Abandoned Coal Mined-Land Research Program
Project Review Seminar

Sixteenth Project Review Seminar

Casper College, Casper, WY

November 16, 2004

The seminar series is sponsored jointly by the University of Wyoming, Office of Research and the

Abandoned Mine Lands Program of the Wyoming Department of Environmental Quality.

Sixteenth Annual ACMLRP Project Review Seminar
Casper College in the Physical Sciences Building, Rm 103, Casper, Wyoming
Tuesday, November 16, 2004, 1:15 p.m. - 4:00 p.m.

All presentations will be open to the public and there is no charge for participation in the Seminar. The agenda will include a brief review and discussion of the progress that has been made to date on each of these projects with time for questions and answers.

The ACMLRP is designed to support projects, which can aid in the development of practical solutions to some of the concerns that face the State and the Nation with respect to reclamation of coalmines. The projects were selected in open competition.

The seminar series is sponsored jointly by the University of Wyoming Office of Research and the Land Quality Division of the Wyoming Department of Environmental Quality. If you would like to have further information about this seminar series or if you would like to be placed on the mailing list to receive information about the ACMLRP, please call the Office of Research at 307/766-5353 or 766-5320.

Sixteenth Annual ACMLRP Project Review Seminar
Casper College, Physical Science Building, Room 103, Casper, Wyoming
Tuesday, November 16, 2004,
1:15 p.m. – 4:00 p.m.

1:20-1:45	**Evaluate the Effect Detonated Borehole Pressures Have on Adjacent Powder Columns and how that Contributes to Nitrogen Oxide Formation in Cast Blasting** Charlie Barnhart	**Final**	**1**
1:50-2:15	**The influence of reclamation management practices on carbon accumulation and soil fertility on coal mine lands in Wyoming** Peter Stahl, George Vance, Lachlan Ingram, Snehelata Huzurbazar, Carol Bilbrough	**Interim**	**2**
2:20-2:45	**The Effects of Seed Mix Species Composition and Seedling Rates on Attaining Species Diversity for Reclaimed Areas** Lyman McDonald, Shay Howlin, Beth Lack, Carol Bilbrough	**Interim**	**4**
2:45-3:00	Break		
3:00-3:25	**Development and identification of Rhizobiaceae (bacterial and Fabaceae (plant) symbioses for enhancing biological inputs of nitrogen in reclamation of disturbed lands** Steven Williams	**Interim**	**5**
3:30-3:55	**Recovery of below ground ecosystem components under different plant communities on reclaimed coal mine lands** Peter Stahl	**Interim**	**6**

Directly following the seminar an open discussion between industry, state and federal officials will be held so that the AML Program's Steering Committee can consider points that are brought forward when developing this year's request for proposals

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November 16, 2004

ACMLRP 2003-2004
WDEQ9569

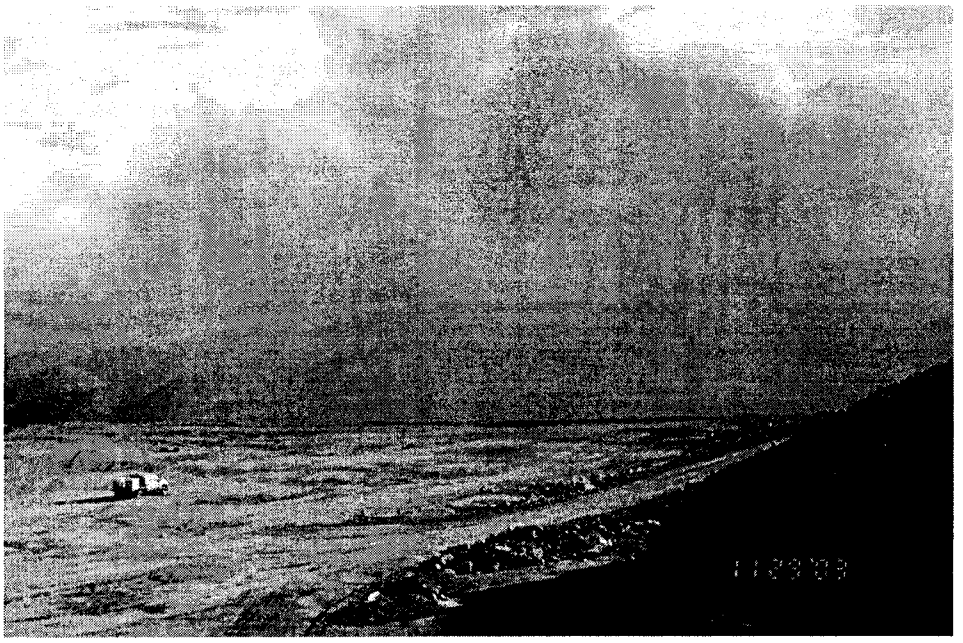
"Evaluate the Effect Detonated Borehole Pressures have on Adjacent Powder Columns and how that Contributes to Nitrogen Oxide Formation in Cast Blasting".

Introduction:

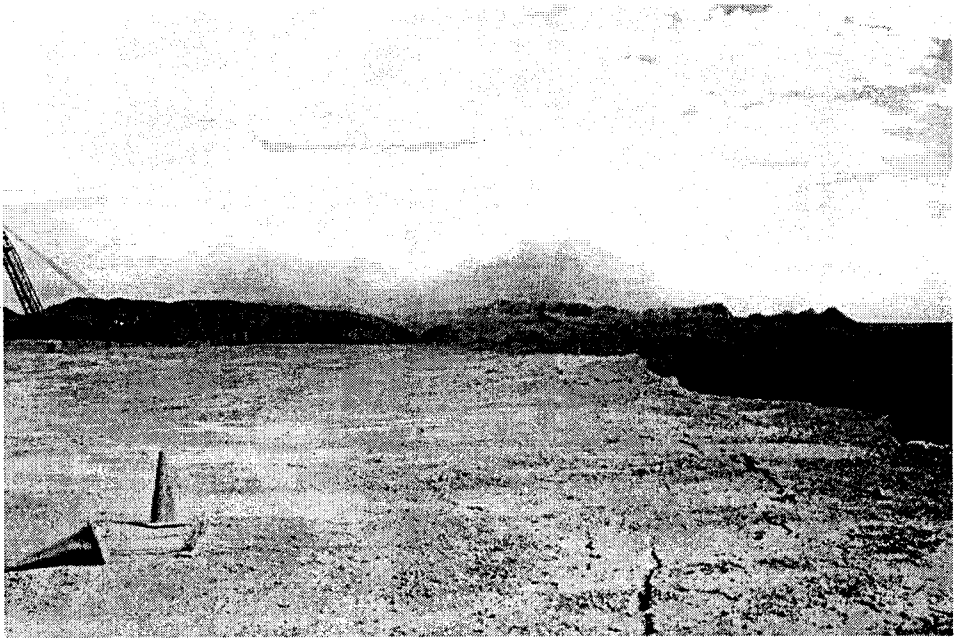
This research effort was to characterize the pressure exerted on boreholes and powder columns within a cast blast pattern. Both the methodology of the pressure measurement and the interpretation of the data are new information to the industry. The pressure data is substantiated by the velocity of detonation (VOD) data, which supports the fact that this particular blasting agent did sustain performance damage from the detonation pressures exerted by adjacent boreholes. Boreholes 30 feet down the face, and 45 feet behind, impacted the powder column with destructive power; however, most of the pressure damage could be avoided with quicker timing sequences.

There is a distinction to be made between the pressure pulse and the pressure volume. The **pressure pulse** is the sudden impact of a pressure wave (2,000 to 8,000 psig) on the powder column that only lasts for tenths of milliseconds. Those pulses have proven to be the damaging force to the 50% emulsion / 50% ammonium nitrate prill blasting agent (50/50) used throughout this study. The pressure pulse travels at 3,500 to 5,500 feet/second depending on water saturation of this alluvial rock. It was demonstrated that the pressure pulse damage could be out-run by a very aggressive timing sequence, but the compression to the new high wall was not desirable. There are measurable pressure pulses in the diagonal boreholes that are within 54 feet of the detonated powder column, but those pulses are the lowest pressures measured.

Following the **pressure pulse** is the **pressure volume** of expanding gases that moves the rock mass. The **pressure volume** begins as asymmetrical cylinder of gas pushing in all directions after the exothermic chemical reaction between ammonium nitrate and the hydrocarbon fuel. The path-of-least-resistance is quickly established and the gas blows the rock face apart; however, significant energy continues to push back into the overburden bench. This pressure volume of expanding gases strains the undetonated powder columns immediately down-the-face in the "A" row and behind in the "B" row. The duration of time the pressure volume is allowed to push on the borehole cylinder has a great impact on how well the borehole will detonate to steady-state-velocity. Minimizing the pressure pulse damage to the blasting agent and minimizing the pressure volume strain on the adjacent borehole cylinder minimizes the amount of deflagration that causes the formation of orange nitrogen dioxide gas. Photographs 1 and 2 demonstrate how quicker timing effects the nitrogen dioxide formation.



Photograph 1: Triton blast #7 on November 29, 2003 created thousands of parts/million nitrogen dioxide. The hole-to-hole timing was 27 ms with the row-to-row timing A to B was155 ms, B to C was180 ms and C to D was 210 milliseconds.

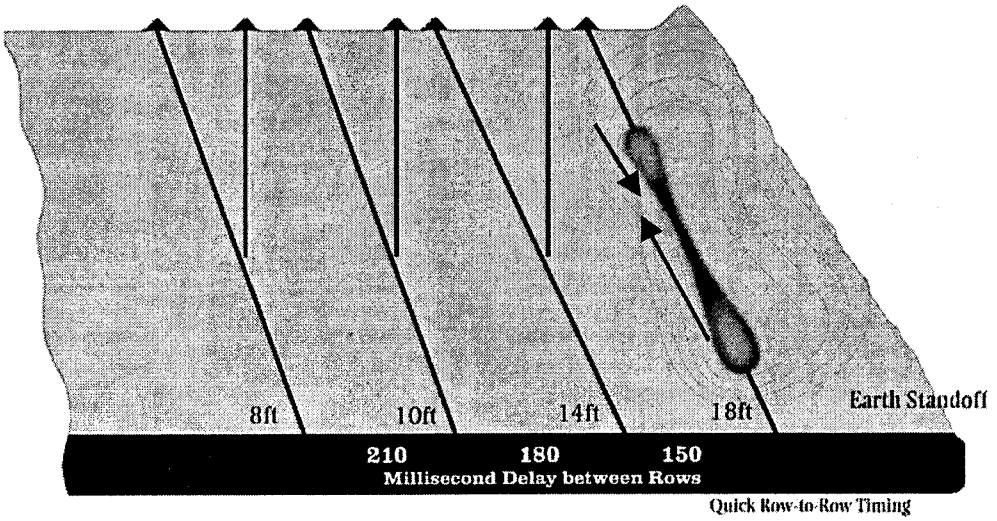


Photograph 2: Triton blast #4 on June 13, 2003 had the shortest delays in any pattern timing hole-to-hole (8ms) and row-to-row (144 ms, 144 ms, 144 ms). The result is no orange smoke in the dust.

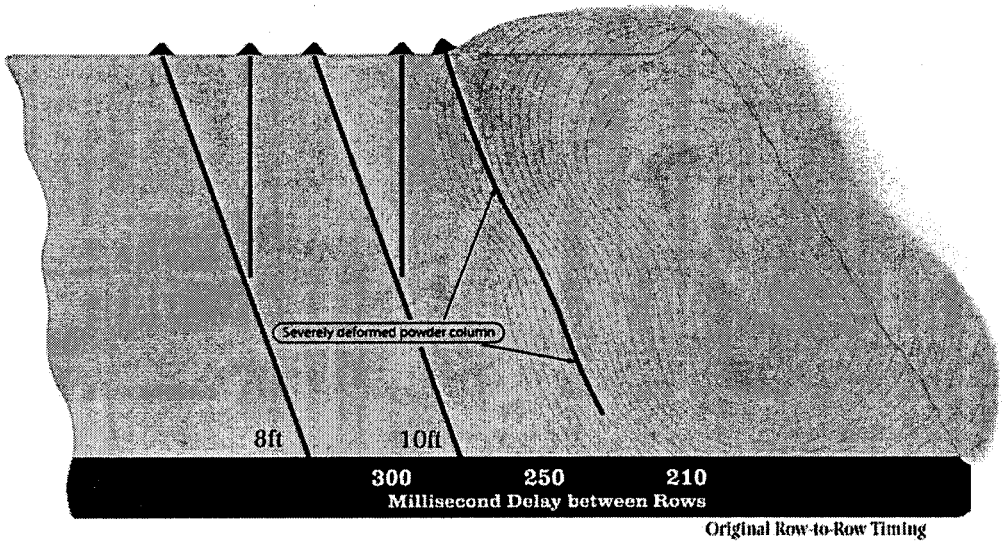
Pressure Effects from Powder Column Detonations on Adjacent Boreholes:

The discussion about speeding up the timing sequence to stop the nitrogen dioxide formation is really about diminishing the pressure effects from powder column detonations on adjacent boreholes. With fast hole-to-hole timing, the **pressure pulse** damage to the adjacent powder column in the same row can be avoided. With fast row-to-row timing, the **pressure volume** damage to the next row of boreholes can be minimized. The only borehole that detonates perfectly is the point-of-initiation (POI) borehole because it is the first. Every borehole after the POI suffers some damage, but the cracking of the borehole cylinder (loss of confinement) and desensitization of the blasting agent (slower VOD) can be optimized such that nitrogen dioxide formation is not a significant reaction.

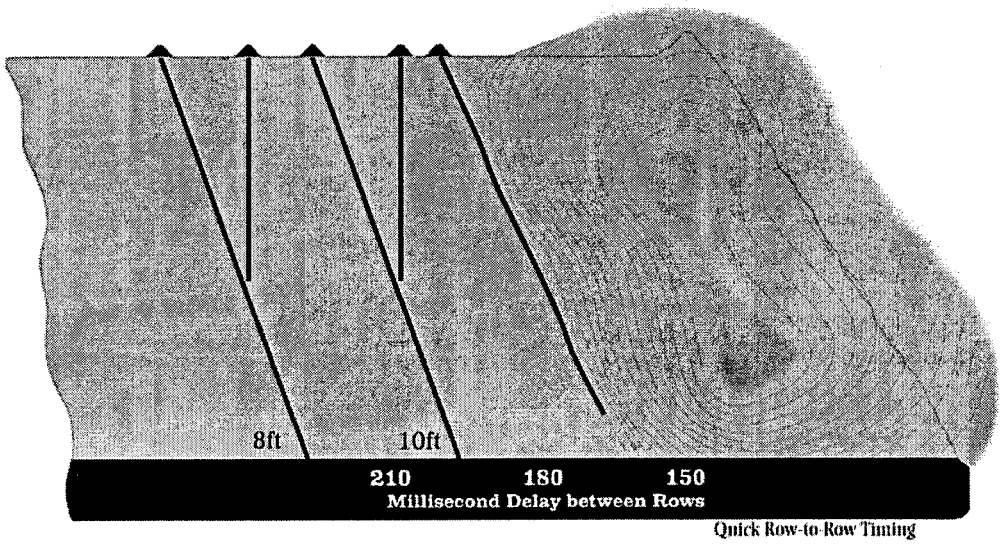
In Triton blasts #1, #2 and #3, the row-to-row timing was long compared to the timing the Blasting Superintendent decided he liked (based on this research), which was 155 ms between A and B, 180 ms between B and C, and 210 ms between C and D (table not included in this brief review). The high-speed photography used for the swell velocity test revealed that the borehole collars were swelling several feet before the initiation of the powder column (Picture 2). That severe movement supported the premise that the pressure volume had fractured the rock all the way through the un-detonated borehole (Picture 2) and caused the powder column to be noncontiguous as well. The nitrogen dioxide formation chemically has to be the result of deflagration; lack of confinement was suspected as the root cause. Deflagration would certainly occur if the borehole cylinder could not hold the vaporizing ammonium nitrate and hydrocarbon fuel together stoichiometrically for a complete detonation reaction (Picture 4). When the more volatile hydrocarbon escapes through the fissures of the fractured borehole cylinder, it leaves the ammonium nitrate fuel lean which results in deflagration and the formation of nitrogen dioxide (Equation 1).



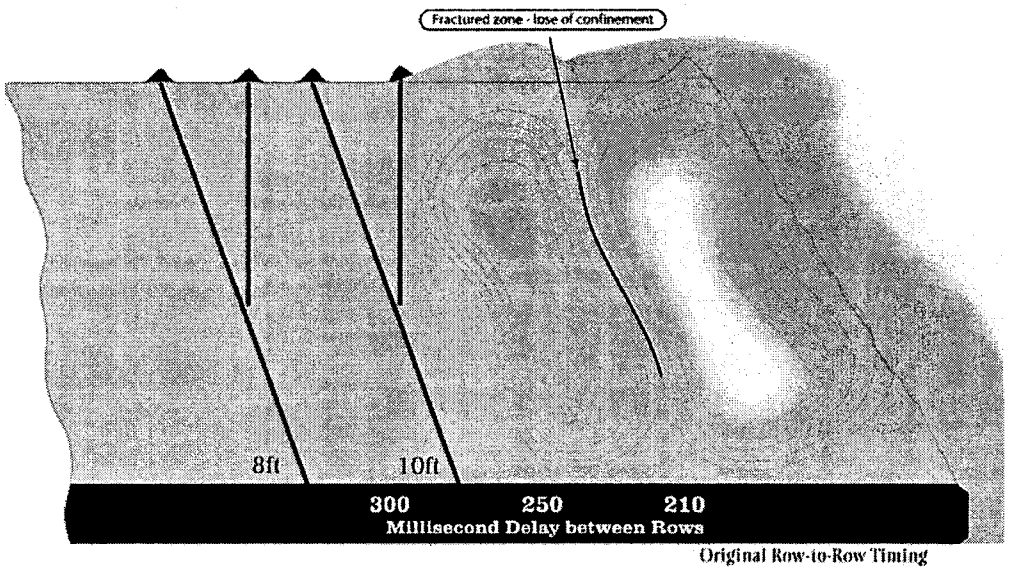
Picture 1: Hypothetical Triton North Rochelle front row borehole detonation. The vertical boreholes contain pressure gauges to monitor the amplitude of the pressure pulse on the powder columns. A 90 foot powder column consumed in 3.5 milliseconds; 63 feet from the bottom up and 27 feet from the top down.



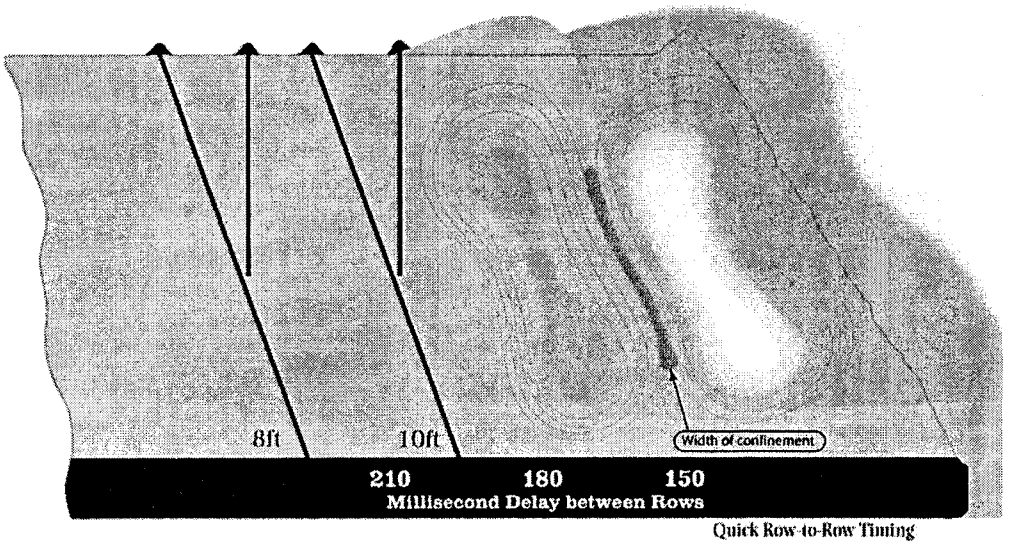
Picture 2: In timing sequences that were greater than 200 milliseconds between rows, the surface swells several feet at the borehole collar before the borehole detonates. The pressure volume severely deformed the borehole cylinders in Triton blasts #1, #2 and #3.



Picture 3: When the timing was changed from blast #3 to blast #5, it was decreased by 76 ms between A and B, 98 ms between B and C, 125 ms between C and D. The surface did not swell at the borehole collar before that borehole detonated. There is less stress on the borehole cylinder with quicker row-to-row timing.



Picture 4: The longer the pressure volume pushes into the overburden bench, the more the rock in front of the undetonated borehole is fractured. When the second row detonates, there is no solid rock left to provide confinement for the initial explosion. This lack of confinement causes the nitrogen dioxide formation.



Picture 5: When there is less time between the row-to-row detonations, several feet of rock in front of the undetonated boreholes is left intact. This provides the containment required by the blasting agent to detonate rather than deflagrate. The confinement only has to last for 3.5 milliseconds before the powder column is consumed.

Deflagration of ANFO (850 °F)

$$2\ NH_4NO_3 + 2\ NH_4NO_3 \text{ ------ } 2\ NO_2 + 3\ N_2 + 8\ H_2O$$

Detonation of ANFO (4,750 °F)

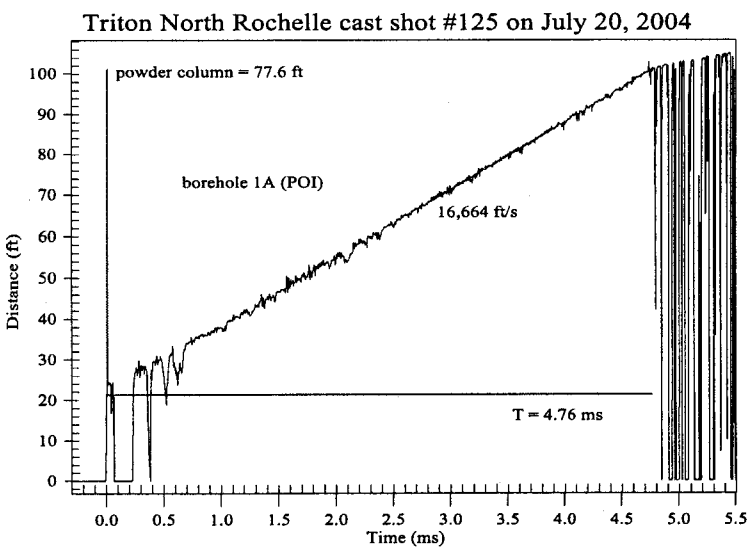
$$3\ NH_4NO_3 + [\text{-}CH_2\text{-}]_n \text{---------} CO_2 + 3\ N_2 + 7\ H_2O$$

Equation 1: Deflagration forms nitrogen dioxide while detonation produces carbon dioxide.

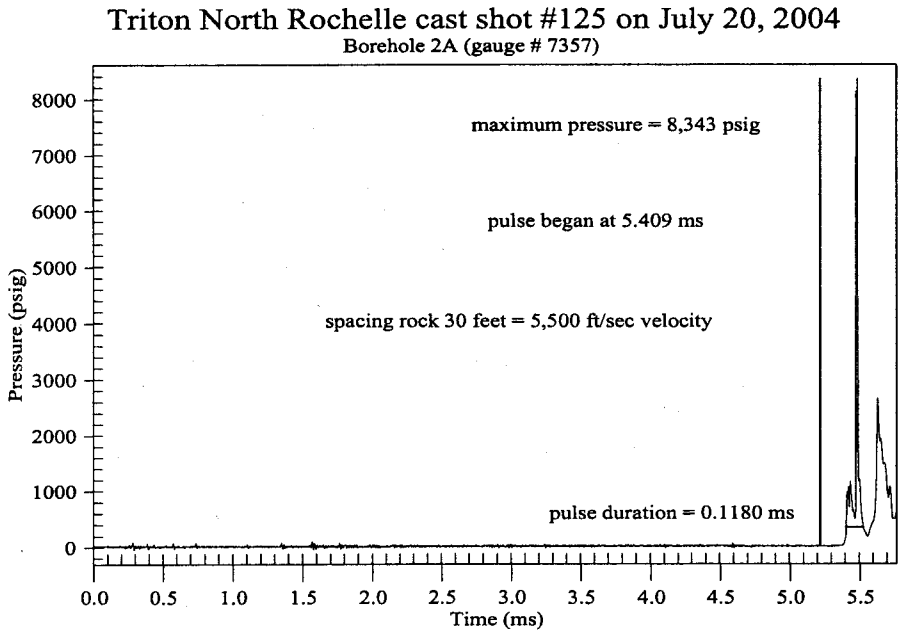
The faster timing sequence used in every other cast blast made a significant impact on the nitrogen dioxide formation. The pressure volume did not have time to crush all of the rock in front of the undetonated boreholes (Picture 3). Consequently, when the second row of powder columns detonate there is just enough intact structure to provide the confinement needed to promote detonation rather than deflagration (Picture 5).

Pressure Measurement Analysis:

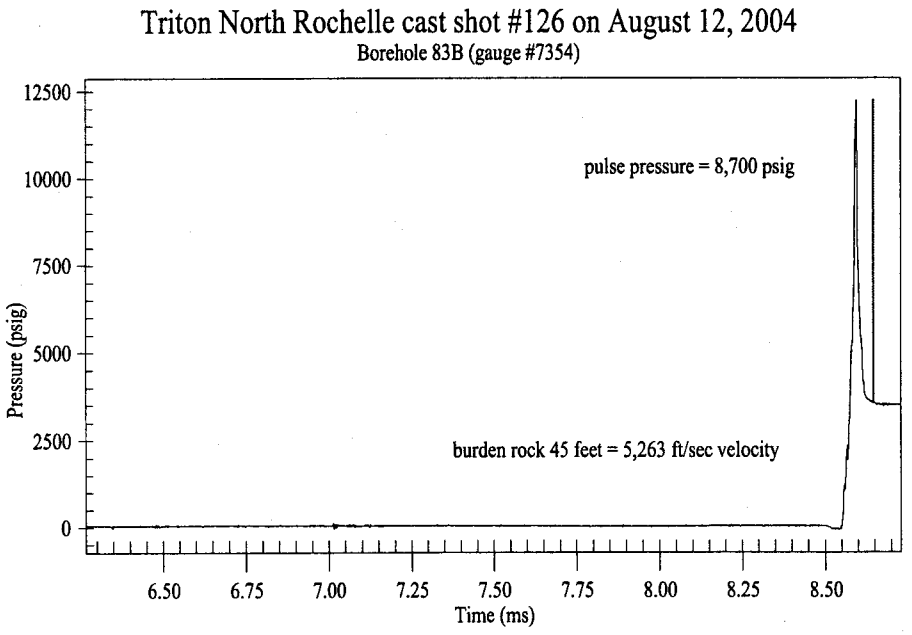
The Triton North Rochelle experiment was consistent throughout the 12 cast blasts. The blast pattern was square with 30 feet of spacing between the holes and 45 feet of burden between the rows. Row A was drilled at a 25° angle, rows B and C angled 20°, with row D angled 15 degrees. All boreholes were filled with 50/50 blasting agent supplied by Nelson Brothers. The POI powder column velocity-of-detonation was always 16,500 to 18,000 feet per second, which demonstrated very good quality control in manufacturing the emulsion and blending it with the ammonium nitrate prill. The powder columns were 70 to 90 feet deep. The stemming was 30, 27, 27 and 40 feet in rows A thru row D respectively. Each borehole received a 40 and 20 meter Icon electronic detonator, the top being timed to detonate 2 milliseconds after the bottom.



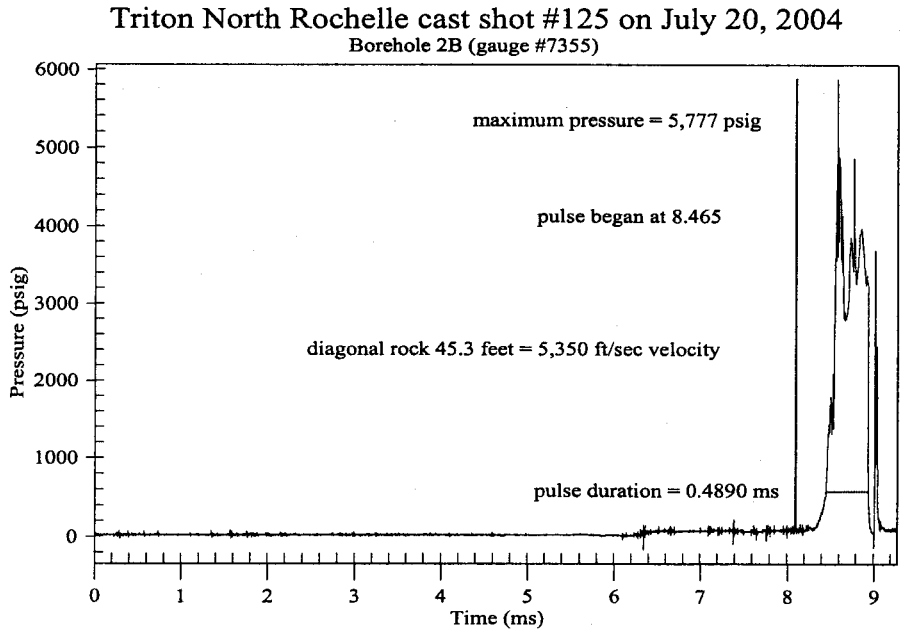
Trace 1: In Triton North Rochelle blast #11 on July 20, 2004, the POI powder column is detonated at steady-state-velocity of 16,700 ft/sec. The POI was used to demonstrate quality control of the blended 50/50.



Trace 2: In Triton North Rochelle blast #11 on July 20, 2004, the powder column 30 feet away from the 1A detonation was 2A. The pressure pulse was 8,300 psig. The velocity for the pulse to reach was 5,500 feet/second.



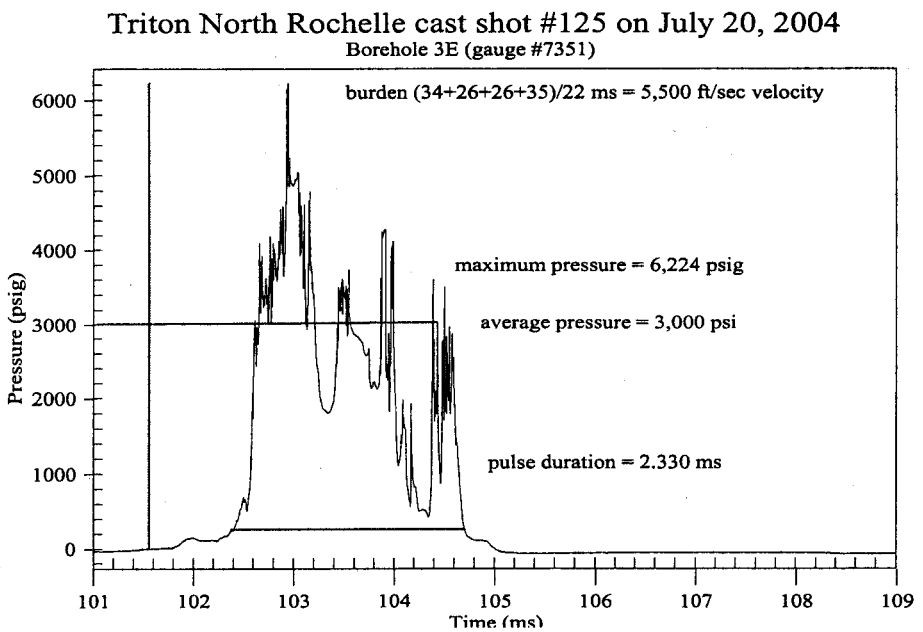
Trace 3: In Triton North Rochelle blast #12 on August 12, 2004, the powder column 45 feet behind the POI detonation was 83B. The pressure pulse was 8,700 psig. The velocity for the pulse to reach was 5,300 feet/second.



Trace 4: In Triton North Rochelle blast #11 on July 20, 2004, the powder column diagonal to the 1A detonation was 2B. The pressure pulse was 5,800 psig. The velocity for the pulse to reach was 5,350 feet/second.

The POI detonation (1A) in cast blast #11 registered a VOD that was within the quality control range of 16,500 to 18,000 fps expected for this 50/50 blasting agent (Trace 1). The powder column 30 feet down the face (2A) received a pressure pulse of 8,300 psig in 5.4 milliseconds (Trace 2). The velocity of the pressure pulse was 5,500 fps. The example of the pressure pulse impact 45 feet behind a powder column detonation was recorded in cast blast #12. Borehole 83B was hit with an 8,700 psig pressure pulse in 8.5 milliseconds (Trace 3). The velocity of that pulse was 5,300 fps. The piezoelectronic trace on borehole 83B may be 12,000 psi but the smaller of the two peak heights was taken as the minimum pressure pulse (Trace 3). A borehole diagonal to the POI powder column detonation in cast blast #11 registered a pressure pulse (Trace 4). A 5,800 psig pressure pulse impacted borehole 2B traveling at a velocity of 5,400 ft/sec (Trace 4).

It becomes obvious from the data that the pressure pulse does slam into the adjacent powder columns with sufficient force to desensitize certain types of blasting agent. In this study, it was apparent that the minimum strength glass micro-balloon was not effective at keeping the 50/50 blasting agent at the 17,000 to 18,000 velocity-of-detonation. To summarize the observations of this pressure study, it can be stated that one pressure pulse reduces the blasting agent VOD by 1,500 fps and a second pressure pulse decreases the VOD by another 2,500 fps. This is only true for the system measured, but is still applicable to any blasting agent that has void volume that can be squeezed out with an 8,000 psi pressure pulse. Blasting agents that are chemically gassed to produce void volume have not been observed so their behavior with pressure pulse desensitization is not known.



Trace 5: In Triton North Rochelle blast #11 on July 20, 2004, the new high wall behind the borehole 3D detonation received a pressure pulse of 6,200 psig. The velocity for the pulse to reach was 5,500 feet/second.

In conjunction with the borehole pressure pulse study, there was an experiment to determine the pressure push into the new highwall and to characterize this pressure for future work. In cast blast #11, the pressure pulse was 6,200 psig with a longer pulse duration than the powder columns in the pattern are subjected. The source of the pulse was from the powder column detonation directly in front, as expected. The pulse traveled at a velocity of 5,500 feet/second just as all the pulses traveled in this particular cast blast.

Pressure Test Findings:

Two pieces of critical data have been identified in the study. The most confirmed data is that the alluvial rock of the Powder River Basin has a pressure pulse transfer rate of 5,500 feet/second. This is important because it means the pressure pulse damage to the poweder column can never be out run with aggressive timing; therefore, the blasting agent needs to be manufactured to withstand this pressure pulse without losing performance. Second, the blasting agent needs to be manufactured to withstand 8,000 psig pressure pulses without loss of performance. As previously mentioned, there are blasting agents that are not susceptible to pressure pulse damage but they are a compromise in other ways; either more manpower is required to install the blasting agent or the blasting agent has less explosive power than 50/50 blasting agent.

The pressure pulse is not the only consideration when cast blasting with smokeless results. The pressure volume effect on the borehole cylinder was extensively studied and successfully reduced with much quicker timing sequences than typically used in cast blasting. The timing was made very precise with the use of electronic detonators. The elimination of nitrogen dioxide in this cast blast study could not have been done with pyrotechnic detonators.

AML Interim Progress Report 2004

Influence of Reclamation Management Practices on Carbon Accumulation and Soil Fertility on Coal Mine Lands in Wyoming

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Introduction

The overall goal of this proposed research is to examine the influence of a number of surface coal mine reclamation management practices on carbon accumulation, organic nutrient pools and soil fertility in reclaimed soils. To accomplish this goal, we have examined the influence of these common management practices (grazing, mulching practices, direct haul/stockpiled topsoiling, and shrub mosaic seeding) on soil organic carbon (SOC) and nutrient concentrations in soil. Data collected will be used to determine mechanisms by which organic matter and nutrients accumulate in these soils and evaluate the potential for enhancing carbon and organic nutrient storage in reclaimed surface mine lands.

Objectives of this study were to examine and compare the influence of different management practices on SOC and microbial biomass carbon (MBC) in reclaimed soils. If any of the measured reclamation management practices prove to optimize C accumulation and show increased organic nutrient contents, these methods could be applied to sequester C and improve soil fertility. Not only would this help to enhance overall soil quality and improve the suitability of the land for bond release but also may assist in mitigating rising concentrations of anthropogenic carbon dioxide in the atmosphere.

Results and Discussion

Soil texture, pH and EC were similar between paired reclamation practices and undisturbed sites within mines (data not shown). Reclamation practices do not appear to be influencing pH and EC and it is unlikely that any of these variables are negatively influencing the accumulation of SOC or levels of MBC in the reclamation soils.

Across all treatments , while there were site to site variations, there was a general increase in SOC observed that coincided with the period of time since reclamation was initiated (Table 1). For the mass of C sequestered to increase to an amount of that above a comparable, undisturbed, prairie site, took a period of greater than about 11 - 14 yrs (Table 2). Although the data is not shown, we observed similar trends for total soil nitrogen also. This suggests that in any analysis it is important to consider the period of time since reclamation was undertaken.

Grazing at the Dave Johnston and Jacobs Ranch mines resulted in greater concentrations of MBC at the 0-5 cm depths than not grazing. The influence of grazing on SOC, however, is not as obvious as conflicting results were obtained from the two mines. Jacobs Ranch grazed site had greater SOC at 0-5 cm than the ungrazed, but Dave Johnston had the opposite with ungrazed site having greater SOC at 0-5 cm depth than the grazed site. The Dave Johnston mine sites had been grazed for six years at long duration (July-October) and low to moderate intensity grazing. Low or moderate grazing, compared to heavy grazing, can result in an accumulation of C in standing and soil surface litter (Schuman et al., 1999). This may have resulted in the lower SOC concentrations in the grazed site compared to the ungrazed site due to possible litter accumulation on the soil surface and/or removal of C through incorporation into livestock biomass. The Jacobs Ranch site had been grazed at a short duration (two - three day periods), and at a high intensity rate for five years. Grazing exclosure studies in shortgrass steppe ecosystems have found higher rates of accumulation of SOC in high intensity grazed sites than in adjacent ungrazed exclosures (Schuman et al., 1999). This higher rate of SOC accumulation may be attributed to a shift in vegetation composition, a reallocation of C from shoots to roots, and an increase of surface litter incorporation into the soil.

The two topsoil handling practices compared (stockpiled vs. direct haul) did not appear to have significant effects on MBC at either the Dave Johnston or Jim Bridger mines. In this study, effects of topsoil management practices on MBC, 11 years after reclamation was initiated were negligible. At the Dave Johnston mine, however, the site reclaimed with stockpiled topsoil had

significantly greater SOC than the direct haul site at all depths. These sites have similar age, topsoil depth, soil texture, pH, and EC so the reason for difference in the concentration of SOC is not apparent.

Table 1. Weighted averages (0 - 30 cm) of the concentration and mass of soil organic carbon and microbial biomass carbon in undisturbed and reclamation soils in semiarid Wyoming.

Mine	Site	SOC (g C/ kg soil)	SOC (kg C/ ha)	MBC (g C/ kg soil)
Dave Johnston	Undisturbed	9.1	35000	122
	Grazed	9.9	44000	109
	Ungrazed	10.7	45000	74.0
	Shrub	5.1	23000	186
	Grassland	5.1	21000	66.0
	Stockpile	5.1	21000	66.0
	Direct Haul	2.3	9600	109
Jacobs Ranch	Undisturbed	13.5	50000	92.0
	Grazed	5.8	25000	243
	Ungrazed	5.5	23000	180
Jim Bridger	Undisturbed	8.8	34000	101
	Direct Haul	8.2	34000	146
	Stockpile	7.0	29000	137
Seminoe	Undisturbed	8.5	34000	110
	Hay	6.8	30000	50.0
	Stubble	9.7	41000	82.0
Belle Ayr	Undisturbed	9.2	37000	368
	Shrub	10.5	42000	528
	Grassland	10.8	41000	140

It is possible that the stockpiled soil simply had a greater SOC concentration when compared to the direct hauled soil when reclamation was initiated; or due to differences in long-term litter inputs by the respective vegetation communities. An alternative explanation is that SOC also included coal contamination from vehicles transporting coal along haul roads, although this has not been confirmed. Finally, it also conceivable that the long-term storage of the stockpiled soil has had a negative impact on the microbial community present, severely impacting their ability to mineralize SOC.

Use of different seed mixtures and the resulting plant communities had no effect on SOC concentrations at neither the Dave Johnston mine nor the Belle Ayr mine. Although there were no differences in SOC, the different seed mixture practices had a significant effect on MBC concentrations at both locations. Vegetation communities derived from shrub seed mixtures

appear to be facilitating larger MBC concentrations than vegetation communities resulting from the grassland seed mixtures used on these semiarid reclamation sites. Studies have shown "islands of fertility" due to the spatial distribution of shrubs and grasses in semiarid ecosystems (Charley and West, 1975), but not all studies reported statistical differences in MBC under the canopy of shrubs when compared to perennial grasses (Bolton et al., 1993).

After 14 years, mulching practices had no effect on MBC concentrations in the stubble mulch and hay crimp mulch sites at the Seminoe mine. The stubble mulch site, however, had significantly greater SOC at the 15-30 cm depth than the hay crimp mulch site. Stubble mulching has been reported to increase infiltration through improvement of soil physical characteristics from deep rooting stubble mulch, in addition to facilitating seeded grass reestablishment on reclamation sites when compared to hay crimp mulching (Pinchak et al., 1985; Schuman et al., 1985). Stubble mulching will also increase SOC accumulation at depth by root inputs rather than just applying organic matter to the surface as is done with hay crimp mulching. Although this is just one years input from stubble mulching over a 14 year period, it appears to have a significant impact considering the slow rate of decomposition in semiarid systems.

Based on the experimental setup of this study it would be difficult to evaluate the time required for reclamation sites to recover to undisturbed values of MBC and SOC, but a few conclusions can be drawn based on presented data. Data shows that, in the mines studied, it takes longer than 11 years for grassland reclamation sites to recover to undisturbed MBC concentrations, while the comparable shrub reclamation sites had recovered to or above undisturbed levels within 11 years. This occurred even though SOC concentrations were almost identical between shrub and grassland seed mixture practices in both comparisons (Table 2). In terms of SOC, recovery appears to be mainly dependant on annual precipitation and age.

It is estimated that there are 0.63 Mha of mined land in the U.S. that could be reclaimed with the potential to sequester C at a rate of 1000-3000 kg C/ha/yr, equaling a total between 0.6-1.9 million metric ton C/yr. This represents the greatest potential rate of SOC sequestration in semiarid grazing lands within the U.S. (Follett et al., 2001). Three of the five mines studied had reclamation sites with SOC concentrations greater than the adjacent undisturbed sites (Table 2). Calculations of SOC sequestration in reclamation sites from mines in this study, that were above undisturbed concentrations, averaged 6,900 kg C / ha above undisturbed values.

Table 2. Age of reclamation site and weighted SOC and MBC values as a ratio to the undisturbed control soil.

Mine	Site	Age	SOC[1]	MBC[1]
Dave Johnston	Grazed	26	**1.25**	0.89
	Ungrazed	26	**1.28**	0.61
	Shrub	11	0.66	**1.53**
	Grassland	11	0.61	0.54
	Stockpile	11	0.61	0.54
	Direct Haul	11	0.27	0.90
Jacobs Ranch	Grazed	11	0.51	**2.63**
	Ungrazed	11	0.46	**1.95**
Jim Bridger	Direct Haul	19	**1.00**	**1.45**
	Stockpile	19	0.86	**1.36**
Seminoe	Hay	14	0.89	0.46
	Stubble	14	**1.21**	0.74
Belle Ayr	Shrub	11	**1.12**	**1.43**
	Grassland	11	**1.12**	0.38

[1] Calculated as a weighted average and divided by undisturbed value

Current reclamation management practices have the potential to affect the levels of SOC accumulation and MBC. With respect to SOC concentrations, comparisons between management practices showed significant differences between all practices except the seed mix practice. Comparisons between management practices with respect to MBC concentrations showed significant differences between all practices except the topsoil handling method. In terms of the years required for recovery of MBC and SOC, no conclusions can be drawn except that sites planted with shrub seed mixtures had MBC recover to undisturbed levels within 11 years while comparable grassland seed mixture sites had not. Proper management can maximize sequestration of C and improve long-term success of reclamation. Management practices that sequester C are helping to mitigate carbon dioxide (CO_2) levels in the atmosphere and reducing the greenhouse effect.

Work to be completed

This project is well on the way to completion. Still to be completed are the laboratory, C- and N-mineralization study which will be undertaken over the winter of 2004-2005. Finally, a litter decomposition experiment is currently under way with the last set of litterbags to removed in 2005.

Publications

Anderson, J.D., P.D. Stahl and L.J. Ingram. 2004. Influence of mineland reclamation practices on microbial community recovery and soil organic carbon accumulation. Proceedings of the 2004 National Meeting of the American Society for Mining and Reclamation and the 25th West Virginia Surface Mine Drainage Task Force, Morgantown, WV, April, 2004.

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2004 ANNUAL PROJECT REVIEW SEMINAR

ABANDONED COAL MINE LAND RESEARCH PROGRAM

The Effects of Seed Mix Species Composition and Seeding Rates on Attaining Species Diversity for Reclaimed Areas

Interim Progress Report
November 10, 2004

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Introduction

Species diversity is an important component of reclaimed landscapes. In reclamation planning to attain diversity, it is essential to understand the effect of seed mixes and seeding rates on species establishment and persistence. Many factors contribute to the successful establishment of a persistent, diverse plant community. However, the seed mix is the key determinant for species presence and affects species relative composition through seeding rates. This quantitative assessment of the relationship between seeding rates, seed mix species composition, and observed cover through time in revegetated areas of Wyoming will provide information to assist in the design of seed mixes to obtain diversity in reclaimed areas. Analyses will be designed to identify species that consistently dominate, persist at low levels, or do not persist in reclaimed lands. Our investigation of the seeding rates will attempt to identify subordinate species that can coexist with dominants if certain combinations of seeding rates are planted.

The focus of this project is to analyze the seed mixes and seeding rates used in Wyoming. In Phase I, analyses were focused at the individual species level. We first examined the relationship between observed cover and seeding rate of each species. We then incorporated the effect of covariates such as topsoil depth and mulching into this analysis. During this phase of the analysis, we quantified species persistence on the reclamation units. We also quantified the number of species that were present in the reclamation that were not seeded (invasions). In Phase II, we will assess how the relationship between cover and seeding rate of each species is affected by other species in the seed mix. We will incorporate factors such as seeding method and management practices to develop multivariate predictive models. Finally, this project will develop an analysis product for LQD to use to continue evaluating seed mix performance as more data becomes available.

Methods/Progress

Our study plan involves conducting a literature review, acquiring vegetation data and reclamation history information, designing the database, entering the data, Phase I analysis, Phase I review, Phase II analysis, Phase II review, and the development of an analysis tool for LQD.

We are reviewing literature on reclaimed mine land revegetation techniques. This literature review has located studies which have investigated the relationships between plant establishment and seed mix composition and seed rates. Many hypotheses generated for Phase II of this study have been developed as a result of this research.

The data acquired for this project came from hard-copy reports and permits filed in the LQD's Cheyenne office. We selected reclamation areas for which diverse seed mixes were planted and adequate time since reclamation has passed. We could only use data from sources with adequate documentation of reclamation methods. The analyses required the spatial linking of data on the reclamation units and vegetation monitoring transects as well as documentation of the seeding activities. We required data for which the seed mixes planted and interim monitoring data were recorded to the species level. We are still perusing LQD files for data that could be included in this analysis. Our ability to incorporate data from a broad range of ecological conditions, seeding mixes, and seeding rates will directly influence the applicability of the results.

To date we have acquired data from 3 mines, Antelope, Belle-ayr, and Eagle Butte. There were 72, 40 and 14 reclamation units for each mine (total=126) and the average age of reclamation was 5.9, 12.2, and 8.7 years respectively. An Access database was developed to house and manage interim vegetation monitoring and reclamation history data for this project. The database contains several tables of data linked together. The goals of this project depended on the ability to link the interim vegetation monitoring data with the seed mix information and any other actions performed on a reclamation unit. All data were checked for quality assurance/quality control (QAQC).

Preliminary Results

The Phase I analysis identified general patterns at the level of the individual species. The relationship between was estimated observed cover of each species and seeding rate of that species using simple linear regression with reclamation units as the experimental unit. For each reclamation unit, the most recent vegetation monitoring data was averaged across transects. Summaries were made for each species and for each of 12 functional groups: introduced annual and biennial forbs, introduced annual grasses, introduced perennial forbs, introduced perennial grasses, introduced perennial cool season grasses, native annual and biennial forbs, native annual grasses, native perennial forbs, native perennial cool season grasses, native perennial warm season grasses, native shrubs, native subshrubs, native succulents (native perennial subshrubs), native trees.

The effect of covariates on these relationships was estimated using the same model. We investigated 3 continuous covariates (age of reclamation, unit size, topsoil depth) and 8 discrete covariates (mine, soil source, mulch indicator, surface preparation, cover crop indicator, fertilizer indicator, grazing indicator, and herbicide spraying indicator). Only one covariate was entered into the model at a time (multivariate models to predict cover will be developed as the next step of this analysis).

Significant positive linear relationships between seeding rate and cover were found for several groups and species: introduced perennial forbs, native perennial cool season grasses, introduced annual and biennial forbs, native subshrubs, and western yarrow. Significant negative linear relationships between seeding rate and cover were found for several groups and species: thickspike wheatgrass, introduced perennial cool season grasses, slender wheatgrass, native annual and biennial forbs, and fourwing saltbrush.

We also investigated the properties of persistent and invasive species. For each species, we calculated a measure of persistence as the proportion of seeded reclamation units that contained the species at the time of monitoring. Native perennial cool season grasses were present in 99% of the 124 units they were seeded in, native annual and biennial forbs were present in 70% of the 27 units they were seeded in, and introduced perennial cool season grasses were present in 68% of the 81 units they were seeded in. Western wheat grass was present in 97% of the 121 units it was seeded in, alfalfa was present in 89% of the 38 units it was seeded in, green needlegrass was present in 83% of the 59 units it was seeded in, and bluebunch wheatgrass was present in 80% of the 71 units it was seeded in.

For each species, we also calculated a measure of invasion as the proportion of the reclamation units that were not seeded with a species but that contained the species at the time of monitoring. Introduced annual and biennial forbs were present in 99% of the

73 units they were not seeded in, introduced perennial cool season grasses were present in 96% of the 45 units they were not seeded in, introduced perennial forbs were present in 82% of the 11 units they were not seeded in, and native perennial forbs were present in 75% of the 52 units they were not seeded in. American vetch was present in 62% of the 119 units it was not seeded in, yellow sweetclover was present in 53% of the 73 units it was not seeded in, and cheatgrass was present in 52% of the 126 units it was not seeded in.

Future Work

The results of the Phase I analysis are currently being reviewed by all investigators. Feedback from LQD, mine operators, and consultants will be solicited. We are in the process of refining the specific analysis questions for the Phase II analysis.

The Phase II analysis will be a detailed analysis to test hypotheses which have been designed to identify explanations for the patterns identified in the first phase of the analysis. In particular, this analysis will investigate the relationship of observed cover of each species to the cover and seeding rates of the other species seeded in the seed mix or detected during interim vegetation monitoring. In addition, this phase will have an exploratory component that will look for patterns that were not apparent in Phase I, particularly the effect of seed mixes. There are three major categories of investigations we will pursue in Phase II: Community Response, Discrete Influences, and Continuous Influences.

The results of the Phase II analysis will be reviewed by all investigators. Collaborations between the biometricians and ecologists will facilitate the identification of ecological explanations for the results obtained by the data analysis. Feedback from LQD, mine operators, and consultants will also be solicited. During the review we will compare the results documented by this analysis with results obtained by more experimental approaches to the same questions. It is expected the experimental results will support the patterns observed in this project.

The final piece of this project will be to develop a protocol (guidelines and programs) for a systematic analysis of the new data available after this project is finished. The analysis will be based on the results we determine to be most useful during Phase I and II of this project.

AML Interim Progress Report
November 2004

DEVELOPMENT AND IDENTIFICATION OF RHIZOBIACEAE (bacterial) AND FABACEAE (plant) SYMBIOSES FOR ENHANCING BIOLOGICAL INPUTS OF NITROGEN IN RECLAMATION OF DISTURBED LANDS.

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Introduction

The symbiotic associations between legumes and bacteria (family Rhizobiaceae) that produce biologically available nitrogen, despite long-term use in crop systems, are not considered as seriously in management of rangeland and shrub lands or in revegetation of such lands. Legumes are not ignored, but it is our contention that there is considerable, undeveloped potential to utilize adapted legumes for revegetation of disturbed lands, especially in surface mined lands. Much of this potential lies in developing inoculants that can be used to enhance nitrogen fixation of legumes under extreme edaphic regimes, such as pH and salt content extremes.

The overall goal of this research is to develop a suite of Rhizobiaceae cultures that are effective in eliciting nodules capable of fixing appropriate levels of nitrogen for these usually arid, ultimately extensively managed lands.

The objectives of this study are to: (1) Develop a collection of Rhizobiaceae cultures appropriate for several genera of range legumes (e.g. Astragalus, Lupinus and others). We will develop general inoculum for general soil conditions, but will also focus on seeking isolates from soils of extreme pHs, and extreme salt contents. (2) Test these isolates on target legumes under controlled settings (light, day length, soils, nutrients and water) for survival, growth and efficacy of the Rhizobium-Legume interaction. (3) Produce a limited number of inoculated plants and test methods of transplanting to the field as well as limited survival, biomass accumulation and nitrogen fixation rates.

This research proposal was awarded funding May 5th of 2004.

Results

Objective 1. Develop a collection of Rhizobiaceae cultures that are appropriate for several genera of range legumes (e.g. genera *Astragalus, Lupinus, Trifolium, Hedysarum, Psoralea*) under extremes of pH, desiccation and salt.

Most of the work that has been done on this project was excavation of leguminous plants from rangelands followed by isolation of bacteria from root nodules.

TABLE 1. Isolates made during the summer of 2004.

COLLECTION NUMBER	PLANT ID	DATE COLLECTED	LOCATION
1	ONOBRYCHIS VICIIFOLIA	27-Jul-04	WHISKEY MT
1	ONOBRYCHIS VICIIFOLIA	27-Jul-04	WHISKEY MT
1	ONOBRYCHIS VICIIFOLIA	27-Jul-04	WHISKEY MT
2	ASTAGALUS CICER	27-Jul-04	PATHFINDER
5b	ASTRAGALUS X	26-Jul-04	W OF TOGWOTEE PASS
6b	ASTRAGALUS X	26-Jul-04	W OF TOGWOTEE PASS
7b	ASTAGALUS CICER	26-Jul-04	PATHFINDER MINE
7b	ASTAGALUS CICER	26-Jul-04	PATHFINDER MINE
7b	ASTAGALUS CICER	26-Jul-04	PATHFINDER MINE
11	ASTRAGALUS Y	26-Jul-04	SPLIT ROCK
11	ASTRAGALUS Y	26-Jul-04	SPLIT ROCK
11	ASTRAGALUS Y	26-Jul-04	SPLIT ROCK
12	TRIFOLIUM SP	31-Jul-04	LOOKOUT TRAIL
12	TRIFOLIUM SP	31-Jul-04	LOOKOUT TRAIL
12	TRIFOLIUM SP	31-Jul-04	LOOKOUT TRAIL
12	TRIFOLIUM SP	31-Jul-04	LOOKOUT TRAIL
12	TRIFOLIUM SP	31-Jul-04	LOOKOUT TRAIL
13	LUPINUS ARGENTUS	26-Jul-04	OLD FAITHFUL ROAD
13	LUPINUS ARGENTUS	26-Jul-04	OLD FAITHFUL ROAD
13	LUPINUS ARGENTUS	26-Jul-04	OLD FAITHFUL ROAD
14	LUPINUS ARGENTEUS	25-Jul-04	LITTLE POPO AGIE
14	LUPINUS ARGENTEUS	25-Jul-04	LITTLE POPO AGIE
15	LUPINUS ARGENTEUS	25-Jul-04	CANYON ROAD SIDE

Objective 2. Test these isolates on legumes under controlled settings for plant survival and growth as well as efficacy of the Rhizobia-Legume interaction.

Effort under this objective has been limited to locating seed sources, devising strategies to break seed dormancy and determining growth habits and requirements of test plants.

TABLE 2: Plant seed materials being tested for germination and growth potential. Some or all of these will be used to test efficacy of rhizobia isolates.

Plant Name	Variety, Other Information	Common Name
•Astragalus canadensis,		Canada milkvetch
•Astragalus cicer (Monarch CT),	Monarch CT	cicer milkvetch
•Hedysarum boreale,	Northern Timp CT	sweet vetch
•Lupinus argenteus,		lupine.
•Onobrychis viciifolia (ESKI),	ESKI	sainfoin
•Oxytropis sericia,		locoweed.
•Thermopsis montana,		yellow banner
•Trifolium sp,		clover
•Vicia americana,		American vetch

Seed obtained through Wind River Seed, Manderson WY 82432

Objective 3. Initiate limited numbers of nursery grown plants and test methods of transplanting to the field.

Although some plants are being grown and inoculated under controlled conditions, none of these are currently slated for transplanting under test conditions in the field.

Summary

Progress has been made during the first six months of this project towards protocols for isolation, identification and storage of nodule bacteria as well as methodology for breaking seed dormancy, germination of seed and growth of seed to maturing plants. Although much of this effort has been organizational in scope, alignment of procedures has prepared us for the spring season of 2005 when the majority of native legumes will potentially be available for sampling. This important interval of early spring sampling often begins as early as mid-March and extends into May and June. We were not able to take advantage completely of this time interval during the spring of 2004.

Acknowledgements

This work is funded by the Abandoned Coal Mine Lands Research Program through a grant (WYDEQ49801). The program resources come through the Wyoming Department of Environmental Quality and are administered through the Research Office of the University of Wyoming. During the summer of 2004, two Summer Research Apprentice Program (SRAP) high school students (So'onafai Pili from Pago Pago, American Samoa and Rebecca Justice from Birmingham, Alabama) participated in parts of this project. Dibya Devkota, a new graduate student, is pursuing her master's degree through this project. All of these organizations, people behind them as well as students are afforded our thanks for their parts in this project.

AML Interim Progress Report 2004
Recovery of Belowground Ecosystem Components
Under Different Plant Communities on Coal Mine Reclamation Sites

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Introduction

The overall objective of this proposed research is to examine recovery of belowground ecosystem components and function under a variety of vegetation communities of different qualities encountered on surface mine reclamation sites in Wyoming. Our approach has been to locate a number of different surface mine reclamation sites of different age and plant community quality for examination of recovery of nutrient cycling, the soil microbial community, and soil structure. Identical analyses will be made at designated reference areas or comparable undisturbed sites of similar soil texture to enable comparison of reclaimed sites relative to each other and to undisturbed adjacent native rangelands. Research sites will include areas invaded by weeds (primarily cheatgrass), areas with and without sagebrush, areas with relatively high species richness and areas with low species richness, areas dominated by crested wheatgrass, and areas with and without a significant warm season grass component. Sites with vegetation that is considered acceptable for bond release or which have already been

bond released will also be examined. We have made arrangements with 8 mines from the three major coal producing regions of Wyoming to provide research sites for this project.

The three basic research objectives we will accomplish to complete this research are:

1) Characterize the plant community in detail at each research site in terms of species richness, diversity, productivity, and cover, as well as shrub, forb, weed, and warm season grass density.
2) Examine key structural and functional characteristics of the belowground component of the ecosystem. Specifically, nutrient cycling using both in-situ and laboratory methods, microbial community structure using Phospholipid Fatty Acid (PLFA) analysis, and soil structure regeneration by analysis of aggregate size distribution and bulk density.
3) Examine statistical relationships between plant community characteristics and belowground ecosystem components to determine if the plant community characteristics accurately reflect recovery of belowground structure and function. We will also determine what plant community attributes are the most accurate and least accurate indicators

Research proposed in this document will address two related issues currently of concern in reclamation of coal mined land, both of which have been listed by the AML Steering Committee as Research Topics for 2004. The two issues are 1) Nutrient cycling status of reclaimed lands and 2) Alternative methods to evaluate reclamation success. These two topics are related in that sustainable nutrient cycling is a crucial ecosystem function that must be reestablished for reclamation to be successful in the long term. As mentioned previously, reclamation success is currently evaluated primarily on characteristics of the reestablished plant community. Productive vegetation indicates, at least in the short term, that plants are obtaining adequate nutrients from soil but does not provide any information regarding integrity of the remainder of the soil ecosystem. Recovery of the soil microbial community, the organisms primarily responsible for decomposition of dead plant material and mineralization of organic nutrients to a form utilizable again by plants (Paul and Clark, 1996), is not monitored. Redevelopment of

soil structure, which is critical to ecosystem functions of the belowground ecosystem (Brady and Weil, 2000; Six et al., 2000), also is not monitored. This research will lead to a better understanding of the relationship between plant community reestablishment and recovery of crucial ecosystem functions such as sustainable nutrient cycling and soil development. Data generated from this work will provide valuable information on reliable plant and soil indicators of reclamation success on coal mine lands.

Progress

This project was initiated in June, 2004. Although preliminary arrangements were made with a number of surface coal mines in Wyoming for research sites (Table 1) during

Table 1. List of Surface Coal Mines participating in this research.

Mine	Contact Person	Region
Jim Bridger Coal Mine	Rena Piper	Green River Coalfield
Rosebud Coal Mine	Tae Tonozzi	Hanna Coalfield
Belle Ayr Mine	Laurel Vicklund	Powder River Basin
Dave Johnson Mine	Chet Skilbred	Powder River Basin
North Antelope/ Rochelle Complex	Scott Belden	Powder River Basin
Jacobs Ranch Coal Mine	Roy Liedtke	Powder River Basin
Cordero Mine	Kim Wolf	Powder River Basin

proposal development, field reconnaissance trips are necessary to confirm the suitability of specific research sites. A number of these trips were made during summer, 2004. A list of the types of reclaimed rangeland plant communities we will include in our study is given in Table 2.

Table 2. List of the types of reclaimed plant communities to be examined.

Bond Released Communities
Communities with good representation of forbs, shrubs and warm season grasses (i.e., communities which relatively high diversity)
Communities dominated by cool season grasses
Communities dominated by warm season grasses
Communities dominated by crested wheatgrass
Communities dominated by sagebrush
Communities invaded by cheatgrass or other weeds

For each type of community examined, we plan to sample two different age classes, one in the range of 5-7 years after initiation of reclamation and the other in the range of 12-15 years after reclamation was initiated. By including those two age classes in our study we can obtain more information on progression of recovery of nutrient cycling, soil organism and soil structure through time for particular types of plant communities. On each mine that we find suitable research sites, an undisturbed reference area or other suitable undisturbed area will be identified for comparison.

The two graduate students required for this project are now enrolled, currently taking classes and are preparing for extensive soil sampling and vegetation analyses in the field next summer.