Abandoned Coal Mined-Land Research Program
Project Review Seminar

Thirteenth Project Review Seminar

UW Outreach Building, Casper. WY

December 5, 2001

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.

Thirteenth Project Review Seminar
ABANDONED COAL MINE LANDS RESEARCH PROGRAM
Wednesday, December 5, 2001 Casper, Wyoming

You are cordially invited to attend the Thirteenth Project Review Seminar for the Abandoned Coal Mine Lands Research Program (ACMLRP), hosted by the University of Wyoming. The Seminar will be held on Wednesday, December 5, 2001 at the UW Outreach Building, 951 N. Poplar, Room 150, Casper, Wyoming beginning at 1:15 p.m.

Speakers will present interim or final reviews on research projects currently funded by the ACMLRP:

The Effects of Varying Topsoil Replacement Depth on Various Plant Parameters within Reclaimed Areas Schladweiler, Munn, Haroian, Belden	**Interim**	**4**
Grass Competition and Sagebrush Seeding Rates: Influence Sagebrush Seedling Establishment Schuman, Hild, Vicklund	**Interim**	**15**
Research and Development of a GIS-Based Data Management and Model Integration Tool for Coal Mine Permitting and Reclamation in Wyoming Kohley, Hamerlinck, Jones, Warner, Schwab, Vicklund, Warner	**Interim**	**22**
Ambient Fine Particle Measurement in the Powder River Basin Chartier, Weitz	**Interim**	**27**
Relationship of soil organic matter content and sustainablenutrient cycling in reclaimed soils Stahl, Schuman, Ingram, Spackman	**Interim**	**31**
Sr isotropic characterization of coal and sandstone aquifers, Powder River basin, Wyoming Frost, Muller-Ogle, Lyman, Heffern	**Interim**	**36**
Effects of Variable Topsoil Replacement Depth on Plant Community Development and Soil Ecosystem Development after 24 Years Bowen, Olson, Schuman, Ingram	**Interim**	**40**
Impacts of Wildlife Utilization on the Big Sagebrush Survival on Reclaimed Mined Lands Strait, Olson, Schuman	**Update from 1990 continuation project**	**49**

Reclamation Handbook – Update Report **56**

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.

2001
Abandoned Coal Mine Land Research Program
Progress Report

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

submitted by:

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December 5, 2001

SUMMARY OF 2001 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 will extend through 2002. Refer to the 1999 summary for a complete description of project construction.

2001 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 2001. 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.

2001 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.

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.

2000 Statistical Methodology

During the spring of 2001, the 2000 vegetation and soil data were analyzed using SAS Version 6.12 on the University of Wyoming mainframe computer using a two-factorial weighted ANOVA since the number of transects or sampled parameter points were not equal. 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). Equality of variances were determined as a prerequisite to ANOVA analysis. Similar methodology will be conducted on the 2001 data when the soil analyses are complete.

The first analysis was by depth over type, treatment, and type*treatment interaction which looked at the reclaimed area vs. both native areas combined. The second analysis was by depth over location, treatment, and location*treatment interaction which looked at all three areas separately.

Treatment differences within the reclaimed treatments themselves, as well as within each reference areas, will be further evaluated on the 2001 data to further clarify the appropriate use of comparison between the reclaimed and the reference areas.

As part of the summary of the 2000 vegetation data only, Sorenson=s (1948) similarity index was applied. Formula for this index is as follows:

$$SI = (2C/A+B)*100$$

where: SI = Similarity index;
A = total number of species in Site A;
B = total number of species in Site B; and
C = number of species common to both sites.

Results

Tables 1 and 2 contain a brief summary for the 2001 reclaimed and reference area data, respectively.

Table 1. 2001 Reclaimed Vegetation Sampling Summary.

Treatment	Average Number Species/Sample	Percent Total Vegetation Cover	Percent Total Cover
6	5.53	42.45	82.44
12	6.60	44.45	82.00
22	5.40	57.55	89.33

Table 2. 2001 Reference Area Vegetation Sampling Summary.

Reference Area	Treatment Equivalent	Average Number Species/Sample	Percent Total Vegetation Cover	Percent Total Cover
Breaks	Top	7.67	66.67	84.81
	Middle	8.22	64.44	86.67
	Bottom	8.00	71.11	89.63
Upland Grass	Top	7.33	71.11	87.04
	Middle	7.67	69.26	89.26
	Bottom	8.11	64.44	88.15

The highest sample adequacy numbers (WDEQ, 1996) were found in the 30cm treatment. Plotting of the these treatment values for total vegetation cover and total cover indicate questionable normality conditions. A similar pattern was seen in the 2001 data. Confidence levels for the treatment replicates that did not reach adequacy according to the WDEQ formula ranged from 62.55 to 89.80.

Significant mean differences (at the $p = 0.01$ level) for the 2000 soil and vegetation data are found in **Tables 3 and 4**.

Results for Sorenson=s index of similarity are found in **Tables 5 and 6** for the 2000 and 2001 data, respectively. The highest calculated percentage of similarity, which is based on presence/absence data only, is 37.04 for the 2000 data and is derived from

comparing the 15cm treatment vs. the Breaks Bottom which should be representative of the 56cm treatment. These values indicate the difficulty in comparing reclaimed vs. native areas in determining success.

Observations from the first SAS analysis (by depth, summarized by type and treatment) include:

- X For every variable except total vegetation, there are significant differences between types, i.e., reclaimed vs. native (reference areas).
- X Significant differences between types existed at each soil depth except the 12-18 depth for pH.
- X No interactions existed between treatment and type.
- X There were no differences between any of the treatments, with the exception of SAR. At the 12-18 inch depth, the average value for SAR in the 56cm replacement was significantly greater than the average value of SAR in the 30cm replacement, i.e., 1.29 vs. 0.92.
- X The influence of type on the various dependent variables is shown below (based on significance tests):

pH:	Reclaimed > Native for depths 0-6 and 6-12
	Native > Reclaimed for depth 12-18
EC:	Reclaimed > Native for all depths
SAR:	Reclaimed > Native for all depths
%TC:	Native > Reclaimed
%TV:	Native > Reclaimed
Avg. #:	Native > Reclaimed
Total #:	Native > Reclaimed

Observations from the second SAS analysis (by depth, summarized by location and treatment) include:

- X For every variable except total vegetation, there are significant differences between locations, i.e., reclaimed vs. upland grassland vs. breaks.
- X Significant differences between locations existed at the shallower soil depths for pH, EC,and SAR. Significant differences between locations existed at all depths for the vegetative parameters of Total Cover, Average No. of Species and Total No. of Species, with the exception of Total Vegetative Cover.
- X No interactions existed between treatment and location.
- X There were no differences between any of the treatments, with the exception of SAR. At the 12-18 inch depth, the average value for SAR in the 56cm replacement was significantly greater than the average value of SAR in the 30cm replacement, i.e., 1.29 vs. 0.92. This observation is the same as for the first run.
- X The influence of location on the various dependent variables is shown shown below (same as for first run):

pH:	Reclaimed > Native for depths 0-6 and 6-12
	Native > Reclaimed for depth 12-18
EC:	Reclaimed > Native for all depths

SAR:	Reclaimed > Native for all depths
%TC:	Native > Reclaimed
%TV:	Native > Reclaimed
Avg. #:	Native > Reclaimed
Total #:	Native > Reclaimed

Table 3. Significant Tests of the 2000 Means for Various Parameters (by Type and Treatment).

Depth (cm)	Dependent Variable	Significant By	Results
0-15/15-30	PH	Type	Reclaimed pH significantly higher from both natural areas.
0-15/15-30/30-45	PH	Type	Reclaimed pH significantly higher from both natural areas.
0-15/15-30/30-45	SAR	Type	Reclaimed SAR significantly higher from both natural areas.
30-45	SAR	Treatment	Treatment SAR significantly higher.
0-15/15-30/30-45	TOTCOV	Type	Reclaimed Total Cover significantly lower from both natural areas.
0-15/15-30/30-45	ASPECIES	Type	Reclaimed Average Species significantly lower from both natural areas.
0-15/15-30/30-45	TOTSPECIES	Type	Reclaimed Total Species significantly lower from both natural areas.

Table 4. Significant Tests of the 2000 Means for Various Parameters (by Location and Treatment).

Depth (cm)	Dependent Variable	Significant By	Results
0-15/15-30	PH	Location	Reclaimed pH significantly higher from one or both natural areas.
0-15/15-30/30-45	EC	Location	Reclaimed EC significantly higher from one or both natural areas.
0-15/15-30/30-45	SAR	Location	Reclaimed SAR significantly higher from one or both natural areas.
30-45	SAR	Treatment	Reclaimed SAR significantly higher from one or both natural areas.
0-15/15-30/30-45/45-61/61-76	TOTCOV	Location	Reclaimed Total Cover significantly lower from one or both natural areas.
0-15/15-30/30-45/45-61	ASPECIES	Location	Reclaimed Average Species significantly lower from one or both natural areas.
0-15/15-30/30-45	TOTSPECIES	Location	Reclaimed Total Species significantly lower from one or both natural areas.

Table 5. 2000 Sorenson Similarity Index (%).

	Treatment		
Reference Area	15cm	30cm	56cm
Upland Grass Top	20.51	9.76	23.53
Upland Grass Middle	21.62	10.26	25.00
Upland Grass Bottom	21.74	12.50	24.39
Breaks Top	20.00	14.29	17.14
Breaks Middle	9.30	8.89	15.79
Breaks Bottom	37.04	20.51	25.00

Table 6. 2001 Sorenson Similarity Index (%).

	Treatment		
Reference Area	15cm	30cm	56cm
Upland Grass Top	21.05	10.26	24.24
Upland Grass Middle	21.62	10.53	25.00
Upland Grass Bottom	21.74	12.77	24.39
Breaks Top	15.00	14.63	17.14
Breaks Middle	9.30	9.09	15.79
Breaks Bottom	27.03	21.05	25.00

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.

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 and 2001 growing season in 2000. Fall moisture, however, was good to adequate in 1999 which aided the growth of species during the 2000 growing season. 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.
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.

Based on a review of Colorado, New Mexico, Montana, Wyoming, and Utah regulations for coal mines, other indices (alpha or beta) include: Simpson=s (1949) index; Jaccard=s Similarity (Community) index or coefficient (1912); a quantitative variation of the Sorenson index (Magurran 1988); Ruzicka=s Index of Quantitative Similarity (1958). 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.

2002 Tasks

X Additional vegetation and soil sampling will be conducted, similar to 2000-2001 methodology. Production estimates will be added.

X Imagery or photography was obtained in 2001 by PRCC to investigate spectral signatures of its native and reclaimed areas, including the current study area. This information will be evaluated for use in the current study.

- The use of 3-D imaging of sample point information, carbon analysis and collection of soil moisture will be evaluated.

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2001

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 to direct and accelerate plant succession toward desired 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 and Young). 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. We have documented sagebrush seedling density under three sagebrush seeding rates and seven grass seeding rates for three growing seasons (1999-2001) and we also assessed the average size of the sagebrush seedlings in 2001.

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, seven grass seeding rates (0, 2, 4, 6, 8, 10, and 14 kg PLS/ha), comprised of a mixture of western, slender, and thickspike wheatgrass were randomly assigned and drill seeded into 6.5 x 27 m plots within each of four, 27 x 45.5 m blocks. 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 1999-2001. Sagebrush seedling size (canopy volume) was also assessed in these permanent quadrats in 2001.

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 size were determined in June 2001 and density was also assessed in October 2001. Sagebrush seedling size 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 ($P \leq 0.05$) in treatment effects were noted, Least Significant Difference methods were used to test treatment mean differences.

Results and Discussion

Sagebrush seedling density data continue to show no statistically significant differences on either of the sampling dates (June and October 2001) for grass seeding rates. However, we continue to have a large decline in sagebrush seedling density at the 14 kg PLS/ha grass seeding rate (Figure 1). Precipitation in 2001 was considerably below normal for the Gillette area and

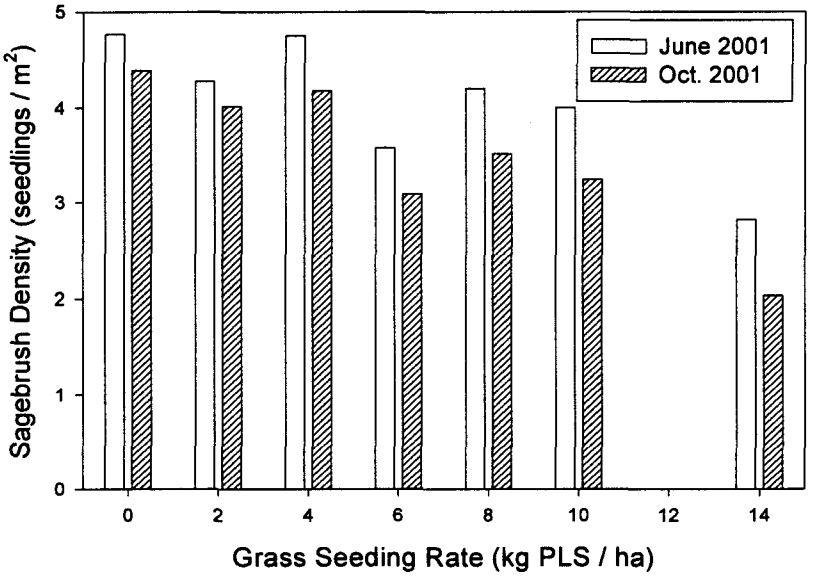


Figure 1. Effect of grass seeding rate on sagebrush seedling density, June and October 2001, Belle Ayr Mine, Gillette, WY (no significant differences within count date).

temperatures were above normal during the growing season. These climatic conditions led to considerable mortality between June and October 2001. October sagebrush densities revealed a declining trend in higher grass seeding

rates althouh not significantly diffeerent (P = 0.12; whereas P ≥ 0.50 in past years). We believe it will become increasingly likely that moisture and space stress could result in significant grass seeding rate effects as this reclaimed plant community matures. Lack of observed differences between grass seeding rates may be partially due to the high degree of variance in sagebrush seedling density within the experimental units. In all cases the standard deviation of a given treatment mean is >80% of the mean, as is typical of plant density data.

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 1.6 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 supports the need for sagebrush seeding rates of ≥2 kg PLS/ha.

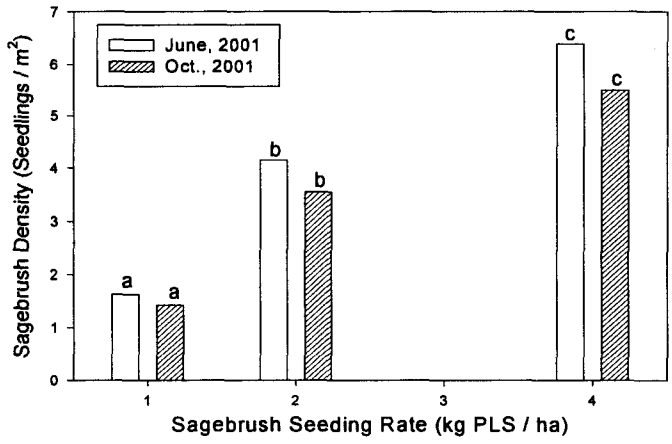
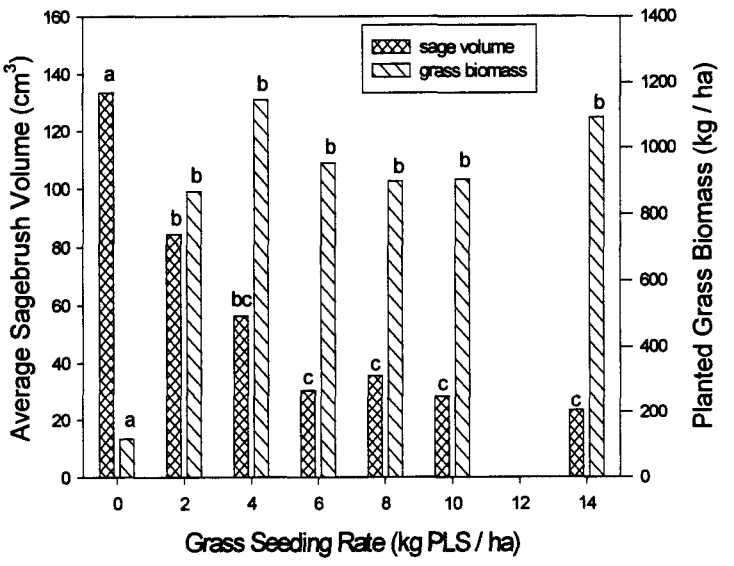


Figure 2. Effect of Wyoming big sagebrush seeding rate on sagebrush seedling density, June and October 2001, Belle Ayr Mine, Gillette, WY. Bars with different letters, within a date, are significantly different (P = 0.05).

To further assess the effects of grass seeding rate (competition) on sagebrush seedlings we measured the size of the sagebrush seedlings and found that grass seeding rate significantly affected the average sagebrush seedling canopy. Figure 3 shows that the seedling canopy was significantly smaller where grass was seeded and at grass seeding rates ≥ 4 kg PLS/ha seedling volume was significantly less than those for 0 and 2 kg PLS/ha grass

seeding rates. This parameter will be assessed again in 2002 to further delineate the effects of grass seeding rate on sagebrush seedling size and its impact on seedling survival potential.

Aboveground grass biomass was not different among grass seeding rates of 2-14 kg PLS/ha (Figure 3). This is a similar response to that observed in 2000 except that last year no differences existed between grass seeding rates >than 4 kg PLS/ha. The fact that grass biomass is not different among grass seeding rates indicates that we can probably reduce grass seeding rates and still continue to have adequate cover and production to ensure soil stability and protection from erosion. We plan to evaluate canopy and basal cover of the



grasses next year in an attempt to further elucidate the potential for lower grass seeding rates that will adequately protect the soil resource, provide equal or greater forage than pre-mine conditions, enhance the potential for Wyoming big sagebrush establishment, and enhance the potential for natural recruitment of native species.

Figure 3. Effect of grass seeding rate on average sagebrush seedling size (canopy volume-June 2001) and planted grass biomass (July 2001), Belle Ayr Mine, Gillette, WY. Different grass seeding rates, within a parameter (grass

biomass or sagebrush canopy volume), with different letter are significantly different (P = 0.05).

Conclusions

Grass seeding rates (competition) continue to show limited effect on the sagebrush seedling density; however, grass seeding rates has definitely affected the canopy volume of the sagebrush seedlings. By influencing sagebrush seedling size, we are sure that this will ultimately have an effect on sagebrush seedling survival and density. Since grass seeding rates are not affecting grass production, it is important to assess the potential of reducing grass seeding rates to enhance establishment potential for desired shrubs and forbs that might be seeded and also to enhance their natural recruitment. This study continues to supply important information on the effects of grass and sagebrush seeding rate on plant community development which will enable us to develop improved reclamation technology.

Publications

Williams, M.I., G.E. Schuman, A.L. Hild, and L.E. Vicklund. 2002. Wyoming big sagebrush density: effects of seeding rates and grass competition. Restoration Ecology (in press)

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Acknowledgements

This study is possible through the cooperation and financial support from the ACMLRP, RAG Coal West, Inc., Belle Ayr Mine, High Plains Grasslands Research Station, USDA-ARS, and the Department of Renewable Resources, University of Wyoming. Appreciation is also acknowledged to everyone that assisted in data collection and analysis, especially to Mary Williams (former graduate student) and Matt Mortenson who took lead roles in the sampling and data analysis.

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Wyoming Abandoned Coal Mine Lands Research Program
Final Project Review
November 2001

Research and Development of a GIS-Based Data Management and Model Integration Tool for Coal Mine Permitting and Reclamation in Wyoming

July 1, 1999 – November 30, 2001

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This report provides a brief project background and summary of work undertaken during the grant period 1 July 1999 through 30 November 2001.

STATEMENT OF NEED

A central focus of the Surface Mining Control and Reclamation Act of 1977 is the collection, analysis, interpretation and application of current, accurate and complete "baseline" data for mine plan, reclamation plan, and bond release monitoring components of the coal mine permit application process. To meet these challenges a need exists for the development of computer application tools capable of: 1) managing large quantities of spatial and non-spatial digital mine and reclamation data; and 2) providing an efficient means for utilizing such information in an integrated data management, analysis, and modeling environment.

STUDY OBJECTIVE

The primary objective of our research was to develop a prototype geographic information system-based software application for the management, analysis and reporting of data associated with major components of the bond release processes for coal mining in Wyoming. The study addressed a number of ACMLRP research topic elements, expanding on the GIS/hydrologic model integration topic (outlined in the *Hydrologic Impact Assessment for Coal Mining Operations* research category[1]) to explore applying a similar GIS-based data management and model integration methodology to soils, vegetation, and wildlife concerns.

The original goal of the two-year project was to design and develop an integrated, modular GIS software application prototype – the *Reclamation Management Tool* (RMT)- containing components for management, analysis, and/or modeling of hydrology, soils, vegetation, and wildlife data. The RMT was to be designed as an extension of a major desktop GIS software product

(ArcView; Environmental Systems Research Institute, Inc., Redlands, CA), with support by a relational database management system compatible with generic mine data formatting requirements (e.g., Microsoft Access). However, in the first nine months of the project, the conceptual design of the application was modified, based in part upon input from the project's advisory group members, as well as the determination of a fundamental difference in the targeted utility of the hydrology module versus those for soils, vegetation and wildlife[2]. Specifically, work on the GIS/hydrology integration migrated toward a focus on modeling and structure design functionality, while work on the soils, (re-)vegetation, and wildlife keyed on tools for tracking these resources for specific bond release requirements. These distinctions led to the creation of two separate, but interoperable ArcView 3x extensions: SedPrePro, providing a interface to SEDCAD 4 (Civil Software Design; Ames, IA) for model parameter inputs and modeling result outputs to the GIS and final result modeling, and the *Reclamation Management Tool* (RMT), providing a GIS – database interface for managing sampling and monitoring data related to topsoil, overburden, seeding, and habitat construction.

RESULTS

The research project resulted in the design and development of two prototype GIS software application tools for coal mine land reclamation activities – SedPrePro and RMT.

SedPrePro Overview. SedPrePro is an ArcView 3.2 extension that was developed to assist pre-processing for the SEDCAD surface water model. SedPrePro provides functionality to develop continuous raster elevation surfaces, predicted stream networks, NRCS Type storm layers, NRCS Curve Number grids, hydrologic structure regimes and user delineated subwatersheds. SedPrePro utilizes these data sources in conjunction with customized time of concentration (Tc) and flow routing algorithms to calculate physical and

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[1] *1999 ACMLRP Call for Proposals*
[2] *Presented at ACMLRP Annual Review Meeting, Gillette, WY, November 29, 2000*

geometric properties of the watersheds and aggregate these properties into SEDCAD parameter input files.

The SedPrePro extension was designed as a 'user friendly' interface to the hydrologic modeling component of SEDCAD. The SedPrePro extension modifies the ArcView Graphical User Interface (GUI) with the addition of two new dropdown menus, *Sedcad PrePro* and *SPP Utilities*. The interface provides enhanced dialogs, buttons and tools to facilitate pre-processing of SEDCAD model inputs. SedPrePro enables the user to rapidly input the majority of structure and networking information required by SEDCAD. Additionally, all subwatershed information, including automatic watershed delineation, determination of area and time of concentration is achieved through the SedPrePro tool.

RMT Overview. The Reclamation Management Tool (RMT) is the combination of an ArcView 3.2 user-interface and a standardized relational database designed to track virtually all elements of reclamation history, from initial disturbance dates to topsoil replacement, re-vegetation and bond release status. The RMT allows end users to query and visualize past and present reclamation activities and easily generate standardized reports and maps for inclusion in annual reports and bond release documents.

The database portion of the system includes 33 Microsoft Access relational tables with a series of customized form menus to ensure the consistent entry, editing and management of reclamation data. The GIS component consists of a modified GUI with a single, multiple-choice dropdown menu that extends ArcView's functionality to interact with the multiple MS Access tables. The RMT

menu invokes a series of custom dialogs in a "wizard" style fashion that allows users to easily query and view reclamation data and generate document-sized maps and reports using the Crystal Reports extension.

CONCLUSION

This project focused on the design and development of a GIS-based software application for coal mine reclamation activities. The project's overarching goal was to explore the potential utility of geospatial technologies for assisting industry and government agencies alike with data management, modeling and information analysis associated with various aspects of coal mine environmental management, particularly bond release requirements.

The SedPrePro and RMT applications demonstrate the opportunity for geographic information system implementation in coal mine land reclamation. SedPrePro provides a valuable tool for parameter development and management with the most widely used stormwater design and sediment control modeling systems in the mining industry. RMT provides a comprehensive, spatially-referenced database management infrastructure for tracking environmental requirements for post-mine bond release.

The research did identify several obstacles, both technical and institutional, to wide implementation of the tools. One technical challenge is the current rapid evolution of data models and programming environments in GIS software applications. A second technical constraint involving gaps in digital data availability and a lack of format interoperability may be addressed with an institutional solution such as development, implementation and adherence to data standards for permit applications and review, as well as monitoring data reporting and bond release application. In addition to standards development, other potential future research related to this project includes tools for imagery analysis for monitoring revegetation and developing methods to better link surface and groundwater modeling tools.

Ambient Fine Particle Measurement in the Powder River Basin

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ACMLRP Annual Summary
December 5, 2001

Contents

1. Introduction
2. Objectives; initial & revised
3. Network design
4. Data collection, summary, dissemination
5. Time line, status
6. Budget

1. Introduction:

Coal mines are regulated, in part, by the impacts that coal production, mine reclamation, and associated activities have on pollution levels in ambient air, through ambient air quality "standards". A new standard for "fine" particles was adopted in 1997 by the USEPA and has been implemented by State and Local air quality agencies, generally beginning in 1999.

The relationship between coal mining activities and the production of fine particles is not well understood. This research project addresses the need for the collection of a high quality data set which will be used to better understand the relationships of coal mining to the generation and transport of airborne fine particles.

This project established a regional network of fine particle measurement instrumentation in Wyoming's Powder River Basin coal mining area, beginning July, 1999. Several measurement techniques are employed to assess their effectiveness and practicality in a rural industrial application. The network is designed to provide data of high spatial and temporal resolution, allowing comparisons against upwind ambient air so that local impacts may be assessed. The establishment and operation of the network is a collaborative effort, with contribution and participation from a variety of organizations, thereby representing a unique approach to ambient air monitoring which serves as a model for regional air monitoring.

The study will provide essential information by which to tailor appropriate and effective industrial development and regulatory strategies to the unique conditions and needs of Wyoming. Also, the study will provide a solid basis for a variety of subsequent research related to fine particulate matter that include the influences of specific coal mining activities, coal transportation, meteorological influences, regional visibility, upwind and neighboring contributions, and for chemical and transport modeling of fine particles.

This project was originally funded for two years, 1999 – 2001. A third year extension of this project was applied for and approved in 2001.

2. Objectives; initial & revised

The original objectives of this research project were to:

1. Determine the spatial and temporal distribution of fine particulate ($PM_{2.5}$) in ambient air in the Powder River Basin coal mining region of Wyoming.
2. Evaluate continuous measurement techniques compared to EPA Reference Method manual sampling measurements.
3. Evaluate the manual method currently employed by Wyoming Mining Association to collect baseline $PM_{2.5}$ data in the Powder River Basin in relationship to the EPA Reference Method.

In 2001 an extension of the project was approved. Objectives 1. and 2. from above were retained. Objective 3. was discontinued as sufficient data had been collected to meet that goal. Two additional objectives were added. The revised project objectives are as follows:

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 continuous 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.

3. Network design:

This network spans monitoring over a north-south tract. Predominant winds in the Powder River Basin are such that this configuration provides upwind and impacted monitoring sites under most meteorological conditions. A variety of monitoring equipment are employed to provide both baseline PM2.5 concentrations, and to allow comparison of various monitoring techniques. For a graphic depiction and description of all monitoring stations the reader is referred to either the Monitoring Network Plan or the Quality Assurance Project Plan which are on file with the Wyoming DEQ Air Quality Division, or can be found on IML's web site at *www.imlinc.com*.

4. Data collection, summary, dissemination:

This project is in its intensive data collection phase. Data collection was stepped up from every-6-days to every-3-days beginning in April, 2000 and this accelerated schedule continued for one year. Some new monitoring equipment was added in May, 2001, and some older monitoring equipment which had satisfied its objectives was decommissioned. Data synthesis and analysis will commence this coming spring as data collection concludes.

Data from the network are summarized as follows:

ACMLRP/Powder River Basin PM2.5 measurements, July, 1999 – September, 2001

Monitoring sites	avg. conc. (µg/m^3)	max conc. (µg/m^3)	2nd hi conc. (µg/m^3)	data recovery (%)
PRB1 (FRM, Buckskin)	5.2	20.9 6/14/00	20.5 8/19/00	73.5
PRB2 (baseline, Belle Ayr), *decommissioned 4/01*	6.6	22.3 8/16/00	19.3 8/28/00	95.4
PRB3 (FRM, Belle Ayr)	5.8	23.8 7/14/00	23.0 8/7/00	93.5
PRB4 (baseline, Belle Ayr,) *decommissioned 4/01*	8.8	34.7 9/15/00	32.0 11/14/99	91.0
PRB5 (FRM Black Thunder)	6.5	22.7 10/24/99	21.5 11/14/99	90.4
PRB6 (baseline, Black Thunder, *decommissioned 4/01*)	6.6	26.5 11/14/99	18.0 8/6/00	94.0
PRB7 (continuous, Black Thunder)	7.9	187.5 11/7/00	28.0 11/14/99	81.4
PRB8 (FRM, Antelope)	3.7	14.5 8/7/00	13.7 8/19/00	70.7
PRB9 (PM10FRM, Black Thunder, *added 7/01*)	52.4	135.7 9/10/01	90.1 7/18/01	81.8
PRB10 (fine/coarse dichot, Black Thunder, *added 7/01*)	8.3/36.2	13.8/97.4 9/10/01	12.4/56.1 9/4/01/7/30/01	88.9/88.9
Nephelometer (Black Thunder) *added 7/01*	n/a	n/a	n/a	not yet operational

All data to date have been supplied to the Wyoming Department of Environmental Quality's Air Quality Division where they are on file. Additionally, data from the network are now also available at the IML web site - *www.imlinc.com.*

5. Time line, status:

This project commenced monitoring July, 1999, and will continue through April, 2002. The project is on schedule and no delays have occurred. 2000/2001 saw the breakdown and repair of samplers, especially PRB1, PRB7 and PRB8 which caused data recovery rates to fall. All samplers are now operational. A portable nephelometer was intended to be operational in July, 2001. The new device

experienced difficulty in startup, was then damaged by a lightning strike, and then had to be returned to the factory again for an EEPROM change. The nephelometer is not yet operational.

Intensive data analysis and synthesis will occur following the end of the ongoing monitoring.

6. Budget:

This project was extended for 1 year, and an additional $75,000 was added to the budget. Funds intended for concluding the 2 year study were rolled over to conclude the 3 year study. The budget through November, 2001 is summarized as follows:

Type	Budget	Charged	Remaining
Personnel	$112,799.00	$73,529.75	$39,269.25
Travel	$42,142.00	$32,761.50	$9,380.50
Support	$5,264.00	$4,009.50	$1,254.50
Supplies	$64,795.00	$55,166.38	$9,628.62
TOTAL COSTS:	$225,000.00	$165,467.13	$59,532.87

Much of the project so far has involved collection and processing of raw concentration data. Activities such as operational data collection, and in-depth analysis and synthesis, will commence as the monitoring activities conclude in April, 2002.

AML Progress Report

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

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Introduction

An important aim of mineland rehabilitation is to ensure wherever possible that the "reconstructed" ecosystem is self-sustaining, requiring minimal or preferably no additional inputs. Therefore, it is critical that soils used in mine reclamation are able to provide sufficient quantities of nutrients for ecosystem sustainability. Many of the nutrients required for plant growth, in particular nitrogen (N) and phosphorus (P) are found in the greatest abundance in soil organic matter (SOM). Equally important is the large amount of carbon (C) found in SOM, which provides "energy" to microbial populations and enables them to mineralize the nutrients in SOM and make available for plant uptake.

One objective of this project is to determine the minimum amount of SOM required to potentially sustain nutrient cycling in disturbed ecosystems. The rate at which N is mineralized (converted from an organic form to a plant available, inorganic form) is usually considered to be the factor most limiting to plant growth in semi-arid ecosystems. Furthermore, in light of a recent paper by

Franzluebbers *et al.* (2000) that generally found a very strong relationship between three day microbial respiration measurements and SOM, 21 day microbial respiration, microbial biomass, and potential soil N-mineralization. This methodology was used to determine whether the same relationships would also hold true for disturbed, semi-arid, soils. If successful, this methodology may be of use as a fast, economical and reliable "indicator" as to the potential ability of reclaimed soils to sustain nutrient cycling.

Methods

Using soil samples collected during the summer of 2000, a series of laboratory incubations were undertaken to assay; microbial respiration at three, ten and 21 days (Anderson 1982); microbial biomass (Franzluebbers *et al.* 2000); and N-mineralization (Keeney 1982). To maximize rates of N-mineralization and standardize soil conditions, all soil incubations were undertaken at -0.5 bar soil moisture. These various assays were then correlated against three-day microbial respiration (along the lines of Franzluebbers *et al.* (2000).

Results and Discussion

Overall, the examined characteristics of these soils (Table 1) were typical of semi-arid environment i.e. generally low concentrations of SOM, total and mineralizable N, and low microbial activity and biomass, relative to cropland or improved pasture systems, reflecting the greater aridity and temperature extremes of these reclaimed ecosystems. In a number of mine sites, N-immobilization, (an overall uptake of N by microbes and indicated by a negative N-mineralization; Table 1) as distinct from N-mineralization, was readily apparent. Net N-immobilization can indicate that N is limiting the rate of SOM decomposition, and subsequently, the further release of nutrients from organic matter. In turn, this can give rise to a high degree of competition between microbes and plants for inorganic N.

It is interesting to note that even in soils only recently replaced (1-3 years old), that the much greater microbial activity in the top 2.5 cm of soil (initially separated when soils were sampled in the summer of 2000 due to concerns that large amounts of carbonaceous material present might have artificially inflated apparent SOM values) and the subsequent decline with depth of microbial activity, SOM, and N, suggest that development of the soil profile may already be occurring.

Relationships between 3 day microbial respiration with both 10 and 21 day respiration, as well as microbial biomass and soil organic C were all highly correlated and highly significant (Fig. 1a, b, c). The relationship between three-day microbial respiration and N-mineralization, while highly significant, was less well correlated (Fig. 1d). On the whole, relationships across all sites followed similar patterns (Correlation's; Table 1) although in a small number of cases, relationships fell apart altogether. At this point we are unable to determine exactly why this is so, but may reflect the type of organic C present i.e. labile C, resistant C, or carbonaceous material. As such, it may mean that the organic C we measured is not readily decomposable, reducing the extent of SOM mineralization.

Ongoing Research

During the summer of 2001, and on the basis of the aforementioned results, we resampled three of the mines; Belle Ayr, Jacobs Ranch and the North Antelope, coal mines. At each of the mines, two reclaimed sites were sampled (near where the initial sampling of summer 2000 had been undertaken) as well as a nearby, native, undisturbed, prairie site. Sampling of these prairie sites will allow us to make comparisons between the self-sustaining, native, prairie ecosystem with the disturbed reclaimed sites.

Sampling consisted of establishing three 12 m transects, with soils sampled at 0, 3, 6, 9 and 12 m at two depths; 0-2.5 and 2.5-15 cm (a total of ten samples per transect, thirty per site). Due to the rapid decline in microbial activity at the 15-30 cm depth (as noted previously), it was decided not to sample the 15-30 cm depth. Finally at each of the sites, 6 replicate quadrats ($0.18m^2$) of above-

ground vegetation were sampled for the purpose of both biomass production as well as total aboveground N content. This will allow us to calculate an estimate for the N requirements of the vegetation at the various sites and compare this with laboratory estimates of N-mineralization.

This coming winter, these soils will be analysed for; organic and inorganic C, total and mineralizable N, pH, texture, -0.5 bar soil moisture, microbial respiration (3, 10 and 21 days) and microbial biomass.

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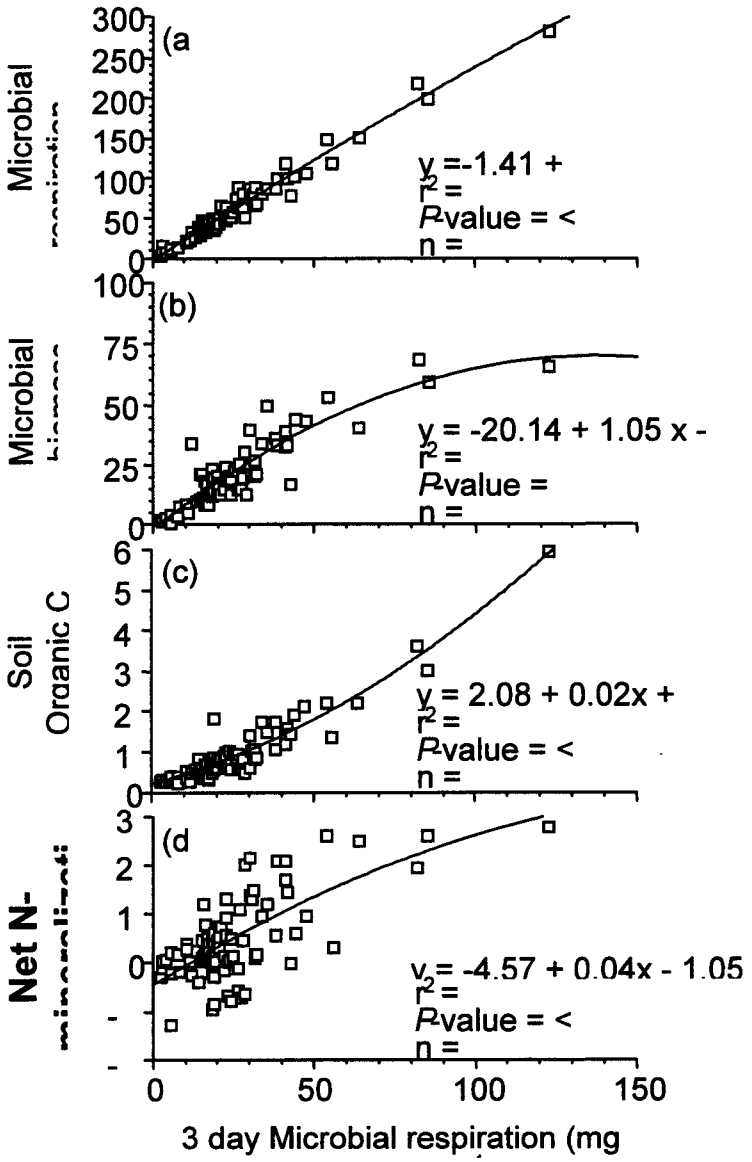

Fig. 1 Regressions of three day microbial
microbial respiration; (b) soil microbial biomass; (c) Soil N-mineralization (net immobilization of N is indicated

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

Interim Report, November 2001

Introductory statement

This project was funded in the Spring 2000 competition, and will be 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 in the isotope geology laboratories.

Purpose

The purpose of this study is 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.

Progress to date

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 is taking 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 recently 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 is 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.

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.

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.

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. The northern area is marked by northeast trending faults that could serve to streamline water flow through coal horizons, thus limiting time of interaction with strontium-bearing material in coal and resulting in lower $^{87}Sr/^{86}Sr$ values, similar to those observed near the recharge area on Jacobs Ranch Mine. This portion of the study is ongoing.

Publications and other dissemination of our research

Articles:

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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.

2001
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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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) affects 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 (*Artemesia 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.

Three 0.18m^2 quadrats were located at each topsoil depth (0, 200, 400 and 600 mm) within each mulch treatment. These quadrats were buffered by 0.30 m from the plot border on the west, a 0.30 m buffer between quadrats, and a 3.1 m buffer on the east edge of the plot. Within each quadrat canopy cover and aboveground biomass were evaluated for each species. A total of 240 quadrats (120-barley stubble and 120-crimped straw) treatment plots, were evaluated. Sampling was completed in June of 2001, a period of peak vegetation production and presence of most early-season or annual species.

Cover was estimated for each species and averaged among the three quadrats within each treatment (Daubenmire 1959). To assess aboveground biomass, plants were clipped by species at ground level within each quadrat and the three quadrats combined. The vegetation samples were dried at 65° C for approximately 12-24 hours, and weighed. Frequency of occurrence for each species was also recorded.

A relative value for each species was calculated for cover, biomass and frequency for each topsoil depth by mulch and fertilizer treatment, and summed to provide an importance value. The importance value indicates species dominance. Relative importance values were used to calculate a Shannon-Wiener diversity index (Krebs 1999), which identifies proportional equivalence of plant species and heterogeneity in a plant community (Whittaker 1977, Krebs 1999).

Analysis of variance was used to evaluate the effects of topsoil depth, mulch type, and N fertilizer treatment on percent vegetation canopy cover, aboveground biomass, species diversity, and species richness. The data were analyzed using a three way analysis of variance. Least significance difference method ($P \leq 0.05$) was used to identify mean differences.

Results and Discussion

Topsoil depth was found to significantly influence canopy cover, biomass, species diversity, and species richness. A mulch x fertilizer interaction was exhibited for canopy cover of grasses and invading species.

Species diversity and richness (# of overall species) were significantly affected by topsoil depth (Fig. 1). As topsoil depth increased both species richness and diversity values decreased. This is believed to be due to the dominance of cool-season grasses in the vegetative community at the deeper topsoil depths that reduced or prevented natural recruitment of native forb, grass, and shrub species. The dense stand of cool-season grasses resulted in little interspace within the community for other species to invade. Significant increases in vegetation diversity and richness were observed where no topsoil was present

compared to 400 and 600 mm of topsoil. The 600 mm topsoil depth resulted in significantly less diversity and richness than all other topsoil replacement depths.

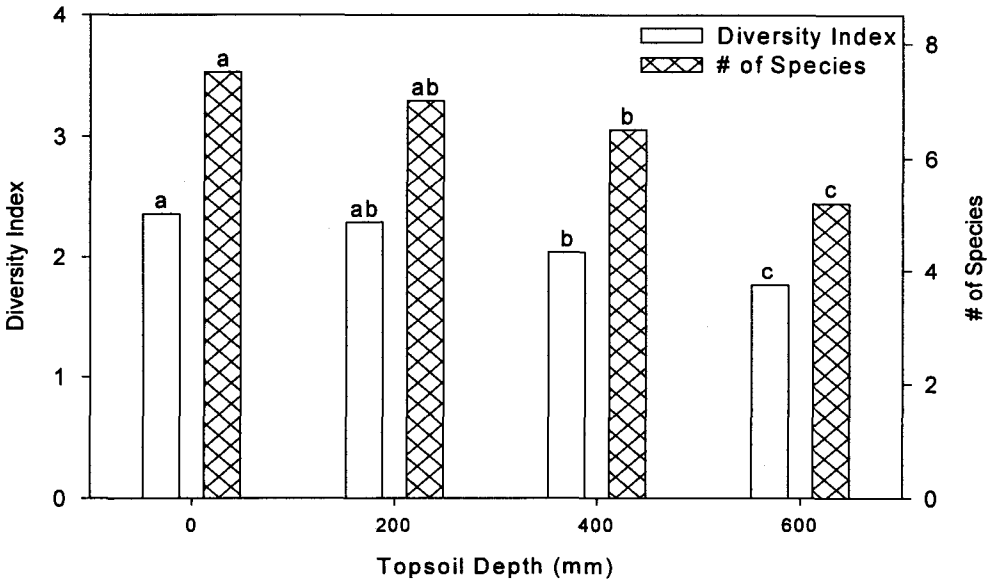

Fig. 1. Diversity Index in relation to # of species in relation to topsoil depth.

Topsoil depth also significantly affected total and seeded species aboveground biomass production (Fig. 2). Total aboveground biomass was greatest at the 400 and 600 mm topsoil depths with production of 72.7 and 78.7 g m^{-2}, respectively. Aboveground biomass was significantly lower at the 0 and 200 mm topsoil depths, 51.15 and 50.56 g m^{-2}, respectively. Seeded species aboveground biomass was significantly greater at 400 mm of topsoil, compared to the other three topsoil depths. Schuman et al. (1985) also reported greater production at the 400 mm topsoil depth in the first 4 years of the study.

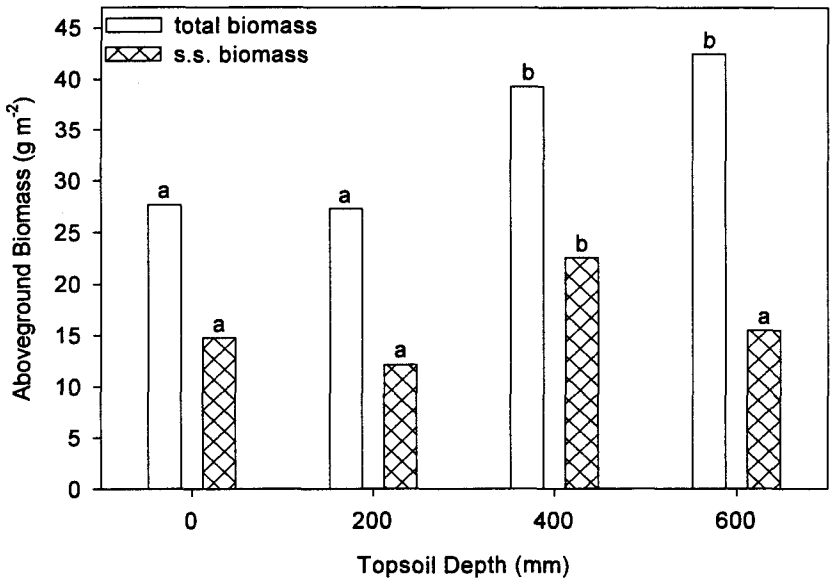

Fig. 2. Total aboveground biomass and seeded species biomass as affected by topsoil depth.

Topsoil depth significantly affected canopy cover of grasses, forbs, seeded species, and invading species (Fig. 3). Canopy cover of grass species was significantly higher for the 400 and 600 mm topsoil treatments compared to the 0 and 200 mm topsoil replacement depths. This trend is similar to that observed for aboveground biomass. Production and canopy cover among seeded species was greatest for western wheatgrass [*P. smithii* (Rydb.) A. Love] across all treatments. However, cover of seeded species was not significantly different across the topsoil depth treatments even though seeded species aboveground biomass production was significantly greater at the 400 mm topsoil depth treatment (Fig. 3).

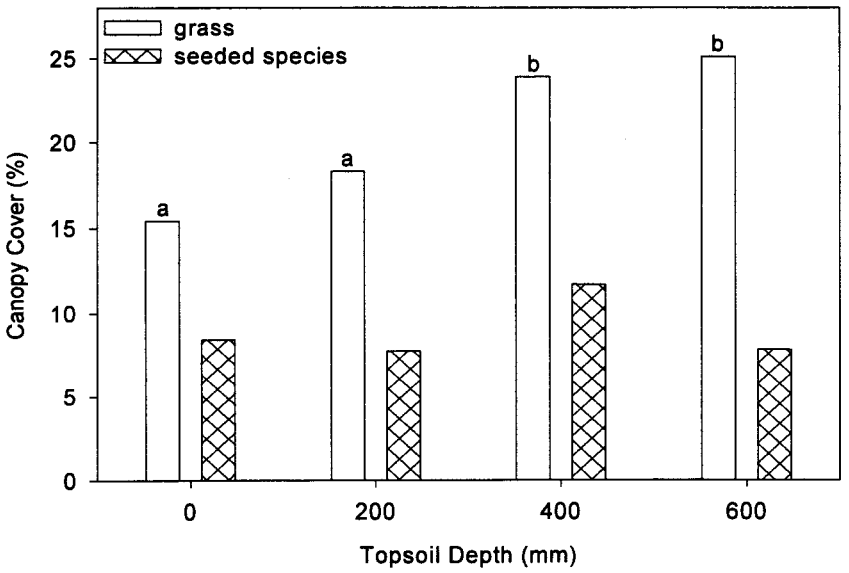

Fig. 3. Canopy cover of grass and seeded species as affected by topsoil depth.

Cover of invading species increased with increasing topsoil replacement depth. This increase can generally be attributed to the invasion of crested wheatgrass at the greater topsoil depths. Invasion by this species, which had been used in earlier reclamation, greatly influenced potential invasion of other species at the greater topsoil depths. Forb species represented significantly less cover at the 200, 400, and 600 mm topsoil depths compared to the 0 mm topsoil depth treatment. These observed cover differences can be attributed to the grass response (cover and biomass) to topsoil replacement depth (Fig. 4).

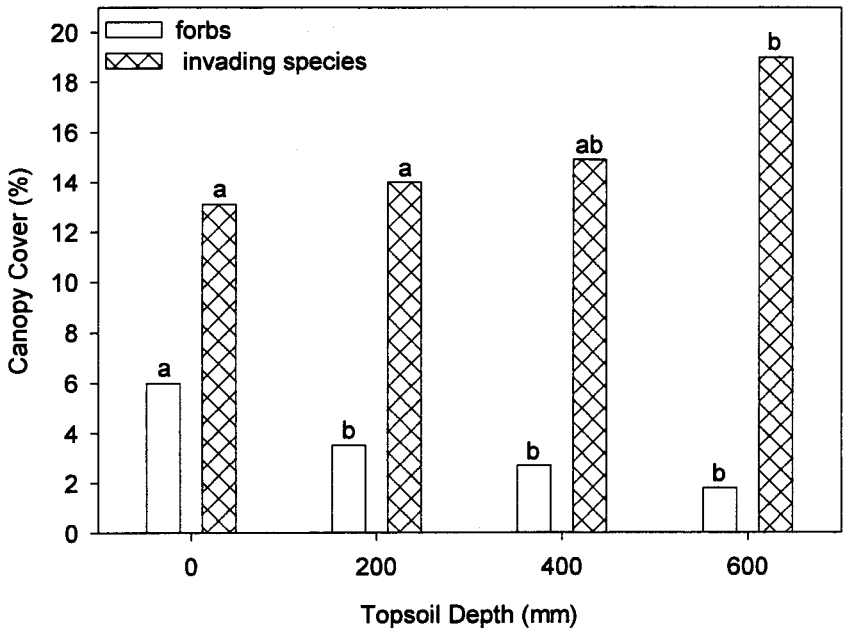

Fig. 4. Canopy cover of forbs and invading species as affected by topsoil depth.

Preliminary results indicate that topsoil depth will affect species diversity and richness. Natural recruitment of local native species seem to be able to capitalize on the open interspace in the plant community that has developed on the 0 and 200 mm topsoil depth treatments. However, at the 400 and 600 mm topsoil depths the plant community is dominated by cool-season grasses that are highly competitive and have greatly limited the natural recruitment of native species (forbs and grasses). Further, greater detailed evaluation of the vegetation data will be accomplished to assess specific species responses to the treatments.

Future Assessments

Soil analysis will be initiated this winter to assess key chemical and biological parameters that might help explain the plant community responses observed. Water infiltration will be assessed in early 2002.

Acknowledgements

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2001
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 1992, 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 survivability remains a challenge years after initial establishment. Reclamation specialists are exploring potential impacts to big sagebrush survivability 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 is 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 studied 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 survivability. 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 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.

On June 12, 2001, 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 mulch treatment and grass seeding rate inside and outside the exclosure. Density of big sagebrush was again determined along the permanent belt transects September 17, 2001.

On June 12, 2001, a ten-pin point frame was placed every 1.2 m along the permanent transects to determine percent vegetative cover, bareground, and litter from 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 a community diversity index.

On June 12, 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, marked plants were identified and recorded as browsed or unbrowsed. Marked big sagebrush plants were also used to measure current annual leader growth. Current annual growth 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 from June to September provided percent utilization during the 2001 growing season.

On September17, 2001, 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./ha), along with percent utilization of big sagebrush by grass seeding rate, provide trends of use and preference of big game browsing by grass seeding rate. 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 utilization between grass seeding rates inside and outside the exclosure. Mean separations were evaluated using Tukey's pairwise comparison test ($p = 0.10$).

Results and Discussion

Big sagebrush density (plants/m^2) from the permanent quadrats 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 newly established permanent belt transects, mean big sagebrush density in June 2001 was highest in the 32 kg PLS ha^{-1} grass seeding rate inside the exclosure (Table 1). There was little difference in mean big sagebrush density among similar grass seeding rates inside and outside the exclosure during 2001, which was anticipated since the exclosure construction was completed just 1 week prior to the summer sampling period. We expect more differences in mean big sagebrush density inside versus outside the exclosure in future sampling periods as wildlife access inside the exclosure is restricted.

Species composition varied within the various grass seeding rates. Mean percent cover of grasses and total vegetation were significantly different between grass seeding rates ($p = 0.05$ and $p = 0.07$, 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. Mean percent cover of shrubs (primarily big sagebrush) increased with higher grass seeding rates inside the exclosure, however, it was not significantly different between grass seeding rates. Mean percent cover of forbs varied between grass seeding rates, displaying no obvious trends both inside and outside the exclosure. 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. This relationship will be explored further with future data collection.

There were no differences in plant species diversity between grass seeding rates inside or outside the exclosure (Table 3). However, since the exclosure was constructed only 1 week prior to sampling, we anticipate diversity index differences between inside and outside in the future as a result of differential browsing impact by wildlife.

Differences in the mean percent of big sagebrush plants browsed inside versus outside the exclosure were contrastingly different during the summer 2001. As expected, the mean percent of browsed big sagebrush plants decreased from the early summer to fall sampling period inside the exclosure (Table 4). High values for the mean percent browsed big sagebrush plants inside the exclosure for the June 2001 sampling period were attributable to browsing events prior to exclosure construction. Reduction of browsing because of exclosure construction and summer re-growth inside the exclosure was expected in the September 2001 sampling period. Likewise, there was significantly higher numbers of browsed big sagebrush plants across all grass seeding rates from the June to September sampling period outside the exclosure (Table 4). We will identify seasonal differences in big sagebrush browsing intensity with future data collection. Mean number of big game pellet groups and presence/absence of rabbit pellets were recorded and cleared from the permanent belt transects during the September 2001 sampling period. However, analysis of pellet groups (by grass seeding rate) outside the exclosure will not be

evaluated until after our early summer 2002 sampling period. This information will provide additional verification on preferential browsing by big game and rabbits as affected by grass seeding rate.

There were no significant differences in mean leader length (mm) and percent utilization between grass seeding rates inside or outside the exclosure during the June 2001 sampling period (Table 5). However, there was significantly ($p = 0.001$) more current annual leader growth in the highest grass seeding rate (44.3 ± 15.7 mm) during the September 2001 sampling period inside the exclosure. A comparison of mean leader length differences between June and September within grass seeding rates inside and outside the exclosure reveals consistently lower mean leader lengths in September inside and outside the exclosure, with the exception of the 32 kg PLS ha^{-1} inside the exclosure (Table 5). This observed trend indicates potentially less than favorable growing conditions (precipitation amounts) during the summer 2001. Since mean leader lengths outside the exclosure were consistently less than mean leader lengths inside the exclosure within respective grass seeding rates, we believe that wildlife utilization impacts were an additional factor contributing to these differences. Mean leader length for grass seeding rates combined were significantly greater inside the exclosure than outside during the summer and fall sampling periods ($p < 0.01$). Generally higher percent utilization among grass seeding rates outside versus inside the exclosure supports the difference observed in mean leader lengths. Future sampling efforts should provide better clarification of the impact of wildlife utilization on plant communities of the reclaimed site as differences inside and outside the exclosure are evaluated over time.

Future Fieldwork

Future sampling of these vegetation parameters inside and outside the exclosure will be conducted during early summer and fall 2002. In addition, the type of wildlife species (big game or lagomorph) utilizing marked big sagebrush plants will be identified by the browsing characteristics of current annual leaders. Specifically, ragged leaders characterize big game use and cleanly severed leaders characterize lagomorphs. Since pellet groups of big game and rabbits were cleared from the belt transects during the September 2001 sampling period, future pellet group counts by treatment type will provide additional information about wildlife utilization outside the exclosure.

Acknowledgments

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individuals who assisted in data collection: Lachlan Ingram, Matt Mortensen, Cliff Bowen, Krissie Peterson, and Margaret Sharp.

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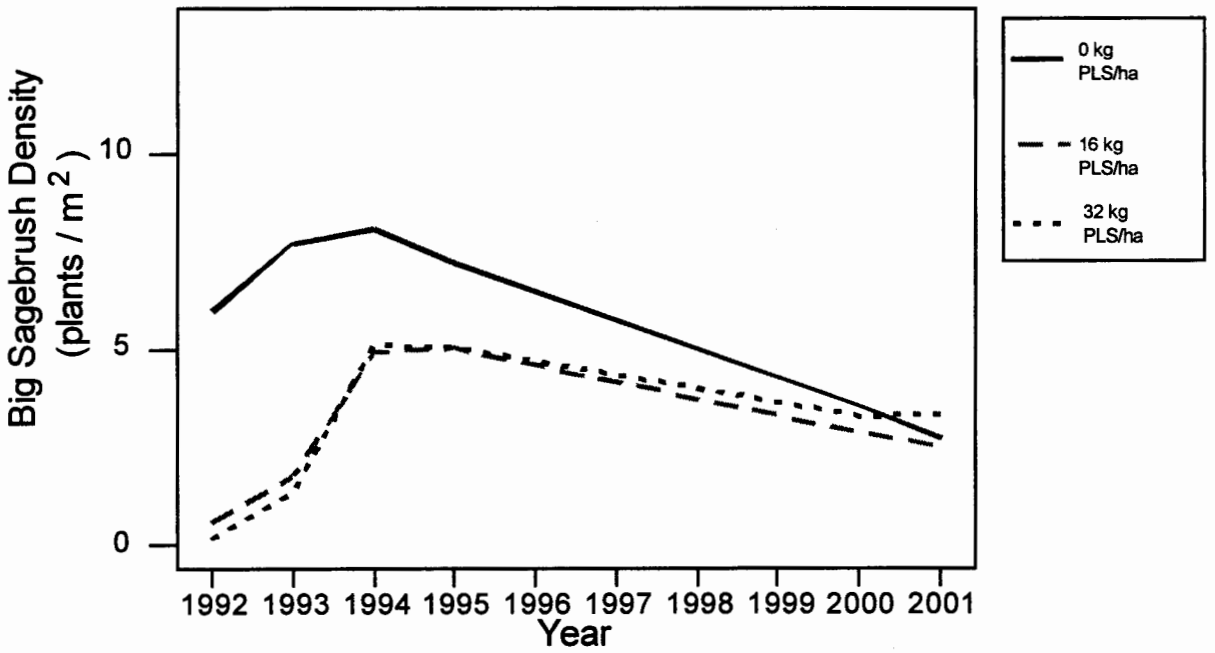

Fig.1. Historical yearly mean big sagebrush density from quadrat sampling by grass seeding rate, North Antelope Coal Mine, Gillette, Wyoming.

Updating the

Handbook of Western Reclamation Techniques, 1996

Interim Project Review
November 2001

Submitted by:

Laurel E. Vicklund, Chairwoman
2001 Handbook Management Committee
and
Philip C. Dinsmoor
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Introduction

This interim progress report is intended to provide the ACMLRP Technical Review and Steering Committees with a summary of the work accomplished on this project during 2001. Included is a brief review of the background and scope of work for the project.

Background

In 1996 the Handbook of Western Reclamation Techniques was created with an award from the ACMLRP and the financial and in-kind support of mining companies, suppliers and consultants to the mines, the academic community, and regulatory agencies. The effort, which was largely voluntary, involved original writings of more than two dozen authors on topics ranging from hydrologic design to revegetation techniques. The writings represent the accumulated knowledge of one or more experts on techniques that have proved successful in the reclamation of coal mined land in the western United States.

Since its initial publication, the Handbook has undergone numerous printings and has now been published on CD ROM. According to the Office of Technology Transfer within the Office of Surface Mining Reclamation and Enforcement, this Handbook has been the most requested product in the federal ACMLRP library. It is being used as a field reference, classroom text, and guidance document throughout the world. By the end of year 2000, more than 900 copies of the Handbook had been distributed.

In November of 2000, the Wyoming ACMLRP Steering Committee approached Ms. Laurel E. Vicklund about the possibility of updating the handbook. They believed that the first edition technologies have evolved, new technologies have been developed, and new reclamation issues have come to the forefront to be addressed. The Steering Committee was also interested in having a second edition that was useable and friendly to a wider range of disciplines.

Ms. Vicklund organized a handbook management committee consisting mostly of organizers and authors of the original handbook. This committee contacted Mr. Phil Dinsmoor of McVehil-Monnett Associates, Inc. (MMA) to assist in the preparation of a proposal to the Wyoming ACMLRP and ultimately to act as project manager for the committee. A proposal was submitted in January 2001, and in February the ACMLRP approved an award to conduct the project. Approval to begin work was received in March.

Proposal

The handbook management committee's proposal included four major tasks. They were to organize the project, author the new or revised material, edit all material, and produce the final product. They anticipated beginning work in the spring of 2001 with completion expected 12 months later. The committee's efforts to organize and direct the project, and the actual authoring of material were to be done voluntarily while project management and production would be accomplished under contract with MMA.

Accomplishments

Generally, work has progressed slower than expected. Because the management committee and authors are donating or volunteering their time, this work often takes a lower priority than envisioned in the proposal.

Initial work was focused on project organization, contacting authors, and identifying which materials needed to be updated and what new information would be added.

Organization

The handbook management committee is acting as a decision-making body. Their decisions are to be carried to the authors and editors by MMA. MMA is also responsible for reporting progress back to the committee.

Survey

The committee compiled a list of twenty-seven potential authors. It included most of those authors involved in the first edition of the

handbook. In addition, a survey was prepared and sent to everyone on this list. The survey was designed to elicit opinions about the:

Need for revisions in original work and willingness to participate
Need for new work in same topic area and willingness to participate
Need for new work in other areas and potential authors for this work

Writing
Of the twenty-seven contacts made, there were twenty-one responses. Only two were unwilling to participate. Additional efforts were made to "find" the remaining six authors. In addition, several new names were added to the list as a result of the survey.

The general consensus of the committee is that revisions are warranted in the topic areas of reforestation, grazing, topsoil, vegetation, land use, seed, and wildlife. New work is desired in the areas of wetlands mitigation and creation, coal and oil/gas interaction, sagebrush establishment, GIS, hydrology, and soil amendments. In addition, it has been suggested that revegetation equipment be addressed.

Estimates of time needed to complete revisions or new sections ranged from 6 weeks to six months. Most of the authors saw little opportunity to begin work until the end of the summer or the field season.

At this time, revisions to several sections are underway, and plans for new sections (most notably wetlands mitigation and creation) are being created. There are still several topic areas for which work has not yet commenced. It is not anticipated that any revised materials will be submitted to the committee before the end of the year.

Projections

Because of the slower than anticipated start, the work will not be completed before summer 2002. This is a reminder that volunteer work usually gets done, but often not according to a predetermined schedule.

The committee will need to finish making their determinations about which sections will be revised or added. This will permit the remaining authors to commence work. Editing of sections will begin as soon as materials are received

from authors. Production of the final document is still expected to require up to two months.