Abandoned Coal Mined-Land Research Program
Project Review Seminar

Fourteenth Project Review Seminar

Casper College, Casper. WY

November 19, 2002

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.

9:45-10:10	**Sr isotropic characterization of coal and sandstone aquifers, Powder River basin, Wyoming** Carol Frost, Kathy Muller-Ogle, Lyman, Ed Heffern	Final	✓
10:15-10:40	**The Effects of Varying Topsoil Replacement Depth on Various Plant Parameters within Reclaimed Areas** Brenda Schladweiler, Larry Munn, Rose Haroian, Scott Belden	Interim	✓
10:45-11:10	**Grass Competition and Sagebrush Seeding Rates: Influence Sagebrush Seedling Establishment** Gerald Schuman, Ann Hild, Laurel Vicklund, Mary Williams	Final	✓
11:15-11:45	**Ambient Fine Particle Measurement in the Powder River Basin** Chartier, Mark Weitz	Final	✓
12:00-1:15	Lunch break		
1:20-1:45	**Relationship of soil organic matter content and sustainablenutrient cycling in reclaimed soils** Peter Stahl, Gerald Schuman, Lachlan Ingram, Lowell Spackman	Interim	✓
1:50-2:15	**Effects of Variable Topsoil Replacement Depth on Plant Community Development and Soil Ecosystem Development after 24 Years** Cliff Bowen, Gerald Schuman, Rich Olson, Lachlan Ingram	Interim	✓
2:20-2:45	**Measurement of Vertical Pressure Generated from Shaped Charge Explosive** Charlie Barnhart	Interim	✓
2:45-3:00	**Break**		
3:00-3:25	**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	✓
3:30-3:55	**Impacts of Wildlife Utilization on Big Sagebrush Survival in Reclaimed Mine Lands** Kristene Partlow, Richard Olson, and Gerald Schuman	Interim	✓
4:00-4:25	**Ecology of the greater sage-grouse in the coal mining landscape of Wyoming's Powder River Basin** Kort Clayton, Kimberley Brown	Interim	✓
4:25-4:50	**Evaluation and Comparison of Hypothesis Testing Techniques for Bond Release Applications** Shay Howlin, Lyman McDonald, Carol Bilbrough	Interim	✓

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.

Sr isotropic characterization of coal and sandstone aquifers, Powder River basin, Wyoming

Carol Frost, Kathy Muller-Ogle, Lyman,
Ed Heffern

Sr isotopic characterization of coal and sandstone aquifers, Powder River basin, Wyoming

Carol D. Frost, Kathy M. Ogle, Robert M. Lyman, and Edward L. Heffern

Final Report, November 2002

Introductory statement

This project was funded in the Spring 2000 competition, and was completed in June, 2002. In addition to the principal investigators listed above, the project supports one M.S. student (Benjamin Pearson), a senior undergraduate student (Jami Viergets), and provides partial support for a senior research scientist and technician in the isotope geology laboratories.

Purpose

The purpose of this study was to evaluate the utility of the Sr isotope composition of groundwaters to characterize coal and sandstone aquifers. If distinct, then this tracer can be used to monitor the impact of coal-bed methane production on adjacent sandstone aquifers. Groundwater acquires Sr by dissolution of minerals or ion exchange reactions on mineral and rock surfaces, hence the Sr isotope ratio represents a time-integrated record of water-rock interaction. Variations in the $^{87}Sr/^{86}Sr$ ratio of groundwaters reflect natural variations of this isotope ratio in geologic materials. The $^{87}Sr/^{86}Sr$ ratio of groundwater is not measurably affected by fractionation or precipitation, and the precision of the $^{87}Sr/^{86}Sr$ ratio analysis (± 0.00001) allows for the detection of small variations in groundwater composition.

Accomplishments

We have three study areas for this project:

- The area in the vicinity of Gillette and Wright, Wyoming, where coal bed methane production has been underway for the longest time, and where most of the wells are located. Carol Frost took primary responsibility for work in this area.
- Jacobs Ranch Mine, near Wright, Wyoming, near the recharge area for Wyodak coal and Wasatch sandstone aquifers. Undergraduate Jami Viergets completed her senior thesis in this area.
- The area NE of Sheridan on the Wyoming-Montana border, where recharge and fluid flow may be primarily controlled by faults and fractures, which is in contrast to the Gillette-Wright area where faults appear to be unimportant. M.S. student Ben Pearson was responsible for this portion of the study.

Results from the Gillette-Wright area

Sr isotope data on groundwater samples from coal and overlying sandstone aquifers in the Gillette-Wright area, eastern Powder River basin, Wyoming, demonstrate that the Sr isotope ratio effectively identifies groundwater from different aquifers and is a sensitive monitor of aquifer interactions. Groundwaters from sandstone aquifers have a uniform $^{87}Sr/^{86}Sr$ ratio of

0.7126-0.7127. Waters from coal seams vary from $^{87}Sr/^{86}Sr$ ratio = 0.7127 near the recharge area to 0.7151 farther into the basin. The distinct Sr isotope signatures of sandstone and coal aquifers may reflect different sources of Sr in these two rock types: Sr in sandstones is held primarily in carbonate cement whereas coals contain more radiogenic Sr in organic matter. The Sr isotope ratio is useful in identifying wells that contain mixed waters, whether due to well construction or to incomplete aquifer isolation. Continued, periodic measurement of the Sr isotope ratio in groundwaters of the Powder River Basin should be helpful in monitoring changes in groundwater hydrology related to coal mining and coal-bed methane activity. These results were published in the premiere journal in the geological sciences, the Geological Society of America's *Geology*.

Results from the Jacobs Ranch Mine area

Groundwaters collected at Jacobs Ranch Mine represent those nearest to the recharge area, and thus are in general the waters with the shortest residence time. These groundwaters have uniform Sr isotopic compositions, regardless of whether the waters were collected from coal, clinker, backfill, underburden, or Wasatch aquifers. At JRM, the $^{87}Sr/^{86}Sr$ isotopic compositions of groundwaters are as follows:

Coal aquifers:	$^{87}Sr/^{86}Sr$ = 0.71137 to 0.71248
Wasatch shale and sandstone aquifers	$^{87}Sr/^{86}Sr$ + 0.71075 to 0.712579
Mine spoil aquifers	$^{87}Sr/^{86}Sr$ = 0.71158 to 0.71193
Clinker aquifers	$^{87}Sr/^{86}Sr$ = 0.711279 to 0.71210
Fort Union shale and sandstone aquifers	$^{87}Sr/^{86}Sr$ = 0.71072

There is complete overlap between waters from these aquifers, rendering them isotopically indistinguishable from one another in this area. The Sr concentrations in these groundwater samples vary considerably, from 0.2 to 8.1 mg/l.

Sr isotopic composition of Sr available for solution in shallow groundwaters can be estimated from the Sr isotopic compositions of leached coal, overburden and clinker. The Sr isotopic composition of the distilled water leach may most closely approximates the composition of Sr that may be dissolved by groundwater; the NaOAc and HCl leaches will more aggressively attack phases such as carbonate. The coal, shale and sandstone water leachates yield Sr isotopic compositions of $^{87}Sr/^{86}Sr$ = 0.7112 to 0.7115, isotopic compositions typical of most groundwater samples collected near the recharge area at Jacobs Ranch Mine. The NaOAc and HCl leaches of these rocks have $^{87}Sr/^{86}Sr$ ratios that extend to higher values, from 0.7112 to 0.7123. (It is noteworthy that the highest leachate ratio, the HCl leachate from Wasatch overburden, is similar to the Sr isotopic ratios of sandstone aquifer samples collected further west into the basin. The leachates from clinker yielded significantly more radiogenic Sr, but the Sr concentrations were very low. Water flows through clinker quickly, which also helps to account for the lack of significant Sr from this radiogenic source in JRM groundwaters. We suggest that groundwaters from shallow depths near the recharge zone obtain their Sr mainly from soluble Ca sulfates present in the near-surface environment, and that this Sr is relatively unradiogenic. These results were presented in the Wyoming Geological Association's Fifty Second Field Conference proceedings.

Results from the Sheridan area

Analysis of groundwater samples collected from producing coalbed methane wells and adjacent sand horizons in the Powder River Basin reveal significant regional variation in strontium ratio and geochemistry. In the Sheridan area in the northwestern Powder River Basin, coal and sandstone waters have low $^{87}Sr/^{86}Sr$ ratios (0.7079-0.7112). Waters are sodium-bicarbonate type and have relatively high TDS (503-3408 mg/L). This is in contrast to the results from the Gillette-Wright area summarized above, where coal and sandstone waters are more radiogenic than those analyzed from the Sheridan area, and the coal and sandstone waters are isotopically distinct.

A series of step-leaching experiments and SEM images of leached material from Spring Creek mine, Montana, suggests that there is a concentration of minerals in the sandstone-siltstone lithology immediately below the coal, possibly related to groundwater mobilization.

This variation suggests that there is a less radiogenic source of strontium in waters in the Sheridan compared to the Gillette areas. Coal horizons in the south are relatively undisturbed, permitting long flow times along relatively uniform paths. Samples from the northern area are close to east-northeast trending faults that could either 1) serve to streamline water flow through coal horizons, thus limiting time of interaction with strontium-bearing material in coal or 2) alter the recharge path by positioning two aquifers with different lithologies, isotopic properties and permeabilities in hydraulic communication with one another. Either mechanism could result in lower $^{87}Sr/^{86}Sr$ values, similar to those observed near the recharge area on Jacobs Ranch Mine.

Our Sr isotope results suggesting incomplete aquifer isolation are consistent with the characteristics of producing CBM wells in this area, in which prolonged dewatering results in little methane production. These results are being prepared for submission to the American Association of Petroleum Geologist's journal, *Environmental Geosciences.*

Publications and other dissemination of our research

Articles (published):

Frost, C.D., Pearson, B.N., Ogle, K.M., Heffern, E.L., Lyman, R.M., 2002, Sr isotopic tracing of aquifer interactions in an area of coal and methane production, Powder River Basin, Wyoming. Geology, 30, p. 923-926.

Frost, C.D., Viergets, J.E., Pearson, B.N., Heffern, E.L., Lyman, R.M., and Ogle, K.M, 2002, Sr isotopic identification of coal and sandstone aquifers and monitoring of aquifer interactions in an area of active coal bed methane production, Powder River Basin, Wyoming. Wyoming Geological Association Fifty Second Field Conference-2001, p. 107-121.

Articles (in preparation):

Pearson, B.N., and Frost, C.D., Sr isotopes as indicators of contrasting aquifer characteristics in an area of coalbed methane production, Powder River Basin, Wyoming and Montana. In preparation for Environmental Geosciences.

Theses:

Pearson, B.N., 2002, Sr isotope ratio as a monitor of recharge and aquifer communication, Paleocene Fort Union Formation and Eocene Wasatch Formation, Powder River Basin, Wyoming and Montana. M.S. thesis, University of Wyoming, May, 2002, 151 pages.

Viergets, J.E., Strontium isotopic identification of aquifers near recharge at Jacobs Ranch Mine in the Powder River Basin, Wyoming. Senior thesis, University of Wyoming, December 2001, 20 pages.

Abstracts:

Pearson, B.P., Frost, C.D., Viergets, J.E., 2001, Strontium isotopes as indicators of regional variation in groundwater systems in an area of coalbed methane production, Powder River Basin, Wyoming. Geological Society of America Abstracts with Programs v. 35, p. A-111.

Pearson, B.P., and Frost, C.D., 2001, Strontium isotopes as tracers in groundwater systems related to coalbed methane production, Powder River Basin, Wyoming. AAPG Bulletin v. 85, p. 2057.

Frost, C.D., 2001, Sr isotopic characterization of coal and sandstone aquifers, Powder River Basin, Wyoming: monitor of aquifer interactions in an area of active coalbed methane development. AAPG Annual Meeting Abstracts v. 10, p. A-67.

Presentations (in addition to those related to the abstracts above):

Frost, Carol, March 2, 2001. Sr isotopes as monitors of rock-water interaction in the Powder River basin coal and sandstone aquifers: implications for coal bed methane production. University of Wyoming Student-Faculty Forum on Environment and Natural Resources, UW Union Senate Chambers.

Frost, Carol, October 2, 2001. A new approach to tracing groundwater in an area of active coal bed methane and surface coal production, Powder River Basin, Wyoming. Laramie Lyceum, "The World Around Us", UW School of Extended Studies Building.

The Effects of Varying Topsoil Replacement Depth on Various Plant Parameters within Reclaimed Areas

Brenda Schladweiler, Larry Munn, Rose Haroian, Scott Belden

2002
Abandoned Coal Mine Land Research Program
Progress Report

THE EFFECTS OF VARYING TOPSOIL REPLACEMENT DEPTH ON VARIOUS PLANT PARAMETERS WITHIN RECLAIMED AREAS

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SUMMARY OF 2002 ACTIVITY

The project was awarded in May 1998. **Task 1** (review existing vegetation/soil information and WDEQ approval) was primarily conducted in 1998 but is somewhat ongoing. **Task II** (construct the study site at the Rochelle Coal Mine) was completed during Fall 1998 to Fall 1999. **Task III** (reference area establishment and field sampling) was initiated in 2000 and continued through 2001 and 2002. Refer to the 1999 summary for a complete description of project construction.

2002 Vegetation Sampling Methodology

Reclaimed Area Treatments

Five random 30m cover intercept transects were sampled within each of three treatment replicates, i.e., 15 transects each in 15(6"), 30(12"), 56(22") cm. Quantitative sampling was conducted during early July 2002. Methodology followed WDEQ, LQD, Rules and Regulations, Appendix A (Revised May, 1998), wherever applicable, or WDEQ Guideline 14.

Vegetation sample points were surveyed by PRCC, NA/RC personnel. Cover sampling was conducted with a 30m line intercept transect; sample hits were read at 1m intervals along the entire length. Sample location selection and cover sampling followed methodology as described in previous summary reports.

Reference Area

Three restricted random 30m cover intercept transects were sampled within each of three reference area Atreatment@ replicates, i.e., top, middle and bottom, or 9 total. Due to the small size of the reference area replicates, randomly generated origins were Arestricted@ to the periphery of each replicate. All other sampling and summarization was similar as described for the reclaimed area treatments above.

2002 Soil Sampling Methodology

Reclaimed Area Treatments

Soil samples were collected at the beginning of each randomly selected cover transect. Samples were collected at maximum 15cm increments to the interface between topsoil and backfill. At that point, an additional 15cm of backfill were collected. All soils were analyzed by the University of Wyoming Soil Test Laboratory for pH and EC. Approximately 25% of these samples were then randomly selected for analysis of SAR on the same extract. If possible, at least one complete soil profile was completed for all three parameters within each treatment. Soil sample locations were surveyed by PRCC.

In addition to sampling described above, three randomly located root profiles into underlying spoil were exposed to determine relative patterns of root distribution in each treatment.

Reference Area

In order to characterize the soils within the Atreatment@ replicates, one soil sample location was randomly located on the 30m cover transect to avoid soil sample locations that were only on the outside edge of the Atreatment@ replicate. At that location, samples were described by horizon in the field but bagged and analyzed on 15cm increments to mirror the methodology employed in the reclaimed area treatments. Soil sample locations were surveyed by PRCC.

2002 Statistical Methodology

The 2001 and 2002 vegetation and soil data were analyzed using SAS (SAS/STAT, 1990) on the University of Wyoming mainframe computer using three primary statistical methodologies, i.e., two-factorial weighted ANOVA since the number of transects or sampled parameter points were not equal, split plot in time, and repeated measures. Dependent variables included pH, EC, SAR, percent total cover, percent total vegetation cover, average number of species per transect, and total number of species (within a replicate). ANOVA analysis was by depth over location, treatment, and location*treatment interaction which looked at the reclaimed area, upland grass reference area, and the breaks grassland reference area separately. Mean separation tests were completed with either Tukey=s HSD (Snedecor and Cochran, 1967) or split plot in time analysis (Steel and Torrie, 1980) in SAS. Significance decision criteria was p less than 0.05.

In addition, 2001 data was evaluated utilizing the following indices according to Magurran (1988): Shannon-Weiner diversity index; Jaccard similarity index; Sorenson similarity index, Morisita-Horn similarity index, Simpson=s diversity index, and Berger-Parker diversity index. 2002 data will be evaluated for similarity as well but was not available for this summary.

2002 Additional

Hyperspectral imagery or photography was obtained in 2001 and 2002 by PRCC to investigate spectral signatures of its native and reclaimed areas. This information was evaluated for use in the current study. However, the 2002 flight was not rectified and distortion on the ground prohibited its use in the current sample design. The 2002 flight has not been evaluated and may not be available for evaluation of the current study.

Results

Tables 1 and 2 contain a brief summary of means for the 2002 reclaimed and reference area, respectively.

Table 1. 2002 Reclaimed Vegetation Sampling Summary.

Treatment	Average Number Species/Sample	Percent Total Vegetation Cover	Percent Total Cover	Production (g/m2)
6	5.80	33.10	81.77	54.91
12	6.00	36.44	81.77	64.54
22	4.93	36.44	85.99	63.17

Table 2. 2002 Reference Area Vegetation Sampling Summary.

Reference Area	Treatment Equivalent	Average Number Species/Sample	Percent Total Vegetation Cover	Percent Total Cover	Production (g/m2)
Upland Grass	Top	5.78	44.43	84.80	40.33

	Middle	5.78	46.29	81.85	42.32
	Bottom	6.67	43.69	84.07	47.39
Breaks	Top	7.33	44.43	81.47	39.46
	Middle	7.33	50.73	86.29	36.60
	Bottom	6.78	48.51	83.70	43.78

Significant mean differences for the 2001 and 2002 soil and vegetation data are found in **Tables 3 and 4**.

Table 3. Significant ANOVA Tests of the 2001 Means for Various Parameters (by Location and Treatment).

Dependent Variable	Significant By	Results
pH	Location	Reclaimed pH significantly greater than both reference areas at 0-15cm and 15-30cm.
EC	Location	Reclaimed EC significantly greater than both reference areas at 0-15cm, 15-30cm, and 30-45cm.
SAR	Location	Reclaimed SAR significantly greater than both reference areas at 0-15cm, 15-30cm, and 30-45cm.
Total Vegetation Cover	Location	Reclaimed Total Vegetation Cover significantly lower than both reference areas.
Average No. Species	Location	Reclaimed Average Species significantly lower than both reference areas.

Significance level, $p < 0.05$

Table 4. Significant ANOVA Tests of the 2002 Means for Various Parameters (by Location and Treatment).

Dependent Variable	Significant By	Results
pH	Location	Reclaimed pH significantly greater than both reference areas at 0-15cm.
EC	Location	Reclaimed EC significantly greater than both reference areas at 0-15cm, 15-30cm, and 30-45cm.
SAR	Location	Reclaimed SAR significantly greater than both reference areas at 30-45cm, 45-60cm, and 60-75cm.
Total Vegetation Cover	Location	Reclaimed Total Vegetation Cover significantly lower than both reference areas.

Average No. Species	Location	Reclaimed Average Species significantly lower than the Breaks reference area.

Significance level, $p < 0.05$

Within the reclaimed area, the highest sample adequacy number calculations for percent total vegetation cover (WDEQ, 1996) were found in two of three of the 56cm treatment replicates and one of three of the 30cm treatment replicates. Confidence levels for the reclaimed treatment replicates that did not reach adequacy according to the WDEQ formula ranged from 73.89 to 87.49.

Within the reference areas, the highest sample adequacy number calculations for percent total vegetation cover were found in the Upland Grass bottom and top. For Breaks Grass, the highest calculated values were found in the bottom and top.

Results for the Shannon Wiener analysis from 2000 and 2001 are presented in **Table 5**. Significant differences existed by: 1) location, i.e., reclaimed and the reference areas, in 2000; and 2) by treatment within the reclaimed area in 2001. *Similar letter designation after the number in the last column indicates* no statistical differences.

Table 5. Shannon Wiener H= means for 2000 and 2001 data, summarized by location and treatment.

Year	Location	Treatment	Parameter	Mean Value
2000	Reclaimed	N/A	H=	1.32b
	Upland Grass	N/A	H=	1.97a
	Breaks Grass	N/A	H=	1.95a
2001	Reclaimed	15 cm	H=	1.80ab
		30 cm	H=	2.17a
		56 cm	H=	1.62b

Significant means within the 2001 and 2002 data as determined by split plot in time analysis are presented in **Tables 6 and 8**. Analysis of the 2000 data is not presented due to the extremely young age of the reclaimed area at the time of sampling. Mean separation results for the 2001 and 2002 data are presented in **Tables 7 and 9.**

Table 6. Significant 2001 Means Derived by Split Plot in Time Analysis for Various Parameters (by Location and Treatment).

Significant Depth (cm)	Dependent Variable	Location	Results
0-15	pH	Reclaimed	pH significantly lower at 30-45cm than deeper or shallower depths.
0-15	pH	Upland Grass	pH significantly lower at 0-15cm than deeper depths.
0-15	pH	Breaks Grass	pH significantly lower at 0-15cm than deeper depths.

0-15	SAR	Reclaimed	SAR significantly lower at 0-15cm than deeper depths.

Table 7. Means separations for split plot in time on 2001 data.

Location	Parameter	Significant Differences between	Depth (cm)	Mean	Grouping
Reclaimed	pH	Some Depths	60-75	7.67	a
			0-15	7.61	a
			45-60	7.56	ab
			15-30	7.50	ab
			30-45	7.20	b
Upland Grass	pH	Some Depths	60-75	7.78	a
			45-60	7.62	a
			30-45	7.17	b
			15-30	6.98	b
			0-15	6.67	c
Breaks	pH	All Depths	60-75	8.20	a
			45-60	7.79	b
			30-45	7.22	c
			15-30	6.96	d
			0-15	6.55	e
Reclaimed	EC	Some Depths	30-45	3.12	a
			45-60	2.78	ab
			60-75	2.48	bc
			15-30	2.43	bc
			0-15	1.87	c
Reclaimed	SAR	Some Depths	60-75	4.45	a

			45-60	2.55	b
			30-45	2.28	b
			15-30	2.01	b
			0-15	1.05	c

Table 8. Significant 2002 Means Derived by Split Plot in Time Analysis for Various Parameters (by Location and Treatment).

Significant Depth (cm)	Dependent Variable	Location	Results
0-15, 30-45	pH	Reclaimed	pH significantly lower at 0-15 and 30-45 than deeper depths.
0-15, 15-30	pH	Breaks	pH significantly lower at 0-15 and 15-30 than deeper depths.
0-15, 15-30	EC	Reclaimed	pH significantly lower at 0-15 and 15-30 than deeper depths.
0-15	SAR	Reclaimed	SAR significantly lower at 0-15 than deeper depths.

Table 9. Means separations for split plot in time on 2002 data.

Location	Parameter	Significant Differences between	Depth (cm)	Mean	Grouping
Reclaimed	pH	Some Depths	60-75	7.71	a
			45-60	7.61	ab
			15-30	7.35	bc
			0-15	7.29	bc
			30-45	7.27	c
Upland Grass	pH	Some Depths	60-75	7.54	a
			45-60	7.48	a
			30-45	7.20	b
			15-30	6.96	b
			0-15	6.60	b
Breaks	pH	Some Depths	60-75	7.63	a
			45-60	7.67	a

			30-45	7.04	a
			15-30	6.80	ab
			0-15	6.36	b
Reclaimed	EC	Some Depths	30-45	3.20	a
			45-60	3.18	a
			60-75	2.81	ab
			15-30	2.24	b
			0-15	1.59	c
Reclaimed	SAR	Some Depths	60-75	4.35	a
			45-60	3.13	b
			30-45	3.02	b
			15-30	1.66	c
			0-15	0.89	d

Significant means within the combined 2000/2001 and 2000/2001/2002 data as determined by repeated measures analysis are presented in **Tables 10 and 12**.

Table 10. Significant Main Effects for Combined 2000/2001 Means for Repeated Measures Analysis.

Depth (cm)	Dependent Variable	Significant By	Results
0-15, 15-30	pH	Location	Reclaimed pH significantly higher than both reference areas.
0-15, 15-30,30-45	EC	Location	Reclaimed EC significantly higher than both reference areas.
0-15, 15-30, 30-45	SAR	Location	Reclaimed SAR significantly higher than both reference areas.
0-15	TOTVEG	Location	Reclaimed TOTVEG significantly less than both reference areas.
0-15	ASPEC	Location	Reclaimed ASPEC significantly less than both reference areas.
0-15	TOTSPEC	Location	Reclaimed TOTSPEC significantly less than both reference areas.

Table 13. Significant Main Effects for Combined 2000/2001/2002 Means for Repeated Measures Analysis.

Depth (cm)	Dependent Variable	Significant By	Results

0-15, 15-30	pH	Location	Reclaimed pH significantly higher than both reference areas.
0-15	pH	Year	Significant difference in at least 2 years.
0-15, 15-30	EC	Location	Reclaimed EC significantly higher than both reference areas.
15-30, 30-45	SAR	Location	Reclaimed SAR significantly higher than both reference areas.
0-15	TOTCOV	Year	Significant difference in at least 2 years.

Root distribution did not visually appear to be negatively impacted by the presence of underlying spoil. However, quantified methods of root distribution were not employed.

Discussion

Significant differences were found between native and reclaimed areas. This point exemplifies the difficulty in selecting native areas as a revegetation success standard for reclaimed areas. Inherent differences resulting from the mining process, i.e., homogenous, replaced soil material make it difficult to compare native areas that have well defined profiles with horizons.

The pH of the native areas is generally lower in the upper horizons than in the lower horizons. Due to homogenous replaced soil material on reclaimed areas, higher pH material is mixed throughout the replaced topsoil depth and could be found in the upper portion. Once the deeper depths are reached in the native areas, it is possible that the pH is higher in the native than the reclaimed. The same argument would apply to EC and SAR which shows higher material throughout the replaced topsoil depth, especially in the upper sampling intervals.

After three years of sampling, total vegetation cover and total cover percentages are higher in the native areas due to the relatively young age of the reclaimed area and relatively low precipitation throughout the 2000, 2001and 2002 growing seasons. The least amount of vegetative cover was noted during the 2002 sampling. Typically, the total cover percentages are higher in a reclaimed environment as litter accumulates with time.

Average species and total species were higher in the native areas. Although, this is a new reclaimed area, the problem of comparing diversity with native areas exists for older reclaimed areas, as well.

Production was somewhat higher in the reclaimed areas. Typically, one would expect reclaimed production to be much higher than native areas but, again, the drought over the last three years has had a marked effect.

Precipitation for the period October 1999 through September 2000 was below normal and resulted in reduced growth for the 2000 growing season. According to records from the mine site, the total annual precipitation for that period was 25.3cm with the majority of the moisture during the months of April and May. Similar patterns existed for the period October 2000 through September 2001 for the 2001 growing season, i.e., total precipitation 26.7cm with the majority during the months of June and July. Records for the period October 2001 through September 2002 indicated a total of 25.02cm with the majority of the precipitation in August and September.

The WDEQ=s approach to diversity varies by District; in addition to indices of diversity or similarity, a matrix table of proposed technical standards by lifeform, based on premine species contributing greater than 2% relative percent cover, is utilized to measure revegetation success. Montana utilizes a similar approach, i.e., 70% performance standard for major lifeform species which contribute at least 1% relative cover to a premine physiognomic type. Although options remain open, the majority of companies and regulators appear to be moving away from the use of similarity or diversity indices.

Based on a review of reclamation plans within coal mine permits on file with WDEQ-LQD, District III, language varies considerably and is generally a mixture of qualitative and quantitative parameters. The Motkya index of similarity (no reference) is one of the most mentioned quantitative tools within these permit sections.

Sufficient analysis has not conducted within this study to date to determine which index is suitable for this set of data. Preliminary results on the 2001 data set did not indicate a clear method that adequately determined differences. Shannon-Wiener is currently being used by other researchers with some success. Within this study, statistical differences in derived Shannon-Wiener indices was found within the 2001 reclaimed area treatments.

Remaining 2002/2003 Tasks

X Remaining statistics will be completed, including analysis of production data and diversity indices on 2002 data

X Fertility analysis of 2002 samples will be compared to 1998 analysis

X The final report for this project will be compiled by April 2003

X At a much later date, it will be determined whether additional field sampling is warranted under the AML research program.

References

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Grass Competition and Sagebrush Seeding Rates: Influence Sagebrush Seedling Establishment

Gerald Schuman, Ann Hild, Laurel Vicklund

2002

Abandoned Coal Mine Land Research Program

Grass Competition and Sagebrush Seeding Rates: Influence on Sagebrush Seedling Establishment

Interim Progress Report

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Introduction

Coal mine reclamation in Wyoming strives to provide a diverse vegetative community with adequate shrub and grass cover to support post-mining land uses. Reclamation techniques are aimed at directing and accelerating plant succession toward desirable and sustainable land uses such as wildlife habitat and livestock grazing. An important component of the post-mine plant community in Wyoming is Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis* Nutt. Beetle andYoung). Studies relating to this important and dominant shrub of our native rangelands (i.e. Schuman et al. 1998; Stahl et al. 1998; Schuman and Belden 2002) have improved our understanding of the role of seedbed preparation, direct seeding, arbuscular mycorrhizae, and seedling survival on the establishment of this shrub on coal mined lands.

Competition from herbaceous plants has a negative effect on big sagebrush seedling establishment (Blaisdell 1949; Richardson et al. 1986; Schuman et al. 1998). However, details of the interaction between this shrub species and grasses seeded together on mined land in Wyoming are not well documented. This lack of specific information has prompted reclamationists to continue to seed shrub and grass species concurrently despite the lack of Wyoming big sagebrush establishment success. Research is needed to further assess the levels of herbaceous competition that will favor sagebrush seedling establishment as well as produce adequate ground cover to ensure stability of the soil resource, yet achieve the shrub density standard set by the Wyoming Department of Environmental Quality, Land Quality Division (WY DEQ 1996). Therefore, this study was initiated to investigate the relationship between Wyoming big sagebrush and a mixture of cool-season grasses seeded concurrently.

Methods and Materials

The study site is located at the Belle Ayr Coal Mine, RAG Coal West, Inc. mine near Gillette, WY. Topsoil was spread on the study site in January 1998 to an average depth of 56 cm. In the spring of 1998 the site was seeded to barley (*Hordeum vulgare* var. 'Steptoe') and in late summer it was mowed to achieve a standing stubble mulch. In December 1998 a mixture of western, slender, and thickspike wheatgrass was randomly assigned and drill seeded into plots, 6.5 x 27 m, within each of four, 27 x 45.5 m blocks, at seven seeding rates (0, 2, 4, 6, 8, 10, and 14 kg PLS (pure live seed)/ha). Each grass main plot was divided into three 6.5 x 9 m subplots, which were randomly assigned to one of three sagebrush seeding rates (1, 2, and 4 kg PLS/ha) and broadcast seeded in March 1999. Prior to any seedling emergence, six 1-m^2 permanent quadrats were established in each sagebrush by grass seeding rate subplot to assess sagebrush seedling density in 1999-2002. Sagebrush seedling volume was also assessed in these permanent quadrats in 2001 and 2002.

Aboveground plant biomass was determined in June 1999, July 2000, and July 2001. Four 0.18-m^2 quadrats were clipped in each of the subplots and plant material separated into planted grasses, other grasses, and forbs.

Sagebrush seedling density and volume were determined in June 2002 and density was also assessed in September 2002. Sagebrush seedling volume was determined by measuring the plants diameter at the widest point, the diameter perpendicular to the first measurement and the plant height. These measurements were obtained to the nearest 0.1 mm. Plant volume was then calculated by assuming the plant shape most closely resembled an ellipse/cone.

Analysis of variance was performed on the plant biomass, sagebrush density and sagebrush canopy data to assess the effect of grass seeding and sagebrush seeding rates. When significant differences ($P \leq 0.10$) in treatment effects were noted, Least Significant Difference methods were used to test treatment mean differences.

Results and Discussion

Sagebrush seedling density data exhibited statistically significant differences for the June and September density counts as affected by grass seeding rate, (Figure 1). Sagebrush seedling densities were significantly lower for the 14 kg PLS/ha seeding rate compared to the 0 PLS/ha grass seeding rates in June. However, no significant differences in sagebrush seedling density were evident for grass seeding rates of 2-10 kg PLS/ha. The same response was observed for the September 2002 sagebrush density data. We expected that we might see a greater effect of grass seeding rate on sagebrush seedling density in 2002 because of the severe drought conditions in the area, but it did not seem to significantly affect sagebrush survival except at the highest grass seeding rate.

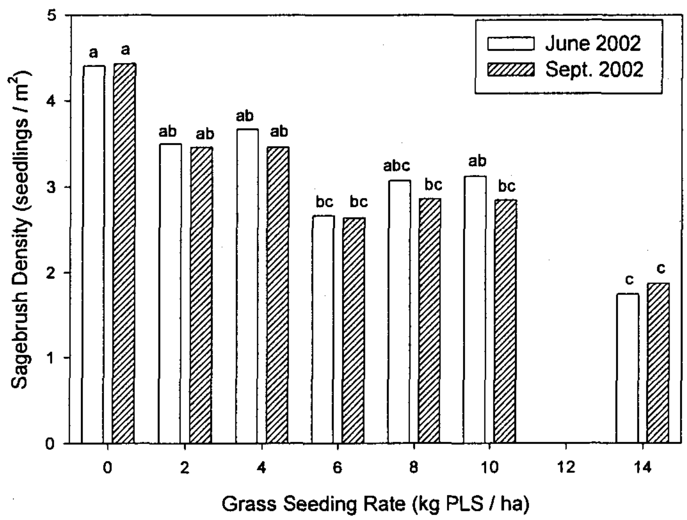

Figure 1. Effect of grass seeding rate on sagebrush seedling density, June and September 2002, Belle Ayr Mine, Gillette, WY (means with the same letter within a date across grass seeding rates are not significantly different from each other, $P \leq 0.10$).

Sagebrush seeding rate continues to exhibit a significant effect on sagebrush seedling density. The 4 kg PLS/ha sagebrush seeding rate continues to produce a significantly greater density of seedlings than either the 2 or 1 kg PLS/ha sagebrush seeding rate (Figure 2). The sagebrush seedling density for the 1 kg PLS/ha seeding rate is now resulting in a density less than 1.4 seedlings/m^2. Using the survival rate of 59% (from peak density) reported by Schuman and Belden (2002) after 8 years to assess density, the sagebrush seeding rate of 1 kg PLS/ha would not result in a sagebrush density that would meet the shrub standard of 1 shrub/m^2 that is mandated by the Wyoming DEQ in the last two years of the 10-year bonding period. Therefore, this data and other research continue to support the need for sagebrush seeding rates of $\geq$2 kg PLS/ha.

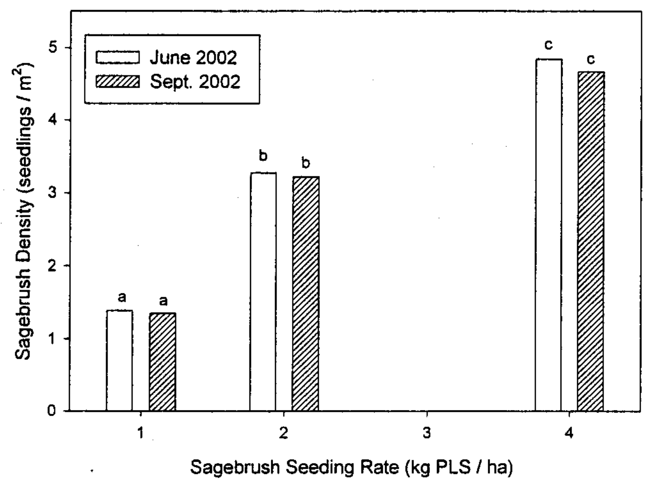

Figure 2. Effect of Wyoming big sagebrush seeding rate on sagebrush seedling density, June and September 2002, Belle Ayr Mine, Gillette, WY. Means with the same letter within a date across sagebrush seeding rates are not significantly different ($P \leq 0.10$).

To further assess the effects of grass seeding rate (competition) on sagebrush seedlings we measured the volume of the sagebrush seedlings and found that all grass seeding rates significantly affected the average sagebrush seedling volume. Figure 3 shows that the 2002 sagebrush seedling volume was significantly smaller where any grass was seeded. In 2001, grass seeding

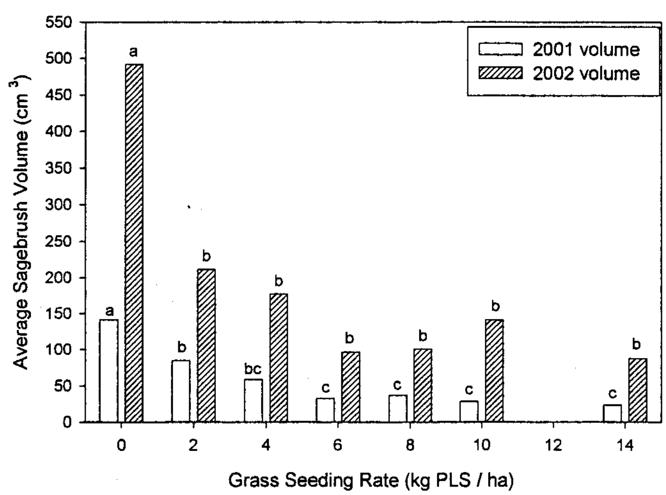

Figure 3. Effect of grass seeding rate on average sagebrush seedling size, Belle Ayr Mine, June

2002. (Means with the same letter within a year across grass seeding rates are not significantly different from each other, $P \leq 0.10$).

rates >4 kg PLS/ha resulted in significantly smaller sagebrush seedling size compared to grass seeding rates ≤4 kg PLS/ha. Sagebrush seedling size was not different for grass seeding rates of 2-14 kg PLS/ha in 2002. The data indicate that with the drought conditions present at the mine any grass competition stressed the sagebrush equally. This is further supported by the fact that the average sagebrush seedling size increased nearly 300% from 2001 to 2002 where no grass competition existed and by only 50-90% where grass competition existed.

Conclusions

Grass seeding rates (competition) continue to have a limited effect on sagebrush seedling density and under drought conditions grass seeding rates have had a limited effect on sagebrush seedling volume. This influence on sagebrush seedling volume, we are sure will ultimately affect sagebrush seedling survival and density. As grass seeding rates have not affected grass production (Williams et al. 2002), these rates could be reduced and thereby enhance the probability of natural recruitment of desirable native species, especially forbs and shrubs. This study has supplied important information on the effects of grass and sagebrush seeding rate on plant community development which will enable us to develop improved reclamation technology. The study is complete and further data analysis will occur and at least one scientific journal article will be prepared on the 2001-2002 sagebrush seedling density and canopy size information. We plan to complete the final report for this project and officially terminate the project by June 30, 2003.

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Ambient Fine Particle Measurement in the Powder River Basin

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Inter-Mountain Laboratories, Inc.

FINAL EXECUTIVE SUMMARY REPORT

Ambient Fine Particle Measurement in the Powder River Basin

An Ambient Air Quality Research Project Performed for the

Abandoned Coal Mine Lands Research Project (ACMLRP)

October 31, 2002

Research Performed by:

iml Air Science

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This work was supported in part by the Abandoned Coal Mine Lands Research Program at the University of Wyoming. This support was administered by the Wyoming Department of Environmental Quality from funds returned to Wyoming from the Office of Surface Mining of the U.S. Department of the Interior.

Ambient Fine Particle Measurement in the Powder River Basin

EXECUTIVE SUMMARY

A 33 month air quality study relating to the concentrations of airborne "fine" particles in Wyoming's Powder River Basin (PRB) was undertaken to develop a baseline data set, to evaluate the usefulness of alternate and enhanced measurement techniques, and to attempt to discern trends, correlations, etc . The data show that fine particle concentrations in the PRB are generally well below federal air quality standards; and exhibit diurnal, seasonal and spatial variations. The results also show that alternate measurement techniques can be useful and effective in gaining a better understanding of the nature of fine airborne particles. The results do not bear out any strong correlations between fine particle concentrations and other, identified and measurable parameters.

This research project represented a unique collaborative effort, supported by a variety of entities in the private and public sectors, as well as the ACMLRP. This collaborative project serves as a model for efficiently collecting and understanding environmental measurements over a wide geographic area with various stakeholders and owners. Following is a list of project participants and contributors:

- IML Air Science
- RAG Coal West
- Triton Coal Company
- Kennecott Energy Company
- Wyoming DEQ, Air Quality Division
- Thunder Basin Coal Company
- Rupprecht & Patashnick Company
- Powder River Coal Company

Note; In this paper and data, fine particle concentrations are shown in units of micrograms per cubic meter (µg/m^3), and are referred to as "PM2.5", which refers

to particles with an aerodynamic diameter of ≤ 2.5 μm. All concentrations shown and analyzed herein are valid, quality-assured measurements.

Background

Air contains a wide variety of gases and particles in addition to its pristine components. Coal mines are regulated by the impacts their activities have on ambient air through air quality "standards" which are defined and enforced through the Wyoming State Air Quality Regulations. Following a comprehensive review of existing standards for airborne particles, a standard for "fine" particles (or PM2.5) was promulgated in 1997 by the U.S. Environmental Protection Agency (EPA). Monitoring networks were subsequently established throughout the U.S. in 1999 by state and local health/environmental agencies, including three sites in Wyoming by the Wyoming DEQ (Cheyenne, Lander, Sheridan). Through this project, an additional fine particle network was established in 1999 in Wyoming's Powder River Basin (PRB), the United States' preeminent coal production region. The relationships between coal mining activities, the generation and transport of fine particles, meteorology and visibility are not well understood. This project produced a high quality baseline data set to help understand these relationships.

Project Objectives

1. Determine the spatial and temporal distribution of fine particulate (PM2.5) in ambient air in the Powder River Basin coal mining region of Wyoming.
2. Evaluate alternative measurement techniques compared to EPA Reference Method manual sampling measurements.
3. Evaluate methods for the determination of fine and course particle fraction concentrations. Collect baseline data for both fine and course fractions.

4. Operate a continuous nephelometer configured for light extinction, a parameter related to visibility. Correlate this data to particulate concentrations.

Network Description:

U.S. EPA Federal Reference Measurements (FRM) were collected at four sites across the PRB, trending from north to south, at the Buckskin, Belle Ayr, Black Thunder and Antelope Mines, respectively. For a map of the mines refer to *www.wma-minelife.com/coal/coalfrm/coalfrm1.htm*. Sampler sites and designations are as follows:

Powder River Basin PM 2.5 Network

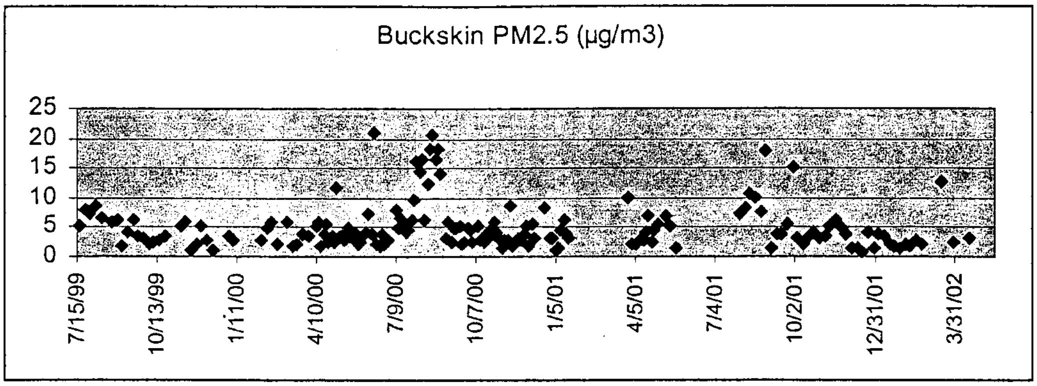
Mine (Site)	I.D.	Serial #	Instrument Type	Run Schedule	Comments
Buckskin (North)	PRB-1	20149	Partisol Plus 2025	6-day	
Belle Ayr (BA-5)	PRB-2	29008	Partisol 2000	6-day	discontinued 4/26/01
	PRB-3	21092	Partisol Plus 2025	6-day	
Black Thunder (scn. 26)	PRB-4	49607	Partisol 2000	6-day	discontinued 4/26/01
	PRB-5	21005	Partisol Plus 2025	3-day	
	PRB-6	20300	Partisol FRM	6-day	
	PRB-7	21101	TEOM	Continuous	
	PRB-9	20154	Partisol FRM PM10	6-day	added 5/24/01
	PRB-10	20120	Partisol Dichot	6-day	added 5/24/01
Antelope (site 3)	PRB-8	21114	Partisol Plus 2025	6-day	

FRM Baseline Data Set

Sampling results from the PM2.5 FRM samplers, trending N-S, are as follows:

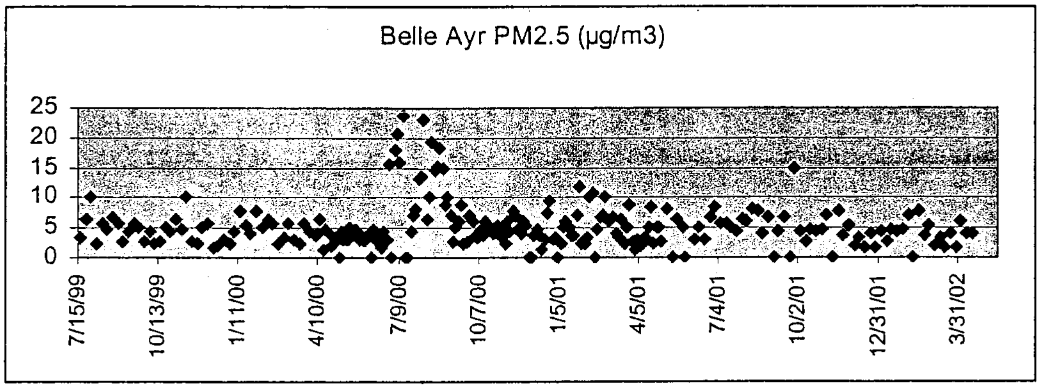
Buckskin Mine FRM (PRB-1) PM2.5 results (μg/m^3):

	1999 (beg 7/19)	2000	2001	2002 (thru 4/15)	overall
average	4.4	5.4	4.7	3.3	4.9
max - date	8.7 – 8/4	20.9 – 6/14	17.7 – 8/29	12.6 – 3/15	20.9 – 6/14/00



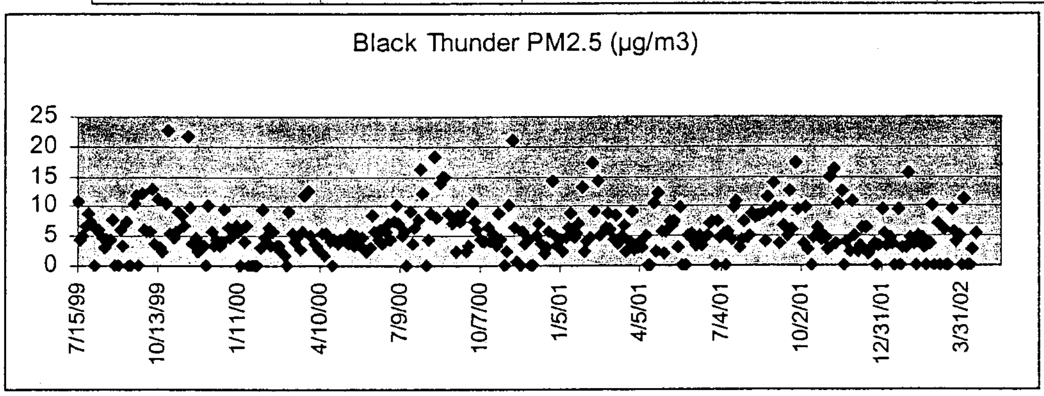
Belle Ayr Mine FRM (PRB-3) PM2.5 results (µg/m^3):

	1999 (beg 7/19)	2000	2001	2002 (thru 4/15)	overall
average	4.6	6.4	5.2	4.2	5.6
max - date	10.1 – 7/29	23.8 – 7/14	14.7 – 9/28	7.8 – 2/13	23.8 – 7/14/00



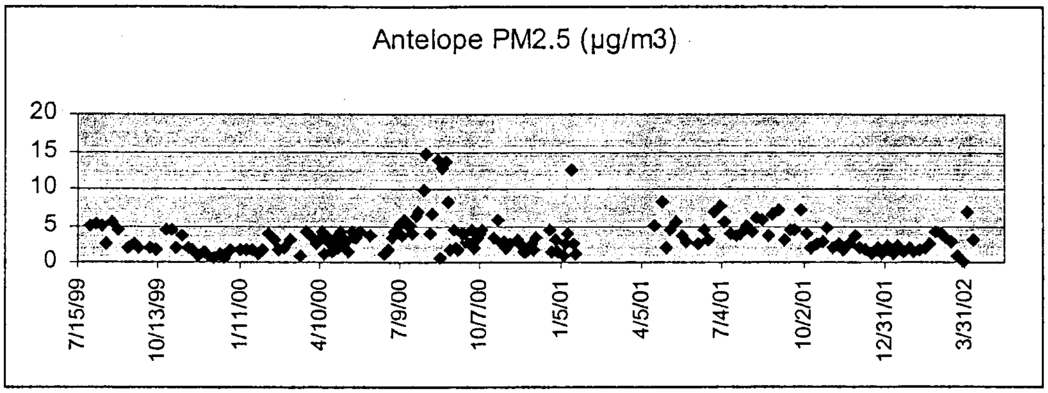
Black Thunder Mine FRM (PRB-5) PM2.5 results (µg/m^3):

	1999 (beg 7/19)	2000	2001	2002 (thru 4/15)	overall
average	7.0	6.1	6.4	5.9	6.4
high - date	22.7 – 10/24	21.1 – 11/11	17.3 – 9/25	15.6 – 1/29	22.7 – 10/24/99



Antelope Mine FRM (PRB-8) PM2.5 results (µg/m^3):

	1999 (beg 7/19)	2000	2001	2002 (thru 4/15)	overall
average	2.6	3.6	3.8	2.4	3.4
high - date	5.4 – 8/22	14.5 – 8/7	12.3 – 1/16	6.7 – 4/2	14.5 – 8/7/00



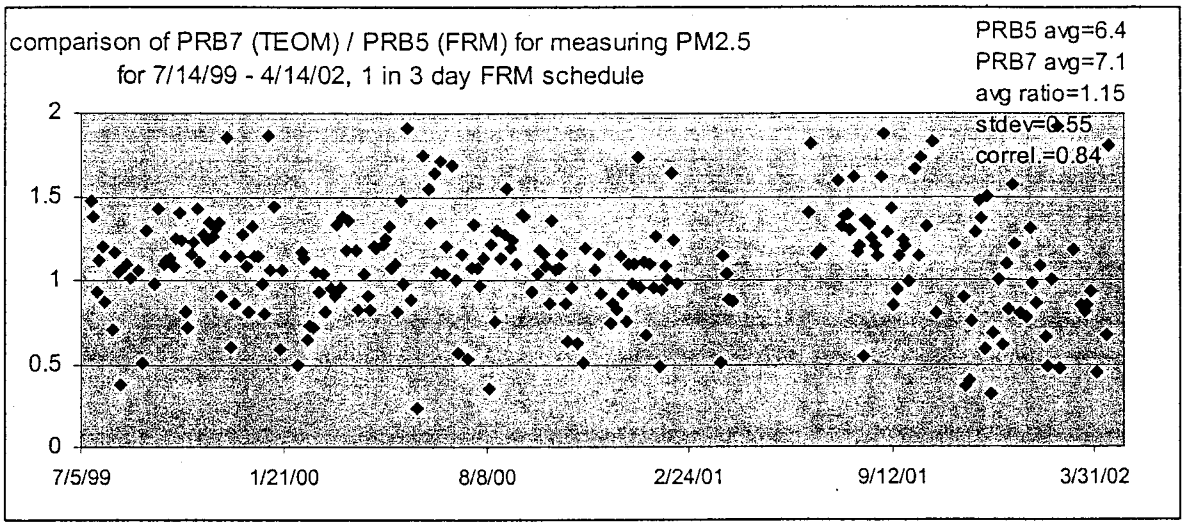
Examination of the above results reveals that PM2.5 concentrations are generally highest in the central PRB, and trend lower both north and southward. The fire season in autumn 2000 is evident at all sites. Seasonal and diurnal trends are not readily discerned from this data, please refer to the following section, and/or the Final Technical Report for more details.

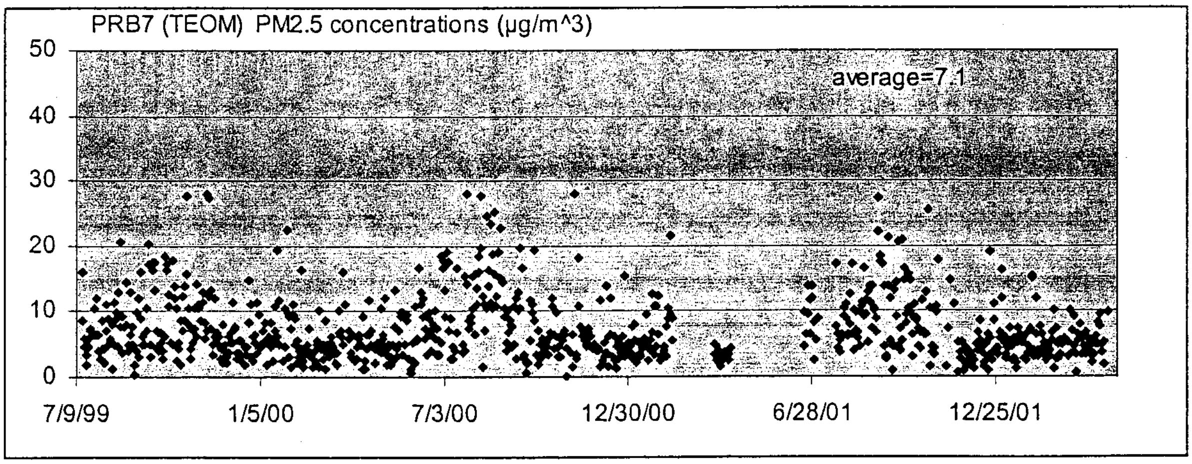
Methods Comparisons

Continuous PM2.5 Measurements:

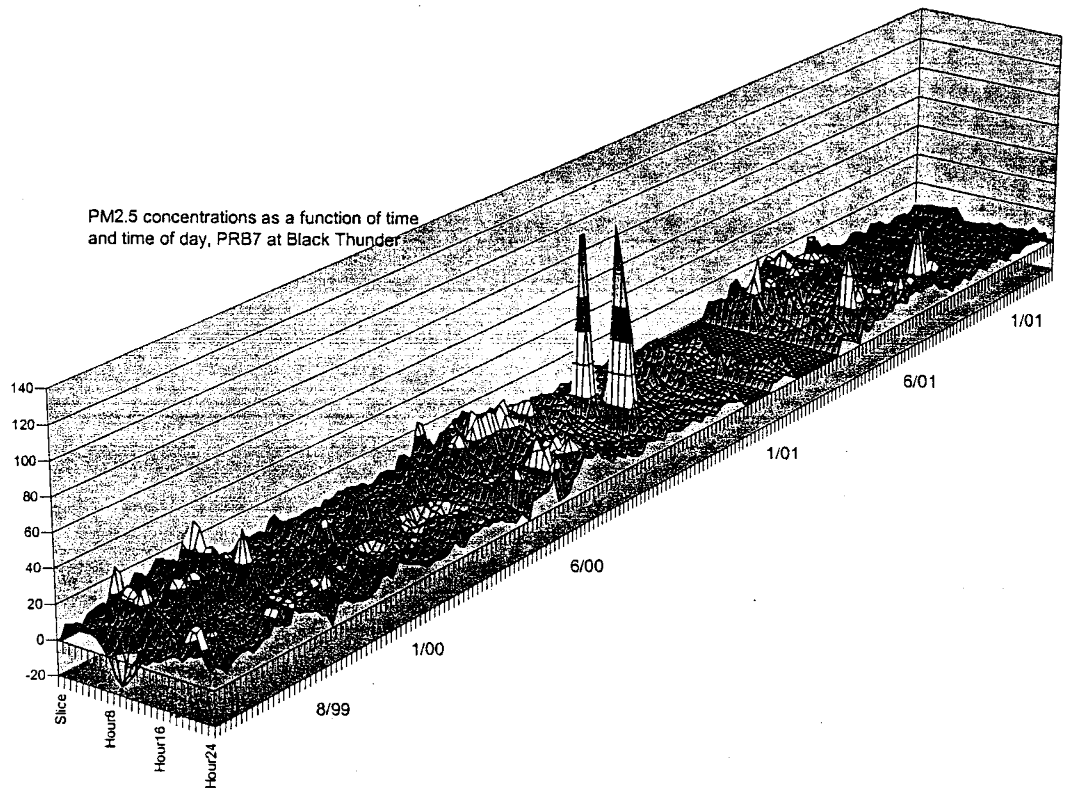
The Federal Reference Method (FRM) for PM2.5 is a manual method whereby a clean, pre-weighed filter is placed in a sampler which then draws ambient air through the filter for a 24-hour period. The sample is thus integrated over a 24 hour period, and can not reveal any diurnal trends or anomalies. A continuous particulate instrument exists which is not a FRM for PM2.5, but which was configured for PM2.5 sampling for this study. Continuous methods offer higher temporal resolution, and more overall data, potentially offering better insights into PM2.5 trends.

The continuous instrument (TEOM) operated alongside a manual FRM sampler during this study. The TEOM provides hourly and daily average data continuously, the FRM sampler operated every 3 days. Following are comparisons of the two samplers, and all the daily data collected from the TEOM.





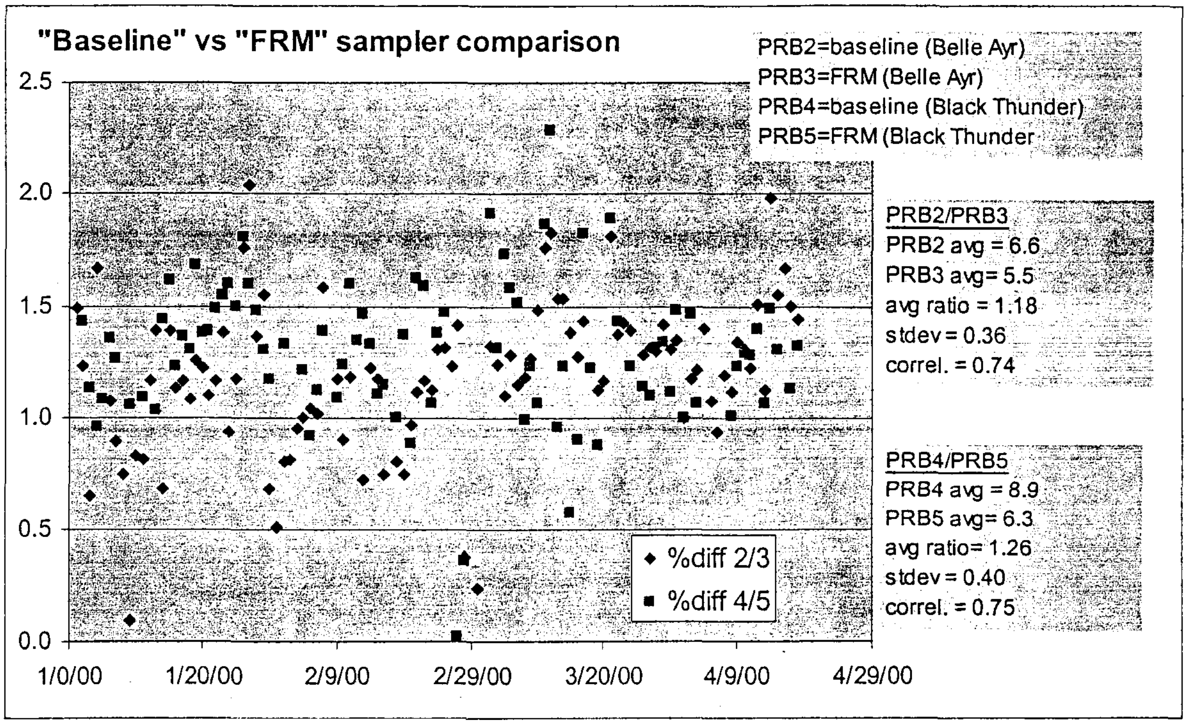
The continuous TEOM instrument showed a high bias of some 15% over the FRM method with reasonably good correlation. The bias varies with concentration, which is not evident in the above graphs. Seasonal and diurnal patterns also emerge from the hourly TEOM data, as shown below.



The reader is referred to the Final Technical Report for more details on diurnal and seasonal trends.

<u>Pre-FRM PM2.5 Sampling:</u>

Prior to deployment of this air monitoring network, the Wyoming Mining Association sponsored collection of "baseline" data with non-FRM samplers (prior to their existence). Following are comparisons:



The baseline samplers exhibit a high bias of some 20% over the FRM method with reasonably good correlation. These data can thus be used for with some confidence to identify trends as monitoring continues. Operation of the baseline samplers were discontinued April, 2000.

Fine/Coarse Measurements and Dichotomous Sampling:

Currently the U.S. EPA has ambient air quality standards for "PM10" and "PM2.5", and associated Federal Reference Method s(FRM) for obtaining valid and comparable measurements. Due to the method of sample collection, PM10 samples currently include the PM2.5 fraction. These two particle size regimes are recognized as having distinctly different source types, and distinctly different epidemiological effects. As such, the U.S. EPA is considering changing its standards to differentiate "fine" particles (PM2.5) from "coarse" particles (PM10 – PM2.5). The PM2.5 FRM satisfies the fine particle standard. EPA is considering simply subtracting PM2.5

FRM measurements from PM10 FRM measurements to derive the coarse fraction. However, the FRM sampling methods and equipment can be quite different, and there is speculation that this simple subtraction method may introduce errors, offsetting or compounding, or both, depending on conditions.

There is a dichotomous sampling platform which physically separates the coarse and fine fractions *in situ*. A prototype dichotomous sampler was operated alongside FRM samplers of various types to evaluate its measurements against standard FRM methods. This research objective was added after 2 years of this 3 year study.

The samplers used for comparison are as follows:

- PRB5 = Partisol style FRM for PM2.5
- PRB9 = Partisol style FRM for PM10
- PRB10 = dichotomous sampler which produces both fine (PM2.5) and coarse fraction measurements (PM10 less PM2.5), and by addition, PM10
- 26-4 high volume FRM for PM10

Following is a table of comparisons and correlations. The reader is cautioned that many of the measurements are of low concentrations, especially the fine (PM2.5) data. Much of this data are down in the resolution of the measurements ("noise") and thus contain inherently higher uncertainties. Combining such values can further compound uncertainties in the analyses. Despite this, some trends and correlations are indicated. PM2.5 measurements from the dichotomous sampler (PRB10) and the FRM sampler (PRB5) show reasonably good agreement. Coarse measurements from the dichotomous sampler (PRB10), and by differencing FMR measurements for PM10 and PM2.5 show poor agreement, which suggests that EPA's consideration for obtaining coarse fractions by simple differencing needs further validation. For a more detailed discussion of these results, please refer to the Final Report.

Insert fine/coarse table

Date	*concentrations (µg/m^3)* PRB10 dichot fine (PM2.5)	PRB10 dichot coarse	PRB10 dichot fine+coarse=PM10	PRB5 FRM PM2.5	PRB9 FRM PM10	26-4 hivol FRM PM10	PRB9 (PM10) - PRB5 (PM2.5) calc. coarse	26-4 (PM10) - PRB5 (PM2.5) calc. coarse	*ratio analyses* PRB10 PM2.5/ PRB5 PM2.5 PM2.5	PRB10 coarse/ [PRB9-PRB5] coarse	PRB10 coarse/ [26-4 - PRB5] coarse	PRB10 PM10/ PRB9 PM10 PM10	PRB10 PM10/ 26-4 PM10 PM10	PRB9 PM10/ 26-4 PM10 PM10
06/18/01	5.1	21.7	26.8	4.9	49.8	22	44.9	17.1	1.03	0.48	1.27	0.54	1.22	2.26
06/24/01	8.9	30.6	39.5	7.6	63.8	39	56.2	31.4	1.17	0.54	0.97	0.62	1.01	1.64
06/30/01	8.2	10.8	19.0	7.3	19.7	14	12.4	6.7	1.12	0.87	1.61	0.96	1.36	1.41
07/06/01	8.2	10.8	19.0	5.5		16		10.5	1.49		1.03		1.19	
07/12/01	6.1	11.4	17.5	5.9		16		10.1	1.03		1.13		1.09	
07/18/01	4.8	50.0	54.8	9.8	90.1	48	80.3	38.2	0.49	0.62	1.31	0.61	1.14	1.88
07/24/01				3.2	10.3	8	7.1	4.8						1.29
07/30/01	8.7	56.1	64.8	7.5	89.5	29	82.0	21.5	1.16	0.68	2.61	0.72	2.23	3.09
08/05/01	6.9	43.6	50.5	4.9	63.0	27	58.1	22.1	1.41	0.75	1.97	0.80	1.87	2.33
08/11/01	9.5	32.8	42.3	8.2	43.0	25	34.8	16.8	1.16	0.94	1.95	0.98	1.69	1.72
08/17/01	11.8	49.2	61.0	8.5	44.4	32	35.9	23.5	1.39	1.37	2.09	1.37	1.91	1.39
08/23/01	5.2	16.9	22.1	4.1	22.0	12	17.9	7.9	1.27	0.94	2.14	1.00	1.84	1.83
08/29/01				9.0	55.6	28	46.6	19.0				0.00	0.00	1.99
09/04/01	12.4	53.8	66.2	9.8	78.5	36	68.7	26.2	1.27	0.78	2.05	0.84	1.84	2.18
09/10/01	13.8	97.4	111.2	9.7	135.7	68	126.0	58.3	1.42	0.77	1.67	0.82	1.64	2.00
09/16/01	6.1	32.1	38.2	5.0		20		15.0	1.22		2.14		1.91	
09/22/01	6.9	33.2	40.1	6.0	49.3	23	43.3	17.0	1.15	0.77	1.95	0.81	1.74	2.14
09/28/01	9.9	28.4	38.3	9.6	46.4	24	36.8	14.4	1.03	0.77	1.97	0.83	1.60	1.93
10/04/01	4.4	2.8	7.2	3.8	7.7	5	3.9	1.2	1.16	0.72	2.33	0.94	1.44	1.54
10/10/01	3.8	16.0	19.8	2.6	26.8	11	24.2	8.4	1.46	0.66	1.90	0.74	1.80	2.44
10/16/01				4.8	23.0	15	18.2	10.2						1.53
10/22/01				5.8	88.8	35	83.0	29.2						2.54
10/28/01	7.4	20.3	27.7	4.6	40.2	18	35.6	13.4	1.61	0.57	1.51	0.69	1.54	2.23
11/03/01				14.7	90.0	55	75.3	40.3						1.64
11/09/01				3.7	60.7	23	57.0	19.3						2.64
11/15/01				12.4	72.2	39	59.8	26.6						1.85
11/21/01	0.6	1.4	2.0	4	55.9	19	51.9	15.0	0.15	0.03	0.09	0.04	0.11	2.94
11/27/01				10.7		8		-2.7						
12/03/01				2.5	36.6	13	34.1	10.5						2.82
12/09/01				6.4		74		67.6						
12/15/01				2	49.4	13	47.4	11.0						3.80
12/21/01				3.8	32.7	11	28.9	7.2						2.97
12/27/01				3.4	56.9	23	53.5	19.6						2.47
01/02/02				5.5	59.5	25	54.0	19.5						2.38
01/08/02				4.8	93.8	55	89.0	50.2						1.71
01/14/02						8								
01/20/02	-0.9	61.4	60.5		113.7	37						0.53	1.64	3.07
01/26/02	2.5	20.4	22.9	2.9	22.3	18	19.4	15.1	0.86	1.05	1.35	1.03	1.27	1.24
02/01/02	2.7	62.6	65.3	4.8	103.9	35	99.1	30.2	0.56	0.63	2.07	0.63	1.87	2.97
02/07/02	4.9	35.8	40.7		111.3	39						0.37	1.04	2.85
02/13/02	3.3	23.3	26.6	4.8	36.2	30	31.4	25.2	0.69	0.74	0.92	0.73	0.89	1.21
02/19/02	4.2	18.1	22.3			14							1.59	
02/25/02	3.2	22.3	25.5	10.3	38.3	20	28.0	9.7	0.31	0.80	2.30	0.67	1.28	1.92
03/03/02	3.4	24.5	27.9	7.2	37.0	14	29.8	6.8	0.47	0.82	3.60	0.75	1.99	2.64
03/09/02	4.3	22.5	26.8	6.1	67.7	42	61.6	35.9	0.70	0.37	0.63	0.40	0.64	1.61
03/15/02	6.8	5.0	11.8		13.4	7						0.88	1.69	1.91
03/21/02				5.8	25.0	13	19.2	7.2						1.92
03/27/02	-0.4	52.7	52.3	5	55.9	26	50.9	21.0	-0.08	1.04	2.51	0.94	2.01	2.15
04/02/02	6.0	10.2	16.2	11	18.9	9	7.9	-2.0	0.55	1.29	-5.10	0.86	1.80	2.10
04/08/02	3.2	2.9	6.1		8.4	5						0.73	1.22	1.68
04/14/02	4.2	33.5	37.7	5.5		29		23.5	0.76		1.43		1.30	
# valid	34	34	34	45	43	51	39	45	29	25	29	30	35	43
average	5.8	29.8	35.6	6.3	53.7	25.0	46.5	19.5	0.97	0.76	1.50	0.73	1.44	2.14
std. dev.	3.4	21.1	22.4	2.9	31.2	15.6	27.3	14.6	0.43	0.27	1.44	0.28	0.50	0.59
max.	13.8	97.4	111.2	14.7	135.7	74.0	126.0	67.6	1.6	1.4	3.6	1.4	2.2	3.8
PRB10 dichot fine fraction & PRB5 (PM2.5):				0.56										
PRB10 dichot calc. PM10 & PRB9 (PM10):					0.82									
PRB10 dichot calc. PM10 & 26-4 (PM10):						0.84								
PRB9 (PM10) & 26-4 (PM10):						0.88								
PRB10 coarse & PRB9-PRB5 calc. coarse:							0.86							
PRB10 coarse & 26-4-PRB5 calc. coarse:								0.80						

PM2.5 versus Visibility:

Visibility s a complex function of a variety atmospheric constituents and conditions, and of human perception. Visibility is not readily defined nor characterized by a single parameter or measurement. Nevertheless, visibility is the assessment of air quality that is most readily and commonly obtained by humans, and as such functions as a *de facto* standard for air quality. Visibility degradation is strongly associated with fine particles, although not in a straightforward fashion.

A prototype portable nephelometer, which measures light scattering, was operated alongside FRM PM2.5 samplers to evaluate its measurements against fine particle concentrations, to see of any general or reasonable correlations could be obtained between the two. This research objective was added after 2 years of this 3 year study. Unfortunately the instrument suffered damage from a lightning strike within its first weeks of operation, and made multiple trips back to the manufacturer for repair, but never generated data of any consistency or confidence.

The Wyoming Department of Environmental Quality (DEQ) operates a visibility assessment system (IMPROVE) nearby in the Thunder Basin National Grasslands. These data were compared against the collected PM2.5 measurements. There was very poor correlation between fine particle mass concentrations and light extinction measurements: the correlation between PM2.5 and visibility in deciviews = -0.10; the correlation between PM2.5 and extinction in Bext = -0.04. This lack of correlation does not come as a surprise considering the complex nature of visibility, and these results confirm that raw mass concentrations of fine particles, without speciation and/or size classification information, is not a good indicator of visibility.

Other Correlations:

It was desired to see if other parameters correlated with fine particle concentrations. Fine particle concentrations were compared to coal production (composited by month, with hourly wind speeds, correlations were 0.17, and -0.03, respectively, which shows that fine particle concentrations do not correlate well with these parameters. It was desired to evaluate fine particle concentrations relative to traffic, and to soil moisture, but reliable data sets were not found.

Conclusions:

This research shows that fine particle concentrations in the Powder River Basin are well below the national air quality Standards of 15 μg/m^3 annual average, and 65 μg/m^3 24-hour average. The results also show that fine particle (PM2.5) concentrations are generally highest in the central PRB, and trend lower both north and southward. Data collected in this project were collected according to Federal Reference Method (FRM) requirements, and represent a high quality baseline data set.

The results also show that data collected prior to the establishment of a FRM are useful for extending this fine particle baseline data set. The study further shows that continuous instruments provide comparable data to the FRM, and offer additional insight to short term, temporal and seasonal trends in fine particle concentrations.

The results call into question the appropriateness of using simple mathematical subtraction of various FRM methods for PM10 and PM2.5 to determining coarse fraction concentrations. The results show that visibility measurements are not good indicators of fine particle mass concentrations. Finally, the results show that fine particle concentrations do not correlate well with wind speed, nor with coal production, at least not when composited on a monthly basis.

Recommendations:

IML recommended to the Wyoming DEQ that this PM2.5 monitoring network continue to be operated in order to maintain the continuity of this data set, and the Wyoming DEQ elected to do so. Although by this study it has been shown that the PRB does not experience high concentrations of fine PM, high concentrations of PM10 have been measured recently, and appear to be trending upward. Understanding the spatial and temporal trends, and causal relationships of all airborne particle concentrations will allow better protection of public health and the environment, while allowing Wyoming to maintain high productivity in this essential coal mining region. New, continuous air quality instrumentation has and is being installed throughout the PRB. We recommend that this improved data be compiled and analyzed, and new analytical and modeling tools be developed to be able to better manage this airshed.

This project served as a model for cooperation between various stakeholders, including energy producers, regulators, industry groups, consultants and instrument designers. When better information is obtained through cooperative efforts, all parties win, and higher value is achieved. We strongly recommend that stakeholders continue to participate and collaborate in regional environmental monitoring, allowing the costs, resources, and benefits to be shared.

Relationship of soil organic matter content and sustainablenutrient cycling in reclaimed soils

Peter Stahl, Gerald Schuman, Lachlan Ingram, Lowell Spackman

AML Progress Report

Relationship Between Soil Organic Matter Content and Sustainable Nutrient Cycling in Reclaimed Soils

Interim Progress Report

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Introduction

An important aim of mine site reclamation is to ensure that wherever possible, the "reconstructed" ecosystem is self-sustaining, requiring minimal and preferably no additional inputs. It is therefore critical that soils used in mine reclamation are able to provide sufficient quantities of nutrients for plant uptake. Many of the nutrients required for plant uptake, in particular nitrogen (N) and phosphorus (P) are found in soil organic matter (SOM). Equally important is the large mass of carbon (C) found in SOM, which provides the chemical energy to sustain microbial populations. Microbial decomposition of this SOM makes nutrients available for plant uptake.

The aim of this project is to determine the minimum amount of SOM in replaced topsoil required to sustain nutrient cycling (i.e. Nitrogen-mineralization) in these reclaimed ecosystems. Also, we have been evaluating the use of a new method to assess soil quality (Franzluebbers et al. 2000) for use with surface mine land reclamation. If successful, this methodology may be of use as a relatively fast, economical and reliable "indicator" of a soil's potential to sustain nutrient cycling.

Methods

Soils were collected during the summer of 2001 from sites on the North Antelope/Rochelle Complex, Belle Ayr and Jacobs Ranch coal mines, and analysed for 3- and 21-day microbial respiration; microbial biomass, N-mineralization, organic C and total N (Stahl *et al.* 2001). At the same time, aboveground biomass was collected, and sub-samples were ground and analysed for total N to determine plant community requirements for N.

Results and Discussion

Correlations between three-day respiration and 21-day microbial respiration, microbial biomass, 21-day potential N-mineralization, organic C, and total N were all highly and significantly correlated (Fig. 1). Our data from reclaimed mine soils indicate that the relationships that Franzluebbers et al. (2000) observed in a range of cropping soils also hold true in both reclaimed, and native, prairie soils.

An important component of this study was to be able to estimate, on the basis of organic C and from our estimates of potential lab N-mineralization, the minimum concentration of SOM required to supply a sufficient amount of N to the plant community. Whereas a significant amount of N-immobilization was observed in soils sampled in 2000, N-mineralization was predominant in the samples collected during 2001, possibly reflecting the more normal precipitation patterns that year. However, our calculations indicate the amount of organic C required to maintain nutrient cycling is lower than what we have observed and expected (Woods and Schuman 1986). Subsequently, we have sampled a site which contains very low concentrations of organic C (see Ongoing Work, below).

There were differences in the correlations between 3-day microbial respiration and the other indicators of soil quality (i.e. 21-day microbial respiration, microbial biomass, N-mineralization, organic C and N) between reclaimed and native soils, although both were highly significant (data not shown). In reclaimed soils, correlations were consistently much tighter than in native soils suggesting that in these disturbed ecosystems the microbial population were more responsive to changes in specific soil environmental characteristics (e.g . organic C and N contents). This disparity between the microbial populations may be the result of differences in the relative availability of C and N between the native and reclaimed soils, with more labile fractions of C and N occurring in the reclaimed soils

Because of the problem of coal particles present in samples giving rise to erroneously high organic C values, an experiment was undertaken in which a soil containing no coal material was spiked with varying amounts of coal and then analysed according to standard protocols. In almost all cases, the amount of measured microbial respiration, microbial biomass, and N-mineralization were all lower in the coal 'spiked' soils. This suggests that despite coal having much higher concentrations of C and N that the microbes are unable to easily or quickly (i.e. within the three week period over which the lab incubations are run) mineralize the C or N within the coal. The one exception was a much greater amount of microbial biomass measured on a pure coal sample, suggesting that the chloroform used in the microbial biomass determinations resulted in a decomposition of the coal material leading to a high estimate of microbial biomass.

Biomass and N concentration of aboveground plant biomass varied considerably, but as a general rule across all three mines, both were much greater on the reclaimed sites than on the native, undisturbed sites. At all sites, however, estimates of potential N-mineralization indicated all soils would have been able to provide sufficient quantities of N for plant growth.

Ongoing work

In the autumn of this year we visited sites at the Pathfinder Uranium mine in Shirley Basin, an old reclaimed uranium mine and sampled areas where overburden material was used as the plant growth medium. As this is likely to be extremely low in organic C, it is more likely we will be to determine a 'threshold point' (Woods and Schuman 1986) where the concentration of organic matter will be unable to provide sufficient quantities of N to maintain a healthy, sustainable, ecosystem.

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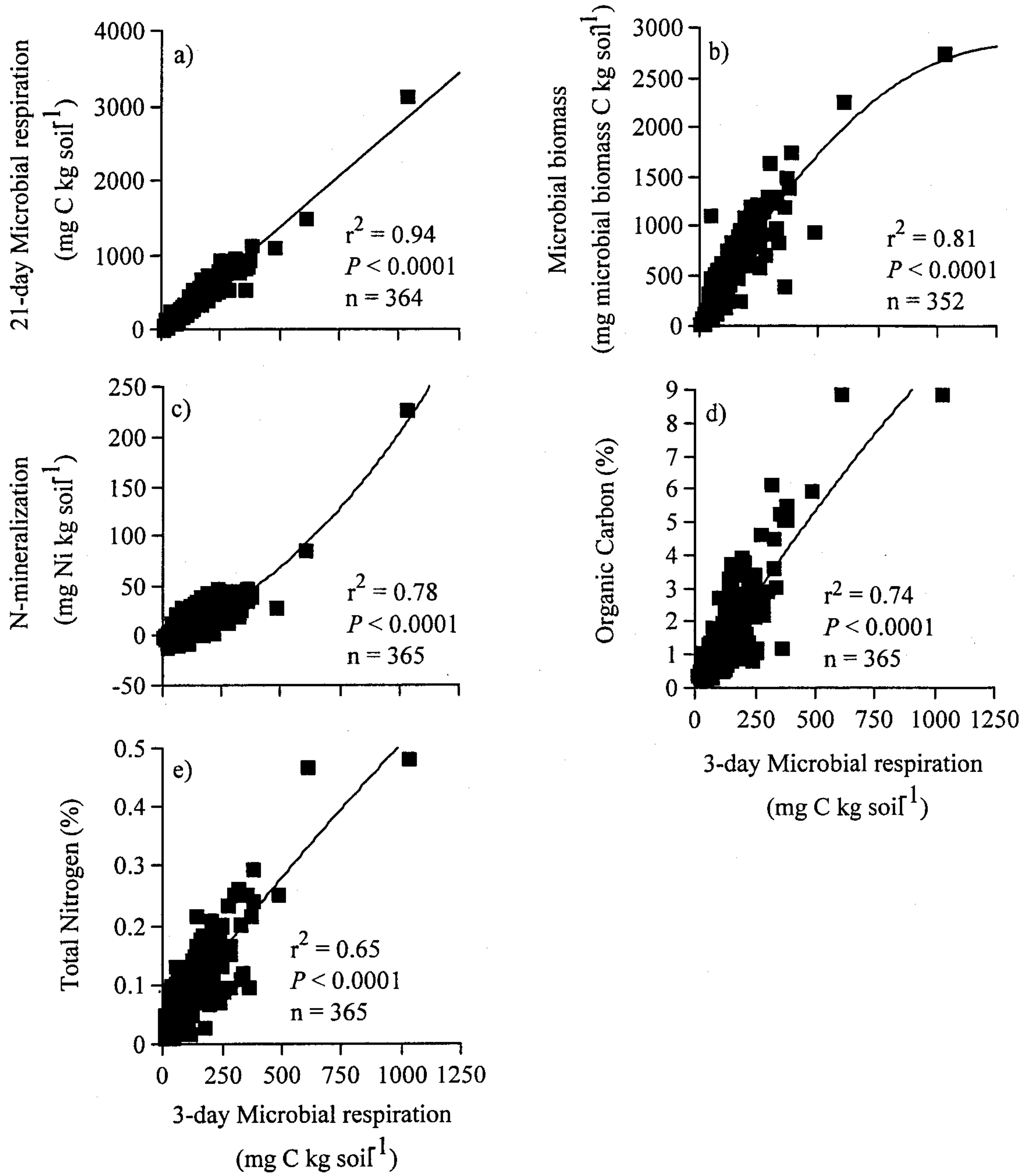

Figure 1. Regressions of 3-day Microbial respiration against: a) 21-day Microbial respiration; b) Microbial biomass; c) Potential N-mineralization; d) Organic C, and; e) Total nitrogen

Effects of Variable Topsoil Replacement Depth on Plant Community Development and Soil Ecosystem Development after 24 Years

Cliff Bowen, Gerald Schuman, Rich Olson, Lachlan Ingram

2002
Abandoned Coal Mine Land Research Program

Effects of Variable Topsoil Replacement Depth on Plant Community Development and Soil Ecosystem Development After 24 Years

Interim Progress Report

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November 19, 2002

Introduction

Achieving plant species diversity is one of the more difficult aspects of today's mining reclamation process. Many researchers have examined the affects of variable topsoil replacement on vegetative community attributes, primarily production (McGinnies and Nicholas, 1980; Power et. al., 1976; Barth and Martin, 1984). Many professionals in the area believe variable topsoil replacement would also contribute to a more diverse plant community. In 1998 a study was initiated to evaluate the short-term (3 years) effects of variable topsoil replacement on plant community diversity (Schladweiler et al., 1998). However, long-term evaluation is needed to evaluate successional change as affected by variable topsoil replacement depth.

Objectives

Using a study established by Schuman et al. (1985) we are examining the long-term (24 years effects of variable topsoil replacement on vegetative community development and soil physical and chemical attributes. Baseline data from the initial 4 years of the study are available for comparison.

Methods and Materials

Topsoil (a mixture A and B horizon material) was originally spread in a wedge, ranging from 0 - 600 mm in depth, over a regraded spoil dump. The topsoil was a fine loamy, mixed Borollic Haplargid, with a pH of 7.1, electrical conductivity of 2.5 dSm^{-1}, and an organic matter content of 2.4%. Topsoil was direct- applied over 1-m of spoil derived from coarse-grained sandstone of the White River Formation. Spoil material below this layer consisted of calcareous and moderately well cemented siltstones and claystones of the Wind River Formation. Organic matter, nitrogen (N) and phosphorus (P) were deficient in both spoil types. Neither spoil contained any elements at toxic levels. Plots received fertilizer amendments at rates of 67 kg P ha^{-1} and 315 kg N ha^{-1}. The experimental design was a completely randomized design with ten replications of each mulch treatment (stubble and surface straw). The area was divided into 20 plots (4.9 x 45.7m), running parallel to the topsoil depth gradient. In spring 1977, one-half of these plots were drill seeded with 50 kg ha^{-1} of 'Otis' barley (*Hordeum vulgare* L.) to establish a stubble mulch treatment. The remaining ten plots were fallowed for future application of the crimped straw mulch treatment. In October, 1977, all plots were drill seeded to a grass mixture of 'Critana' thickspike wheatgrass [*Elymus lanceolatus* (Scribner & J.G. Smith) Gould], green needlegrass (*Stipa viridula* Trin.), slender wheatgrass [*E. trachycaulum* (Link.) Gould ex Shinners], and 'Rosana' western wheatgrass [*Pascopyrum smithii* (Rydb.) A. Love] at a total seeding rate of 15.5 kg ha^{-1} pure live seed. The mixture contained equal numbers of seed for each species. Wyoming big sagebrush (*Artimesia tridentata* ssp. *wyomingensis*) and rubberrabbit brush (*Chyrsothamnus nauseosus*) were also seeded at 0.5 kg ha^{-1}. Barley straw was hand scattered on the previously fallowed plots at a rate of 5000 kg ha^{-1} and crimped in two directions (Schuman et al. 1985). In 1979 N fertilizer treatments were added to the study to assess the effect of a single 268 kg N ha^{-1} compared to four annual applications of 67 kg N ha^{-1} (Schuman et al. 1991). Each N fertilizer treatment was randomly assigned to five stubble and five surface straw mulch plots.

In August 2001 three of the five replications of each mulch x fertilizer treatments were randomly selected and sampled at each topsoil replacement depth using a hydraulic truck mounted soil sampler. Samples were taken to a depth of 750 mm and divided into four increments (0-50, 50-200, 200-400, and 400-750 mm). The 600 mm topsoil depth core was divided the same as the other three replacement depths except for the final increment. This sample was divided at the topsoil/spoil interface resulting in a core increment of approximately 600-750 mm instead of 400-750 mm. This was done in order to strictly analyze the properties of the underlying spoil. These samples were analyzed for total nitrogen (N), organic carbon (C), clay content, and soluble salts (sodium, calcium, magnesium, potassium).

At the same time these samples were taken for chemical analysis additional cores were taken in order to determine bulk density. Only two of the three replications sampled for chemical analysis were sampled for bulk density.

A three-way analysis of variance was used to determine the effects of topsoil replacement depth, mulch, and fertilizer treatment on soil physical and chemical parameters.

Results

Topsoil depth had significant effects on the amount of organic carbon, total nitrogen, and clay content of the soil profile. An inconsistent mulch x fertilizer interaction was observed, primarily in the analysis of soluble salts. Further analysis is needed to identify and explain these findings.

Percent organic carbon (C) was highest in the 0-50 mm increment of the profile with the 200 and 600 mm topsoil depths being the highest (Fig. 1). The 400 mm depth was not significantly different from the 200 mm depth although amounts were significantly lower where no topsoil was replaced. The 400 and 600 mm depths exhibited the highest overall organic C amounts as opposed to the 0 and 200 mm depths. The 200 mm depth exhibited the most inconsistent response among core increments with the 400-750 mm increment yielding higher levels of C than the 200-400 mm increment.

Percent total nitrogen (N) followed the same pattern of significance as organic C (Fig. 2). The 200 and 600 mm depths were highest in 0-50 mm increments with the 400 and 600 mm depths having the highest overall amounts. The 200 mm depth showed the same inconsistent response as seen with organic C. Increased topsoil depths have higher levels of C and N because topsoil contains more of these elements than does spoil. Higher biomass production and water infiltration are also believed to be largely responsible for these trends due to the increased water storage in these profiles. These factors largely impact nutrient cycling, which in turn have a strong effect on C and N levels. Water infiltration measurements showed a near 100% increase in the 400 and 600 mm depths over the 0 and 200 mm depths, combined total average infiltration of 125 mm to 67 mm over a two hour period, respectively.

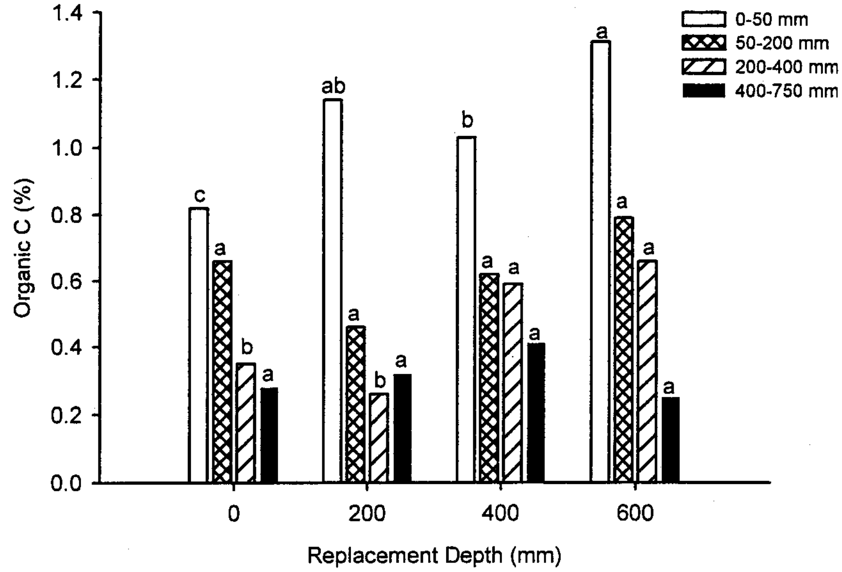

Figure 1. Percent organic carbon by replaced topsoil depth among core increments (bars with the same letter within depth increment are not significantly different, P≤0.05).

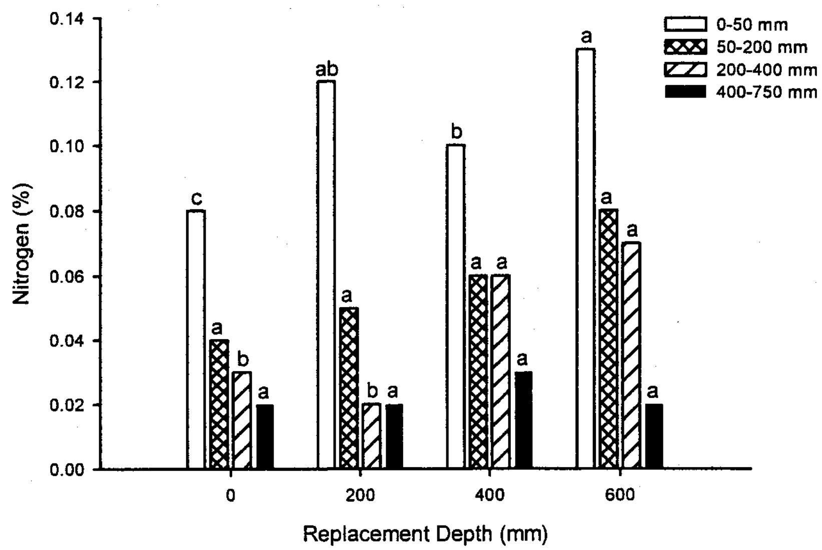

Figure 2. Percent total nitrogen by replaced topsoil depth among core increments (bars with the same letter among core increment are not significantly different, P≤ 0.05).

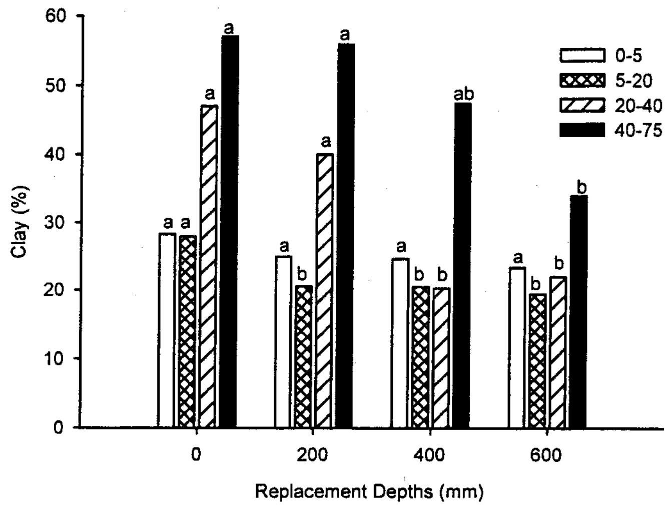

Figure 3. Percent clay by replaced topsoil depth among core increments (bars with the same letter among core increments are not significantly different, $P \leq 0.05$).

Particle size distribution analysis indicated higher percent clay content in the spoil below the replaced topsoil was higher (Fig 3.) This would explain the much lower infiltration rates at the shallower replacement depths as opposed to the deeper depths. Soil texture is going to be directly related to the properties of soil/spoil materials used to reclaim the site. Natural deposition of topsoil is believed to be the reason for the lack of significance among the 0-50 mm increments across replacement depths.

Future Assessments

Vegetation data from 2001 will be correlated with the soils data from 2002 in order to establish an optimum range of topsoil replacement for a productive and sustainable ecosystem. Data will also be compared against data from the original study in order to identify longer term trends in vegetation community development and edaphic changes. The data from this study will be prepared and submitted for scientific publication.

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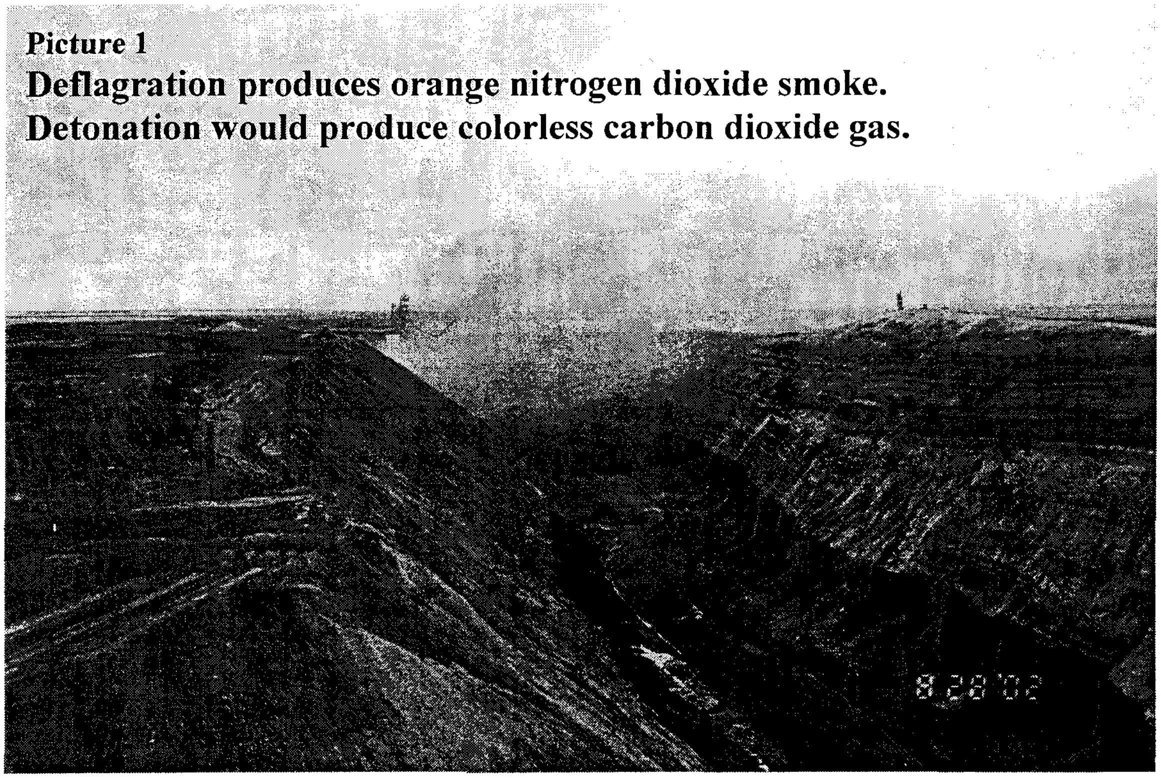
Measurement of Vertical Pressure Generated from Shaped Charge Explosive

Charlie Barnhart

Measurement of Vertical Pressure Generated from Shaped Charge Explosive

The data discovery from this ACMLRP is key to a body of research that is being conducted to find the solution to the "orange cloud" in surface coal mining.



Picture 1
Deflagration produces orange nitrogen dioxide smoke.
Detonation would produce colorless carbon dioxide gas.

Simply stated, there are two dominant chemical reactions possible when ammonium nitrate/fuel oil (ANFO) based blasting agent is ignited: detonation and deflagration (**Equation 1 & 2**). The undesirable chemical reaction that causes the Nitrogen Dioxide (**Picture 1**) formation is an environmental and health concern to the State of Wyoming, which can be resolved by controlling parameters of the borehole and blasting agent.

Detonation of ANFO (4,750 ^{o}F)

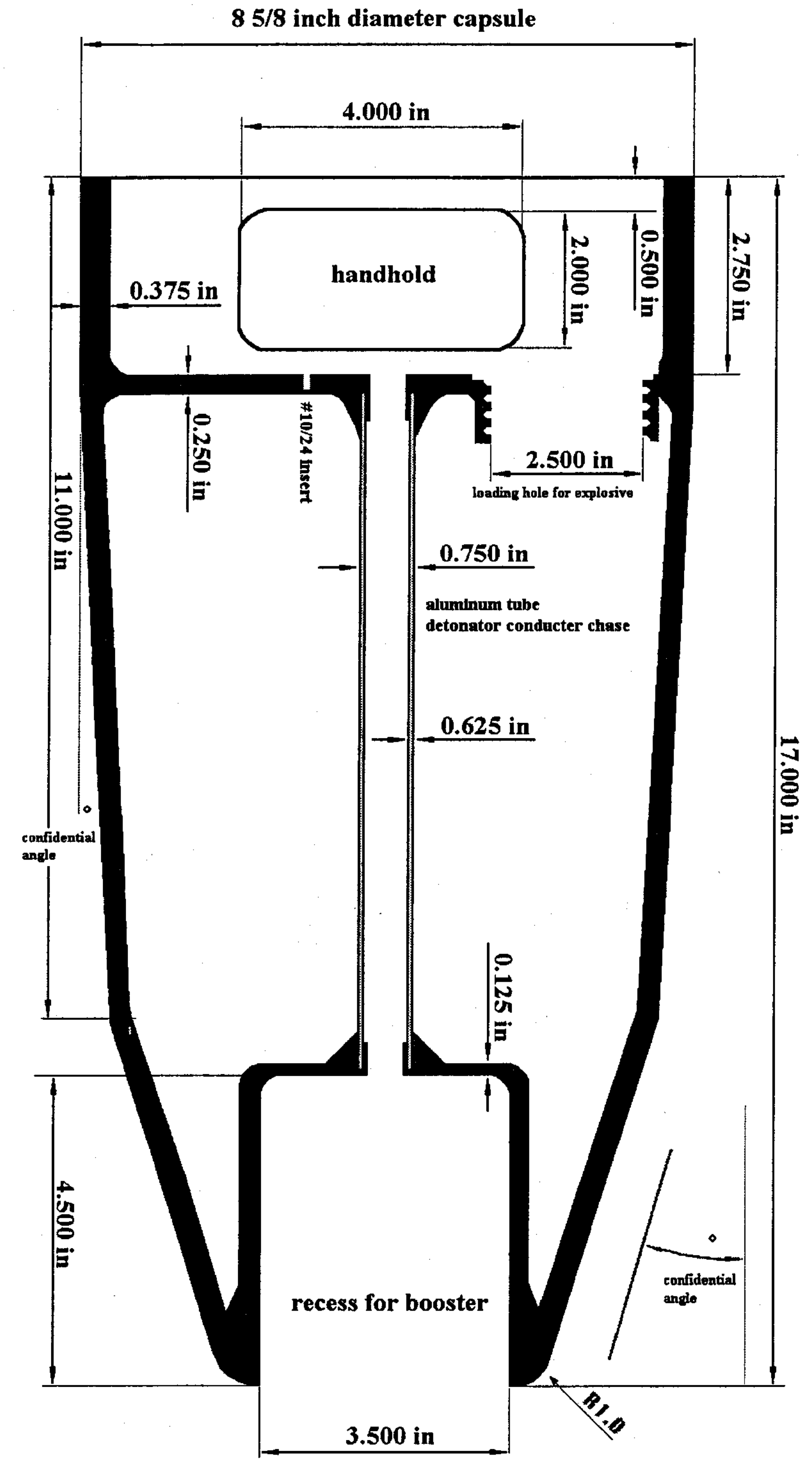
$$3\ NH_4NO_3 + [-CH_2-]_n \text{---------} CO_2 + 3\ N_2 + 7\ H_2O$$

Equation 1

Deflagration of ANFO (850 ^{o}F)

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

Equation 2

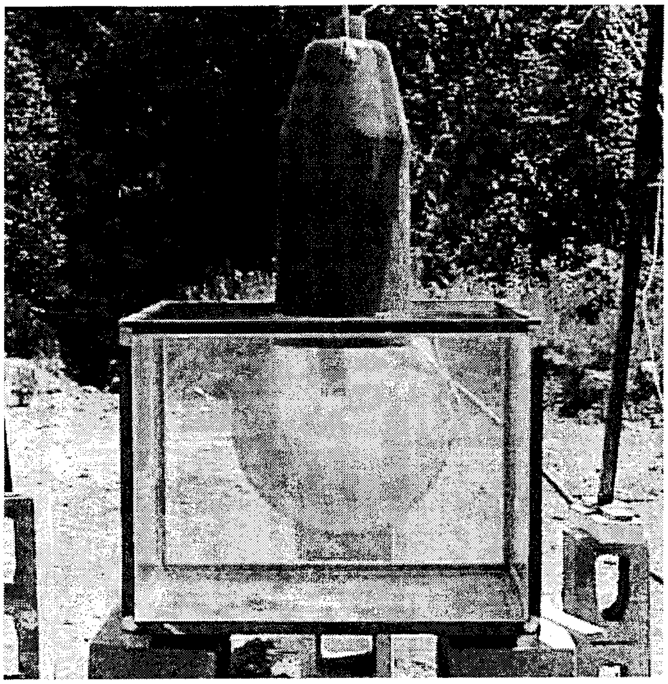


He

One of the problems with controlling the parameters of the blast is that the industry does not have all the tools they need, which has lead to the creation of a shaped charge detonation system (**Drawing 1**).

Plastic Capsule
The design dimensions and configuration of the shaped charge detonation system for the injection molding process.
Drawing 1

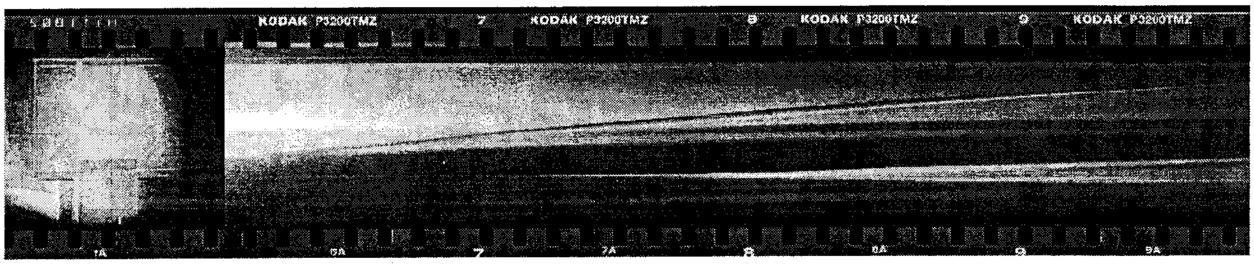
A plastic capsule has been engineered to take the power of a conventional 1-pound Pentolite booster and amply the energy. The magnitude of the Pentolite booster and the shaped charge detonation system were compared by a sophisticated photographic method called streak testing. MREL Explosives Products Limited performed the streak testing on five capsules and five Pentolite boosters to compare the pressure and shock attenuation properties of each.
The streak test consists of flashing light through water and exploding the test charge into the water such that the water becomes opaque. The time and duration of the opacity is captured on a strip of film that is spun in a drum at 1,000,000 revolutions per minute. This produces a streak on the film (**Film 1**), which is then turned, into a graphical data. The flash is produced by a cardboard cylinder filled with argon gas that is light off with a 1-pound Pentolite



Streak Test of Capsule

The shadowed image below the capsule is a 1-pound Pentolite booster hanging freely in the argon filled cylinder, which will become the flash bomb. The capsule is suspended two inches deep in the water filled glass tank. The capsule is fitted with a 1-pound Pentolite booster, which will ignite the 25 pounds of emulsified blasting agent inside the capsule. The shock wave from the explosion of the capsule will case the water to become opaque, which is recorded on a film as a black streak.

Picture 2

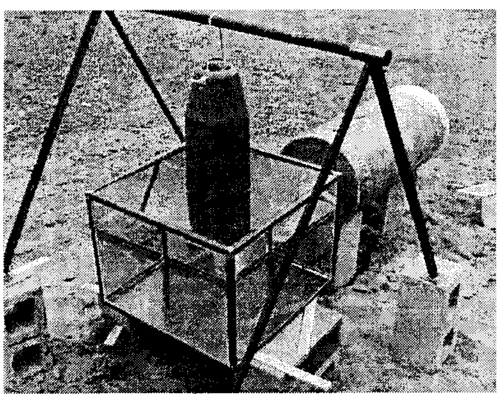


booster (**Picture 2**) just 1 millisecond before the test charge is ignited with a 1-pound Pentolite booster.

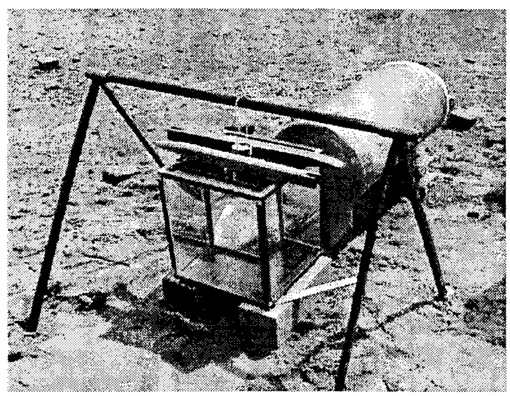
The conclusions of the streak test for the shaped charge initiated with a one pound Pentolite booster (Picture 4) and for the 1 pound Pentolite booster alone (Picture 5) are reported in the MREL report as follows:

Streak Film of Capsule Test

The view as seen through the streak camera is on the left side of the film. The image inverted such that the capsule is on the bottom of the film. The 1 millimeter wide black streak that runs at a 6-degree angle across the film is the data derived from the steak test.
Film 1

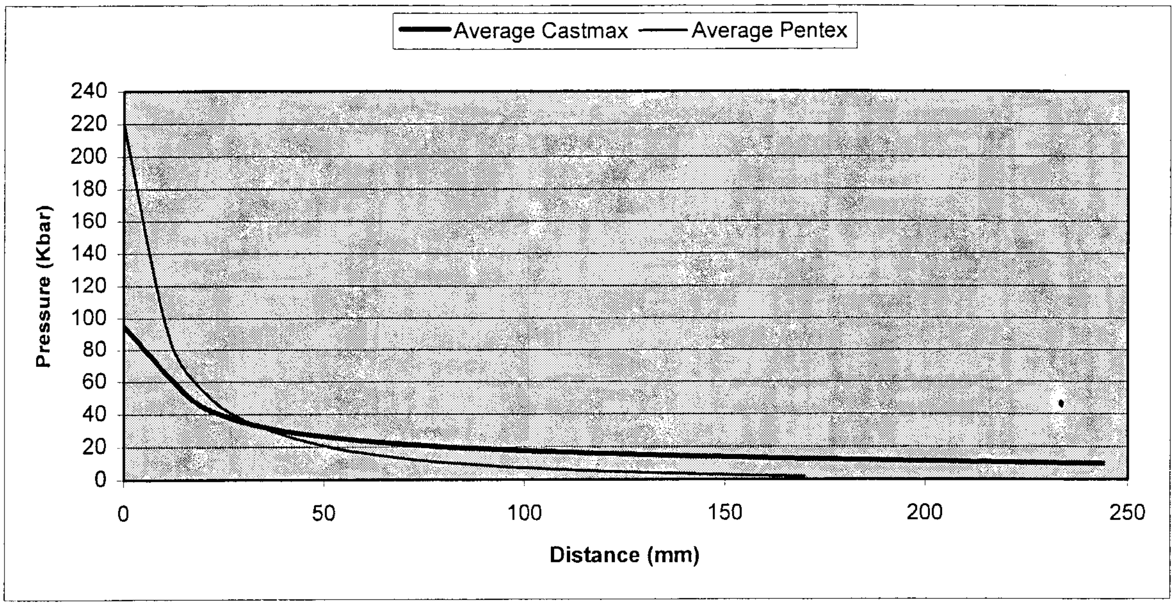


25# Shaped Charge Steak Test
Picture 4



1# Pentolite Booster Streak Test
Picture 5

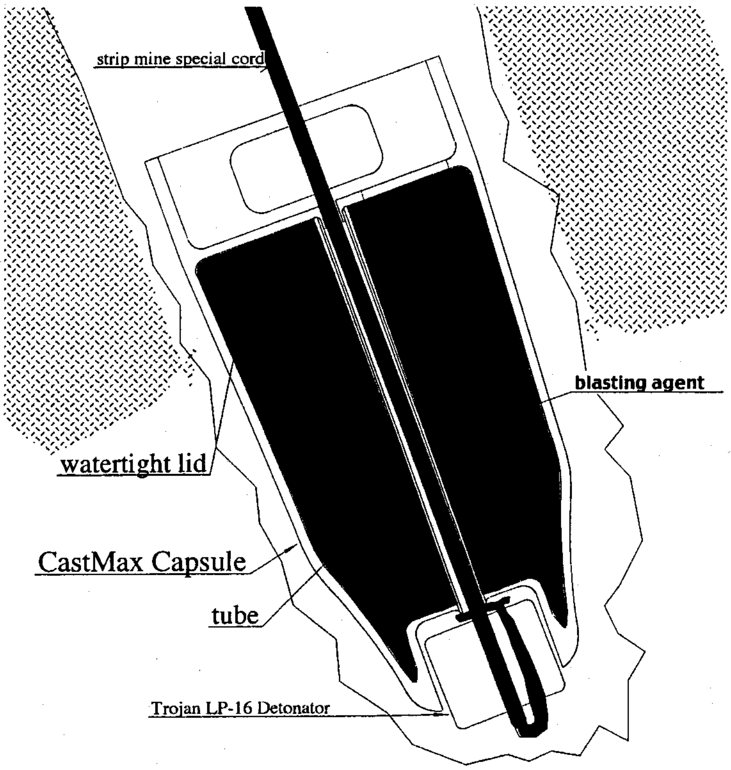
Graph 1: COMPARISON OF SHOCK PRESSURE IN WATER AS A FUNCTION OF DISTANCE FOR THE CASTMAX AND PENTEX PRIMERS.



"This investigation has evaluated the detonation pressure and shock/pressure transmission characteristics of the CastMax booster system, and compared these properties with the pressure characteristics of a commercial Pentolite primer used extensively in the mining industry. Measured detonation pressures for both the CastMax booster (filled with emulsion) and the Pentolite primer compare well with accepted literature and/or calculated detonation pressures. As expected, the detonation pressure for the Pentolite primer (220 kbar) is much larger than the detonation pressure of the emulsion (95 kbar). However, it is clear that larger pressures are transmitted to greater distances in the acceptor medium (water) for the CastMax booster than for the Pentolite primer. At a distance of 2 inches (50 mm) the pressure from the CastMax is of the order of 26 kbar vs. 20 kbar for the Pentolite primer. At distances of 4 inches (100 mm) and 6 inches (150 mm), the pressure differential increases: 17 vs. 7 kbar and 14 vs. 3 kbar respectively.

The ability of the CastMax booster to transmit significant shock pressures to a much greater distance in the acceptor charge should result in an increased capacity for shock initiation of the acceptor charge. The coupling of this detonation property with the increased amount of hot detonation gases, and larger shock surface associated with the CastMax booster, provides every indication that the CastMax booster should allow for easier initiation of bulk explosives in the borehole."

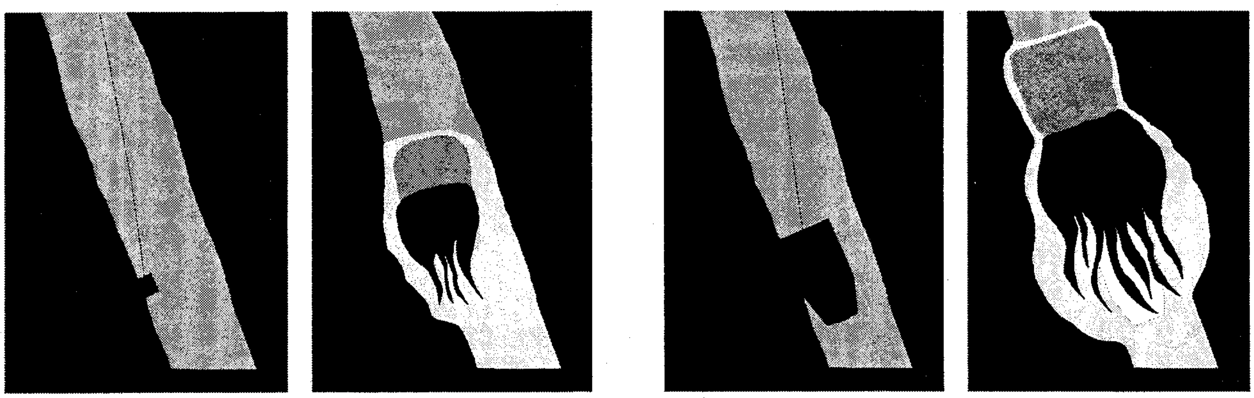
The streak test clearly demonstrates that pressure from the end of the shaped charge detonation system is significantly greater and longer in duration than from the end of a Pentolite booster alone (**Graph 1**). This data can then be extrapolated to indicate that the shaped charge can be used to bring the borehole-blasting agent to detonation more quickly than the booster alone.



Capsule in Borehole

The shaped charge detonator system is designed to span as large a diameter of the borehole as possible. The 1-pound Pentolite booster in the bottom of the capsule initiates the 25 pounds of protected blasting agent that then discharges a supersonic fireball of heat and pressure to ignite the entire circumference of the borehole-blasting agent.
Drawing 2

Not only does the capsule shape and enhance the booster's energy, it also guarantees that the first blasting agent initiated by the booster has been protected from wetting, crystallization, absorption and/or separation. The bottom of the borehole is an unknown environment and quite often has the very worst blasting agent in the borehole so it is important to supply some guaranteed that the booster contacts non-compromised blasting agent immediately upon initiation.



Pentolite versus Shaped Charge Detonation System in Borehole

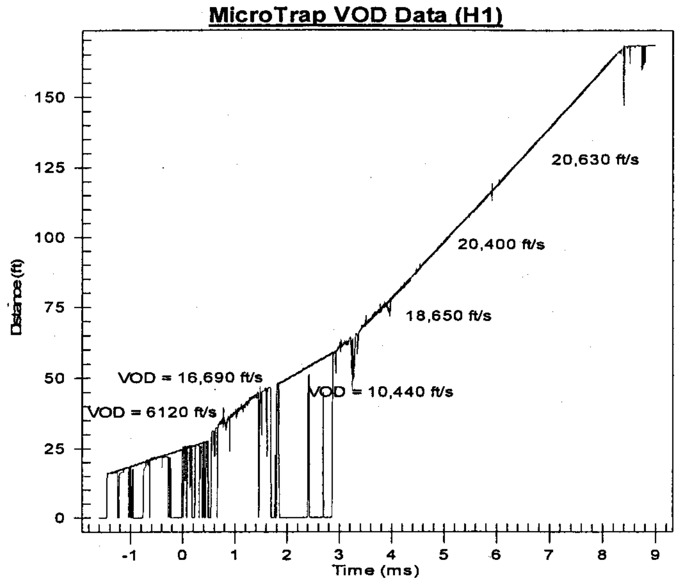
Supersonic fireball of heat and pressure from capsule is pointed the right direction in an angled borehole and puts the energy further up the borehole than does the Pentolite booster.
Drawing 3

The capsule also acts to get the booster off of the borehole wall in the angled holes (**Drawing 3**) so that when exploded it does not fracture the wall through to the next borehole and cause it to be compromised. Any measure of control that can be applied to the initiation of the borehole will help stop deflagration.

Velocity of Detonation in Cast Blast Borehole

The VOD starts at 6,120 feet per second for 2 milliseconds, the fireball spreads to the circumference of the borehole and the VOD climbs to 10,440 ft/sec. At 60 feet up the borehole the detonation reaction completely takes over and the VOD reaches steady-state-velocity at 20,400 ft/sec.

Graph 2



Powerful borehole initiation has been identified as one of the controllable parameters to obey in achieving maximum VOD; plus the force of powerful initiation influences other parameters like confinement. Any blasting practice that increases the VOD reduces the likelihood of deflagration and, consequently, the amount of "orange smoke" produced.

It is obvious from the VOD trace in **Graph 2** that there can be some degree of deflagration occurring before the borehole reaches detonation velocity, even if the blasting agent is in good condition. The data starts out at 6,000 fps, climbs to 10,000 fps and finally reaches 20,000 fps for more than 60% of the blast. To minimize this slow start, the reaction needs to instantaneously initiate the entire circumference of the borehole with as much energy as possible. The source of initiation is one of the most important, yet underrated, factors in eliminating deflagration. The booster needs to be positioned in non-compromised blasting agent that is sensitized to a minimum VOD of 18,000 fps. Control of these factors will maximize the VOD at the very onset of the chemical reaction and decrease the possibility of deflagration.

Industrial Alchemy has designed the CastMax™ shaped charge detonation system that is filled with 25 pounds of high-energy emulsion. The plastic capsule's contents are protected from every unknown element at the bottom of a borehole that can compromise the integrity of the blasting agent surrounding the booster. When the booster is initiated, it ignites the shaped charge such that the discharge from the end of the CastMax is like a cannon blast aimed up the diameter of a 10 5/8" powder column.

This ACMLRP demonstrates that the shaped charge does work to increase the energy of the booster as predicted and further full-scale experimentation with the capsule is warranted.

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

AML Progress Report

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 research project 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 will examine the influence of commonly used management practices (i.e., grazing, mulching, direct haul/stockpiled topsoiling, and shrub mosaic seeding) on organic carbon and nutrient concentrations in soil, determine the 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.

Information obtained through this research will provide reclamationists with effective strategies for building soil carbon and organic nutrients and contribute significantly to the current scientific understanding of soil carbon and organic nutrient dynamics in reclaimed environments. The observed phenomenon of organic carbon accumulation in reclaimed soils on surface mined lands should be viewed as a mechanism by which the coal mining industry is contributing to the reduction of atmospheric CO_2 through increased carbon storage and improved soil fertility.

Progress

This project was initiated at the end of June, 2002 with the receipt of funding. Although preliminary arrangements were made with seven surface coal mines in Wyoming for research sites during proposal development, field reconnaissance trips were necessary to confirm the suitability of specific research sites. During the past summer, we visited the mines listed in our proposal to assess sites for comparison of reclamation management practices and identify appropriate undisturbed control sites. After discussions with reclamation specialists at the mines, examination of mine reclamation files and maps, and inspection of field locations, research sites were chosen at the mines listed in Table 1, along with the management comparisons to be conducted at each mine.

Table 1. Mines chosen for field research sites and management comparisons.

Mine	Management comparison
Belle Ayr Mine	grazed vs. ungrazed
	shrub mosaic vs. non-shrub mosaic
Cypress-Shoshone Mine	shrub mosaic vs. non-shrub mosaic
Dave Johnson Mine	grazed vs. ungrazed
	shrub mosaic vs. non-shrub mosaic
	direct-hauled topsoil vs. stockpiled topsoil
Jacobs Ranch Mine	grazed vs. ungrazed
Jim Bridger Mine	direct hauled topsoil vs. stockpiled topsoil
	shrub mosaic vs. non-shrub mosaic
Medicine Bow Mine	stubble mulch vs. hay mulch

Soil sampling was initiated in September, 2002. During September and October, three areas were sampled on the Dave Johnson Mine; one for a comparison of ungrazed and grazed reclamation, one for a comparison of shrub mosaic site vs. a non-shrub mosaic site, and an undisturbed, native prairie control site. Also sampled this fall were a site reclaimed with stockpiled topsoil and another reclaimed with direct hauled topsoil at the Jim Bridger Mine. Finally, we also sampled three areas at the Medicine Bow Mine for a comparison of the influence of stubble mulching and native hay mulching as well as an undisturbed control site. At all of these sites, soils were sampled at three depths; 0-5 cm, 5-15 cm, and 15-30 cm along transects established in each of the areas sampled.

Laboratory analyses of organic carbon content, total nitrogen, soil pH, electrical conductivity and microbial biomass carbon for soil samples collected this fall are currently under way.

The litter decomposition study using native vegetation collected in the field scheduled to be started in the fall of 2002 has been delayed. As a result of the drought that was prevalent over much of Wyoming this past year, growth and biomass production of native vegetation was extremely low to non-existent. It was therefore necessary to grow plant material under glasshouse conditions which has delayed establishment of the litter bag experiment to spring of 2003.

Impacts of Wildlife Utilization on Big Sagebrush Survival in Reclaimed Mine Lands

Kristene Partlow, Richard Olson, and Gerald Schuman

2002
Abandoned Coal Mine Land Research Program

Impacts of Wildlife Utilization on Big Sagebrush Survival on Reclaimed Mined Lands

Interim Progress Report

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Introduction

Wyoming big sagebrush (*Artemisia tridentata* Nutt ssp. *wyomingensis* Beetle & Young), if present in pre-mined ecosystems, is required to be re-established according to the Surface Mining Control and Reclamation Act of 1977 and the Wyoming Environmental Quality Act of 1973 (Wyoming Department of Environmental Quality 1996). The process of re-establishing this shrub has been difficult for reclamation specialists. In 1990, Schuman et al. (1998) evaluated the effects of various topsoil, mulch, and grass seeding rate treatments on the re-establishment of Wyoming big sagebrush. Their study demonstrated the positive benefits of direct-placed topsoil compared to stockpiled topsoil and of various mulch treatments on re-establishment of big sagebrush on a site at North Antelope Coal mine south of Gillette, Wyoming.

However, ensuring big sagebrush survival remains a challenge years after initial establishment. Reclamation specialists are exploring potential impacts to big sagebrush survival beyond edaphic and vegetative factors. Impacts of wildlife browsing may be a major influence on big sagebrush survival for some mines. Newly reclaimed coal mine lands often provide young, highly palatable and nutrient-rich plant communities that attract wildlife species such as mule deer (*Odocoileus hemionus*), pronghorn antelope (*Antilocapra americana*), cottontail rabbits (*Sylvilagus audubonii baileyi*), and jackrabbits (*Lepus townsendii* and *Lepus californicus melanotis*). Since adjacent native rangelands usually contain older, mature shrubs of lower palatability and nutrient value, wildlife are attracted to the reclaimed areas where greater herbaceous material and juvenile shrubs are present. Cool-season grasses and some shrub species, including big sagebrush, generally dominate seeding mixtures used for reclamation. The restriction on public access and prohibited hunting on mine property provides an environment that encourages wildlife to habitually utilize these reclaimed areas.

To investigate the influence of wildlife utilization on big sagebrush growth and survival, a game-proof exclosure was constructed on a portion of the original North Antelope study site established by Schuman et al. (1998) to provide comparative data on browsed versus unbrowsed big sagebrush. Differences in plant community composition and diversity are also being evaluated inside and outside the exclosure.

Past research has enabled reclamation specialists to successfully establish big sagebrush on reclaimed lands. Reclamation specialists must now develop successful post-reclamation management practices to increase big sagebrush survival. Quantitative information on utilization levels of big sagebrush by wildlife and browsing impacts on long-term seedling survival are needed. This project will evaluate the historical progression of big sagebrush density from initial seeding to the present, assess vegetation canopy cover, determine community composition, similarity, and diversity, evaluate utilization levels of big sagebrush by wildlife, evaluate browsing impacts on big sagebrush survival, and explore potential management practices to reduce browsing impacts.

Methods and Materials

The original big sagebrush establishment study design (Schuman et al. 1998) was utilized in the current project. This original study was initiated in August 1990, on approximately 1.2 ha of leveled coal mine spoil and included the following treatments: topsoil management (fresh stripped and 5 year old stockpiled topsoil), mulch type (stubble mulch, surface-applied straw mulch, stubble and surface-applied straw mulch, and no mulch), and grass seeding rate (no perennial grass seeded, 16 kg PLS [pure live seed] ha^{-1}, and 32 kg PLS ha^{-1}). All treatments were randomly located in a randomized block, split-split plot design with 3 replications. Topsoil treatment plots were 15 by 60 m with mulch subplots measuring 15 by 15 m and grass seeding rates sub-subplots measuring 15 by 5 m. Each of the 4 mulch types occurred within each of the 3 replications of fresh and stored topsoil treatments. The stockpiled topsoil plots were excluded from study in this project because of the noted benefits of fresh topsoil. The 3 grass seeding rates were randomly established within each of the 4 mulch treatments. Nine quadrats (1 m^2) were permanently staked in each of the grass seeding rate sub-subplots in 3 belts of 3 quadrats, lying in an east-west direction and located 1 m from the edge of each subplot. Permanent belt transects (2 by 12 m) were also established in the center of each grass seeding rate sub-subplot. The only other alteration to the original study was the addition of a game-proof exclosure, constructed June 4, 2001. Dimensions of the constructed exclosure are 90 by 30 m and 3.05 m tall. The exclosure encloses half of each of the 3 replicated topsoil treatments. Therefore, the same number of mulch treatment subplots and grass seeding rate sub-subplots are located inside and outside the exclosure. The fence is constructed of woven wire with chicken wire extending along the ground surface about 0.5 m high along the fence to exclude rabbits.

Big sagebrush density was determined using the original quadrats and the newly established belt transects. Density was summarized as the mean number of plants m^{-2} in each grass seeding rate inside and outside the exclosure. Density of big sagebrush was determined in June and September 2001, and April and September 2002.

Percent cover of vegetation, bareground, and litter was determined using a ten-pin point frame placed every 1.2 m along the permanent transects for a total of 100 pin-hits per transect. Mean percent cover was calculated for each grass seeding rate inside and outside the exclosure. Mean plant species cover was converted to relative cover and used in calculating community diversity and similarity indices. Percent cover was determined in June 2001 and 2002.

In June 2001, four big sagebrush plants were selected within each grass seeding rate sub-subplot and marked by attaching plastic zip-lock ties at the plant base. In June and September 2001, and April and September 2002, marked plants were recorded as browsed or unbrowsed. In April and September 2002 type of browser (big game vs. rabbit) was also recorded for marked plants outside the exclosure. Marked big sagebrush plants were also used to measure leader length. Leader length was summarized as the mean leader length per plant for each grass seeding rate inside and outside the exclosure. The difference in mean leader length provided percent seasonal utilization.

In September 2001, April 2002, and September 2002, pellet groups of big game (antelope and mule deer) were counted, recorded, and removed from the permanent belt transects. Big game pellet group densities (no. m^{-2}), along with percent utilization of big sagebrush at the various grass seeding rate, provide trends of use and preference of big game browsing. Rabbit fecal pellets were recorded (presence or absence) and removed from belt transects.

Analysis of variance (ANOVA) was used to evaluate differences in big sagebrush density, percent vegetative cover, diversity indexes, number of pellet groups, percent big sagebrush plants browsed, mean leader length, and percent seasonal utilization between grass seeding rates inside and outside the exclosure. Mean separations were evaluated using Tukey's pairwise comparison test ($\alpha = 0.10$).

Results and Discussion

Big sagebrush density (plants m^{-2}) from permanent quadrat data displayed increases the first 2 years (1993 and 1994) following seeding (1992), but then declined during subsequent years across grass seeding rate (Fig.1) and mulch treatment (Schuman and Belden 2002). Although there were no significant differences, mean big sagebrush density was generally highest across historical sampling years in the 0 kg PLS ha^{-1} grass seeding rate. Within the permanent belt transects, mean big sagebrush density was highest in the 32 kg PLS ha^{-1} grass seeding rate inside the exclosure (Table 1). There were no significant differences in mean big sagebrush density between grass seeding rates inside or outside the exclosure during 2001 or 2002. Although not significant, big sagebrush densities outside the exclosure are decreasing more rapidly than those inside. We expect more differences in mean big sagebrush density inside versus outside the exclosure in future sampling periods as wildlife access is restricted inside the exclosure.

Species composition varied within grass seeding rates in 2001. Mean percent cover of grasses and total vegetation were significantly different between grass seeding rates ($p = 0.05$ and 0.07, respectively) inside the exclosure but not outside (Table 2). Mean percent cover of grasses and total vegetation declined with increasing grass seeding rate both inside and outside the exclosure in both years. There was significantly more grass and total vegetation cover inside ($p < 0.001$) and outside the exclosure ($p = 0.001$) in 2001 compared to 2002. Mean percent cover of shrubs (primarily big sagebrush) increased with higher grass seeding rates inside the exclosure in 2001and 2002, however, there was no significant differences between grass seeding rates. Preliminary data analysis suggests a possible competitive interaction between grass species at higher seeding rates for available water and soil nutrients, resulting in reduced mean percent grass cover at higher seeding rates. Likewise, increased mean percent cover of shrubs at higher grass seeding rates indicates that big sagebrush benefits from competitive interaction with grass species, at least inside the exclosure. Schuman and Belden (2002) also reported greater sagebrush survival at the greater grass seeding rates.

There were no differences in plant species diversity between grass seeding rates inside or outside the exclosure in 2001 or 2002 (Table 3). However, diversity indices were significantly lower in 2002 compared to 2001 inside and outside the exclosure ($p = 0.022$ and $p < 0.001$, respectively). Sorenson's similarity index of species between grass seeding rates was greater in 2001 compared to 2002 values (Table 4). Differences in diversity and similarity values between 2001 and 2002 are due to lower precipitation amounts in 2002 and related differences in community composition.

The mean percent of browsed big sagebrush plants decreased inside the exclosure during the project period, but were consistently heavily browsed outside the exclosure (Table 5). The high values for mean percent browsed big sagebrush plants inside the exclosure during June 2001 were attributable to browsing events prior to exclosure construction. Reduced browsing inside the exclosure in September 2001 was anticipated following exclosure construction and summer re-growth. Likewise, there was significantly higher numbers of browsed big sagebrush plants across all grass seeding rates following the June 2001 sampling period outside the exclosure (Table 5). In April 2002, the browsing animal (big game or rabbit) was identified outside the exclosure (Fig. 2). In all grass seeding rates rabbits were the primary browser of sagebrush rather than big game.

Mean number of big game pellet groups and presence or absence of rabbit pellets were recorded and cleared from the permanent belt transects during the September 2001 sampling period. In April and September 2002, pellet group analysis indicated presence of rabbit in all transects outside the exclosure. In April 2002, the occurrence of big game pellets along belt transects was less frequent, between 0.05 and 0.08 groups per m^2. There were no differences in pellet groups of big game by grass seeding rate.

There were no significant differences in mean leader length (mm) between grass seeding rates inside or outside the exclosure in June 2001, April 2002, and September 2002 (Table 6). However, there was significantly ($p = 0.001$) greater leader length in the highest grass seeding rate (44.3 ± 15.7 mm) during the September 2001 sampling period inside the exclosure. Mean leader length for grass seeding rates combined were significantly greater inside the exclosure than outside during all sampling periods ($p < 0.01$). Big sagebrush plants inside the exclosure continue to respond to the protection from browsing. Big sagebrush plants outside the exclosure displayed continued decrease in mean leader length during the 2001 and April 2002 sample periods. However, mean leader lengths exceeded previous length measurements in September 2002.

There were no differences in percent summer utilization between grass seeding rates (Table 6). However, there were significant differences between all grass seeding rates in percent winter utilization ($p < 0.001$). Due to the increase in leader length between April and September 2002, we were unable to calculate the second season's summer utilization.

Acknowledgments

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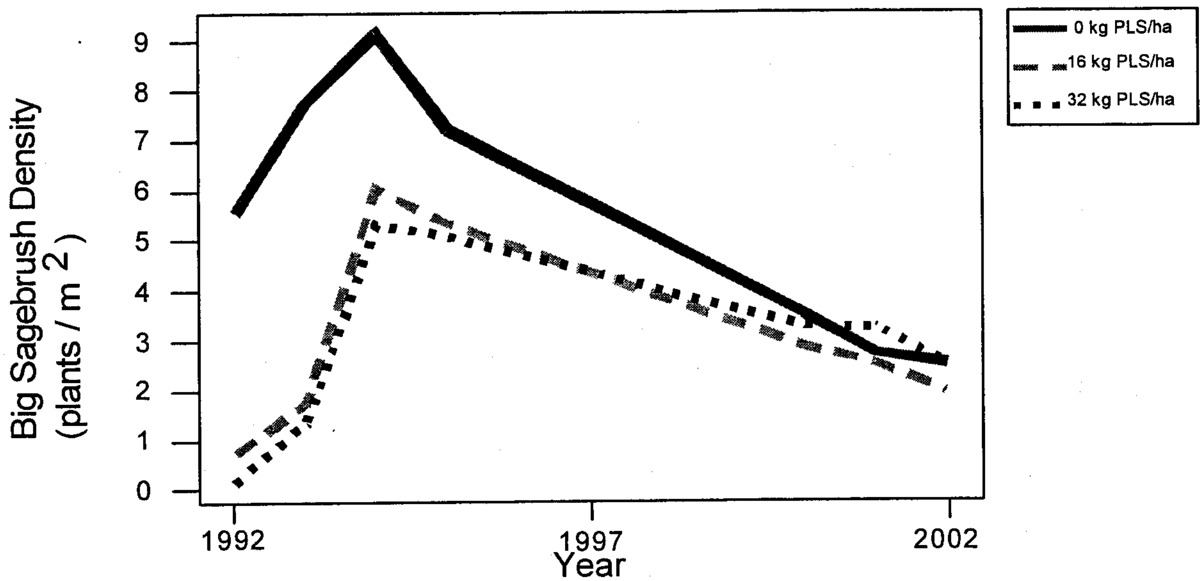

Fig.1. Historical yearly mean big sagebrush density from quadrat sampling by grass seeding rate, North Antelope Coal Mine, Gillette, Wyoming.

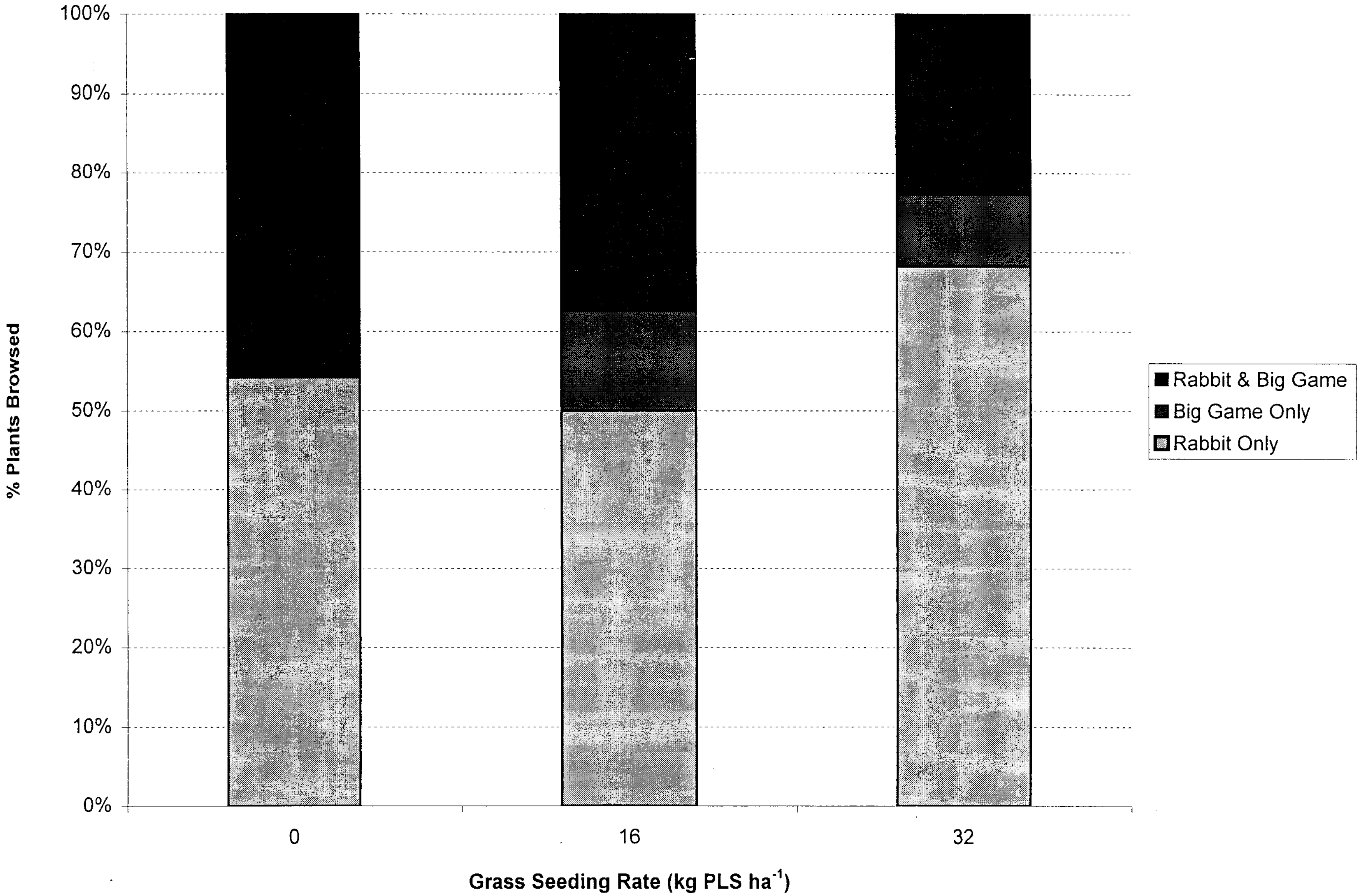

Fig. 2. Percent of big sagebrush (*Artemisia tridentata*) plants browsed by wildlife per grass seeding rate (kg PLS/ha) outside the exclosure in April 2002, North Antelope Coal Mine, Gillette, Wyoming.

Table 1. Mean density (±SE) of big sagebrush (*Artemisia tridentata*) along belt transects by grass seeding rates (kg PLS ha^{-1}) inside and outside the exclosure, North Antelope Coal Mine, Gillette, Wyoming, 2001 and 2002.

Grass Seeding Rate	Inside			Outside		
	0	16	32	0	16	32
June 2001	2.4[1] ± 1.3a[2]	2.0 ±1.5a	3.6 ± 1.3a	2.2 ± 1.5a	2.0 ± 1.4a	2.1 ± 1.1a
September 2001	2.4 ± 1.2a	2.0 ± 1.5a	3.4 ± 1.3a	2.2 ± 1.3a	2.1 ± 1.4a	2.1 ± 1.0a
April 2002	2.2 ± 1.2a	1.8 ± 1.4a	3.4 ± 1.2a	1.5 ± 1.1a	1.4 ± 0.8a	1.7 ± 1.0a
September 2002	2.07 ± 1.0a	1.9 ± 1.5a	3.3 ± 1.3a	1.3 ± 1.1a	1.3 ± 0.9a	1.4 ± 0.9a

[1] Plants m^{-2}

[2] Numbers in the same row by location (inside or outside the exclosure) with the same letter are not significantly different from one another (One-way ANOVA; Tukey's pairwise comparisons,$\alpha = 0.10$)

Table 2. Mean percent cover of grasses, forbs, and shrubs by grass seeding rates (kg PLS ha^{-1})inside and outside the exclosure, North Antelope Coal Mine, Gillette, Wyoming, 2001and 2002.

		Inside			Outside		
	Grass Seeding Rate	0	16	32	0	16	32
Year							
2001	Grasses	40.2 ± 2.0a[1]	37.0 ± 1.7ab	29.7 ± 6.5b	37.7 ± 13.2a	37.7 ± 6.7a	32.8 ± 10.3a
	Forbs	8.8 ± 2.9a	10.3 ± 4.7a	8.8 ± 1.3a	11.3 ± 7.5a	10.5 ± 9.3a	11.5 ± 4.0a
	Shrubs	0.7 ± 1.2a	1.3 ± 0.6a	1.7 ± 1.8a	0.8 ± 1.4a	1.3 ± 1.3a	0.8 ± 0.8a
	Total	49.7 ± 3.8a	48.7 ± 5.3ab	40.2 ± 4.0b	49.8 ± 7.8a	49.5 ± 3.5a	45.2 ± 5.5a
2002	Grasses	24.3 ± 5.4a	17.8 ± 2.4a	18.5 ± 1.0a	23.7 ± 7.8a	15.8 ± 7.9a	15.7 ± 6.0a
	Forbs	9.2 ± 3.7a	10.5 ± 3.8a	7.5 ± 1.8a	8.0 ± 5.8a	10.0 ± 1.7a	9.2 ± 2.2a
	Shrubs	1.5 ± 1.3a	2.0 ± 1.7a	4.0 ± 3.8a	0.17 ± 0.3a	1.17 ± 1.6a	0.33 ± 0.58a
	Total	35.0 ± 3.8a	30.3 ± 2.0a	30.0 ± 4.3a	31.8 ± 3.6a	27.0 ± 8.2a	25.2 ± 3.8a

[1] Numbers in the same row by location (inside and outside the exclosure) with the same letter are not significantly different from one another (One-way ANOVA; Tukey's pairwise comparisons, $\alpha = 0.10$)

Table 3. Mean Shannon-Weiner diversity indices by grass seeding rate (kg PLS ha^{-1}) inside and outside the exclosure, North Antelope Coal Mine, Gillette, Wyoming, 2001-2002.

	Inside			Outside		
Grass Seeding Rate	0	16	32	0	16	32
June 2001	0.67 ± 0.03a [1]	0.66 ± 0.1a	0.72 ± 0.1a	0.70 ± 0.08a	0.64 ± 0.1a	0.63 ± 0.05a
June 2002	0.52 ± 0.1a	0.46 ± 0.1a	0.50 ± 0.3a	0.41 ± 0.1a	0.41± a	0.38 ± 0.1a

[1] Numbers in the same row by location (inside and outside the exclosure) with the same letter are not significantly different from one another (One-way ANOVA; Tukey's pairwise comparisons, $\alpha = 0.10$)

Table 4. Summary of Sorenson's similarity index of species based on relative importance values from each grass seeding rate (kg PLS ha^{-1}) inside and outside the exclosure, North Antelope Coal Mine, Gillette, Wyoming, 2001-2002.

Grass Seeding Rates	Inside 0	Inside 16	Inside 32	Outside 0	Outside 16	Outside 32
0	\	0.78[b]	0.59	\	0.57	0.61
16	0.88[a]	\	0.67	0.83	\	0.92
32	0.85	0.96	\	0.81	0.85	\

[a] Values below the lines represent similarity values for 2001 sampling.

[b] Values above the lines represent similarity values for 2002 sampling.

Table 5. Mean percent (± SE) big sagebrush (*Artemisia tridentata*) plants browsed by grass seeding rates (kg PLS ha^{-1})inside and outside the exclosure, North Antelope Coal Mine, Gillette, Wyoming, 2001 and 2002.

	Inside			Outside		
Grass Seeding Rate	0	16	32	0	16	32
June 2001	41.7 ± 40.2a[1]	29.2 ± 28.9a	29.2 ± 7.2a	37.5 ± 12.5a	25.0 ± 21.7a	34.5 ± 13.5a
September 2001	8.3 ± 14.4a	4.2 ± 7.2a	12.5 ± 12.5a	100 ± 0b	100 ± 0b	100 ± 0b
April 2002	0a	0a	0a	100 ± 0b	100 ± 0b	100 ± 0b
September 2002	0a	0a	0a	100 ± 0b	100 ± 0b	100 ± 0b

[1] Numbers in the same row by grass seeding rate with the same letter are not significantly different from one another (One-way ANOVA; Tukey's pairwise comparisons, α = 0.10)

Table 6. Mean leader length (mm) and seasonal percent utilization (± SE) of marked big sagebrush (*Artemisia tridentata)* plants by grass seeding rates (kg PLS ha^{-1}) inside and outside exclosure, North Antelope Coal Mine, Gillette, Wyoming, 2001 and 2002.

	Inside				Outside			
Grass Seeding Rate	0	16	32	Mean	0	16	32	Mean
June 2001	37.5 ± 16.2a[1]	28.4 ± 8.6a	37.2 ± 10.3a	34.4 ± 12.7A[2]	19.8 ± 8.1a	20.2 ± 8.4a	17.5 ± 9.3a	18.9 ± 8.8B
September 2001	33.8 ± 21.9a	24.7 ± 12.1a	44.3 ± 15.7b	33.3 ± 19.3A	15.8 ± 7.8a	16.8 ± 8.3a	13.8 ± 5.8a	14.8 ± 7.8B
April 2002	47.0 ± 18.2a	43.7 ± 13.8a	48.6 ± 18.0a	46.4 ± 16.7A	7.6 ± 5.7a	10.1 ± 5.9a	10.6 ± 9.2a	9.4 ± 7.1B
September 2002	62.1 ± 24.2a	61.1 ± 10.9a	63.4 ± 20.2a	62.2 ± 19.0A	23.2 ±23.9a	23.4 ± 5.1a	22.9 ± 14.3a	23.1 ± 15.7B
% Summer Utilization					20.7 ± 16.4a	14.9 ± 12.5a	20.1 ± 11.1a	
% Winter Utilization					53.7 ± 3.8a	43.2 ± 4.0b	23.6 ± 2.1c	

[1] Numbers in the same row by location (outside or inside exclosure) with the same lowercase letter are not significantly different from one another (One-way ANOVA; Tukey's pairwise comparisons, $\alpha = 0.10$)

[2] Mean numbers in the same row with the same uppercase letter are not significantly different from one another (One-way ANOVA; Tukey's pairwise comparisons, $\alpha = 0.10$)

Ecology of the greater sage-grouse in the coal mining landscape of Wyoming's Powder River Basin

Kort Clayton, Kimberley Brown

Ecology of the greater sage-grouse (*Centrocercus urophasianus*) in the coal mining landscape of Wyoming's Powder River Basin

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Interim Report, November 2002

Introduction

The greater sage-grouse (*Centrocercus urophasianus*) has been extirpated from peripheral portions of its range and populations have declined in most other areas (Connelly and Braun 1997). Habitat loss, degradation, and fragmentation have been major factors contributing to population declines.

In the Powder River Basin of northeast Wyoming, sage-grouse occur in close proximity to coal mines. Such large-scale surface coal mining has the potential to negatively affect grouse populations in many ways including: behavioral disturbance, vehicle collisions, habitat loss, and habitat fragmentation. Some authors have investigated the effects of mining, and made recommendations for mitigating impacts and reclaiming sage-grouse habitat after mining. However, few studies have examined the movements and habitat preferences of grouse in the vicinity of active mines.

In light of long-term conservation concerns for sage-grouse and the continued expansion of coal mining in the Powder River Basin, it is important to understand how grouse use the landscape in the vicinity of active mines and how lands can be reclaimed after mining to benefit those local populations. To address those issues, this three-year investigation of the movements, habitat preferences, and demographics of sage-grouse in the vicinity of several active coal mines in the southern Powder River Basin was initiated in spring 2001.

This research will help define which vegetation parameters are preferred by sage-grouse during different seasons throughout the year in the southern Powder River Basin. Such local information, combined with previously published data from other regions, will provide a clearer picture of how well current reclamation practices provide habitat for sage grouse and how practices might be improved. Spatial data collected during this study will reveal areas that are consistently used by grouse and may help to define the potential impact of mining on this population and delineate priority areas for post-mining shrub establishment. This study will also lend valuable data to the Wyoming Game and Fish Department's (WGFD) planning and management efforts, particularly towards development of the upcoming Powder River Basin Sage-grouse Conservation Plan. State-wide and local conservation plans and their resulting management are needed to prevent federal listing of the sage-grouse under the Endangered Species Act. Such a listing would significantly impact coal mining operations in Wyoming.

Study Area

The focus of this study is the Rochelle lek complex sage-grouse population. Leks comprising that complex are located approximately 25 km southeast of Wright, Campbell County, Wyoming. Recent counts from the two active leks in the Rochelle complex yielded a conservative population estimate of fewer than 100 birds. Predominant habitats within the ~1,200 km^2 study area include: herbaceous rangeland (~63%), sparse big sagebrush (~20%) moderately dense big sagebrush (~14%), and ponderosa pine (~1%). Portions of five active coal mines occur within the study area. Other significant activities in the area include pervasive livestock (cattle and sheep) grazing, conventional oil and gas extraction, and coal bed methane development.

Methods

Methodology for capturing and radio tracking grouse, measuring vegetation, and assessing nest success follow procedures used by most contemporary sage-grouse researchers (Connelly et al. 1991, Fischer et al. 1993, Gregg et al. 1994, Sveum et al. 1998).

Grouse were captured during spring 2001 and 2002 in the vicinity of active leks using spotlights and either a long-handled fishing net (Giesen et al. 1982) or a net gun. They were fitted with 14-24 g necklace-style radio transmitter (Advanced Telemetry Systems, Isanti, MN) and released at the point of capture. Collared grouse were re-located approximately every 10 days using both hand-held and vehicle mounted receiving systems. Specifically, biologists "homed in" with the vehicle from roads and then walked until the grouse were seen. Precautions were taken to avoid flushing incubating hens from their nests or dispersing young broods.

Data collected at all relocation sites included: UTM coordinates, notes on group size and composition (age/sex), canopy cover and height of big sagebrush, and maximum droop height of grasses. During spring, summer, and fall, we also measured canopy cover of grasses, forbs, cacti, litter, and bare ground. Sagebrush canopy cover was measured along two 10 m perpendicular, intersecting transects (Canfield 1941). Percent cover of other variables was estimated within nine 20 x 50 cm plots (Daubenmire 1959) spaced equidistantly along the sagebrush cover transects. Sagebrush and grass height were also measured at nine points along the sagebrush cover transects. During winter months, snow depth was measured nine points along those transects.

Additional variables measured at nest sites included: the species, height, and crown volume of the nest shrub, and big sagebrush density (stems/m^2) within a 25 m^2 plot centered on each nest. Measurements were not taken at nest sites until after hens and broods had dispersed from the area. Nest fate (hatched or depredated) was determined from the condition of the eggs and shell membranes.

To facilitate an analysis of habitat preferences, in July 2002 we sampled the previously described habitat variables at 97 sites that were selected through a stratified-random process based on digital land-cover data provided by the WGFD.

Preliminary Results

To date, 29 grouse (21 hens and 8 males) have been captured and radio-collared. Ten of those birds were captured in spring 2001, and 19 during 2002. Estimated annual survival (Heisey and Fuller 1985) for female grouse was 0.51 in 2001 and 0.82 in 2002. Estimated male survival during those years was 0.16 and 0.63, respectively. Although cause of death could not be determined with certainty, it appeared that 8 of 10 mortalities were the result of predation; 4 by mammalian predators and 4 by raptors. One male probably died as a result of wounds suffered from fighting with other males on the lek. The death of one hen remains unexplained, but may be disease related.

Nest initiation was 100% for radio-collared hens during both years. Nests (n = 21) were located from 267 to 8,822 m (**mean = 2,948 m**) from the lek of capture. Clutches (n = 10) ranged from 6 to 9, and averaged 7.7. Nest success was 0.57 (4/7) in 2001 and 0.43 (6/14) in 2002. All but one nest failure was attributed to predation. Of depredated nests in both years, only one hen ever re-nested (that nest was successful).

The area occupied by all radio-collared grouse (100% minimum convex polygon, Mohr 1947) from April 2001 through August 2002 was 353.5 km^2. Of grouse that were relocated at least 9 times after being captured (n = 18), individual home ranges varied from 0.9 to 160.7 km^2, and averaged 28.7 km^2. The median individual home range was 13.0 km^2. Seasonal population ranges are presented in Table 1.

Table 1. Seasonal population range (100% Minimum Convex Polygon) statistics of 31 radio collared sage-grouse from the Rochelle lek complex in southern Campbell County, Wyoming.

Season	n	Seasonal range (km^2)
Breeding/pre-nesting (16 March-30 April)	101	35.6
Nesting/early brood rearing (1 May-15 July)	128	133.9
Summer/late brood rearing (16 July-31August)	89	278.3
Autumn (1 September- 31 October)	21	87.3
Winter (1 November-15 March)	36	54.8
Overall	375	353.5

Table 2. Summary of vegetation parameters (mean and SE) at 21 nests and 246 use-sites of radio collared sage-grouse, and at 97 random locations in southern Campbell County, Wyoming.

Parameter	Nest sites	Use sites	Random sites
Sagebrush canopy cover (%)	26.5 (2.3)	15.2 (0.7)	5.5 (0.8)
Sagebrush height (cm)	34.7 (2.1)	33.0 (0.8)	18.9 (1.5)
Nest shrub height (cm)	56.9 (2.8)	---	---
Nest shrub crown volume (m^3)	1.9 (0.3)	---	---
Sagebrush density (stems/m^2)	1.1 (0.1)	---	---
Grass height (cm)	16.1 (0.8)	16.0 (0.4)	13.3 (0.4)
Grass cover (%)	29.4 (2.1)	35.9 (1.5)	28.9 (1.8)
Forb cover (%)	6.6 (1.3)	5.9 (0.5)	2.4 (0.5)
Litter cover (%)	23.2 (4.8)	31.3 (1.9)	32.7 (1.4)
Bare ground (%)	41.1 (4.7)	34.2 (1.7)	32.5 (2.1)

Future Analyses

Productivity, survival, and home range data will be qualitatively compared with published information from populations in less industrialized landscapes. We will analyze habitat preferences using sampled vegetation parameters and digital land-cover data. We also hope to address distances from roads, mine activities, and drainages/wetlands using GIS software. More advanced analyses may also be conducted to assess landscape variables and habitat suitability within the range of both the Rochelle grouse population and the southern Powder River Basin in general. Such analyses would facilitate habitat and population models that could address the potential impacts of future mining.

Acknowledgments

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Evaluation and Comparison of Hypothesis Testing Techniques for Bond Release Applications

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ANNUAL PROJECT REVIEW SEMINAR 2002
STATUS REPORT

for

Evaluation and Comparison of Hypothesis Testing Techniques for Bond Release Applications

November 19, 2002

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The purposes of this project are to evaluate the statistical methods used in the vegetation comparisons for bond release, and to develop recommendations for modification of the statistical methods in Appendix A, LQD coal rules and regulations. Wyoming regulations currently do not specify explicit formulas for vegetation hypothesis tests for bond release evaluation. Several reclaimed mine areas have met the minimum time requirements to begin data collection for the evaluation of their reclamation efforts, however to date, only a few bond release applications have been processed by WDEQ/LQD in Wyoming. One reason that so few bond release applications have been submitted in Wyoming may be due to the mine operators' perceptions that the regulations require unreasonably large sample sizes to achieve sample adequacy requirements prior to hypothesis testing for bond release. As a result, WDEQ/LQD is in the process of evaluating and re-writing this section of Appendix A. This project is intended to provide a scientific basis for changes to Appendix A.

Bond release datasets were obtained from Wyoming, New Mexico, and Colorado to compare different statistical methods of evaluating bond release. New Mexico and Colorado were chosen because they had bond release data for mines that were ecologically similar to Wyoming. Most datasets contained three parameters: cover (%), forage production (lb/acre or g/m^2), and vegetation density (stems/acre). Each dataset was reviewed for negative or other nonsense values using standard QA/QC procedures.

Although not specified in Appendix A, classical hypothesis testing (one-sided t-test) is commonly used to evaluate bond release in the state of Wyoming. This approach has problems for both the mine operators and the State. From the mine operator's point of view, the problem occurs when the vegetation parameter on the bond release area is "close enough" to the reference area. For example, assume production on the bond release area is 97% of the production on the reference area. With a large enough sample size and small variance, 97% is significantly below 100% according to the classical hypothesis testing procedures. This is a problem for the mine operator because the State may not give the bond money back.

From the State's point of view, the problem with classical hypothesis testing occurs when the vegetation parameter on the bond release area is very different from the reference area. For example, assume production on the bond release area is 75% of the production on the reference area. With a small sample size or large variance, 75% is not significantly different from 100%. This is a problem for the State because the statistical test indicates the reclamation is adequate when, in fact, it does not meet the statutory requirement of "equal to or better than premine conditions". The t-test yields the incorrect result if the value for the bond release area is "too far from the reference", or if the study design was poor and resulted in small sample size and/or large variance.

We suggest defining bioequivalence and using bioequivalence tests as the basis for determining bond release. For example, if vegetation production on the bond release area is greater than 80% of the production on the reference area then the areas are "bioequivalent" with respect to production. The level that the reclamation must attain (e.g. 80%) is a political and biological decision. The hypothesis for bioequivalence testing is: Production on bond release area is less than or equal to 80% of reference area. The areas are not bioequivalent, and the bond is not released. The alternative is: Production on bond release area is greater than 80% of reference area. The areas are bioequivalent, and the bond is released.

To conduct the bioequivalence test, we construct the ratio of mean vegetation parameter in the bond release area to the mean vegetation parameter in the reference area. A confidence interval on the ratio is estimated based on the designated alpha level and variance. When the ration is greater than 0.8, a confidence interval that does not include 0.8 will reject the null hypothesis and support the conclusion that the areas are bioequivalent.

Hypothetical data were generated to simulate the performance of classical hypothesis testing and bioequivalence testing. Both tests were conducted on data with varying effect sizes (ratio of mean vegetation parameter in the bond release area to the mean vegetation parameter in the reference area) from 0.75 to 1.25. The coefficient of variation of the data was varied from 0.1 to 0.5.

Results from the simulation at 0.75 demonstrate the mistakes made by the classical hypothesis testing method when the bond should not be released. When the variance increases, the test will release the bond unless the sample size is large. Sample adequacy guidelines in Appendix A were developed to ensure the sample sizes are large and decrease the chance the bond will be returned in this case.

Results from the simulation at 1.25 demonstrate the performance of the tests when the bond should be released. With low variance, both tests are performing well. As the variance increases, the bioequivalence test requires adequate sample sizes to ensure the bond is released, though the actual sample requirement depends on the effect size.

We also re-sampled from real data to simulate the results of classical hypothesis testing and bioequivalence testing. The re-sampled data was generated with sample sizes from 2 to 50 to determine how many samples were needed to find bioequivalence at the observed effect size. With the effect sizes and variance present in real bond release data, both tests perform well with modest sample sizes.

Work on this project will continue through March of 2003. A final report will include specific recommendations for Appendix A. Final results will be presented at the annual AML project review seminar in 2003.

AML Progress Report

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 research project 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 will examine the influence of commonly used management practices (i.e., grazing, mulching, direct haul/stockpiled topsoiling, and shrub mosaic seeding) on organic carbon and nutrient concentrations in soil, determine the 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.

Information obtained through this research will provide reclamationists with effective strategies for building soil carbon and organic nutrients and contribute significantly to the current scientific understanding of soil carbon and organic nutrient dynamics in reclaimed environments. The observed phenomenon of organic carbon accumulation in reclaimed soils on surface mined lands should be viewed as a mechanism by which the coal mining industry is contributing to the reduction of atmospheric CO_2 through increased carbon storage and improved soil fertility.

Progress

This project was initiated at the end of June, 2002 with the receipt of funding. Although preliminary arrangements were made with seven surface coal mines in Wyoming for research sites during proposal development, field reconnaissance trips were necessary to confirm the suitability of specific research sites. During the past summer, we visited the mines listed in our proposal to assess sites for comparison of reclamation management practices and identify appropriate undisturbed control sites. After discussions with reclamation specialists at the mines, examination of mine reclamation files and maps, and inspection of field locations, research sites were chosen at the mines listed in Table 1, along with the management comparisons to be conducted at each mine.

Table 1. Mines chosen for field research sites and management comparisons.

Mine	Management comparison
Belle Ayr Mine	grazed vs. ungrazed
	shrub mosaic vs. non-shrub mosaic
Cypress-Shoshone Mine	shrub mosaic vs. non-shrub mosaic
Dave Johnson Mine	grazed vs. ungrazed
	shrub mosaic vs. non-shrub mosaic
	direct-hauled topsoil vs. stockpiled topsoil
Jacobs Ranch Mine	grazed vs. ungrazed
Jim Bridger Mine	direct hauled topsoil vs. stockpiled topsoil
	shrub mosaic vs. non-shrub mosaic
Medicine Bow Mine	stubble mulch vs. hay mulch

Soil sampling was initiated in September, 2002. During September and October, three areas were sampled on the Dave Johnson Mine; one for a comparison of ungrazed and grazed reclamation, one for a comparison of shrub mosaic site vs. a non-shrub mosaic site, and an undisturbed, native prairie control site. Also sampled this fall were a site reclaimed with stockpiled topsoil and another reclaimed with direct hauled topsoil at the Jim Bridger Mine. Finally, we also sampled three areas at the Medicine Bow Mine for a comparison of the influence of stubble mulching and native hay mulching as well as an undisturbed control site. At all of these sites, soils were sampled at three depths; 0-5 cm, 5-15 cm, and 15-30 cm along transects established in each of the areas sampled.

Laboratory analyses of organic carbon content, total nitrogen, soil pH, electrical conductivity and microbial biomass carbon for soil samples collected this fall are currently under way.

The litter decomposition study using native vegetation collected in the field scheduled to be started in the fall of 2002 has been delayed. As a result of the drought that was prevalent over much of Wyoming this past year, growth and biomass production of native vegetation was extremely low to non-existent. It was therefore necessary to grow plant material under glasshouse conditions which has delayed establishment of the litter bag experiment to spring of 2003.