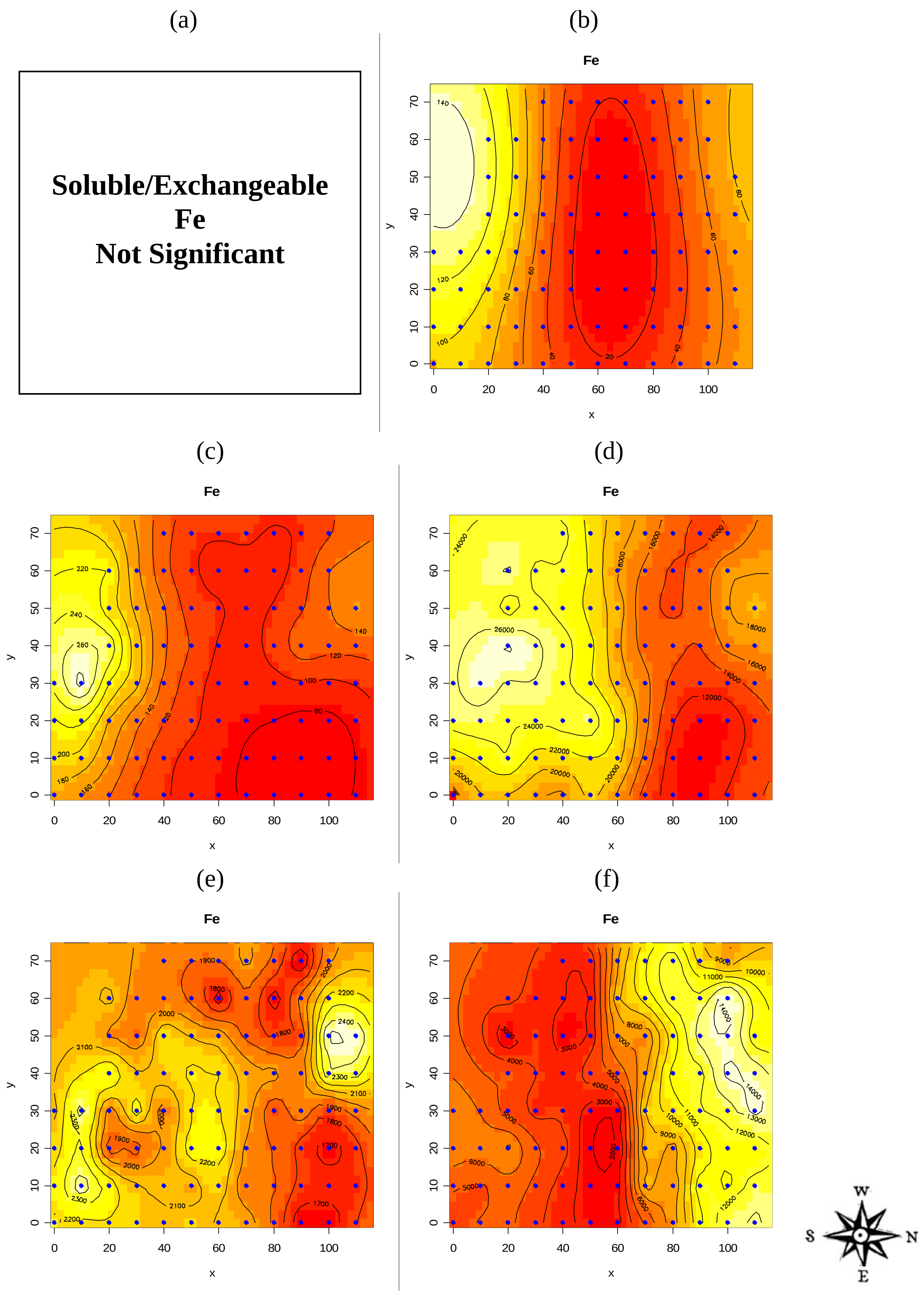

Fig 5: Iron associated with: (a) soluble and exchangeable, (b) specifically sorbed/weakly bound, (c) non-crystalline Fe/Mn oxides, (d) crystalline Fe/Mn oxides & organically complexed, (e) residual organic, and (f) residual inorganic phases. Darker colors (e.g. red) = relatively low concentration. Lighter colors (e.g. white) = relatively high concentration.

Lead

All but the soluble/exchangeable phase (Fig 6 (a)) had two-sided p-values of <0.10. The soluble/exchangeable phase concentrations were mostly below detection (data not shown). Specifically sorbed/weakly bound and non-crystalline Fe/Mn oxide associated Pb had slightly higher concentrations on the site's south side (Fig 6 (b) and (c)). Crystalline Fe/Mn oxides/organically complexed Pb concentration was greater on the site's south side (Fig (d)). Residual organic and residual inorganic Pb concentrations were greater on the north side (Fig (e) and (f)). Of all fractions the greatest Pb concentration was found in the crystalline Fe/Mn oxide and organically complexed phase. Soldatini et al. (1976) indicated that OM and clay were the dominant constituents contributing to Pb adsorption in soils. As with other metals, if Pb were originally present in greater quantities as relatively mobile phases, then a significant positive phase shift has occurred towards more immobile Mn phases (i.e. crystalline Fe/Mn oxide and organically complexed phases).

Manganese

All but the soluble/exchangeable phase (Fig 7 (a)) and specifically sorbed/weakly bound phase (Fig 7 (b)) had two-sided p-values of <0.10. These two phases were not affected by reclamation efforts. Non-crystalline Fe/Mn oxide and crystalline Fe/Mn oxides/organically complexed Mn concentrations were elevated on the site's south/west side (Fig 7 (c) and (d)). Residual organic Mn showed a single area on the east/north side of the site with high Mn concentrations (Fig 7 (e)). Residual inorganic Mn concentrations were greatest on the site's north side (Fig 7 (f)). The greatest Mn concentrations were found in the non-crystalline Fe/Mn oxide and crystalline Fe/Mn oxides/organically complexed phases (and at least two to four times greater than both soluble/exchangeable and specifically sorbed/weakly bound phases; data not shown). Shuman (1985) found that most of the total Mn was found in the organic and Mn oxides fractions. As a note, non-crystalline and crystalline Mn oxides can also form coprecipitates with Fe oxides. Manganese availability is also affected by redox conditions, so Mn fractionation may have been influenced by low water levels, a function of sample collection time (October 2006).

Zinc

All phases had two-sided p-values of <0.10. Soluble/exchangeable Zn concentrations were greatest on the site's south side (Fig 8 (a)). Specifically sorbed Zn concentrations were greatest on both the site's north and south sides (Fig 8 (b)). Zinc associated with non-crystalline Fe/Mn oxide and crystalline Fe/Mn oxides/organically complexed phases was greatest on the south side of the contour map (Fig 8 (c) and (d)). Residual organically bound Zn content was greatest on the site's north/west side with some elevated concentrations on the south/east side (Fig 8 (e)). Residual inorganic Zn concentration was greatest on the site's north/west side (Fig 8 (f)). Zinc concentration was uniform across all phases; no single phase dominated. Ramos et al. (1994) found that the distribution of zinc followed the order of Fe/Mn oxides > carbonates ≥ residual > > organic > exchangeable. Zinc complexation increased with the humification of OM (Adriano, 2001). With additions of organic amendments to soils in the form of solid OM (as opposed to soluble OM, such as humic and fulvic acids) in general, tend to shift Zn to more non-bioavailable forms (Shuman, 1999). Since soluble phases primarily dominated the south side of the site, a reduction in biosolids/lime application caused Zn to continue to be more prevalent in mobile phases.

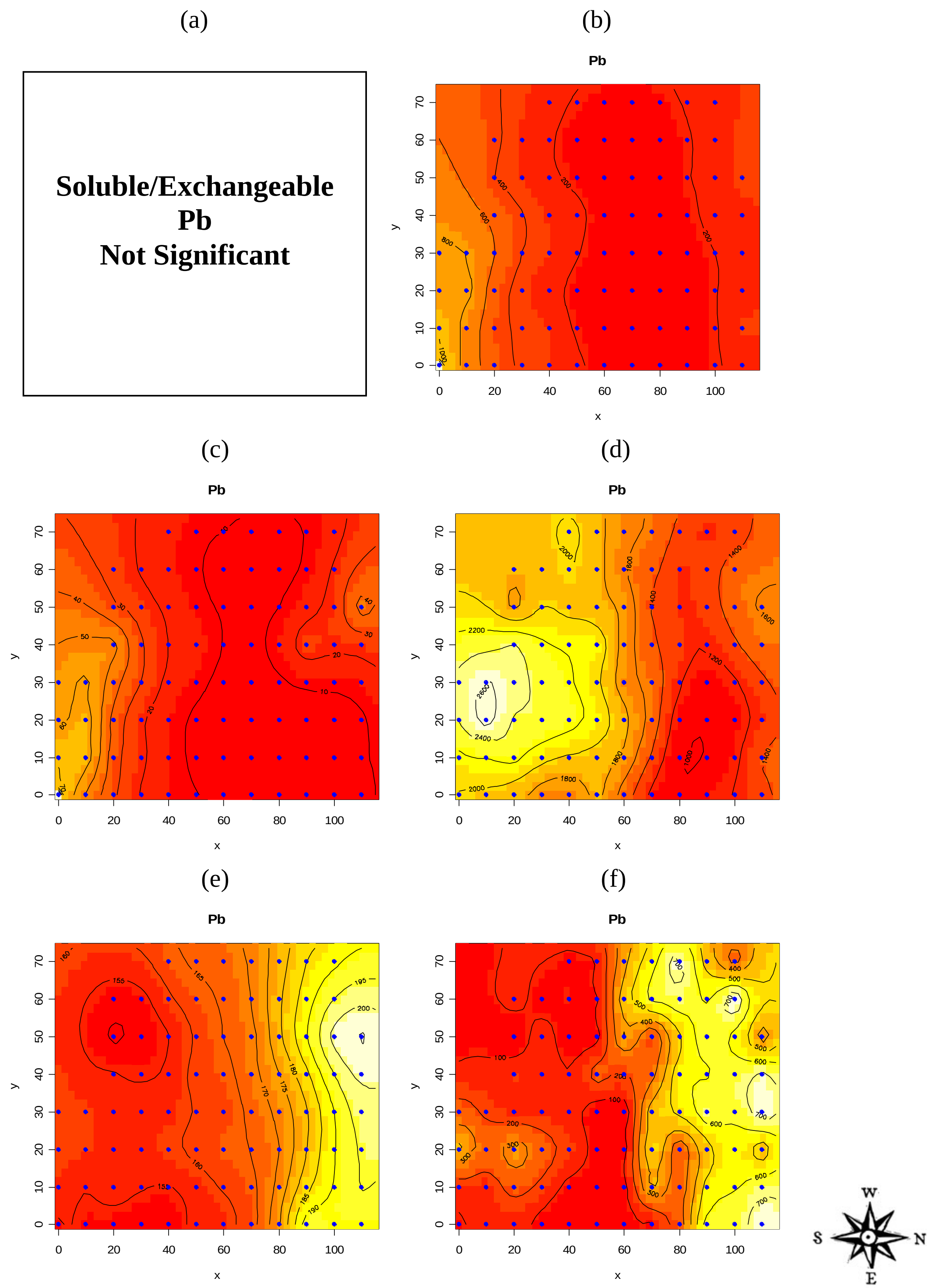

Fig 6: Lead associated with: (a) soluble and exchangeable, (b) specifically sorbed/weakly bound, (c) non-crystalline Fe/Mn oxides, (d) crystalline Fe/Mn oxides & organically complexed, (e) residual organic, and (f) residual inorganic phases. Darker colors (e.g. red) = relatively low concentration. Lighter colors (e.g. white) = relatively high concentration.

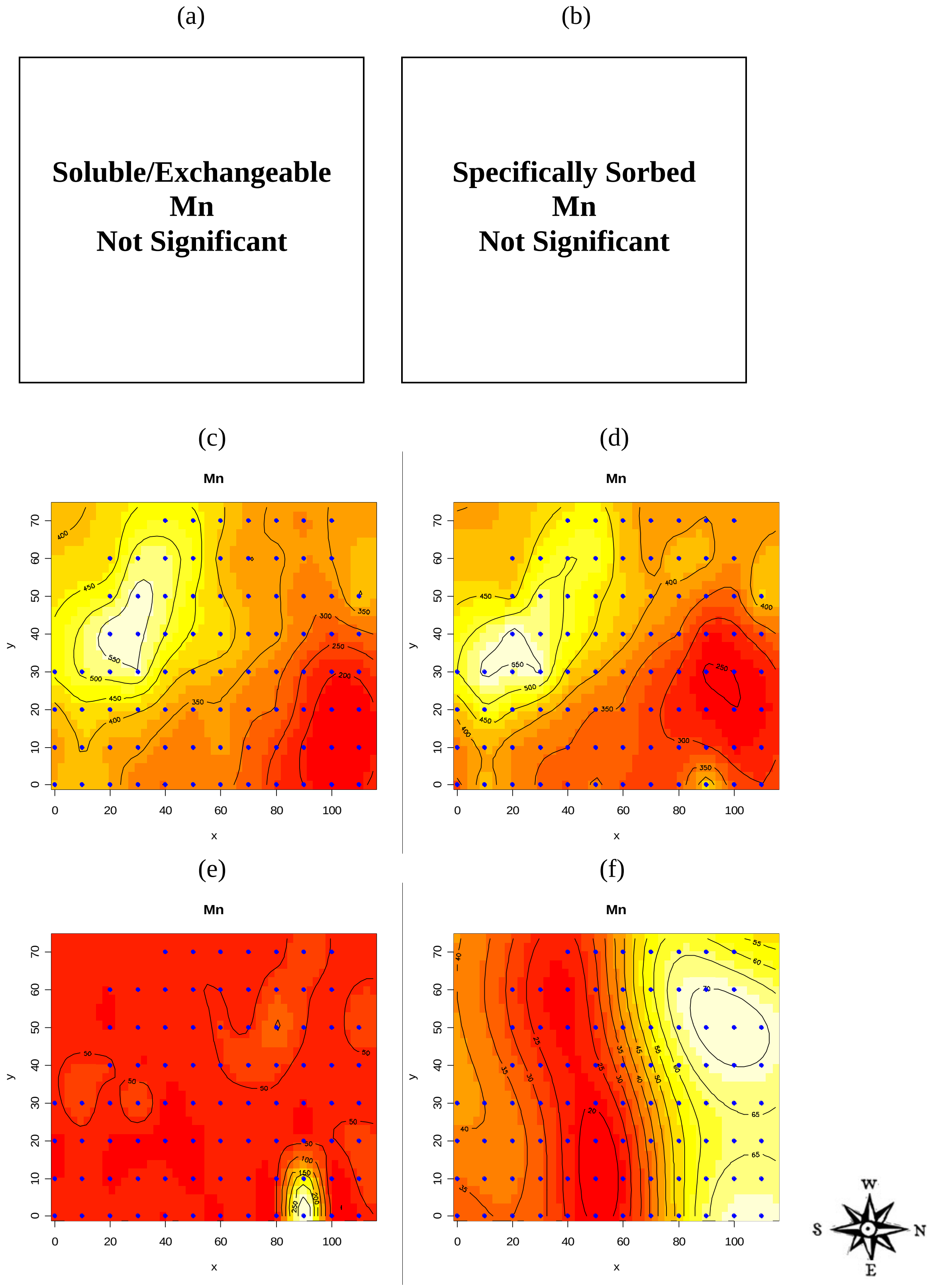

Fig 7: Manganese associated with: (a) soluble and exchangeable, (b) specifically sorbed/weakly bound, (c) non-crystalline Fe/Mn oxides, (d) crystalline Fe/Mn oxides & organically complexed, (e) residual organic, and (f) residual inorganic phases. Darker colors (e.g. red) = relatively low concentration. Lighter colors (e.g. white) = relatively high concentration.

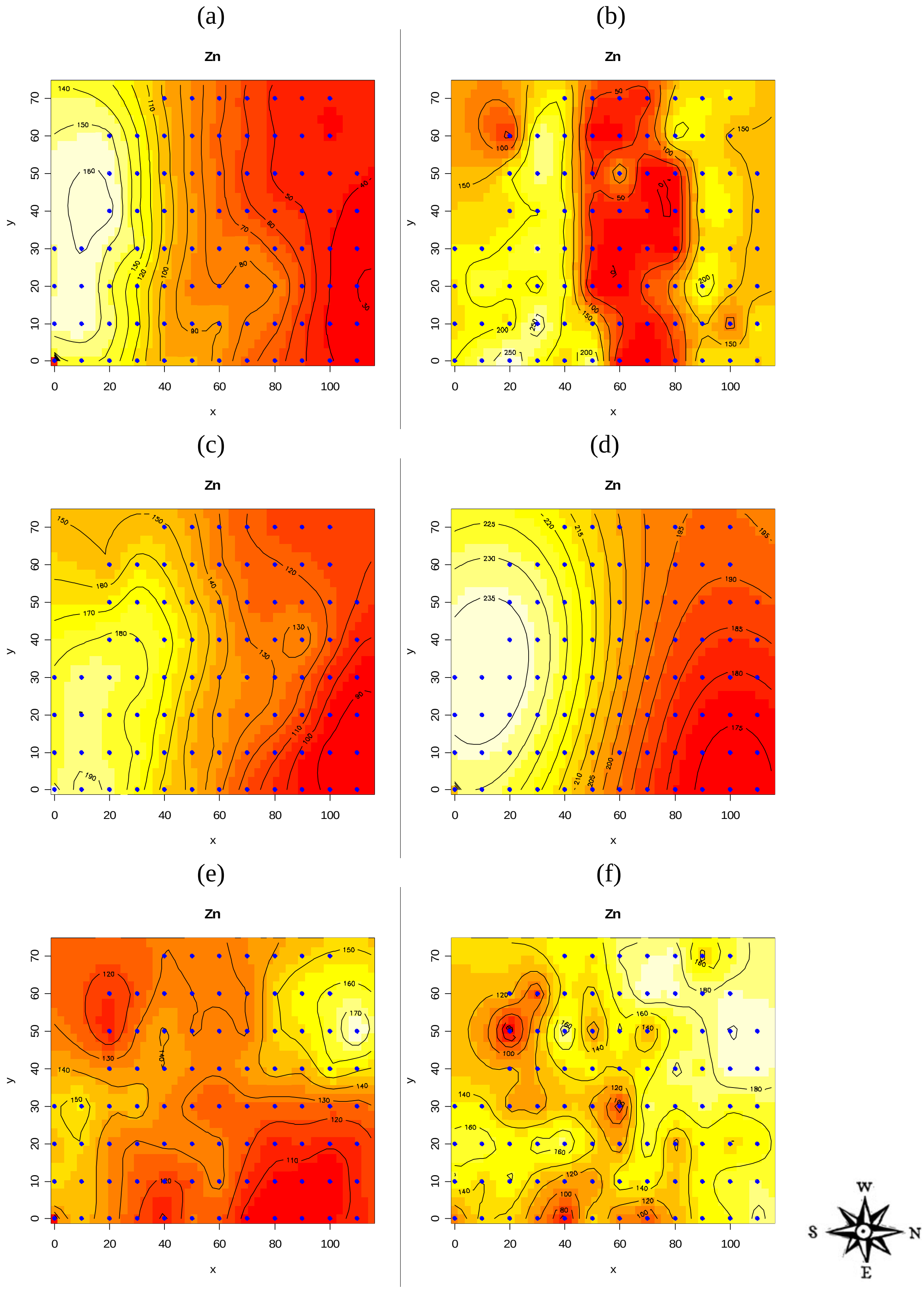

Fig 8: Zinc associated with: (a) soluble and exchangeable, (b) specifically sorbed/weakly bound, (c) non-crystalline Fe/Mn oxides, (d) crystalline Fe/Mn oxides & organically complexed, (e) residual organic, and (f) residual inorganic phases. Darker colors (e.g. red) = relatively low concentration. Lighter colors (e.g. white) = relatively high concentration.

Spatial Cross-Correlations: Metal Fractionation Steps vs. Basic Soil Characteristics

Cadmium was negatively correlated with pH, EC, inorganic nitrogen, organic nitrogen, and organic carbon for the first five steps and a positive correlation of step 6 and organic nitrogen and carbon (Table 1 (a)). Inorganic carbon had no effect on any of the steps, assuming $CdCO_3$ was not formed. This could be a function of lime increasing pH, consuming H^+ ions, and thus increasing exchange sites for reaction.

Copper step 1 had negative correlations with pH, EC, and inorganic nitrogen (Table 1 (b)). Step 2 showed negative correlations with pH, EC, inorganic nitrogen, organic nitrogen, and organic carbon. Step 3 had negative correlations with pH, EC, inorganic nitrogen, and organic nitrogen. Step 4 showed a positive correlation with organic carbon and negative correlations with the remaining basic soil characteristics. Step 5 was positively correlated with organic nitrogen and organic carbon, and negatively correlated with inorganic carbon. Step 6 showed positive correlations with EC, inorganic nitrogen, organic nitrogen, and organic nitrogen, and a negative correlation with inorganic carbon.

Iron step 1 had positive correlations with EC, inorganic nitrogen, and organic carbon (Table 1 (c)). Step 2, 3, and 4 had negative correlations with pH, EC, inorganic nitrogen, organic nitrogen, and organic carbon. Inorganic carbon for steps 2 and 4 varied with step 2 being negatively correlated and step 4 being positively correlated. Step 5 had negative correlations with EC, inorganic nitrogen, organic nitrogen, and organic carbon. Step 6 was negatively correlated with inorganic carbon while the rest of the basic parameters were positively correlated. With step 6 (the residual inorganic phase) having positive correlations, one can assume that as pH increased the stable residual mineral phases increased.

Lead and manganese in the first four steps primarily were negatively correlated with the basic soil analysis (Table 1 (d) and (e). Steps 5 and 6 reversed this trend, with Pb and Mn primarily being positively correlated with the basic analysis. This positive correlation was found in the residual organic and residual inorganic phases of the fractionation.

Zinc was primarily negatively correlated with the basic soil analysis in the first five steps, while in step 6 it was positively correlated (Table 1 (f)). Since step 6 had a positive correlation, an assumption can be made that as pH increased residual Zn mineral phases increased.

Table 1. Cross correlations between basic soil analysis and (a) cadmium, (b) copper, (c) iron, (d) lead, (e) manganese, and (f) zinc steps 1 (soluble/exchangeable), 2 (specifically sorbed/weakly bound), 3 (non-crystalline Fe/Mn oxides), 4 (crystalline Fe/Mn oxides/organically complexed), 5 (residual organic), and 6 (residual inorganic).

(a)

Cd Steps	pH	EC	Inorg N	Org N	Inorg C	Org C
1	-	-	-	-	NS	-
2	-	-	-	-	NS	-
3	-	-	-	-	NS	-
4	-	-	-	-	NS	-
5	-	-	-	-	NS	-
6	NS	NS	NS	+	NS	+

(b)

Cu Steps	pH	EC	Inorg N	Org N	Inorg C	Org C
1	-	-	-	NS	NS	NS
2	-	-	-	-	NS	-
3	-	-	-	-	NS	NS
4	-	-	-	-	+	-
5	NS	NS	NS	+	-	+
6	NS	+	+	+	-	+

(c)

Fe Steps	pH	EC	Inorg N	Org N	Inorg C	Org C
1	NS	+	+	NS	NS	+
2	-	-	-	-	-	-
3	-	-	-	-	NS	-
4	-	-	-	-	+	-
5	NS	-	-	-	NS	-
6	+	+	+	+	-	+

(d)

Pb Steps	pH	EC	Inorg N	Org N	Inorg C	OrgC
1	NS	-	-	NS	NS	NS
2	-	-	-	-	NS	-
3	-	-	-	-	NS	-
4	-	-	-	-	+	-
5	NS	+	+	+	NS	+
6	+	+	+	+	-	+

(e)

Mn Steps	pH	EC	Inorg N	Org N	Inorg C	Org C
1	NS	-	-	NS	NS	NS
2	NS	-	-	NS	NS	NS
3	-	-	-	-	+	-
4	-	-	-	-	+	-
5	NS	+	+	+	NS	+
6	+	+	+	+	-	+

(f)

Zn Steps	pH	EC	Inorg N	Org N	Inorg C	Org C
1	-	-	-	-	NS	-
2	-	-	-	-	-	-
3	-	-	-	-	NS	-
4	-	-	-	-	+	-
5	NS	-	-	-	NS	NS
6	NS	+	+	+	NS	+

CONCLUSIONS

Biosolids are becoming a more sought after tool for reclaiming contaminated mining sites. This study was conducted to determine the effect of biosolids and lime on the reclamation of a heavily contaminated fluvially deposited mine tailings site near Leadville, Colorado. We utilized a sequential trace metal extraction scheme to identify dominant metal pools and to assess bioavailability. Thus, the fractionation of the heavy metals from the site gives important information on the location, behavior, and availability of these metals in the environment. Cadmium was found primarily in the soluble/exchangeable and specifically sorbed/weakly bound phases, potentially plant-available and mobile. Copper was found primarily in organically complexed and residual organic phases, relatively immobile phases. Iron was found primarily in the crystalline Fe/Mn, residual organic, and residual inorganic phases, relatively immobile phases. Of all phases, Pb concentration was greatest in the crystalline Fe/Mn oxides and organically complexed phase, a relatively immobile phase. Manganese was primarily found in relatively immobile non-crystalline and crystalline Mn oxides. Zinc was equally distributed through all six steps.

Overall, the greatest concentration of mobile metal phases was observed at the south end of the site. This finding, as compared to the rest of the site, may have been due to a lack of uniformly applied or incorporated biosolids, or not enough lime applied to raise soil pH and complex excess metals in more immobile phases. If mobile phases were present in greater concentrations over the entire site prior to reclamation, then a positive phase shift has occurred towards more immobile metal phases following reclamation. We are currently conducting research to relate plant species richness, plant metal concentrations/uptake, and microbial community response to reclamation success.

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THE YEGGE ROAD SHADED FUEL BREAK : A JEFFERSON COUNTY COMMUNITY WILDFIRE PROTECTION PLAN PROJECT IMPLIMENTATION CASE STUDY

George Greenwood, Wildfire Mitigation Specialist
Walsh Environmental Scientists and Engineers, LLC
4888 Pearl East Circle, Suite 108
Boulder, CO 80301

ABSTRACT

The framework for developing a Community Wildfire Protection Plan (CWPP) is provided in the Healthy Forest Restoration Act of 2003 (HFRA). Developing effective strategies that will reduce the hazards and risks wildfire poses to a community, subdivision, or designated Wildland-Urban Interface (WUI) is the primary goal of any CWPP. Strategies may include creating or improving defensible space around private homes, enhancing the effectiveness of local emergency response, or the strategic reduction of hazardous forest or rangeland fuels. The Jefferson County Division of Emergency Management has implemented the development of a series of CWPPs for Fire Protection Districts (FPD) within the county through a FEMA pre-disaster grant award. Each CWPP provides detailed and prioritized mitigation recommendations, including forest management practices that rely on selective timber reduction to reduce the likelihood of catastrophic wildfire, enhance the safety of residents and fire fighters, and provide an opportunity for forest health restoration. Action plan implementation requires collaborative support on private lands and National Environmental Policy Act (NEPA) compliance for mitigation conducted on federal lands.

The Yegge Road shaded fuel break was identified in the Inter-Canyon FPD CWPP as a prioritized strategic fuel reduction recommendation for the Jennings Road WUI. Implementation is being funded, in part, through a Colorado State Forest Service (CSFS) grant award that requires a completed and certified CWPP. The Yegge Road shaded fuel break is being constructed along road margins in accordance with *Fuel Break Guidelines for Forested Subdivisions and Communities.* Phased thinning is being conducted in dense stands of Douglas-fir and ponderosa pine. In addition to fuels reduction, timber mitigation provides ecological benefits that directly enhance forest health, reduces the likelihood of insect and pathogen migration, and creates a sustainable environment for understory diversification.

INTRODUCTION

Wildfire is a naturally occurring and important component of the Montane and Subalpine ecosystems that dominate much of Front Range of the Rocky Mountains. These pine forests, rangelands, and grasslands common to the western United States (US) are characterized as "fire-dependent" ecosystems that have evolved over thousands of years to be resilient to wildfire occurrence, and in the case of some species, dependent on wildfire to maintain stand health or even trigger reproduction.

Since the early 20th century land and forest management practices for these same regions were designed around a simple protocol, "Prevent Wildfires." While originally intended to protect human settlement and forest resources, the practice of fire exclusion proved to be short sighted. Naturally occurring fuels have accumulated to hazardous levels and historically diverse vegetation profiles have become dominated by more aggressive species affecting landscape scale ecosystems. These dense, weakened, and homogeneous stands are much more susceptible to widespread insect and pathogen infestations, as well as catastrophic scale wildfires.

Record-setting demographic growth in the western US have precipitated a significant population shift into these same forested regions that are at highest risk for catastrophic wildfire. With populations surging there are more structures, residents, and supporting infrastructure in fire-prone areas than ever before, directly compromising the safety of residents and emergency responders.

Over the last decade catastrophic wildfires have shifted from rare to commonplace seasonal events. Suppression costs and associated economic losses continue to rise. It became evident that programs and funding designed to identify and address the cause of the problem were needed.

The *National Fire Plan* (NFP) was developed in August 2000, following a landmark wildland fire season. The intent of the NFP was to better support severe wildland fires, address the impacts to communities, and ensure sufficient firefighting capacity for the future. The NFP addresses five key points:

- Firefighting,
- Rehabilitation,
- Hazardous Fuels Reduction,
- Community Assistance, and
- Accountability.

The *Healthy Forests Initiative* (HFI) was launched in support of the NFP in August, 2002 with the intent to reduce the risks severe wildfires pose to people, communities, and the environment. By protecting forests, woodlands, shrublands, and grasslands from unnaturally intensive and destructive fires, HFI helps improve the condition of our public lands, increases firefighter safety, and conserves landscape attributes valued by society.

President Bush signed the *Healthy Forests Restoration Act of 2003* (HFRA) in December 2003. HFRA contains a variety of provisions to speed up hazardous-fuel reduction and forest-restoration projects on specific types of Federal land that are at risk of wildland fire and/or of insect and disease epidemics. The HFRA helps States, Tribes, rural communities and landowners restore healthy forest and rangeland conditions on both public and private lands.

Community Wildfire Protection Plans (CWPP) are authorized and defined in Title I of HFRA which places renewed emphasis on community planning by extending a variety of benefits to communities with a wildfire protection plan in place. Critical among these benefits is the option of establishing a localized definition and boundary for the wildland-urban interface (WUI) and the opportunity to help shape fuels treatment priorities for surrounding federal and non-federal lands.

The CWPP, as described in the Act, brings together diverse local interests to discuss their mutual concerns for public safety, community sustainability and natural resources. It offers a positive, solution-oriented environment in which to address challenges such as local firefighting capability, the need for defensible space around homes and subdivisions, and where and how to prioritize land management – on both federal and non-federal land (CSFS, undated).

In a concerted effort to address the wildfire hazards facing its communities and residents, the Jefferson County Division of Emergency Management applied for, and was awarded a FEMA pre-disaster mitigation grant. Funding is being utilized to develop CWPPs for a number of fire districts located within the county. Each CWPP is collaboratively developed with input from residents, local fire officials, county emergency services, and appropriate public land management agencies. Each plan delineates Wildland-Urban Interface zones within the assessment area, identifies specific wildfire threats facing these areas, and prioritizes mitigation actions designed to reduce those threats. Converting these recommendations into actions remains the biggest challenge for CWPP implementation.

The Yegge Road shaded fuel break project is an example of how a CWPP can guide and drive the implementation of forest management and fuel reduction in the wildland urban interface.

THE INTER-CANYON FIRE PROTECTION DISTRICT CWPP

Yegge Road is located in the heart of the Inter-Canyon FPD, southwest of Denver, CO in central Jefferson County. The district's proximity to Denver and the Denver Technical Center and easy access on State Highway 285, make this area attractive to the thousands of individuals who choose the commuting life style of mountain living and a city job (Figures 1, 2).

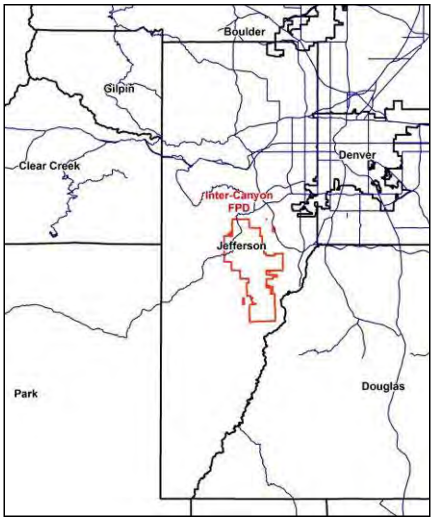


Figure 1. Regional proximity of the Inter-Canyon FPD

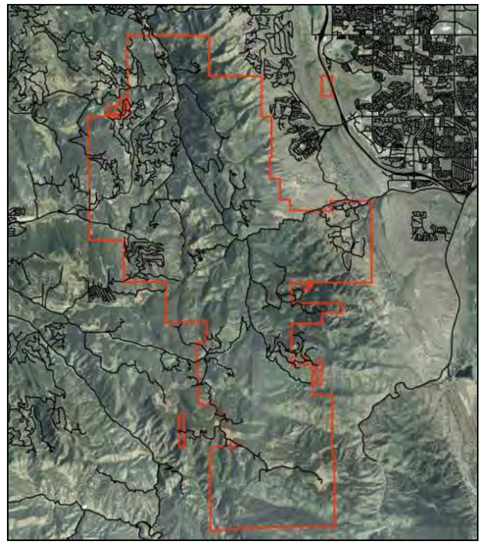


Figure 2. Major access roads within the assessment area

The terrain of the district is characterized by the heavily dissected foothills of lower Turkey Creek and Deer Creek Canyons (Figure 3). Vegetation found in the region is typical for the lower elevation Montane ecosystem of the central and southern Colorado front range. Slope aspect dictates available moisture which, in turn, controls vegetation. In the Inter-Canyon region this is characterized by Douglas-fir dominated north facing slopes with some mixed ponderosa pine, and open stands of ponderosa pine, Gambel oak, and grassy meadows on the dryer south facing slopes.

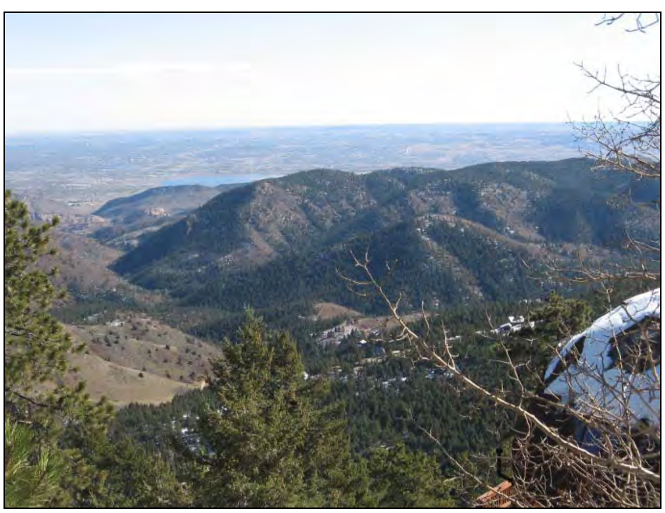


Figure 3. Deer Creek Canyon in the central region of the Inter-Canyon FPD

The risk of catastrophic wildfire in areas like the Inter-Canyon FPD is significant. Fire danger grows with each passing growing season, while population growth pushes development further into fire-prone wildland areas. Residents are often unaware of measures that can and should be taken to lower the risk of loss and increase the safety margin in the event of a wildfire. Community outreach can play an important role in the educational process, as well as providing a forum for the collaboration needed to drive effective implementation.

Although the CWPP development process is flexible, HFRA does require that a collaborative approach be utilized throughout the planning life-cycle. At a minimum this involves input from county officials, local fire authority, state forest service, and any affected federal land management agencies. However it is the participation and buy-in of the area's residents that really drives the long term success of the plan as strategic recommendations are implemented over time.

Public Outreach

Community outreach is an important component of the CWPP process. It is a valuable educational tool through which residents can learn about wildfire, fire behavior, and the resources available to help reduce the wildfire hazards and risks inherent with mountain living in Colorado. CWPP marketing efforts may include articles in local publications, mailers, and community meetings. These programs are designed to raise local awareness and help plant the seeds of grass-roots activism, leading to local action plan ownership once the CWPP is completed (Figure 4).

Figure 4. Inter-Canyon residents participate in a CWPP community meeting

Working with local fire officials, public agencies, and community stakeholders through strategic planning sessions and open community meetings, wildland-urban interface delineations are established and areas of concern and values at risk are identified (Figure 5).

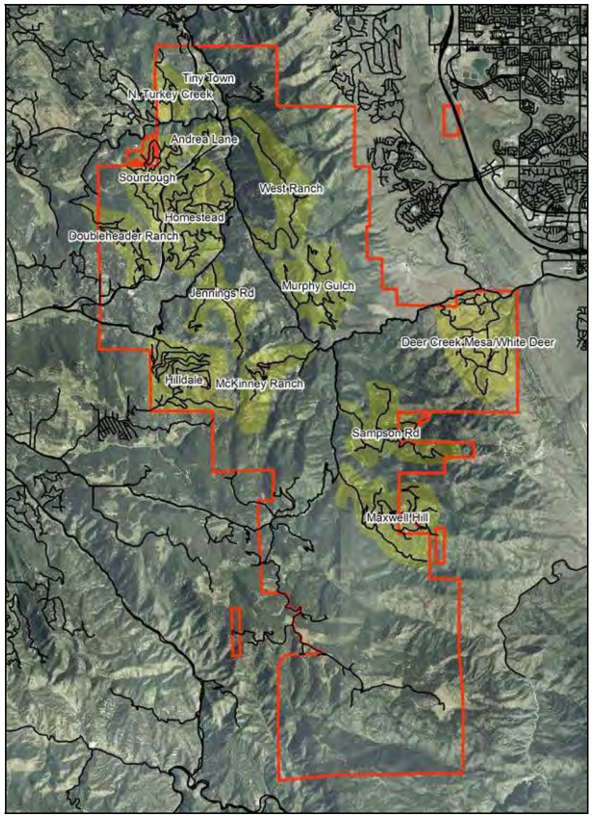


Figure 5. Wildland Urban Interface communities identified in the Inter-Canyon FPD

Participating homeowners and homeowner associations can help focus CWPP mitigation recommendations on hazards they have personally identified and communicated to project core team members (Figure 6).

Figure 6. Yegge Road resident discusses shaded fuel break strategy with an Inter-Canyon FPD officer during a CWPP community meeting

Mitigation Strategies

Successful community wildfire hazard and risk reduction depends on the implementation of a number of on-going activities. Leading the list is proactive involvement of community members and the support of local fire management officials. This collaboration creates the momentum necessary to drive fuel treatment projects, keeping the programs active year after year.

Maintain collaborative momentum - Community and stakeholder involvement is a critical component of developing a successful CWPP, but the same is true implementing, sustaining, and monitoring the plan over time. It is important to maintain momentum within the community after the CWPP is completed. Without continued community support momentum stalls and projects falter.

Create Defensible Space and Reduce Structural Ignitability - Actions taken by the individual homeowner are often the most effective means to protect what may be your most valuable investment from wildfire loss. Any homeowner could start the process today. There are a number of services the County and State Forest Service have developed for homeowners and proactive associations.

Secure Community Evacuation Routes - Community access improvements coupled with fuels mitigation along these important routes are critical actions that benefit the welfare of residents as well as emergency responders. Road improvements to primary or secondary evacuation routes may be as straight forward as seasonal grading, constructing or improving turnarounds at dead ends, widening a particularly tight switchback, or improving a section of road that would not support fire access.

Shaded Fuelbreaks – Fuel breaks, particularly along theses evacuations routes is an attractive treatment option for several reasons; 1) it provides a cost effective method to reduce hazardous fuels with convenient access to the project area for both treatment and fuel removal, 2) the road bed can be used as a firebreak anchor point from which to extend thinning operations into the forest margin, 3) roads provide ingress/egress for firefighting apparatus as well as residents and fuel breaks along these routes strategically reduces fire behavior where it is needed the most.

Improve the Capacity of Emergency Response - Strategic emergency water access, especially in rural mountainous areas, is an important factor in wildland firefighting, particularly in the early stages of an incident. Community surveys include water resource assessment and provide recommendations to improve access where needed. Enhancements to local emergency response capacity may also include apparatus and equipment upgrades, mapping and GIS, staff recruitment, communications, training and certification, and pre-suppression planning.

Forest Treatments - Strategic forest thinning improves forest health, diversifies ecosystems and wildlife, and provides important fuel breaks in the forest canopy in areas that may otherwise support catastrophic canopy fire. Forest treatments are ideally located along ridge tops and may involve constructing fuel-free firebreaks or shaded fuelbreaks.

Maintain Supporting Actions - Several on-going activities fall under the umbrella of "supporting actions". These include but are not limited to – continual grant research and application efforts; review and revisions if necessary to local statutes for current and future homeowners relating to defensible space, structural ignition, water, and emergency access.

Yegge Road Mitigation Recommendations

Residents of Yegge Road expressed concern during the first public meeting that forest conditions surrounding the only viable evacuation route would prevent safe evacuation in the event of a wildfire ignition along Jennings Road or Turkey Creek Canyon (Figures 7, 8).

Figure 7. Forest encroachment on lower Yegge Road

Figure 8. Surface and ladder fuels

As a result of this input, the Jennings Road area was designated an Inter-Canyon FPD WUI and ground surveys were completed and a community hazard mitigation plan was developed and incorporated into the Inter-Canyon CWPP draft release. Mitigation recommendations were developed to address all facets of wildfire hazards and risks associated with the area. These include road improvement to allow 2-way emergency traffic, switchback improvement to accommodate emergency apparatus turning radius, permanent emergency water supply at Jennings Road and Turkey Creek Road, and secondary emergency evacuation route development/improvement for both Yegge Road and Jennings Road. In order to secure safe evacuation along Yegge Road, a shaded fuel break is recommended along the road margins. Mitigation recommendations were reviewed and approved by local residents at the second public meeting.

The Yegge Road shaded fuel break is a component of a comprehensive fuel reduction strategy designed to create a series of fuel breaks that cut across the central portion of the fire district, tying in with meadows, roads, highways, and other firebreaks. They form buffers around subdivisions, facilitate safer evacuation, and create strategic breaks in areas of continuous forest canopy (Figure 9). The strategic positioning of these fuel break components is based on existing vegetation and fuel models, topography, evacuation, expected fire behavior, and proximity to values at-risk.

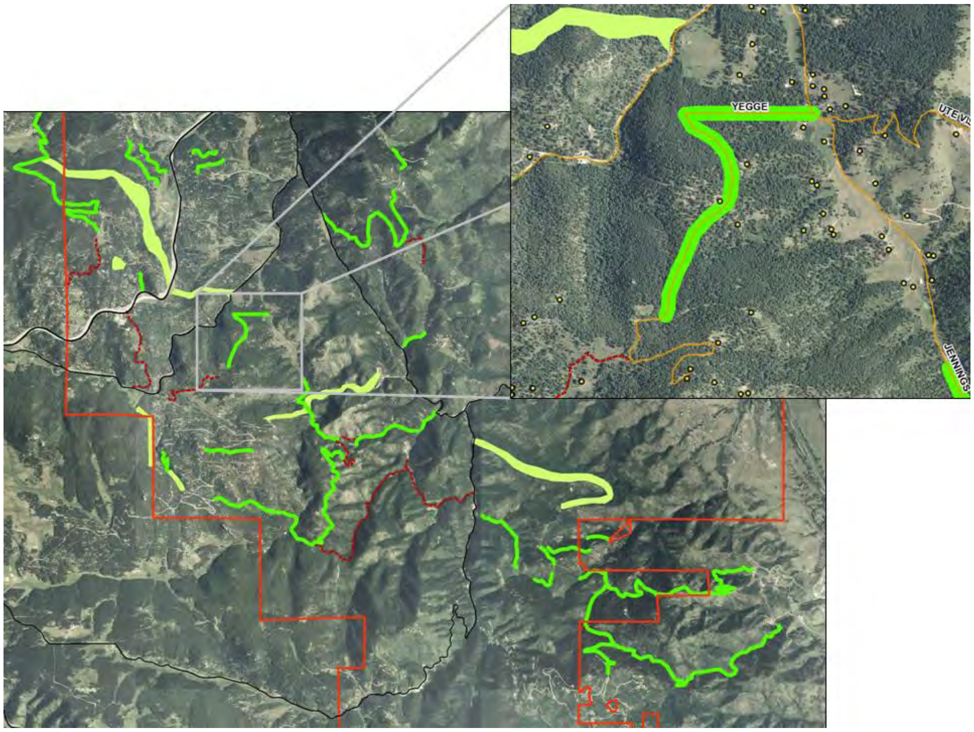


Figure 9. Locations of recommended forest treatments, emergency access routes, and shaded fuel breaks from the Inter-Canyon FPD CWPP

FUELBREAKS

Although the term fuelbreak is widely used in Colorado, it is often confused with firebreak. The two are entirely separate, and aesthetically different, forms of forest fuel modification and treatment.

- A firebreak is strip of land, 20 to 30 feet wide (or more), in which all vegetation is removed down to bare, mineral soil each year prior to fire season.

- A fuelbreak (or shaded fuelbreak) is an easily accessible strip of land of varying width (depending on fuel and terrain), in which fuel density is reduced, thus improving fire control opportunities. The stand is thinned, and remaining trees are pruned to remove ladder fuels. Brush, heavy ground fuels, snags, and dead trees are disposed of and an open, park-like appearance is established.

Fuelbreak Limitations

Fuelbreaks provide quick access for wildfire suppression. Control activities can be conducted more safely due to low fuel volumes. Strategically located, they break up large, continuous tracts of dense timber, thus limiting uncontrolled spread of wildfire.

Fuelbreaks can aid firefighters greatly by slowing fire spread under normal burning conditions. However, under extreme conditions, even the best fuelbreaks stand little chance of arresting a large phenomenon called "spotting," can drop firebrands 1/8-mile or more ahead of the main fire, causing very rapid fire spread. These types of large fires may continue until there is a major change in weather conditions, topography, or fuel type.

Fuelbreak Locations

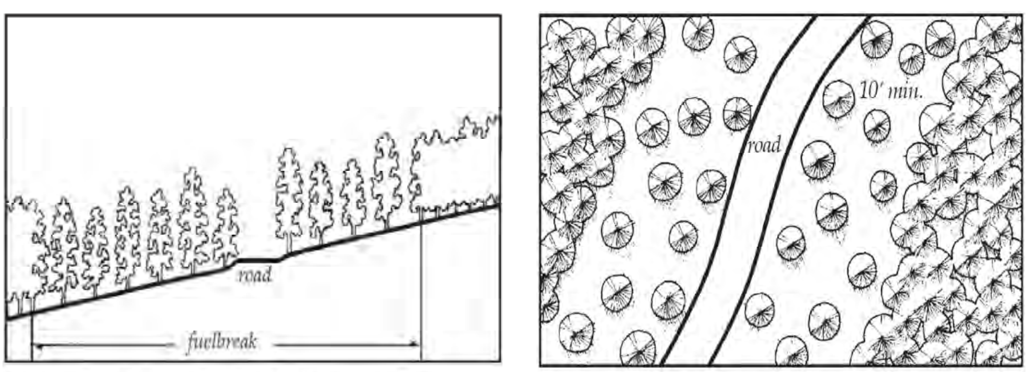
In fire suppression, an effective fire line is connected, or “anchored,” to natural or artificial fire barriers. Such anchor points might be rivers, creeks, large rock outcrops, wet meadows, or a less flammable timber type such as aspen. Similarly, properly designed and constructed fuelbreaks take advantage of these same barriers to eliminate “fuel bridges”, which can carry the fire across control lines.

Since fuelbreaks should normally provide quick, safer access to defensive positions, they are necessarily linked with road systems. Connected with county-specified roads within subdivisions, they provide good access and defensive positions for firefighting equipment and support vehicles. Cut-and fill slopes of roads are an integral part of a fuelbreak as they add to the effective width of modified fuels (Figure 10).

Fuelbreaks without an associated road system, such as those located along strategic ridge lines, are still useful in fire suppression. Here, they are often strengthened and held using aerial retardant drops until fire crews can walk in or be ferried in by helicopter.

Preferably, fuelbreaks are located along ridge tops to help arrest fires at the end of their runs. However, due to home site locations and resource values, they can also be effective when established at the base of slopes. Mid-slope fuelbreaks are least desirable, but under certain circumstances and with modifications, these too, may be valuable.

Fuelbreaks are located so that the area under management is broken into small, manageable units. Thus, when a wildfire reaches modified fuels, defensive action is more easily taken, helping to keep the fire small. For example, a plan for a subdivision might recommend that fuelbreaks break up continuous forest fuels into units of 10 acres or less. This is an excellent plan, especially if defensible space is completed around homes and structures, and thinning for forest management and forest health are combined with the fuelbreak (Dennis, Undated).



Cross-section of a typical fuelbreak built in conjunction with a road.

Plan view of fuelbreak showing minimum distance between tree crowns.

Figure 10. Principals of a Shaded Fuelbreak

PROJECT IMPLEMENTATION

Some of the biggest obstacles facing mitigation project implementation are access to funding availability of skilled field resources, and collaborative community buy-in. For the Yegge Road shaded fuel break project, these obstacles were successfully addressed through rapid action at the county and homeowner levels that paved the way for significant wildfire hazard and risk reduction within the first available field season.

With the successful completion of the district-wide CWPP, a major requirement for most federal and state grant sources was in place. A prioritized action plan based on a standardized wildfire hazard and risk field assessment, fire behavior analysis, and community input, was ready for implementation (Figure 11).

Figure 11. Rocco Snart, Jefferson County Sheriff's Office Fire Management Officer, leads a discussion during a Yegge Road media event with County Sheriff Ted Mink, County Commissioner Kathy Hartman, and local residents

Implementation funding was secured by the Jefferson County Sheriff's Office Fire Management Division through a State Fire Assistance (SFA) program grant. SFA grants are available through National Fire Plan and are dedicated to assist interface communities manage the unique hazards they find around them. Through this funding source a seasonal mitigation crew was organized that is dedicated to forest management and thinning projects on private lands within the county. Working collaboratively with certified foresters from the CSFS, sound forest management practices are utilized in the process of hazardous fuels reduction planning.

Support for the Yegge Road project is strong at all levels of involvement. The Old Dirt Road Homeowners Association, which includes Yegge Road residents, provided 100% homeowner support for fuel break implementation (Figure 12). This level of buy-in by private landowners greatly simplifies and streamlines project implementation. To date, 7 acres of road margins have been treated, with 13 acres in progress, and 5 acres to commence in the 2008 cutting season.

Figure 12. Residents trim ladder fuels

In addition to strong homeowner support, The Yegge Road shaded fuel break provides the Jefferson County Division of Emergency Management crucial validation of its long-range fuels mitigation strategy. It serves as the model and cornerstone for fuels reduction on a larger scale and broader scope across the county, and beyond (Figures 13, 14, 15).

Figure 13. Senator Mike Kopp pitches in

Figure 14. County Commissioner Kathy Hartman and the Yegge Road Crew

Wildfire and the measures we can take to reduce the threat of loss are politically charged and emotional topics. Education, strategic planning, and effective on-going action provide the basis for collaboration and is the most viable path toward effective hazardous fuels reduction.

Figure 15. Support from Senator Kopp, Sheriff Mink, Commissioner Hartman, FMO Snart, and active homeowners help make the Yegge Road shaded fuel break project a go-forward model for mitigation implementation

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PARALLEL TRENDS IN THE RECLAMATION INDUSTRY

Ed S. Kleiner
President Comstock Seed Co
Gardnerville, Nevada

For the past 30 years, our industry has focused on rural industrial reclamation, concentrating on mining, utility corridors, fires, and highways. The arid west has seen unprecedented growth, with urban expansion filling in favorable valley locations and expanding into surrounding foothills. This foothill expansion is causing unprecedented impacts on the local ecology, including the disruption of watershed function, increased wind and water erosion, increased fire frequency, and disruption of wildlife corridors. Coupling this trend with persistent drought, local governments have been forced to adopt ordinances that conserve resources. Developers are now being required to establish drought tolerant vegetation on cut and fill slopes and common areas that will not require long-term maintenance, fertility, and irrigation. With increasingly scarce water resources and tighter budgets, this trend has taken on a degree of urgency.

These new urban projects mirror our rural industrial projects. Both strive for physical stability, long-term low maintenance, and minimal use of long-term resources. The ecological parameters of the disturbance habitat have helped to mold the management plans for obtaining successful reclamation. For example, both types of projects share a common list of native and introduced plant species that can survive in our arid climate. Further, the urban agencies have benefited greatly from our long-term experiences in the rural industrial sector, basically by jump-starting urban reclamation plans without having to "reinvent the wheel." Compare the similarities between the urban and rural projects on this poster. Both sectors can benefit from a meeting of the minds relating to reclamation issues.

SOMMERSETT HOUSING/GOLF DEVELOPMENT

In the summer of 2001, developers initiated construction on a 2500 home and gold course development on the northwest foothills of Reno, Nevada. Due to the hilly terrain, the project is characterized by extensive cut and fill work. The architect defined an ambitious program for topsoil salvage and drought tolerant native vegetation for the cut slopes and common areas. The vegetation parameters have been dictated by Reno and Washoe County for all new developments in order to conserve water and reduce long term maintenance budgets for common areas. This project also included temporary irrigation for all revegatation efforts. The success of this project has created a native shrub-steppe community that was more common prior to the grazing impacts of the late 1800's. The species list included the following:

SPECIES	PLS LBS/ACRE	
Grasses		
Agropyron spicatum	4.80	
Agropyron trachycaulum(nurse crop)	4.80	16.50
Elymus cinereus	2.40	

Poa sandbergii	2.50	
Festuca ovina	2.00	
Shrubs		
Artemisia tridentata wyomingensis	.30	
Chrysothamnus nauseosus	.20	
Grayia spinosa	.40	5.50
Ephedra viridis	.30	
Purshia tridentata	1.00	
Prunus andersonii	.50	
Atriplex canescens	1.80	
Atriplex contertifolia	1.00	
Flowers		
Balsamorhiza sagittata	1.00	
Linum lewisii	.50	
Lupinus argenteus	.50	3.00
Penstemon palmeri	.40	
Peony brownii	.20	
Eriogonum umbellatum	.20	
Achillea millefolium	.20	
Total PLS #/acre:	25.00	

MCCARRAN ROAD CUT RENO, NEVADA

The last section of Reno's four-lane belt route involved a deep cut and fill through steep terrain in southwest Reno. In the spring of 1994, the contractor began by removing the top 6-8 inches of topsoil and stockpiling for nine months. This topsoil included all organic material and roots from the existing sage steppe community. The plant material was chipped into a manageable product for ease of blending and reapplication. When the final cuts had been completed, the contractor left the surfaces rough textured and loose. The topsoil and chipped plant material was reapplied onto these roughened cut slopes and packed.

The following seed blends were hydro seeded onto most of the steep road cuts in late fall. The cut generally ran from east to west so the exposures are south and north facing, creating two distinct microhabitats. Due to these contrasting conditions, two different seed blends were hydro seeded. The south-facing slope received a more drought tolerant seed blend than the north facing slopes. Last, the south facing slopes received an aspen erosion control mat. Like many of our rural industrial jobs, this job did not include temporary irrigation.

North facing seed blend

Species	Variety	PLS #/acre
Grasses		
Festuca longifolia	Durar	6.00
Poa ampla	Sherman	4.00
Agropyron cristatum	Ephraim	6.00
Elymus elymoides	Native	3.00

Shrubs		
Atriplex canescens	Native	3.30
Artemisia tridentata wyomingensis	Native	3.00
Chrysothamnus nauseosus	Native	3.70
Flowers		
Gaillardia aristata		4.00
Penstemon palmerii		5.00
Eriogonum umbellatum		2.00
	Total PLS #/acre:	41.00

South facing seed blend

Species	Variety	PLS #/acre
Grasses		
Agropyron smithii	Arriba	3.10
Agropyron cristatum	Fairway	1.60
Elymus elymoides	Native	1.80
Festuca ovina	Covar	1.60
Hilaria jamesii	Viva	3.00
Shrubs		
Atriplex contertifolia	Native	5.00
Flowers		
Linum lewisii		3.30
Eschscholtzia californica		1.70
	Total PLS#/acre:	21.10

GOLF COURSE ROUGHS

Developers of golf course roughs are following the same mandates as the housing developers. Turf management is labor intensive requiring large amounts of water and repeat nutrient applications while established native roughs require little of either. Coupled with a reduced maintenance budget, everybody benefits. Public perception of naturalized landscapes is our biggest challenge. Native landscapes are “rough” looking and homeowners and golfers that cater to these developments have more traditional perceptions of what “aesthetic” landscapes should look like. We must continue to educate the public about ecological considerations that influence our decisions about responsible arid landscaping practices.

COLLOSEUM MINE CLARK MOUNTAINS SOUTHERN NEVADA

The Colloseum mine site is located at a 5000' mountain pass in the mojave-sage steppe transition zone southwest of Las Vegas, NV. Transition zones are characterized by a wide variety of species representing both ecotypes. This particular area is dominated by a mix of Pinion, Juniperus, Coleogyne, and a variety of Cacti.

Topsoil from the tailings pond area was stockpiled on the south end of the property and redistributed over the tailing area at varying depths from 1-6 feet. The company initiated a seed-harvesting program at the site and inventoried several species for later reclamation. In the fall of 1994 these species were incorporated into a blend of commercial species and the blend was seeded uniformly throughout the reclamation areas. On flat surfaces, seed was broadcast and chain dragged while all sloped areas were hydroseeded. Constructed mounds on the tailings area were seeded with a double application rate. Also, the company had a cacti transplant program that involved a temporary storage area and replanting across the tailings area.

The company did not apply fertilizer due to their experiences at previous projects where fertilizer stimulated weed growth.

RESULTS

We have been able to revisit this site for twelve growing seasons and the response of the seed blend has been quite varied. In general, the flat open areas on the tailings pond were colonized by Atriplex and Chrysothamnus. In contrast, the sloping surfaces were colonized by Senecio, Eriogonum, and Penstemon. Over time, forbs have generally been displaced by shrubs. Many of the species supplied by the company's harvests are evident on the sloping areas as well. Several genera of cacti survived the transplant program. The Yucca were most successful.

By the eighth season, we were seeing Juniperus and Coleognye in isolated places. Hopefully, over time, these two species continue to expand and more closely mirror the surrounding undisturbed community.

QUARRY FILL WASHOE STATE PARK LAKE TAHOE CALIFORNIA

During the summer of 2001, 84,000 yards of fill was removed from an estuary at South Lake Tahoe and placed in an abandoned four-acre quarry at Washoe State Park. The fill was graded and compacted to re-create sheet flow and small swales, tying in with local topography and adjacent drainages. The finished surface was winterized with hydromulch and placement of straw wattles along the contour.

We collected seed during the 2000 and 2001 seasons with some seed directed to supercell and container production.

During 2002, the California Tahoe Conservncy incorporated into the soil a blend of organic materials into the surface including pine needles, wood chips, dairy manure, yard waste, and mineral additives. An excavator de-compacted the top 3 feet of fill material prior to incorporation of the organic material. Also, dead snags were collected from adjacent Lodgepole forest and distributed throughout the site.

The seed was hand broadcast and covered with one inch of pine needle mulch. Containerized plants were planted during the fall once precipitation began. Last, some wattles were reset and interpretive signs were put out explaining the project and requesting no disturbance.

During 2003 spring, additional containerized plants were put in. The tree seedlings were watered once and some weeds were pulled.

SPECIES LIST

Direct seeding

Elymus elymoides	Squirreltail	40.00 PLS lbs
Hesperostipa comata	Needle and thread grass	.75 BK lbs
Poa secunda	Sandberg bluegrass	2.00 Bk lbs
Lupine lepidus	Torrey's lupine	1.00 PLS lbs
Ribes roezlii	Sierra gooseberry	.35 PLS lbs

Containerized plants

Pinus jeffreyi	Jeffrey pine	70 quart containers
Pinus jeffreyi	Jeffrey pine	10 3-gallon containers
Pinus ponderosa	Ponderosa pine	485 2-0 cells
Salix lemmonii	Lemmon's willow	10 1-gallon containers
Elymus elymoides	Squirreltail	1562 supercells
Poa secunda	Sandberg bluegrass	550 supercells
Hordeum brachyantherum	Meadow barley	200 supercells
Hesperostipa comata	Needle and thread grass	30 supercells
Rosa woodsii	Mountain rose	200 supercells
Lupinus lepidus	Torrey's lupine	200 supercells
Eriogonum umbellatum	Sulfer buckwheat	200 supercells
Artemisia tridentata	Mountain sagebrush	200 supercells

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PINE CREEK MINE RECLAMATION

This project involved stabilizing 90 acres of historic tailings ponds. The tailings are located at the top of Pine Creek Canyon, which is located at 7500' on the eastern front of the Sierras 15 miles northwest of Bishop California. Heavy winds and harsh winter conditions were continually sending sediments down the canyon. The USFS reached an agreement with the current owner to stabilize these ponds by placing six inches of local alluvium on the ponds as a cap and seeding with a desired seed mix. Fortunately, the client analyzed the tailings and found them to be relatively benign and saturated with water. The contractor excavated 80,000 yards of alluvium from a historic barrow pit just east of the tailings. They installed a 6 inch cap and left a slight grade on the tailings surface. The seed was broadcast and dragged just prior to winter. Snow was falling during the last few days of seeding.

The USFS required that 1500 lbs of local seed to be collected for this project. We agreed to collect as much local seed as possible but emphasized to the USFS that this priority needs to allow room for aggressive colonizers whether native or not. We have seen many project designs where the native philosophy has compromised short-term physical stability by excluding colonizers.

This job has been successful with initial colonization of native colonizers as well as germination of many later seral shrubs. In the end, we will continue to expand our inventory of early seral natives and hope to strike a good balance between natives and the need for physical stability without introducing aggressive species that may interrupt normal seral advance.

THE SEED BLEND

SPECIES		PLS #/ACRE
Grasses		
Indian ricegrass	Achnantherum hymenoides	.15
Bluegrass sandberg	Poa secunda var. juncifolia	2.50
Wildrye Great Basin	Leymus cinereus	4.00
Wildrye creeping	Leymus triticoides	1.25
Squirreltail bottlebrush	Elymus elymoides	1.30
Desert needlegrass	Achnantherum speciosa	.25
Shrubs		
Rabbitbrush rubber	Chrysothamnus nauseousus	.15
Desert bitterbrush	Purshia glandulosa	3.00
Basin sagebrush	Artemisia tridentata tridentata	.50
Bittercherry	Prunus emarginata	.25
Desert peach	Prunus andersonii	.65
Forbs		
Giant blazing star	Mentzelia laevicaulis	.10
Buckwheat sulfur	Eriogonum umbellatum	.30
Buckwheat nakedstem	Eriogonum nudum	.08
Buckwheat flat-top	Eriogonum fasciculatum	.10
Louisiana sagebrush	Artemisia ludoviciana	.45

Prickly poppy	Argenome munita	.20
Penstemon	Penstemon speciosa	.10
Dusty maidens	Chaenactis douglasii	.10
	Total PLS lbs per acre:	15.43

This blend applied 160 seeds per square foot. We have found that Poa, Leymus, and Achnantherum all exhibit slow germination and low seedling vigor. We were fortunate that seeding occurred in the fall, allowing the species to winter over and gain the benefits from the cool stratification and spring freeze/thaw cycles. The most aggressive colonizers included the three forbs, Mentzelia, Artemisia ludoviciana, and Argenome munita. Chrysothamnus was also initially quite common.

MT HOOD HIGHWAY IMPROVEMENT

In 1998, the Federal Highway Administration initiated a highway and intersection improvement project at the Mt Hood Meadows ski resort that involved an overpass construction and extensive cut and fill construction. The project was set for completion late fall 2000. The U.S. Forest Service requested that local seed be collected for reclamation and awarded a two-year seed collection contract for the fall of 1998 and 1999. The species list included early seral colonizers that we found thriving on existing disturbed areas including the following list. The USFS allowed us to compliment our native collections with commercial grass cultivars.

Species	Variety	PLS #/acre
Grasses		
Agropyron trachycaulum	Pryor	5.00
Agropyron riparian	Sodar	5.00
Agropyron trichophorum	Greenleaf	7.00
Bromus carinatus	VNS	7.00
Forbs		
Lupine latifolius	Broadleaf lupine	1.50
Anaphalis margaritaceae	Pearly everlasting	.50
Achillea millefolium	Yarrow	.50
Solidago Canadensis	Canada Goldenrod	1.00
Shrubs		
Ceanothus velutinus	Snowbrush	2.00
Vaccinium membranaceum	Big leaf Huckleberry	.50
Xerophyllum tenax	Beargrass	2.00
	Total PLS #/acre:	32.00

Once construction was completed, the contractor re-applied salvaged topsoil to the new cut slopes. A tackifier was sprayed onto the new cut slopes during the summer prior to the fall seeding to provide temporary stability. Once fall arrived, the slopes were hydro-seeded with a slurry containing the seed and a mixture of organic soil amendments and the tackifier. The slopes held up through the first winter with over 200 inches of snow. The first summer growth included a good showing of the native colonizers as well as the slender wheatgrass.

CONCLUSION

All seven projects share concerns for soil quality and stability. Aside from ecotypic variation, the seed and plant material lists share many common species. Whether the project is urban or rural, a common group of native and introduced species have proven their ability to survive in our arid ecotypes. Seral advance is evident at most of these sights yet they are generally a long ways from restoration to the surrounding undisturbed ecotype. Continuing drought, increased fire frequency, local impacts, and weeds could upset the stability of these young plant communities but hopefully, they are advancing to a condition that will be dynamic and diverse enough to survive perturbation. Stay tuned.

SOIL FERTILITY MANIPULATION AND GRASS SEEDING FOR RESTORATION OF A CANADA THISTLE INFESTED SITE

Julie Knudson[1]*, Paul Meiman[1], Edward Redente[1], George Beck[2], Cynthia Brown[2], and Mark Paschke[1]

[1]Department of Forest, Rangeland and Watershed Stewardship, Warner College of Natural Resources, Colorado State University, Fort Collins CO 80523, USA

[2]Department of Bioagricultural Sciences and Pest Management, College of Agricultural Sciences, Colorado State University, Fort Collins CO 80523, USA

*Corresponding Author: Julie Knudson, email: julie.knudson@colostate.edu, ph: 970-420-1915

ABSTRACT

Canada thistle (*Cirsium arvense*) continues to infest private and public lands across the western United States at an alarming pace. Efforts to control this noxious perennial plant through herbicide use and restore valuable forage, wildlife habitat, and/or esthetics to these invaded sites through revegetation efforts have met with mixed success and public response. Concerns over chemical toxicity and the use of non-native species for revegetation efforts have forced some land managers to search for alternative restoration methods. Unfortunately, many non-herbicide treatments tested thus far have demonstrated limited utility for long term control, and the often slower establishment rate of native plant species relative to non-native species have resulted in limited experimentation with native species for this purpose. For this research, it was proposed that soil fertility manipulation be further investigated as a control measure for Canada thistle. It was hypothesized that manganese (Mn) fertilization and/or organic matter addition could significantly reduce Canada thistle infestation. It was also proposed that a common native revegetation grass – western wheatgrass – be evaluated against a common non-native revegetation grass – intermediate wheatgrass – for its potential utility in post-treatment restoration of a Canada thistle infested site. A three year field study was conducted near Platteville, Colorado, to determine the response of Canada thistle to twenty treatment combinations of Mn fertilization (present/absent), organic matter addition (present/absent), fall herbicide application (present/absent), and seeding of western wheatgrass (present/absent) or intermediate wheatgrass (present/absent). Results show similar benefits for western wheatgrass and intermediate wheatgrass. Organic matter addition was not an effective control.

KARN'S MEADOW WETLAND REHABILITATION ALONG FLAT CREEK IN JACKSON, WYOMING

Rachel Markko
Natural Resources Specialist
Teton Conservation District
Jackson, Wyoming

ABSTRACT

Starting in the spring of 2007, Teton Conservation District staff, and other contributing partners, began a project to rehabilitate sections of the Karn's Meadow wetland along Flat Creek within the town of Jackson, Wyoming. This was necessary due to recent creek enhancement construction improvements made to Flat Creek in order to restore its water quality and riparian habitat. Volunteers, government agencies, non-profits, and local businesses helped clean up trash, treat noxious weed species, cut and plant native willows (*Salix* spp.), lay down top soil, plant native seeds, water, and cover each area with Jute burlap matting for erosion control and stability. In the mostly grass-dominated upland, we planted a mix of western wheatgrass (*Pascopyrum smithii),* thickspike wheatgrass (*Elymus lanceolatus),* tufted hairgrass (*Deschampsia caespitosa),* bluebunch wheatgrass (*Pseudoroegneria spicata),* big bluegrass (*Poa secunda),* mountain brome (*Bromus marginatus),* slender wheatgrass (*Elymus trachycaulus),* and American vetch (*Vicia americana).* The resulting native vegetation propagation has been a success. We have achieved a 75% regrowth in all our willow plantings, noxious weeds are at a maintenance level, and the native seed mix is establishing itself very well. We are excited to see this springs results as we continue to monitor and maintain the rehabilitated sites in Karn's Meadow wetland along Flat Creek.

BEST MANAGEMENT PRACTICES FOR REMEDIATION/RESTORATION OF DEGRADED SOILS IN THE CENTRAL GREAT PLAINS REGION

Maysoon M. Mikha[1*], Merle F. Vigil[1], Joseph G. Benjamin[1], Dave J. Poss[1], and Francisco J. Calderon[1]

[1]USDA-ARS, Central Great Plains Research Station, Northern Plains Area, 40335 CR GG, Akron, CO 80720

ABSTRACT

Farmlands in the Central Great Plains Region (CGPR) have lost topsoil through wind and water erosion induced by tillage and poor soil management (Wheat-fallow management). Productivity of degraded/eroded soils can be restored using organic amendment such as manure and improved crop and soil management. Our objectives are to: **(i)** identify optimal rates of manure to supply nutrients to typical dryland crops in the CGPR; **(ii)** determine the rate of improvement of soil physical and chemical properties associated with manure amendment/management; and **(iii)** quantify the difference in restoration of eroded soils using manure as an amendment versus managing those same soils with legume grass mixtures and chemical fertilizer. The experiment, established off on a farmer field near Akron, Colorado has a randomized complete block design with crops/soils managed using manure amendment compared with soils/crops managed with commercial fertilizer. Treatments include a tillage variable (deep plow, shallow sweep, and no-tillage), manure and commercial nitrogen rates (none, low and high). Changes in soil physical, chemical, and biological properties as well as grain yield are evaluated every year. The preliminary data (for one growing season) suggests that manure addition increases the productivity of eroded soils in the Central Great Plain Region. In subsequent years this experiment (after multiple manure applications) could result in changes in soil parameters and increased yield. This report will provide "benchmark" measurements of the treatments being studied and first year grain and biomass yields.

INTRODUCTION

Farmlands in the CGPR have lost topsoil through wind and water erosion induced by tillage and poor soil management (wheat-fallow). These soils are now degraded with low soil quality and productivity. Some of the soil quality parameters that are affected by poor soil management include: soil compaction, infiltration rate, soil water holding capacity, soil nutrient exchange capacity, soil aggregation and aggregate stability, organic carbon build up, soil pH, and soil microbial ecology. In addition to wind and water erosion, numerous studies have indicated that soil degradation is a result of soil organic matter lost through increased soil disturbance and decomposition (Angers et al., 1993; Lal et al., 1995). Productivity and quality of degraded/eroded soils can be restored using manure and improved management. Manure amendment is a management practice that can improve the nutrient status of the soil (Vitosh et al., 1997) and increase soil organic carbon levels (Mikha and Rice, 2004). Aoyama et al.

* Corresponding author (Maysoon.Mikha@ars.usda.gov)

(1999a) observed an increase in soil organic matter with addition of manure and the subsequent increase the formation of slaking-resistant soil aggregates. Aoyama et al. (1999b) concluded that applying manure contributed to the accumulation of aggregates-protected C and N. Similarly, Mikha and Rice (2004) reported that aggregate-protected labile carbon and nitrogen was significantly greater with manure amendment when compared with chemical fertilizer treatment. The combination of no-till management withy manure amendment further increased the formation and stabilization of soil aggregates and increased the physical protection of soil carbon and nitrogen (Mikha and Rice, 2004; Jiao et al., 2006).

Tillage practices can alter soil organic matter and effect soil erosion. Tillage practices can reduce soil organic matter by (i) increasing residue mixing into the soil which increases aeration and enhances residue decomposition, (ii) destroying soil aggregate and exposing previously protected soil organic matter to soil fauna, and (iii) increasing losses due to soil erosion (Blevins and Frye, 1993; Beare et al., 1994; Tisdall, 1996; Paustian et al., 1997). Tillage systems may also affect soil physical condition. Kladivko (2001) reported that tillage practices change soil water content, soil temperature, and aeration. However, no-tillage systems increase surface soil organic matter as a result of increased residue accumulation, less residue mixing, oxidation, and soil disturbance, high soil water content, reduced soil temperature, proliferation of root growth and biological activity, and decreased risks of soil erosion (Blevins and Frye, 1993; Eghball et al., 1994; Lal et al., 1994; Six et al., 1999). Many studies have shown that increased soil organic matter with no-tillage management (Carter, 1992; Beare et al., 1994; Six et al., 1999) improves soil aggregation and aggregate-associated soil organic matter (Mikha and Rice, 2004).

Organic amendment such as manure can have a positive effect on soil quality by improving soil porosity and preventing soil crust formation (Pagliai et al., 2004). Continuous manure application over several years, can have a positive effect by reducing soil bulk density (Miller et al., 2002; McVay et al., 2006). Reduction in soil bulk density and greater soil porosity are clear indicators for reduced soil compaction, improved aeration, greater infiltration and improved conditions for plant root penetration.. Frye and Blevins (1997) reported that improving plant productivity is related to enhanced root growth, crop yield, and plant biomass. Also, the addition of organic material as a nitrogen source (manure and/or compost) can mitigate the negative effects of excessive tillage on grain yield and soil organic carbon conservation (Eghball and Power, 1999; Singer et al., 2004; Mando et al., 2005). Similarly Eghball et al. (2004) documented, the residual effect of increased nutrient availability due to multiple years of manure application increase corn grain yield for one growing season and influence soil properties for several years (Eghball et al., 2004).

The impact of manure applications and tillage practices on plant productivity has been studied intensively for more than 30 years. However, the effects of multiple years of beef manure application combined with different tillage systems on improving soil quality parameters and the productivity of eroded soil are not well documented in dryland systems. The objectives of this study are; (i) Identify optimal rates of beef manure to supply nitrogen and phosphorus to typical dryland crops in the CGPR; (ii) determine the rate of improvement of crop yield, soil physical, chemical, and biological properties associated with dryland manure management of eroded soils; and (iii) Quantify the advantages of restoring eroded soils using manure as an amendment versus managing those same soils with chemical fertilizer.

METERIALS AND METHODS

Site Management

The experimental area consists of 4.8 hectares while the plot area consists of 1.7 hectares. The large remainder is due to requiring large alleys to manage full size farm equipment. Individual experimental units (plots) are 13.7 m wide and 15.2 m long (45 feet wide and 50 feet long). The experimental design is a randomized complete block with four replicates. The replicates are arranged such that three are parallel to each other across the slope. The fourth is split with the first ten plots adjacent to replicate one and the last ten plots adjacent to replicate two.

Cropping Sequence

Crop rotations used are typical to the Central Great Plains Region. The rotation currently being used is corn (2006) – proso Millet (2007) – forage Winter Triticale (2008). The crop rotation in subsequent years will be decided according to weather pattern (temperature and precipitation). The crops are normally planted on all of the plots and alleys ways. In 2006, before manure and tillage treatments were established, corn was planted through all plots in the east west direction (perpendicular to planting in 2007 and 2008) in a plant 2 skip 2 row configuration.

Manure Application

Manure is applied in the fall to allow for winter precipitation to restore moisture lost during tillage operations. Manure is applied using a Meyer spreader. This manure spreader was used at low RPM to obtain a uniform spread width of 2.7 m. Calibration of the manure spreader was performed by driving the manure spreader over a tarp and then weighing the manure collected on the tarp. The rear gate was left open during application and rates were controlled by changing ground speed. Beef manure was obtained from a local feedlot. Samples of the manure "piles" to be used were taken and analyzed for nutrients to determine amount of nutrients applied to the plots.

There is a low and a high manure rate applied for each tillage treatment. The low was determined by estimating the amount of nitrogen required to meet crop needs average over the next six years. The high rate is two times the low rate for fertilizer and three times the low rate for manure. Realizing that this is in excess of crop nutrient needed this high rate was used to ensure an increase in the amount of organic carbon applied. One of our hypotheses is that these higher rates of manure will significantly increase soil organic matter and improve soil physical properties in these plots.

Table 1. Manure Factors relative to treatment and tillage depth.

Tillage Treatment	Frequency	Low	High
		----- kg/ha -----	
No-tillage	Annual	1X	3X
Sweeps (13 cm depth)	Annual	1X	3X
Deep tillage (36 cm depth)	Bi-Annual	2X	6X
Deep Tillage	One time	6X	18X

Five levels of manure were applied to the plots in fall 2006 depending on the treatment (Table 1). A 1X rate is applied to plots for which there is an annual application on a low fertilizer/manure treatment. The rate factor applied was based on frequency of application and the rate. For example the rate for the Deep tillage, one time treatment was determined by taking the 1X rate times six (since we are estimating fertility needs for the next six years) for the low manure nitrogen rate, while the high rate of the same treatment would have an 18X rate. The amount of manure (that meet the nitrogen requirement) for different treatment combination is presented in Table 2.

Table 2. Fertilizer and manure application rates by treatment.

	Fertilizer Application			Manure Application					
Crop	Date	Low	High	Date	1X	2X	3X	6X	18X
		--- kg N/ha ---			---------------- kg N/ha ----------------				
Proso Millet	22-Jun-07	30	60	20-Nov-07	83	160	260	458	1342
Winter Triticale	16-Oct-07	30	60	5-Oct-07	65	0	187	0	0

Plot Operations

Manure was applied November 16th, 2006 for the 2007 proso millet crop. The tillage treatments for the manure plots were performed the same week just after manure application. The tillage treatments for the fertilizer and control plots were performed the following week because of time constraints. The fertilizer for these plots was not applied until the spring, immediately prior to planting (Jun 22nd, 2007). The deep tilled plots were packed in the spring to firm the soil to ensure good seed to soil contact at planting time. Spray operations were performed at and prior to planting proso millet to control weeds. No herbicide applications were done after the proso millet was planted. The proso millet was swathed with a plot harvester after 95% of the head had changed from green to mature. The rest of the plots were swathed soon after. The proso was picked up with a plot combine two week later after it had sufficiently dried.

RESULTS AND DISSCUSIONS

Precipitation in 2007 was less than normal (Figure 1) especially during the critical period of millet germination. Crop soil water used during the growing season was calculated by adding the amount of precipitation (from planting (Jun 22nd) to harvesting (September 26th)) to the differences between soil water content at planting and harvesting. Throughout the growing season, crop soil water use ranged between 18.1 cm to 27.7 cm integrated to 120 cm deep soil profile (Table 3). Soil water contents at planting (Jun 22nd, 2007) ranged between 15%-19% in the surface 15 cm (data not shown). Similarly, soil water contents in the whole 120 cm profile ranged from 15% to 19.1% (data not shown). In general, soil water contents at field capacity range17% to 20% depending specific soil type. This indicates that soil water contents were adequate for planting, but a lack of precipitation during June and July may have reduced final millet yields. Our 2007 grain yield data documents, tillage, N source (manure vs. fertilizer) and N rate effects on millet production (Figure 2). The effect of different tillage practices and nitrogen rate were more pronounced with manure than fertilizer treatment. The combination of

Table 3: Soil inorganic nitrogen (kg N ha^{-1}) and plant total soil water used (cm) during 2007 growing season integrated to 120 cm depth.

		------- Preplant --------		--- Growing Season ----
Tillage	Nitrogen type	NH_4^+-N	NO_3^--N	Total Soil Water Used
		------ kg N ha^{-1} -------		------------ cm-----------
No tillage	3X[†] manure	11.0	27.5	26.0
	High[‡] fertilizer	10.8	21.8	27.7
	1X[††] manure	10.9	25.2	25.6
	Low[‡‡] fertilizer	10.9	21.5	24.3
	Control[!]	11.1	15.8	24.1
Sweep[§] tillage	3X manure	11.8	46.1	25.5
	High fertilizer	10.7	18.1	25.6
	1X manure	10.5	25.3	26.1
	Low fertilizer	10.7	11.4	25.9
	Control	10.7	17.8	26.3
Deep tillage (2y)[#]	6X manure	12.0	72.7	23.3
	2X manure	12.5	53.0	22.4
Deep tillage (6y)[*]	18X manure	11.8	128.5	22.1
	6X manure	12.1	108.1	23.2
Deep tillage[&]	High fertilizer	10.8	22.1	18.2
	Low fertilizer	11.1	44.0	18.1

[†] Manure applied at 260 kg N ha^{-1}.
[††] Manure applied at 83 kg N ha^{-1}.
[‡] Fertilizer applied at 60 kg N ha^{-1}.
[‡‡] Fertilizer applied at 30 kg N ha^{-1}.
[!] No nitrogen added (0 kg N ha^{-1}).
[§] Tillage at 13 cm depth.
[#] Manure addition equivalent to two years (458 kg N ha^{-1} for 6X and 160 kg N ha^{-1} for 2X and mixed with the soil profile at 36 cm depth.
[*] Manure addition equivalent to six years (1342 kg N ha^{-1} for 18X and 458 kg N ha^{-1} for 6X and mixed with the soil profile at 36 cm depth.
[&] Fertilizer addition equivalent to one year (60 kg N ha^{-1} for high N and 30 kg N ha^{-1} for low N) and mixed with the soil profile at 36 cm depth.

no-tillage and manure amendment increased millet yield by 27% (at low nitrogen rate) and by 20% (at high nitrogen rate) compared with the combination of sweep-tillage and manure

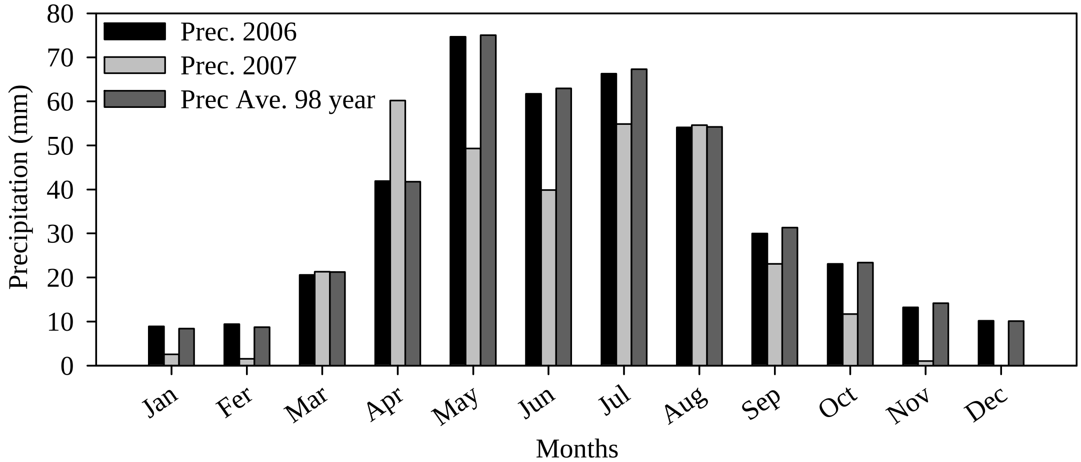

Figure 1. Monthly precipitation for 2006, 2007, and 98 years average at Akron, Colorado.

treatment (Figure 2). Millet grain yield increased as manure nitrogen rate increased by 17% when managed with no-tillage and 23% when managed with sweep tillage. The greater grain yields associated with no-tillage combined with manure amendment could be due to soil water conservation during the early growth stage of millet. Deep-tillage showed a reduction in millet

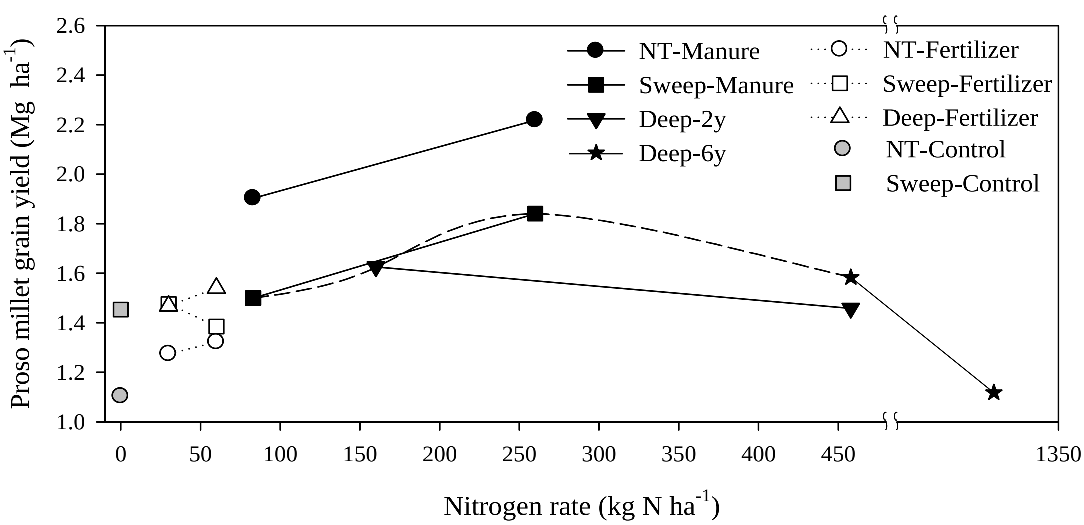

Figure 2. Proso millet yield (Mg yield ha^{-1}) as affected by nitrogen rate and different tillage ptactices. (NT): no-tillage; (Deep-2y): manure application once and equivelent to 2 years N rate and tillage at 36 cm depth; (Deep-6y): manure application once and equivelant to 6 years N rate and tillage at 36 cm depth; and (Deep-fertilizer): nitrogen application equivelant to 1 year N rate and tillage at 36 cm depth.

yield as the manure nitrogen rate increases. There was 10% and 29% reduction in millet yield as manure nitrogen rate increased from 83 to 260 (kg N ha^{-1}) and from 458 to 1342 (kg N ha^{-1}), respectively. However, across tillage (sweep and deep tillage) a maximum yield (with manure treatment) was observed (represented by dash line in Figure 2) around 260 (kg N ha^{-1}) where the yield was reduced as manure nitrogen increase thereafter (Figure 2). The excessive amount of manure nitrogen that was applied with deep-2y and deep-6y in combination with low precipitation could have reduced millet growth and grain yield. Grain yield increased with the combination of no-till and fertilizer (by 4%) and deep-tillage (by 5%), while a reduction was observed with sweep-tillage (by 7%) as the rate of inorganic fertilizer increased from 30 to 60 kg N ha^{-1} (Figure 2). Because this is just the first year of production for this experiment, no explanation can be given for the reduction of grain yield for sweep-tillage with high fertilizer rate compared with low fertilizer rate. Overall, grain yields were 44% greater with no-tillage combined with manure amendment than with no-tillage and fertilizer.

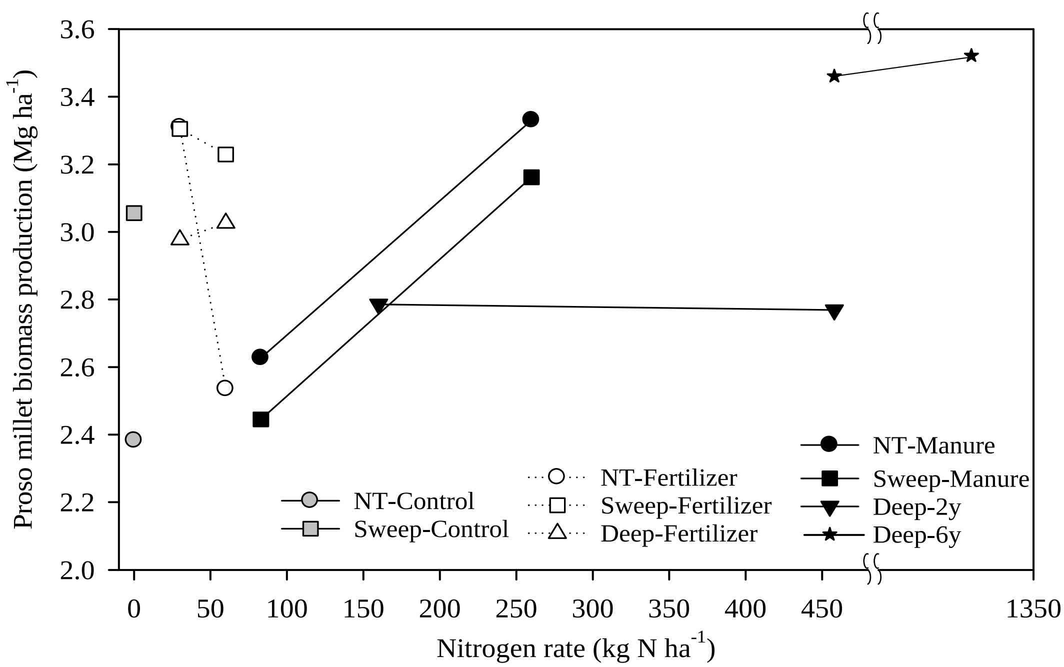

Figure 3. Proso millet biomass (Mg ha^{-1}) as affected by nitrogen rate and different tillage ptactices. (NT): no-tillage treatment; (Deep-2y): manure application once and equivelent to 2 years N rate and tillage at 36 cm depth; (Deep-6y): manure application once and equivelant to 6 years N rate and tillage at 36 cm depth; and (Deep-fertilizer): nitrogen application equivelant to 1 year N rate and tillage at 36 cm depth.

Proso millet biomass production exhibited a similar trend as the grain yield especially with the combination of no-till and manure amendment and sweep-tillage manure (Figure 3). High N rate translated to high plant biomass production. High crop water use translated to high yield except with sweep-tillage manure and deep-2y manure, where high yield were associated with low water usage (Figure 4). There were no changes in crop water use in relation to high and low grain yields associated with deep-fertilizer treatment.

In summary, the preliminary data suggests that manure additions could improve the productivity of unproductive (eroded) soils in the CGPR. No specific explanations can be given for treatment differences since we have only one growing season and the environmental factors (temperature, precipitation, and evapotranspiration) could have more effect on final grain yields than our imposed treatments. In subsequent years it will be important to determine the improvement in different soil parameters and to document yield effects from different management practices. Several additional “benchmark” measurements (physical, chemical and biological) are being made on the soils in these plots and these measurements will be repeated periodically throughout the duration of the experiment.

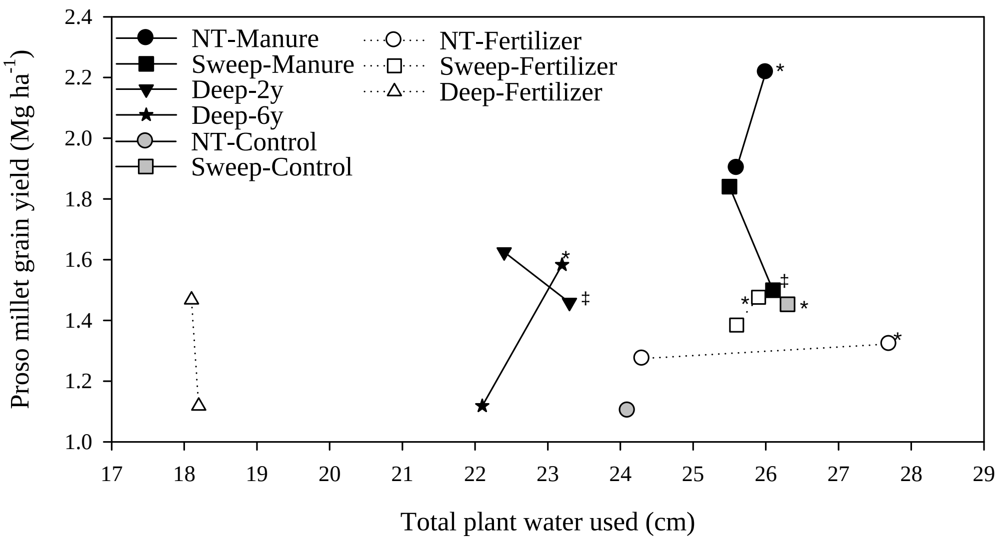

Figure 4. Relationship between proso millet yield (Mg ha^{-1}) and total soil water used (cm) throughout the 2007 growing season as affected by nitrogen rate and different tillage ptactices. (*) represents high grain yield associated with high water usage and (‡) represents high grain yied assiciate with low water usage.

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HISTORY OF RECLAMATION AT THE QUESTA MINE – A CASE HISTORY

Anne Wagner, PhD
Manager, Environmental and Public Policy
Chevron Mining Inc. – Questa Mine

The Chevron Mining Inc. Questa Mine (formerly Molycorp) is an underground molybdenum mine in northern New Mexico. Underground mining operations began in 1918 and 1965 marked the beginning of nearly 20 years of open pit operations. In 1982, underground mining resumed and open pit mining ceased. The rock piles created during the open pit operations cover nearly 700 acres of steep, primarily south facing slopes in the Red River Canyon.

In the mid-1980s, Molycorp began working with the Soil Conservation Service (SCS, now the NRCS) to investigate reclamation on the rock piles, primarily focusing on grass and shrub species. In the early 1990s, New Mexico State University – Mora Research Center began evaluating the potential for reforestation on the rock piles. Following the initial investigations, large-scale plantings were undertaken on several of the rock piles. In 2003 Molycorp launched a new, large scale test plot program with input from stakeholders, including State agencies and NGOs.

The poster will cover the results of the early investigations and discuss the shift in focus from 1980s reclamation species to the consideration of forest species, similar to the surrounding ecosystem. The poster will include the importance of stakeholder engagement in the reclamation planning process.

MOUNTAIN COAL COMPANY, WEST ELK MINE, DRY FORK OF MINNESOTA CREEK, RECLAMATION PHOTOGRAPH PROJECT, 2004-2007

Michael K. Ward

Michael Ward Outdoors, LLC
38905 Back River Road
Paonia, CO 81428

ABSTRACT

Over the past 4 years (2004-2007) reclamation photo-points have been established and taken on lands being utilized for coal development activities by Mountain Coal Company, near Somerset, Colorado. This paper discusses methods related to the photo-reclamation project and results of revegetation efforts in the project area, including photographs of a representative group of 18 photo-points.

INTRODUCTION

During the 2004, 2005, 2006 and 2007 field seasons, photo-points were established and digital photographs were taken in several areas where Mountain Coal Company has conducted coal exploration and development activities since 1996. These sites are located on mine property as well as on the Gunnison National Forest. Michael Ward Outdoors, LLC was contracted to perform this work. The reason MCC is conducting the photo survey reconnaissance is so that they can determine when they should conduct additional vegetation surveys to apply for and get approval for Phase 3 release of bond with the Colorado Division of Reclamation, Mining and Safety (CDRMS).

PROJECT DESCRIPTION

Photo-points were generally marked with pin flags or with native materials and GPS coordinates were noted. Past years photographs were also used to more accurately relocate photo-points. Up to 155 photo-points have been established during the four year period.

Since there is insufficient space to include all 155 photo-points in this paper, a representative sample of 18 points is depicted. Those 18 photo-points are located in the Long Draw drainage of Deep Creek, and show pre-reclamation and reclamation over three of the four years. In most cases, photographs for the 2006 season are omitted to allow space for pre-reclamation/post-reclamation pictures in 2004. (Although only 18 photo-points are shown, data from all photo-points where reclamation has occurred is included in Table 3 in the Conclusion.)

The area where these roads and drill sites are located is on north, south and east facing, 20-50% side-slopes with sandstone subsoils, and in most cases minimal top soil. Disturbed areas are primarily in the Mountain Shrub Vegetative Community with Gambel oak *(Quercus gambelii*), snowberry *(Symphoricarpos oreophilus)*, chokecherry *(Prunus virginiana)* and serviceberry *(Amelanchier alnifolia)* being the predominant vegetative species. Drill sites and roads were brought back to near original contour in the summer of 2004. Topsoil which was available was re-applied and the areas were seeded and either straw-mulched or covered with erosion control blankets. Electric fences, to preclude livestock grazing, were installed on the more harsh sites and re-seeding occurred on MDW 16-03 in 2005.

Table 1 shows the seed mix and application rate used:

Table 1: Mountain Shrub Community	
Species	PLS lbs/acre
Mountain Brome	3
Prairie Junegrass	3
Western Wheatgrass	4
Indian Ricegrass	2
Sandburg Bluegrass	3
Bluebunch Wheatgrass	3
Showy Daisy	1
Lanceleaf Coreopsis	1
Golden Banner	1
Totals	21

A subjective rating system was initiated in 2005 and utilized again in 2006 and 2007. The system used % groundcover, height of vegetation and encroachment of native shrubs as rating parameters. Rating categories are: Excellent, Good, Fair, and Poor as shown in Table 2.

Table 2: Vegetative Rating Parameters

Rating	**Groundcover**	**Vegetation height**	**Encroachment**
	%	**Inches**	**Feet**
E	81-100	30+	20+
G	61-80	16-29	10-19
F	31-60	6-15	3-9
P	0-30	< 6	<3

Long Draw Road Pt 1 (S) (N 38 53' 19.7", W 107 25' 25.8") <u>4-29-04 & 10-4-04</u>

<u>6-30-05.</u> Ground-cover 30-50%, grass and forbs average 8-10" high.	**<u>7-6-07.</u> Ground-cover 65-80%, grass and forbs 14-30" tall, (average 20"), 10' chokecherry encroachment on western edge.**

Long Draw Road MDW 16-04 (E) (N 38 53' 15.1", W 107 25' 13.1") <u>4-29-04 & 10-4-04</u>

<u>6-30-05.</u> Road 70-80% ground-cover, location only 10-30%, lot of matting remaining.

<u>7-6-07.</u> Road 90% ground-cover (avg. 36" tall); location 50-70%, grass/forbs on location avg. 18" tall.

MDW 16-03 West Entry (E) (N 38 53' 10.1", W 107 24' 58.3")
<u>4-26-04 & 10-4-04</u>

6-30-05. **Ground-cover 30-50% in roadway, vegetation 6-8" tall.**

7-6-07. **Drill site ground-cover 50-70%, ROW 70-90%, grass/forbs avg. 18" tall.**

MDW 16-03 (N) (N 38 53’ 11.0”, W 107 24’ 56.1”) 4-26-04

MDW 16-03 Top (N-NW) (N 38 53’ 9.0”, W 107 24’ 56.1”) 10-4-04

6-30-05. Minimal revegetation, ground-cover 30-40% in places, with 6-10”grass. Reseeded after photo taken.

7-6-07 Ground-cover 90% on top, 70-90% overall, grass 18-24” tall. Oak, chokecherry encroachment 5’-10’ on top edge.

MDW 16-02 (S) (N 38 53' 11.7", W 107 24' 52.3") <u>4-26-04 & 10-4-04</u>

<u>6-30-05.</u> Fill-side ground-cover 10-15%, upper side 20-30%. Grasses average 8" tall.

<u>7-6-07.</u> Roadway ground-cover 10-15%, remainder 65-80%, grasses average 14" tall. Snowberry, chokecherry, oak invasion 5-10' on edges.

MDW 17-03 (NW) (N 38 53' 01.1", W 107 24' 56.6")
<u>4-26-04</u>

MDW 17-03 Top (SE) (N 38 53' 01.3", W 107 24' 56.9")
<u>10-4-04</u>

<u>6-30-05.</u> Minimal re-vegetation, 10% ground-cover with 8-10" grass. Canada thistle SW corner location.

<u>7-6-07.</u> Big improvement over 2006, 50-70% ground-cover with 20-30" grass. Electric fence is hot.

MDW 15-03.5 (W) (N 38 53' 17.7", W 107 25' 02.0")
<u>4-29-04 & 10-4-04</u>

6-30-05. **Ground-cover 10-15% with scattered 14-24" grass on sandstone soil.**

7-6-07. **Ground-cover 60-80%, average 18-24" grass.**

Long Draw Rd Pt 2 (NW) (N 38 53' 21.2", W 107 24' 56.4")
<u>4-29-04 & 10-4-04</u>

<u>6-30-05.</u> Ground-cover 10-25% on sandstone. Grass averages 24", but scattered.

<u>7-6-07.</u> Ground-cover 50-70%, grass/forbs 16-30".

17-02 Rd Pt 1 (N) (N 38 53’ 19.5”, W 107 24’ 52.8”) <u>4-29-04 & 10-4-04</u>

<u>6-30-05.</u> Ground-cover 50-60% with forbs and grass 16-20” tall.	**<u>7-6-07.</u> Ground-cover 70-90%, forbs and grass 18-24” tall with some Canada thistle. Moderate bracken fern encroachment.**

17-02 Rd Pt 2 (SE) (N 38 53' 18.7", W 107 24' 42.2")
<u>4-29-04 & 10-4-04</u>

<u>6-30-05.</u> Ground-cover 40-60% with forbs and grasses averaging 20"tall. Some oak encroachment on edges.

<u>7-6-07.</u> Ground-cover 80-90% with forbs and grasses 18-30" tall (ave.24"). Some oak, chokecherry encroachment on edges, also musk thistle on site.

MDW 16-01 Rd Entry (NW) (N 38 53’ 07.0”, W 107 24’ 42.9”) <u>4-29-04 & 10-4-04</u>

<u>6-30-05.</u> Ground-cover 30-50% with 12-16” grass.

<u>7-6-07.</u> Ground-cover 70-90% with 16-24” grass/forbs, 5-10’ chokecherry-oak encroachment.

MDW 16-01 Rd Entry (N) (N 38 53’ 07.0”, W 107 24’ 42.9”)
<u>4-29-04 & 10-4-04</u>

<u>6-30-05.</u> Ground-cover 30-50% with 12-16” grass.

<u>7-6-07.</u> Ground-cover 70-90% with 16-24” grass/forbs, 5-10’chokecherry-oak encroachment.

MDW 16-01 (S) (N 38 53’ 09.0”, W 107 24’ 42.7”) <u>4-29-04 & 10-4-04</u>

<u>6-30-05.</u> **Ground-cover 60-70% with 24” grass on north end, 50-70% weed cover on drill location.**

<u>7-6-07.</u> **Ground-cover 70-90%, grass/forbs 16-24” avg. 20”. Chokecherry encroachment up to 40’ on west side. Abundant musk thistle.**

MDW 17-02 (N) (N 38 52' 58.0", W 107 24' 46.3") <u>4-29-04 & 10-4-04.</u>

<u>6-30-05.</u> Fillslope ground-cover 40-50% with 14-20"grass. Upper slope ground-cover 10%.

<u>7-6-07.</u> Electric fence hot, ground-cover 60-90%, 20-30"grass, average 24", 5' snowberry-oak encroachment. Minimal Canada thistle.

MDW 17-02 Rd Entry (S) (N 38 52' 59.6", W 107 24' 45.4") <u>4-29-04 & 10-4-04</u>

<u>6-30-05.</u> Basically same as site 17-02, but access road with 30-50% groundcover.

<u>7-6-07.</u> Electric fenced, lower slope ground-cover 80-95%, upper slope 40-70%, 20-30"grass/forbs, average height 24".

Drill Site 15-02. <u>6-19-04</u> (N 38 53' 24.9", W 107 24' 48.1") Brought to natural contour in 2003.

<u>6-30-05.</u> Ground-cover 50-70% with 24" grass and several bare spots.

<u>6-24-06.</u> Ground-cover 50-70% with 16-24" grass/forbs and several bare spots.

<u>7-6-07.</u> Ground-cover 60-80% with grass/forbs averaging 24". Yellow sweet clover abundant.

Drill Site 15-01. <u>6-19-04</u> (N 38 53’ 24.5”, W 107 24’ 43.5”). Brought to natural contour in 2003.

<u>6-30-05.</u> Great revegetation. Ground-cover 70-90%, grass 24-30” in road, 18-24” on site.

<u>6-24-06.</u> Ground-cover 80-90%, grass 18-24”tall. Re-vegetation not as good as in 2005.

<u>7-6-07.(Pg 33, 2005)</u> Ground-cover 80-90%, grass/forbs average 24” tall. Chokecherry encroachment 10-15’ on bottom edge. Some Canada thistle on location and in access road.

Drill Site 15-03. 6-19-04 (N 38 53' 23.0", W 107 24' 52.3"). Brought to natural contour in 2003.

<u>6-30-05.</u> Ground-cover 30-50% with grasses 12-16" and some chokecherry encroachment.

<u>6-24-06.</u> Ground-cover 40-60% with grasses/forbs 14-20", 5-10' oak/serviceberry invasion.

<u>7-6-07.</u> Ground-cover 60-80%, grass/forbs average 24", snowberry, chokecherry, oak, aspen invasion up to 30' on edges.

CONCLUSIONS

Table 3 shows summarized results of site ratings.

Table 3: Rating Comparisons for 2005, 2006 and 2007.

Category	**Site Ratings by Year**	**% by Category**	**Site Ratings by Year**	**% by Category**	**Site Ratings by Year**	**% by Category**
	2005	2005	2006	2006	2007	2007
Excellent	8	**9**	9	**9**	14	**12**
Good	32	**36**	53	**55**	67	**59**
Fair	37	**42**	31	**32**	26	**23**
Poor	12	**13**	3 *	**3**	6	**5**
Total Sites	**89**	100	**96**	99 **	**113**	99**
			* - Insufficient time for reveg.	**-1% due to rounding		**-1% due to rounding

While Table 3 illustrates general vegetative improvement over the past 3 years, a percentage comparison of Good + Excellent Site Ratings shows 72% in 2007 (81 site ratings) as opposed to 65% in 2006 (62 site ratings) and 45% in 2005 (40 site ratings). This also means that only 28% of the 2007 site ratings are in the Fair-Poor category as compared to 35% of the 2006 Site Ratings and 55% in the 2005 Site Ratings. Sites reclaimed in 2007 are not included in Table 3 since there was not enough time for vegetation to establish, although some of these sites reclaimed earlier in the summer showed signs of some grass production. Table 3 results show the general progression of revegetation on these sites over a 1 to 3 year time period (2004-2007), and reflect the need for several field seasons to establish good stands of vegetation on disturbed sites in the project area.

Vegetation on all pre-2006 areas is becoming established, although some specific sites may need additional attention. Reclamation work performed during the 2004 field season is becoming well established while that accomplished later will need another one to three years for vegetation to reach its potential and stabilize. Invasion by native species such as Gambel oak, serviceberry, snowberry and chokecherry is taking place, especially along disturbed edges. Invasion by noxious weeds such as Canada thistle is also occurring in isolated areas, and noxious weed control is ongoing.

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Participant List 18th High Altitude Revegetation Workshop Modified Dates Held: 3/4/2008 to 3/6/2008		
1. Tyler Abbott Bureau of Land Management 5353 Yellowstone Road Cheyenne, WY 82009 Telephone: 307-775-6227 Fax: 307-775-6042 tyler_abbott@blm.gov	2. Nick Adamson Highlands Ranch Metro District 3280 Redstone Park Cir. Highlands Ranch, CO 80129 Telephone: 720-240-5917 nadamson@highlandsranch.org	3. William Agnew Granite Seed Co. 1697 W 2100 N Lehi, UT 84043 Telephone: 801-768-4422 Fax: 801-768-3967 bill@graniteseed.com
4. Richard Alward Aridlands Natural Resource Consulting 281 28 Road Grand Junction, CO 81503 Telephone: 970-270-1973 ralward@aridlands-nrc.com	5. Nate Ament Tamarisk Coalition P.O. Box 1907 Grand Junction, CO 81502 Telephone: 970-256-7400 nament@tamariskcoalition.org	6. Crystal Andrews CO Dept. of Agriculture 700 Kipling St. Suite 4000 Lakewood, CO 80215 Telephone: 303-239-5767 crystal.andrews@ag.state.co.us
7. Denise Arthur ESCO Associates 667 Hurricane Hill Dr Nederland, CO 80466 Telephone: 303-499-4277	8. Julie Ash Walsh Environmental 4888 Pearl E. Circle Suite 108 Boulder, CO 80301 Telephone: 720-308-7840 Fax: 303-443-0367 jeash@walshenv.com	9. Bill Avery Petroleum Field Services 1801 W 13th Ave Denver, CO 80204 Telephone: 303-928-7128 Fax: 303-423-8765 steve@petro-fs.com
10. Richard Avila Arkansas Valley Seed 4625 Colorado Blvd Denver, CO 80216 Telephone: 303-320-7500 Fax: 303-320-7516 dlweigand@seedsolutions.com	11. Laura Backus Biohabitats 1752 Platte St, Suite 200 Denver, CO 80202 Telephone: 303-477-0660 Fax: 303-477-4648 lbackus@biohabitats.com	12. Mike Banovich Colorado Department of Transportation 4201 E. Arkansas Avenue Shumate Bldg Denver, CO 80222 Telephone: 303.757.6542 Fax: 303.757.9445 michael.banovich@dot.state.co.us
13. Phil Barnes Shell Oil 4582 S. Ulster St Suite 1400 Denver, CO 80237 Telephone: 303-305-4016 phil.barnes@sehll.com	14. Stephanie Barr 1708 Springfield Drive Fort Collins, CO 80521 USA Telephone: 970-309-5380 rustycricket@yahoo.com	15. Matt Bartlett Quality Contracting 2577 E 79th Ave Denver, CO 80229 Telephone: 303-996-3544 lis.vicchiarelli@qqu3.com

16. Jim Bauer US BLM 2987 Prospecter Dr Casper, WY 82604 Telephone: 307-261-7600 joe_meyer@blm.gov	17. Robin Bay Habitat Management, Inc. 14 Inversness Dr. East STE G-228 Englewood, CO 80112 Telephone: 303-770-9788	18. Russell Beam ESCO Associates PO Box 18775 Boulder, CO 80303 Telephone: 303-499-4277 Fax: 303-499-3050 russellbeam@mindspring.co m
19. Sue Beatty P.O. Box 700 El Portal, CA 95318 Telephone: 209-379-3290 Fax: 209-379-2176 Sue_Beatty@nps.gov	20. Eric Billmeyer Rocky Mountain Field Institute 3310 Colorado Ave Colorado Springs, CO 80904 Telephone: 719-650-6659	21. Rebecca Bilodeau Tetra Tech MMI 3801 Automation Way Suite 100 Fort Collins, CO 80525 Telephone: 970-223-9600 Fax: 970-223-7171 Rebecca.bilodeau@mfgenv.c om
22. Dan Binkley Colorado Forest Restoration Inst. 1472 Colorado State University Fort Collins, CO 80523 Telephone: 970-491-6519	23. Janet Binns Colorado Div. Reclamation, Mining and Safety 1313 Sherman Street, Room 215 Denver, CO 80203 Telephone: 303-866-3567 Fax: 303-832-8106 janet.binns@state.co.us	24. Danguole Bockus National Park Service 2465 S. Townsend Ave Montrose, CO 81401 Telephone: 970-249-1914 ex.432 Fax: 970-240-0504 danguole_bokus@nps.gov
25. Denny Bohon US Forest Service South Platte Rd 19316 Goddard Ranch Ct Morrison, CO 80465 Telephone: 303-275-5625 Fax: 303-275-5642 dbohon@fs.fed.us	26. Megan Bowes Boulder Open Space and Mountain Parks 66 S. Cherryvale Rd Boulder, CO 80303 Telephone: 720-564-2084 bowesm@bouldercolorado.gov	27. Tom Bowman Bowman Construction Supply 14440 Mead Court Longmont, CO 80504 Telephone: 970-535-0863 Fax: 970-535-0866
28. Dave Bradford Paonia Ranger District USDA Forest Service PO Box 1030 Paonia, CO 81428 Telephone: 970-527-4131	29. Beth Brenneman US Forest Service PO Box 948 Glenwood Springs, CO 81602 Telephone: 970-945-5232 beth_brenneman@blm.gov	30. Dwayne Breyer Truax Company, Inc. 4300 Quebec Avenue North New Hope, MN 545428 Telephone: 763-537-6639 Fax: 763-537-8353 truax@pclink.com

31. Cynthia (Cini) Brown Bioagricultural Sciences & Pest Mgmt. Dept (1177) Campus Delivery 1177 Colorado State University Fort Collins, CO 80523 Telephone: 970-491-1949 cynthia.s.brown@colostate.ed u	32. Sandy Brown Colorado Div. Reclamation, Mining and Safety 1313 Sherman Street, Room 215 Denver, CO 80203 Telephone: 303-866-3567 Fax: 303-832-8106 sandy.brown@state.co.us	33. Joe Brummer Colorado State University Soil and Crop Sciences Dept. 1170 Campus Delivery Fort Collins, CO 80523 USA Telephone: 970-491-4988 joe.brummer@colostate.edu
34. David Buckner ESCO Associates 1077 Cherryvale Rd PO Box 18775 Boulder, CO 80308 Telephone: 303-499-4277	35. Monica Buhler National Park Service 1583 Foresta Rd El Portal, CA 95389 Telephone: 209-379-3293 Fax: 209-379-2176 monica_buhler@nps.gov	36. Brett Burgess US BLM 2987 Prospecter Dr Casper, WY 82604 Telephone: 307-261-7600 joe_meyer@blm.gov
37. Dave Buscher Buscher Soil and Environmental P.O. Box 156 Rollingsville, CO 80474 Telephone: 303-258-7280 Fax: 303-258-0233 davidbuscher@cs.com	38. Anya Byers Colorado Fourteeners Initiative 607 10th Street Suite 306 Golden, CO 80401 Telephone: 303-278-7650 Fax: 303-278-7365 anya@14ers.org	39. Jeff Campbell CC&V Gold Mining Company 100 N. Third Street Victor, Co 80860 Telephone: 719-689-4029 Fax: 719-689-3254 proberts@anglogoldashantina .com
40. Juliann Campbell PO BOx 9057 Durango, CO 81302 Telephone: 970-884-2985 juliannc@frontier.net	41. Kenneth Carlson Habitat Management, Inc. 14 Inverness Dr. East Ste G-228 Englewood, CO 80112 Telephone: 303-770-9788	42. Richard Carr C-M Environmental Group 62 Beaver Run Road Pinedale, WY 82941 Telephone: 307-367-8500
43. Dave Cesark Williams 706 Washington CT Grand Junction, CO 81503 Telephone: 970-683-2281 dave.cesark@williams.com	44. Bridget Clayton BLM 2425 S Grand Avenue Glenwood Springs, CO 81601 Telephone: 970-947-5224 Fax: 970-947-5267 bridget_clayton@blm.gov	45. Brendan Close Boulder County Parks and Open Space 5201 St. Vrain Longmont, CO 80503 Telephone: 303-678-6110 bclose@bouldercounty.org
46. Robert Coppin Tri-State G&T 1100 W 116th Ave Westminster, CO 80234 Telephone: 303-254-3349 Fax: 303-254-6066 rcoppin@tristategt.org	47. Joseph Cosenva CSU Student 2229 Primrose Dr Fort Collins, CO 80526 Telephone: 970-221-1806 jcosenva@colostate.edu	48. Sheryl Costello Forest Health Protection USDA Forest Service 740 Simms St. Golden, CO 80401 Telephone: 303-236-9552

49. Nancy Cressey BKS Environmental Associates, Inc. PO Box 3467 Gillette, WY 82717 Telephone: 307-686-0800 Fax: 307-686-0880 ncressey@bksenvironmental.com	50. Tim Croissant Yosemite National Park PO Box 700 El Portal, CA 95338 Telephone: 208-379-3297 tim_croissant@nps.gov	51. Rich Cuellar Highlands Ranch Metro District 3280 Redstone Park District Highlands Ranch, CO 80129 Telephone: 720-240-5917 nadamson@highlandsranch.org
52. Cathy Curtis Colorado Department of Transportation 4201 E. Arkansas Avenue Denver, CO 80222 Telephone: 303.757.9174 Fax: 303.757.9445 cathy.curtis@dot.state.co.us	53. Bill Dailey Highlands Ranch Metro Park District 3280 Redstone Park Circle Highlands Ranch, CO 80129 Telephone: 720-240-5917 bdailey@highlandsranch.org	54. Pat Davey USDA and RCS 655 Parfet St 200C Lakewood, CO 80215 Telephone: 720-544-2839 Patrick.Davey@co.usda.gov
55. Connie Davis Aggregate Industries P.O. Box 337231 Greeley, CO 80633 Telephone: 970-336-6526 connie.davis@aggregate.com	56. Natasha Davis Forest, Rangeland & Watershed Stew. Dept. 1472 Colorado State University Fort Collins, CO 80523 Telephone: 970-491-5238	57. Aimee Davison P.O. Box 1666 Big Piney, WY 83113 Telephone: 307-367-7904 Fax: 307-367-4285 aimee.davison@shell.com
58. Gary Dean U.S. Forest Service 308 Hwy 189 N Kemmerer, WY 83101 Telephone: 307-877-4415 gdean@fs.fed.us	59. Claire DeLeo Boulder County Parks & Open Space 5201 St. Vrain Road Longmont, CO 80503 Telephone: 303-678-6205 cdeleo@bouldercounty.org	60. Joelene Diehl Conservation Seeding & Restoration Inc. 506 Center Street West Kimberly, ID 88341 Telephone: 208-423-4835 joelene@csr-inc.com
61. Jim Dooley Forest Concepts 3320 W. Valley Highway North Auburn, WA 98001 jdooley@forestconcepts.com	62. Jim Doyle Tetra Tech 1900 S. Sunset St. Suite 1-F Longmont, CO 80501 Telephone: 303-772-5282 jim.doyle@tetratech.com	63. Stephanie Dreiling Consolidated Divisions Inc. 5585 W Airport Road Sedalia, CO 80135 Telephone: 303-471-1522 Fax: 303-470-3197 stephanied@cdi-services.com
64. Nancy Dunkle Retired National Park Service 333 S. Miller St. Lakewood, CO 80226 Telephone: 303-986-8764 ngdunkle@earthlink.net	65. Matthew Dupire Bureau of Land Management 220 E. Market St. Meeker, CO 81641 Telephone: 970-878-3839 Fax: 970-878-3805 Matthew_Dupire@blm.gov	66. Greg Eckert National Park Service 1201 Oakridge Drive, Suite 200 Fort Collins, CO 80525 Telephone: 970-225-3594 Fax: 970-225-3585 greg_eckert@nps.gov

67. Dirk Eichler Water's Edge Reclamation PO Box 418 63 City Rd 520 Fraser, CO 80442 Telephone: 970-726-4903 Fax: 970-726-4660 lildirtworks@rkymtnin.com	68. James Eierdam 2401 Evergreen Dr. Fort Collins, CO 80521 Telephone: 970-689-0479 james.eierdam@gmail.com	69. Gerard Eldridge 905 South Pennsylvania Denver, CO 80209 Telephone: 303-733-4557 gerardeldridge@comcast.net
70. Joshua Eldridge Colorado State University 406 Starling St Fort Collins, CO 80526 Telephone: 970-491-4992 eldridge6@hotmail.com	71. Michael D. Ellis Ellis Env. Engr., Inc. 4342 Ulysses Way Golden, CO 80403 Telephone: 303-279-8532 glendakay@att.net	72. Wayne Erickson Habitat Management, Inc. 14 Inverness Dr. East Ste. 228 Englewood, CO 80112 Telephone: 303-770-9788 Fax: 303-925-1838 werickson@habitatmanagem entinc.com
73. Scott Esser Rocky Mountain National Park HC-61 Box 32031 Estes Park, CO 80517 Telephone: 608-345-4920 scott_esser@nps.gov	74. Collin Ewing U.S. Fish and Wildlife Service 764 Horizon Dr. Bldg B Grand Junction, CO 81506 Telephone: 970-243-2778 x18 Fax: 970-245-6933 collin_ewing@fws.gov	75. Charlie Fifield US BLM 2987 Prospecter Dr Casper, WY 82604 Telephone: 307-261-7600 joe_meyer@blm.gov
76. Joe Fobert Watersaver Company Inc PO Box 16465 Denver, CO 80216 Telephone: 303-289-1818 Fax: 303-287-3136 joe.fobert@watersaver.com	77. David Francomb US Forest Service BLM Energy Office 2425 S. Grand Ave Suite 101 Glenwood Springs, CO 81601 Telephone: 970-947-5237 Fax: 970-947-5267 dfrancomb@fs.fed.us	78. Crystal Freeman Colorado State University 2212 Verment Dr. Apt. F 202 Fort Collins, CO 80525 Telephone: 303-907-1708 Crystallfreeman@aol.com
79. John Fusaro USDA NRCS 2150 Centre Ave Bld A Suite 116 Fort Collins, CO 80526 Telephone: 970-295-5658 donna.goodsell@co.usda.gov	80. Mark Fusco Denver Botanic Gardens 909 York St Denver, CO 80206 Telephone: 303-356-3323	81. Mike Gardner Williams Energy 1058 CR 215 Parachute, CO Telephone: 970-263-2760 michael.gardner@williams.co m

82. John Giordanengo Wildlands Restoration Volunteers 2515 E. Sterling Circle Suite 201 Boulder, CO 80301 Telephone: 303-543-1411 john@wlrv.org	83. Jack Glavan Pikes Peak Highway PO Box 1575, MC 060 Colorado Springs, CO 80901 Telephone: 719-385-7714 jglavan@springsgov.com	84. Donna Goodsell USDA NRCS 4407 29th St Ste 300 Greeley, CO 80634 Telephone: 970-330-0380 x201 donna.goodsell@co.usda.gov
85. George Greenwood Walsh Environmental 4888 Pearl East Circle Suite 108 Boulder, CO 80301 Telephone: 303-443-3282 Fax: 303-443-0367 ggreenwood@walshenv.com	86. Jeremy Grinwald Highlands Ranch Metro District 3280 Redstone Park District Highlands Ranch, CO 80129 Telephone: 720-240-5917 nadamson@highlandsranch.org	87. Russ Haas USDA-NRCS P.O. Box 1458 Bismarck, ND 58504 Telephone: 701-530-2026 Fax: 701-530-2112 russ_haas@nps.gov
88. Jon Hager Energy Laboratories, Inc. P.O. Box 5688 Helena, MT 59604 Telephone: 877-472-0711 Fax: 406-442-0712 mcobb@energylab.com	89. Sarah Hanlon 360 N 9th St #103 Laramie, WY 82072 Telephone: 307-631-5100 wyowild@uwyo.edu	90. Rick Hanson USDA FS Rifle 0094 Co. Rd. 244 Rifle, CO 81650 Telephone: 970-625-6848 Fax: 970-625-2532 bsuits@fs.fed.us
91. Victoria Hartman National Park Service Resources Management Science PO Box 700 El Portal, CA 95318 Telephone: 209-379-2171 victoria_hartman@nps.gov	92. Wendell Hassell Pawnee Buttes Seed, Inc PO Box 100 Greeley, CO 80632 Telephone: 970-356-7002 Fax: 970-356-7263 infor@pawneebuttesseed.com	93. Peter Hays Colorado Div. Reclamation, Mining and Safety 1313 Sherman St Suite 215 Denver, CO 80203 Telephone: 303-866-2555 peter.hayes@state.co.us
94. Robby Henes Southwest Seed Inc. 13260 Road 29 Dolores, CO 81323 Telephone: 970-565-8722 Fax: 970-565-2576 swseed@southestseed.com	95. Walter Henes Southwest Seed Inc. 13260 Road 29 Doloreo, CO 81323 Telephone: 970-565-8722 Fax: 970-565-2576 swseed@southweastseed.com	96. Patrick Hickey Sugnet & Moore Environmental 555 Rivergate Lane BI-101 Durango, CO 81301 Telephone: 970-259-9595 Fax: 970-259-0050 phickey@sugnet.com

97. David Hirt Boulder County Parks & Open Space 5201 St. Vrain Road Longmont, CO 80503 Telephone: 303-678-6218 dhirt@bouldercounty.org	98. Kelly Hodgson Bureau of Land Management PO Box 68 Kremmling, CO 80459 Telephone: 970-724-3015 kelly_hodgson@blm.gov	99. Heather Houston Western Ecological Resource 711 Walnut Street Boulder, CO 80302 Telephone: 303-449-9009 Fax: 303-449-9038 heather@westerneco.com
100. Darek Huebner Barrick Goldstrike PO Box 29 Elko, NV 89803 Telephone: 775-778-8262 dhuebner@barrick.com	101. Terry Hughes USDA Forest Service 2250 Highway 50 Delta, CO 81416 Telephone: 970-874-6698 Fax: 970-874-6619 thughes@fs.fed.us	102. Roger Hybner USDA-NRCS Bridger Plant Materials Center 98 S. River Rd Bridger, MT 59014 Telephone: 406-662-3579 Fax: 406-662-3428 roger.hybner@mt.usda.gov
103. David Johnson Western Ecological Resource 711 Walnut St. Boulder, CO 80302 Telephone: 303-449-9009	104. Lee Johnson Bowman Construction Supply 10801 E. 54th St Denver, CO 80239 Telephone: 303-389-9534 lee@earthnet.net	105. Pam Johnson Arapaho National Wildlife Refuge 28111 Hwy 125 Walden, CO 80480 Telephone: 970-723-8202 x6 Fax: 970-723-8528 amy_thornburg@fws.gov
106. Steve Johnson Natural Resource Services, Inc. P.O. Box 19332 Boulder, CO 80308-2332 Telephone: 303-915-3211 Fax: 720-652-4792 stevej@nrsiservices.com	107. Danielle Johnston Colorado Division of Wildlife 2581 E Ave Rifle, CO 80650 Telephone: 970-420-8375 danielle.biyeu@state.co.us	108. Chris Jones Western State Reclamation 3756 Imperial Street Fredrick, CO 80516 Telephone: 303-833-8827 cjones@wsreclimation.com
109. Rachel Jones BKS Environmental Associates, Inc PO Box 3467 Gillette, WY 82717 Telephone: 307-686-0800 Fax: 307-686-0880 rjones@bksenvironmental.com	110. Dave Jordan Pikes Peak Highway PO Box 1575, MC 060 Colorado Springs, CO 80901 Telephone: 719-385-7714 djordan@springsgov.com	111. Sue Kamal CoNPS 1504 Lakeside Drive Greeley, CO 80631 Telephone: 970-353-9240 kamalsue@gmail.com

112. Roy Karo Peabody Energy P:O Box 670 Hayden, CO 81639 Telephone: 970-276-5217 Fax: 970-276-5222 rkaro@peabodyenerg.com	113. Warren Keammerer KEC, Inc 5858 Woodbourne Hollow Rd Boulder, CO 80301 Telephone: 303-530-1783 wrkeam@comcast.net	114. Chris Keough Rocky Mountain Native Plants Company 3780 Silt Mesa Rd. Rifle, CO 81650 Telephone: (970) 625-4769 Fax: (970) 625-3276 ckeough@rmnativeplants.com
115. Jennifer Kesler Boulder County Parks & Open Space 5201 St. Vrain Road Longmont, CO 80503 Telephone: 303-678-6217 jkesler@bouldercounty.org	116. Jessica Kirkpatrick Kirkpatrick Environmental 101 Tamarisk Dr. Parachute, CO 81635 Telephone: 970-683-1780 kaylambert@kirkpatrickenvironmental.com	117. Ed Kleiner Comstock Seed 917 Hwy 88 Gardnervile, WV 89460 Telephone: 775-265-0090 Fax: 775-265-0040 ed@comstockseed.com
118. Evan Kleiner Comstock Seed 917 Hwy 88 Gardnerville, WV 89460 Telephone: 775-265-0090 Fax: 775-265-0040 ed@comstockseed.com	119. Jack Knaub Hanes Geo Components 9931 East 47th Ave Denver, CO 80238 Telephone: 303-307-8111 Fax: 303-307-8112 jack.knaub@hanesindustries.com	120. Julie Knudson CSU 812 Redwood Court Bellvue, CO 80512 Telephone: 970-420-1915 julie.knudson@colostate.edu
121. Jayne Kopperl EDAW/AECOM 1809 Blake St. Suite 200 Denver, CO 80202 Telephone: 303-308-3514 jane.kopperl@edaw.com	122. David Korzilus US BLM 2987 Prospector Dr Casper, WY 82604 Telephone: 307-261-7600 joe_meyer@blm.gov	123. James Kulbeth Department of Defense, Fort Carson Directorate of Public Works, Attn: IMWE-CAR-PWE 1638 Elwell Steet, Bldg 6236 Fort Carson, CO 80913 Telephone: 719-526-1685 Fax: 719-526-2091 james.kulbeth@us.army.mil
124. Lynn Kunzler Utah Division Oil Gas and Mining 1594 West North Temple Suite 1210 Salt Lake City, UT 84114 Telephone: 801-538-5310 Fax: 801-359-3940 lynnkunzler@utah.gov	125. Bill LaBarre Rocky Mountain Native Plants Company 3780 Silt Mesa Rd. Rifle, CO 81650 Telephone: (970) 309-4300 Fax: (970) 625-3276 wjlabarre@yahoo.com	126. Richard Lancaster CSU-Bioagricultural Sciences & Pest Mgmt Campus Delivery 1177 Colorado State University Fort Collins, CO 80523 Telephone: 970-491-4671 richard.ecopsych@gmail.com

127. Julie Laufman USDA FS TEAMS Enterprise 1839 S. Newcomb Porterville, CA 93257 Telephone: 559-781-1166 Fax: 559-781-0294 jlaufman@fs.fed.us	128. Rich Lennes Quality Contracting 2577 E 79th Ave Denver, CO 80229 Telephone: 303-996-3544 lisa.vicchiarelli@qqu3.com	129. Ann Lezberg 2325 Cedarwood Drive Fort Collins, CO 80526 Telephone: 970-222-4917 allezberg@yahoo.com
130. John Lott USDA Forest Service 1405 Hollipark Drive Idaho Falls, ID 83401 Telephone: 208-557-5782 Fax: 208-557-5826 jlott@fs.fed.us	131. Paul Lyons EMNRD/Mining & Minerals Division 1220 South St. Francis Dr Santa Fe, NM 87505 Telephone: 506-476-3439 Fax: 505-476-3402 paul.lyons@state.us	132. Carl Mackey URS Washington Division PO Box 1717 Commerce City, CO 80037 Telephone: 303-286-4825 ocsreg@lamar.colostate.edu
133. Randy Mandel Rocky Mountain Native Plants Company 3780 Silt Mesa Rd. Rifle, CO 81650 Telephone: (970) 379-3169 Fax: (970) 625-3276 rmnative@earthlink.net	134. Joseph Marcoline University of British Columbia PO Box 32391 Santa Fe, NM Telephone: 505-231-6119 jmarcoli@eos.ubc.ca	135. Rachel Markko Teton Conservation District PO Box 1070 Jackson, WY 83001 Telephone: 307-733-2110 Fax: 307-733-8179 rachel@tetonconservation.org
136. Nancy Matchett Colorado State Parks 13787 S. Hwy. 85 Littleton, CO 80125 Telephone: 303-791-1957 x128 nancy.matchett@state.co.us	137. Dan Mathews Colorado Div. Reclamation, Mining and Safety 1313 Sherman Street, Room 215 Denver, CO 80203 Telephone: 303-866-3567 Fax: 303-832-8106 dan.mathews@state.co.us	138. Jeremy Mayhew Wyoming Game & Fish Dept. 260 Buena Vista Lander, CO 82520 Telephone: 307-332-2688 jeremy.mayhew@wgf.state.wy-us
139. James McArdle Colorado Div. Reclamation, Mining and Safety 1313 Sherman St #215 Denver, CO 80203 Telephone: 303-866-3789 jim.mcardle@state.co.us	140. John McCarty USDI Bureau of Land Management 1849 C Street NW (L.S. 302) Washington, DC 20240 Telephone: 202-785-6574	141. Steven McGeehan Analytical Sciences Lab University of Idaho Hom Res. Center 2222 W. Sixth St. Moscow, ID 83844 Telephone: 208-885-7900

142. Heather McLaughlin Routt County PO Box 773598 Steamboat Springs, CO 80477 Telephone: 970-870-5337 Fax: 970-879-3992 hmclaughlin@co.routt.co.us	143. Floyd McMullen 3111 S Jasmine Way Denver, CO 80222 Telephone: 303-757-0546 famcmullen@gmail.com	144. Peter McRae Quattro Environmental, Inc 649 I Avenue Coronado, CA 92118 USA Telephone: 619-522-0044 Fax: 619-522-0055 pmcrae@san.rr.com
145. Jim Meining Aquatic and Wetland Co. 9999 WCR 25 Fort Lupton, CO 80621 Telephone: 303-442-4766 Fax: 303-857-2455 jimm@aquaticanotwetland.com	146. Daryl Mergen Mergen Ecological Delineations, Inc. 1835 Parkview Boulevard Colorado Springs, CO 80906 Telephone: 719-459-1280	147. Maysoon Mikha USDA-ARS Central Great Plains Research Station 40335 County Rd. GG Akron, CO 80720 Telephone: 970-345-2259 carolyn.brandon@ars.usda.gov
148. Vicky Miller Dugout Cannon Mine PO Box 1029 Wellington, UT 84542 Telephone: 435-636-2869 Fax: 435-636-2897 vmiller@archcoal.com	149. Weldon Miller AG-Renewal, Inc. 1519 E. Main Street Weatherforld, OK 73096 Telephone: 580-772-7059 Fax: 580-772-6887 weldon.miller@sbcglobal.net	150. Joe Moeny New Mexico State University 609 N Cooper Street Silver City, NM 88061 Telephone: 505-646-3399 jmoeny@nmsu.edu
151. David Moore Pawnee Buttes Seed, Inc. PO Box 100 Greeley, CO 80632 Telephone: 970-356-7002 Fax: 970-356-7263 info@pawneebuttesseed.com	152. Marques Munis Colorado State Universtiy 2428 Clearview Ave Fort Collins, CO 80521 Telephone: 323-447-7022 munnis224@hotmail.com	153. Jason Musick Colorado Div. Reclamation, Mining and Safety 1313 Sherman Street, Room 215 Denver, CO 80203 Telephone: 303-866-3567 Fax: 303-832-8106 jason.musick@state.co.us
154. Gregory Nafftz Sustane Natural Fertilizer of America, Inc. 1148 Humbug Way Auburn, CA 95603 Telephone: 530-823-9636 Fax: 530-823-2530 Nafftz@sbcglobal.net	155. Jody Nelson DOE Legacy Mangement/S.M. Stoller Corp 11025 Dover St #1000 Westminster, CO 80021 Telephone: 720-377-9677	156. Scott Nelson Highlands Ranch Metro District 3280 Redstone Park Circle Highlands Ranch, CO 80129 Telephone: 720-240-5917 nadamson@highlandsranch.org

157. Dan Nosal USDA NRCS PO Box 688 Franktown, CO 80116 Telephone: 303-688-3042 daniel.nosal@co.usda.gov	158. David Novak TERA Environmental Consultants 1100, 815-8th Avenue S.W. Calgary, AL TIS-1E7 Canada Telephone: 403-265-2885 Fax: 403-266-6471 dnovak@leracnv.com	159. Ann Odasz ESCO Associates PO Box 18775 Boulder, CO 80308 Telephone: 303-499-4277 annodasz@mindspring.com
160. Rea Orthner Western Ecological Resource Inc. 711 Walnut Street Boulder, CO 80302 Telephone: 303-449-9009 rea@westerneco.com	161. Maureen O'Shea-Stone Walsh Environmental 4888 Pearl East Circle #108 Boulder, CO 80301 Telephone: 303-443-3282	162. Bob Parsons Park County Weed & Pest Control Dist. PO Box 626 Powell, WY 82435 Telephone: 307-754-8884
163. Roger Pasch Energy Laboratories, Inc. P.O. Box 5688 Helena, MT 59604 Telephone: 877-472-0711 Fax: 406-442-0712 mcobb@energylab.com	164. Mark Paschke CSU 1472 Campus Delivery Fort Collins, CO 80525 Telephone: 970-491-0760 mark.paschke@colostate.edu	165. Mark Phillips Phillips Seeding 11843 Billings Ave Lafayette, CO 80026 Telephone: 303-665-2618 Fax: 303-828-0229
166. Lonnie Pilkington Rocky Mountain National Park 1000 W. Hwy 36 Estes Park, CO 80517 Telephone: 970-586-1364 lonnie-pilkington@nps.gov	167. Mary Louise Polzin Interior Reforestation Co. Ltd. 4142 McPhee Rd Cranbrook, BC V1C 4J6 Canada Telephone: 250-426-5300 Fax: 250-426-5311 mlpolzin@intref.bc.ca	168. Jesse Rawson US BLM 2987 Prospecter Dr Casper, WY 82604 Telephone: 307-261-7600 joe_meyer@blm.gov
169. Ed Redente MWH, Inc. 1825 Sharp Point Dr. Suite 110 Fort Collins, CO 80525 Telephone: 970-212-2776 edward.f.redente@mwhglobal.com	170. Francis Rengers Engineering & Hydrosystems Inc. 8122 Southpark Ln #205 Littleton, CO 80120 Telephone: 303-683-5191 francis.rengers@enghydro.com	171. Dayna Rich Colorado Reptile Humane Society 9127 Birch St. Thornton, CO 80229 Telephone: 970-310-0674 dayna.rich@gmail.com

172. Mike Ricketts USDA Forest Service PO Box 10 Granby, CO 80446 USA Telephone: 970-887-4133 Fax: 970-887-4102 mricketts@fs.fed.us	173. Kelly Rieber Nilex Environmental 15171 E Freemont Dr Centennial, CO 80112 Telephone: 303-766-2000 krieber@nilex.com	174. Julie Rieder Restoration Ecology Lab Campus Delivery 1472 Colorado State University Fort Collins, CO 80523 Telephone: 970-491-5772
175. Leland Roberts 220 W Main St. Farmington, NM 87401 Telephone: 505-327-2486 leland@bclenvironmental.com	176. Matt Roberts US BLM 2987 Prospecter Dr Casper, WY 82604 Telephone: 307-261-7600 joe_meyer@blm.gov	177. Bryce Romig Climax Molybdenum Co. PO Box 68 Empire, CO 80438 Telephone: 303-569-3221 bryce_romig@fmi.com
178. David Rux Petroleum Field Services 1801 W 13th Ave Denver, CO 80204 Telephone: 303-928-7128 Fax: 303-423-8765 david@petro-fs.com	179. John Samson Wyoming Department of Transportation 5300 Bishop Blvd Evironmental Service Section Cheyenne, WY 82009 Telephone: 307-777-4416 Fax: 307-777-4193 john.samson@dot.state.wy.us	180. Eddy Sanders Down to Earth Compliance 7845 E Harvard Ave. Denver, CO 80231 Telephone: 303-306-1606 esanders@trustdtec.com
181. Jason Sauer Boulder County Parks and Open Space 5201 St. Vrain Road Longmont, CO 80503 Telephone: 303-678-6236 jsauer@bouldercounty.org	182. Steve Sauer Boulder County Parks and Open Space 5201 St. Urain Longmont, CO 80503 Telephone: 303-678-6110 ssauer@bouldercounty.org	183. Ron Schreibeis Rocky Mountain Reclamation PO Box 1695 Laramie, WY 82073 Telephone: 307-745-5235 Fax: 307-745-5230 rmrl@vcn.com
184. Joel Schreiber The Wild Flower Farm 33601 Hwy. 6 Edwards, CO 81631 Telephone: 970-926-5504 Fax: 970-926-5506 joel@thewildflowerfarm.com	185. Kate Schwarzler Otak 36 N Fourth Street Cabondale, CO 81623 Telephone: 970-963-1971 Fax: 970-963-1622 kate.schwarzler@otak.com	186. Jim Sewell Shell 4794 Gould Cir Castle Rock, CO 80109 Telephone: 303-222-6360 jim.sewell@shell.com
187. Dr. Anna Sher Denver Botanical Gardens 909 York St. Denver, CO 80206 Telephone: 720-863-5393 taylorc@botanicgardens.org	188. Joe E Shoemaker Peabody Energy - Twentymile Coal 29515 Routt County Road 27 Oak Creek, CO 80467 Telephone: 970-870-2785 jshoemaker@peabodyenergy.com	189. Michael Shoemaker Williams Production PO Box 370 Parachute, CO 81635 Telephone: 970-285-9377 x2769 mike.shoemaker@williams.com

190. Kay Sinclair Colorado Division of Wildlife 317 W. Prospect Fort Collins, CO 80526 Telephone: 970-443-3221 kay.sinclair@state.co.us	191. Trez Skillern USDA Forest Service 3063 Sterling Circle Suite 1 Boulder, CO 80301 Telephone: 303-245-6430 Fax: 303-443-1083 tskillern@fs.fed.us	192. Vincent Sortman Biohabitats, Inc 1752 Platte Street Suite 200 Denver, CO 80202 Telephone: 303-477-0660 Fax: 303-477-4648 vsortman@biohabitats.com
193. Ed Spence USDA NRCS 655 Parfet St. Rm E300 Lakewood, CO 80215 Telephone: 720-544-2869 donna.goodsell@co.usda.gov	194. Ray Sperger Ark Ecological Services 901 S. Pierson Way Lakewood, CO 80226 Telephone: 303-985-4849 ersperger@gmail.com	195. Lindsay Springer Rocky Mountain National Park HC-61 Box 31957 Estes Park, CO 80517 Telephone: 970-231-1902 lindsay_springer@nps.gov
196. Harvey Sprock USDA NRCS 4401 29th St Greeley, CO 80634 Telephone: 970-330-0380 donna.goodsell@co.usda.gov	197. Rachel Steeves City of Fort Collins-Natural Areas Program PO Box 580 Fort Collins, CO 80522 Telephone: 970-221-6641 Fax: 970-416-2211 rsteeves@fcgov.com	198. Crystal Strouse City of Fort Collins Natural Areas Program PO Box 580 Fort Collins, CO 80522 Telephone: 970-217-6691 Fax: 970-416-2211 cstrouse@fegov.com
199. Brandt Swanke Newpark Mats and Integrated Services 2900 Hwy 93 Carencro, LA 70520 Telephone: 303-670-2706 Fax: 337-896-1971 rgrace@newpark.com	200. Dale Swenarton 11287 Ranch Place Westminster, CO 80234 Telephone: 303-621-4945 chinook4@india.com	201. Lisa Tasker E.M. Ecological, LLC 411 Fox Run Dr. Carbondale, CO 81623 Telephone: 970-948-4857 Fax: 970-704-1523 lisatasker@earthlink.net
202. Clark Tate Tamarisk Coalition P.O. Box 1907 Grand Junction, CO 81502 Telephone: 970-256-7400 ctate@tamariskcoalition.org	203. Brian Taylor AV Range Project 17850 County Road JJ Rocky Ford, CO 81067 Telephone: 719-254-7984 Fax: 719-254-7986 mpennington@rural-com.com	204. Jennifer Taylor Tetra Tech EC Colorado Rocky Mountain Arsenal 72nd Avenue at Quebec Street Commerce City, CO 80022 Telephone: 303-289-0800 Fax: 303-289-0815 jennifer.taylor@hecintha.com

205. Lisa Taylor Summit County Weed Program PO Box 626 Frisco, CO 80443 Telephone: 970-668-4218 LisaT@CO.summit.co.us	206. Dustin Terrell Sharp Bothers Seed 101 East 4th Street Road Greeley, CO 80631 Telephone: 9703564710 Fax: 9703561267 dterrell@sharpseed.com	207. Art Terry US BLM 2987 Prospecter Dr Casper, WY 82604 Telephone: 307-261-7600 joe_meyer@blm.gov
208. Mike Terry Forest Concepts, LLC 3320 West Valley Hwy N Suite D110 Auburn, WA 98001 United States Telephone: 253.333.9663 Fax: 253.833.2639 mperry@forestconcepts.com	209. Gary Thor Department of Soil & Crop Sciences Colorado State University Fort Collins, CO 80523 Telephone: 970-484-4999 garythor@lamar.colostate.edu	210. Amy Thornburg Arapaho National Wildlife Refuge 28111 Hwy 125 Walden, CO 80480 Telephone: 970-723-8202 x5 Fax: 970-723-8528 amy_thornburg@fws.gov
211. Rachel Tilton Earth Saver PO Box 310 Yolo, CA 95697 Telephone: 530-681-2691 Fax: 530-668-5140 rachel@earth-savers.com	212. Bob Timberman USFWS/Partners for Fish and Wildlife 953 Jackson Cr #32 Walden, CO 80225 Telephone: 303-236-4773 Fax: 303-236-4005 donna_lakamp@fws.gov	213. Matt Tobler Blue Mountain Environmental Consulting 937 Mallard Dr Fort Collins, CO 80521 Telephone: 970-224-0851 matt@bluemountain1.com
214. James Tolstrup High Plains Environmental Center 1854 Piney River Drive Loveland, CO 80538 Telephone: 970-622-9676 jim@suburbitat.org	215. Alex Tonnesen Western Native Seed PO Box 188 Coaldale, CO 81222 Telephone: 719-942-3935 wns@coaldale-co.us	216. Blake Treadway Kirkpatrick Environmental 1574 14.5 Road Loma, CO 81524 Telephone: 970-683-1779 kaylambert@kirkpatrickenvironmental.com
217. Tim Van Wyngarden ACZ Laboratories, Inc. 2773 Downhill Drive Steamboat Springs, CO 80487 Telephone: 970-879-6590 Fax: 815-31-3857 timv@acz.com	218. Carla Vik ESCO Associates PO Bix 18775 Boulder, CO 80308 Telephone: 303-499-4277 carlavandervoort@mindspring.com	219. Ryan Vincent City of Fort Collins-Natural Areas Program PO Box 580 Fort Collins, CO 80522 Telephone: 970-416-2133 rvincent@fcgov.com

220. Joe Vinson NM-Mining & Minerals Div. 1220 S. St. Francis Dr. Santa Fe, NM 87505 Telephone: 505-476-3414 Fax: 505-476-3406 joe.vinson@state.nm.us	221. Anne Wagner Chevron Mining Inc. Questa Mine PO Box 469 Questa, NM 87556 Telephone: 575-586-7625 awagne@chevron.com	222. DaLynn Walker Bowman Construction Supply 14440 Mead Ct Longmont, CO 80504 Telephone: 970-535-0863 Fax: 970-535-0866 dalynn@bowmanconstruction supply.com
223. Ethan Waltermire Colorado Seed Laboratory 1170 Campus Delivery Fort Collins, CO 80523-1170 Telephone: 970-491-4379 ethan.waltermire@colostate.e du	224. Scott Wanstedt Blue Mountain Energy, Inc. 3607 CR 65 Rangely, CO 81648 Telephone: 970-675-4322 Fax: 970-675-4399 swanstedt@deserado.com	225. Michael Ward Michael Ward Outdoors 38905 Back River Road Paonia, CO 81428 Telephone: 970-527-4269 mkw12@juno.com
226. David Weigand Arkansas Valley Seed 4625 Colorado Blvd Denver, CO 80216 Telephone: 303-320-7500 Fax: 303-320-7516 dlweigand@seedsolutions.co m	227. Noel Weisenbacher Habitat Management Inc. 14 Inverness Dr. E., Suite A-100 Englewood, CO 80112 Telephone: 3037709788 xt. 113 nweisenb@habitatmanagementi nc.com	228. Wilhelm Welzenbach Geomatrix 1001 S. Higgins Ave., Building B-1 Missoula, MT 59801 Telephone: 406-529-2577 wwelzenbach@geomatrix.co m
229. Mindy Wheeler WP Natural Resource Consulting, Inc. PO Box 520604 Salt Lake City, UT 84152 Telephone: 801-699-5459 wheelermindy@yahoo.com	230. Bridgette White University of Wyoming Agricultural Economics, Dept. 3354 1000 E. University Ave. Laramie, WY 82071 Telephone: 307-766-2386 Fax: 307-766-6403 bwhite@uwyo.edu	231. Bryan Whiteley 114 East Bonanza Place Parachute, CO 81635 Telephone: 970-319-0898 bryan.whiteley@encana.com; landstewards@msn.com
232. Ron Whiteman Bowman Construction Supply Inc 10801 E 54th Ave Denver, CO 80239 Telephone: 303-884-4795 ron@bowmanconstructionsup ply.com	233. Mike Wilkinson 19394 Silver Ranch Rd Conifer, CO 80433 Telephone: 303-697-5424 wilkandson@aol.com	234. Stephen Williams Department of Renewable Resource -3354, UW Laramie, WY 82071 USA Telephone: 307-766-2683 sewms@uwyo.edu

235. Susan Winslow Bridger Plant Material Center USDA NRCS Route 1 Box 1189 Bridger, MT 59014 Telephone: 406-662-3579	236. Ben Wissinger Colorado State University 2133 Krisron Rd D-303 Fort Collins, CO 80525 Telephone: 720 -338-8287 benwiss@simla.colostate.edu	237. Jim Wright US BLM 2987 Prospecter Dr Casper, WY 82604 Telephone: 307-261-7600 joe_meyer@blm.gov
238. Terry Wright US Fish and Wildlife Service Rocky Mountain Arsenal NWR Bldg 121 Commerce City, CO 80266 Telephone: 303-289-0232 terry_wright@fws.gov	239. Diane Yates Jacobs Carter Burgess 707 17th Street Suite 2300 Denver, CO 80202 Telephone: 303-820-4855 Fax: 303-820-2402 Diane.Yates@jacobs.com	240. Crystal Yates-White Pitkin County Land Management 76 Service Center Rd. Aspen, CO 81611 Telephone: 970-920-5214 Fax: 970-920-5374 crystalyw@co.pitkin.co.us
241. Bryce Young Buchanan Consultants, LTD PO Box 2459 Farmington, NM 87499 Telephone: 505-327-2486 bryce@bclenvironmental.com		

SUMMARY OF SUMMER TOURS 1974-2007

Assembled by Wendell Hassell and Mike Ellis

Since 1974, the HAR Committee has sponsored biennial conferences and annual field trips to unique mountainous revegetation project and research sites. All Conferences have been held at Fort Collins, Colorado, in conjunction with CSU, except the 1980 conference, which was held at the Colorado School of Mines in Golden, Colorado. Summer Field Tours have been conducted at the following sites:

YEAR	AREA TOURED	SITES TOURED
1974	Vail/Climax, CO	Vail Ski Area, AMAX Climax Molybdenum Mine
1975	Empire, CO	AMAX Urad Molybenum Mine, Winter Park Ski Area, Rollins Pass Gas Pipeline
1976	Idaho Springs/ Silverthorne, CO	US Highway 40 Construction, Keystone Ski Area
1977	Aspen/Redstone, CO	Snowmass Ski Area, CF&I Pitkin Iron Mine, Mid-Continent Coal Redstone Mine
1978	Estes Park, CO	Rocky Mountain National Park
1979	Silverton/ Durango, CO	Purgatory Ski Area, Standard Metals Sunnyside Mine Bayfield Range Experiment Program
1980	Vail/Climax, CO	I-70 Vail Pass Highway Construction Revegetation Ten Mile Creek Channelization, Copper Mountain Ski Area, AMAX Climax Molybdenum Mine
1981	Crested Butte/ Gunnison, CO	AMAX Mt. Emmons Molybdenum Project, Western State College, Homestake Pitch (Uranium) Mine, CF&I Monarch Limestone Quarry
1982	Steamboat Springs, CO	Mt. Werner Ski Area, Howelson Hill Ski Jump, Colorado Yampa Energy Coal Mine, P&M Edna Coal Mine
1983	Rifle/Meeker, CO	CSU Intensive Test Plots, C-b Oil Shale Project Upper Colorado Environmental Plant Center, Colony Oil Shale Project
1984	Salida, CO Questa, NM	Domtar Gypsum Coaldale Quarry, ARCO CO_2 Gas Project Molycorp Molybdenum Mine, Red River Ski Area
1985	Cooke City, MT	USFS Beartooth Plateau Research Sites Bridger Plant Materials Center
1986	Leadville, CO	Peru Creek Passive Mine Drainage Treatment, California Gulch/Yak Tunnel Superfund Site, Colorado Mountain College
1987	Glenwood Springs/ Aspen, CO	I-70 Glenwood Canyon Construction, Aspen Ski Area
1988	Telluride/Ouray/ Silverton, CO	Ridgeway Reservoir, Telluride Mt. Village Resort, Idarado Mine, Sunnyside Mine

YEAR	AREA TOURED	SITES TOURED
1989	Lead, SD	Terry Peak Ski Area, Glory Hole and Processing Facilities of Homestake Mining Co., Wharf Resources Surface Gold Mines Using Cyanide Heap Leach
1990	Colorado Springs/ Denver, CO	Castle Concrete's Limestone Quarry, Cooley Gravel Quarry (Morrison), E-470 Bridge and Wetland near Cherry Creek. Littleton Gravel Pit Restoration to Parkland
1991	Central Colorado	Alice Mine, Urad Tailings, Pennsylvania Mine at Peru Creek, Yule Marble Quarry near Marble, and Eagle Mine Tailings and Superfund Clean Up near Minturn and Gilman
1992	Northern Colorado	Rocky Mountain National Park, Harbison Meadow Borrow Pit, Alpine Meadow Visitor Center, Medicine Bow Curve Revegetation, Hallow Well Park
1993	Central and Southern Colorado	Mary Murphy Mine, Summitville Mine, Wolf Creek Pass, Crystal Hill Project
1994	Northeastern Utah	Utah Skyline Mine, Burnout Canyon, Huntington Reservoir Hardscrabble Mine, Royal Coal, Horse Canyon Mine
1995	North Central Colorado	Eisenhower Tunnel Test Plots, Henderson Tailing Test Plots, Wolford Mountain Reservoir, Osage and McGregor IML Site Seneca II and 20 Mile Coal Mines (Steamboat Springs)
1996	Southwest Colorado	UMTRA Site (Durango), Sunnyside Mine (Silverton), Idarado Mine (Telluride), Southwest Seed Co. (Dolores)
1997	Southwest Colorado	Cresson Mine (Cripple Creek), San Luis Mine, Bulldog Mine (Creede)
1998	Lead, SD	Richmond Hill Mine, Wharf Resources, Homestake's Red Placer, Sawpit Gulch, WASP Reclamation Project
1999	Northern New Mexico	Molycorp's Questa Mine, Hondo Fire Revegetation Work, Pecos National Monument, El Molino Site, Cunningham Hill Mine
2000	Central Colorado	Boardwalk at Breckenridge, Eagle Mine, Independence Pass, and Climax Mine
2001	Estes Park, Colorado	Rocky Mountain National Park
2002	Western Colorado	I-70 Glenwood Canyon, CSU Intensive Test Plots, Upper Colorado Environmental Plant Center, Rocky Mountain Native Plants, Union Oil Shale Project
2003	Colorado Front Range Foothills	Hayman, High Meadow, Buffalo Creek and Walker Ranch Fire Sites
2004	Vernal, Utah Area	Upper Strawberry River Drainage Projects and Simplot's Phosphate Mine
2005	Colorado Front Range	Caribou "Mudfest" Restoration Site Lakewood Pipeline Project Cherry Creek State Park Bluff Lake Nature Center
2006	Southeastern Wyoming	Horsecreek Limestone Mine I-80 Roadside Revegetation (Summit Rest Area) Snowy Range Road (Medicine Bow Mountains)
2007		No tour was held

HIGH ALTITUDE REVEGETATION COMMITTEE MEMBERSHIP

Denise Arthur	ESCO Associates	667 Hurricane Hill Dr	Nederland	CO	80466
Phil Barnes	Shell Oil Company	1260 Woodland Valley Ranch Dr	Woodland Park	CO	80863
Joe Brummer	Colorado State University	1170 Campus Delivery	Ft. Collins	CO	80523
David Buckner	ESCO Associates	P. O. Box 18775 1077 S Cherryvale Rd	Boulder	CO	80308
Jeff Campbell	Cripple Creek & Victor Gold Mining	AngloGold Ashanti POB 191	Victor	CO	80860
Vic Claassen	Land, Air & Water Resources	Univ of Calif – Davis 2446 Bucklebury	Davis	CA	95616
W. Jack Clark	Clark Mining Services	6052 S. Newport St.	Centennial	CO	80111
Jeff Connor	Rocky Mtn Natl Park	1000 Highway 36	Estes Park	CO	80517
Robin L. Cuany	Colorado State University (retired)	7351 Manderly Way	Knoxville	TN	37909
Nancy Dunkle	Natl Park Service (retired)	333 S. Miller Street	Lakewood	CO	80226
Michael D. Ellis	Ellis Environmental Engineering	4342 Ulysses Way	Golden	CO	80403
Russ Haas	USDA – NRCS	220 E Rosser Ave	Bismarck	ND	58502
Wendell G. Hassell	Pawnee Buttes Seed Inc	7866 Marshall St	Arvada	CO	80003
Don Hijar	Pawnee Buttes Seed Inc	P. O. Box 100 605 25th Street	Greeley	CO	80632
Mickey Jojola	New Mexico State Lands Program	409 Lower San Pedro	Espanola	NM	87532
Warren Keammerer	Keammerer Ecol Consultants	5858 Woodbourne Hollow Rd	Boulder	CO	80301
Lynn Kunzler	Utah Div of Oil, Gas & Mining	1594 West North Temple #1210	Salt Lake City	UT	84114
John A. Lawson	Mine Waste Program	ID Dept of Environmental Quality 1410 North Hilton	Boise	ID	83706
Carl Mackey	Washington Group International	P. O. Box 1717 Rocky Mtn Arsenal Project	Commerce City	CO	80037
Randy Mandel	Rocky Mountain Native Plants	3780 Silt Mesa Road	Rifle	CO	81650
Donna Mickley	USDA, Forest Service	740 Simms Street	Golden	CO	80401
Jody Nelson	Kaiser-Hill Ecology/PE Group	Rocky Flats Site, Building B460 10808 Hwy. 93 #B	Golden	CO	80403-8200
Ben Northcutt	International Erosion Control Assoc	3001 S. Lincoln Ave. #A	Steamboat Springs	CO	80477
Mark Paschke	Colorado State University	1472 Campus Delivery	Ft. Collins	CO	80523
Jeff Pecka	Systems Planning Group	5973 E. Irwin Place	Centennial	CO	80112
Gary Peterson	Colorado State University	1170 Campus Delivery	Ft. Collins	CO	80523
Mark Phillips	Phillips Seeding & Reclamation	11843 Billings	Lafayette	CO	80026
Ed Redente	MWH Americas, Inc.	1825 Sharp Point Drive, Suite 118	Fort Collins	CO	80525
Bryce Romig	Phelps Dodge Mining Co.	Climax Mine, Hwy 91	Climax	CO	80429
Steve Spaulding	Ute Pass Christmas Trees Inc.	4680 Mariposa Lane	Cascade	CO	80809
Ed Spence	USDA-NRCS	655 Parfet Street #E300	Lakewood	CO	80215
Ray Sperger	Ark Ecological Services	901 South Pierson Way	Lakewood	CO	80226
Gary L. Thor	Soil and Crop Sciences Dept	Colorado State University	Fort Collins	CO	80523
Krystyna Urbanska	Swiss Federal Inst of Technology	Zurichbergstrasse 38 CH-8044, Zurich	Switzerland		
Scott Wanstedt	Blue Mountain Energy Inc.	3607 County Road 65	Rangely	CO	81648
Mindy Wheeler	WP Natural Resource Consulting	P. O. Box 520604	Salt Lake City	UT	84152
Ronald Whiteman	Bowman Construction Company	10801 East 54th Avenue	Denver	CO	80239
Sarah Wynn	National Park Service - DSC	12795 Alameda Parkway	Denver	CO	80225