2000 Billings Land Reclamation Symposium

REFERENCE AREA REALITY CHECK

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ABSTRACT

Application of revegetation success criteria regulations during initial permitting of surface coal mining operations in Colorado predominantly required the use of reference areas; small enclosures (0.8-2.0 ha) of native vegetation communities which would provide the parameter values for vegetation cover, herbaceous production, woody plant density, and species composition during a liability release evaluation. During the past two decades of revegetation experience at surface coal mining operations, it has become apparent that the reference areas do not reflect the character of the early seral vegetation communities developing after revegetation. Data from revegetation monitoring and bond release evaluations in the eastern plains and Colorado plateau support this observation. Therein lies the conundrum. What is the useful purpose in comparing one or several, native vegetation communities to a revegetated community? One alternative to employing reference areas is a modified historic record. An area is selected that most closely approximates the early seral stages of a revegetated area and the desired post-mining land use. This area is sampled for the desired parameters for a specified period, including a range of precipitation regimes. An abandoned homestead pasture at the West Elk Mine near Somerset, Colorado was selected by Mountain Coal Company and the Colorado Division of Minerals and Geology as such an area. Three years of data from this study area indicates excellent correlation between the precipitation regime and vegetation cover and herbaceous production, leading to the development of a realistic simple predictive model for revegetation success criteria for these parameters.

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INTRODUCTION

The Colorado Surface Coal Mining Reclamation Act (CRS 34-33-120 and 121) performance standards require that reclamation establish "a diverse, effective, and permanent vegetative cover of the same seasonal variety native to the area of land to be affected and capable of self-regeneration and plant succession at least equal in extent of cover to the natural vegetation of the area." In implementing the provisions of the statute, the constructors of the Colorado regulations concluded that in order to meet revegetation success, reclaimed and revegetated areas must have a stabilizing cover of vegetation of the same seasonal variety as that disturbed, and for those areas that are not cropland or to be developed (the majority of areas in Colorado), herbaceous production, species diversity, and woody plant density equal to that of the vegetation on the approved reference area or standards.

While it is obvious from the comments and discussion regarding the use of technical standards (such as USDA and USDI technical guides) for establishment of revegetation success criteria in the federal regulatory program (Federal Register 1979), reference areas are the first method discussed and the predominantly employed method in Colorado (CDMG rule 4.15.7.2(d)). A review of the forty-four coal mines currently active or in reclamation in Colorado (December 1999) revealed that thirty-two use one or more reference areas to judge one or more vegetation parameters for reclamation success. Of the twelve mines that do not use reference areas, ten are, or were, small underground mines that had been operated prior to the passage of SMCRA and state reclamation statutes. One is a large surface mine and one is a large underground mine whose alternative approach is discussed below. There are sixty-seven total reference areas for these mines, of which fifty are shrub or tree dominated vegetation communities, fifteen are dominated by graminoids, and two are extended reference areas that encompass a variety of vegetation physiognomy.

A CONUNDRUM OF COMPARISON: REVEGETATED vs. NATIVE COMMUNITIES

The overarching concern with using a reference area in evaluating the success of revegetation centers on comparison of a native vegetation community with an anthropogenic vegetation community. There are two predominant concerns with comparing native vegetation communities with reclaimed vegetation communities; first, the revegetated community has been developed on a significantly different (or altered) physical environment, and second, revegetation success comparisons are being made between a mature native vegetation community and an early seral stage vegetation community.

Revegetated communities on mined areas generally have a significantly different physical environment. The geology and stratigraphy of the area has been altered through fragmentation, extraction, and replacement. With the removal and replacement of the rock layers, the topography of the reclaimed landscape has been changed, often creating a more uniform landscape than that present prior to disturbance. The fragmentation, removal, and replacement of the rock materials has altered the groundwater hydrologic regime in the disturbance area, and likely has altered the surface water hydrology from the standpoint of drainage location, drainage pattern complexity, and chemical composition of the water. Removal, stockpiling, and replacement of topsoil or suitable plant growth media changes the character of the original soil profile as well as the numbers and character of macro- and microorganisms within the removed and replaced soil, including the dormant seed bank. Lastly, the revegetated communities are young, they represent early seral stages in the development of the vegetation community.

The native vegetation communities that are being used as reference areas have their own set of characteristics. Whether largely unaffected by man's presence or modified in the last centuries, the native vegetation communities have developed over long periods of time, generally hundreds or thousands of years. As a result of this lengthy development, the vegetation communities are complex, in terms of numbers of species and their distribution throughout the landscape. Native vegetation communities have adapted to the physical and biotic environment in macro- and micro- distributional patterns, resulting in patchiness, and distributions dependent on time of species arrival and competition. Contrasted to revegetated communities, the native communities are old, and represent later stages in vegetation community development.

Therein lies the conundrum. Is it reasonable to expect comparability between these two disparate types of vegetation communities? Rickliefs (1973) reports the results of vegetation community successional studies as particularly variable, ranging from twenty to forty years recovery time for Colorado eastern plains grasslands (Shantz 1917) to 150 years for a forest climax (Oosting 1942), while a complete successional sequence from barren sand to climax forest may require a millennium (Olson 1958).

Empirical Evidence from Colorado

To evaluate the question posed above, a review of quantitative data from revegetated mine sites and their associated reference areas was conducted. The mine sites selected represent locations that have been quantitatively evaluated by the author and represent disparate locations within Colorado. Table 1 presents a summary of salient vegetation information from the mines.

Meadows No. 1 Mine

The Meadows No. 1 Mine was located in Routt County, Colorado between Steamboat Springs and Craig. The open pit strip mine was opened in 1976 at an elevation of approximately 2375 meters (7800'). The pre-disturbance vegetation of the mine site included mountain shrub, sage steppe, and mixed grassland. The reference area for the mine was a mix of big sage (*Artemisia tridentata*) and smooth brome (*Bromus inermis*), reflecting both native vegetation and grazing interseeding. The reclaimed area was revegetated to a mix of cool season graminoids and forbs. The reclaimed area was seeded in the spring of 1984 and final bond release sought in late 1996. The information from two vegetation studies prepared in support of the final bond release application (Savage and Savage 1994, 1996) is found in Table 1.

While total vegetation cover from each of the areas is equivalent in both years, the distribution of relative cover is widely different. Relative cover of woody shrubs in the sage-grass dominated reference area is significantly greater in both years. Within the reference area in 1995, a very wet year in the area, the response of ephemeral forbs (present but dormant in the seed bank) to the increased moisture is evident, with a doubling of relative cover. Herbaceous production in both areas varied significantly in response to the precipitation regime, however, relative contributions of graminoids and forbs remained relatively equivalent. The most significant difference between the reference area and the revegetated area in species numbers is the lack of woody species on the revegetated area.

Bacon Mine

The Bacon Mine is located in El Paso County, Colorado east of Colorado Springs. This mine was operated briefly in the early 1980's and reclaimed in 1989. Approximately 29 acres was reclaimed and revegetated at an elevation of 1860 meters (6100'). The pre-disturbance vegetation of the mine site was warm season short grass prairie, dominated by blue grama (*Bouteloua gracilis*). The reference area for the mine is a small (1.2 ha) enclosure of the native *Bouteloua* vegetation community. The reclaimed area was revegetated to a mix of warm and cool season graminoids, forbs, and woody shrubs. Reseeding was undertaken in the autumn of 1989. Information in Table 1 for the Bacon Mine is contained in the application for final bond release (Savage and Savage 1998, 1999).

Total vegetation cover on both the reference area and revegetated area is equivalent. Significant differences exist in the distribution of the cover. The reference area exhibits dominance by graminoids, not unexpected for a short grass prairie community. The reference area also contains a small component of succulents and woody shrubs, predominantly cacti (*Echinocereus* and *Opuntia polyacantha*) and yucca (*Yucca glauca*) and well as the opportunistic broom snakeweed *(Guterrezia sarothrae*). In deference to the regulatory authority, and in order to meet woody plant density requirements, the reclaimed area was seeded with relatively aggressive woody shrubs (particularly *Atriplex canescens*), which now contribute significantly to relative cover, as well as creating a distinctly different community structure within the surrounding short grass prairie. To assuage concerns regarding the ability to successfully revegetate warm season grasses, a number of cool season grasses were seeded (*Agropyron dasystachyum*, *Agropyron smithii*, *Agropyron trachycaulum*, and *Stipa viridula*). As with the *Atriplex canescens*, these species have flourished and created a significantly different community structure.

Table 1. Comparision of Reference Areas and Revegetated Areas at Three Colorado Coal Mines

	Total	Relative Cover				Herbaceous Production			Number of Species			
Location	Cover	graminoid	forb	succulent	shrub	total	graminoid	forb	graminoid	forb	succulent	shrub
Meadows No. 1 Mine												
1994 Reference Area	52.20	46.63	15.03		38.34	114.78	98.03	16.75	5	9		4
1994 Revegetated Area	47.33	68.71	30.78		0.51	135.75	107.19	28.57	11	6		1
1995 Reference Area	68.60	41.35	32.01		26.64	406.19	317.42	88.77	4	15		3
1995 Revegetated Area	60.13	62.81	37.19			342.32	269.28	73.04	15	9		0
Bacon Mine												
1998 Reference Area	53.20	75.97	22.26	0.65	1.13	155.37			5	12	3	1
1998 Revegetated Area	60.50	59.15	31.83	0.12	8.90	240.01			11	6	1	3
1999 Reference Area	59.87	78.59	19.68	1.15	0.57	140.09			5	13	3	1
1999 Revegetated Area	59.60	70.11	25.06		4.83	187.70			14	11		3
Keenesburg Mine												
1998 Reference Area	45.00	36.77	2.91	0.53	59.79	109.65	101.55	8.10	5	3	1	1
1998 Revegetated Area (1985)	40.20	86.64	9.75	3.25	0.36	165.45	153.29	12.16	8	5	2	1
1998 Revegetated Area (1986)	44.20	86.25	7.50	2.50	2.50	152.67	141.93	10.73	10	5	1	1
1998 Revegetated Area (1987)	43.80	60.84	25.89	2.27	11.00	179.84	154.99	24.85	13	7	1	1
1998 Revegetated Area (1995)	33.40	55.66	44.34			108.71	79.87	28.84	10	9		

notes: cover values in percent (%), hebaceous production values in grams/square meter

Keenesburg Mine

The Keenesburg Mine is located in Weld County, Colorado approximately fifty miles northeast of the Denver metropolitan area. Mining occurred between 1980 and 1988. Reclamation operations have been ongoing since 1985. Approximately 413 acres was disturbed during the operation, with 195 acres reclaimed by the end of 1998 (CEC 1998). The mine elevation is approximately 1460 meters (4800'). Although the expected vegetation community would be similar to that of the Bacon Mine with a mix of warm season grasses and forbs, the pre-disturbance vegetation consisted largely of a shrub community dominated by sand sage (*Artemisia filifolia*). The dominance of this shrub is likely due to the long history of range grazing, the porous nature of the aeolian sandy soils, and the low level of annual precipitation (31.5 cm). The reference area for the mine is dominated by *Artemisia filifolia* with contributions by *Stipa viridula*, *Calamovilfa longifolia*, *Andropogon hallii*, and *Bouteloua gracilis*. Reclaimed areas at the mine have been revegetated to a seed mix dominated by warm season grasses. In order to improve the post-mining vegetation community, no *Artemisia* or other woody species were included in the seed mix.

Since 1994, the author has been conducting annual monitoring of the reference area and revegetated areas (Savage and Savage 1994a, 1995, 1996a, 1997, 1998a). Qualitative observations of the revegetated areas reveal continued development of a warm season graminoid prairie community. Reference area observations over the same period reveal a shrub-dominated community with low diversity. In 1998, the reference area and four revegetated areas ranging in age from three to thirteen years were quantitatively sampled. Table 1 presents selected results. As with the other mines examined, total vegetation cover is equivalent on all areas except the three-year-old revegetation. The differences lie in the composition of the vegetation cover. The shrub *Artemisia filifolia* dominates the reference area. Graminoids account for approximately one-third of the relative cover and forbs three percent. Within the older revegetated areas graminoids dominate, with significant contributions by forbs, succulents, and shrubs. Herbaceous production remains greater on the revegetated area, largely due to the absence of competition from *Artemisia*. The revegetated areas contain greater numbers of species, particularly graminoids and forbs.

Conclusions

The above three mines are illustrative of the concerns with using reference areas for generating revegetation success criteria for vegetation communities. In two of the above reference areas, a predominantly shrub dominated community is or was being compared to a predominantly herbaceous community. In the other example, a revegetated community differing significantly in structure and composition was created to satisfy one revegetation success parameter at the expense of others. Though overall total vegetation cover was generally equivalent, the structure of the vegetation cover and composition of the relative cover of the vegetation communities was not. Herbaceous production was generally greater on the revegetated communities, as would be expected since there were significantly less woody species that were not sampled. The species composition of the reference and revegetated communities differed significantly, with a general dominance of graminoids in the revegetated areas, largely due to seeding greater numbers of graminoids. While forb numbers are relatively consistent between reference and revegetated areas, the majority of forbs within the reference areas are native and ephemeral; the majority of forbs in young revegetated areas are annual invaders.

ALTERNATIVE REVEGETATION SUCCESS CRITERIA

These differences require investigation of other measures for evaluation of successful revegetation of the early seral stage revegetated areas. One option has been widely applied for the evaluation of woody plant density and species diversity (composition). This option allows the regulatory authority to set revegetation success criteria for these two parameters based on pre-mining data. While this is commonly done, it begs the question of the legitimacy of utilizing native pre-mine vegetation community characteristics to set revegetation success criteria for the early seral stage revegetation community.

Two additional options exist in the present Colorado regulations for setting revegetation success criteria for vegetation cover and herbaceous production: technical standards from technical document sources approved by the Colorado Division of Minerals and Geology (CDMG) and the Director of the Office of Surface Mining Reclamation and Enforcement (OSMRE), and historic records. Neither of these options has been widely used in Colorado due to the lack of approved technical documents and the need to collect a historic record of vegetation parameters over a number of years (typically five to seven).

The Modified Historic Record Approach

Development of the Approach

During the initial permitting of the Mountain Coal Company (MCC) West Elk Mine (a large underground coal mine in Gunnison County, Colorado) in 1980 and 1981, revegetation success was proposed to be based on two reference areas established in Sylvester Gulch. As two vegetation communities were initially disturbed during the construction of surface facilities at the mine, a dry meadow reference area and an oakbrush reference area were established. The reference areas were to be used for evaluation of total vegetation cover and herbaceous production during revegetation evaluations for bond and liability release.

In 1995, the West Elk Mine began an expansion project that involved additional surface development and expansion of the surface facilities. As a result of these projects, additional vegetation communities would be disturbed at the mine. Additional reference areas would need to be established and an existing reference area would need to be relocated. Location, establishment, and maintenance of reference areas for each vegetation community disturbed or affected was no longer a viable option for determining revegetation success criteria. An evaluation of technical standard and historic record approaches to establishing revegetation success criteria for total vegetation cover and herbaceous production was undertaken.

Meetings and discussions with CDMG yielded agreement on a site-specific historic record approach to establishing revegetation success criteria for cover and herbaceous production based on a reasonable expectation of the vegetation community to be established after reclamation. MCC and CDMG selected a vegetation community in the immediate vicinity of the mine that closely approximated the biologic composition and character of a post-mine plant community as well as the physical characteristics of the affected areas of the mine. Reconnaissance of the mine site and adjacent areas under the mines control revealed three locations characteristic of early seral stage vegetation communities. After collaboration and on-site inspections, one site was selected. This vegetation community was an abandoned homestead and pasture area surrounded by the native oakbrush, mountain shrub and sagebrush communities above the existing facilities area. The vegetation community and physical characteristics of the site (slope, aspect, drainage patterns) closely approximated the anticipated character of the reclaimed landscape and vegetation community.

Use of historic records to generate revegetation success criteria has always been based on obtaining a representation of the range of parameter values for the historic record community. This meant quantitatively sampling a range of environmental conditions that would affect the vegetation parameters. As the physical characteristics of the site selected were very similar to those of the disturbed areas of the mine, the significant apparent variable was moisture, or precipitation regime.

In order to obtain a representative record of the variability of the microclimate of the area, and therefore the effect on vegetation growth, it was determined that three years representing the variability of precipitation to be encountered at the site would comprise the historic record.

For the purposes of the historic record; one low, one average, and one high precipitation year would be represented, based on precipitation records from a weather recording station in the area. Precipitation data over a ninety-year period was analyzed to specify a precipitation regime range. From the historic precipitation records, a "normal" precipitation regime (in inches of precipitation) was developed based on the amount of precipitation received during the eight months preceding the growing season (October through May). The months comprising the precipitation regime were selected as those months during which precipitation would most likely have a significant effect on the following growing season's vegetation. Serendipitously, these months also corresponded with the period of the majority of precipitation at the mine. Determination of the year type (low, average, or high) was made based on the precipitation sum preceding the growing season. Low and high precipitation years were defined as years where the precipitation sum differed by approximately 23 percent (one standard deviation) or more from the average precipitation sum for the October-May time period.

After the selection of the historic record vegetation community within the historic record study area in concert with CDMG, the selected area was initially quantitatively sampled for four vegetation parameters during 1996; vegetation cover, herbaceous production, species composition, and woody plant numbers. Additionally, the soil characteristics of the selected area were quantitatively analyzed and evaluated.

Results: 1996-1998

Quantitative sampling of the historic record vegetation community took place in 1996, 1997, and 1998. The precipitation regime in 1996 was characterized as dry, 1997 was normal by definition, and 1998 was intermediate between 1996 and 1997.

The historic record vegetation community was selected because of a close resemblance (location, elevation, aspect, soils, and vegetation community structure) to the dry meadow herbaceous vegetation community present within the West Elk Mine permit area (Savage and Savage, 1996b, 1997a). The dry meadow community was sampled in 1982 (baseline) and the dry meadow reference area was sampled in 1982 and 1995 (Mountain Coal Company, 1997, Savage and Savage, 1995a). While the dry meadow community is no longer being quantitatively sampled, it is productive to compare observations made at the historic record vegetation community to those from the dry meadow community and dry meadow reference area within Sylvester Gulch. Table 2 provides a comparison of the sampled parameters for the dry meadow community, dry meadow reference area, and the historic record vegetation community from the years 1982 through 1998.

A Predictive Model: An Unexpected Benefit

Figure 1 depicts the relationship between total vegetation cover and total herbaceous production and precipitation regime in the historic record vegetation community (HRSA), the dry meadow community (DM) and the dry meadow reference area (DMRA). Five years of data from the three communities illustrates distinct relationships directly related to the precipitation regime. With three years of data, it appears that the communities have characteristics that warrant separating them into individual units. The historic record vegetation community total vegetation cover and total herbaceous production values vary significantly from those of the dry meadow community and dry meadow reference area. Though the range of precipitation values does not correspond exactly, it is apparent that the historic record vegetation community has total vegetation cover values slightly higher than those of the dry meadow community and dry meadow reference area. Total herbaceous production values in the historic record vegetation community are much less than those recorded for the dry meadow community and dry meadow reference area.

Figure 1. Comparison of Total Vegetation Cover and Total Herbaceous Production with Precipitation Regime in the Dry Meadow and Historic Record Vegetation Communities

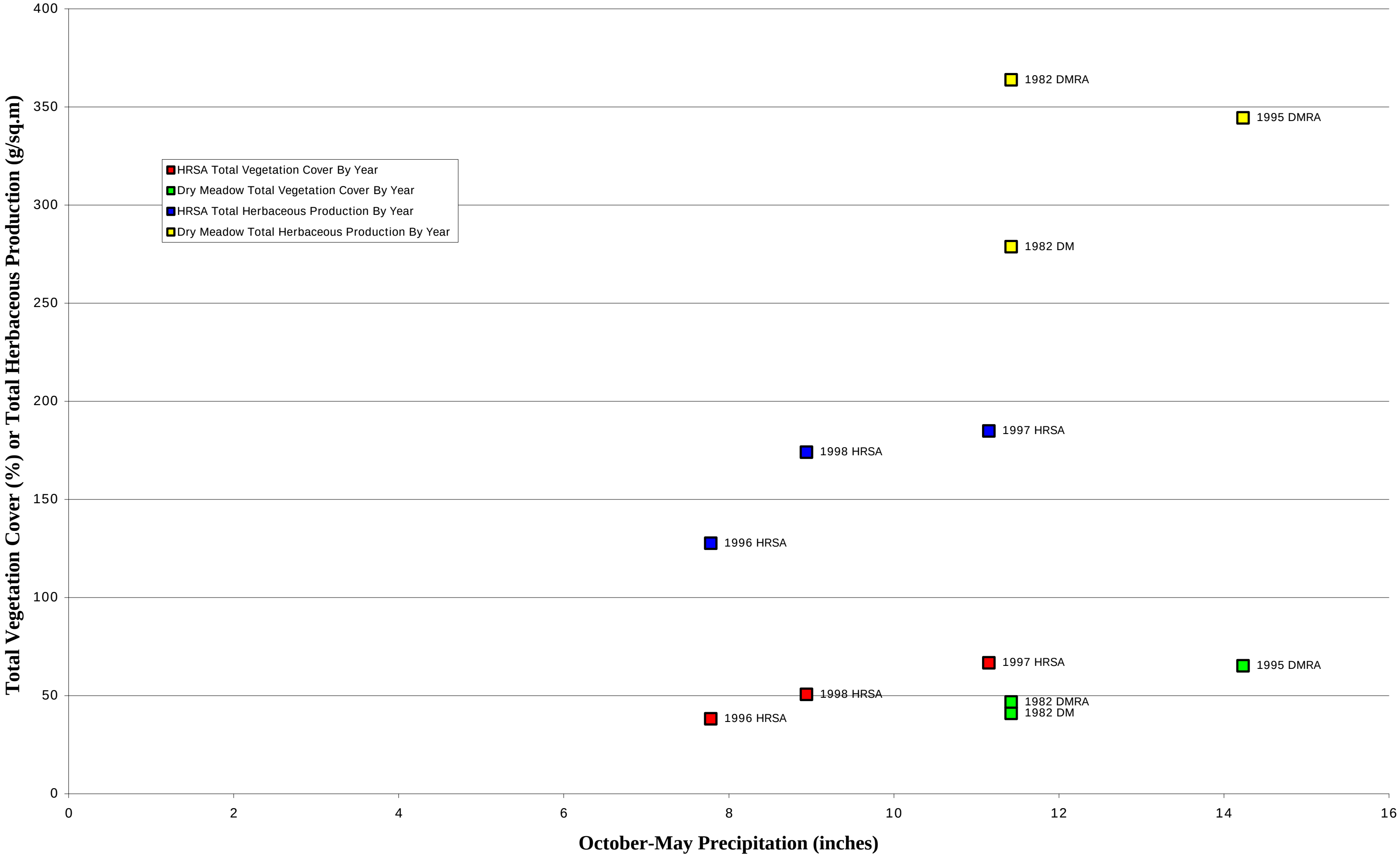

Table 2. Comparison of Vegetation Parameters in Graminoid Communities at the West Elk Mine

Date and Location	Growing Season Precipitation (in.)	Mean Cover (%)	Herb. Production (g/sq. meter)	Total Species Number*
1982 Dry Meadow	11.42	40.97	278.86	13
1982 Dry Meadow Reference Area	11.42	46.85	363.91	15
1995 Dry Meadow Reference Area	14.23	65.20	344.50	21
1996 Historic Record Veg. Comm.	7.78	38.27	127.71	6
1997 Historic Record Veg. Comm.	11.15	66.80	184.94	15
1998 Historic Record Veg. Comm.	8.94	50.67	174.06	12

* note: species number reflects species with cover equal or greater than 0.1 %

Mathematical evaluation of the relationship between precipitation regime and total vegetation cover and total herbaceous production was undertaken. In 1998 (Savage and Savage 1998b), data was separated by vegetation community, either historic record vegetation community or dry meadow community (undisturbed or reference area). Using this data, both total vegetation cover and total herbaceous production are positively correlated with precipitation. The data from the historic record vegetation community show a very strong correlation for both total vegetation cover and total herbaceous production (r=0.99 and r=0.86, respectively). For the dry meadow communities the correlation was strong for total vegetation cover (r=0.97), but very low for total herbaceous production (r=0.29).

Based on the strength of the correlation for the historic record vegetation community, linear regressions were calculated for both total vegetation cover and total herbaceous production. For total vegetation cover in the historic record vegetation community, the linear equation $y = 8.311862x - 25.3039$ explained approximately 98 percent of the variation in total cover (y variable) through use of precipitation (x variable). Within the range of values sampled, this indicates that total vegetation cover can be satisfactorily predicted through use of the October-May precipitation value. Using the linear regression equation for total herbaceous production ($y = 15.39103x + 19.25399$) plotted against October-May precipitation, the explained variation was approximately 75 percent.

Refinement of these regression equations through additional data collection will likely lead to models through which expected total vegetation cover values and total herbaceous production values can be predicted based on October-May precipitation values. This would prove a useful tool in establishing realistic revegetation success criteria for the West Elk Mine.

SUMMARY

Two decades of experience in revegetating disturbances associated with coal mining operations has revealed that establishment of revegetation success criteria based on comparisons with native, relatively undisturbed vegetation communities presents questions of equity and applicability, given the significant differences in seral stage development and physical environmental conditions between the two types of communities. Alternative solutions to the use of reference areas are available based on careful selection of vegetation communities that represent the seral stage of development a revegetated community should be expected to attain during the extended liability period. When such an approach was undertaken at an underground coal mine in Colorado, subsequent evaluation of the data for vegetation cover and herbaceous production yielded a predictive mathematical model based on precipitation data. Use of the model will provide a sliding scale for two revegetation success criteria; closely tailoring expected results to environmental conditions.

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2000 Billings Land Reclamation Symposium

THE USE OF REFERENCE AREAS FOR BOND RELEASE OF RECLAIMED RANGELAND IN NORTH DAKOTA

Guy Welch

ABSTRACT

The revegetation success of reclaimed rangeland in North Dakota is demonstrated by using reference area data or technical standards based on SCS (NRCS) data. This report compares production, diversity and seasonality standards of silty range sites derived from reference areas to those from NRCS data. Data from silty range site reference areas established at six North Dakota surface coal mines was used for this evaluation. It was collected over a period of two (Beulah Mine) to ten (Glenharold Mine) years during 1989 through 1998. The reference areas' mean production (1,657 lbs./acre) was less than the NRCS technical standard (1,888 lbs./acre) and significant year to year differences due to annual climatic variations were observed. Reference area diversity determined using weight data averaged one count less than the NRCS technical standard (5) while diversity determined using cover data was equal to the NRCS technical standard. The reference areas' seasonality values tended to be significantly higher than the NRCS technical standard (14.5 %), and cover data tended to produce higher values (34.9%) than weight data (24.4%). The NRCS technical standards were developed from rangeland in excellent ecological condition while the reference areas tend to be in good range condition. Thus, the measured parameters responded as expected.

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INTRODUCTION

SMCRA and North Dakota law and rules (North Dakota State Program, 1998) require that reclaimed native rangeland be established with a diverse, effective and permanent vegetative cover that is at least equal to that of lands in the surrounding area under equivalent management. Production, cover, diversity, seasonality and permanence are parameters used to demonstrate reclamation success on native grasslands in North Dakota. North Dakota revegetation guidelines allow the use of range site reference areas or technical standards derived from NRCS data to prove reclamation success. The technical standards for diversity and seasonality are developed based on composition by weight from NRCS range site descriptions for plant communities in excellent ecological condition; and individual species comprising 5 percent or more composition by weight are counted to establish the diversity standard. Diversity and seasonality standards from reference areas are developed by using either weight or cover data. Individual species comprising 5 percent or more composition by weight or 3 percent or more by relative cover are counted to establish a diversity standard from reference areas. The seasonality standard is the relative composition of all warm season species.

Production and cover data from at least one reference area are required to bond release reclaimed rangeland in North Dakota. Actual production from the major pre-mine soil types is used to develop the bond release production standard. NRCS production values can be used for soils not represented by reference areas but the NRCS values must be adjusted for annual climatic variation. The ground cover standard is developed from reference areas or fixed standards. For the sites not represented by a reference area, the cover standard is 73 percent basal or 83 percent first-hit based on studies by Ries and Hofmann (1984).

Reference areas must represent the geology, soil, slope and vegetation of the permit area. However, it is not practical to establish reference areas for every pre-mine range site, and thus NRCS derived technical standards may be used in conjunction with reference area data to develop standards for tracts requested for bond release. Technical standards are weighted by pre-mine range site acreage to develop the bond release standards for production, cover, diversity and seasonality. The reclaimed tract must equal or exceed the standards for final bond release.

The silty range site is typically the predominant pre-mine range site and, in most instances, is the range site that is expected to be the most similar to postmining conditions. Therefore, silty reference areas are used extensively to verify reclamation success. There were two objectives to this report. 1) To compare NRCS-based technical standards to those derived from the reference areas, and 2) to compare diversity and seasonality standards derived from production data to those derived from cover data.

METHODS

Six mining companies submitted silty reference area monitoring data so that the standards for production, diversity and seasonality developed from each of these data sets could be compared with the technical standards based on NRCS data. Thirty-three data sets gathered from 1989 through 1998 were evaluated. Five of the silty reference areas are located in the Missouri Slope Major Land Resource Area (MLRA) while one reference area, Falkirk, is located in the Coteau MLRA. The sampled silty reference areas have been officially approved as reference areas at each of the mines and were sampled in accordance with methods approved by the North Dakota program. Production data was typically sampled using ¼ meter square quadrant, and cover was measured using a 10-point frame. The NRCS standards for diversity and seasonality are based on species composition by weight (SCS, 1975 and 1987). The reference area standards for these parameters are based on species composition by weight as well as by cover. Table 1 shows the years reference area data were collected from the silty reference areas established at the six different mines.

Table 1: Years Reference Areas Sampled

Reference Area Location	Years Sampling Data Collected									
	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Center	x	x	x	x	x					x
Coteau						x		x	x	x
Falkirk					x	x	x			
Glenharold	x	x	x	x	x	x	x	x	x	x
Indian Head		x	x		x	x	x	x	x	x
Beulah									x	x

RESULTS AND DISCUSSION

Production

The NRCS production standards for the mines' silty reference areas range from 1800 to 2100 pounds per acre with an average value of 1888 pounds per acre. This value was calculated by weighting the NRCS production standard with the number of samples obtained at each reference area location. NRCS production values are based on silty range sites in excellent ecological condition. The reference areas tended to be in good range condition and their actual production during the 10-year period ranged from 780 to 2593 pounds per acre, averaging 1,657 pounds per acre. The 90% confidence interval estimate for the reference mean was 1,526 to 1,788 pounds per acre. The reference areas' mean yields were comparable to the NRCS standards only at the Falkirk and Beulah Mines. The comparison, however, was based on only two to three years of observations when more favorable weather conditions may have prevailed. A comparison of mean production values from the reference areas and the NRCS technical standards is given in Table 2.

Table 2: NRCS and Reference Area Production Data

Reference Area Location	Soil Type	NRCS Standard Yield	Reference Area Production Data		
			Mean Yield	No. of Years Sampled	Range
Center	Williams	2,000	1,458	6	851 - 1,983
Coteau	Williams	2,000	1,625	4	1,294 - 2,324
Falkirk	Williams	2,100	2,150	3	1,903 - 2,593
Glenharold	Amor	1,800	1,672	10	1,169 - 2,049
Indian Head	Amor	1,800	1,463	8	780 - 2,352
Beulah	Amor	1,800	2,280	2	2,242 - 2,318
Mean		1,888	1,657	-	-

Diversity

Using production data, a species was counted towards diversity if it comprised at least 5% of the total production. Only native, non-noxious grass and sedge species were counted. According to the NRCS range site description data, the diversity value for a silty range site in the Missouri Slope and Coteau MLRA is 5 and 7, respectively, and averaged 5.2 (or 5) for the six mines. The NRCS derived diversity standard is based on production data measured by weight. Based on production data, the mean diversity values for the reference areas were less than NRCS diversity values, except for the Beulah Mine, and averaged 4.1 (or 4). The actual diversity values ranged from 3 to 6 with a value of 4 occurring 48 percent of the time. Table 3 compares the NRCS derived diversity standards with the reference area standards derived from production data.

Table 3: Diversity based on Production Data

Reference Area Location	NRCS Standard Diversity Value	Reference Area Production Data		
		Mean Diversity Value	No. of Years Sampled	Range
Center	5	4.3	6	4 - 6
Coteau	5	3.5	4	3 - 4
Falkirk	7	5.3	3	5 - 6
Glenharold	5	3.4	10	3 - 4
Indian Head	5	4.4	8	4 - 5
Beulah	5	5.0	2	5 - 5
Mean	5.2	4.1	-	-

With cover data, a species must comprise at least 3% of the relative composition to be counted towards diversity. Table 4 indicates that the mean diversity value of the silty reference areas was 4.7 (or 5). The cover diversity values ranged 3 to 10 with 5 being present 39 percent of the time. The majority of the cover data was gathered using basal-hits; however, first-hits were recorded at the Falkirk and Beulah reference areas. The highest diversity values were obtained using first-hit measuring methods while the basal-derived values were lower and, generally, lower than the

NRCS derived standard. The NRCS derived standard is based on production data measured by weight.

Table 4: Diversity based on Cover Data

Reference Area Location	NRCS Standard Diversity Value	Reference Area Cover Data		
		Mean Diversity Value	No. of Years Sampled	Range
Center	5	5.0	6	3 - 7
Coteau	5	4.3	4	4 - 5
Falkirk	7	5.0	3	5 - 5
Glenharold	5	3.8	10	3 - 5
Indian Head	5	4.6	8	4 - 5
Beulah	5	8.5	2	7 - 10
Mean	5.2	4.7	-	-

Seasonality

A silty range site in the Missouri Slope MLRA is comprised of 15% warm season species, by weight, when the range site is in excellent ecological condition. In the Coteau MLRA the value is 10%, according to NRCS range site description data. The NRCS weighted warm season composition of all the reference areas was 14.5%. The actual warm season species composition from the reference areas was 24.4% based on the production data (Table 5), and 34.9% based on cover data (Table 6). Based on production data, the seasonality values ranged from 8.5% to 49.5%. Based on cover data, the seasonality values ranged from 13.6% to 69.0%. The seasonality values derived from either production or cover data far exceeded the seasonality values based on NRCS data at each mine site. Tables 5 and 6 compare the NRCS derived seasonality standards with reference area derived standards based on production and cover data.

Table 5: Seasonality based on Production Data

Reference Area Location	NRCS Standard Seasonality Value	Reference Area Production Data		
		Mean Seasonality Value	No. of Years Sampled	Range
Center	15	30.3	6	18.1 - 44.4
Coteau	15	35.1	4	25.0 - 49.5
Falkirk	10	25.8	3	14.0 - 37.0
Glenharold	15	21.3	10	11.8 - 35.4
Indian Head	15	14.2	8	8.5 - 21.4
Beulah	15	40.3	2	39.3 - 41.3
Mean	14.5	24.4	-	-

Table 6: Seasonality based on Cover Data

Reference Area Location	NRCS Standard Seasonality Value	Reference Area Cover Data		
		Mean Seasonality Value	No. of Years Sampled	Range
Center	15	51.5	6	28.9 - 68.3
Coteau	15	50.0	4	37.0 - 69.0
Falkirk	10	21.6	3	15.7 - 23.0
Glenharold	15	29.1	10	17.5 - 46.0
Indian Head	15	26.7	8	13.6 - 44.5
Beulah	15	37.3	2	33.0 - 41.6
Mean	14.5	34.9	-	-

SUMMARY

Production, diversity and seasonality standards derived from silty reference areas were compared to technical standards derived from NRCS data. The silty reference areas production values averaged 231 pounds less than the NRCS derived estimate. Significant annual variations in production were observed which are evidently due to year to year climatic differences. In a few instances, total production nearly doubled or was reduced by 50 percent between consecutive years. Diversity determined using weight data remained relatively stable throughout the 10-year period but averaged one count less than the NRCS technical standard. Diversity based on cover data varied as much as plus or minus two counts between consecutive years but on average equaled the NRCS technical standard. Seasonality values varied considerably between years and the average value computed from production data was less than the value computed from cover data. However, the reference areas consistently averaged higher seasonality value, using either production or cover data, compared to the NRCS derived standard. This may be due to the differences in range condition between the reference areas and the NRCS range site description data. North Dakota's program requires that the same measurement methods be used for the reclaimed land and the reference area when sampling for bond release purposes. Therefore, the differences noted between the measurement methods should not be a factor when releasing reclaimed rangeland from bond. Reference areas should be monitored annually since significant annual climatic changes can occur, and both measurement methods should be considered. Annual monitoring will allow trend analysis of the data, which may be an important consideration at the time of final bond release.

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SUCCESSFUL RECLAMATION TECHNIQUES AND BOND RELEASE FOR A COAL MINE IN WYOMING

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ABSTRACT

Bond release criteria and successful reclamation techniques are discussed for one of the coal mines in south-central Wyoming. This mine participated in developing the bond release criteria for 43 hectares of Category 4 land (land where coal was removed prior to May 3, 1978). The process of bond release was completed on August 13, 1999, after four rounds of technical review between the operator and the Land Quality Division (LQD) of the Wyoming Department of Environmental Quality (WYDEQ) staff. The guidance document concerning bond release criteria is still in preparation. This was one of the first cases of bond release for Category 4 coal mine land in Wyoming. The bond release evaluation was based on the analysis of grading, positive drainage, overburden suitability, depressions, topsoil, wildlife, grazing, hydrology, and vegetation. Postmining land usages for the mine are livestock grazing and wildlife habitat. The dominant vegetation type at the mine is western wheatgrass complex/sagebrush grassland growing on sandy/clay loam. Spoil piles were graded, ripped, sampled, covered with topsoil, harrowed, seeded with a cover crop or hay mulch and finally seeded with specific mine reclamation seed mixture. The cover crop included winter wheat, or barley and was applied at the rate of 46 kg ha^{-1}. Several seed mixtures were utilized (at the rate of approximately 15 kg Pure Live Seed ha^{-1}) comprised of mainly cool season perennial grasses and shrubs. Different seed mixtures were planted on different types of soil (loamy soil, sandy sites, and drainage channel bottoms). Shrub/warm season grass seed mixtures were planted at a rate of 4.6 kg ha^{-1}. Fertilizer was not applied and native hay mulch was applied at the rate of 4.9 tons ha^{-1}.

Additional key words: reclamation, revegetation, bond release, coal mines.

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Introduction

Bond release criteria and reclamation practices and revegetation results are discussed for the Rosebud coal mine located in south-central Wyoming. Since the mine started operation in 1964, a few subsequent environmental laws were passed regulating mining and reclamation activities. There were no reclamation laws in effect prior to May 24, 1969 when the Wyoming Open Cut Land Reclamation Act (OCLRA) was implemented. This act established general requirements for the postmining topography, and stated that "reasonable effort must be made to encourage the revegetation of lands disturbed by mining operations" (WYDEQ, LQD, 1998 a). The Wyoming Environmental Quality Act (WEQA), adopted July 1, 1973, established more comprehensive requirements for environmental protection and mine reclamation in regards to the post-mining uses of land, surface topography, revegetation, protection of topsoil, handling wastes and management of the hydrologic system. The first Land Quality Division Rules and Regulations became effective May 25, 1975. Specific performance standards required that the postmine slopes not exceed the average of the pre-mine slopes in the area, that drainage be reestablished and that the land be restored to a condition equal or greater than the highest previous use. These regulations also required submittal of quantitative data to verify vegetation cover amounts and required the restoration of wildlife habitat. The Surface Mining Control and Reclamation Act (SMCRA) went into effect on May 3, 1978. These various acts established bond release criteria for land affected by mining activities during the specific time such land was affected. Establishment of a vegetation cover is one of the basic requirements for final bond release and revegetation results are discussed for the Rosebud mine.

Mine location

Rosebud Coal Sales Company (RCSC) is located in the Hanna Basin, in south-central Wyoming, 113 km northwest of Laramie. The basin is characteristic of a plains-type topography ranging from 1950 m asl to 2250 m asl. The climate is semiarid with an average annual temperature of 4°C and an average annual precipitation of 28 cm with the maximum occurring in the spring. The mining operation began at the present location in 1964. Presently, the mine is in the reclamation phase of operation. The affected area covers 1639 hectares and contained 11 pits. RCSC used a mining technique that is classified as area strip mining with overburden removed using scrapers and draglines.

Bond release criteria

The Wyoming Department of Environmental Quality (WYDEQ), Land Quality Division (LQD), in cooperation with industry has established five regulatory time frames or categories for assigning bond release criteria for reclaimed mined land (WYDEQ, LQD, 1998 a). A guidance document outlining the specific criteria for bond release on each of these five categories is still in preparation however, the major criteria have been established. Finalization of the bond release guidance document is a high priority for LQD and the coal industry.

LQD bond release criteria

The LQD approach to bond release is based primarily on the time frame when an area was initially affected and/or when coal removal was completed and which law/rule was in effect at the specific time. Five categories were established. Land, where mining operations were completed: before May 24, 1969 (date of the implementation of Wyoming Open Cut Land Reclamation Act-OCLRA) belongs to Category 1; between May 24, 1969 and June 30, 1973 (date when the Wyoming Environmental Quality Act-WEQA was adopted) belongs to Category 2; between July 1, 1973 and

May, 24, 1975 (LQD Rules and Regulations became effective) belongs to Category 3; between May 25, 1975 and May 3, 1978 (date of the implementation of the Surface Mining Control and Reclamation Act-SMCRA) belongs to Category 4; and after May 3, 1978 to present belongs to Category 5.

A general summary of bond release requirements for each category is provided in Table 1. Bond release requirements include: postmine topography and erosional stability verification, topsoil depth verification, release from sediment control, evaluation of the hydrologic system, overburden suitability evaluation, quantitative vegetation cover and productivity sampling, species diversity, shrub density, and minimum bond release period. All these elements are analyzed during field inspections and verified on the basis of submitted documents. The main general bond release consideration before requesting final bond release is to obtain release from the area bond (for pit backfill), release from sediment control and reclamation or rehabilitation (if ponds are to be left for the post-mining land use) of sediment ponds. Any remedial work must be completed before the areas can be released from the bond. Water quality and quantity of approved postmining impoundments must follow the requirements included in LQD Guideline No.17 (WYDEQ, LQD, 1996).

Table 1 Bond release requirements for five categories land (WYDEQ, LQD, 1998 a).

Bond release requirement	**Category 1** Pre-5/24/1969 Pre-OCLRA	**Category 2** 5/24/1969-6/30/1973 OCLRA	**Category 3** 7/1/1973-5/24/1975 post-EQA/pre 1975 rules	**Category 4** 5/25/1975-5/3/1978 post-1975 rules/pre SMCRA	**Category 5** 5/3/1978-present post-SMCRA
Postmine topography verification	no	Minor scrutiny 1)spoil peaks and ridges graded; 2)documentation and results of all attempts of seeding	Must conform to approved plan [1], but LQD will only pursue obvious inconsistencies or instability. Drainage systems must be stable and functioning		Must conform to approved plan. Drainage systems - functional and stable
Overburden suitability evaluation	no	no	yes		
Verification of erosional stability	no	Minor scrutiny	yes		
Topsoil depth evaluation	no	no	No topsoil depth verification		Depth verification
Stability of permanent impoundments	no	no	Analysis of conditions of permanent impoundments		
Release from sediment control	no	no	no - but absence of excessive sediment release must be ascertained		yes
Quantitative vegetation sampling	no	no	no	yes: for one growing season[1]	yes: for two consecutive growing seasons [1]
Minimum bond release period[2]	none	none	5 years	5 years	10 years
Shrub density requirements	no	no	no	no	yes: goal and standard as appropriate

1) at the end of the bond release period

2) Time required after final seeding before this area can be inspected for potential release from bond

OCLRA-Open Cut Land Reclamation Act

SMCRA-Surface Mining Control and Reclamation Act/Wyoming State Program

Bond release requirements for the Rosebud mine

The Land Quality Division and Rosebud Coal Sales Company have been working on the development of final bond release procedures for the Rosebud mine. The initial meetings began on March 22, 1995 and the requirements are still in preparation. In the meanwhile, the process of bond release for the Category 4 land in Pit 9 was completed on August 13, 1999, after four rounds of technical review between the operator and LQD staff (RCSC, 1998/99). The Final Bond Release Requirements document was written as an agreement reached between RCSC and the WYDEQ (Final bond release..., 1995). The list of criteria, by category, comprising the final bond release package is presented in Table 2.

Requirements concerning grading, positive drainage, overburden suitability, depressions, and topsoil were included in the regraded spoil packages that were approved by the LQD. The Rosebud mine voluntarily participated in the Regraded Spoil Program and documents were submitted progressively while specific pits were reclaimed. The submitted packages contained reclaimed contour maps, cross-sections, locations of spoil samples and their chemical characteristics, and a longitudinal profile of major stream channels. As-built contour maps were compared to the approved reclaimed surface map in the permit document and the LQD allowed a deviation in elevation of +/- 3 meters from the approved elevations (WYDEQ, 1998 b). The land units have been backfilled to final contours, with drainage configurations restored as approved in the permit document. The various Regraded Spoil Approval Packages were referenced in the final bond release package.

Restoration of wildlife habitat was evaluated through Annual Report reviews and Permit maps. Surface water hydrology was evaluated through the annual survey cross-section data on all second and third order reclaimed drainages presented in Annual Reports and through regraded spoil packages on first order drainages. Suitability of permanent impoundments for Category 4 and 5 lands are analyzed before requesting bond release. Groundwater data were referenced from the current Annual Report and this is a requirement for the Category 5 land only. Quantitative vegetation data from the reclaimed area were compared to vegetation baseline data for the appropriate vegetation type, adjusted for climatic variation using control area data.

On the basis of the Final Bond Release Requirement documents, the bond was released for an area consisting of 43 hectares of Category 4 land in Pit 9. This Category includes lands where operations were completed between May 25, 1975 and May 3, 1978. The field evaluation was based on the analysis of the following criteria: grading, positive drainage, overburden suitability, depressions, topsoil, wildlife, grazing, hydrology, and vegetation (Table 2).

Table 2 Final Bond Release Requirements for land Category 4 and 5 (Rosebud mine).

Requirements	**Category 4** 5/25/1975- 5/3/1978 post-1975 rules/pre SMCRA	**Category 5** 5/3/1978-present post-SMCRA
Grading	• The design and "as-built elevations are within +/-3 meters. • Regraded area blend in with adjacent native, undisturbed lands.	
Positive drainage/depression	• 617 m^3 and larger requires permit from the State Engineer's office.	
Overburden suitability	• Sampling in accordance with permit. Data submitted with regraded spoils packages demonstrated suitable overburden in top 1.3 meters.	
Topsoil	• No depth verification	• Depth verification
Wildlife	• Wildlife habitat features restored and shrubs reestablished	
Grazing	• Land demonstrated to be able to withstand grazing at pre-mine levels.	
Hydrology	• Review of annual surveyed cross-section data on second and higher order reclaimed drainages	
	• Analysis of the stability and suitability of permanent impoundments for post-mine land use.	
		• Analysis of groundwater recharge capacity
Vegetation	• Production and cover estimated of reclaimed areas and compared with baseline.	
Vegetation sampling	• One year of monitoring data at the end of 5 year periods of vegetation establishment.	• Two years of monitoring data at the end of 10 year periods of vegetation establishment.
Species composition/ diversity	• Qualitative analysis based on a seed mixture from the approved mine permit.	• Quantitative and qualitative analysis of reclaimed areas compared to baseline based on: - species and life form % cover, - relative cover, - relative frequency, - utility and number of individual species and life forms
Shrub density	• Not required	• Goal- 1 shrub/m^2 on 10% land (3/27/1981-8/6/1996) • Standard - 1 shrub/m^2 on 20% land (post 8/6/1996)

The bond release area blended well with the adjacent native undisturbed land. The approximate original contours of the land were reestablished and elevations were within +/- 3 meters of the approved post-mining topography (Table 2). Positive drainage was established and depressions 617 m^3 or smaller did not require a permit from the State Engineer's office. Topsoil depth verification was not needed for the Category 4 land (as well as Category 1, 2 and 3 land). However, for Category 5 land, the topsoil depth needs to be verified in the field by an LQD representative. Wildlife habitat restoration was evaluated for the Category 4 and 5 lands.

Grazing effects were analyzed for Category 4 and 5 lands on the basis of ability of vegetation to recovered and it was compared to such ability prior mining. This was analyzed on the basis of the vegetative production data collected during the last growing season of the bond release period for Category 4 lands or on the basis of successful implementation of an approved grazing program in conjunction with the collection of vegetation cover data. A grazing plan is required to be presented by the operator.

Vegetation data were evaluated by comparison of the baseline control area data and current control area data. If the difference is 10% or more, then a climatic adjustment is needed. The Rosebud mine has chosen three control areas: shallow loamy, steep loamy, and very shallow range sites. The shallow loamy range sites comprised 76% of the total mine disturbance, the steep loamy and very shallow loamy sites each comprised 12% of the total acreage. Production and cover data from this bond release area were compared to the most productive control area, the shallow loamy site. Vegetation sampling is required for one year, at the end of a five-year period of vegetation establishment for Category 4 land, and two years at the end of a 10-year period for Category 5 land (Table 2). The other approach for Category 4 land is to establish the successful implementation of an approved grazing program. Baseline plant communities were documented on maps. Each plant community, and its control areas, was sampled for: vegetation cover by species, total cover, total ground cover, and bare ground. This was determined using line transects with a 25-meter line and 125 points or "hits" per line. Annual herbaceous production was analyzed for two plots of 0.5 m^2 randomly placed along each cover transect.

Shrub density requirements applies to Category 5 land only. Lands disturbed between March 27, 1981 and August 6, 1996 have a shrub density <u>goal</u> of 1 shrub m^{-2} on 10% of the affected lands. Lands disturbed after August 6, 1996 have a shrub density <u>standard</u> of 1 shrub m^{-2} on 20% of the affected lands. The operator must document the effort to apply best available current technology to obtain the shrub density goal, but if the goal is not achieved no further action is required. In such case, the land should be compared to grassland not to shrub land for the bond release purpose.

One of the difficulties with bond release at the Rosebud mine is the patchwork pattern of various land categories and reclaimed areas. For example Pit No.9 (where 43 hectares of Category 4 land was released) contained 9 reclaimed units differentiated by the time of being reclaimed, seed mixture, and topsoil depths. Within each unit, various parcels were disturbed at different times. For example one of the units contained 13 parcels that were disturbed during three different time periods. Another complication is the number of different disturbance time frames for the Rosebud mine, which differ from time frames established by LQD. This issue of tracking disturbance areas containing various categories can be complicated and can affect the reporting of acreage of disturbed areas.

The approach for evaluating bond release would be to choose a relatively homogenous area such as an entire pit area including an entire watershed. Unfortunately, such an approach is complicated by different drainage patterns, varying slopes and aspects, and different reclamation units. One way the LQD approach such obstacles was to tabulate and "bank" the reclaimed acreage by vegetation type. The 76% of reclaimed acreage was compared to shallow loamy range sites, 12% to steep loamy, and 12% to very shallow range sites. These types of range sites are the same as current control areas. The percentage of the acreage of specific land categories, at the end of the bond releases process should not exceed its percentage of the reclaimed area totals. RCSC, in coming years, will apply for bond release on all of the reclaimed areas. The basic requirements for various land categories have been established but specific criteria for the Category 5 bond release is still in preparation.

Reclamation practices

The mine (1639 hectares) has been fully reclaimed as of October, 1999 with the exception of the railroad loop. Postmining land usages for the mine are livestock grazing and wildlife habitat. A western wheatgrass complex/sagebrush grassland growing on sandy/clay loam is the dominant reclaimed vegetation unit at the Rosebud mine.

Grading and topsoiling

Rolling hills and irregular surfaces were established to minimize erosion, conserve soil moisture and promote a greater diversity of vegetation types. A dragline method of mining creates favorable conditions for such diverse landscape. The landscape of the reclaimed mine consists mostly of hills with slopes not exceeding a ratio of 4:1 and a network of drainages. These types of surfaces facilitate the postmine land uses of domestic livestock grazing and wildlife habitat. In addition, rockpiles were constructed in the area to improve raptor and small game habitats. RCSC made an outstanding effort to reestablish a diverse landscape, to create micro-topographic diversity including small depressions, transplanted shrub clumps, and stockponds.

Spoil was recontured, sampled and analyzed to demonstrate suitability for plant growth. Suitability of spoil and topsoil are specified in Guideline No.1- Topsoil and Overburden (WYDEQ, LQD, 1994). After spoil preparation, areas were ripped on the contour, cross-ripped, and /or disced depending on the compaction to minimize erosion and slippage of the soil (RCSC, 1994). Topsoil was replaced by scrapers from stockpiles and applied at a minimum thickness of 15 centimeters. Reapplied topsoil was disced, chisel plowed or roller harrowed on the contour immediately after application to increase the roughness of the soil surface and minimize erosion. Contour ditches were installed on long slopes to prevent erosional cuts and concentrations of runoff. All second and higher order channels were constructed as stable channels for the 100 year runoff.

Seeding

The prepared areas were planted with a cover crop in the fall or spring and with the native mixture planted into the cover crop the following fall (RCSC, 1994). The cover crop consisted of winter wheat (planted in the fall) or barley (planted in the spring) applied at the rate of 46 kg bulk ha $^{-1}$. The seeding of the cover crop was performed on the contour with flatter areas seeded perpendicular to the prevailing winds. Cover crops increase the moisture conservation, site stabilization, and are an effective trap for snow. At times instead of a cover crop, hay mulch was crimped into the soil followed by the planting of the native seed mixture. Native hay mulch applied at the rate of 4.9 tons ha^{-1} was used to protect the soil surface from erosion, retard evaporation, and increase infiltration of rain and snow melt.

Fall planting occurred from mid September to mid-October. The permanent seed mixture was planted on the contour with a rangeland drill. The types of seed mixture depended on the topography of the retopsoiled mine spoil, type of soil, and dates of the initial disturbance. Two seed mixtures were used due to the two main soil texture types. A third seed mixture was seeded at the bottom of drainage channels. The components of seed mixtures evolved over time. The seed mixtures did not contain warm season grass species after 1984. Cool season grass species are more adapted to the dry climate. Specially adaptable to Wyoming conditions and better able to stabilize disturbed lands are sod forming grasses. In the seed mixture applied at the Rosebud mine, 38% of the revegetation species were sod-forming grasses and 62% were bunch grasses. Seed mixes were generally applied at a rate of approximately 15 kg Pure Live Seed ha^{-1}.

Establishing shrub communities

Shrub communities are often difficult to establish on reclaimed lands. The Rosebud mine has achieved good reclamation results in reestablishing diverse shrub/ perennial grass communities. At the Rosebud mine drilling and broadcasting shrub seeds or transplanting were used. When drilling was used, the outer compartments of the seed box were partitioned off for shrub seed placed in the two sections. This practice decreased the competition that exists when shrub seed is mixed with grass and forb seeds. Broadcasting was done by hand or by a broadcaster mounted on the rangeland drill in the case of planting very fine seeds at shallow depth. The seeding rate of broadcasting was double that of the drill seeding rate. The transplanting of shrubs done by hand or by a front-end loader is quite expensive. According to mine staff, the most important point for successful transplanting was to move the plant while it was dormant, and locate it at the proper site (protected from the harsh weather and where there was moisture accumulation). Transplanting activities at the Rosebud mine were limited to older revegetated areas that lack in shrubs (RCSC, 1994). Shrub patch seed mixture contained Big sagebrush, Fourwing saltbush, Gardner saltbush, Rubber rabbitbrush, Winterfat, Blue flax, Yellow sweetclover, Bluebunch wheatgrass, Slender wheatgrass, and Western wheatgrass. Big sagebrush was broadcast seeded only. The rest of the mixture was drill seeded at the rate of 4.6 kg ha^{-1} or broadcasted at the rate of 9.2 kg ha^{-1}.

Reclamation results

Rosebud's reclamation practices have resulted in the reestablishment of a diverse perennial grass/shrub vegetative cover which supports the post-mining land uses. An example is 43 hectares of Category 4 land in Pit 9 that was released in 1999. This area was sampled for vegetation cover and production during the 1998 field season. For land Category 4 there are no standards for species diversity and composition, therefore the sampling results were compared with the approved seed mixture for this area.

Table 3. Cover and relative cover of various lifeforms in control and revegetated areas (LQD, 1999).

Lifeform	Native Control		Revegetated area		Seed mix
	% cover	% relative cover	% cover	% relative cover	% by weight
Perennial cool season grass	27.7	42.1	64.9	92.6	83.3
Perennial warm season grass	0.4	0.6	0	0	0.4
Annual grass	0	0	0.1	0.2	0
Perennial forbs	3.0	4.5	2.4	3.4	0.6
Annual forbs	0.1	0.1	1.1	1.5	0
Full Shrubs	26.7	40.5	1.4	2.0	13.1
Half Shrubs	3.7	5.7	0	0	2.2
Total	61.6		69.9		

The cover data indicated that perennial cool season grasses dominated the area (Table 3) (LQD, 1999). Shrub establishment was more difficult although they were planted at a relatively high rate (15.3% of the total seed mixture). This thought to be caused by the competition of the perennial cool season. For Category 4 land there are no shrub density requirements.

Revegetation in the bond release area met the standards for bond release described in WYDEQ, LQD (1998 b). Vegetation cover stabilized the land, was capable of self-renewal under natural conditions and was comparable to the surrounding undisturbed areas. Vegetation was capable of withstanding grazing pressure, wildlife habitat was restored and the approved post-mining land use goals were met.

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Land Quality Division (LQD), 1999. July Bond Release Inspection Report, 1999. pp.8

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REVEGETATION EVALUATIONS -- HOW LONG MUST WE WAIT?

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ABSTRACT

Is revegetation a "permanent" fix that will function indefinitely? Or is it merely a long-lived cover crop? When monitored for more than a decade, revegetation success becomes a time-dependent variable. This investigation focuses on how well short-term evaluations in Butte, Montana, related to midterm results. Twenty single-species plantings replicated in three treatments in a primary succession scenario were evaluated over a 15-year period. The treatments were preparatory crop (green manure), stockyard manure, and no amendment. Each stand was numerically ranked on a scale of one to ten every few years. The correlations between second-year and 15th- year evaluations ranged from 43 to 60 percent. The correlations between sixth-year and 15th- year evaluations were stronger in two of the three treatments, and yet the appearance of vegetation six years following planting may be an inadequate basis for prescribing treatments over large areas at great cost. By the 11th year, correlations of ratings with year 15 were greater than 80% in two treatments, but only 66% in the remaining treatment. The number of satisfactory and unsatisfactory stands in all treatments tended to equilibrate between years 10 and 15, presumably for the life spans of successful species. Correlations were strengthened by the high number of early revegetation failures, which always remained failures. Correlations were weakened by plantings that established and persisted for several years but later declined. Since fertility and nutrient cycling are major limitations in primary succession, the highest correlations were found within the most successful treatment: stockyard-manure amendment. We believe that our findings relating short-term to midterm plant performance are relevant where plant-limiting substrates (biologically inert coversoils, contaminated soil, tailings, etc.) are being revegetated. It can take a decade for plant-limiting site factors to manifest themselves in plant performance, or for nutrient immobility to curtail primary production. Eventually, long-term trends become the dominating ones.

Key words: premature revegetation evaluations, short-term and midterm plant performance, hard-rock revegetation, primary succession, nutrient mobility, organic amendments, fertility.

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It is familiar that many successions do not occur in time scales convenient for human examination... Robert McIntosh

INTRODUCTION

Long-term studies are rare in the ecological sciences (Michener 1997). In evaluating revegetation treatments, an ecological perspective is often subordinate to the pressure to declare victory or conclude investigations while funds are available. Briggs and others (1995) observed that many riparian revegetation projects have been evaluated just two or three years following project completion, leaving questions of long-term success unaddressed. Josselyn and others (1993) found that the lack of uniform, long-term monitoring and the application of knowledge gleaned from past projects to new ones was the least effective element of wetland restoration programs. The same often is true of upland revegetation.

The test plots investigated here were seeded in 1981 and sampled throughout a 15-year period. Many of the findings from these revegetation trials apply to a particular type of substrate, climate, organic amendment, and set of species. More generally, this 15-year monitoring program showed how long it may take to evaluate accurately the effectiveness of revegetation prescriptions in a primary succession scenario. The primary questions was, to what degree are early evaluations indicative of later trends and long-term success?

TEST PLOT CONDITIONS, TREATMENTS, AND LAYOUT

Location

The study area is located southeast of the Texas Avenue overpass near the Berkeley Pit in Butte, Montana. Butte is located at latitude 45.95, longitude 111.05. The test plots are at about 1,676 m (5,500 feet) elevation. Climate is cool and dry. Based on National Oceanic and Atmospheric Administration (NOAA) compilations, average annual precipitation between 1964-1998 was 32 cm (12.8 inches). During that period, precipitation exceeded 46 cm (18") in four years, but in six years it was less than 23 cm (9"), including a series of three consecutive years. Mean annual snowfall is 145 cm (57"). Mean monthly temperature is 4º C (39º F), ranging from around -8º C (17º F) in December and January to slightly more than 16 º C (60º F) in July and August. The frost-free season is 60 to 80 days.

Substrates

The test area began as a flat, coarse substrate of residual soil, not necessarily the original soil surface, covered in places with mine waste and slag. The residual soil contains significantly more clay than granitic borrow material, and hence has greater cation exchange capacity (CEC) and water-holding capacity. Concentrations of metals in the buried soil and waste rock have not been characterized, but 15 years after test plot construction, reactivity was extremely acid to strongly acid (pH = 4.5 to 5.5).

In 1979, what appeared to be mine waste in the southwest portion of the test area was leveled and covered to a depth of about 15 cm (6") inches with about 1,300 m^3 (1700 cy) of pit-run crushed limestone (minus 1/4 inch) from the quarry west of Anaconda. Portions without mine waste appeared to decomposed granite (grus). A layer of granitic alluvium 0.5 to 0.6 meters (1.6 to 2.0 feet) thick was applied over the entire area, which was approximately 220 by 90 meters (two hectares, five acres).

Coversoil material applied at the Texas Avenue test plot area consists of coarse, granitic alluvium from the southeast corner of the Berkeley Pit. As applied, this material was devoid of organic matter. Textures range from very gravelly, loamy coarse sand to gravelly, coarse sandy loam with an approximate range in clay content of four to eight percent. Rock fragments are predominantly pea gravel from decomposed granite (grus) with some larger angular gravel from granite and alpite. Rock fragments (>2 mm) comprise 20 to 40 percent of the coversoils material by volume. This material has characteristically low CEC and water-holding capacity. Fifteen years following application, field pH of coversoils ranged from mildly alkaline (pH = 7.4) to moderately alkaline (pH = 8.0). After drying, laboratory analysis indicated moderately alkaline pHs of 8.2-8.3.

Distinctions between coversoils originating as deep borrow materials and those originating from the A or A + B horizons of stripped soils are extremely important. Coversoils from deep borrow materials contain virtually no organic matter and lack important soil organisms such as heterotroph and nitrifying bacteria, fungi, ammonifying organisms, mycorrhizal fungi, and protozoa. It is useful to think of them as “biologically inert coversoils” because nutrient quantity and mobility eventually become critical limiting factors. In addition to having humus and soil organisms, native soils in uplands around Butte have a higher clay content than granitic coversoil material and have developed distinct horizons, whereas coversoils are relatively uniform throughout.

Amendments

The area was divided into three treatments along east-west boundaries. Before permanent planting, all treatment areas were fertilized with 340 kg/ha (300 pounds/acre) of 16-20-0 and 113 kg/ha (100 pounds/acre) of 0-0-60. All treatment areas were chisel-plowed and harrowed several times in late October. Anaconda Minerals Company/ARCO did the site preparation work and provided some seed.

The northern portion was planted to winter wheat in June 1981. This preparatory crop did not establish well, although short-term effects were evident. That summer, approximately 380 m^3 (500 cy) of stockyard manure were applied to the middle segment, or about 570 m^3/ha (300 cy/A). The depth of the poorly incorporated manure averaged two inches. The southern third received no amendment other than fertilizer. In the interest of brevity, we will refer to the treatments as no amendment (NA), preparatory crop treatment (PCT), and stockyard manure treatment (SMT).

After a decade and a half, soils of the PCT and NA areas could not be distinguished based on physical or chemical characteristics. Soils of the SMT had greater organic content and fertility than soils of the NA and PCT areas (Table 1). With the exception of alfalfa plantings, plant-available and organic nitrogen was very limited in soils of areas not treated with stockyard manure. Since partially decomposed manure fragments remained at the surface in the SMT, the two- to six-inch-depth increments best characterize the effects of manure amendment.

Seedings

The USDA Soil Conservation Service (SCS, now Natural Resource Conservation Service, NRCS) provided seed of 14 cultivars from the Bridger Plant Material Center and oversaw planting, which was done by the Anaconda Minerals Company using a 10-foot Brillion seeder in early November 1981. A dormant fall seeding, such as this one, aims at germination the following spring when moisture conditions are optimal. In this report, the year following planting (i.e., 1982) is considered year one.

Plot layout is portrayed in Figure 1, with cultivars identified. (Cultivars won't be mentioned again, in the interest of brevity, unless more than one cultivar of a species was seeded.) Twenty plots, each planted to an individual species, were made across the three treatments. Large test plots are approximately 12 meters wide by 30.5 meters long (40' x 100'), whereas the smaller ones are six meters wide. The smaller planting accommodated limited quantities of some types of seed. More than 15 years after planting, the crisp boundaries of successful seedings remain.

Management

Mining ceased in 1983 and ownership changed in 1986, so the plots were not refertilized and weeds were uncontrolled. Once seeded, the plants were on their own. This scenario is not unusual in the Butte-Anaconda area and is a practical test of revegetation treatments.

SAMPLE AND STATISTICAL METHODS

Plant performance was sampled in two ways. SCS personnel provided stand ratings in years 1, 2, 3,4,5,6,7, and 11. Various attributes were ranked. The most useful for evaluating revegetation success was "stand ratings." Each stand was numerically ranked on a scale of one to ten. In this report, these rankings were used for statistics and further combined to distinguish satisfactory, moderately satisfactory, and unsatisfactory stands.

In year 15, each planting/treatment was evaluated for species canopy coverage (Daubenmire 1959) with ten 0.5 m^2 rectangular plots. Plots were systematically located at least three meters from boundaries. The chief advantage of this ocular estimation technique is that it provides species composition information with minimal sampling. The frame perimeter was marked to indicate reference area percentages, e.g., one percent, five percent, 10 percent, etc.

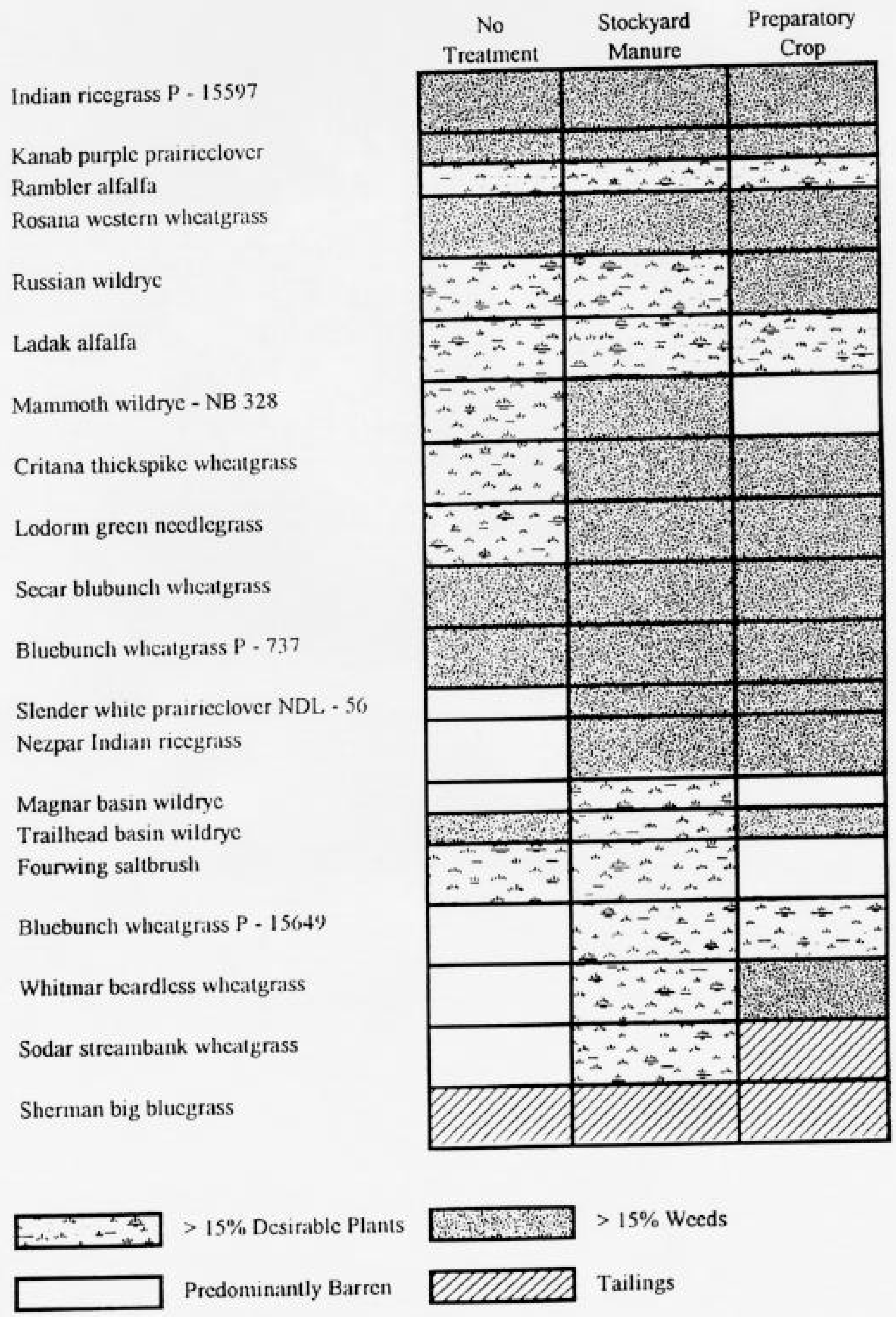

FIGURE 1. Treatment and Planting Layout at the Texas Avenue Test Plots.

Table 1. Nitrates and Organic Matter in Manured and Nonmanured Coversoils at Texas Avenue Test Plots, 15 Years Following Fertilization. (Based on samples from four grass and one alfalfa seedings.)

DEPTH INCREMENT (INCHES)	MANURED	NONMANURED
	NO_3 (Mg/Kg)	
0-2	30.0	2.6
2-6	2.5	0.6
6-12	0.6	0.5
	ORGANIC MATTER (%)	
0-2	6.9	0.6
2-6	1.1	0.1
6-12	0.2	0.1

For this report, the quantitative cover data collected in year 15 were transposed to rank level, complementing data collected in earlier years. The Kruskal-Wallis (nonparametric) one-way analysis of variance was used to determine significant differences in rankings among years. Significant differences were defined based on $p<0.05$, but the results were identical for $p<0.1$. The Spearman Rank Correlation procedure was used to evaluate the degree of association of stand rankings in years 2 vs. 15, 6 vs. 15, and 11 vs. 15.

RESULTS

Figure 1 portrays the general appearance of the test plots after 15 years. Satisfactory plots in Figure 1 indicate >15% canopy coverage of desirable species in each plot -- not just planted species. Red and white clover contributed to the cover of desirable species in the NA and to a lesser extent in the PCT areas. Quackgrass and some other wheatgrasses outside their planting areas contributed to the quantity of desirable species in the eastern portion of the SMT. Birdsfoot trefoil, reportedly never planted, was a major factor in the satisfactory rating of a bluebunch wheatgrass planting in the PCT. However, the stand ranks used in statistical evaluations are based solely on the planted species.

Plant Performance

In August 1983, when stands were two years old, the vegetational appearance of treatments often belied long-term performance. Early monitoring is more useful in documenting the establishment dynamic than in predicting eventual success. By the sixth year, the number of successful species was sometimes greater (SMT and PCT areas), sometimes less (NA area) than in the second year. However, it was not until approximately year 11 that plant performance equilibrated, presumably for the life spans of the dominant species (Table 2). Figures 2 through 5 indicate the performance of representative species through time in different treatments.

In the SMT and NA areas, the correlation between second- and 15th-year stand ratings began in the 40 to 60 percent range. Ratings in year six were somewhat better correlated with year 15 (Table 3). By year 11, correlations with year 15 were greater than 80 percent. In the PCT area, the correlation of second- and 15th-year stand ratings was similar, but instead of strengthening, the correlation of sixth- and 15th-year ratings weakened. This can be explained by a great increase in the number of satisfactory ratings in the sixth year, but in later years the number of satisfactory ratings declined to initial levels (Table 2). The correlation between years 11 and 15 also was weaker than in the other treatments (Table 3), although the number of satisfactory treatments remained constant (Table 2). Summing up, the older the stands, the more ratings approach equilibrium. But even after 10 years, a risk of premature evaluation remains.

No Amendment. Establishment and early plant growth of nonweedy species were best in the NA area. In year two, 11 species/cultivars were rated good to excellent. The best were Ladak alfalfa and Russian Wildrye.

Fifteen years later, spotted knapweed was the dominant species across the NA area. Among planted species only alfalfa could be called a success apart from volunteers. Canopy coverage of the two alfalfa varieties averaged 41 percent, with only two percent knapweed cover. However, the Rambler alfalfa stand contained 34 percent cheatgrass, whereas Ladak alfalfa had only about five percent. Alfalfa had spread to adjacent planting areas, where it helped Russian wildrye, presumably by providing available nitrogen. The beneficial role of alfalfa and previously identified volunteer legumes in accelerating primary succession is obvious.

Rank correlations (Table 3) indicate that stands less than about 10 years old were poor indicators of later stand condition. Rankings in year two did not differ significantly from year six. Year six ratings also didn't differ from year 15. Rankings in the 11th year did not differ from year 15, but were dissimilar from years one and six.

Table 2. Stand Condition in Relation to Years Since Planting. (n = 20 plots/treatment.)

SPECIES RATINGS	NO AMENDMENT 2	6	11	15	PREP. CROP TREATMENT 2	6	11	15	MANURE TREATMENT 2	6	11	15
SATISFACTORY	11	9	2	2	2	7	2	2	2	8	3	3
MOD. SATISFACTORY	4	4	3	3	5	4	0	0	5	5	7	4
UNSATISFACTORY	5	7	15	15	13	9	18	18	13	7	10	13

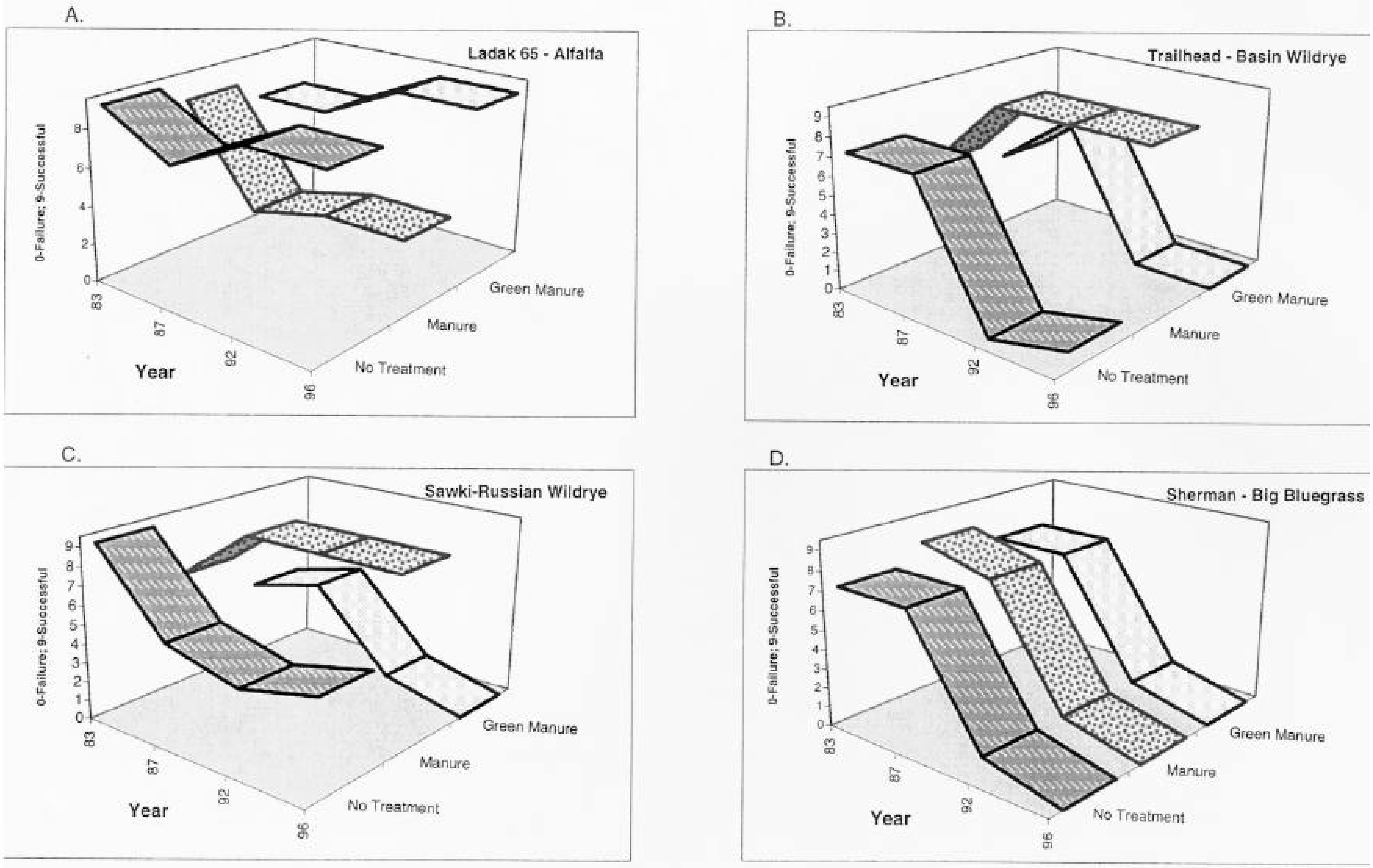

FIGURE 2. Three classes of plant performance. Alfalfa (A) was the only satisfactory seeded species on non-manured substrates 15 years after planting. Basin wildrye (B) and Russian wildrye (C) established slowly and persisted only on the manured coversoil. Big bluegrass (D) established strongly but did not persist – a type of performance that weakens between-year correlations

Table 3. Spearman Rank Correlations.

YEAR	NO AMENDMENT	PREP. CROP TREATMENT	MANURE TREATMENT
	%		
2 vs. 15	43	49	60
6 vs. 15	50	32	71
11 vs. 15	81	66	84

Preparatory Crop Treatment. Ultimately the PCT area came to resemble the NA area, but in the early years differences were significant. Whereas three-quarters of the plantings in the NA area were initially successful to some degree, fewer than half were satisfactory in the PCT. Most successful were big bluegrass and Ladak alfalfa. By year six, the PCT had 11 satisfactory and moderately satisfactory plantings (Table 2), still lower than other treatments but a marked improvement from year two.

After 15 years, the area initially planted with winter wheat had the poorest overall plant performance. Levels of cheatgrass and knapweed were the same as in the NA area. Only alfalfa could be judged a success, but both alfalfa cultivars did better in the NA area.

Although the PCT seemed to have negative effects on plant performance in both the short- and long-term, it is extremely unlikely that a preparatory crop was harmful. Soil/substrate factors may have varied across the test area, and for reasons not obvious alfalfa did not spread in the PCT area. Also, volunteer legumes were not as abundant as in the NA area. Reduced abundance of soil-nitrifying symbionts probably impaired the performance of other species within the NA area. Because contagious distributions often are phenomena in themselves, we cannot conclude that the relative lack of volunteer legumes was caused by the PCT, and in fact more legumes have volunteered since completion of this study..

Rank correlations (Table 3) indicate that early stand ratings were mediocre predictions of long-term plant performance. Sixth-year rankings were particularly poor predictors of plant performance in year 15. Rankings in years two and six did not differ significantly, nor did rankings in years 11 and 15. The relation of ranking in years 11 and 15 was weaker than in other treatments.

Stockyard Manure Treatment. After 15 years, total live plant cover was almost double that of other treatments. The yield advantage of rather heavy manure amendment can remain 40 years after treatment (Heady 1952). The manured amendment resulted in the most satisfactory perennial grass performance but also the most weeds. Knapweed cover was double, and cheatgrass cover triple the amounts found in NA and PCT areas.

All the grasses performed better on the more fertile, physically enhanced soils. The following grasses, most of which did poorly on other treatments, were at least marginally satisfactory in the SMT: thickspike wheatgrass (which also volunteered into the Ladak alfalfa planting), bluebunch wheatgrass, slender wheatgrass, quackgrass and Kentucky bluegrass (both volunteers), basin wildrye (two cultivars), and Russian wildrye. Of these, Russian wildrye and basin wildrye were the standout successes, both in abundance and in demonstrated ability to exclude weeds.

The early appearance of the SMT area, however, was not promising. Two years after planting, almost every stand in the SMT was rated very poor to fair. Weeds were abundant, and only big bluegrass and streambank wheatgrass established stands that were judged good in year two. Of the ultimately successful grasses, basin wildrye was rated fair, and Russian wildrye was rated a little below that. However, vigor of plants established at that time was better than in nonmanured treatments. None of the legumes did as well in the SMT as in the NA area. Typically, nitrogen additions reduce nodule weight and density (Alexander 1991, Chapter 19).

Rank correlations between years six and 15 were better than in other treatments (Table 3), probably because soil fertility wasn't so limiting in the manured treatment. By year 11, rankings were well correlated with plant performance in the 15th year. Correlations between years were stronger in all cases, and there were no significant differences among mean ranks in any years.

DISCUSSION

Most revegetation failures at Texas Avenue and on the Butte Hill can be attributed to the interactions of five factors:

1. Droughty, infertile, and shallow soils,
2. Lack of adequate N and nitrogen cycling,
3. Species/cultivars unsuited to their environment,
4. Elevated metal concentrations in coversoils, and
5. Weed infestations.

Some combination of these limiting factors typify much of the revegetation being done in the Butte-Anaconda area and at hard rock mines elsewhere.

The observations reported here indicate that plant performance a half-dozen years after planting can be a poor basis for predicting how well seedings will ultimately perform. Even on *in situ* soils, revegetated plant communities are in a state of flux for at least three years following establishment. Not only can composition shift significantly, but productivity often exceeds sustainable levels. Ziemkiewicz and Takyi (1990) found that revegetation in cold regions often appears successful for several years, only to deteriorate as surface cover diminishes and erosion occurs, largely as a result of nutrient immobilization.

In revegetating barren substrates, single plantings may not be realistic approaches to enduring plant communities. The lack of available nitrogen and the tendency for nutrient immobilization are so limiting that a combination of good organic amendment and nitrogen fixation are the quickest routes to a substrate that can support enough plants to prevent accelerated erosion. What would otherwise take centuries, including the development of nutrient reservoirs in the organic fraction and a functioning soil food web, can in important respects be compressed into a few decades. At that time, slower-growing species requiring lower soil fertility are most appropriate and in many cases should be planted.

If a single seed mix is planted, one has to ask what will happen when the initial generation of plants dies. The longevity of plants relative to professional careers is a major limitation to successional studies. Woody plants are long-lived, but even individual bunchgrasses may persist for three decades (Houston 1982, Appendix 6, figure 6.15.), and the life spans of genets are indeterminate. When successions occur, will they be the more or less natural successions of natives or the unnatural successions of exotics? Rarely is this investigated.

CONCLUSION

Our evaluations over a 15-year period show that plant performance rankings six years following seeding may have only a 50 percent correlation with plant performance nine years later. About two-thirds of the plantings across all treatment were rated as satisfactory in year six, but most of them ended up dominated by knapweed and assorted other weeds. Hence, we conclude that the appearance of vegetation six years following planting may be an inadequate basis for prescribing treatments over large areas at great cost.

In this study, correlations were bolstered by plantings that quickly failed and remained failures. Correlations would be even lower if long shots such as prairie clover, Indian ricegrass, and fourwing saltbush has been replaced with more likely prospects.

Enhanced revegetation success on the manured treatment in conjunction with the satisfactory performance of alfalfa alone on the NA and PCT treatments after 15 years indicates how important it is to provide plant-available nitrogen in a substrate lacking a nitrogen reservoir. With nitrogen fixation comes productivity, and with productivity comes niches for decomposer soil organisms which also are agents of soil aggregation. Primary succession is largely a matter of soil development, largely through autogenic processes, in which the site becomes suitable for different species or plant communities. In this progression (as it is often conceived), competitive species generally replace stress-tolerant species and ruderals (*sensu* Grime 1979). The fact that the manured treatment had twice the plant cover of other treatments and the only fully satisfactory stands of grass also indicates the need for an organic nutrient pool and soil food web.

Where important limiting conditions are present, treatment evaluations must focus not just on short-term performance, but also on how the treatment addresses each limiting factor. Revegetation success is a time-dependent variable. Eventually, long-term trends become the dominating ones.

We believe that our findings relating short-term to midterm plant performance have relevance beyond the particulars of these test plots. They are applicable when revegetating plant-limiting substrates (primary succession, contaminated soil, tailings, etc.) but not topsoil with an accumulation of organic matter and a healthy pool of soil microorganisms.

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CULLED FINDINGS

In some cases, the course of plant succession following the death of planted dominants is likely to be affected more by the status of the soil and propagule influx than the species composition of initial revegetation.

The success of *Trifolium pratense* and *T. repens*, volunteers in the NT and to a lesser extent the PCT area, is potentially one of the most useful developments at the Texas Avenue test plots. With 6 percent canopy coverage across all plantings, these species ranked third in abundance behind knapweed and alfalfa. Since sampling in 1997, clover coverage appears to have increased in both nonmanured treatments, and *Melilotus officinalis* and *Medicago lupulina* are locally well-represented some years. Not only can legumes can be recommended for planting on coarse, infertile soils in a cold continental climate, they well may invade without assistance. Their demonstrated ability to reproduce gives them special status among the successful species. Where planted species are fairly dense and plant competition is keen, especially for soil moisture, they perform less well. In other words, they're pioneers.

It was Daubenmire's conviction (1968, p. 39) that the presence/abundance of each species reveals something about the plants' environment -- whether or not we can discern it. At the test plots, some weeds were associated with infertile substrates, others with more fertile, organic-rich soils, and the most pernicious weed around Butte (spotted knapweed) is well-suited to both substrates. The NT and PCT areas invited these colonizers: *Phacelia hastata*, *Chaenactis douglasii*, and *Achillea millefolium.* Common weeds were *Gypsophila paniculata* (Table 4) and *Linaria dalmatica*, the latter often a weed of rocky substrates. These species were rare on the manure treatment in 1996.

Cheatgrass did much better on the SMT. Elsewhere it was found in abundance only in conjunction with the taprooted, late developing alfalfa, which also made nitrate much more available in the soil. Quackgrass was virtually absent from other treatments, but volunteered on the manure substrate. Kentucky bluegrass is another species that prospered on more fertile soils. While never abundant, dandelions were found only on the manure treatment.

Spotted knapweed was the most abundant species on all treatments. Cover was approximately 15 percent on infertile substrates and twice that on the SMT. In the terminology of Grime (1979) but perhaps defying his classification, this biennial could be classed a "stress-tolerant, competitive ruderal" – a most successful combination.

We conclude by cautioning that faulty revegetation assessments are likely to occur based on premature evaluation. Once important decisions have been implemented, there is a tendency for all parties to declare victory and decamp. Failures boost no one's career, and there are powerful incentives for both regulators and responsible parties to boast success when both have shared responsibility for design and implementation of reclamation plans.

Based on our research at Butte, grass/forb stands that exhibit progressive decline within five or six years are good candidates for ultimate revegetation failure -- not that they can't play important roles in revegetation when temporal factors are considered in fashioning revegetation prescriptions. In contrast, the apparently satisfactory condition of stands even after more than five years may unreliably indicate eventual success. Stands rated good or excellent after 10 years are likely to persist for the life spans of the dominant species. However, reproduction is a separate issue -- and one seldom monitored. It is possible that the best revegetation at Butte is no more than a persistent preparatory crop. Whether further vegetational development will lead to semi-natural vegetation or fields of exotic weeds remains unknown.

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STATUS OF LAND CAPABILITY BASED PIPELINE RECLAMATION ASSESSMENT IN ALBERTA

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ABSTRACT

Pipelines in Alberta, Canada, require a reclamation certificate be issued for them by the Alberta government upon abandonment in order for the operator to no longer be liable for further reclamation on the right-of-way. The only current exception may be for lines that are "plowed-in". For a reclamation certificate to be issued the right-of-way must be deemed to have land capability equivalent to that which existed prior to the area being disturbed for the pipeline. This requires a judgement by Alberta Environment personnel. Much discussion has taken place over time on the issue of what should be assessed and how it should be assessed. This paper discusses the work of a group of oil and gas industry and government personnel, along with non-oil and gas members, to develop an acceptable system for assessing the reclamation status of a pipeline right-of-way. The process and technical portions of the work, as well as the current status of the work is presented.

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INTRODUCTION

Concern about the environmental impacts from construction of pipelines has brought legislation governing their construction, operation and decommissioning even though most people are not aware of the presence of pipelines. They are generally buried and rarely are seen as the soil over them continues to support pre-disturbance activities such as agriculture, forestry and wildlife habitat.

Within Alberta there was no legislated requirement for the reclamation of disturbed lands prior to 1963 when the Surface Reclamation Act was proclaimed (Brocke 1988). Ten years later, in 1973, the Land Surface Conservation and Reclamation Act was proclaimed. This new Act required that environmental protection and reclamation be part of the development planning (Landsburg and Fedkenheuer 1990). A review and approval system that included Environmental Impact Assessments and Development and Reclamation Approvals was subsequently implemented. Regulatory changes were made in 1983 and again in 1993 with the passage of the Alberta "Environmental Protection and Enhancement Act" (Alberta Environmental Protection 1994).

The 1993 legislation contained a requirement to return land disturbed by pipeline construction to an equivalent land capability at the time of abandonment. Equivalent land capability is currently defined as, "The ability of the land to support various land uses after reclamation is similar to the ability that existed prior to any activity being conducted on the land, but that the individual land uses will not necessarily be identical" (Powter 1998).

The requirement to have equivalent land capability at the time of application for a reclamation certificate brought the need to be able to measure equivalent land capability. Some documentation is required to enable the regulator to acknowledge that the area is suitably reclaimed and to release the proponent from further reclamation liability, as well as to assure the public that a suitable reclamation job has been done. This documentation has been difficult to obtain agreement on and it has been the subject of much discussion since the mid-1980s. The definition of reclamation success and how to measure it was the topic of a workshop in 1992 (Mahnic and Toogood 1992). Following the workshop, focus shifted to oil and gas wellsite reclamation criteria development for several years where a parameter based checklist was developed and used. For these areas, specific individual parameters are compared on and off the wellsite and each must pass or the site fails.

There has been a desire by some to utilize this system for pipelines as well. Others have suggested using a capability rating system such as has been used in agriculture for many years. It is recognized that some modifications may be required to either system if they are to be applied to pipelines. In 1996, NOVA Gas Transmission Ltd. (NGTL) offered to take the lead in working to develop a land capability rating system to demonstrate what it might contain and how it might work for pipeline reclamation assessment. This paper addresses the approach, the results, and the current status of the approach.

PROCESS

In 1995, as interest in reclamation standards for pipelines again began to increase, several joint government-industry working groups were established. In mid-1996, a version of the wellsite reclamation criteria was modified and tabled for consideration as pipeline reclamation criteria. The wellsite criteria are basically a parameter-by-parameter pass or fail system.

To deal with the issue of developing a capability-based assessment of pipeline reclamation, a varied group of people were required around the table. A group of people consisting of representatives from government regulatory bodies, industry and also some independent experts, were invited to participate. The group was formally named the NGTL External Soils Advisory Board.

As NGTL initiated the Board, it subsequently provided much of the administrative support as well as the Chair (A.W. Fedkenheuer) and Assistant chair (J.D. Burke). A key component of this board were members that were not directly involved in oil and gas from an industry or government regulatory perspective. They brought both a practical and scientific perspective to the Board, as well as considerable experience.

The Board's primary short-term objective was to develop a pipeline reclamation evaluation tool. There was much discussion as to when this tool would be applied, either at post-construction or upon abandonment of the pipeline or at both times. It was agreed that the Board would focus on abandonment criteria which would be applied at the end of the life of a pipeline. In this way, the operator would know, in the planning stages of construction, what would be measured at the end. This would encourage good planning of soils handling and other environmental issues during construction in order to minimize the cost over the life of the pipeline.

Important components of the reclamation evaluation tool as identified by the Board were:

- scientific validity,
- identification of important environmental parameters,
- clear description of how to measure those environmental parameters,
- relatively easy usage,
- cost-effectiveness, and
- provision of reproducible results.

It was also a desire that time not be spent initially building new systems but to evaluate systems and processes already available. In the end, it was decided that a visual assessment as well as several others, one with a more detailed level than the visual, but not requiring laboratory analyses, and another allowing for laboratory analyses needed to be developed. As well, the Land Suitability Rating System (Agronomic Interpretations Working Group 1995) and a version of the wellsite reclamation criteria system (Wellsite Criteria Working Group 1995) were tested. Along with these systems, a landowner reclamation evaluation form was also developed.

Following agreement on the systems to use, the Board retained three senior consultants to take the systems to the field and evaluate their field performance. This was done in October and November, 1997. The consultants were sent to three central areas of the province and asked to employ the systems on five pipeline segments, chosen by representatives of the Board, in each area. The consultants were not to be on the same site at the same time, nor were they to discuss their findings with each other until after their reports had been submitted to the Board. One day was spent in the field by the Board and each consultant was visited at a different pipeline location. Subsequent to the receipt of the reports, three members of the Board undertook to summarize the consultant reports into one summary report.

The Board took the results of the 1997 field evaluation and the consultant recommendations and revised the evaluation tool into a three-step process for a re-test in the field season of 1998. One step was a landowner reclamation evaluation form that reflects the parameters being assessed by consultants. The other two steps were done by consultants. During Phase 1, factors under landscape (drainage, coarse fragments and micro-topography), vegetation (plant growth and species composition) and soil (color, texture and surface structure) must be met in order for the site to pass. If the area fails the Phase 1 portion, assessment must continue under a Phase 2 evaluation consisting of a more detailed soils assessment only.

The 1998 field study covered a range of ecological conditions in Alberta. This included approximately five pipeline sites in the dry Prairies, salt-affected and clayey soils in the Aspen Parkland region, the southern Boreal Forest, and the foothills Montane. All areas included both cultivation and grazing land uses.

RESULTS

Accomplishments of the Board consist of: development of Board objectives, an evaluation tool framework, tool parameters, an evaluation process, completion of a field evaluation study in 1997 and 1998, comparison of seven systems initially in 1997, comparison of selected modified systems in 1998, development of a summary report for each of the 1997 and 1998 field studies, completion of landowner reclamation evaluations and completion of two manuals describing the systems and how to use them (NGTL External Advisory Board 1999a, b).

General results from the 1997 field study comparing the on-right-of-way areas to the off-right-of-way were:

- Agreement on pass/fail results among the three consultants who visited the same sites was about 45 percent in all of the reclamation evaluation systems tested in 1997, except for the Visual system where there was about 90 percent agreement,
- Across the 18 quarter sections (65 ha, 160 ac) in the study, the average topsoil depth was 16 cm (+/- 8 cm) both on and off the pipeline right-of-way. Topsoil depth recordings by the consultants reflected this natural variability as one consultant reported finding 10 to 26 cm of topsoil, another reported finding 10 to 19 cm and the third consultant reported 12 to 26 cm. These readings were all for the same 65 ha and were done by qualified

soils professionals. This is a reflection of the natural variability across an agricultural field,

- Topsoil thickness alone is a poor indicator of reclamation success. Systems that relied heavily on topsoil depth as a measure of reclamation success had failure rates of greater than 40 percent based on topsoil depth by itself, while removing the topsoil depth parameter resulted in failure rates of about 15 percent,
- Using the visual parameters caught about 73 percent of 183 right-of-way transect failures. This means many of the failures were apparent to the evaluator before subsurface parameters were evaluated.

In response to the results from the 1997 field test, a general field protocol was developed along with a Phase 1 and 2 pipeline reclamation assessment process (NGTL External Advisory Board, 1999b).   In addition, a process was developed for obtaining the landowner's assessment of the reclamation on his property (NGTL External Advisory Board 1999a).

The field protocol covers field procedure issues such as developing map units, how to handle small problems or spot units, selection of controls, transect location, minimum size area to evaluate, how to deal with variability, what is equivalent land capability, how to deal with the topsoil issue (land capability depends on more than just topsoil thickness) and what to do with special circumstances where an over-ride may be desirable. Also discussed is how to determine whether a transect and a pipeline segment, should pass or fail. Recommendations are included for what pre-field preparation should be undertaken as well as for field procedures and how to approach the final assessment and reporting.

The Phase 1 level includes detail and guidance regarding each of the components, Landscape, Soils and Vegetation. The factors evaluated in the Landscape component are surface drainage, coarse fragments (number of stones, wood fragments, amount of gravel) and micro-topography. Factors to be evaluated in surface Soil are soil color (estimate of soil organic matter content), surface aggregate size and strength (evaluation of compaction, soil admixing) and soil texture. Vegetation factors in Phase 1 are plant growth (plant density, cover, height, health) and species composition (focus on unsuitable species including weeds).

Phase 2 is intended to be implemented on those transects or pipeline segments that fail Phase 1. In Phase 2 the emphasis is on the soils component as no landscape or vegetation evaluation is done in this phase. Both mineral and organic soil are addressed in the primary areas of water supplying ability, various surface and subsurface factors, and internal drainage.   This phase is based on a modification of the Land Suitability Rating System put forth by the Agronomic Interpretations Working Group (1995).

The landowner evaluation is targeted to evaluate similar factors to those in the Phase 1. Specific parameters are: surface drainage/ponding, stoniness, surface roughness, topsoil color, surface clods, tilth, plant cover or density, crop yield, crop growth, plant species and weeds. The landowner is also asked for an overall assessment of the right-of-way on his land with respect to whether it is similar to the off-right-of-way or at least 20 percent better or worse.

In the 1998 field study, pipeline segments were evaluated in 32 quarter sections (65 ha, 160 ac) by each of three consultant companies in August and September by applying both Phase 1 and Phase 2 to all areas. Results of the study were:

- On 44% of the line segments all three consultants agreed whether the area passed or failed the Phase 1. Of the remaining areas, in 34% of the cases two of three consultants passed them and in the remaining 22%, two of three consultants failed them,

- In 66% of the Phase 2 assessments all three consultants agreed (all were passes), of the remaining line segments 28% were rated as passes by two of three consultants and 6% were rated as fails,
- There were no cases where an area passing Phase 1 was failed under the Phase 2 assessment. This implies this part of the system works as designed,

In the landowner input part of this process, the following results were obtained:

- In the 1998 study, 94% of the 31 landowners contacted responded, with some encouragement, by filling out the forms evaluating reclamation success as they saw it for the study pipelines on their land,
- 72% of the line segments were rated as passes by the landowners,
- The landowner evaluation and the Phase 1 rating by all three consultants agreed on 72% of the line segments (15 pass and 6 fail ratings, respectively),
- On three line segments (10%) the landowners rated the area as pass and the Phase 1 ratings by all these consultants was a fail.

Following revisions to the reclamation evaluation tool in 1999, the manuals (NGTL External Advisory Board 1999a,b) were forwarded to the Alberta Pipeline Environmental Steering Committee (APESC). They subsequently forwarded them to Alberta Environment for circulation to approximately 200 organizations and individuals for review and comment prior to releasing them for a widespread trial in the year 2000.

SUMMARY

In summary:

- The general concept of a land capability based, relatively rapid Phase 1 "screening" assessment and an "as required" more detailed Phase 2 soil evaluation is workable and appears to address the proper concerns and issues,
- The weaknesses identified thus far in the process are manageable,
- Landowners are willing to participate, there is generally good agreement between the landowner and consultant ratings, and the landowner evaluation form can be a useful first evaluation of pipeline reclamation,
- orientation (training) sessions are expected to increase the level of agreement among evaluators,

- The Phase I evaluation tool should include Landscape (drainage, coarse fragments and micro-topography), Soil (color, surface aggregate size and strength), and Vegetation (plant growth and species composition) parameters, and
- The process is ready for a broad-based trial in summer, 2000, and a subsequent revision, if necessary in fall.
- Alberta Environment, with the support of the Alberta Pipeline Environmental Steering Committee (APESC), has sent both manuals out to various organizations and individuals for review.

ACKNOWLEDGEMENTS

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2000 Billings Land Reclamation Symposium

HOW NORTH DAKOTA MINE RECLAMATION STANDS IN TIME

David Bickel[1]

ABSTRACT

The long-term fitness of reclaimed environments can be evaluated by comparing the brief time interval in which successful reclamation has been achieved under SMCRA with long-term climatic patterns. Short-term records of groundwater aquifers, surface water bodies, county annual crop production, temperature and precipitation at or near surface mines in west central North Dakota are compared with longer-term climatic records. Directly measured weather records exist only since the late 19th Century. Tree ring chronologies and drought indices reconstructed from them extend back to the 17th Century and are available for the Northern Plains. Drought indices generally show stronger relationships with mining related variables than do precipitation or temperature alone, because indices include these variables and memory of duration as inputs. Reclamation over the past 20 years has occurred concurrently with a severe drought period in the late 1980's, followed by a notable wet period in the 1990's. Spectral analysis of the PDSI record indicates that the 20 years of modern reclamation have probably included high frequency events in the regional climate. Although not extremes in the paleoclimatic record, annual scale weather events were of above normal duration and intensity during the period from 1979 through 1998, and were sufficient to test the resilience of reclaimed systems to climatic variations characteristic of the Northern Plains over the past 300 years.

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INTRODUCTION

North Dakota enacted its first surface coal mining reclamation law in 1969, which became more stringent with each biannual legislative session until interim federal regulation based on the Surface Mining Control and Reclamation Act of 1977 (SMCRA) came in force in 1978. North Dakota law based on SMCRA and U.S. Office of Surface Mining Regulation and Enforcement (OSM) permanent program regulations became effective on August 1, 1980. In the formative years of surface mine regulation in the 1970's, successful reclamation of mined land to fully productive agricultural use was largely unproved, and the permanence of stability and productivity on reclaimed lands over long periods of time was commonly questioned. Mined lands successfully reclaimed under SMCRA are now common, and fundamental questions are seldom raised about their long term fitness over a scale of hundreds or even thousands of years or the suitability of the regulatory framework that shaped them.

Departures from present land uses driven by changes in population demographics and technology cannot be predicted nor can long-term changes in climate. However, the long-term fitness of reclaimed environments can be evaluated somewhat by comparing the brief time interval in which successful reclamation has been achieved under SMCRA with historic climatic patterns on the Northern Great Plains. This approach assumes that similar patterns will reoccur in the future albeit modulated by natural millennial scale changes or human interventions. Along with evaluating the climatic extremes that may face successfully reclaimed areas in the future, comparison of the SMCRA time frame with longer climatic records lets us consider the fitness of our regulatory requirements and expectations for accommodating the potential range of long-term climatic variation.

This report compares short-term records of groundwater aquifers, surface water bodies and vegetation production at or near surface mines with long term climatic records. Data specific to west central North Dakota includes about 50 years of records from US Weather Service stations in Beulah, Center and Underwood, ND. The longest records include Palmer Drought Indices calculated for the region from weather station records extending back to 1895 and proxy values reconstructed to 1691 from tree ring chronologies as described by Cook, et al. (1996). Other tree ring chronologies not reconstructed into proxy climate data and lake sediment records from eastern North Dakota were also available but not used. Environmental records from mines or mining areas spanning all or most of the last 20 years are less common but include NDPDES water discharges from mines, vegetation production on mine reference areas, average annual county crop production records, and monitoring well head levels.

The climate of western North Dakota is cool, semiarid and continental with hot periods in summer months having maximum temperatures above 95°F and more frequent cold waves in winter with minimum temperatures below -20°F. The average annual precipitation at Beulah, ND is about 16 inches with most falling as thundershowers in spring and summer. Winter snow cover is generally light but variable and provided by periodic snowstorms. Late winter and early spring warm periods typically produce rapid melting of accumulated snow. Since evapotranspiration and plant use typically exceeds late spring and summer rainfall contributions, retention and infiltration of snowmelt water is a significant source of recharge for the hydrologic regime.

Woodhouse and Overpeck (1998) review the several air masses that influence Great Plains precipitation climatology. Dry westerly Pacific circulation, cold and dry arctic air and warm, moist tropical flow from the south interact seasonally to produce typical Northern Plains weather as well as extreme events and patterns of varying frequency. Drought on the Great Plains appears controlled by anticyclonic circulation over the region which is sustained by anticyclones over the eastern central Pacific and Atlantic Oceans which block Gulf of Mexico moisture from reaching the Great Plains. The Bermuda high when positioned normally directs moist Gulf air moving around it into the central United States. When the high is northeast of its normal position, moist air flows into the eastern United States. Sea surface temperatures in the Equatorial Pacific and the El Niño-Southern Oscillation (ENSO) seem to influence summer precipitation on the Northern Great Plains. Relationships between western US low frequency weather patterns and the approximate 20-year solar-lunar cycle have been found in enough proxy climatic records for it to be considered a climatic factor in the western US. However, a physical link between solar-lunar cycles and the atmospheric circulation controlling climate in the western US has not been demonstrated. The causes of persistent multi-year to century scale weather patterns are poorly understood.

MATERIALS AND METHODS

Data in this analysis came from two sources, monitoring reports and bond release applications submitted by mining companies to fulfill regulatory requirements of mine permitting and from NOAA and USDA Internet sites which distribute environmental data. All environmental data submitted to meet regulatory requirements are publicly available, but commonly not in digital format at present. Some typical data sets are listed in Table 1.

Direct meterologic and hydrologic measurements can be manipulated and combined to characterize or monitor weather events more accurately than the records of individual environmental variables. Climatic indices of varying complexity are used worldwide (Hayes, 1999) but all have strengths and limitations suited to certain uses and regional climates. The Palmer Drought Severity Index (PDSI) is widely used in the USA and Canada and seems best suited to regions with relatively uniform topography. Extensive background information and data sets for the Palmer indices are available from several sources on the Internet.

The PDSI uses evapotranspiration, soil moisture gain, runoff, soil moisture loss and precipitation along with the previous month's PDSI value in a recursive calculation to get a value for the current period. This calculation also includes a moisture balance term that is dependent upon a month falling within or transitioning from a wet or dry period. Values are calculated simultaneously each month for each of these three possible states, and the value ultimately used is determined by conditions in subsequent months defining a wet or dry spell. This strong feedback mechanism more accurately portrays climatic reality by lessening the impact of a short reversal amid an established wet or dry period. Palmer (1965) and Guttman (1991) give details on computation of the PDSI. The multi-month delays in getting a final PDSI value led to use of a modification, termed the Palmer Hydrologic Drought Index (PHDI), that avoids the PDSI's backtracking to define transitions between wet and dry spells and provides immediate availability of a final value. The two indices are identical during an established wet or dry period and differ only during transitions between wet and dry spells. Correlation of both indices with mining-related variables early in this investigation confirmed that the PDSI generally provided correlations equal to the PHDI.

Daily climatic data from U.S. Weather Service stations are generally available for sites close to North Dakota mines for about the last 50 years. Longer daily weather records are available for a few stations in the state. Longer directly measured records extend into the latter decades of the 19th Century but are fewer and less continuous. Proxy climate data are records obtained from measurement of a natural process that is controlled by climate and has made a permanent record of climatic effects that can cover periods of time for which direct measurements are not available. Tree rings provide reconstructed proxy records of climatic variability over an annual scale. Temperature, precipitation and climatic indices can be reconstructed by correlating tree ring properties with instrument data from overlapping time intervals, and the derived regression relationships are used to reconstruct climatic records from tree ring data spanning earlier time intervals.

The drought indices data sets used here were obtained from two Internet sites. Monthly PDSI, PHDI, temperature and precipitation from U.S. Weather Service records were obtained from the NOAA National Climatic Data Center Web site at www.ncdc.noaa.gov/ onlineprod/drought/ftppage.html. These data were for North Dakota regional climatic Division 4 which includes the west-central region where mines and counties considered in this report are located. Annual PDSI values from U.S. Weather Service data and reconstructed from tree ring data for Grid Point 65 in west-central North Dakota by Cook, et al. (1996) were obtained from the NOAA Paleoclimatology Program Web site at www.ngdc.noaa.gov/paleo/usclient2.html. The instrument based PDSI data in this set were updated from 1995 through 1998 using the average of June through August PDSI values for North Dakota Division 4 to approximate the methods of Cook, et al. (1996). The reconstructions selected tree ring chronologies that showed strong responses to drought to develop the nation-wide 155-point grid of proxy data. The reconstruction at Grid Point 65 included tree ring records from Minnesota, South Dakota and Montana. A few tree ring chronologies are available in the International Tree Ring Data Bank (http://tree.ltrr. arizona.edu/~grissino/ itrdb.htm) for sites closer to the coal mining areas of North Dakota. However, these sites were not checked for suitability as proxy climatic records for this investigation, and Sieg, et al. (1996) note possible limitations to deriving reliable long climatic records from these bur oak chronologies.

Characteristic time series records of vegetation and water resources at or in the vicinity of operating surface mines and spanning all or most of the last 20 years were first correlated with regional temperature, precipitation and the PDSI. Sufficient pairs of data were

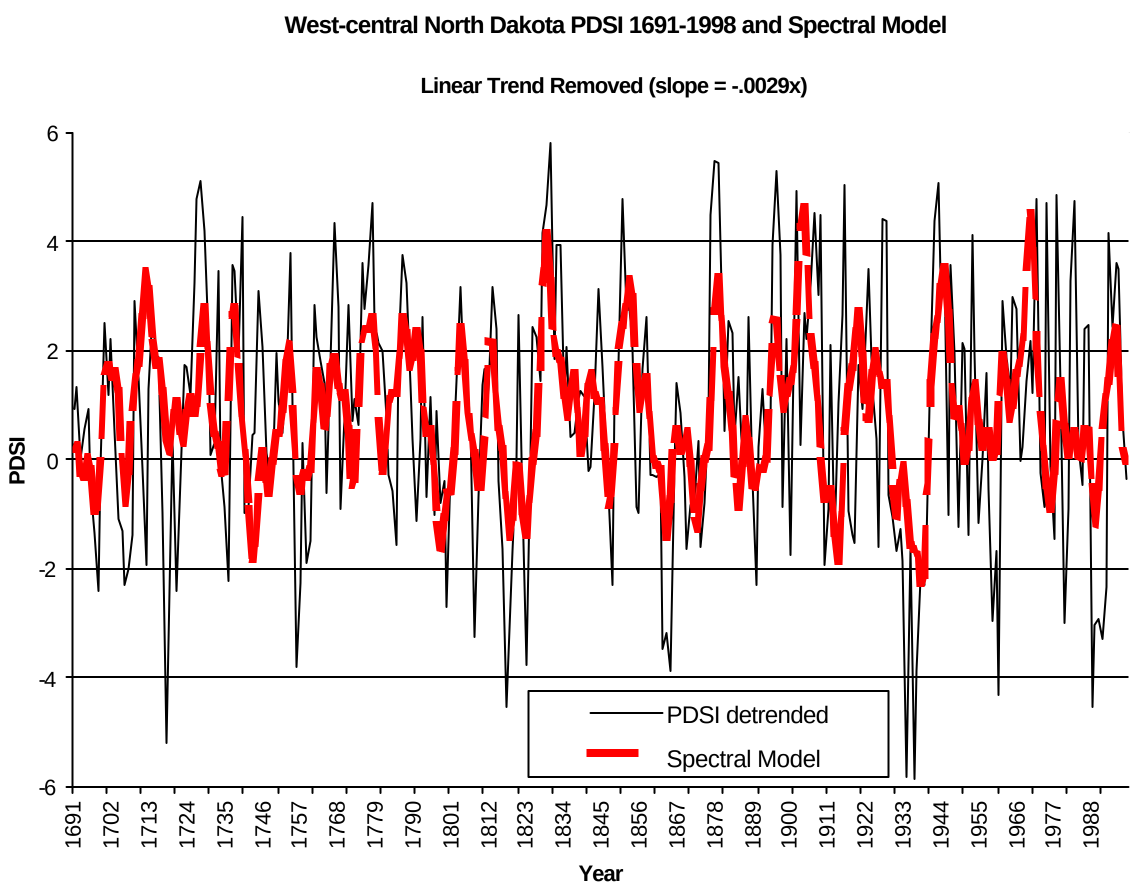
Table 1

Examples of correlation of mine-related vegetation production and hydrologic variables with temperature, precipitation and the PDSI.

Dependent Variable	Independent Climate Variable	Years of Run	Sample Periods	n	Correlation Coefficient	R^2	F ratio (MSR/MSE)	p - Value	Relationship (p<.05=signif.at 0.95 confidence level)
NDPDES discharges from all mines	Region 4 Precipitation	1986-98	annual	12	0.4087	0.167	2.21	0.1655	not significant
NDPDES discharges Glenharold Mine	Region 4 Precipitation	1986-98	annual	12	0.5061	0.2561	3.79	0.0766	not significant
NDPDES discharges from all mines	PDSI	1986-98	annual	12	0.8066	0.6507	20.49	0.0009	significant
NDPDES discharges Glenharold Mine	PDSI	1986-98	annual	12	0.6375	0.4064	7.53	0.0191	significant
Falkirk Mine Monitoring Well 3-2	PDSI	1984-97	quarterly	75	0.4698	0.2207	20.96	0.0000	significant
Falkirk Mine Monitoring Well 3-2	Underwood, ND quarterly precip.	1984-97	quarterly	55	0.1873	0.0351	1.96	0.1670	not significant
Falkirk Mine Monitoring Well 9-3	PDSI	1984-97	quarterly	72	0.4535	0.2056	18.38	0.0001	significant
Falkirk Mine Monitoring Well 9-3	Underwood, ND quarterly precip.	1984-97	quarterly	55	0.2967	0.088	5.21	0.0264	significant
Falkirk Mine Monitoring Well 19-2	PDSI	1984-97	quarterly	57	0.3151	0.0993	6.17	0.0160	significant
Falkirk Mine Monitoring Well 19-2	Underwood, ND quarterly precip.	1984-97	quarterly	55	0.2833	0.0802	4.71	0.0344	significant
Falkirk Mine Monitoring Well 92-1	PDSI	1984-97	quarterly	75	0.0713	0.0051	0.38	0.5407	not significant
Falkirk Mine Monitoring Well 92-1	Underwood, ND quarterly precip.	1984-97	quarterly	55	0.3004	0.0923	5.36	0.0245	significant
Mercer Co. Spring Wheat yield bu/ac	PDSI	1929-1998	annual	69	0.4764	0.227	19.97	0.0000	significant
Mercer Co. Spring Wheat yield bu/ac	Region 4 Precipitation Apr-Spt.	1929-1998	annual	69	0.3323	0.1104	8.44	0.0050	significant
Mercer Co. Spring Wheat yield bu/ac	Region 4 Average PDSI Apr-Spt	1929-1998	annual	69	0.2901	0.0841	6.25	0.0149	significant
Mercer Co. Spring Wheat yield bu/ac	Region 4 Average Temp. Apr-Spt	1929-1998	annual	69	0.1659	0.0275	1.93	0.1698	not significant
Oliver Co. All Wheat yield bu/ac	PDSI	1919-1998	annual	79	0.4211	0.1773	16.81	0.0001	significant
Oliver Co. All Wheat yield bu/ac	Region 4 Average PDSI Apr-Spt	1919-1998	annual	79	0.2376	0.0565	4.67	0.0338	significant
Oliver Co. All Wheat yield bu/ac	Region 4 Precipitation Apr-Spt.	1919-1998	annual	79	0.2178	0.0474	3.89	0.0523	significant
Oliver Co. All Wheat yield bu/ac	Region 4 Average Temp. Apr-Spt	1919-1998	annual	79	0.1716	0.0294	2.37	0.1280	significant
Glenharold Mine Reference Area lb/ac Thin Claypan	Region 4 Average Temp. Apr-Spt	1979-1998	annual	19	0.4577	0.2095	4.77	0.0424	significant
Glenharold Mine Reference Area lb/ac Thin Claypan	Region 4 Precipitation Apr-Spt.	1979-1998	annual	19	0.5354	0.2866	7.23	0.0150	significant
Glenharold Mine Reference Area lb/ac Thin Claypan	Region 4 Average PDSI Apr-Spt	1979-1998	annual	19	0.5208	0.2712	6.7	0.0186	significant
Glenharold Mine Reference Area lb/ac Thin Claypan	PDSI	1979-1998	annual	19	0.4995	0.2496	5.99	0.0249	significant
Glenharold Mine Reference Area lb/ac Silty Range Site	Region 4 Average Temp. Apr-Spt	1979-1998	annual	19	0.1353	0.0183	0.34	0.5696	not significant
Glenharold Mine Reference Area lb/ac Silty Range Site	Region 4 Precipitation Apr-Spt.	1979-1998	annual	19	0.4259	0.1814	3.99	0.0612	not significant
Glenharold Mine Reference Area lb/ac Silty Range Site	Region 4 Average PDSI Apr-Spt	1979-1998	annual	19	0.311	0.0967	1.93	0.1819	not significant
Glenharold Mine Reference Area lb/ac Silty Range Site	PDSI	1979-1998	annual	19	0.1961	0.0384	0.72	0.4074	not significant
North Dakota Coal Production (tpy)	PDSI	1920-1998	annual	78	0.0297	0.0008	0.07	0.7951	not significant
North Dakota Coal Production (tpy)	Hemisphere Temp. Deviation (Mann et al. 1998)	1920-1998	annual	78	0.66612	0.4437	61.42	0.0000	significant

compared to show the relationship of climate variables to mine related phenomena over the time interval of SMCRA-based mine reclamation. The regional PDSI data for Grid Point 65 was selected as the best climatic indicator for providing a long and well-documented record for this investigation. A hybrid data set was used with instrument records extending back through 1895 and reconstructed values covering the period from 1691 to 1894 (Figure 1). The 20 years from 1979 through 1998 were considered the span fully influenced by modern mine regulation, and this subset was then correlated year by year with each 20-year interval from 1691 to 1978. The lengths of runs of positive or negative PDSI values were evaluated as a measure of wet and dry spells. Patterns of intensity were examined through the occurrence of severe wet or dry years which are generally defined as having PDSI values at or more extreme than +3 or –3. Spectral analyses were made of the PDSI and results of the year-wise correlation to identify major cycles for comparison with the 20 years of modern reclamation. Algorithms in Microsoft Excel 97 and Statgraphics Plus Version 3.1 were used for data analysis.

Figure 1



RESULTS

The PDSI correlated as well as or better than regional temperature and precipitation records with various mine-related water resources and vegetation production data (Table 1). It was assumed that local weather data would generally correlate better with local mine variables than would regional averages or indices. However, the PDSI provided better correlations with static water levels in shallow monitoring wells at Falkirk Mine than precipitation totals at nearby Underwood, ND. It correlated poorly with the hydrograph from a deeper monitoring well, Well 92-1, which is completed in the lower of two lignites mined at Falkirk Mine. It correlated better with NDPDES discharges and estimated county production of wheat and hay than did regional precipitation. Regional precipitation had slightly stronger but comparable correlation with reference area production data from Glenharold Mine. The PDSI appeared to be the best available variable representatiing the regional climatic conditions influencing water and vegetation resources related to mine reclamation in west-central North Dakota.

Year-wise correlation of the PDSI record for 1979 through 1998 with the record from 1691 through 1978 found 14 closely matching intervals with correlation coefficients of 0.40-0.78 among the total number of positively correlated intervals (Table 2). In 7 of the matches, 2 or 3 successive years showed positive correlation in this range and these were considered one match. A time plot of all correlation values showed about 22 cycles over the 288-year record that could be modeled with a 12.8-year cycle (Figure 2). To confirm these results, time series plots for the two intervals were visually correlated on a light table as an independent exercise. The manual correlation found 8 20-year intervals in the period 1691-1978 that showed close correlation with 1979-98. Comparison of starting dates of matches from the two methods (Table 2) shows reasonable agreement allowing for some differences in interpretation of fit. The correlation coefficient appeared to identify matching patterns effectively, but produced comparable correlation coefficients for a few intervals that lacked consistent match over the entire 20-year period. The correlation coefficient generated low positive values (highest 0.297) over a late 1930's interval that matched well visually, and the visual correlation method seemed to be overly discriminating and possibly biased toward strong agreement in amplitude. The climatic pattern in the west-central North Dakota PDSI from 1979 to 1998 has occurred multiple times in the reconstructed regional PDSI.

The pattern in the lengths of wet and dry intervals is the distinguishing characteristic of the years 1979-98 in west-central North Dakota. The first 9 years of the period were alternating 2-year wet and dry spells through 1987. These are followed by 5 dry years, 4 wet years and by 2 dry years in 1997-98. The PDSI record from 1691 to 1998 has 177 wet and 131 dry years distributed in 104 alternating wet and dry spells of 1 to 13 years in length (Figure 2). The 5-year dry spell from 1988-92 ranked as 5th longest in the record and above the 75th percentile with the longest dry period being the 12 years from 1929 to 1940. The 4-year wet period from 1993-1996 ranked 15th longest and at the 75th percentile with the longest wet spell running 13 years from 1770 to 1782. The lengths of periods had a slight linear trend of decreasing period duration (slope of –0.01x) and seemed to show a transition to shorter climatic periods occurring near the beginning of the last quarter of the 19th Century. Wet and dry spells 5 years or longer in length are listed in Table 2. With exception of the 1929-40 drought, the latter part of the 19th and most of the 20th Century appeared characterized by more frequent changes between wet and dry conditions than occurred prior to the 1880's. The periodic pattern in the length of spells seemed to agree with measured and reconstructed event frequency patterns reported for the ENSO by Michaelsen (1989).

Table 2

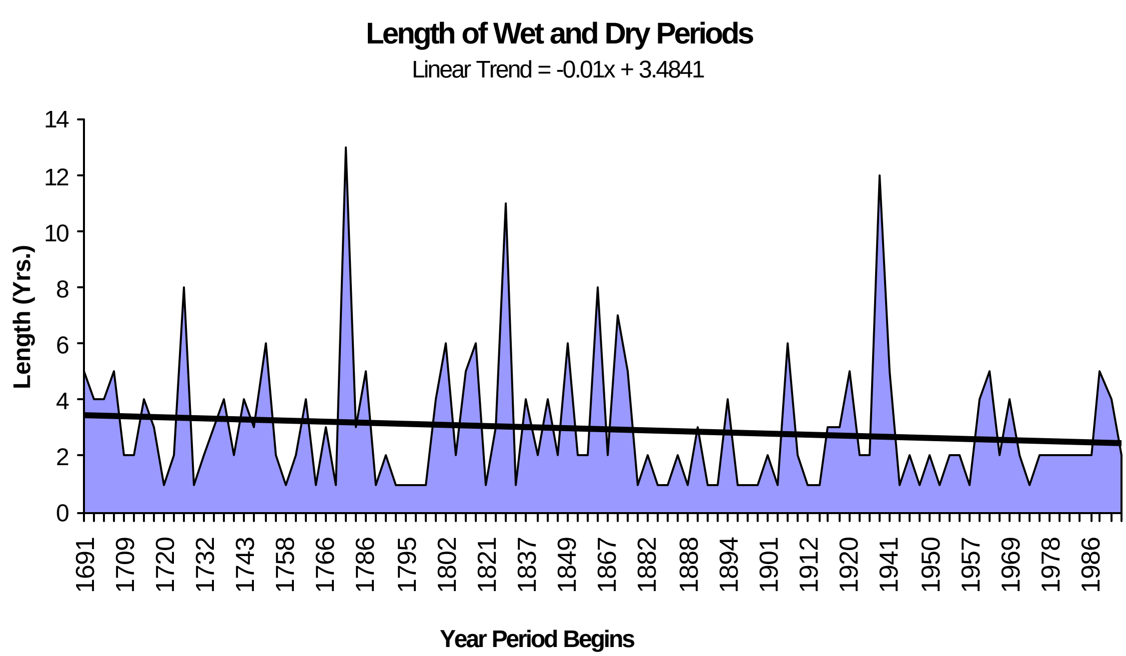
Years of events in the West-central North Dakota climatic record

Correlation (.40-.78) of 1979-98 with 20-year intervals beginning:	Visual Curve Matching: 1979-98 with 20-yr. intervals beginning:	Periods of 5 or more Wet Years	Periods of 5 or more Dry Years	Severe Wet Years	Severe Dry Years
		1691-95			
			1704-08		
1709	1711				1718
1723		1723-30		1726-29, 33, 37-38, 40	
1746	1750	1750-55		1754	
1763					
1772		1770-82		1767, 1775, 77-78	
1789	1775	1786-90		1787	
		1802-07	1815-20		
1807	1808	1810-14			1817, 23
		1825-35		1828-30, 32-33	
1836		1849-54	1859-66	1851	
1854		1876-80	1869-75		
1862	1865			1877-79	1865
1880	1883			1895-97	
		1904-09		1902, 07, 09, 16	
1924			1929-40	1927-28	1934, 36-37
	1935	1920-24			
		1941-45		1942-43	
1948	1952			1953	
1961		1962-66		1972, 75, 78	1961
				1983	
			1988-92		1988, 91
				1993	

With severe drought or wet conditions defined as PDSI values at or more extreme than 3.0 or –3.0, 1691 to 1998 had 40 wet years and 10 dry years that represented severe to extreme conditions (Table 2). The 1979-98 period had two severe wet years, 1983 and 1993, and two severe dry years, 1988 and 1991. Throughout the record, severe wet and dry years occurred during multi-year periods of corresponding wet or drought with the exception of 1975 which was a single-year severe wet period. Events related to wet conditions rather than drought have characterized climatic history in the region for the past 300 years. Over the preceding 308 years in west-central North Dakota, there have been more wet than dry spells spanning 5 or more years, and there have been 4 times as many severe wet years as dry years.

Periodicity in climatic records and their relationship to known and hypothesized forcing mechanisms is extensively documented. Cook et al. (1997) investigated drought rhythms in the western United States using the grid network of 115 regional PDSI reconstructions that includes the grid point 65 data set used here. They counted the number of points each year with a PDSI less than –0.1 as a drought index and found significant spectral peaks in the data at 20-23, 7.8, 4.1 and 2.5 years. Cursory spectral analysis of the grid point 65 data set in the present investigation found proximate fits for the 20-23, 7.8 and 4.1-year periods observed by Cook, et al. (1997) in the larger western US data set. Periodogram evaluation and fitting of a spectral model (Figure 1) after removal of a slight linear trend (R^2=0.31) found significant periods of 4.1, 7.5, 8.3, 9.3, 12.8, 19, 22, 23 and 61.6 years in the data set. A 20-year moving average over the data showed 5 cycles that were estimated adequately (R^2=0.58) with 58 and 72-year periods. Correlation coefficients from year-wise correlation of the 1979-98 interval across the data set were fitted with the 12.8 and 9.3-year periods (R^2 = 0.30). The 8.3 to 12.8 year periods suggest the 11-year sunspot cycle which Cook, et al. (1997) did not find in their investigation. A low frequency period at 58 to 62 years may be comparable to similar periods Michaelsen (1989) found in ENSO data.

Figure 2



DISCUSSION

The PDSI has several advantages over other climatic variables for comparing the past 20 years with the climatic history of western North Dakota. The index is widely used, well documented and high quality proxy data sets are publicly available. Data correlate well with time series records of plant growth and water resources related to mine reclamation, and the structure of the index makes evaluation of the intensity and duration of climatic events relatively easy.

Comparisons of paleoclimate with annual scale mine-related events become less meaningful further back in time, because there are few high-resolution proxy climatic data for the western U.S. before the 17th Century. High quality tree ring chronologies from long-lived tree species are uncommon and records from even less common banded fluvial, eolian, and lake sediments rarely have the distinct and continuous annual record of tree rings. Woodhouse and Overpeck (1998) reviewed reconstructed drought information for the Great Plains region and noted that two drought events in the 13th and 16th Centuries evidently exceeded the severity, length and geographic extent of 20th Century droughts, and similar or longer drought periods occurred prior to the 13th Century. Mann, et al. (1998) reconstructed Northern Hemisphere temperature anomalies from 1400 to present and concluded that the last decade had the warmest intervals in the millennium; although, the late 11th, 12th and 14th Centuries had mean temperatures similar to the mean for the second half of the 20th Century.

Strong but complex periodicity exists in all climatic data, and any 20-year segment would correlate with multiple intervals over a 300 year span in such a system. The two essential questions, beyond the repetition of climatic cycles, are have the last 20 years included enough variety in climatic events to assure that modern mine reclamation has successfully coped with conditions likely to occur on the scale of centuries and how does the 20-year span of SMCRA compare with the periods of cycles in the regional climate?

The 20-year time interval in which our regulatory program matured and successful reclamation occurred under SMCRA began with alternating biennial wet and dry periods followed by a longer drought and wet spell. The 1993-96 wet period and 1988-92 drought were longer than three-fourths of the comparable intervals in the past three centuries. The 50 years with severe to extreme PDSI values were not uniformly distributed over the 308-year record, so four occurring in the past 20 years exceeded expectations from a uniform distribution and strengthened 1979-98 as a representative sample of long-term climatic events. The duration and intensity of events in the PDSI data agree well with climatic events that were notable for their impact on human affairs. Although, the duration of spells defines extreme wet or drought periods in the PDSI record better than their intensity, the severe drought years, 1934, 1936, 1937, 1988 and 1991 mark the 1930's and the 1988-92 droughts. Wet events are more prominent in the climatic record for west-central North Dakota than drought; however, the region is commonly perceived as being drought prone largely because dry spells of moderate intensity or length have far greater impact on human affairs than wet spells of comparable severity and duration.

Cook, et al. (1997) infer that North Dakota is significantly less drought prone than most of the United States west of the Mississippi River. Mock (1991) found from a cluster analysis of weather station precipitation records over the Great Plains that North Dakota and eastern Montana form a distinct region of high June rainfall. Data selected for paleoclimatic analysis in North Dakota should honor these boundaries in regional weather, but attempts to differentiate patterns within the region will probably be limited by the poor availability over most of the state of good tree ring chronologies for climate reconstruction. The shorter life span and limited availability of suitable bur oak stands have forced climate reconstructions so far to rely on pine records in the extreme southwest of North Dakota and adjacent states and on chronologies from Minnesota for proxy data. Paleoclimate reconstructions from tree rings spanning three centuries for subdivisions within the climatic region may not be feasible for North Dakota, but bur oak chronologies within the state probably hold good climatic records for about the last 150 years that may be useful in localized water resources investigations.

Although economically and emotionally hard to bear, stress of the above normal lengths and intensities of wet and dry events during the SMCRA years in western North Dakota have contributed to the quality and resilience of modern surface mine reclamation and the regulatory frame work that guides it. Periods roughly of 4, 7, 12, 20 and 60-year frequencies appear to be present in the climatic record of western North Dakota. The 20 years of modern reclamation have probably encompassed the high frequency patterns in the regional climate. All of the currently operating large-scale surface mines in North Dakota will continue for at least two or more decades in operation or final reclamation. At least 40 years of reclamation practice and environmental monitoring can be anticipated for these operations which will span all but the low frequency climatic cycles.

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2000 Billings Land Reclamation Symposium

RECLAMATION INFORMATION MANAGEMENT SYSTEM FOR THE SURFACE MINING INDUSTRY

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ABSTRACT

Coal mine operators in Montana and Wyoming and regulatory agencies have expressed interest in developing the conceptual framework for a Reclamation Information Management System (RIMS). The system would provide a means for standardized handling of information relating to reclamation activities on surface mines that will ultimately lead to full bond release. The initial emphasis would be on the later phases of bond release that involve restoring native plant communities. Bitterroot Restoration, Inc., working with surface mine operators and regulatory agencies, is developing this conceptual framework. RIMS will be a phased process. Phase I is the concept development phase. Phase I will include technical concept development, i.e. database structure, reporting formats, core functionality, selection of appropriate internet-compatible tools, and discussion of data sources and data integrity/security. Phase I will also include needs identification, which will involve communication with surface mine operators and regulators, summary of current information flow vs. desired information flow patterns, and discussion of priorities for Phase II pilot implementation. During Phase II, we would implement a pilot RIMS involving two or more surface mine operators and regulatory agencies. Phase III would be an expanded implementation.

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2000 Billings Land Reclamation Symposium

NORTH DAKOTA PRIME FARMLAND RECLAMATION PROGRAM

Dean Moos

ABSTRACT

North Dakota adopted prime farmland regulations following the passage of SMCRA in 1977. Many of the currently permitted areas are grandfathered or exempt from the prime farmland standards. The mine operator must submit an operations and reclamation plan for the prime farmland areas that are subject to the prime farmland regulations. North Dakota regulations allow the mixing of prime topsoil and subsoil with nonprime topsoil and subsoil, respectively, provided that the mixed soil is of equal or better quality than that of the prime farmland soil. Full restoration of production must be achieved for a minimum of three years before final bond release can be granted.

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INTRODUCTION

Currently, there are four large surface mines operating in North Dakota. These mines are located in central and western North Dakota and produce approximately 30 million tons of lignite per year. The soils in this area developed from glacial till and soft sedimentary bedrock. The pre-mining land use of the area consists primarily of cropland and native grassland. Small grains, primarily spring wheat, are the dominant crops grown in the area. Average annual precipitation in this area is approximately 16 inches.

In central and western North Dakota, 13 soil types have been identified as prime farmland soils by the Natural Resource Conservation Service (NRCS). These prime soils occur primarily on footslopes, swales, or mild depressions and are usually 5 to 30 acres in size. Generally, the prime farmland soils receive run-on water from higher surrounding upland areas that do not meet prime farmland criteria.

In many cases, the soils of the adjacent prime and nonprime areas are morphologically similar. They differ only in thickness of the A and B horizons, presence of argillic horizons, depth to carbonates, etc. The prime soils generally have a thicker, darker (higher organic matter content) topsoil layer and a thicker solum (A and B horizons) than the adjacent nonprime soils.

The prime soils generally have a higher productive capacity than the adjacent nonprime soils. Numerous studies (Richardson and Wollenhaupt 1983, Schroeder and Doll 1984, and Wollenhaupt and Richardson 1983) have shown that the higher productivity of the prime soils is due to their more favorable moisture regime because of the additional water received as runoff from the adjacent upland areas. The authors did not believe that the higher productivity of the prime soils was related to their inherent soil properties other than higher soil water availability due to their landscape position.

Identifying and Reclaiming Prime Farmland

Mining companies are required to identify prime farmland areas as part of the permit application. This determination is based on the NRCS county soil surveys that have been completed for each county in the state. The NRCS has identified the soil map units in each county that are considered prime farmland. The NRCS county soil surveys are prepared at a scale of 1:20,000 and the minimum size delineation is approximately five acres.

The mining company is also required to prepare a detailed soil survey for each permit area. A Professional Soil Classifier prepares this soil survey and it is more detailed than the NRCS Soil Survey. This survey is prepared at a scale of 1:4800 and the minimum size delineation is approximately two acres. The detailed soil survey is used to determine the soil salvage depths and the adequacy of the soil resources for reclamation. It is also used for the development of site-specific reclamation success standards.

When the NRCS soil survey map (from which the prime farmland determination is made) is enlarged to the same scale and overlain on the detailed permit soil survey map, the locations of prime farmland as mapped by the NRCS may not correspond with those shown on the detailed soil survey map. Stomberg (1985) found that within the areas mapped as prime farmland by the NRCS, about 35% of the acreage was actually comprised of nonprime soils and, for any particular landowner, nonprime soils comprised from 22 to 91% of the areas mapped as prime in the county soil survey. The prime farmland section of Surface Coal Mining Permit NAFK-9503 for the Falkirk Mine indicates nonprime components (based on the detailed soil survey) comprise from 7 to 93% of the prime farmland delineations within this permit area. Oftentimes, the discrepancies may be minor, such as similar, nonprime soils being included in the prime delineation; however, significantly contrasting soils may be within the prime delineation. If significant differences exist between the two surveys, the NRCS and the Professional Soil Classifier who prepared the permit soil survey may be requested to field review the questionable areas and, if necessary, make the appropriate adjustments.

Several exemptions to the prime farmland success standards exist. Lands that the permittee had the legal right to mine before August 3, 1977 and are part of continuous mining plan that was under permit before August 3, 1977 are exempt from the prime farmland standards. This is commonly referred to as the "grandfather clause". In addition, areas not "historically used as cropland" are not subject to the prime farmland standards. These include native grassland areas, tame pastureland, woodlands, and industrial areas.

Of the 55,425 acres currently under permit at the four active mines, approximately 26,665 acres (48%) are exempt (grandfathered) from the prime farmland standards. There are approximately 4285 acres of prime farmland within the 28,760 acres that are not grandfathered from the prime farmland standards.

Since 1975, North Dakota has required the removal and segregation of both topsoil and subsoil from <u>all</u> mined lands. Topsoil normally consists of the A horizon and the upper part of the B horizon, typically the dark colored organic-rich, non-calcareous, non-sodic, and non-saline upper horizons of the soil profile. Subsoil typically consists of the calcareous, non-sodic and non-saline material to a depth of 5'. The stark color change between topsoil and subsoil makes it a fairly simple task for trained equipment operators to successfully segregate topsoil and subsoil materials.

The actual handling of prime and nonprime soils is similar with the exception that the prime farmland soils are removed, stockpiled, and respread separately from nonprime soils. A total of 48 inches of topsoil and subsoil (if available) must be removed and respread on the prime farmland areas. Required respread depths of nonprime areas are typically determined by the graded spoil quality with total soil respread depths ranging from 24 to 48 inches depending on graded spoil quality. Mine operators prefer to direct respread soils when possible, but when suitable areas are not available for direct respreading, the soil materials must be stockpiled.

Reclaimed prime farmland areas must have topography similar to the pre-mine prime farmland areas, i.e., concave or swale positions with gentle slopes (0-6% slopes) to ensure they receive run-on water. Schroeder (1991) found that lower slope positions (footslope and toeslope positions) had a positive effect on available soil water at planting and wheat yields. The postmining topography of all reclaimed lands, including prime farmland areas, must be approved by the Commission prior to beginning soil respread.

Typical cropland (prime and nonprime) reclamation consists of planting a pre-crop mixture of grasses and legumes following soil respread. The purpose of the pre-crop mixture is to stabilize the soil following reclamation and promote soil structure development. After a few years, the pre-crop mixture is plowed down and cropping with small grains begins. Recently, some mining companies have gone directly into small grain production following soil respread rather than planting the reclaimed areas to a pre-crop mixture of grasses and legumes.

North Dakota prime farmland rules allow for the mixing of prime topsoil and subsoil with nonprime topsoil and subsoil, respectively, provided that the mixed soil is of equal or better quality. The permittee must demonstrate that the mixed soil is of equal or better quality than that of the prime farmland soils. If this demonstration cannot be made, the prime and nonprime materials must be handled separately.

Mixing of prime and nonprime subsoil has been routinely allowed in those instances where the resulting mixture is of equal or better quality. The permittee must include a comparison in the permit application demonstrating that the resulting mixture will be of equal or better quality; i.e., that the prime and nonprime subsoil materials are of similar quality. In certain instances when the adjacent nonprime subsoil is of marginal quality, segregation of the prime subsoil is required.

Historically, prime topsoil has been segregated from nonprime topsoil. Halvorson and Nathan (1993, 1995) and Halvorson (1996) indicated that certain prime and nonprime topsoil materials could be mixed without affecting crop yields or reclamation success. This research found that landscape position was the most important factor in determining reclamation success of reclaimed prime farmland.

The dominant prime and nonprime soils in the coal-mining region of North Dakota are very similar in terms of soil classification, drainage class, bulk density, and texture. Generally, the prime soils tend to have slightly thicker A and B horizons. A comparison of the soil properties based on laboratory analysis of typical prime and nonprime soils of the coal-mining region of North Dakota is provided in Table 1. A weighted average is provided for the topsoil and subsoil materials of the prime and nonprime soils. The prime and nonprime soils in Table 1 are similar in chemical and physical characteristics.

Table 1. Comparison of Williams & Bowbells Topsoil & Subsoil Properties Based on NRCS Lab Data (weighted averages).

Soil Property	Williams soil (nonprime)		Bowbells soil (prime)	
	Topsoil	Subsoil	Topsoil	Subsoil
n (# of pedons)	4	4	3	3
Average Topsoil Thickness	10.2	40	22.3”	37.7
Electrical Conductivity (mmhos/cm)	0.57	0.71	0.71	0.43
Sodium Adsorption Ratio	0.12	1.9	Not available	1.33
Calcium Carbonate Equivalent	< 0.1	14.1	Not available	7.6
Organic Matter %	3.38%	0.5%	2.8%	0.96%
% Sand	27%	23.1	26.6%	29.3%
% Clay	28.4	29.2	29.3%	31.5%

In 1997, The Falkirk Mining Company submitted the first proposal to mix prime and nonprime topsoil materials. Table 2 provides a comparison of the soil laboratory data of the most common prime and nonprime soil types occurring within this permit area. These three soil types comprise approximately 80% of the entire permit area.

Table 2. Comparison of Williams, Bowbells, and Falkirk Topsoil Properties Based on Soil Lab Data Submitted with Permit NAFK-9503 (weighted averages).

Soil Property	Williams soil (nonprime)	Bowbells soil (prime)	Falkirk soil (prime)
N (# of pedons)	20	3	26
Average Topsoil Thickness	12.2”	17.1”	19.5
Electrical Conductivity (mmhos/cm)	0.33	0.46	0.41
Sodium Adsorption Ratio	0.41	0.35	0.39
Calcium Carbonate Equivalent	1.66	1.67	1.57
pH	6.7	7.1	6.9
Organic Matter %	2.77%	3.06%	2.9%
% Sand	31.5	28.5%	30.8%
% Clay	25.3%	23.8%	23.2%

Falkirk’s proposal to mix certain prime and nonprime topsoil materials was approved. The Commission determined that the practice of segregating prime and nonprime topsoil was not warranted in this permit area and that the benefits of such segregation were negligible for the following reasons:

- The dominant prime and nonprime soils are very similar in chemical and physical characteristics.

- A significant amount of mixing of prime and nonprime topsoil is already taking place under the current practice of segregating prime and nonprime topsoil materials. (The detailed soil survey shows that a considerable amount of nonprime soils are within the areas identified as prime by the NRCS.)
- The required productivity standard for the reclaimed prime areas is generally not significantly higher than the nonprime cropland areas (frequently less than a bushel per acre for spring wheat).
- The topsoil respread thickness for prime and nonprime respread areas is not significantly different. Usually the prime topsoil thickness is only slightly thicker (oftentimes less than 2" difference) than the adjacent nonprime areas.

Even though segregation of the prime and nonprime topsoil is currently being practiced, a significant amount of mixing of prime and nonprime topsoil is taking place due to the amount of nonprime "inclusions" within the prime areas. These nonprime inclusions lower the site specific productivity standards for the prime areas and result in thinner topsoil respread thicknesses. Although mixing of prime and nonprime topsoil was approved at the Falkirk Mine, the permittee is still required to meet the required revegetation standard for the prime areas for three years prior to bond release.

The types and amounts of nonprime topsoil that can be mixed must be restricted to similar prime and nonprime soils with only minor inclusions of dissimilar soils. In Falkirk's case, mixtures of prime and nonprime topsoils will be limited to no more than 10% of volume of certain nonprime soils; however, no restrictions were placed on the amount of similar prime and nonprime soils that could be mixed.

Determining Reclamation Success

North Dakota has a 10-year revegetation responsibility period, i.e., the reclaimed area must remain under bond for a minimum of 10 years from the last augmented seeding. Production (crop yield) is the only vegetation parameter that must be assessed on prime farmland for final bond release. Reclamation success is achieved when the annual average crop production from the area is equal to or greater than that of the approved reference area or standard with 90% statistical confidence for a minimum of 3 years on reclaimed prime farmlands. The nonprime cropland must meet the appropriate production standard with 90% statistical confidence for the last 2 consecutive years of the 10-year liability period or 3 out of 5 consecutive years starting no sooner than the eighth year of the responsibility period. The productivity of the nonprime cropland must also be restored to 100% of the pre-mine level.

For assessment of revegetation success of reclaimed prime farmland, the permittee may use either a reference area standard or a technical standard based on NRCS data. These methods provide procedures for climatic correction of yields. A separate yield standard must be developed and separate yield measurements must be taken for each landowner's property. Spring wheat must be used to determine reclamation success for at least 2 of the 3 years that productivity measurements are taken. Barley or oats may be used for the remaining year.

The cropland reference area standard combines a reference area with NRCS productivity indices for soil mapping units. This method is well suited to reclaimed prime farmland tracts and reclaimed nonprime cropland tracts that subtend only a few soil map units. A cropland reference area is established for soil mapping units that were predominant in the reclaimed tract prior to mining. The reference area must include one or two reference soils which singly or together occupy more than 50% of the reclaimed tract. The reference area must be topographically similar to the reclaimed tract and must be established in the vicinity of the mine area.

If the reference area contains prime and nonprime soil map units, each soil map unit in the reference area must be separately harvested or sampled to determine the yield of each. The crop yield of one of the reference soils must be used along with the NRCS soil productivity indices to calculate the expected yields for the other premining mapping units not represented in the reference area. The current year's actual yield from the reclaimed tract is then compared to the derived standard. The yield standard must be derived for each year that the reclaimed tract is evaluated for bond release. Appropriate statistical tests must be applied as necessary to determine if the yields are significantly different.

Under the technical standard using only NRCS productivity indices, productivity index values for all premining soil map units that existed in the reclaimed cropland tract are obtained. Index values are converted to yields using the assigned county yield for the Productivity Index of 100%. A yield value is determined for each soil mapping unit in the tract and multiplied by the acreage each mapping unit occupied in the tract. These weighted yields are summed and divided by the total acreage of the tract to obtain a weighted average yield per acre. This value is the unadjusted yield standard for the reclaimed cropland tract. NRCS yield ratings for productivity indices are based on long-term average data and do not account for annual climatic variations. Therefore, the unadjusted yield standard must be adjusted using one of the four approved methods. The most common method is to adjust the standard using county-wide average yield data published annually by the Agricultural Statistical Service.

To date, no final bond release applications have been received for reclaimed prime farmland in North Dakota.

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2000 Billings Land Reclamation Symposium

TILLAGE AND PRIOR CROP EFFECTS ON RECLAIMED MINELAND SMALL GRAIN YIELDS

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ABSTRACT

Compaction caused by heavy equipment during soil respreading may restrict root growth plus reduce air and water movement which may lead to poor vegetative growth. The objective of this study was to determine the effect over time of two initial tillage treatments and prior cropping history on spring wheat yields. Split-split plot designs were used to determine the effects of tillage and prior cropping at the Knife River Corporation Mine near Beulah and the Basin Cooperative Services Glenharold Mine near Stanton, North Dakota. Initial tillage treatments applied in 1989 were chisel (6-inch depth) or subsoiling (24-inch depth). All subsequent tillage on the spring wheat plots consisted of a chisel/disk/harrow operation prior to planting each spring. Half of all forage strips were killed in the fall following the third year of growth, the rest after six years, and planted to spring wheat. All spring wheat plots were fertilized for a minimum yield of a 40 bu/ac. Initial tillage treatments had very little effect on either spring wheat or forage yields over the five or more years of data collection. Early yields were probably affected more by the dry conditions that prevailed in the late 1980s and early 1990s. Prior forage crops grown on the plots had more significant effects on resultant spring wheat yields but the results varied over years due to variability within the plots; the differences in yield, in most cases, were not large. Over time, initial tillage had little or no consistent effect on spring wheat yields. Forages grown for several years before the initial spring wheat crop also do not have a consistent effect on spring wheat yields but did require initially heavier fertilization than the continuous spring wheat plots.

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INTRODUCTION

Soil compaction can be defined as compressing soil particles together resulting in higher bulk density (weight per unit volume). As bulk density increases, soil porosities and pore sizes (especially the large pores or macropores) decrease. Generally speaking, a compacted soil has poor aeration, low nutrient and water availability, slow permeability, and mechanical impedance to root growth (Raney et al. 1955).

Phillips and Kirkham (1962) stated that mechanical impedance to root growth measured with a cone penetrometer may be a better indicator than bulk density since the cone more closely represents the resistance a root may encounter. One study (Materechera et al. 1992) indicated that the size of the root had a significant influence on whether or not the root penetrated compacted layers and that root tips were much larger for plants grown in compacted versus noncompacted subsoils. Also, bulk density and penetrometer resistances were both found to be highly correlated to root length density in the lower portion of a reclaimed root zone (Thompsom et al. 1987).

Meek et al. (1988) showed that surface traffic similar to that applied by a producer reduced alfalfa yields by about 10% compared to areas with no surface traffic. When the entire surface was compacted, yields were reduced by about 17% from noncompacted surfaces.

Climatic factors such as freezing/thawing and wetting/drying cycles have been thought to alleviate some compaction. However, Voorhees (1990) found that freeze-thaw cycles in Minnesota failed to reduce compaction caused by large farm machinery even 9 years after the initial compaction. In addition, compaction in arid climates may last even longer since the soils in the fall generally contain insufficient amounts of soil water for frost heaving to occur (Brenneman 1991).

Tillage has probably been the most prevalent method employed to alleviate soil compaction although results on subsequent yields of crops have been mixed. For example, Barnhisel et al. (1988a) found that subsoiling increased wheat yields over non-subsoiled areas for two out of three years in one study but ripping and/or subsoiling had no significant effect on bulk density and generally reduced alfalfa yields in another study (Barnhisel et al. 1988b). In a recent study, Pikul and Aase (1999) found that while some residual effects of subsoiling on soil properties were found 2.5 years after subsoiling, soil changes attributed to subsoiling had no significant effect on wheat yields.

Surface mine operators have become acutely aware of the deleterious effects of soil compaction caused by large equipment especially since the passage of the Surface Mining Control and Reclamation Act of 1977 (SMCRA). Since 1975, North Dakota law has required reclaimed lands to have productivity values equal to that of the premine state. If vegetative growth is restricted due to poor rooting conditions as a result of soil compaction, then reaching these premine productivity levels becomes difficult and release from bonding requirements becomes tenuous.

This reclaimed mineland study was developed to evaluate two major objectives. The first objective was to determine the effects of initial tillage on bulk density and various crop yields with time. And secondly, the study was to determine the effect of prior crops grown for various lengths on subsequent small grain yields.

METHODS AND MATERIALS

Experimental sites were established in the spring of 1989 on reclaimed mineland locations at the Basin Cooperative Services Glenharold Mine near Stanton, North Dakota and the Knife River Corporation mine near Beulah, North Dakota. Both locations had been reclaimed the previous fall using scrapers that respread an average depth of 12 inches of topsoil and 24 inches of subsoil. Each location was 390 by 160 feet (approximately 1.5 ac) in size.

Each location was divided into four strips lengthwise upon which alternate tillage treatments of either chisel (6 inch depth, 24 inch spacing) or subsoiler (24 inch depth, 20 inch spacing) were applied. A broadcast application of 100 lbs/ac of ammonium nitrate was applied and followed by a light disk/harrow operation. Each location was then divided into half perpendicular to the tillage treatments and each of these halves further subdivided into six equal-sized strips. Five forage crops (monocultures and mixes) and Stoa spring wheat were randomly seeded into the strips at the rates shown in Table 1 to give four subplots for each crop by tillage treatment. Mining personnel seeded all but the spring wheat plots. All spring wheat plots (after harvest the first year) were fall chiseled and spring disked/harrowed before seeding.

Table 1. Seeding mixtures and rates used on the tillage locations.

Seeding Mixture	**Rate (lbs/ac)**
Alfalfa (*Medicago sativa* L.)	10
<u>Native Mix</u> Sideoats grama (*Bouteloua curtipendula*) 33% [1] Green needle (*Stipa viridula*) 19% Big bluestem (*Andropogon gerardii*) 17% Western wheatgrass (*Pascopyrum smithii*) 14% Blue gram (*Bouteloua gracilis*) 11% Slender wheatgrass (*Elymus trachycaulus*) 6%	18
<u>Precrop Mix</u> Alfalfa 33% Pubescent wheatgrass (*Thinopyrum intermedium*) 20% Tall wheatgrass (*Thinopyrum pentium*) 20% Smooth bromegrass (*Bromus inermis*) 20%	15
Pubescent wheatgrass	8 / 10 [2]
Tall wheatgrass	8 / 10 [2]
Spring wheat (*Triticum aestivum*)	75

[1] Percent of mixture by weight
[2] Higher rate at Knife River location

Soil bulk density was measured by depth from soil cores removed following spring wheat planting each spring. Soil fertility samples were taken in the fall from all spring wheat subplots following harvesting. Fertilizer was broadcast and drill applied in the spring on the spring wheat subplots based upon these fertility samples to produce a 40 bu/ac crop.

All forage and spring wheat plots were hand harvested. Following sample harvesting, the remaining forage and spring wheat was removed from the subplots by either mine personnel or cooperating farmers.

Following the third year of spring wheat harvest, each tillage strip was subdivided lengthwise into half. Random halves of each tillage strip were sprayed to kill all vegetationand fertility samples taken. These former forage subplots and the spring wheat subplots were then fall chiseled for preparation for planting in the spring. The remaining forage plots were similarly treated following the sixth year of the study.

All site data were analyzed as a nonrandomized modified strip-split block design. Where appropriate, least significant difference (LSD) values at the P=10% level were calculated.

RESULTS AND DISCUSSION

The mean characteristics of the soil materials are listed in Table 2. The Knife River location was somewhat more coarse textured than the Glenharold location but pH values and electrical conductivity values were similar. The sodium adsorption (SAR) value for the subsoil at Glenharold was higher than expected and greater than that allowed by rules (a value of 10) for subsoil. However, it was thought that the slightly higher value for SAR at this location had only a little or no effect on the yields measured.

Table 2. Mean physical and chemical properties of the respread soil materials at the two reclaimed mineland locations.[1]

	Glenharold		Knife River	
Variable[2]	**Topsoil**	**Subsoil**	**Topsoil**	**Subsoil**
Sand (%)	27	23	65	56
Silt (%)	48	45	20	24
Clay (%)	25	32	15	20
pH	7.8	8.0	7.7	7.8
EC ($S\ m^{-1}$)	0.1	0.3	0.1	0.2
SAR	2.5	11.4	0.4	0.8

[1] 12 replications per mean value, 1989 cores

[2] EC is electrical conductivity and SAR is sodium adsorption ratio

Tillage treatment had essentially no significant effect on bulk density by depth either initially or over time (Table 3) except for the 0 to 1 foot depth in 1990 and the 2 to 3 foot depth in 1992 at Knife River. The lack of significant differences between tillage treatments in 1989 was caused by the fertilizer broadcast, disk/harrow and planting surface traffic which followed the tillage treatments. Variability among years was also affected by soil moisture at sampling plus additional settling and surface traffic.

Table 3. Calculated bulk density mean values (g/cc) for the two tillage treatments at the two tillage treatments at the two research locations.

	Year of Data				
	1989	**1990**	**1991**	**1992**	**1994**
			Glenharold		
			0 to 1 foot		
Chisel (CH)	1.22	1.72	1.50	1.52	1.30
Subsoiled (SS)	1.16	1.62	1.45	1.52	1.26
			1 to 2 feet		
CH	1.40	1.73	1.64	1.75	1.41
SS	1.29	1.70	1.58	1.75	1.40
			2 to 3 feet		
CH	1.43	1.71	1.36	1.62	1.49
SS	1.42	1.74	1.61	1.80	1.48
			Knife River		
			0 to 1 foot		
CH	1.49	1.72	1.46	1.52	1.56
SS	1.48	1.62	1.45	1.52	1.53
			1 to 2 feet		
CH	1.73	1.45	1.64	1.75	1.69
SS	1.56	1.70	1.57	1.75	1.65
			2 to 3 feet		
CH	1.58	1.71	1.63	1.62	1.62
SS	1.56	1.74	1.61	1.80	1.66

The initial tillage treatments also showed very few significant effects on forage and spring wheat yields at the two mineland locations as shown in Tables 4 and 5. Most of the differences found were attributed to variability within rather than between the tillage treatments. In addition, the overall difference between the tillage treatments varied only slightly between the two locations. The subsoiled plots at both locations showed generally higher yields for the forage crops in the latter years of the study. This may be an indication that the subsoiler tillage may be more beneficial after several years by possibly allowing for deeper root penetration into the profile. This would, of course, allow for potentially greater water and nutrient uptake if available at the deeper depths.

The significant differences found within the spring wheat data were largely attributed to variability in the yield data from within the tillage treatment subplots. However, the significant difference in 1989 at the Knife River location was attributed to deeper water penetration from a large rainstorm (estimated at about 2 to 3 inches in an hour) that occurred just after the subsoiling treatment was finished but before the chisel plots were chiseled. This allowed the rain to penetrate much more deeply in the subsoiled plots as compared to the soon-to-be chisel plots. In a similar manner, the large increase in wheat yields from 1993 to 1994 at Glenharold was attributed to increased soil water. The 1993 crop was hailed out and did not draw down the water that was available for the entire growing season as was the case at Knife River.

Table 4. Tillage effects on forage and spring wheat yields at the Glenharold location.

Tillage	1989[1]	1990	1991	1992	1993	1994	1995	1996	Mean
				Year of Data					
				Alfalfa (t/ac)					
Chisel (CH)	-	0.9	1.0	0.7	1.5	1.7	-	-	1.1
Subsoiled (SS)	-	0.8	1.1	0.6	1.9	2.3	-	-	1.3
LSD(0.10)[2]		NS	NS	NS	NS	NS			
				Native Mix (t/ac)					
CH	-	0.6	1.1	0.7	1.1	1.5	-	-	1.0
SS	-	1.1	1.4	0.7	1.3	1.8	-	-	1.2
LSD(0.10)		NS	NS	NS	NS	NS			
				Precrop Mix (t/ac)					
CH	-	0.8	1.9	0.9	1.9	1.5	-	-	1.4
SS	-	1.1	1.7	0.8	2.1	1.6	-	-	1.4
LSD(0.10)		NS	NS	<0.1	NS	NS			
				Pubescent Wheatgrass (t/ac)					
CH	-	1.3	2.0	1.1	1.5	1.6	-	-	1.5
SS	-	1.2	2.2	0.9	2.1	2.0	-	-	1.7
LSD(0.10)		NS	NS	NS	0.5	NS			
				Tall Wheatgrass (t/ac)					
CH	-	0.5	1.1	1.1	1.5	1.8	-	-	1.2
SS	-	0.4	1.1	1.0	1.5	2.4	-	-	1.3
LSD(0.10)		NS	NS	NS	NS	0.5			
				Spring Wheat (bu/ac)					
CH	1.6	19.7	21.5	19.8	ND[3]	57.9	12.0	ND	22.1
SS	1.5	18.0	21.1	18.6	ND	56.2	13.9	ND	21.6
LSD(0.10)	NS	NS	NS	0.5	-	NS	NS	-	

[1] No forages were harvested the first year.

[2] Least significant difference at the P=0.10 level. NS indicates no significant difference between mean values.

[3] ND=no data, crop was lost due to a hail storm.

Another factor that may have contributed to the lack of significant differences between the tillage treatment for both the forages and wheat yields was the amount of precipitation received. Table 6 shows the deviation from "normal" rainfall from planting to harvest of the spring wheat (forages were usually harvested first but the trends did not differ much). All but two years at Glenharold and three years of the experiment at Knife River had less than "normal" rainfall as determined by the difference between the long-term average from nearby National Oceanic and Atmospheric Administration weather stations and the rain gages set up at each location.

Table 5. Tillage effects on forage and spring wheat yields at the Knife River location.

				Year of Data					
Tillage	**1989[1]**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995[1]**	**1996[1]**	**Mean**
				Alfalfa (t/ac)					
Chisel (CH)	-	0.6	1.0	0.7	1.6	0.9	-	-	1.0
Subsoiled (SS)	-	1.0	0.9	0.8	1.5	1.0	-	-	1.1
LSD(0.10)[2]		NS	NS	NS	NS	NS			
				Native Mix (t/ac)					
CH	-	1.1	1.3	0.8	1.3	1.1	-	-	1.1
SS	-	1.4	1.5	1.0	1.4	1.1	-	-	1.3
LSD(0.10)		NS	NS	NS	NS	NS			
				Precrop Mix (t/ac)					
CH	-	1.2	1.5	1.3	2.0	1.1	-	-	1.4
SS	-	1.4	1.6	1.2	1.9	1.0	-	-	1.4
LSD(0.10)	-	NS	NS	NS	NS	<0.1			
				Pubescent Wheatgrass (t/ac)					
CH	-	1.5	1.9	1.3	2.0	1.1	-	-	1.6
SS	-	1.8	2.0	1.4	2.0	1.2	-	-	1.7
LCD(0.10)		NS	NS	NS	NS	NS			
				Tall Wheatgrass (t/ac)					
CH	-	1.7	1.5	1.0	2.0	1.3	-	-	1.6
SS	-	1.6	1.5	0.9	1.7	1.4	-	-	1.5
LCD(0.10)		NS	NS	NS	0.2	NS			
				Spring Wheat (bu/ac)					
CH	2.7	11.0	15.7	22.2	39.8	28.8	29.4	41.2	23.8
SS	10.9	12.8	17.6	22.3	39.3	28.1	29.6	43.4	25.5
LCD(0.10)	2.0	NS	0.9	NS	NS	NS	NS	NS	

[1] No forage harvests in the first nor after the sixth year of study.

[2] Least significant difference at the P=0.10 level. NS indicates no significant difference between mean values.

Table 6. Deviation from long-term normal rainfall for the spring wheat crops grown at the two mineland locations.

Location	1989	1990	1991	1992	1993	1994	1995	1996
				Year of Data				
				Deviation from Long-term Normal (in)				
Glenharold	- 3.1	2.3	- 0.9	- 3.1	ND[1]	- 2.3	0.9	ND
Knife River	- 1.6	3.4	- 0.7	- 3.8	4.4	- 2.9	2.0	- 0.3

[1] No data since the crop was lost due to a hail storm.

Table 7 shows the effects of growing the forages either 3 or 6 years on the resultant spring wheat yields. The below normal rainfall amounts contributed to the below expected yields at both locations in 1992. The coarser-textured reclaimed soil at Knife River also contained less available soil water, on average within the subplots, than did the soils at Glenharold (data not shown) which also contributed to the difference seen in 1992. Although the rainfall amount was below normal in 1994 at Glenharold, this location had very good yields because of excellent stored soil moisture. The significant differences were believed to have been the result of stand variability within the plots

Table 7. Prior cropping effects on spring wheat yields at the Glenharold and Knife River mineland locations.

	Location									
	Glenharold					Knife River				
Prior Crop[1]	1992	1993	1994	1995	1996	1992	1993	1994	1995	1996
	Spring Wheat Yield (bu/ac)									
SG	18.7	-[2]	57.0	13.0	-[2]	22.2	39.6	28.4	29.5	42.3
AL3Y	21.0	-	60.3	8.5	-	13.9	47.7	27.6	32.8	42.4
NM3Y	24.3	-	56.4	12.3	-	19.3	46.2	28.0	33.1	45.1
PM3Y	22.0	-	56.8	11.9	-	13.8	52.6	30.1	33.2	41.6
PW3Y	22.0	-	55.4	12.1	-	17.4	46.6	27.6	31.4	35.7
TW3Y	20.3	-	53.3	15.8	-	18.4	45.4	28.4	32.8	42.6
AL6Y				14.6	-				25.9	46.0
NM6Y				12.0	-				21.5	49.7
PM6Y				11.1	-				24.8	45.8
PW6Y				12.5	-				19.8	44.0
TW6Y				17.9	-				24.5	44.8
LSD(0.10)[3]	2.4	-	3.4	2.8	-	1.9	NS	NS	2.4	NS

[1] SG= small grain, AL= alfalfa, NM= native mix, PM= precrop mix, PW= pubescent wheatgrass, and TW= tall wheatgrass. 3Y and 6y indicate the number of years of forage growth before seeding to spring wheat.

[2] Crop lost to hail.

[3] Least significant difference at the P=0.10 level. NS indicates no significant difference.

since the plots were only fertilized for a 40 bu/ac crop standard. A late seeding date in 1995 at the Glenharold location due to wet conditions resulted in the low yields that were obtained and probably caused the significant difference seen in Table 7.

The Knife River location plots showed no significance differences among mean values for prior cropping effect in 1993 and 1994. The main controlling factor for both years was water availability (both soil and rainfall) for crop growth. The above-normal rainfall in 1993 was directly responsible for the increased spring wheat yields above the 40 bu/ac standard. Removal of some of the fertilizer for the breakdown of the forage residues in 1995 caused the 6-year old plots to have significantly smaller spring wheat yields. As was the case in 1993 and 1994, the main contributing factor controlling yields in 1995 was available water and thus no significant difference were found.

CONCLUSIONS

The initial tillage treatment applied at these two reclaimed mineland locations, chisel and subsoiling, had no significant effect on forage and spring wheat yields for the following six years. Traffic across the surface following the initial tillage treatments (including planting, harvesting, and preparation for the next planting) most likely was the cause of no significant differences in bulk densities by depth measured over the years. The data would also seem to indicate that some reduction in yield for spring wheat would be likely after forages are grown due to applied fertilizer being used for residue breakdown. However, by the second year following the conversion from forage to spring wheat, the spring wheat yields seem to be more dependent upon available water assuming adequate fertilizer has been applied. Late seeding also resulted in decreased yields since the crop had to get established during the hotter portion of the growing season.

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2000 Billings Land Reclamation Symposium

THREE MINES - THREE CLIMATIC REGIONS

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ABSTRACT

A visual comparison (nonscientific review) of reclamation efforts in three climatic regions. Climatic regions for this paper include arid, semi-arid, and tropical. Bentonite mines in Colony, Wyoming (semi-arid) and Lovell, Wyoming (arid) and a barite mine in Camamu, Brazil (tropical). Brief history of each mine and the method of mining. We will discuss soil resource and handling for revegetation efforts at each mine. Finally, a discussion of revegetation practices in each climatic region and the reclamation performance.

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INTRODUCTION

What is bentonite? Bentonite is a clay mineral that is the result of the alteration of volcanic ash. Wyoming bentonite originated from volcanic ash ejected in western Wyoming and Idaho during the late Cretaceous period about 120 million years ago. Prevailing westerly winds blew the ash into Mowry Sea that cover most of the northern plains. Because of the chemical alteration to the ash by the sea water, Wyoming bentonite is a sodium-based bentonite. Most of the world's known reserves of sodium bentonite are found in the northern great plains of the United States. Bentonite is used in everything from drilling muds to pharmaceutical applications.

What is Barite? Barite is a heavy industrial mineral with specific gravity of 4.5. Barite is used in making paint, drilling mud additive, fine glass, and medical x-ray fluids.

Location

This paper represents reclamation observations made by company personnel at three of its mines. The Colony Mine is 85 miles northeast of Gillette, Wyoming, in Wyoming's Black Hills - Bentonite Spur District. The Lovell Mine is 100 miles south of Billings, Montana in Wyoming's Big Horn Basin. Finally, Camamu, Brazil is 650 miles north of Rio de Janeiro along Brazil's central coast.

Colony is located in a semi-arid climate zone with an annual precipitation of 16 inches. Rolling to flat topography with sagebrush dominate grasslands to rough barren breaks with hardpan soil conditions. Soils are typically clay-loam with thickness ranging from 5-30 inches. Lovell is located in an arid climate zone with an annual precipitation of 6-8 inches. Soils are typically sandy-loam with thickness ranging from 2-20 inches. Camamu is located in a tropical climate zone with an annual precipitation 80 inches. Organic vegetal soil that is less than 6 inches.

Brief History

Mining by the company in the Colony district began in the mid 1930's. We built the Colony Plant and rail line in 1948. Wyoming's first reclamation regulations were past in 1969. The majority of the land ownership is by private ranchers. Lovell mining began in 1977 and we built the Lovell Plant in 1981. The plant was temporary shut down between 1986 and 1994. Bentonite Performance Minerals is the world's third largest producer of bentonite, because of production achieved at the Colony and Lovell mines. Camamu began its mining operation in 1953. In the 1980's Brazil past a reclamation law. Three consulting firms conducted several environmental remediation studies during the 1990's.

Bentonite Mining for Colony & Lovell Mines

Bentonite mining is surface cast-back strip mining. A sequence of small pits with a volume between 50,000 and 150,000 yards (2-5 acres in size) is used to mine the clay deposit. BPM has developed a "tiered" (a stair step) system of backfill previous pits with material from the next pit. This consists of placing poor quality spoil from the pit excavation to fill the lower third of the previous pit. The upper portion of shale from the next pit is placed on top of the poor quality material. Third lift material (paralithic) immediately below the subsoil from the next successive pit is then placed on top of the upper shale spoil of the previous pit. Then we can haul to the backfill and place subsoil and topsoil on top of the third lift material. Overburden has bentonitic clay lenses that are high in sodium salts. By selectively handling overburden we can isolate material of lower quality from the root zone. The backfills are contoured to blend in with surrounding topography. As we strip each progressive pit, spoil is used to reclaim the previous pits in a timely and contemporous manor.

Revegetation Efforts for Colony & Lovell Mines

We schedule all permanent revegetation efforts (seedbed preparations and seeding) for the fall during October-November period of each year after the backfill has been contoured and topsoiled. The fall seeding allows us to maximize water retention of the winter and spring precipitation. In addition, weather conditions and soil conditions during the spring may not allow farm equipment to properly prepare the seedbed. We conduct all seedbed preparations on the contour. Revegetation of the disturbed lands is accomplished by preparing the seedbed with a spring tooth chisel plow. We have mounted a seedbox onto the chisel plow enabling an economical one pass seeding operation. The chisel plow creates deep furrows to trap moisture for the revegetation effort and control erosion.

The Colony Seedmix applied is the following:

Common Name	Scientific Name	lbs/PLS
Prairie Sandreed	*Calamovilfa longifolia*	2.0
Thickspike Wheatgrass	*Agropyron dasystachyum*	1.5
Western Wheatgrass	*Agropyron smithii*	3.0
Bluebunch Wheatgrass	*Agropyron spicatum*	1.0
Indian Ricegrass	*Oryzopsis hymenoides*	2.0
Green Needlegrass	*Stipa viridula*	1.0
Alkali Sacaton	*Sporobolus airoides*	1.25
Great Basin Wildrye	*Elymus junceus*	0.5
Russian Wildrye	*Elymus cinerus*	1.5
Purple Prairie clover	*Dalea purpurea*	0.25
Fall rye	*Secale cereale*	10.0
	Total	25.0

The fall rye is seeded as nurse crop with permanent seedmix. The fall rye protects the soil from erosion, adds organic mulch, and reduces weed infestation until the permanent vegetation is established. Permanent vegetation species were selected because of their drought and alkaline tolerance, and we discovered most of the species during the baseline study.

The Lovell Seedmix applied is the following:

Common Name	Scientific Name	lbs/PLS
Gardner Saltbush	*Atriplex gardneri*	7.0
Four-wing Saltbush	*Atriplex canescens*	1.5
Alkali Sacaton	*Sporobolus airoides*	2.0
Bluebunch Wheatgrass	*Agropyron spicatum*	2.5
Indian Ricegrass	*Oryzopsis hymenoides*	2.5
Prairie Sandreed	*Calamovilfa longifolia*	2.0
Russian Wildrye	*Elymus cinerus*	2.5
	Total	20.0

Rubber Rabbit brush *Chrysothamnus nauseosus* is spot seeded on side slopes. Permanent vegetation species were selected because of their drought and alkaline tolerance, and we discovered most of the species during the baseline study.

We can describe the seeding method as broadcasting, and nothing dragged behind the plow to cover the seeds. We apply no fertilizer, amendments nor irrigation to reclaimed ground. In my opinion, water is the limiting factor for successful revegetation. By preparing the seedbed to trap as much moisture as possible until the plant matures with deep roots to reach subsoil moisture.

Revegetation results at Colony are very visible. We have restored the tall grass prairie with a minor shrub component. Results at Lovell are also impressive by restoring shrub habitat with an increased grass component compared with the undisturbed land.

Camamu Barite Mining

The mining operation is located on a small off the coast of Brazil. Historically they conducted mining on two islands. Today mining is limited to the larger island. Small truck- shovel operation is used to mine barite. Spoil from the advancing pit sequence is used to backfill the previous pit. The overburden is acidic with high levels of aluminum. The backfill is contoured to reduce erosion. We salvage and stockpiled vegetal soil to be used to reclaim the pit sequence.

Revegetation Efforts at Camamu

We construct terraces across the pre-law spoil piles for erosion control. Every ten meters a tree was transplanted. Small trees (20-30 cm in height) were either purchased, donated or removed from the advancing pit area to be transplanted. Three species of trees were used for the ongoing revegetation efforts: Dende palm, Eucalyptus, and Pine. A 20X30X10 cm hole was prepared for each tree. Vegetal soil was placed into the hole to support the small trees. This gave the trees moisture retaining soil media and nutrients. To protect these trees from the harsh tropical sun, we constructed a canopy with palm leaves. Between the trees, we transplanted native sod from the advancing pit area. We worked the area between the transplants to encourage the invasion of native vegetation. Wherever possible furrows were made by the D-6 to breakup the compaction-hardpan and provide increase moisture retention.

Revegetation results 90 percent of the small trees transplanted have survived. The trees have grown 300 percent in 8 months. The sod transplants also have a survival rate near 90 percent. The sod has expanded to cover 20 times the area of original transplant size. The reclamation goal for Camamu mine is to stabilize the disturbed area s, revegetate the land, and establish a productive post-mine land use. The reforestation the islands will achieve these goals and provide an income source for the island’s population.

2000 Billings Land Reclamation Symposium

ENHANCING DIVERSITY THROUGH SUBSTRATE VARIABILITY

Douglas E. Romig and David L. Clark[1]

ABSTRACT

Reclamation diversity continues to receive much attention in reaction to the apparent homogeneity of many reclaimed rangelands in the west. Despite improved seed mixes and topsoil handling, reclaimed minelands in New Mexico remain relatively uniform, often dominated by a few aggressive grasses and four-wing saltbush. To date, regulators and operators have primarily focused on species richness or intra-community diversity of reclaimed plant communities, presumably because it is the easiest to evaluate. In conjunction with cautious suitability guidelines for rootzone reconstruction, this has sometimes led to the reestablishment of a single shrub-grassland plant community. While there are a number of parameters that influence post-mine diversity, we believe the physical and chemical variability of soil substrates is often overlooked and vital to creating long-term landscape diversity. Native soil-landscapes exhibit a broad spectrum of physio-chemical properties that give rise to large-scale, horizontal diversity between plant communities. Through the suitability guidelines and soil salvaging operations, there is a dramatic reduction of soil variability from pre-mine soils. Moreover, baseline information is seldom fully utilized in reclamation plans to increase species diversity or landscape heterogeneity. In this review of soil handling plans at selected mine sites, we critique the regulatory constraints that guide reclamation toward uniformity. In particular, rules regarding soil substitution, topsoil redistribution, desired plant community, potentially toxic materials, and landform reconstruction need to provide more flexibility to build soil-landscapes that enhance inter-community or horizontal diversity. Opportunities to offset this decrease in the soil variability will be illustrated while considering agronomic and toxicity issues.

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INTRODUCTION

While numerous studies over the past 25 years have addressed reconstructed minesoils and their relationship to post-mine diversity and production, reclamation diversity continues to receive much attention. We've been successful establishing minimal diversity within a shrub-grassland built on clean four foot root zones and seed mixes dominated by selected (aggressive) grasses. That pattern has demonstrated its limits with respect to horizontal diversity and many would argue that it needs adjustment.

Post-mine productivity has long been a topic of reclamation research. McCormack (1976), quoted extensively in SMCRA's preamble, argued for selective handling of soils with maximum potential and productive capacity. Many authors have focused on the minimum soil replacement depth needed for maximum post-mine productivity in the upper Great Plains (Merrill et al., 1985; Power et al., 1981; Barth and Martin, 1984). Though actual recommendations for soil depth depended on post-mining land use and spoil quality, all have concluded that a deeper soil produces more biomass.

Several authors have focused on varying the reconstructed soil properties and soil handling methods to increase post-mine diversity. DePuit (1984) recognized a number of soil handling strategies to increase diversity including direct haul, separate lifts of soil horizons, use of supplemental materials, depth variation, fertilization/treatment differences, and selective handling of soil types. In reclamation trials in oil shale areas in NW Colorado, soil properties associated with low productivity (shallow depth, high SAR and elevated coarse fragments) inhibited grass dominance, resulting in higher diversity (Stark and Redente, 1985; Biondini and Redente, 1986). A recent double wedge experiment in New Mexico demonstrated that within five years of a uniform seeding, specific spoil/soil depths gave rise to distinct plant communities (Buchanan et al., 1999).

Topographic effects on water redistribution has been shown to influence species diversity and production. Stark and Redente (1985) found a significant inverse correlation between a landscape positions ability to retain or harvest water and species richness measure by the Shannon Index. Merrill and coworkers (1998) observed those landscape positions that collected water tended to minimize production differences despite varying subsoil and total soil thickness.

To date, bond release applications approved by the New Mexico Mining and Minerals Division (MMD) have easily met the intra-community (alpha) diversity standards established in permits. Yet our post-mine plant communities continue to appear rather homogenous, with minor differences related to planting date and climatic variability during stand establishment. Prodgers and Keck (1996) attributed the apparent homogeneity to the lack of physiognomic (community structure) differences that are not discernable to the eye, even though measured floristic differences may be evident. We need to be clear here because we're comparing apples and oranges: alpha diversity is being achieved, but we desire more beta or inter-community diversity. It is our belief that there are two processes working in tandem that continue to guide us toward uniform appearing post-mine plant communities: homogenous reconstructed soil materials and "standard" reclamation methods.

Prodgers and Keck (1996) posed the question whether increased diversity on reclaimed minelands is truly desirable, implying that regulators were unwilling to permit strategies that would result in increased diversity. In New Mexico, we hope to encourage diversity without it becoming burdensome in an economic or regulatory sense. We fully understand to enhance post-mine diversity we must allow flexibility in reclamation plans. Moreover, we must know what we are capable of accomplishing given the tools and materials at our disposal. Here we examine some premine soil-landscapes to look for clues and opportunities to build more diverse plant communities and landscapes following mining. We also review the soil handling and reclamation plans at selected mine sites and critique the regulatory constraints that guide reclamation toward uniformity.

PREMINE LANDSCAPES & DIVERSITY

Baseline soils and vegetation data are the best means to decipher the intrinsic diversity of a native landscape and identify gradients that may increase reclamation diversity. Examination of the physical and chemical variability of soils that influence premine plant communities can assist in the development of reclamation plans that may produce greater diversity.

To illustrate how baseline data might be used to help design a diverse and beneficial post-mine landscape, we consider a current case in northwest New Mexico. The Bureau of Land Management recently changed the land use in the vicinity of an active coal mine to exclude grazing and improve mule deer winter range. The original reclamation plan developed by the mine operator for a grazing post-mine land use must now be revised for wildlife exclusively. This presented an opportunity to consider alternative reclamation methods that could potentially create more post-mine diversity and support wildlife.

The premine toposequence illustrates the relationship between genetic soil (A & B horizons) depth and differing plant communities (Figure 1). The Pinon-Juniper woodland was a major premine community found on shallow, gravelly soils on ridges and shoulder slopes. Portions of the P-J type were chained in 1961, and these areas subsequently developed into highly diverse mixed-shrub communities. Moving downslope, Sagebrush-grassland and Grassland communities occupied deeper Aridisols of alluvial fans and upland valleys. In upland drainages, arroyos, and swales, deep alluvial Fluvents support shrubland communities of greasewood and sagebrush.

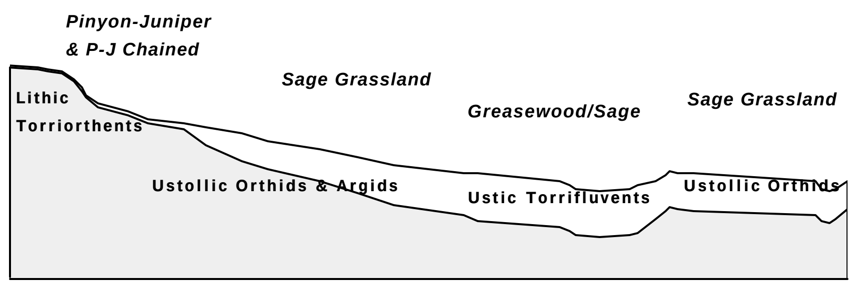

Figure 1: Toposequence of premine soils and associated plant communities in NW New Mexico. Genetic soil (A & B horizons) are indicated by clear portion of the figure

Similarities between the premine plant communities are given in Table 1. Despite the moderately high level of similarity as measured by Sorenson's (1948) Index, when one views the premine landscape it is easy to discern the different plant communities. This physiognomic diversity is certainly what most reclamationists would like to recreate, but we must recognize that the species differences are not that extreme.

Table 1: Sorenson's Index of Similarity for premine plant communities in NW New Mexico

Plant Community	Pinon-Juniper	P-J Chained	Grassland	Sage Grassland
P-J Chained	0.70	-		
Grassland	0.47	0.53	-	
Sage Grassland	0.66	0.61	0.67	-
Greasewood/Sage	0.64	0.55	0.62	0.76

In desert ecosystems of North America, soil salinity, sodicity and cation relationships have been shown to affect plant distributions and species diversity, especially at the landscape scale (Wallace et al., 1973; Franco-Vizcaino et al., 1993). Gates and others (1956) found significant edaphic differences between soils occupied by various shrub species in Utah, though no one species was completely restricted by a narrow range of a specific soil factor. Sagebrush and winterfat distribution were restricted by relatively high levels of salinity and sodium. Shadscale typically occupied soils with more intermediate levels of salt and sodium in the subsurface. Soils under greasewood were often, though not exclusively, high in salt throughout and alkaline below 6 in. (Gates et al., 1956).

Examination of the soil physical and chemical properties in the northwest NM premine toposequence (Figure 2) shows similar plant-soil relationships as described by Gates et al. (1956). For EC and SAR, variability increases both within and between soils as one moves downslope. While Greasewood-sagebrush communities may not be desirable in a reclaimed landscape, they are found on soils that are saline-alkali, especially at depth. This suggests that it may be necessary to have higher EC and sodicity in the lower portions of the reconstructed soil for certain post-mine plant communities.

Clay at depth is typical of well developed Aridisols with argillic horizons. In this landscape, argillic clay often occurs under Sagebrush grasslands (Figure 2). Current suitability standards restrict material >45% clay, presumably for agronomic and permeability reasons. Rejection of certain spoil materials could be a consequence of sample collection and preparation techniques (i.e. over-grinding) that may mask the positive effects of coarse fragments and minimal weathering that alleviate compaction and permeability problems.

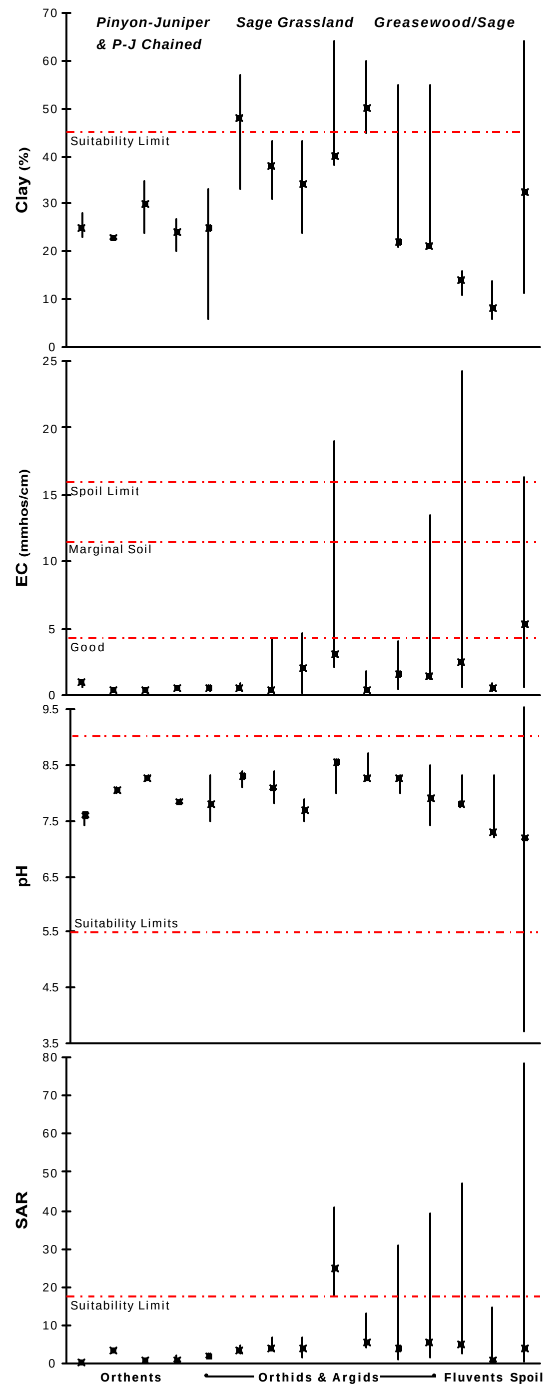

Figure 2: Physio-chemical variability of selected soils along a premine toposequence. Weighted average for salvageable topsoil indicated by marker; lines show variability within soil profile. Expected spoil variability on far right from premine

Soil reactivity appears to be uniformly alkaline across the landscape. Opportunities to introduce some habitat diversity based on acidic soil pH exist when one considers the expected variability of the spoil materials (Figure 2). Fortunately the spoils also have low acid generation potential. But with a truck-shovel operation, it is expected that only small areas of lower pH areas will occur sporadically in the regrade. The use of spoil pH as a gradient seems unlikely.

Figure 2 demonstrates that native plant communities in New Mexico often thrive on what the current guidelines and rules consider unsuitable. Suitability standards truncate the natural variability of soils and may need to be revisited if we desire reclamation diversity. For example, State and Federal single-factor suitability guidelines for sodicity were originally developed from agricultural standards (SAR=13) and modified for the purposes of SMCRA. New Mexico has graduated SAR suitability thresholds linked to clay content, but sodicity hazards are dependent on several other factors including pH, EC, mineralogy and soil-water regime (Munk, 1996). More recent agricultural standards recognize that relatively high levels of sodicity (e.g., SAR=40) are tolerable in the lower root zone when one considers other soil properties in the hazard assessment (Munk et al., 1999).

POST-MINE DIVERSITY

In New Mexico, we have been pleased by the level of alpha diversity on much of our reclaimed lands. Given that, we would still like to have more horizontal, inter-community diversity in reclamation within the liability period without imposing additional standards.

In the premine landscape, we discovered some opportunities to manipulate certain soil gradients that give rise to distinct plant communities: soil depth, texture, salinity and sodicity. But the gradients in native landscapes are quite different than those we encounter in reclaimed soils. Naturals soils are highly correlated to landscape position and vary less on a local scale. Properties of reclaimed soils vary across short distances from 1-10 m, while total variation is reduced on a larger scale (Schafer, 1979). Moreover, most minesoils properties have a weak spatial correlation at best, often exhibiting random variation horizontally (Keck et al., 1993; Keck and Wraith, 1996). The resultant gradients for plants in reclamation are both reduced and less connected than in natural landscapes (Prodgers and Keck, 1996). Suitability guidelines further constrain potential landscape variability as spoil and mitigation materials must meet a narrower set of criteria. As reclamationists, we need to overcome the homogenization of mining/reclamation process if we desire more post-mine diversity.

It goes without saying that the factors that created a diverse native landscape (parent material, organisms, climate, topography, and time) will not assist us much during the liability period. Because spoils and reclaimed soils are intimately mixed, we must create more dramatic soil habitat variations in reclamation if horizontal diversity is a goal. This may require regulators to rethink performance and suitability standards while asking the question what is truly phytotoxic or inhibits plant establishment so that the post-mining land use is not achieved. Regulators, however, cannot go it alone; operators need to propose alternative plans that enhance diversity that work within their specific mine operations.

For example, uniform soil replacement depth has been a standard reclamation method for the past 20 years. Uniform topdressing thickness makes for easy permit review and inspection, but it is a relic and slight misinterpretation of McCormack's (1976) observations on Eastern reclamation methods where the A and B horizons are segregated. McCormack's focus was on post-mine productivity, which has been shown to exclude diversity (Stark and Redente, 1985; Prodgers and Keck, 1996). He also suggested that only topsoil be uniformly returned and the B horizon material be place on the graded spoil "to the planned thickness to form the subsurface horizons." One final note about uniformity – only with respect to soils is it applied in the rules and uniformity is clearly discouraged for slopes and stream channels.

Returning to our example in northwest NM, standard topsoil replacement methods would likely recreate post-mine soils that have six inches of topsoil over 42 inches of neutral spoil.

Physically, the reconstructed soil would resemble those associated with Sagebrush-grasslands with deep effective root zones but modest genetic soil materials (Figures 3). To expect greater diversity beyond the inherent richness of the Sagebrush-grassland and the reclamation seed mix would be unreasonable.

A possible reclamation plan that would, in the view of the MMD, lead to successful achievement of the post-mine land use might include the following. The re-establishment of Pinyon-Juniper woodlands would be both difficult and of questionable value for the mule deer winter range land use, and the PJ type is abundantly available on unmined lands in the area. Reclamation that emulates the PJ-chained type could be accomplished by establishing a half-dozen shrub species, along with four or five taxa each of relatively noncompetitive grasses and forbs. Since spoil materials are not consolidated enough to be considered paralithic (Keck et al., 1993), this community may require a thin veneer of topdressing (<2”) over very coarse soil substitute materials on post-mine uplands to replicate the shallow, rocky premine soils. These upland sites would be slow to develop vegetative cover, but a fairly high percentage of coarse fragments would help stabilize the steeper slopes. A somewhat less diverse, but more productive, sagebrush-grassland revegetation could be readily established using standard reclamation techniques of seeding shrubs and predominantly warm season grasses into relatively deep soils (6-12”) on gentle lower slopes with north and east aspects. A cool season native grassland type on deeper soils would provide spring forage on south and west aspects. In place of the erosive greasewood bottomlands, reclaimed swales and bottoms (>12” topsoil) could be seeded with more aggressive, alkali-tolerant (and perhaps non-native) wheatgrasses, ryegrasses, and rhizomatous forbs. Within this matrix, occasional rock piles, ledges, talus slopes, and small depressions would further enhance vegetative diversity and wildlife habitat.

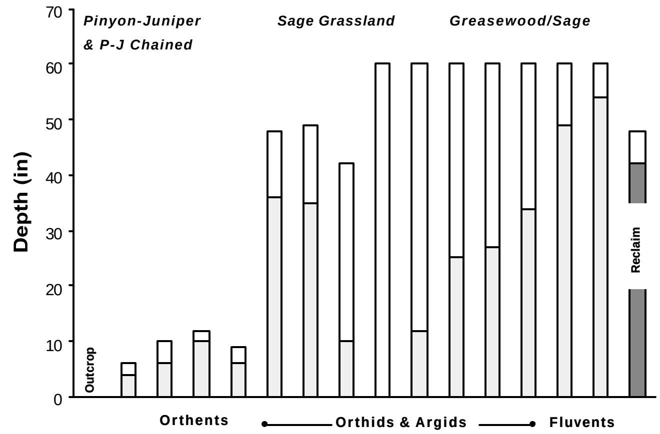

Figure 3: Soil depth along a topographic gradient in NW New Mexico. Genetic (A & B) horizons are clear portion of bars. Shaded portion is the effective depth of the profile. Typical reclaimed soil on

The past 20 years of coal mine reclamation history has shown that if enhancing diversity requires an excessive amount of paper work, it rarely happens. The key to making the plan become reality is to create a framework that will allow the operator to construct the various reclaimed communities and features without the need for constant permit modification, and that simultaneously gives the regulatory authority assurance that the reclamation plan is being followed. Narrative descriptions of the topographical settings and the approximate sizes that will be targeted for the reclaimed communities and features give the operator more flexibility than maps. Adequate detail should be provided in the reclamation plan so that an inspector can verify that an approved procedure was or is being used at any given location.

Establishing different technical standards or reference areas for comparison with each reclamation community will probably be advantageous, particularly with respect to stocking and production. As seen in Table 1, premine communities as visibly different as Pinyon-Juniper and Grassland may share fifty percent of their species composition. Communities with more similar physiognomy are even more similar in terms of species makeup. It seems unlikely that revegetation efforts would result in greater inter-community (beta) diversity than existed prior to disturbance of “native” communities. The establishment of inter-community species diversity standards for reclaimed areas therefore seems unreasonable, and establishing the approved species on the approved acreage should be considered satisfactory. The exclusion from quantitative revegetation standards for roads, water bodies, and rock piles can and should be extended to other small diversity enhancing features.

SUMMARY

The following are a sample of strategies that have been (or could be) employed by coal mine operators and regulatory authorities in an attempt to increase post-mine diversity and the achievement of the post-mine land use:

Reclamation Plans

1. Create dramatic variations in soils to enhance horizontal diversity using chemical and physical soil properties.
2. Vary soil depths according to topographic position and aspect and tailor seed mixes to soil depths as previously described. Consider hydrologic properties of various landscape positions and their contribution to post-mine diversity.
3. Use specialized seed mixes of saline- or alkali-adapted species on reclaimed areas having marginally suitable spoil within the root zone.
4. Avoid soil laydown on erosion control terraces and transplant shrubs directly in spoil. The terraces concentrate soil moisture, and soil is deposited from adjacent slopes over time. The temporary absence of topdressing favors shrub establishment. Small depressions provide similar advantages for vegetation requiring mesic soils.
5. Create ledges, outcrops, and talus slopes. These features do not have to be particularly high or extensive to provide habitat diversity for plants and animals. Ten to fifteen-foot relief is ample, and even ledges that are three or four feet tall can trap snow and provide burrowing sites. The key to incorporating these features during reclamation is to permit opportunistic construction where competent rock is available.
6. Expand the seeding window to allow early spring and late fall seedings. Designate substitute species and seeding rate ranges, so that operators can take advantage of, rather than be troubled by, variations in weather, soil moisture, topdressing and seed bank sources (e.g., stockpiled or live-hauled, weedy or pristine), and seed availability.
7. Make reclamation plans flexible by describing methods to be applied to and take advantage of certain regraded landforms rather than using maps. Minimize the need for permit modifications.
8. Be patient whenever non-uniform reclamation is attempted. Establishment of the desired species often takes three to five years harsher sites.

Regulatory Considerations

1. Encourage the use of soil substitute materials at any time rather than when there is a deficit of topsoil. These materials are often more coarse textured and skeletal, and can be used to armor slopes or replicate paralithic/torric soil conditions.
2. Revisit spoil/soil suitability standards and have them capture more of the variability found in premine soils. Keck and Wraith (1996) suggest that clear distinctions be made in suitability criteria between properties that severely limit plant growth or present environmental hazards and those that represent the normal variability found in native soil landscapes. Allow for a

small percentage of inhibitory soil properties to occur in the reclamation based on the distribution of native soil properties.

3. Use multiple factors rather than single factors to determine hazard associated with marginal soil chemistry components such as SAR and selenium.
4. Promote variable rather than uniform topdressing replacement in order to resemble premine soil landscapes.

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2000 Billings Land Reclamation Symposium

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

Brenda K. Schladweiler[1], Larry C. Munn[2], Rose Haroian[3], and Scott Belden[3]

ABSTRACT

Within native ecosystems, plant cover, production and diversity are often affected by the amount, type and quality (physical and chemical) of the topsoil present. Reclaimed areas at coal mines have federally mandated post-mining cover and production standards which are not difficult to meet; however, pre-mine levels of plant diversity have been difficult to attain.

According to current mining regulations, a uniform topsoil replacement depth must be utilized over a given mine permit area. For mine permit areas that have widely varying topsoil depths within large portions of their permit area, this poses significant complications from a mine planning standpoint. Approving variances for such conditions of existing coal mines often results in concerns from the Wyoming Department of Environmental Quality. Widely varying topsoil availability is inherent to abandoned mine situations where topsoil is often lacking or very limited.

In order to address concerns over utilizing varying topsoil replacement depth within a given permit area to enhance plant diversity, a study was funded by the Wyoming Abandoned Coal Mine Land Research Program (ACMLRP) to: 1) determine if shallower replacement depths of topsoil enhance plant species diversity; 2) determine if shallower replacement depths of topsoil affect vegetation cover and production; 3) evaluate the quality of replaced topsoil through time and between variable replacement depths; and based on these findings, 4) determine if variable soil replacement depths enhance the development and/or differentiation of post-mine vegetation communities.

Information derived from this study will be used to quantitatively assess the issue of variable topsoil replacement depths and resulting plant diversity, as well as other vegetation parameters. This issue is currently a concern within the state's mining industry, as well as the regulatory authority. Information from this study will be used to assess the direction of future reclamation work regarding vegetation/topsoil issues.

Study site construction was completed in Fall 1999. Data collection will be initiated in Summer 2000 and extend through Summer 2002. This paper presents the status of the project to date.

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INTRODUCTION

In order to address concerns over utilizing varying topsoil replacement depth within a given permit area to enhance plant diversity, a study was funded by the Wyoming Abandoned Coal Mine Land Research Program to: 1) determine if shallower replacement depths of topsoil enhance plant species diversity; 2) determine if shallower replacement depths of topsoil affect vegetation cover and production; 3) evaluate the quality of replaced topsoil through time and between variable replacement depths; and based on these findings, 4) determine if variable soil replacement depths enhance the development and/or differentiation of post-mine vegetation communities.

Based on these objectives, the following specific null hypotheses will be tested: 1) variable topsoil replacement depths do not influence vegetation cover and production; 2) variable topsoil replacement depths do not influence plant diversity; and 3) quality, in terms of electrical conductivity and pH, of the replaced topsoil layer will not deteriorate with topsoil depth.

ACTIVITY SUMMARY TO DATE

This project has been divided into three major tasks. This does not include summarization of the data on an annual basis and disseminating information to interested parties, both ACMLRP funding requirements.

Task I, Review Existing Vegetation/Soil Information

Previous topsoil depth studies on mined lands have included, in part: DePuit 1984; Doll, et al. 1984; Faught 1989; Fox 1993; Halvorson, et al. 1986; Oddie and Bailey 1988; and Schuman, et al. 1985. Previous literature was reviewed in addition to Wyoming Department of Environmental Quality, Land Quality Division (WDEQ-LQD) mine permit volumes (Appendix D-8, Vegetation, and D-7, Soil) and annual reports for various mines throughout the state on record at the WDEQ-LQD offices in Cheyenne, Sheridan (for Campbell County), and Cheyenne (for Converse County).

Task II, Establish and Construct the Study Site

The study site is located on the Rochelle Mine which is approximately 10 miles southeast of Wright, Wyoming. Refer to Figure 1. Rochelle Mine provided the equipment and manpower necessary to construct the field site. Site selection was determined by specific mine limitations, i.e., spoil grading, spoil sampling, topsoil/seeding contractor schedules.

The study site location was rough graded in Spring 1998. Block construction activities were conducted from late August to October 1998 with the exception of the cover crop seeding which was conducted in early December 1998. A two year extension on this project enabled the cover crop aspect of typical reclamation at the Rochelle Mine to be maintained. The permanent reclamation seed mix was seeded in late November 1999 and was derived to represent the pre-mining Breaks Grassland vegetation type. Within the time frame of the study, the permanent reclamation will be evaluated for three growing seasons (2000, 2001, and 2002).

The area was mowed during the 1999 growing season (mid-July). Mowing of the cover crop is a normal practice at the Rochelle and North Antelope Mines to reduce competition from the barley stubble with the permanent seed mix.

The chosen design alternative was randomized complete block (RCB) and was chosen based on mine limitations with equipment and available area. Within the RCB, one contiguous rectangular area was selected within the reclaimed topography with three distinct replicate blocks. Refer to Figure 2 which also depicts 1998 soil sample locations. Treatment alternatives included: 1) 22 inch "designated permit" replacement depth; 2) 12 inch replacement depth; and 3) 6 inch replacement depth. The treatment blocks were constructed on: 1) a uniform site to control variables other than topsoil depth (e.g., similar slope, aspect, stockpiled topsoil source, and seed mix); and 2) a landscape position that would best represent a pre- and post-mine Breaks Grassland community. Slopes were generally 5:1 and west-facing. The three designated depths were approximate over the treatment replicate and will have minor variation based on weather limitations present during 1998, topsoil source, and equipment utilized for topsoil replacement.

Treatment replication dimensions were 175 feet by 250 feet. A 25 foot buffer strip on all sides of the treatment replication was considered to minimize edge effect between replications due to equipment limitations. Therefore, a sample area of 125' x 200' was created within each treatment replication. Corners of treatment replicates were staked with appropriate depth indicators for equipment operators. Both Rochelle and BKS personnel were present during the course of study area construction to visually ensure proper depth placement.

Normal backfill suitability sampling of the study site was conducted by Rochelle Mine on 500 foot centers prior to topsoil placement. Refer to Table 1 for analysis. Approximate three-year-old stockpiled material was utilized for this area and was previously removed from former Breaks Grassland topography. Soils within undisturbed Breaks Grassland type consist of shallow entisols on side slopes and hill tops with moderately deep to deep entisols on fans and narrow drainages.

Existing Breaks Grassland and Upland Grassland native reference areas will be used to distinguish plant community development and differentiation between treatments. The RCB design was utilized in these native areas as much as possible. Three distinct areas were chosen in each reference area to represent the general slope, aspect and soil depth found in the reclaimed portion of the study. Within these three areas, general replication of the 22, 12, and 6 inch blocks were chosen, wherever possible.

In order to establish baseline soil fertility status at the reclaimed area treatments and reference areas, a minimum of 2 sample locations were collected within each reclaimed treatment replication. For general comparison purposes only, two samples within each of two native areas by soil depth were also gathered. Samples, at six-inch increments, were collected at 2 random locations within each respective treatment block before cover crop seeding on reclaimed areas in 1998. In the reference areas, samples were collected by horizon up to paralithic contact. Analysis parameters followed Table I-3 in WDEQ-LQD, Guideline 1 (1994). Listed analysis parameters include: organic matter, pH, electrical

conductivity (EC), nitrate-nitrogen, phosphorus, potassium, soluble cations: calcium (Ca), magnesium (Mg), and sodium (Na), sodium adsorption ratio, texture and particle size analysis. The University of Wyoming Soil Testing Laboratory conducted the analysis. Refer to Table 2 for results.

The study site, including treatments, were marked after permanent reclamation seeding in November 1999. Original corners were surveyed by Rochelle personnel and were easily remarked after equipment disturbance.

Task III, Obtain Quantitative Information

Vegetation and soil information gathering will be initiated in summer 2000. Field data collection will be conducted in 2000, 2001 and 2002. Cover, production, and plant diversity will be evaluated over all treatment levels.

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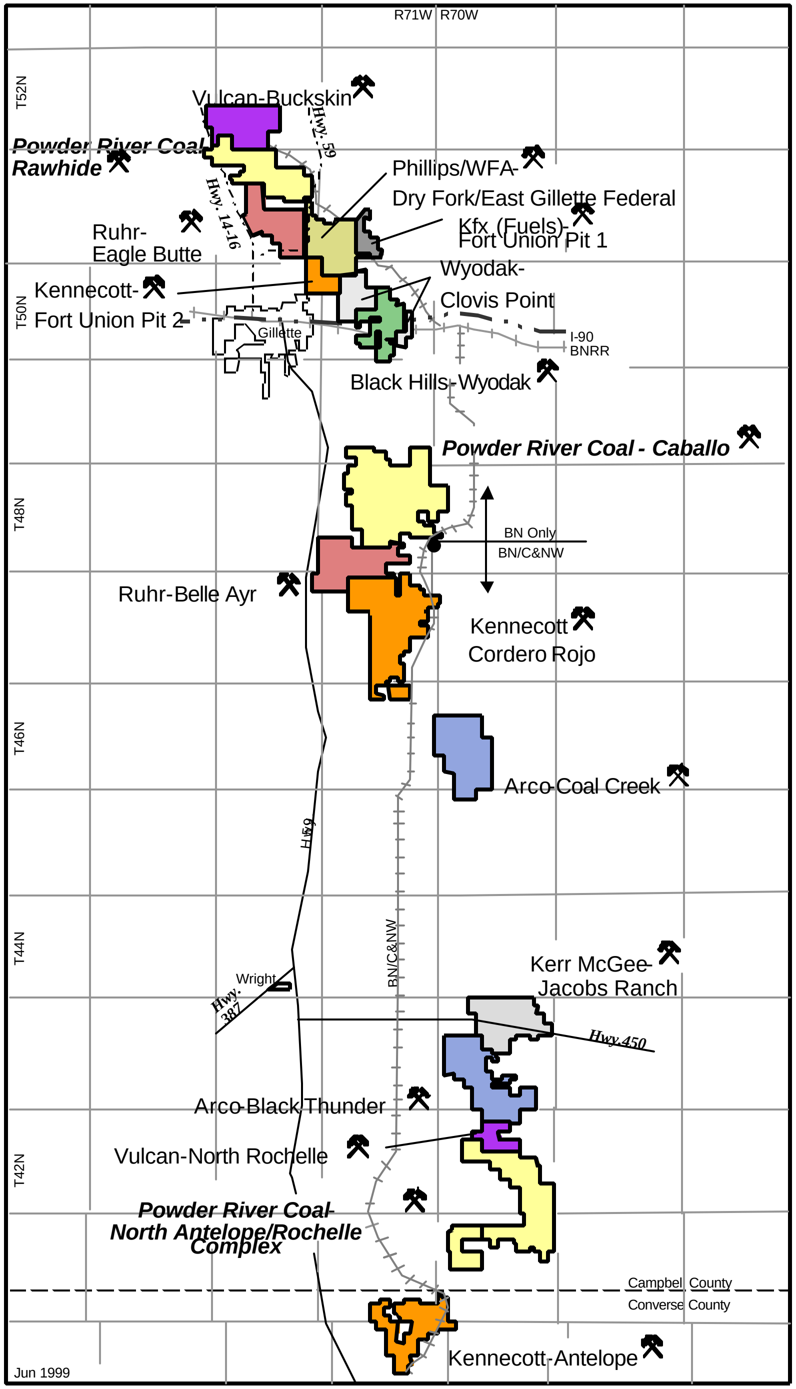
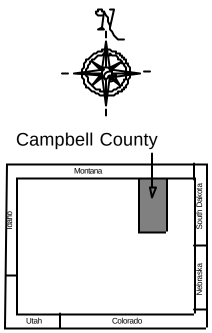


FIGURE 1. LOCATION OF NORTH ANTELOPE/ROCHELLE PERMIT AREA WITHIN EASTERN POWDER RIVER BASIN



Denotes Active Mine

FIGURE 2. SOIL SAMPLE LOCATIONS WITHIN TREATMENTS.

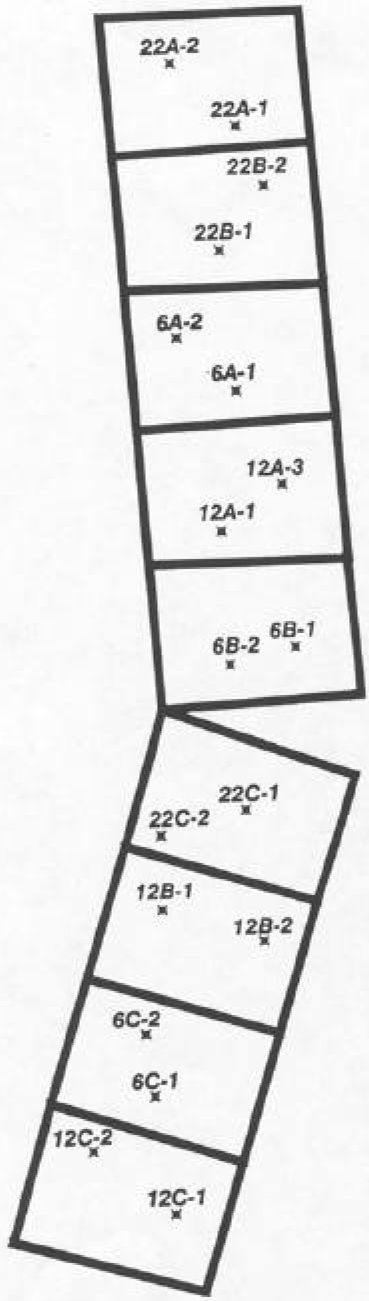


Table 1. 1998 Backfill Suitability Analysis in the Vicinity of the AML Variable Topsoil Study (WDEQ-LQD Guideline 1, 1994).

Location	Depth (ft)	pH	EC mmhos/cm	SAR	TOC %	Total S %	Total S ABP t/1000t	Nitrate N ppm	Hot Water Selenium ppm	AB-DTPA Se ppm
98BF27	0-2	7.8	1.23	7.61	5.6	0.05	11.6	2.90	0.11	
	2-4	7.9	1.42	8.72	6.1	0.06	4.24	6.70	0.14	
98BF28	0-2	7.5	1.55	5.89	6.6	0.13	2.81	1.48	0.19	
	2-4	7.4	1.81	5.87	7.8	0.24	-0.91	2.26	0.19	
98BF32	0-2	7.5	1.33	6.47	7.6	0.13	7.88	2.40	0.12	
	2-4	7.7	1.33	6.62	7.2	0.12	6.74	2.92	0.15	0.18
98BF33	0-2	8.0	1.25	6.97	5.2	0.05	5.47	0.90	0.18	
	2-4	8.0	1.24	6.73	5.3	0.06	5.09	1.02	0.20	
98BF34	0-2	7.8	1.39	6.19	4.2	0.04	3.29	3.84	0.21	
	2-4	7.8	1.31	5.81	4.2	0.04	2.45	0.98	0.17	
98BF39	0-2	6.5	2.98	4.54	6.4	0.15	-0.42	0.34	0.12	
	2-4	5.1	4.04	3.90	6.5	0.24	-4.47	0.26	0.11	0.15
98BF41	0-2	7.2	2.69	6.43	5.9	0.13	2.70	10.10	0.30	
	2-4	7.4	1.88	6.90	5.6	0.06	3.70	6.28	0.26	
98BF42	0-2	6.8	3.18	5.72	7.0	0.10	2.13	1.98	0.30	
	2-4	7.1	2.87	4.99	3.9	0.18	-1.95	2.66	0.14	
98BF43	0-2	7.4	4.60	5.13	5.1	0.14	0.30	14.20	0.36	0.40
	2-4	7.4	5.16	5.51	5.2	0.14	4.65	12.70	0.30	
98BF-44	0-2	6.3	3.92	4.30	6.9	0.17	-1.85	4.26	0.22	
	2-4	6.4	4.01	4.43	7.7	0.16	0.20	10.20	0.2	

Table 2. Study Area Compared to Breaks/Upland Grassland Reference

BREAKS SAMPLE LOCATION	**WEIGHTED VALUES**		
	Depth	**EC dS/m**	**SAR**
b-6-1	0-6	1.15	0.22
b-6-2	0-6	0.59	0.21
b-12-1	0-6	0.45	0.33
b-12-2	0-6	0.57	0.21
	6-12	0.64	0.20
b-22-1	0-6	0.39	0.36
	6-12	0.42	0.56
	12-18	0.42	0.56
b-22-1	0-6	0.57	2.95
	6-12	0.92	4.47
	12-18	1.33	4.61

UPLAND GRASSLAND SAMPLE LOCATION	**WEIGHTED VALUES**		
	Depth	**EC dS/m**	**SAR**
ug-6-1	0-6	0.30	0.48
	6-12	1.32	1.12
	12-18	1.86	1.29
ug-6-2	0-6	4.13	1.74
	6-12	10.16	4.34
ug-12-1	0-6	3.97	2.61
	6-12	7.78	3.97
	12-18	11.12	4.28
ug-22-1	0-6	1.15	0.36
	6-12	1.01	0.60

SAMPLE LOCATION	**AVERAGE VALUES**		
	Depth	**EC dS/m**	**SAR**
6a1, 6a2, 6b1, 6b2, 6c1, 6c2	0-6	2.0	0.7
6a1, 6a2, 6b1, 6b2, 6c1, 6c2	6-12	1.5	2.6
6a1, 6a2, 6b1, 6b2, 6c1, 6c2	12-18	1.9	4.7
12a1, 12a2, 12b1, 12b2, 12c1, 12c2	0-6	2.0	0.9
12a1, 12a2, 12b1, 12b2, 12c1, 12c2	6-12	2.2	1.5
12a1, 12a2, 12b1, 12b2, 12c1, 12c2	12-18	1.7	3.0
12a1	18-24	1.9	5.5
22a1, 22a2, 22b1, 22b2, 22c1, 22c2	0-6	2.9	1.7
22a1, 22a2, 22b1, 22b2, 22c1, 22c2	6-12	3.1	1.8
22a1, 22a2, 22b1, 22b2, 22c1, 22c2	12-18	2.4	1.3
22a1, 22a2, 22b1, 22b2, 22c1, 22c2	18-24	1.9	3.2
22b2, 22c2	24-30	1.7	2.2

Table 3. Study Area Permanent Seed Mix for 2.5 Acres

Mix # 28037			
Shrub-Grass Mix/Drill	**% Pure**	**Lbs. Pls**	**Pure * Lbs**
Prairie Sandreed	0.0346	31.27	1.08
Munro Globemallow	0.0353	31.27	1.10
Western Wheatgrass	0.0670	31.27	2.10
Rocky Mountain Penstemon	0.0691	31.27	2.16
Green Needlegrass	0.0714	31.27	2.23
Sandberg Bluegrass	0.0738	31.27	2.31
Little Bluestem	0.0755	31.27	2.36
Cicer Milkvetch	0.1037	31.27	3.24
Thickspike Wheatgrass	0.1368	31.27	4.28
Fourwing Saltbush	0.1418	31.27	4.43
Gardner Saltbush	0.1559	31.27	4.87
Other Crop	0.0004	31.27	0.01
Inert Matter	0.0343	31.27	1.07
Weed Seed	0.0004	31.27	0.01
Subtotal			**31.25**
Mix # 28038			
Shrub-Grass Mix/Broadcast	**% Pure**	**Lbs. Pls**	**Pure * Lbs**
Winterfat	0.0708	9.21	0.65
Blue Grama	0.0775	9.21	0.71
Wyoming Big Sagebrush	0.1117	9.21	1.03
Subtotal			**2.39**
Total			**33.64**

2000 Billings Land Reclamation Symposium

ALTERATION OF TOPSOIL DEPTH FOR SHRUB ESTABLISHMENT

By

Tim W. Meikle[1], Vern Pfannenstiel[2], and Roy Karo[3]

ABSTRACT

Topsoil is vital to the establishment of many grass and forb species on reclamation areas. Woody species, however, have a greater adaptation to coarse, rocky and shallow soils and may be inhibited by grass competition resulting from topsoil application. The purpose of this study was to investigate edaphic controls of plant community establishment by comparing shrub growth and survival on topsoiled and graded spoil treatments. Adjacent topsoiled and non-topsoiled plots were planted with serviceberry (*Amelanchier alnifolia*), chokecherry (*Prunus virginiana*) and Gambel's oak (*Quercus gambelii*). A total of ten 50 m2 belt transects were randomly placed along a baseline within each plot. Data was collected annually for three years. Variables measured included presence/ absence, herbaceous cover, growth and mycorrhizal colonization. Shrub survival was significantly higher ($p<0.5$) on the non-topsoiled treatment (76%) than the topsoiled treatment (47%). Neither growth nor mycorrhizal colonization varied between treatments. Herbaceous cover, however, was similar in both treatments and provided minimal competition to shrubs. Factors other than plant competition appear responsible for differences in shrub survival on the site.

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INTRODUCTION

The Colorado Surface Coal Mine Reclamation Act of 1979 requires woody plant restoration as criteria for bond release in the coal mining regions of northwest Colorado. Woody plant restoration has been problematic, however, due to quickly establishing rhizomatous grasses and browse by deer and elk (Mathews and Savage 1990). The ability to control grass competition could greatly increase shrub survival and establishment within shrub establishment areas. In particular, the control of grass establishment through modification of soil depth and quality could result in a method for shrub establishment that also reduces reclamation costs. The purpose of this study was to investigate edaphic controls of plant community establishment by comparing shrub growth and survival on topsoiled and graded spoil treatments.

Plant community composition is ultimately determined by the physical, chemical and biological properties of the substrates on which they form. Indeed, restorationists have attempted to manipulate and predict community composition based upon specific soil factors. Several studies have demonstrated that soil nitrogen level strongly affects plant community composition (Tilman and Wedin 1991; McLendon and Redente 1992). Researchers have also used soil texture and depth in attempts to predict species composition and establishment (Blomquist and Lyon 1993; Chambers, Brown et al. 1994; Pendleton, Nelson et al. 1996; Brown, Sidle et al. 1991). In general, these studies have identified strong relationships between increasing grass biomass and increasing nutrient level and soil quality. Thus, topsoil application on shrub restoration areas may create edaphic conditions that typically select for grass as opposed to shrubs.

A divergent concept is the designed placement of spoils on shrub establishment areas to provide an environmental filter that favors shrub establishment. The concept of "environmental filtering" is best described by Wilson as a condition in which species are excluded from a site based upon their inability to tolerate the physical environment (Wilson 1999). For example, serviceberry (*Amelanchier alnifolia*), chokecherry (*Prunus virginiana*), and Gambel's oak (*Quercus gambelii)* are particularly well adapted to coarse soils and rocky sites (USDA 1988). Creation of these conditions may well favor shrub establishment while creating unfavorable conditions for the vigorous establishment of competing grasses.

STUDY AREA

The study area is Seneca II Mine which is located in the Upper Yampa River Basin near Hayden , Colorado. The area is characterized by mountainous terrain with deeply dipping coal seams. Dominant vegetation of native areas consists of sagebrush/grass communities on lower elevations of the site and mountain shrub communities at mid-elevations. Characteristic shrubs within the mountain shrub community are serviceberry, chokecherry, and Gambel's oak. Rainfall varies from 16 to 20 inches with most occurring as snowfall during the winter months.

METHODS

The study was conducted on an unreclaimed northwest-facing slope. The treatments tested were: 1) topsoil application of approximately 21 centimeters; and 2) unaltered spoil. Half of the slope received topsoil application while the other half remained bare. A commercial tree planting crew planted the site with a mixture of containerized serviceberry, chokecherry, and Gambel's oak during fall 1995. Neither seed nor fertilizer were applied to the site.

Soil analysis was conducted on both topsoil and spoil substrates (Table 1). Spoil had a larger clay fraction and higher salinity level than topsoil. Topsoil, in contrast, contained higher levels of organic matter and nitrogen. Phosphorus, potassium and pH were similar between the two substrates. As an observation, the spoil portion of the site contained a substantially higher portion of rock.

The site was monitored for a period of three years. A total of ten randomly placed 2 meter X 25 meter transects were placed within each treatment plot. Variables measured on the site were presence/absence of woody species, herbaceous cover, shoot height, root length, and mycorrhizal status. Herbaceous cover was measured by placing five 0.5 meter X 0.5 meter quadrats along each transect line and visually estimating cover. Mycorrhizal status was measured from root cuttings that were cleared, stained, and evaluated using standard methodologies. Analysis consisted of comparison of variables and factors using Analysis of Variance.

Table 1. Physical and chemical characteristics of treatment substrates.

	Topsoil	Spoil
Texture	silt loam	silt clay loam
pH	6.7	6.9
Salts (mmhos/cm)	0.9	1.7
Organic Matter (%)	2.5	1.3
Organic N (lbs/acre)	46.7	31.7
Nitrate-N (ppm)	32.7	4.3
Phosphorus (ppm)	10.0	14.3
Potassium (ppm)	103.3	100.0

RESULTS

Shrub survival was significantly higher ($p<0.05$) on the spoil treatment (76%) than on the topsoil treatment (47%) (Table 2). This mirrors a consistent trend since the beginning of the study with mortality occurring on the topsoil treatment at a dramatically higher rate. The topsoil treatment lost approximately 20% of its plants annually while the spoil treatment lost approximately 9% of its plants annually. Gambel's oak had high survival rates on both treatments (spoil=84%; topsoil=71%) which were not significantly different from one another. Serviceberry and chokecherry were strongly significant, however. Serviceberry survival was 62% on the spoil treatment versus 38% on the topsoil treatment. Chokecherry was 82% on the spoil treatment versus 31% on the topsoil treatment.

Table 2. Summary of results (Similar letters indicate no significant difference).

Treatment	Survival (%)	Shoot Length (cm), n=150	Root Length (cm), n=8	Mycorrhizal Colonization (%), n=8
Topsoil	47a	12.5a	28.6a	100a
Spoil	76b	11.8a	29.5a	87.5a

Neither shoot height nor root length were significantly different between treatments. Shoot length on both treatments appears substantially limited by continuous browse from resident deer and elk herds. Initial heights of plants were 10.7, 12.1, and 9.0 centimeters respectively for serviceberry, chokecherry, and Gambel's oak. After three growing seasons, shoot height had increased to a mere 13.0, 12.5, and 11.0 centimeters respectively. A large majority of shrubs were noted as browsed during each monitoring period which accounts for poor top growth. An estimated 45% - 88% of all shrubs were browsed on an annual basis. The roots, in contrast, had increased dramatically in length. Initial root lenth was approximately 20.3 centimeters for all species. After three years, roots had extended to 28.0, 28.7, and 30.4 centimeters for serviceberry, chokecherry, and Gambel's oak, respectively. Neither media appeared to inhibit rooting which was to be expected as they had very similar texture.

Plant competition did not significantly affect survival in this study. Indeed, grass competition was non-existent during the course of the study with less than 1% cover by grasses on either site during the course of three years. During the second year of monitoring, weed cover on the topsoil treatment tended to be substantially higher with 11.5% cover as opposed to 3.4% cover on the spoil treatment. After three growing seasons, weedy species, such as Canada thistle (*Cirsium arvense*), appeared in similar amounts (8.6% vs. 8.3% cover) in spoil and topsoil treatments. Overall, plant competition never appeared to reach levels that would inhibit establishment of woody species on the site.

Colonization by mycorrhizal fungi was essentially the same between the topsoil and spoil treatment at the end of three years. Neither treatment appeared to inhibit or promote colonization within the timeframe of the study.

DISCUSSION

In contrast to our original theory, plant competition did not significantly alter shrub establishment potential on either site. Lack of a seed bank and possibly herbicide application prior to planting prevented large amounts of grass or weed coverage from developing. Despite sufficient levels of nitrate-N in the topsoil, these species did not establish and dominate either site. Thus, this study did not provide an adequate test the "environmental filter" concept. Despite this, the study did identify that shrub survival was significantly greater and plant growth similar on graded spoil substrates.

Browse damage is most likely responsible for the higher mortality on the topsoil treatment. Other studies have identified this as a limiting factor on heavily used sites (Hoffman and Wambolt 1996). The spoil substrate may have mitigated the impacts of browse due to substrate texture. A majority of shrub mortality occurred during the year following substantial browse damage. It is hypothesized that the lower bulk density of the topsoil may cause deer and elk to pull up entire plants rather than simply nipping the tips of the shoots. In contrast, the heavier spoil substrate may anchor seedlings more securely and prevent removal of the roots. Intact but extracted plants were found on the site as evidence. This phenomenon has been observed at other heavily browsed sites.

Existing volunteer plant cover may also have mitigated the loss of shrubs due to browse. Plants with the greatest growth were observed in the canopy of Canada thistle suggesting that herbivores avoided browsing these microsites. A more desirable, short-lived plant species that provides similar protection could potentially be used over large areas to increase growth on shrub restoration sites.

CONCLUSION

Research has successfully demonstrated the benefits of topsoil application to grass establishment. Where restoration objectives are different and topsoil resources are limited, however, topsoil may impede the establishment of desired plant associations. This is particularly true in the establishment of mountain shrub communities of Colorado. Spoil provided a superior media for shrub survival in this study. The results do not necessarily reflect differences in edaphic factors however, but a greater tolerance to browse pressure. Although plant competition was not determined to be a factor, the concept of "environmental filters" to selectively promote establishment of shrubs over grasses deserves further research.

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2000 Billings Land Reclamation Symposium

MIXED SHRUB RECLAMATION: THE RECLAMATION OF AN IMPORTANT HABITAT

Bruce Waage[1], Chris Yde[2], Pete Martin[3] and Steve Regele[4]

ABSTRACT

Current regulations under the Surface Mine Control and Reclamation Act (SMCRA) require that land disturbed by surface coal mining be reclaimed to a condition that supports the approved postmining land use. Western Energy Company's Rosebud Mine occurs in the eastern Montana ponderosa pine belt typified by wide-open valleys outlined with rugged steep buttes. Livestock grazing and wildlife usage are the primary premining and postmining land uses.

While mined land generally has been reclaimed to a productive, useful state for both livestock and wildlife, need for improvements to Western Energy's reclamation program was evident. The State regulatory authority and reclamation managers at the mine recognized that the postmining land surface had been simplified and in some instances overly smoothed. Consequently, it appeared that important habitats such as the mixed shrub type have not been replaced, postmine plant species diversity for wildlife associated with these sites maybe reduced, and the likelihood of achieving one aspect of our reclamation goals and standards was questionable.

The "mixed shrub" term is used in this paper to include three U.S. Soil Conservation Service (now the NRCS) Technical Range Site Descriptions "thin breaks", "badlands" and "thin hilly". These range sites are similar in several aspects. Slopes are generally steep, with some nearly vertical escarpments, ranging from 25 to 75 percent. Soil development is nearly absent with sandy, shale, or clay parent material exposed at the surface. Total annual herbage production (dry air) is low, ranging from 100 pounds per acre in unfavorable years to 900 pounds in favorable years. These types, however, provide important habitat components for a number of plant and animal species.

Western Energy's reclamation program now includes the mixed shrub habitat type. It enhances both the topographic and vegetative diversity required for these postmine habitats. The habitat needs for both niche specific wildlife and vegetation species are being provided. Wildlife habitat generalists and cattle also use this type for both food and shelter. Results are presented with the understanding that these sites are in an early seral developmental stage.

Key words: Topography, thin breaks, diversity reclamation badlands, vegetation

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INTRODUCTION

The Montana Strip and Underground Mine Reclamation Act (MSUMRA) and the associated Administrative Rules of Montana (ARM) require that all disturbance within active coal mines be reclaimed to the approximate original contour (AOC). As defined by ARM 17.24.301(13) AOC means "that surface configuration achieved by backfilling and grading of disturbed areas so that the reclaimed area, including any terracing or access roads, closely resembles the general surface configuration of the land prior to disturbance and blends into and compliments the drainage pattern of the surrounding terrain, with all highwalls, spoil piles, waste piles, and depressions [except as provided in ARM 17.24.503(1)] eliminated."

Current coal mining regulations also require that land disturbed by mining be reclaimed to a condition that supports the approved postmining land use (ARM 17.24.762). The approved postmine land uses are livestock grazing and wildlife habitat. To a lesser extent, agricultural fields (small grains and alfalfa hayland) have been approved through the alternate reclamation process. Although currently reclaimed areas are recognized to be highly productive and useful for both wildlife and livestock, generally showing an increase in vegetative production and cover, there has been concern that the reclaimed landscape has been modified (i.e. simplified, overly smoothed topographically) to the detriment of landscape, vegetation and wildlife diversity. Therefore, the quality of the postmine habitats as it relates to diversity may be reduced for a select group of plants and wildlife species.

Complex topographic features found in nature contribute to vegetative diversity and the formation of microhabitat niches. Odum (1959) emphasized that "the ecological niche of an organism depends not only on where it lives but also on what it does." In our region, many important habitat features for various plants, as well as for big game, small mammals, raptors and other wildlife are found in areas of steep slopes, incised drainages and "badlands". Wood et.al. (1989) indicated badlands were especially important as they accounted for fifty percent or more of the use measured by both mule deer and white-tailed deer in a Montana prairie environment. Mackie (1991) states that mule deer are morplogically adapted to steep rugged terrain. The term "badlands" is used as defined in U.S.D.A. Soil Conservation Service Technical Range Site Descriptions (Zacek et.al. 1977). Other site descriptions included therein are "thin breaks" and "thin hilly". All three of these sites are common in areas mined by Western Energy Company (WECO). The "mixed shrub" term is used in this paper in relation to these three site descriptions.

ROSEBUD MINE

Premine "Mixed Shrub" Habitat

WECO's Rosebud Mine occurs in the eastern Montana ponderosa pine belt typified by wide-open valleys outlined with rugged steep buttes, intermixed with the "mixed shrub" habitat type. At the Rosebud Mine, the "mixed shrub" type comprises approximately 250 acres or one percent of the total premine habitat. This habitat typically occurs on exposed elevated ridges and on steep side slopes. The sites have underdeveloped soils and are generally underlain with weathered and highly eroded sandstone and shales. The “mixed shrub” type is most distinguished by the lack of soil development and exposed topographic positions (ECON, 1983). Hard rock and resistant bed outcroppings at different levels on steep irregular slopes are also commonly associated with this type (Zacek et.al. 1977).

The great variability in regard to soil and topographic makeup results in plant species and wildlife use unique to these sites. At many points within the “mixed shrub” area, vegetation is almost non-existent. ECON (1983) reported a standing crop of 681 pounds per acre for this type compared to 1,212 pounds per acre for the sagebrush grassland types. Although these sites have low vegetation production, they are important for wildlife because of topographic and vegetative diversity. Some native plant species are found only on these sites, and now with the “mixed shrub” reclamation, these plants are found only at these sites within reclamation. The 1983 ECON study identified seven plant species found only on the “mixed shrub” samples. Expanded to an equalized acreage comparison, this number amounts to 73 unique plant species per 1000 acres compared to 6 unique species per 1000 acres for the other identified habitat types on the Rosebud Mine.

“Mixed Shrub” Reclamation

WECO developed and implemented the reclamation of the “mixed shrub” habitat type to address three issues.

- To replace the “mixed shrub” plant community and the diversity of plant species, with special emphasis on shrub species lost during mining as per ARM 17.24.711.
- To advance premine topographic diversity (AOC) ARM 17.24.301 (13)
- To improve habitat for a variety of wildlife species.

One purpose of the mixed shrub replacement is to comply with ARM 17.24.711 requiring reestablishment of vegetation of equal utility to natural premine vegetation. Such reclamation also establishes or enhances important wildlife habitat which would be lost without this habitat being reclaimed as per ARM 17.24.751(2)(f). “Mixed shrub” sites provide diverse patterns of slope, gradient, aspect, increased edge, thin soils and topographic relief as exist in the premine landscape. By providing these characteristics, vegetation requiring this environment for establishment, survival and self propagation will establish and thrive over the long term. The “mixed shrub” reclamation is furthering our goal of reestablishing native vegetation found on the land prior to mining and facilitating the achievement of bond release on mined lands.

Mixed-shrub reclamation increases topographic and vegetative diversity, both of which are valuable to wildlife, by providing terrain features not found in much of the previous reclamation performed at the Rosebud mine. These terrain features, though they represent a very small percentage of premine and postmine area, are important as they contribute to a more complete postmine ecosystem encompassing habitat for wildlife. Topographic relief enhances animals ability to escape and hide. It also provides thermal protection in the form of warm, wind free winter habitat, as well as shaded areas during warmer weather. The importance of habitat diversity for wildlife species is supported by a large amount of literature (Laycock 1980). For that matter, the same can be said for livestock. The environmental characteristics of natural hill, ridge and breaks habitat in Montana include largely undeveloped soils, drastic topographic relief and variable vegetation community types (Wentdland et al 1992). In New Mexico strip mine reclamation, it was found that species diversity, richness and abundance of birds, small mammals and larger mammals were higher on the diverse unreclaimed spoil than they were on the reclaimed lands (Steele and Grant 1982).

In a North Dakota study (Wollenhauph and Richardson, 1982) of 5,000 acres of forty year old strip mine spoil piles which are similar in topography to the mixed shrub reclamation, the different niches on the variety of slopes and aspects were found to promote vegetative diversity. Every draw, even those exceeding a 100% slope, had woody, grass and forb vegetation. The areas between spoil piles, as exists in the mixed shrub reclamation, were found to have "The most remarkable vegetation establishment." "Mixed shrub" reclamation is also consistent with rule ARM 17.24.751. (2) (e) "…the operator shall… ensure that reclamation will provide for habitat needs of various wildlife species in an equal or greater capacity than was provided prior to mining. Special attention must be given to inanimate elements such as rock outcrops, boulders, rubble, dead trees, etc., that may have existed on the surface prior to mining and to plant species with proven nutritional and cover value for fish and wildlife." The "mixed shrub" reclamation is an attempt to provide for the habitat needs of wildlife known to frequent these areas. Boulders, rubble and gumbo knobs (similar to that which existed prior to mining) are an integral component of the "mixed shrub" reclamation.

The "mixed shrub" reclamation work is accomplished on a site specific basis primarily with D11 caterpillar dozers and 651 caterpillar scrapers. Occasionally, front-end loaders and 14 foot blades are also utilized. Seed is normally applied in a mixture of water and fiber mulch at the rate of approximately 12 PLS pounds per acre. The seed mix applied to the mixed shrub site, Area D, Rosebud Mine was as follows:

Mixed Shrub – grass

Species	Variety	Origin	PLS mix %
Western wheatgrass	Rosana	MT	15.2
Bluebunch wheatgrass	Secar	WY	16.0
Green needle grass	Lodorm	MT	15.9
Sideoats grama	Pierre	SD	15.9
Indian ricegrass	Nezpar	MT	15.9
Little bluestem	Camper	NE	16.2
Fourwing saltbush	native	WY	4.9

Mixed shrub – forb & shrub

Species	Variety	Origin	PLS mix %
Fringed sagewort		MT	1.7
Prairie sagewort		WY	2.0
Sulphur buckwheat		NV	9.8
Big sagebrush		WY	60.8
Silver sagebrush		WY	7.5
Winterfat		NM	13.1
Rubber rabbitbrush		UT	5.1

Tubelings (1-0, 10 cu. in.) are also planted on the mixed shrub sites. Since the spring of 1998 there have been 300 *Pinus ponderosa*, 200 *Juniperus scopulorum,* 900 *Chrysothamnus nauseosus,* 300 *Rhus trilobata* , 200 *Artemisia tridentata* ,and 600 *Artemisia cana* hand planted on the Area D site. A survey of woody plant density conducted by Steven Viert (1999) resulted in the data shown in Table D2. The total density of 3753.5 live plants per acre is encouraging for the initial revegetation and should increase with time.

Discussion

Numerous professionals have stated that present reclamation practices often permanently reduce or eliminate premine topographic diversity (Wendtland et al 1992). Specifically concerning strip mine reclamation, provisions of the law which limit steep slopes and rimrock terrain dissected by draws, result in the almost complete elimination of topographic diversity (Harju 1980). Reclamation for wildlife should stress diversity of habitat, topography and vegetation. Reclamation of premining contours with creation of irregularities of terrain is encouraged for wildlife (Harju 1980).

Some coal-mining reclamation rules seem to conflict with each other and with the stated goals and intent of reclamation. Yde (1999) made the following statement regarding some of the mining regulations: "It appeared that a straight forward approach had been established that ensured reclamation to a condition that closely approximated the premine situation. However, several rules were adopted that actually conflicted with the AOC (Approximate Original Contour) requirements, each other and/or the intent of the law. Examples of these include:

- The requirement that slopes could not exceed 5(h): 1(v) unless otherwise approved by the Department.
- Soil must be redistributed in a manner that achieves approximate uniform thickness.
- The nine-inch rill and gully rule.
- Elimination of depressions unless they were approved by the Department or were less than 1 yd^3 in size.

In Montana, as well as much of the West, the premine landscape is often steeper than 5(h): 1(v), contains a variety of topographic and erosional features, and is covered by a variety of growth media of varying depths. A diversity of vegetation is supported by this topographic and substrate diversity. The combination of topographic and vegetative diversity supports a diverse wildlife community while providing for livestock grazing"

Statutory mandates to reestablish a "…diverse, effective, and permanent vegetative cover… capable of self-regeneration …", and to "… minimize disturbance and adverse impacts … on fish, wildlife, and related environmental values and achieve enhancement of such resources where practicable… taking into consideration the physical, climatological, and other characteristics of the site…" are notable Montana coal-mine reclamation requirements. As stated by Regele (1997) " The ability to meet these mandates is often compromised or negated by ardent desires to homogenize postmine landscapes, by minimizing the variability of postmine planting substrates and by completely eliminating steep slopes, highwall rock outcrops, spoil piles, nick points, etc."

Montana's coal program has revised many of the Administrative Rules to encourage the development of a more diverse postmine landscape to enhance the diversity goals. The "Mixed Shrub" habitat reclamation is just one approach being used by WECO to meet the intended goal of providing the diverse topography, plant community and wildlife habitat required following mining.

Table D2
Reclaimed Woody Plant Density - 1999

Thin Breaks - Erosion Feat. Area - Habitat Type - Area D		Based on Evaluation of 10 2m x 100m Belt Transects						
		No. of Plants by Life Stage					Total	Total
Species	Life Form	Seedling	Young	Mature	Decadent	Dead	Young & Mature	Young & Mature Per Acre
Artemisia tridentata	Shrub			12			**12**	**24.3**
Atriplex canescens	Shrub		67	393			**460**	**930.8**
Ceratoides lanata	Half-Sh		125	1205			**1330**	**2691.2**
Chrysothamnus nauseosus	Shrub			3			**3**	**6.1**
Juniperus scopulorum	Tree		8				**8**	**16.2**
Pinus ponderosa	Tree		36		1		**36**	**72.8**
Rhus trilobata	Shrub			3			**3**	**6.1**
Xanthocephalum sarothrae	Half-Sh			3			**3**	**6.1**
Total by Life Stage		**0**	**236**	**1619**	**1**	**0**	**1855**	**3753.5**

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2000 Billings Land Reclamation Symposium

THE TOPSOIL DILEMMA

George F. Vance[1] and Lowell K. Spackman[2]

ABSTRACT

Wyoming's noncoal small mines are defined as surface mining operations involving not more than 7,650 m^3 (10,000 cubic yards) of overburden and 4 ha (10 acres) of affected land in any one year. A dispute over topsoil material classifying as overburden reached the highest court in Wyoming. Although the Wyoming Department of Environmental Quality (WDEQ) classifies topsoil and subsoil separate from overburden, as defined in the Wyoming Noncoal Rules and Regulations, Wyoming statutes defines overburden as "... all of the earth and other materials which lie above the mineral deposit and also means such earth and other materials disturbed from their natural state in the process of mining, or mining from exposed natural deposits." For small mines, the amount of material classifying as overburden for a 4 ha (10 acre) area amounts to a depth of approximately 19 cm (7 1/2 inches), or for a 0.4 ha (1acre) area to a depth of about 190 cm (75 inches). As the regulatory agency for small mines, WDEQ has considered topsoil separate from overburden for several reasons. Topsoil and subsoil is salvaged and reused for reclamation of the disturbed site and topsoil represents surface soils that will support plant life. Information is presented on the chemical and physical properties of samples collected from topsoil and subsoil piles and native areas at a small Wyoming gravel mining operation. A greenhouse study was also conducted using thickspike wheatgrass (*Agropyron dasystachyum*), a cool-season grass, and blue grama (*Bouteloua gracilis*), a warm-season grass. Results show that soil materials supported the growth of plants, and that plants grew best in the surface A and B horizon material. Inferences from this study suggest the Wyoming statutes should be changed to accommodate the distinct properties of topsoil, subsoil and overburden (e.g., spoil).

Additional Key Words: Guidelines, Noncoal Mines, Spoil, Subsoil, Wyoming Statutes

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INTRODUCTION

In 1996, owners of a small gravel-mining operation appeared before the Wyoming Environmental Quality Council (WEQC), an official administrative committee that resolves issues involving the Wyoming Department of Environmental Quality (WDEQ), for possible violations of the state's small mining rules and regulations (EQC, 1997). The question of topsoil and subsoil being part of overburden was heard by the WEQC due to the definition of overburden in the Wyoming statutes. The Wyoming Supreme Court (WSC) subsequently ruled in favor of the EQC, with Justice William Taylor stating that the statutory definition of overburden "could not be more clear". However, Taylor went on to say that the definition "is pivotal in the regulatory scheme governing reclamation efforts in the mining process because topsoil must be separately preserved and managed" (Laramie Boomerang, 1998). His comments suggest that while topsoil and subsoil must be considered overburden when calculating volumes, the soil should also be managed separately from overburden materials. However, this distinction is not totally clear in the Wyoming Statutes (W.S.) of the Environmental Quality Act.

Wyoming's noncoal small mines are defined as "surface mining operations involving not more than ten thousand (10,000) yards of overburden and ten (10) acres of affected land in any one (1) year" (W.S.§35-11-401(j)). The Wyoming Statutes define overburden as "all of the earth and other materials which lie above the mineral deposit and also means such earth and other materials disturbed from their natural state in the process on mining, or mining from exposed natural deposits." Although the statutes do not define spoil material, the WDEQ - Land Quality Division (LQD) Noncoal Rules and Regulations do define this term. These rules state that "Spoil means overburden removed during the mining operation to expose the mineral and does not include the marketable mineral, subsoil or topsoil." Therefore, the WDEQ has consistently required separating topsoil and subsoil from overburden so mine operators use the highest quality materials in reclaiming the disturbed areas.

A general definition of topsoil is provided in the Statutes. According to these Statutes, "Topsoil means soil on the surface prior to mining that will support plant life." However, a more specific definition is provided in the WDEQ-LQD Noncoal Rules and Regulations. Chapter 1 of these rules further states that "Topsoil means the A and E Horizons or any combination thereof," while "Subsoil means the B and C Horizons excluding consolidated bedrock material." Inclusion of topsoil and subsoil as overburden for volumetric calculations has confused the users of the statutes and regulations. This confusion may result in minimal amounts of surface soil removal in some mining operations. The effects of including soil with overburden in the criteria that defines the allowable amount of material removed is discussed further in the Summary and Conclusions section.

The objectives of this study were to determine the chemical and physical properties of samples collected from topsoil piles, subsoil piles and an unmined area at the small, gravel-mining operation that was the focus of citizen, WDEQ, WEQC, and WSC concerns. A greenhouse study was also conducted using the gravel-mine soil and subsoil materials. Both a warm-season and cool-season grass were seeded in the soil or subsoil materials to evaluate their plant growth potential. These plant species were selected because of their value in revegetating disturbed environments (Munshower, 1994). In addition to field and greenhouse results, we also present changes that should be considered in modifying the Wyoming Statutes for Small Mines.

MATERIALS AND METHODS

The study site is located east of Casper, WY and is classified as a small gravel mine based on the intent to mine 10 acres or less per year. The site is situated between an unimproved road and a Burlington Northern Railroad right-of-way. Site topography is classified as a flood plain bench that contains sorted gravels. Precipitation in the area averages an annual rate of 30 cm (12 inches). Site use was mainly for rangeland purposes, with the grazing conditions considered fair to good.

Boreholes of the permitted area indicated the soil profile depth was within the 0 to 150 cm (0 to 60 inch) range specified in a NRCS Soil Survey. An attempt was made by the operators to strip and preserve the upper soil material (A and B horizons) for future reclamation. These horizons are referred to as the topsoil for proposes of this investigation. The lower or subsoil materials below the topsoil and above the gravel bed interface were also stripped and stockpiled separately. A thin lens (- 15 cm or 6 inches) of calcareous precipitate existed between the bottom of the soil profile and the gravel. A portion of the calcareous material was used as a mining product to bind the segregated gravel.

During the initial quarry process, topsoil from the area to be mined was stripped and placed in three stockpiles that were marked Stockpile J, L and M. One subsoil stockpile (marked Stockpile K) was also created from the remaining material that was removed to expose the calcareous precipitate lens and gravel seam. Soil samples were collected from the stockpiles and a native area using a bucket auger. Two to three holes were bored on top of the stockpiles, which were spaced across the pile depending upon its size. The depth of samples ranged from 0-20, 20-40 and 40-100 cm (0-8, 8-16, and 16-40 inches). Three boreholes were also sampled on adjacent undisturbed lands that were expected to be mined the following year. Soil samples on these unmined sites were collected from depths of 0-10, 10-30, 30-90 and 90-165 cm (0-4, 4-12, 12-36, and 36-66 inches). Chemical and physical analyses were preformed in the University of Wyoming soil test laboratory (Table 1). Texture was determined using the feel method, coarse fragments by separating the greater than 2mm particles using dry sieving, organic matter (OM) with dry combustion, $CaCO_3$ by titration, pH and electrical conductivity (EC) in saturated paste extracts, and P and N by standard soil fertility tests.

The greenhouse study involved the preparation of four 7.5 cm (3 inch) pots containing each stockpiled and native soil material. A total of 156 pots were prepared with half planted in thickspike wheatgrass (*Agropyron dasystachyum*), a cool-season grass, and half blue grama (*Bouteloua gracilis*), a warm-season grass.

RESULTS AND DISCUSSION

Topsoil and Subsoil Characterization

Results of the chemical and physical analysis of topsoil and subsoil stockpiles (Table 1) suggest the materials are suitable for use as a surface cover. Based on WDEQ-LQD Guideline No. 1 for topsoil suitability (Table 2), all stockpiled materials have pH, EC, texture and coarse fragments that are considered suitable or marginally suitable. Except for sample L2C, which has a high %coarse fragment and %$CaCO_3$ contents, the rest of the topsoil stockpiled materials appear to be well suited as materials acceptable for reclamation purposes. Subsoil stockpiled materials had higher pH levels and generally greater contents of $CaCO_3$ than the stockpiled topsoil. The stockpiled subsoil materials were classified as marginally suitable because of their high pH, but the high %$CaCO_3$ may also limit these materials for revegetation purposes.

Table 1. Physical and chemical characteristics of topsoil/subsoil stockpiles and native materials from a small, gravel-mine operation.

Sample Number	Sample ID	Depth (cm)	Texture	Coarse Frag (%)	OM (%)	Paste pH	EC (dS/m)	$\%CaCO_3$	PO_4-P (mg/kg)	NO_3-N (mg/kg)
				TOPSOIL PILE						
1	**J1A**	**0-20**	**scl**	**4.0**	**0.6**	**8.0**	**0.4**	**0.7**	**2**	**1**
2	**J1B**	**20-40**	**scl**	**2.6**	**0.9**	**8.2**	**0.5**	**2.8**	**2**	**4**
3	**J1C**	**40-100**	**scl**	**3.0**	**0.8**	**8.1**	**0.4**	**2.8**	**4**	**2**
4	**J2A**	**0-20**	**scl**	**2.2**	**1.1**	**7.9**	**0.4**	**0.8**	**2**	**3**
5	**J2B**	**20-40**	**scl**	**3.7**	**1.6**	**7.9**	**0.8**	**2.1**	**8**	**17**
6	**J2C**	**40-100**	**scl**	**3.8**	**1.0**	**8.3**	**0.4**	**3.6**	**4**	**18**
7	**J3A**	**0-20**	**cl**	**0.3**	**1.2**	**8.3**	**0.3**	**0.9**	**2**	**3**
8	**J3B**	**20-40**	**sl**	**2.0**	**1.2**	**8.0**	**0.5**	**1.1**	**8**	**10**
9	**J3C**	**40-100**	**scl**	**3.3**	**1.2**	**8.1**	**0.4**	**2.4**	**4**	**4**
				TOPSOIL PILE						
10	**L1A**	**0-20**	**ls**	**3.7**	**0.8**	**8.1**	**1.0**	**1.1**	**4**	**7**
11	**L1B**	**20-40**	**ls**	**1.5**	**0.4**	**8.1**	**0.7**	**1.1**	**4**	**6**
12	**L1C**	**40-100**	**ls**	**5.3**	**0.7**	**8.3**	**0.4**	**1.5**	**2**	**4**
13	**L2A**	**0-20**	**ls**	**1.2**	**0.6**	**8.1**	**0.5**	**1.7**	**4**	**1**
14	**L2B**	**20-40**	**sl**	**15.1**	**0.7**	**8.0**	**0.6**	**1.9**	**4**	**10**
15	**L2C**	**40-100**	**sl**	**25.9**	**0.6**	**8.1**	**0.6**	**24.2**	**4**	**7**
				TOPSOIL PILE						
16	**M1A**	**0-20**	**sl**	**0.4**	**0.9**	**8.0**	**0.6**	**0.8**	**4**	**3**
17	**M1B**	**20-40**	**sl**	**2.2**	**0.9**	**8.0**	**0.6**	**1.2**	**2**	**6**
18	**M1C**	**40-100**	**sl**	**0.7**	**1.2**	**8.0**	**0.5**	**0.6**	**2**	**3**
19	**M2A**	**0-20**	**sl**	**2.1**	**1.0**	**8.0**	**0.5**	**1.3**	**2**	**3**
20	**M2B**	**20-40**	**sl**	**2.0**	**0.9**	**8.0**	**0.5**	**1.6**	**2**	**1**
21	**M2C**	**40-100**	**sl**	**1.0**	**1.0**	**8.1**	**0.5**	**1.2**	**2**	**2**
				SUBSOIL PILE						
22	**K1A**	**0-20**	**scl**	**10.8**	**0.4**	**8.7**	**0.4**	**10.3**	**2**	**1**
23	**K1B**	**20-40**	**scl**	**10.6**	**0.5**	**8.6**	**0.5**	**7.1**	**2**	**1**
24	**K1C**	**40-100**	**scl**	**7.3**	**0.4**	**8.7**	**1.0**	**9.3**	**2**	**0**
25	**K2A**	**0-20**	**scl**	**4.5**	**0.7**	**8.6**	**0.4**	**6.8**	**2**	**0**
26	**K2B**	**20-40**	**scl**	**6.2**	**0.5**	**8.9**	**0.4**	**9.2**	**2**	**0**
27	**K2C**	**40-100**	**scl**	**11.8**	**0.4**	**8.7**	**1.0**	**9.2**	**2**	**1**
				NATIVE SOILS						
28	**B1A**	**0-10**	**sl**	**0.2**	**1.4**	**7.6**	**0.4**	**NR**	**6**	**0**
29	**B1B**	**10-30**	**sl**	**0.9**	**1.1**	**8.0**	**0.4**	**1.1**	**4**	**0**
30	**B1C**	**30-90**	**sl**	**0.6**	**0.6**	**8.2**	**0.4**	**4.1**	**2**	**0**
31	**B1D**	**90-165**	**sl**	**5.7**	**0.2**	**8.7**	**0.9**	**9.1**	**2**	**0**
32	**B2A**	**0-10**	**sl**	**<0.1**	**1.4**	**7.7**	**0.5**	**NR**	**6**	**0**
33	**B2B**	**10-30**	**sl**	**0.1**	**0.9**	**7.9**	**0.5**	**1.9**	**4**	**0**
34	**B2C**	**30-90**	**sl**	**1.4**	**0.5**	**8.4**	**0.5**	**5.1**	**2**	**0**
35	**B2D**	**90-165**	**sl**	**3.8**	**0.2**	**9.2**	**0.8**	**8.1**	**2**	**0**
36	**B3A**	**0-10**	**sl**	**0.6**	**1.6**	**7.1**	**0.4**	**NR**	**12**	**1**
37	**B3B**	**10-30**	**sl**	**0.6**	**1.2**	**7.9**	**0.4**	**NR**	**6**	**0**
38	**B3C**	**30-90**	**sl**	**3.1**	**0.5**	**8.2**	**3.4**	**8.6**	**2**	**0**
39	**B3D**	**90-165**	**sl**	**0.4**	**0.3**	**8.3**	**7.3**	**7.8**	**2**	**0**

scl = sandy clay loam, cl = clay loam, sl = sandy loam, ls = loamy sand,:NR = not reactive

Native soil samples had consistent physical and chemical characteristics based on the depth of sampling. Surface horizons (0-10 cm or 0-4 inch depth) were highest in OM and phosphorus, with the lowest values for coarse fragments, pH, EC and %$CaCO_3$. Subsoil materials collected from the 90-165 cm (36-66 inch) depth were generally the highest in coarse fragments, pH, EC, and %$CaCO_3$, and lowest in OM and phosphorus. The high pH and %$CaCO_3$ may also limit the revegetation potential of these deeper subsoil materials. Although this material was not analyzed, calcareous materials from the gravel/subsoil interface would be expected to have high salt contents, high pH levels and potentially high %coarse fragments that would impede the growth of most revegetation plant species.

Some mixing of topsoil and subsoil during stockpiling is generally expected. However, examination of samples from topsoil pile L suggests that significant amounts of gravel (%coarse fragments) were inadvertently combined with topsoil materials. For example, topsoil samples L2B and L2C have distinctively high %coarse fragment contents, and L2C has the highest %$CaCO_3$ of all the samples evaluated in this study.

Table 2. Wyoming Department of Environmental Quality criteria for topsoil (or topsoil substitutes) and overburden suitability. From WDEQ-LQD Guideline No. 1 (1984)

Parameter	Suitable	Marginally-Suitable	Unsuitable
pH	5.5 - 8.5€	5.9 - 5.5 8.5 - 9.0	<5.0 >9.0
EC (dS/m)	0 - 8	8 - 12	>12
Texture		clay, silty clay, sand	
Coarse Fragments (%)	<25%	25 - 35%	>35%

Greenhouse Study

Once the grasses germinated, the plants were watered on a biweekly basis for 3 months. Pots were randomly distributed to prevent selective growth due to light, temperature and watering conditions. Although field variables would be expected to vary from those encountered in the greenhouse, including temperature, moisture, light, and wind conditions, the study provides information on the general soil properties that could potentially impact the revegetation of the small mine using the salvaged topsoil and subsoil materials.

Thickspike wheatgrass, a cool-season grass, resulted in better overall growth when compared to blue grama, a warm-season grass. The greenhouse study indicated there were differences in biomass production between the two plant species in the different topsoil/subsoil materials. It should be noted, however, that both plant species did grow and would be useful for revegetation purposes.

For Topsoil Stockpile J, thickspick wheatgrass growth was best in samples collected from borehole 2 represented by samples J2A,B,C, although good plant growth was also established in boreholes 1 and 3 (J1A,B,C and J3A,B,C) materials. Blue grama growth appeared to be impeded in samples from borehole 1, but grew well in borehole 2 and 3 samples.

For Topsoil Stockpile L samples, favorable thickspike wheatgrass growth was noted in soils collected from both boreholes (L1A,B,C and L2A,B,C). Blue grama, however, grew best in the surface soils collected from both boreholes, with a general decrease in biomass production with depth. Borehole 1 (L1A,B,C) materials resulted in better plant growth for blue grama than did borehole 2 (L2A,B,C) soils. Thickspike wheatgrass also grew well in Topsoil Stockpile M soil materials (M1A,B,C and M2A,B,C). As with the other topsoil stockpile materials, blue grama growth was less than that of thickspike wheatgrass and showed little variation in the overall biomass production for the different soils tested.

Subsoil Stockpile K was the only stored subsoil material sampled. With thickspick wheatgrass there was an evident trend in better plant growth with increasing depth of the subsoil material collected. A different trend was noted with blue grama - better growth was found with subsoil samples collected from borehole 2 (K2A,B,C).

Native soils were also better growth media for thickspick wheat grass than for blue grama. While little difference was noted with plant productivity for blue grama from topsoil and subsoil samples B1A,B,C, B2A,B,C, and B3A,B,C, samples collected from the bottom of the profile containing materials from the calcareous gravel/subsoil that interface reduced blue grama germination and growth. From the three borehole samples collected in the native area it was evident that topsoil samples resulted in the greatest thickspike wheatgrass production. Interesting among the latter results is that samples from the deepest sample depth (samples B1D, B2D and B3D) resulted in relatively good growth of thickspick wheatgrass in two of the three materials.

SUMMARY AND CONCLUSIONS

Results suggest that soil materials collected from the gravel mine topsoil and subsoil stockpiles are capable of supporting the growth of the two plant species tested. Plants generally grew best in the topsoil material. The study also demonstrates that lower biomass production resulted from blue grama as compared to thickspick wheatgrass. Inferences from this study suggest the Wyoming statutes should be changed to accommodate and differentiate the distinct properties of topsoil, subsoils and overburden (e.g., spoil) and their relationship to reclamation efforts to restore the environmental quality of disturbed landscapes. These changes need to address the confusion found in the current statutes.

Wyoming Statutes state that "Overburden means all of the earth and other materials which lie above the mineral deposit and also means such earth and other materials disturbed from their natural state in the process of mining, or mining from exposed natural deposits." A major problem associated with this definition is based on the original description of a small mine. For example, in a 4 ha (10 acre) area, 7,650 m^3 (10,000 yards) of overburden, including soil, is the amount of material collect from the surface to a depth of approximately 19 cm (7½ inches). Many soils in Wyoming have depths much deeper than seven inches. Even if only 0.4 ha (1 acre) is considered for a small mining operation, the law still only allows operators to remove overburden to a depth of about 190 cm (75 inches). The intent of the law was probably not to be this restrictive. WDEQ as the regulatory agency for small mines has considered topsoil/subsoil separate from overburden for several reasons, including: 1) topsoil is salvaged and reused for reclamation of the disturbed site, 2) spoil is defined as overburden removed during the mining operation to expose the mineral and does not include the marketable mineral, subsoil or topsoil, whereas topsoil means "soil on the surface prior to mining that will support plant life", and 3) distinctive references are made throughout the statutes that refer to overburden, topsoil and subsoil as separate entities.

Suggested Modifications to Wyoming's Statutes Governing Small Mines

Included below are suggested modifications to the proposed 1999 Wyoming Senate file and House bill that did not receive favorable recommendations in the respective legislative Joint Minerals, Business and Economic Development Interim Committees. Due to a lack of compromise by legislators in both governing bodies, the 1999 proposals were not advanced out of committee.

Several concerns were noted by individuals opposed to the file and bill; however, one of the primary reasons both file and bill failed was due to the inclusion of a forty (40) acre (16 ha) size limit for small mines. Currently, ten (10) acre (4 ha) limits are used for small mines, but enlarging the area to be designated as a small mine concerned some legislators, in part, because of the need for regulating larger mines by more rigorous standards. It is our opinion that this change doomed the file and bill from further consideration by both Senate and House bodies, respectively. These issues are separate concerns and should be addressed independently.

Separating topsoil and subsoil from overburden needs to be addressed in the Wyoming Statutes for Small Mines. As noted in the previous section, an area the size of current small mining designation would allow only the removal of 19 cm (7½ inches) of all surface material above the mineral, per year. Clearly, this does not take into account the fact that topsoil and subsoil will be utilized in the future for reclamation purposes. Currently, WDEQ-LQD Noncoal Rules and Regulations prevent small mine operators from handling topsoil, subsoil, and overburden as one material. Operators are required to present plans on how topsoil and subsoil will be salvaged and utilized in revegetation efforts. Bond release is dependent on completing reclamation of the small mine disturbance area. Revegetation success is directly related to the salvage and subsequent replacement of the soil.

In conclusion, we suggest both Wyoming's Senate and House be presented with a file and bill from Joint Minerals, Business and Economic Development Interim Committees in the 2000 legislative session that only considers topsoil/subsoil criteria. There should be adequate protection of this material for use in successful reclamation programs proposed for each small mine. Future legislative considerations involving reclamation efforts should be coordinated with WDEQ, EQC, and small mine operators.

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2000 Billings Land Reclamation Symposium

IN-PLACE TOPSOIL PRESERVATION AND STORAGE AS AN EXPERIMENTAL PRACTICE

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ABSTRACT

When planning a new mine, all aspects of final reclamation, including erosion control, slope stability, channel reconstruction, and revegetation must be considered in the initial facility design and permitting processes. As part of this process, mine construction planning must include the regulatory requirements for topsoil removal, storage and replacement. In steep, rugged and rocky canyons of central Utah, salvaging topsoil can be difficult, expensive, or even impossible. West Ridge Resources is conducting an Experimental Practice at its new West Ridge Mine that involves protecting topsoil in place rather than using the traditional method of salvaging and stockpiling the soil. On steep slopes and in ephemeral channel areas where topsoil removal was difficult, the undisturbed topsoil was protected in place by covering the soil with geotextile fabric prior to placement of mine yard construction non-toxic fill material. Saving topsoil in place should not only preserve soil structure but also soil integrity, which includes the integration of soil, roots and rocks. This Experimental Practice procedure has the added benefits of preserving the original ground surface configuration, existing stream channel and bank morphology which all should work together to promote reclamation slope stability and erosion control.

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INTRODUCTION

During 1999, West Ridge Resources, Inc., (West Ridge) constructed a new underground coal mine in eastern Carbon County, Utah. The Surface Mining Control and Reclamation Act, 1977, (SMCRA) provides an opportunity for a regulatory authority to approve experimental practices that encourage advances in mining and reclamation, as long as the practices are at least as environmentally protective as the existing regulations. Construction of a new underground coal mine presented an opportunity to try an alternative material handling practice that could result in improved reclamation success.

Construction practices at underground Utah coal mines commonly require access to coal outcrops along steep canyon walls. To create level areas adjacent to the coal outcrops, canyon drainages are filled with materials from adjacent cut slopes. Extreme rocky conditions and steep canyon slopes minimize topsoil salvage. When topsoil resources are salvaged, stockpiling and mixing activities reduce natural variations in soil characteristics, ultimately reducing vegetative diversity. Reclamation of steep cut slopes often results in construction fill being retained in canyon bottoms with topsoil placed over the fill. Difficulties in duplicating the soil/rock matrix existing prior to mining can affect reclaimed slope and channel stability.

As prescribed under SMCRA, an Experimental Practice allowing a variance from the topsoil salvage requirements at Code of Federal Regulations Part 30 (30 CFR), Section 817.22, was approved by the Utah Division of Oil, Gas and Mining and the U. S. Office of Surface Mining, Reclamation and Enforcement. The approved Experimental Practice allowed the operator to bury in-situ topsoil under imported and native fill rather than salvaging these soils. A geotextile fabric was used to protect the in-situ topsoil from contamination. In place protection of the topsoil maintains the pre-mine topsoil volumes and diversity.

SMCRA also requires diverse plant community establishment (30 CFR 817.111(a)(1)), wildlife habitat restoration and enhancement (30 CFR 817.97(a)), and land form restoration to approximate original contour (30 CFR 817.102(a)). To obtain approximate original contour, the restored mine area must generally resemble the original surface configuration and complement the drainage pattern of the surrounding area (30 CFR 701.5). Restored drainages must be stable and must minimize additional contributions of suspended solids to streamflow (30 CFR 817.43(a)). The Experimental Practice at the West Ridge Mine was designed to incorporate these performance standards. Uncovering the buried soil surface assures removal of fill and restoration of the original contour. Topsoil preserved in-place is expected to enhance vegetative diversity. The retained soil/rock matrix and the channel geomorphology are expected to enhance channel stability while closely approximating original contour.

METHODS

Site Description

The West Ridge Mine is located in a steep, narrow canyon called "C" canyon, approximately 25 miles east of Price, Utah, in the Book Cliffs Coal Field. The Book Cliffs, a high plateau, forms an exposed, rugged escarpment with south and southwest exposures, and it is dissected by canyons such as C canyon.

The Book Cliffs lie within the Price River Basin between 1525 and 3050 m (5,000 and 10,000 feet) above mean sea level. Precipitation in the Book Cliffs varies from 254 to 508 mm (10 to 20 inches) with a mean annual precipitation around 305 mm (12 inches); most precipitation occurs during the late summer and early fall. From October through April above 1830 m (6000 feet), precipitation is primarily snowfall. Temperatures range from summer highs near 35^{B}C (95^{B}F) to lows less than -18^{B}C (0^{B}F) during the winter months.

Geology

Rock outcrops exposed along the Book Cliffs escarpments are primarily sandstone, mudstone and shale. Outcrops within the project area are part of the Cretaceous Mesaverde Group consisting of the Blackhawk Formation and the Castlegate Sandstone. The coal resource is located in the Blackhawk Formation which includes various sequences of mudstone, siltstone, shale and sandstone. The West Ridge surface facilities are developed where the Lower Sunnyside coal seam outcrops from the Blackhawk formation, while the Castlegate Sandstone, a massive sandstone unit from the Price River Formation, is exposed near the edge of the disturbed area in the north fork of C Canyon.

Hydrology

The C Canyon drainage is ephemeral and flows in response to precipitation or snow melt runoff. Flows within ephemeral drainages in this region are infrequent; however, when flows occur they are often high volume flows of short duration. Water monitoring conducted above and below the mine site did not record any flow during the 1997 and 1998 seasons.

The C Canyon drainage is comprised of large sandstone boulders embedded with cobble sized to fine materials (see Figures 1 and 2). Boulders may be greater than 3 m (10 feet) along the long axis. Where boulders form a large pile in the channel, elevation drops and natural grade controls develop in a stair-step fashion. The elevation drops are steep and range from about 1 to 3.5 m (3-12 feet) in height. Up-gradient from these rock controls, the channel slope flattens to the next rock control structure which rises quickly. The average gradient of C-Canyon in the mine site area is approximately 6.4%.

Soils

Figure 3 shows the mine site and areal extent of the soil unit. Soils within the West Ridge Mine facility area are described in two soil surveys:

•€ A *Third Order Soil Survey* conducted for Carbon County, Utah (Jensen and Borchert, 1988), delineates the West Ridge mine site soils as primarily Rock Outcrop-Rubbleland-Travessilla complex, slopes 30-70%, 30-60 m (100-200 feet) long, elevation ranging from 1980 to 2650 m (6,500 to 8,700 feet). The southeast portion of the mine yard includes Midfork family-Commodore complex soils, slopes 50-70%, 60-90 m (200-300 feet) long, elevation 2410 to 2895 m (7,900-9,500 feet).

Figure 1. Right fork C Canyon above grade control structure.

Figure 2. Right fork C Canyon grade control structure.

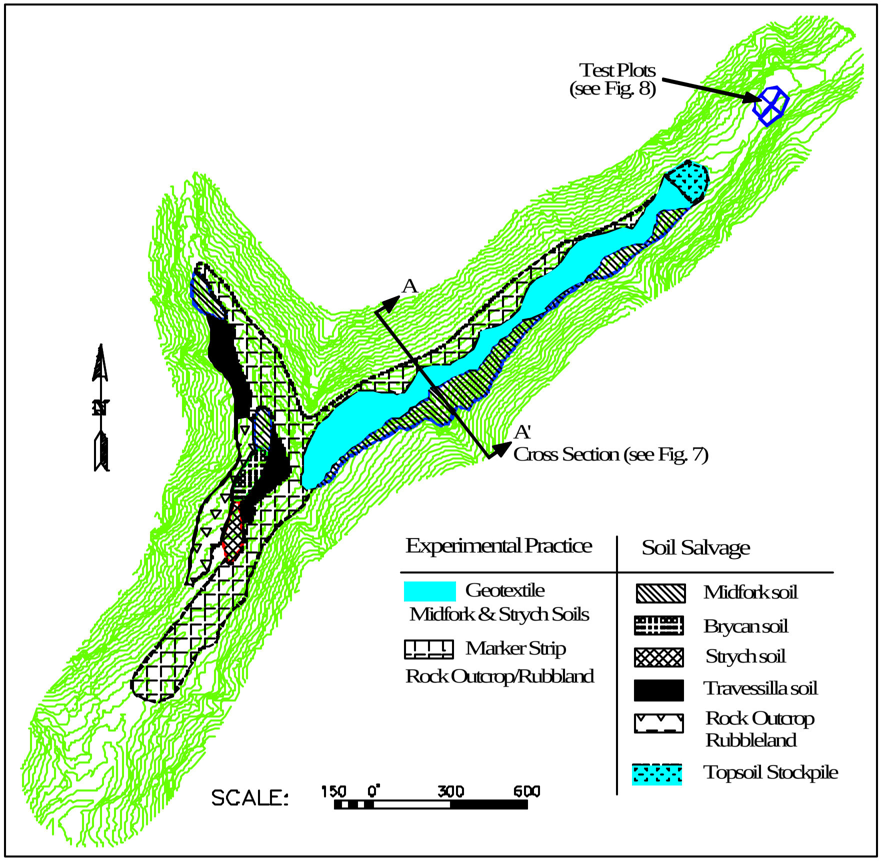

Figure 3. Mine site soils map

•€ The *First Order Soil Survey* (Nyenhuis, 1997) delineates five soil mapping units within the mine yard. These soil units are Rock Outcrop, Rock Outcrop-Rubbleland-Travessilla complex, Strych stony fine sandy loam, Midfork very stony fine sandy loam, and Brycan loam (see Figure 3). The Travessilla complex soil is classified as an Entisol, the Strych soil is classified as an Aridisol, and the Brycan and Midfork units are classified as Mollisols. Table 1 shows chemical and physical characteristics of these soils.

The soil surveys identified the Midfork, Brycan and Strych soils as providing salvageable topsoil material while the Rock Outcrop and the Rock Outcrop-Rubbleland-Travessilla complex includes salvageable Travessilla soil in isolated pockets. Soil volumes available for salvage within the 6.76 ha (16.69 acre) disturbed area include 6717 m^3 (8,785 yd^3) from the Midfork unit, 592 m^3 (774 yd^3) of Brycan soil and 6217 m^3 (8,131 yd^3) of Strych, assuming 0.46 m (18 inches) average soil salvage depth. Soil salvage is estimated to be 7714 m^3 (10,089 yd^3) in the Rock Outcrop-Rubbleland-Travessilla complex.

Vegetation

Plant communities in C Canyon are dominated by shrubs and small to large trees, with approximately equal understory and overstory cover values. The three vegetation communities, pinyon/juniper, Douglas fir/Rocky Mountain juniper and Douglas fir/maple, are clearly associated with slope aspect and soil units.

A pinyon/juniper community occurs on south and southeast facing slopes and on soils with high rock content, such as the Rock Outcrop-Rubbleland-Travessilla complex. Predominant species are two-needle pinyon (*Pinus edulis* Engelm.), Douglas fir (*Pseudotsuga menziesii* (Mirbel) Franco), bitterbrush (*Purshia tridentata* (Pursh) DC), and Utah juniper (*Juniperus osteosperma* (Torr.) Little). Total vegetative cover is about 53%.

Midfork and Brycan soils support a Douglas fir/Rocky Mountain juniper community. Slopes with this community have a northwest aspect and are dominated by Douglas fir, *Penstemon* sp., Rocky Mountain juniper (*Juniper scopulorum* Sarg.), mountain lover (*Pachystima myrsinites* (Pursh) Raf), and spike fescue (*Leucopoa kingii* (Wats.) W. A. Weber). Total vegetative cover in this area is about 75%. The soil surface in the Douglas fir/Rocky Mountain juniper community has significant cover from cryptogams, including unusually large numbers of liverworts.

The Strych soil is in the bottom of the right (main) fork of C Canyon. The vegetation in this area is a Douglas fir/maple community dominated by Douglas fir, Rocky Mountain and bigtooth maple (*Acer glabrum* Torr. and *A. grandidentatum* Nutt. in T. & G.), Rocky Mountain juniper and mountain lover. Vegetative cover is about 66%. The canyon bottom in the left fork has Rock Outcrop-Rubbleland-Travessilla complex soil and is dominated by pinyon and juniper.

Methods

West Ridge used both the traditional method for salvaging and stockpiling topsoil and an Experimental Practice for preserving topsoil in place. The Experimental Practice was proposed for areas under the fill where restoring the original, pre-existing soil structure and slope configuration would be difficult, and where the reclaimed slope stability is expected to be enhanced by retaining the original soil and surface configuration (See Figure 3 for areas where the Experimental Practice was used). Table 2 summarizes soil salvage and preservation activity conducted at the site. The traditional and experimental practices used within the 6.76-ha (16.69-acre) disturbed area were as follows:

•€ Traditional methods for salvage and topsoil resource protection prior mine pad and surface site facilities construction occurred on approximately 2.13 ha (5.25 acres).

•€ The Experimental Practice for preserving topsoil resources in place, with minimal surface disturbance, was conducted on 4.71 ha (11.64 acres). The in-place topsoil is buried beneath fill for the life of mine and will be unearthed at reclamation. Two different methods are employed for the Experimental Practice:

    1.€ Marker strips - Brightly colored marker strips were placed on 2.4-m (8-foot) centers within the Rock Outcrop-Rubbleland areas to delineate the location of the original soil surface. This Experimental Practice was used on approximately 2.94 ha (7.27

Table 1. First Order Soil Survey Chemical and Physical Characteristics.

Soil Name Taxonomic Class	Texture	pH	EC mmhos/cm	Saturation %	SAR	Selenium* ppm	Boron* ppm	Carbonate %
Surface Facility area								
Travessilla Torriorthent	loam	7.8	0.28	35.1	0.37	<0.02	0.20	16.4
Midfork Cryoboroll	loam, sandy loam	6.4 - 8.0	0.25 - 0.41	30.1 - 38.2	0.25 - 0.54	<0.02 - 0.10	0.10 - 0.38	1.5 - 12.6
Brycan Haploboroll	sandy loam	7.0 - 8.2	0.27 - 0.40	28.9 - 36.8	0.25 - 0.50	<0.02	0.14 - 0.34	6.4 - 9.0
Strych Calciorthid	sandy loam	6.8 - 7.8	0.28 - 0.31	29.6 - 56.2	0.38 - 0.53	<0.02 - 0.02	0.11 - 0.29	0.5 - 2.7
Gravel Borrow Area								
Herndandez Calciorthid	loam, sandy loam	7.5 - 8.2	0.38 - 8.2	22 - 41	0.31 - 9.0	<0.01 - 0.10	<0.2 - 1.6	10 - 38
Topsoil Borrow Area								
Atrac Camborthid	loam, sandy loam, clay loam, sandy clay loam	6.5 - 8.5	0.20 - 2.85	27.2 - 56.2	0.27 - 4.59	<0.02 - 0.06	0.09 - 1.62	0.3 - 25.8
Strych Calciorthid	loam, sandy loam, sandy clay loam	6.8 - 8.3	0.25 - 0.42	27.7 - 36.5	0.38 - 0.65	<0.02	0.07 - 0.38	0.4 - 15.0

* Hot water soluble

acres). The marker strips are commercially available and are made of long lasting, non-degradable material, such as plastics, nylon or other synthetics.

2.€ Geotextile marker - Geotextile was placed over the Strych, Brycan and Midfork soils to protect the existing topsoil. This Experimental Practice was used on approximately 1.69 ha (4.17 acres). The geotextile was chosen primarily for strength and longevity. In a buried condition away from ultraviolet radiation, the geotextile is expected to retain essentially all of its original strength for at least 20 years. The geotextile strength is not affected by moisture, or contact with earthen materials and is manufactured specifically for use in long life situations, such as under highways, railroad grades, dams and other similar applications (see Appendix A for manufactures specifications). The geotextile is overlapped during installation and secured at the edges to provide complete soil coverage.

Construction and Reclamation Sequences

Imported fill material was hauled in by trucks from an off-site, commercial gravel pit and placed on top of the geotextile. Native construction fill was obtained within C Canyon from cutslopes constructed above the upper pad elevation. The imported and native fills were placed in

Table 2. Soil Salvage and Preservation Summary

Soil Unit	Total Disturbed (ha)	Soil Salvage (ha)	Experimental Practice (ha)	Total Soil Available* (m^3)	Actual Soil Salvage (m^3)	Experimental Practice Soil Preserved In-Place* (m^3)
Brycan	0.13	0.13	0	592	727	0
Midfork	1.47	1.03	0.44	6721	3651	2000
Strych	1.36	0.11	1.25	6220	536	5721
RO/RL Travessilla	3.80	0.85	2.94	7718	3695	5981
Totals	6.76	2.13	4.63	21251	8817	13703

*Soil volumes based on:
Average .0.46 m of topsoil depth for Brycan, Midfork, & Strych
Average 0.20 m of soil depth for Rock Outcrop-Rubbleland Travessilla Complex

separate, compacted lifts until the required yard elevations were reached. To ensure imported fill is removed, bright marker flagging was placed between the native and imported fills. The imported fill does not contain any toxic or unsuitable material and meets the soil suitability criteria recommended by the Division of Oil, Gas and Mining guidelines (see Table 1). Fill material typically ranges from 3 to 12 m (10 to 40 feet) deep and will remain in place during mine operation, an estimated 20 years.

Figure 4 illustrates the construction sequence in a series of generalized cross sections. The geotextile fabric and marker strip installation are shown in Steps 2 and 3, and in Figures 5 and 6. Figure 7 is a generalized cross section of the finished mine yard.

Reclamation will be completed in the reverse order from the construction sequence. During final reclamation the imported pad fill will be removed and hauled off site exposing the geotextile layers and flagged surfaces that allow equipment operators to determine the boundaries between buried soils and fills. Native materials will be used to backfill cutslopes above the pad and the surface will be topsoiled treated and revegetated.

In geotextile and marker strip areas, the exposed soil surface will be gouged. Hay will be worked into the soil at the rate of 2245 $kg \cdot ha^{-1}$ (2,000 pounds per acre) to relieve soil compaction and increase moisture absorption. Gouging depressions will be about 0.6 by 1.0 m and 0.5 m deep (about 24" by 36" and 18" deep) and create a pattern to control erosion through water and sediment retention. All species in the seed and planting mixes are native to the area. The operator will broadcast seed in the fall, followed by mulching with 2245 kg·ha^{-1} (2,000 pounds per acre) of straw and 561 kg·ha^{-1} (500 pounds per acre) of wood fiber hydromulch with a tackifier (in addition to the hay worked into the soil).

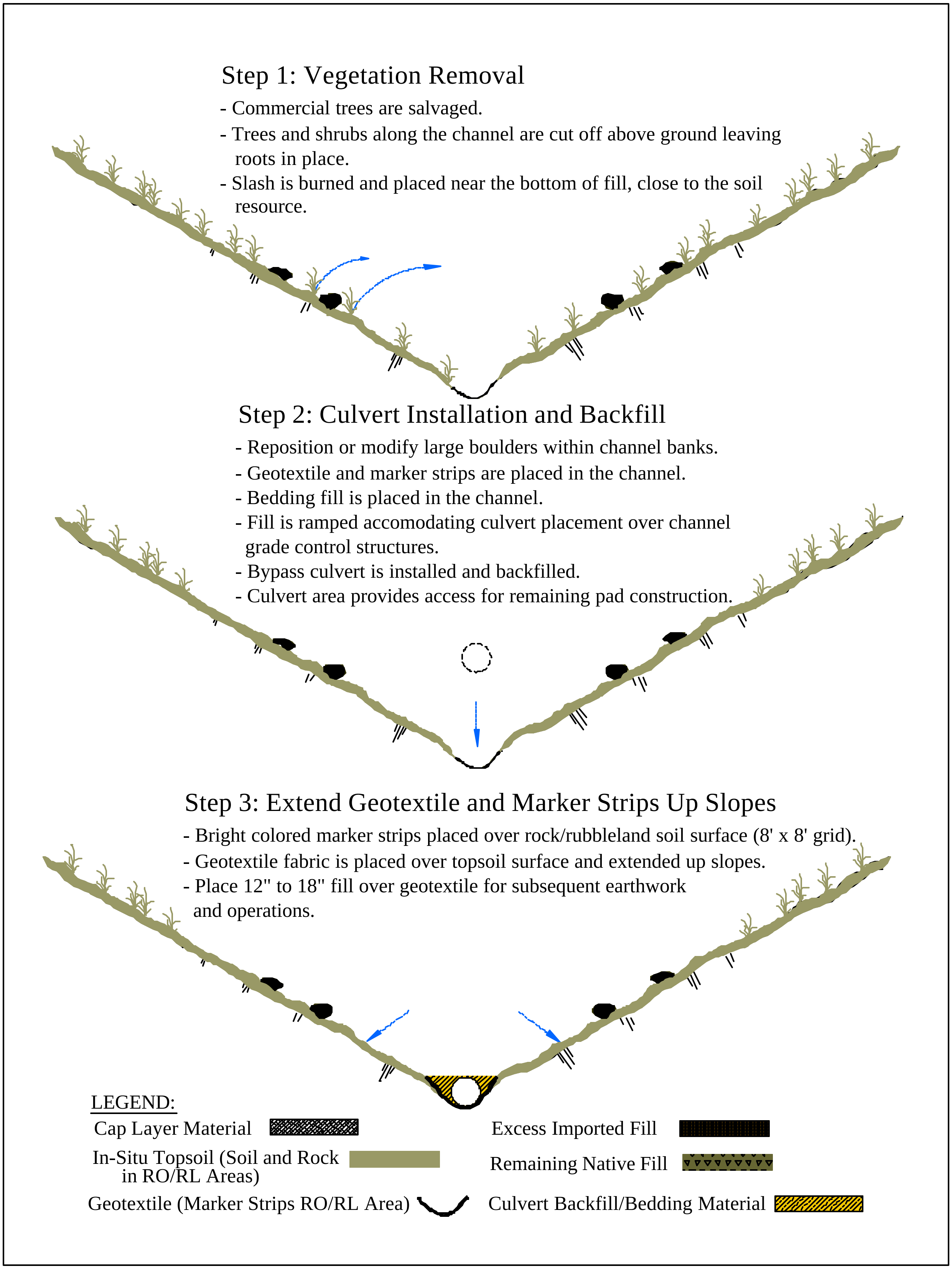

Figure 4. Construction sequence.

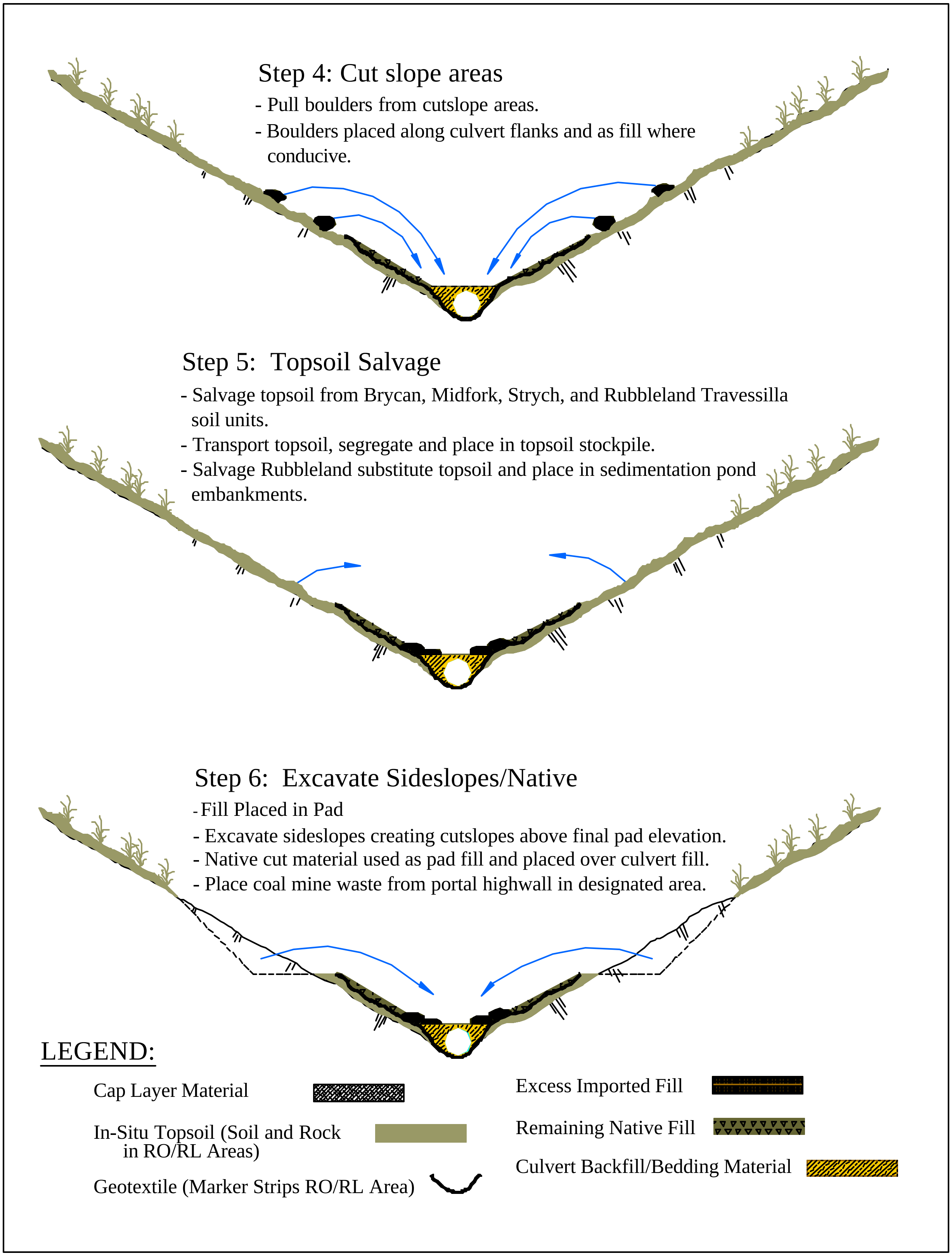

Figure 4. Construction sequence (continued).

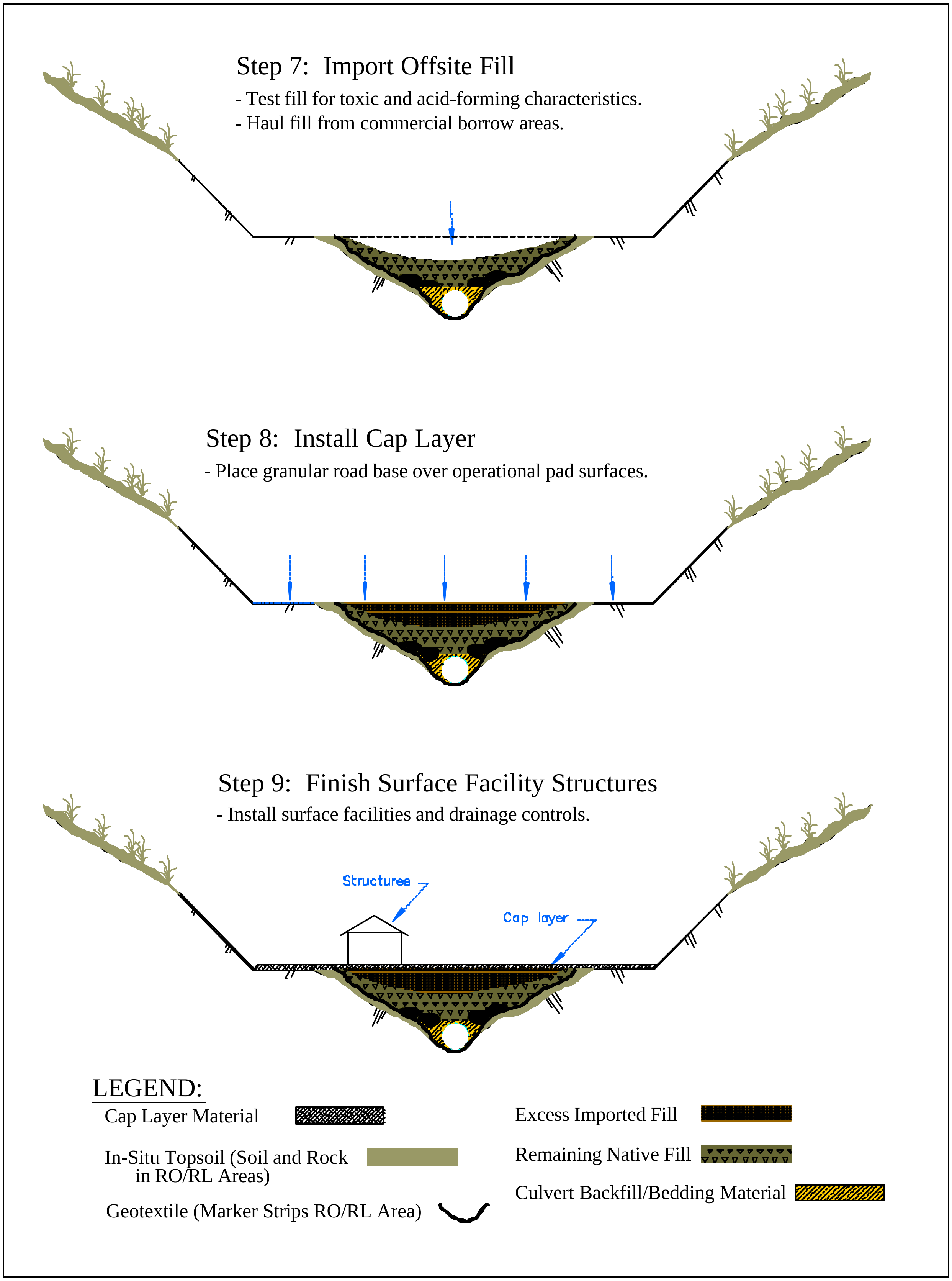

Figure 4. Construction sequence (continued).

Figure 5. Imported construction fill being placed over geotextile fabric.

Figure 6. Marker strips over Rock Outcrop-Rubbleland and channel.

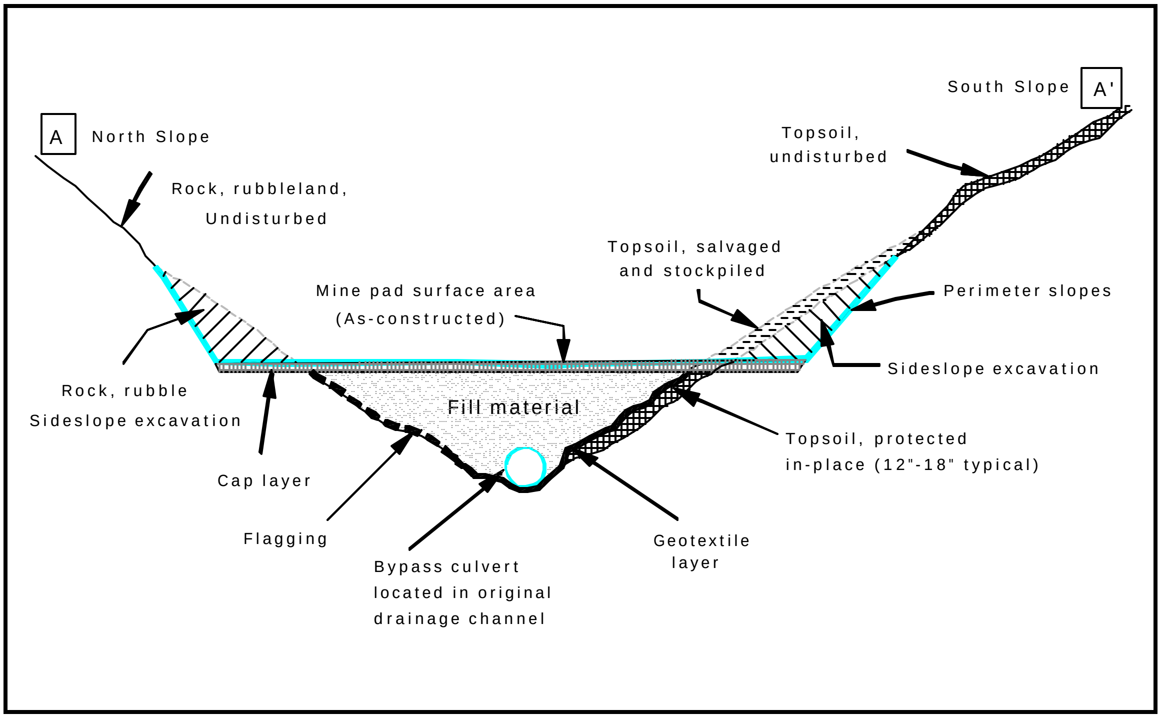

Figure 7. Generalized cross section.

Test Plot

To test the Experimental Practice, a test plot was established to simulate the mine yard construction sequence. The test plots will be used to compare reclamation results for "buried topsoil" with "salvaged and replaced topsoil." The test plot area, constructed in spring 1999 during the initial mine yard construction, was placed where both Strych and Midfork soil types occur equally over the test plot. The test plots are divided into four different quadrats. The Midfork covers the south and east quadrats and the Strych covers the north and west quadrats (see Figure 8). The soils were moved according to the steps illustrated in Figure 8 and the final quadrat descriptions are as follows:

- North Quadrat - This cut area provides the Strych topsoil salvaged for the west quadrat.

- East Quadrat - This cut area provides the Midfork topsoil salvaged for the south quadrat and provides the Midfork subsoil (fill) for the west quadrat.

- South Quadrat - This fill area retains the Midfork topsoil in place and is covered with geotextile fabric. The Midfork topsoil salvaged from the east quadrat is stockpiled over the retained Midfork soils.

- West Quadrate- This fill area retains the Strych topsoil in place and is covered with geotextile fabric. The Midfork subsoil salvaged from the east quadrat is placed in 0.6-meter (2-foot) compacted lifts to a depth of about 1.8 m (6 feet) over the retained Strych soil. Geotextile is placed

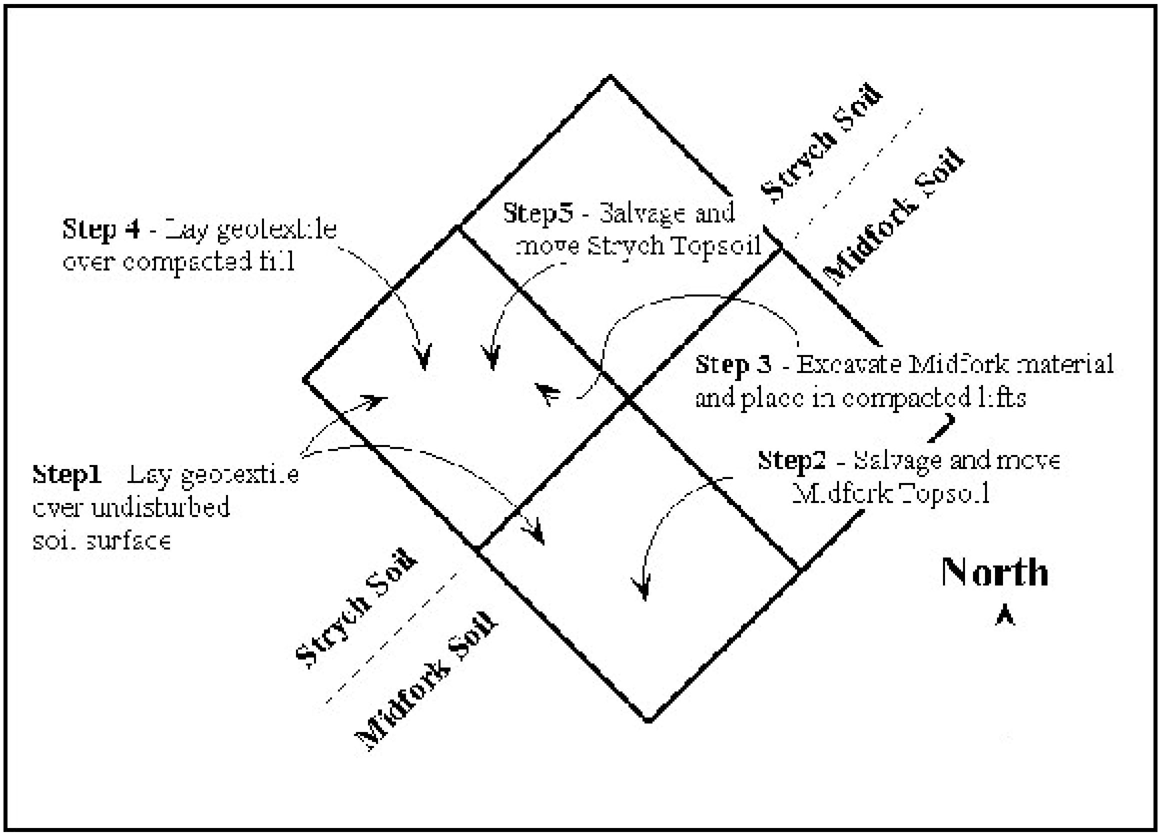

Figure 8. Test plot diagram.

over the fill, and salvaged Strych topsoil from the north quadrat, is stockpiled over the fill.

The West Quadrat area is designed to simulate in-place topsoil preservation and the effects of construction fill over topsoil. The material used from the north and east quadrats, and placed on the west and south quadrats, simulate traditional topsoil salvage and storage including cut, backfill and topsoil replacement.

In five years, the test plots will be reclaimed using treatments proposed to be applied during mine reclamation. After the test plots are reclaimed, the operator will monitor them for an additional five years, or until vegetative results are determined to meet cover and diversity standards as compared to the reference area for both traditional and Experimental Practice areas. A pre-selected topsoil borrow area will be used to obtain soils for final reclamation if the test plots show that the Experimental Practice will fail to establish successful re-vegetation. The borrow area was selected based on similar soil chemical and physical characteristics as those found in C Canyon (see Table 1 for chemical and physical characteristics).

DISCUSSION

Potential Benefits

Approximate Original Contour Restoration

Traditional coal mining operations require cut and fill practices to create pad areas. Reclaiming the steep cut faces to meet stability requirements can result in slopes that are less steep than pre-mining slopes and in some cases can cause the channel base to be elevated above the original channel. Problems associated with these final land configurations can include unstable channels, steep channel gradients, and erosive conditions. By committing to uncover the buried soils, the original contour and channel configuration will be retained in these areas. After reclamation, the drainages and slopes in the Experimental Practice area will be in almost exactly the same configuration as before mining.

Channel

The Experimental Practice will minimize changes to channel geomorphology which should result in decreased erosion and downstream sedimentation and a stable channel configuration similar to what existed before mining construction, reducing downcutting or headcutting. Although some of the largest rocks were moved out of the channel, the base of the channel and most grade control structures were retained; therefore, the channel is expected to be more stable than a reconstructed drainage over fill.

Soils

Soil salvage within the Rock Outcrop-Rubbleland areas at the West Ridge Mine would have been difficult due to topography and the extremely rocky nature of the native soils. Little topsoil would have been salvaged. Topsoil removal, stockpiling and redistribution result in soil loss and adversely affect soil characteristics, such as soil structure and the soil, root and rock makeup. The Experimental Practice will minimize these losses and enhance reclamation success.

Saving topsoil in place retains the existing soil structure and the natural soil integrity. Unlike stockpiled soil, soil buried in-place is protected from wind and water erosion. Soil structure is important for plant growth because it influences water movement, soil moisture, temperature, air, and root penetration. Each of these factors affects other soil development processes. Soil integrity is provided by the natural occurrence of soil particles, roots, and rocks that influence the physical properties of soil, thus affecting soil stability and productivity. Once fills are removed and buried soils are exposed, soil stability should be enhanced because many rocks, tree stumps, and large roots will still be intact.

Vegetation

Traditional soil salvage and replacement is not conducive to creating a diverse plant community. Most mine operators, especially those operating in space-restricted areas, salvage and store topsoil without

Figure 9. Reclaimed area in foreground.

regard to segregating varying soil types. When the mine is reclaimed, many of the rocks in the soil may be used for riprap, so the resulting soil tends to be a homogenous mixture with little rock microrelief. In Utah, this can lead to a predominance of grasses on reclaimed sites and little structural diversity or ecotone development (Figure 9, Standardville). Less desirable species, such as rabbitbrush and snakeweed, tend to invade the site.

A more diverse seedbed with a variety of soil conditions, including differing soil texture, rock content, structure, depth, and topography, gives greater variation in habitat conditions and is more likely to result in a wider species composition and improved structural diversity within the plant community. More variety improves habitat for a wider variety of wildlife species.

The Experimental Practice provides a means to preserve most of the surface topographic variability on part of the West Ridge Mine property. This should result in additional microclimates where a variety of plant forms can establish and provide more diverse wildlife habitat.

Because the soils are closely associated with particular plant communities, leaving the soils in place as part of the Experimental Practice should speed development of the communities that existed prior to mining.

Regulatory Concerns with the Experimental Practice

The soil regulations are intended to protect and preserve the topsoil resource for the purpose of revegetation, and supporting the designated post-mining land use. The proposed Experimental Practice, including operation and reclamation procedures, should provide protection equal to or greater than that obtained through traditional methods.

Concerns and issues related to the proposed Experimental Practice are listed and discussed below:

Soil Compaction

During construction, installation of construction fill will compact the in-place soils. Through the life of the mine, pad-fill materials will further compact the soil over time. However, during reclamation, the mine operator will gouge the surface about 0.46 m (18 inches) deep and incorporate alfalfa hay. Gouging and hay incorporation, combined with natural processes (e.g., freeze/thaw), should alleviate compaction and allow vegetation to establish. Little difference is expected between the Experimental Practice and traditional practices because backfilling and grading operations compact subsoils and replaced fills. When using traditional topsoil replacement methods, surface compaction is diminished in the top 0.46 m (18 inches) using common surface treatments; in the Experimental Practice areas, gouging will similarly relieve compaction.

Decreased Soil Microbial Activity

Microorganisms are beneficial in plant establishment and growth (Cundell, 1977). Soil that has been stockpiled for several years has fewer microorganisms when it is uncovered as compared to undisturbed areas (Fresquez et al., 1982). Buried soils are expected to have little microbial activity when they are uncovered after 20 years. However, it is the authors' opnion that there will be little difference between soils buried in place and soils placed in a large stockpile.

Natural inoculation is likely to occur quickly since the site is surrounded by undisturbed areas. Nearly all of the proposed disturbed area is less than 60 m (200 feet) from undisturbed areas. At a nearby reclaimed coal mine, cryptobiotic soils have become established naturally on a soil borrow area after eight years (R. Davidson, personal observations). West Ridge has committed to conducting a soil activation treatment on the test plots.

Contamination

Native soils could be contaminated by imported fill material. A buffer of native fill or non toxic imported fill will be placed between the native soil surface and imported fill. Bright marker flagging placed between the native and imported fill will allow equipment operators to determine the boundary line between these materials.

After removing imported fill, native fill will be excavated and placed on the cutslopes to achieve approximate original contour. Mixing native fill with the undisturbed Brycan soil should be minimized by using the geotextile fabric. There will be some mixing in Rock Outcrop-Rubbleland areas, but the native fill is essentially the same material as the Rock Outcrop-Rubbleland soil (see Table 1). In addition, soil will not be salvaged in the Rock Outcrop-Rubbleland areas in the traditional regulatory scenario, so there is no disadvantage to the Experimental Practice.

Economics

West Ridge did not do a detailed cost comparison between the Experimental Practice and traditional soil salvage, but the project manager believes construction costs will show little difference between the two methods (D. Shaver, personal communication). Reclamation costs are expected to be slightly lower using the Experimental Practice because there will be less backfilling and less soil handling. Subsequently, there will be much less work to reestablish the channel and fewer stability and revegetation problems are expected.

CONCLUSION

This Experimental Practice procedure which retains topsoil in place not only preserves soil structure but also soil integrity, which includes the integration of soil, roots and rocks. The Experimental Practice should preserve the original ground surface configuration, the existing stream channel and bank morphology, which should promote reclamation slope stability and erosion control. The Experimental Practice described in this paper is expected to have several benefits, but a complete analysis will have to wait until after reclamation of the mine in about 30 years. In five years, West Ridge will reclaim the test plots, and those results will assist in determining success of the Experimental Practice. The proposed reclamation plan should result in vegetative cover that meets or exceeds SMCRA performance standards.

ACKNOWLEDGMENTS

We appreciate the cooperation of West Ridge Resources, particularly Jean Semborski, Dave Shaver, and Mike Glasson, in providing information for this paper.

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APPENDIX A

The geotextile fabric will have the following minimum properties:

MECHANICAL PROPERTIES		UNITS
Grab Tensile Strength		
ASTM D 4632		
MD @ Ultimate	0.89 (200)	kN (lbs)
CMD @ Ultimate	0.89 (200)	kN (lbs)
MD/CMD Elongation @ Ultimate	15	%
Mullen Burst Strength		
ASTM D 3786	2756 (400)	kPa (psi)
Trapezoidal Tear Strength		
ASTM D 4533	0.33 (75)	kN (lbs)
Puncture Strength		
ASTM D 4833	0.40 (90)	kN (lbs)
UV Resistance after 500 hrs.		
ASTM D 4355	70	% Strength
HYDRAULIC PROPERTIES		
Apparent Opening Size		
ASTM D 4751	0.300 (50)	mm(US sieve)
Permissivity	0.05	sec-1

2000 Billings Land Reclamation Symposium

TOPSOIL STOCKPILING vs. EXPOSURE TO TRAFFIC; A CASE STUDY ON AN IN-SITU URANIUM WELLFIELD

Peter D. Stahl, Barry L. Perryman, Shankar Sharmasarkar, and Larry C. Munn[1]

ABSTRACT

Management of soils on mine sites is crucial to post-mining reclamation. We conducted a study to determine which of the following two topsoil management strategies results in the least negative impact to the soil and best promotes site reclamation on in-situ uranium wellfields: 1) removal of topsoil from an entire wellfield and stockpiling until mining activity is complete; or 2) leaving the majority of topsoil on the wellfield allowing it to be exposed to disturbance associated with wellfield development activity (primarily heavy vehical traffic). The study was conducted by comparing selected soil properties from areas on in-situ uranium wellfields that were managed by the two strategies stated above and with adjacent relatively undisturbed sites. Results indicated that levels of vehicular traffic on wellfields did not cause significant soil compaction and that removal and stockpiling of topsoil results in more negative impacts than disturbance inflicted when topsoil is left in place.

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INTRODUCTION

Management of soils on lands subjected to human perturbation is crucial to post-disturbance restoration of the impacted area. Because soils are a fundamental component of terrestrial ecosystems from which most organisms obtain essential materials such as nutrients and energy, as well as habitat, successful restoration of a disturbed area is highly dependent on maintenance of soil quality. Therefore, management practices which minimize detrimental impacts of human activities to the soil resource can prevent further site degradation and facilitate site restoration.

Removal and stockpiling of soil from an area is a method commonly employed to protect this valuable resource from loss or damage due to human activities such as surface mining operations, contamination with foreign materials, or compaction from vehicular traffic. Removal and stockpiling of topsoil, however, has serious detrimental effects on it's physical, chemical and biological properties and usually results in a significant reduction in soil quality (Pedersen et al., 1978; Severson and Gough, 1983; Visser et. al., 1984). These impacts include complete loss of the vegetation growing in the topsoil, destruction of soil structure and elimination of the habitat topsoil provides for a myriad of organisms. Therefore, the negative effects of removing and stockpiling a topsoil must be considered in comparison to the impact of the site disturbance on soil properties and related considerations such as reclamation and revegetation. For example, the detrimental impacts of topsoil removal and stockpiling are relatively minor compared to complete loss due to removal and mixing with overburden were it not salvaged before surface mining. Revegetating a surface-mine site with respread stockpiled topsoil is less problematic than a site with no topsoil. On the other hand, few soil disturbances other than complete loss or contamination with toxic materials, have as many adverse effects as removal and storage.

Soil compaction often results from human activities on a site, especially when vehicular traffic is involved. Compaction, in most cases, is detrimental to soil structure; causing a reduction in volume of pore space, increasing bulk density and alteration of hydraulic properties. These changes can affect the movement of water and solutes in soil (Ankeny et al., 1990). Growth and metabolism of organisms in the soil can be adversely affected through a loss of colonizable habitats (Foster, 1988) and reduced gas and water exchange (Huysman et al., 1989; Kaiser et al., 1991). Plant growth in compacted soils can be adversely affected through reduced root extension and shoot growth (Taylor and Brar, 1991; Lipiec et al., 1991) as well as lowered nutrient uptake due to nutrient restriction (Dolan et el., 1992). Vehicular traffic on soil is a common cause of compaction, the extent of which is related to the natural compressibility of the soil, amount of traffic and weight of vehicles. Fine textured soils and wet soils are most compressible (Plaster, 1997). The impact on soil is generally limited to the area directly beneath the vehicles' wheels.

In-situ extraction of uranium is a recently developed method for obtaining uranium from deep deposits without excavation of overlying materials. Acidified water is pumped down into deposits where uranium goes into solution; the solution is then pumped back to the surface for removal of uranium. In-situ uranium wellfield development activities potentially damaging to soils on the site include well drilling, small building and road construction, pipeline installment, and vehicular traffic associated with these activities. The topsoil management strategy commonly employed at in-situ uranium extraction wellfields was salvage of topsoil from pipeline right-of-ways, building, drilling and storage sites as well as access roads subjected to repetitive heavy duty vehicular traffic. Wellfield traffic, however, is not limited to the access roads but includes substantial off road traffic from access roads to individual well drilling sites. Under this management plan, it is estimated that topsoil was removed from less than 15% of the entire wellfield area leaving much of the remaining soil exposed to random vehicular traffic. Recently, an alternative topsoil management strategy has been proposed that would involve topsoil removal from the entire wellfield and storage until wellfield activities are completed.

The objective of this research has been to determine which of the following two topsoil management strategies result in the least negative impact to the soil resource on in-situ uranium wellfields and best promotes site restoration: 1) removal of all topsoil from an entire wellfield and stockpiling until it is respread or 2) leaving the majority of topsoil on a wellfield in place, removing topsoil from selected areas of heaviest disturbance where it might be lost or contaminated such as mudpits, pipeline right-of-ways, and access roads. The basic question involved in this comparison is whether wellfield development activities, primarily heavy vehicular traffic, results in more or less damage to the topsoil resource than removal of topsoil from an entire wellfield, indefinite storage, and subsequent replacement.

METHODS

This study is based on analysis and comparison of selected soil properties at the Highland Uranium Project near Glenrock, WY and the Irigaray Ranch Uranium Mine near Pumpkin Buttes, WY as well as relatively undisturbed sites directly adjacent to both mines for comparative purposes. Vegetation characteristics of disturbed and relatively undisturbed sites were also examined at the Highland Uranium Project as indicators of the influence of soil management practices on site revegetation. In-situ uranium wellfields at these mines were managed according to the strategies described above.

At the Highland Uranium Project, two different aged wellfields were examined; a wellfield at which the mining process was initiated 2 years prior to sampling (Wellfield F) and one at which mining was initiated 7 years prior to sampling (Wellfield C). Soil samples were obtained from areas on both wellfields that had been subjected to the following management practices: 1) Topsoil removed, stockpiled and replaced (**stockpiled**); 2) Topsoil left in place, subjected to wellfield development activities (**in-situ**).

At the Irigaray Ranch Uranium Mine, at which mining activities were initiated 17 years prior to sampling, soils were collected from areas which had been subjected to the following management practices: 1) Topsoil removed and stockpiled but not replaced (**stockpiled**); 2) Topsoil left in place, subjected to wellfield development activities (**in-situ**); 3) Subsoil left in place after topsoil removal, subjected to wellfield development activities (**stripped**).

Native, relatively undisturbed topsoil from undeveloped areas directly adjacent to in-situ uranium wellfields were sampled at both mines for comparative purposes.

Soil samples were collected from the stockpiled, in-situ and stripped wellfield sites by first identifying areas that had been so managed. Replicate samples (ca. 1500 g) were then obtained at a depth of from 3 to 15 cm. Samples of native, relatively undisturbed soils were collected at regularly spaced intervals on a randomly placed transect in an undeveloped area directly adjacent to the wellfields. Native soils were sampled from the same depth as wellfield soils. All soil samples were placed in a cooler immediately after collection, returned to the laboratory and placed in cold storage within 12 hrs of collection.

Specific soil properties examined and compared in this study include: soil texture, pH, bulk density, electrical conductivity, water infiltration rate, extractable phosphate and nitrogen, total nitrogen, organic matter, microbial biomass carbon and mycorrhizal fungal spore numbers.

Water infiltration rate measurements were conducted in the field at the time of sampling (Bertrand, 1965). Intact soil cores were also collected in the field for soil moisture content and bulk density determinations using the methods of Klute (1986) and Blake and Hartge (1986), respectively. Microbial biomass carbon in soil samples was determined by chloroform fumigation and extraction with 0.5 M K_2SO_4 on 20 g sieved field moist soil samples (Tate et al., 1988; Horwath and Paul, 1994). Mycorrhizal fungal spore examinations were performed as described by Stahl and Christensen (1982). All other soil analyses were conducted by the University of Wyoming Soil Testing Lab.

Soils data was analyzed using single factor analysis of variance (Systat, 1992) to test the hypothesis of main effects and post-hoc analysis t-tests (Systat, 1992) to compare mean values between treatments.

RESULTS AND DISCUSSION

All soils sampled at the Highland Uranium Project were very fine textured. At Wellfield C, soil from both the stockpiled and in-situ managed areas as well as the adjacent native area were classified as clays or silty clays. Stockpiled, in-situ and native soil from Wellfield F were all classified as silty clays. Soils from the Irigaray Ranch Uranium Mine were only slightly less fine textured than those at Highland Uranium Project. Soil from three of the four management types examined at Irigaray (in-situ, stripped and native) were silty clays whereas stockpiled soil was classified as a silty clay loam. Topsoil management practices compared in this study probably have little influence on soil textural characteristics. That is, stockpiling and wellfield activities will most likely not alter soil particle size. Soil texture, however, may have important implications as to how it is affected by management and disturbance. For example, fine textured soils, such as those at the two mines examined in this study, are known to be highly susceptible to compaction (Brady, 1990).

Native, relatively undisturbed soil at the Highland Uranium Project had pH values just below neutral (Table 1). At Wellfield C, in-situ soil was found to have a pH value slightly higher but statistically similar to the native soil. Stockpiled soil from Wellfield C had a pH of over 7.7 and was determined to be statistically different than native and in-situ soil. At Wellfield F, both in-situ and stockpiled soil had similar soil pH values which were statistically higher than the nearby native soil. At the Irigaray Ranch Mine, native soil was found to have a pH value of close to 8. In-situ and stockpiled soil had ph values slightly lower than, but not statistically different from, the native soil. Stripped soil had a pH value statistically lower than all others.

All soils examined in this study from the Highlands Uranium Project had high bulk density including the relatively undisturbed native soil (Table 1). At Wellfield C, native soil, in fact, had highest bulk density and was followed, in order, by in-situ soil and stockpiled soil. At Wellfield F, where all three soil bulk density values were quite close to one another, stockpiled soil was found to have the highest bulk density while native and in-situ soil had identical bulk density values. Bulk density of all soils from the Irigaray Ranch Mine were lower than those from the Highland Uranium Project. At this mine, native, relatively undisturbed soil had lowest bulk density. Of the three disturbed soils analyzed, in-situ had the lowest bulk density value followed by stripped and stockpiled, respectively. These data suggest that heavy vehicle traffic associated with wellfield activities does not cause enough soil compaction to affect soil bulk density. In fact, the soil with highest bulk density observed in this study was a native soil adjacent to Wellfield C. This native site was obviously grazed by cattle and may have been compacted to some extent by grazing. Data on soil bulk density collected in this study indicate that no long term compaction of topsoil resulted from mining activities on Wellfields C or F at the Highland Uranium Project or at the wellfield examined at the Irigaray Ranch Mine.

Native soil directly adjacent to Wellfield C at the Highland Uranium Project had a mean organic matter content value of 2.25 percent (Fig. 1). In-situ soil from Wellfield C had a statistically similar value of 2.28 percent. Stockpiled soil from Wellfield C had slightly greater than half as much organic matter as either the native or in-situ soil with a mean value of 1.20 percent. The three differently managed soils from Wellfield F all had statistically different mean organic matter content values; native soil had the greatest, followed by in-situ soil and then by the stockpiled soil which had lowest organic matter content at less than 1 percent. Analysis of variance in the data from soils collected at the Irigaray Ranch Mine showed that stripped and stockpiled soils had organic matter contents significantly lower than nearby native soil. In-situ soil had a mean organic matter content value that was not significantly different than native soil (Fig. 1).

Data from the 2 year old wellfield (Wellfield F) showing reduced levels of soil organic matter in both the in-situ and stockpiled soils suggests that the initial disturbance of wellfield activity under both management strategies (heavy vehicle traffic vs. removal and stockpiling) has negative effects on soil organic matter levels, although more pronounced under stockpiling. At the 7 year old site (Wellfield C), however, organic matter levels in the in-situ soil are statistically similar to native soil and organic matter remains low in the stockpiled soil suggesting that it is taking more time for organic matter levels to increase in stockpiled soil. The low levels of soil organic matter in both the in-situ and stockpiled soils at the 2 year old wellfield may be due to the interuption of plant primary productivity and associated microbial secondary productivity by wellfield development activity. The more rapid increase in soil organic matter content in in-situ soil may be the result of more timely recovery of plant and microbial productivity on in-

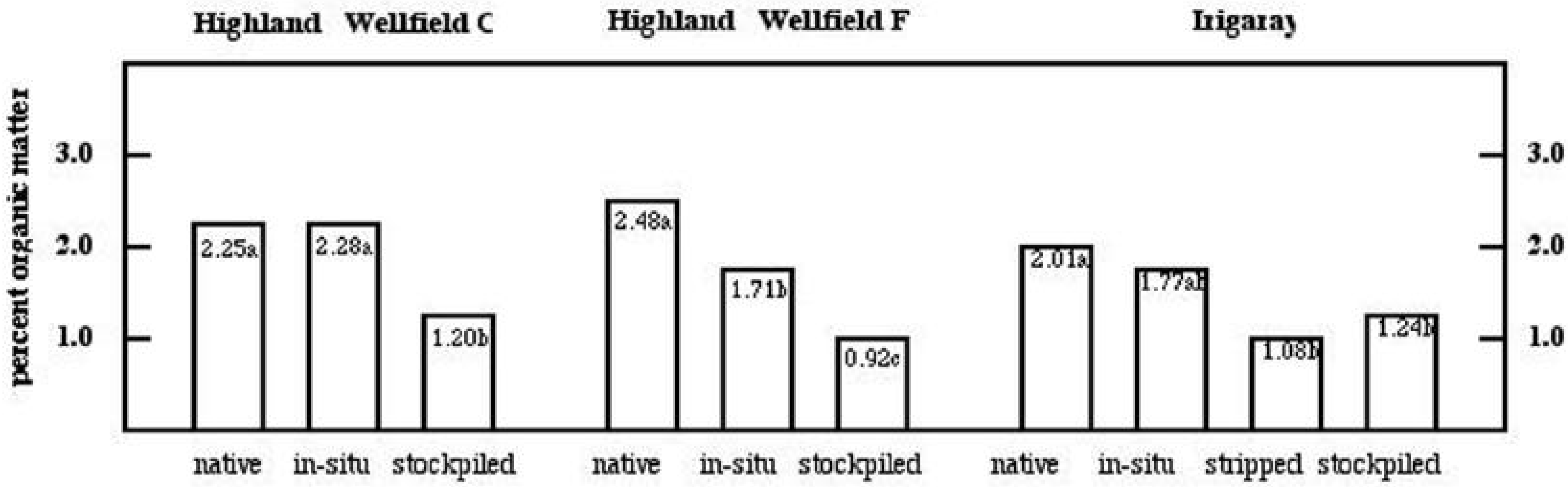

Figure 1. Soil organic matter contents

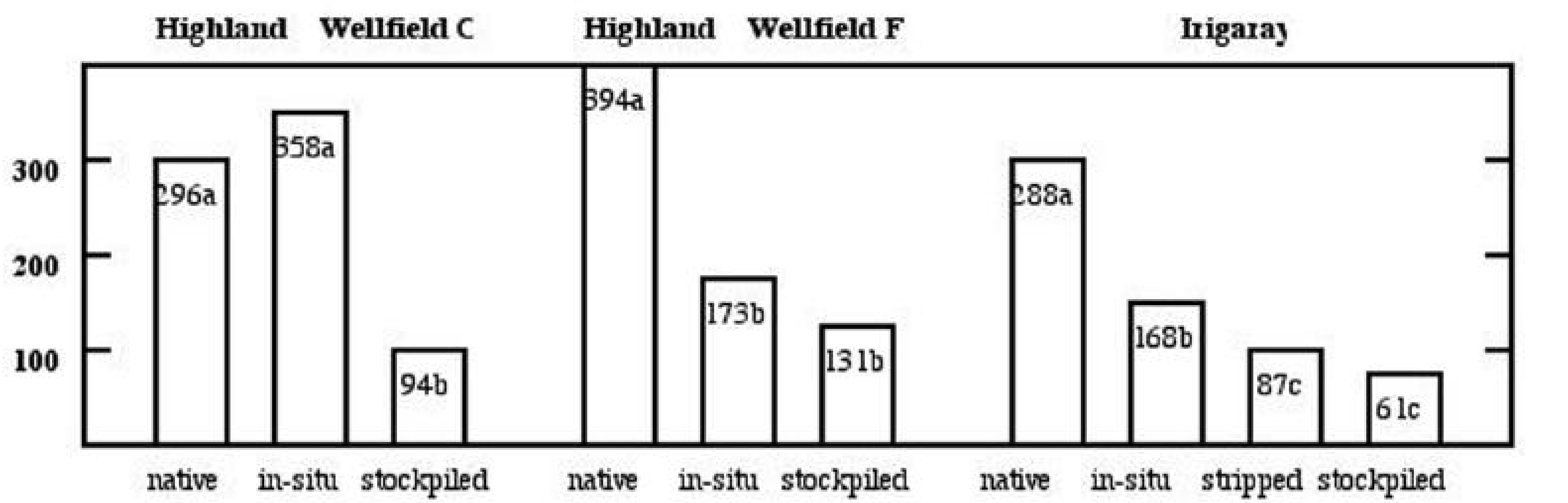

Figure 2. Arbuscular mycorrhizal spore numbers

situ soil. Data from the Irigaray Ranch Mine show that stripped soil and soil in stockpiles continue to have reduced levels of organic matter after 17 years.

Measurements on soils from Wellfield C at the Highlands Uranium Project showed that all three soils had mean EC values between 0.26 and 0.41 decisiemens per meter (Table 1). Analysis of variance (ANOVA) indicated that these values were all statistically similar. At Wellfield F, stockpiled soil had a statistically higher mean EC value than either native or in-situ soils which were statistically similar. At the Irigaray Ranch Mine, stripped and stockpiled soils had significantly greater mean EC values than the native, relatively undisturbed soil. In-situ soil had a mean EC value that was not statistically different than native soil.

Data from Wellfield F and the Irigaray Mine indicate that removal, storage and replacement of topsoil may result in an increase in soil electrical conductivity but stockpiled soil in Wellfield C did not have an elevated EC. Results from this study are inconclusive as to the influence of topsoil stockpiling on soil EC. In-situ management did not appear to affect soil EC.

Measurements of infiltration rates on Wellfield C at the Highland Uranium Project demonstrated that all three soils had different rates of water intake (Fig. 2). Stockpiled soil had the greatest infiltration rate followed in decreasing order by in-situ soil and then finally native soil. At Wellfield F, measurements showed that the stockpiled and in-situ soils had very similar infiltration rates and were greater than that of the adjacent native soil. Comparing infiltration rates of Irigaray soils, native soil had the greatest rate of water intake followed by in-situ soil and stripped soil, respectively.

Infiltration rates generally correlated well with bulk density values, except at Wellfield F where bulk density of all three soils were similar. At both Wellfield C and the Irigaray Ranch Mine soils with highest bulk density had lowest infltration rates. Data collected in this study provides no evidence that mining activity negatively impacts water infiltration rate of in-situ soils. Results are inconclusive as to the influence of removal and stockpiling on infiltration rates.

Analysis of variance in the data from soil samples collected at the Highlands Uranium Project indicated that there were no statistical differences in the amount of available phosphate in the three soils from Wellfield C or in the soils from Wellfield F (Table 1). All of the soils sampled at the Irigaray Ranch Mine, including the native soil, were found to contain low levels of available phosphate. Soils from the stripped an stockpiled treatments, however, were found to have undetectably low levels of available phosphate. The two different topsoil management practices employed at the Highland Uranium Project do not appear to be influencing available phosphate content. Stripped and stockpiled soils at the Irigaray Mine, however, do have significantly lower available phosphate contents than native and in-situ soils. The exact reason for this is not apparent.

Soil samples from Wellfield C at the Highland Uranium Project indicated that stockpiled soil had similar levels of nitrate to the native soil (Table 1). In-situ soil had slightly, but significantly, higher nitrate levels. At Wellfield F, in-situ soil had similar nitrate levels to native soil while stockpiled soil had significantly greater amounts. All soils at the Irigaray Ranch Mine had similarly low amounts of nitrate. Results of nitrate analyses conducted on soils in this study are do not show any apparent trends and are difficult to interpret but show no obvious effects of management practices.

Analysis of the data from soils collected at the Highland Uranium Project shows that at Wellfield C in-situ soil had a total nitrogen content statistically similar to native soil adjacent to the wellfield while stockpiled soil had significantly lower total nitrogen contents (Table 1). Identical results were obtained from Wellfield F; native and in-situ soils had similar levels of total nitrogen while that in stockpiled soil was significantly lower. Results of total nitrogen analysis on soils from the Irigaray Ranch Mine resembled those from the Highland Uranium Project. Total nitrogen contents of in-situ soil were not statistically different than native soil while both the stripped and stockpiled soils had significantly lower total nitrogen.

Because most of the nitrogen in surface soils is associated with organic matter, lower levels of total soil nitrogen in stockpiled soil at the Highland Uranium Project and stockpiled and stripped soils at the Irigaray Ranch Mine may be a result of the low levels of soil organic matter in these soils.

Results of the soil analyses from the Highland Uranium Project indicate that at Wellfield C in-situ soils had similar numbers of mycorrhizal fungal spores to the adjacent native, relatively undisturbed site (Fig. 3). Stockpiled soil in Wellfield C had about one third as many spores as the native and in-situ soils. At Wellfield F, both the in-situ and stockpiled soils were found to have significantly lower spore numbers than the native soil. Examination of spore populations in soils from the Irigaray Ranch Mine that show that all of the managed soils (in-situ, stripped and stockpiled) had statistically lower numbers of mycorrhizal fungal spores than did native soil. Lowest spore numbers were found in stripped and stockpiled soils and were significantly lower than in in-situ soil.

The observation that mycorrhizal spore numbers were similarly low in both the in-situ and stockpiled soils in the 2 year old wellfield (Wellfield F) suggests that the initial disturbance of wellfield activity may impact mycorrhizal spore numbers under both the management strategies (heavy vehicle traffic vs. removal and stockpiling) in a similar ways. At the 7 year old site (Wellfield C), however, spore numbers in the in-situ soil are statistically similar to native soil and spore numbers remain low in the stockpiled soil suggesting that it is taking more time for mycorrhizal fungal spore numbers to recover in stockpiled soil. The initial decline in spore numbers is probably due to damage to the vegetation, which provide the fungus with carbon and a source of energy. The more timely recovery of spore numbers in in-situ than in stockpiled soil may be due to more rapid recovery of vegetation on in-situ soil. Data from the Irigaray Ranch Mine show that stripped soil and soil in stockpiles will have to recover from very low spore levels.

At the Highlands Uranium Project on Wellfield C, soil microbial biomass levels were statistically similar in the native and in-situ soils (Fig. 4). Stockpiled soil had significantly lower amounts of microbial biomass with about one third that found in the other two soils. Native soil adjacent to Wellfield F had highest levels of the three soils sampled at this site. Although the mean value for microbial biomass in in-situ soil was almost four times that in stockpiled soil, no statistically significant differences in these means were revealed by t-tests. Analysis of variance in the data from soils collected at the Irigaray Ranch Mine showed that stripped and stockpiled soils had similar microbial biomass contents which were significantly less than nearby native soil. In-situ soil from the Irigaray Ranch Mine had a mean microbial biomass content that was not statistically different from the native soil or the stripped and stockpiled soils.

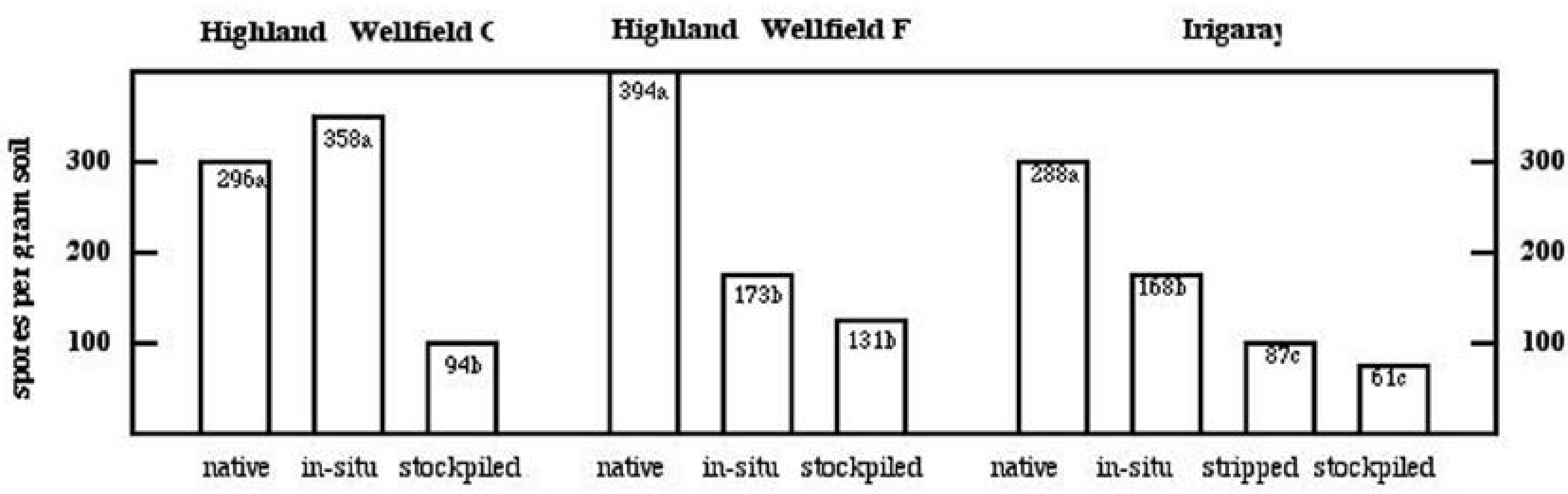

Figure 3. Arbuscular mycorrhizal spore numbers

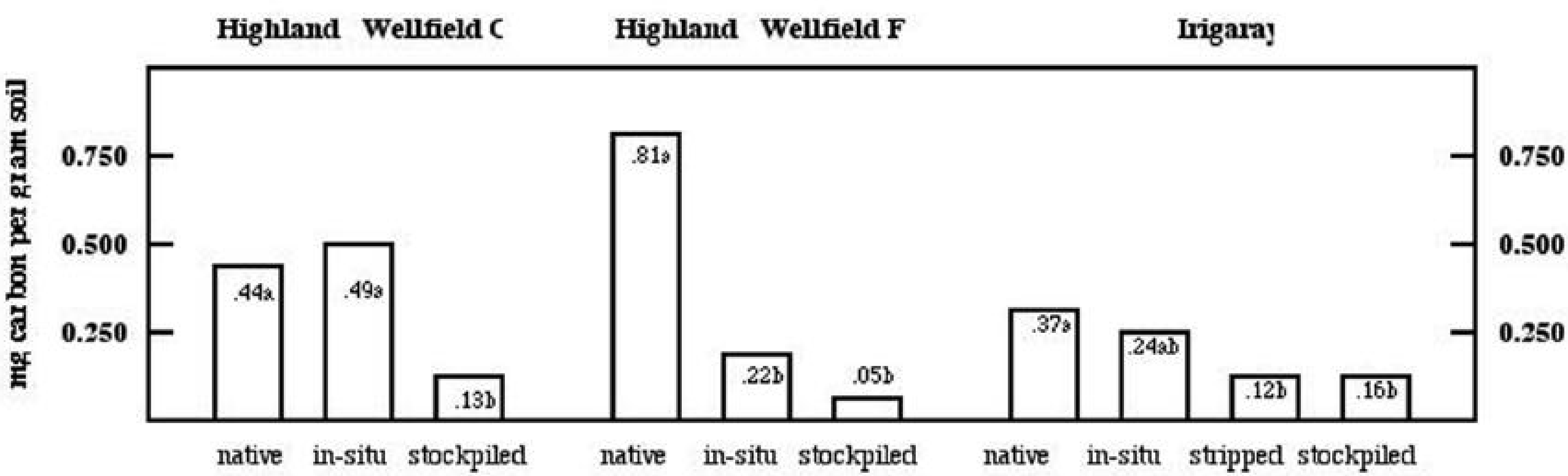

Figure 4. Soil microbial biomass carbon

The data on soil microbial biomass contents displayed the same type of trends observed in soil organic matter data and mycorrhizal fungal spore data. Again, the data indicate that initial wellfield activity of either heavy vehicle traffic on in-situ soil or removal and storage of stockpiled soil result in a similar decline in levels of microbial biomass. Microbial biomass levels recover much more rapidly, however, in in-situ soils, possibly due to the faster reestablishment of vegetation.

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DESIGN AND IMPLEMENTATION OF A STEEP SLOPE REVEGETATION PROJECT

Steven G. Renner [1]

ABSTRACT

The State of Colorado, Division of Minerals and Geology is in the process of accomplishing reclamation of a previously permitted coal mining operation located in a high mountain basin. Five underground coal mine portal facility sites are situated in a rugged sub-alpine environment at an average elevation of 10,000 feet. Annual precipitation averages about thirty-one inches per year.

The underground mines were developed in the 1950's and 1960's along the flanks of Huntsman Ridge in the coal bearing Mesaverde Group. Due to the extremely steep topography, backwalls to over one hundred feet in height were excavated into the steep slopes. The excavated material was downcast over the edge of the mine benches created during excavation of the backwalls. The downcast material formed an artificial colluvial cover over the underlying Mancos Shale slopes. The downcast material, or mine bench outslopes, approach angle of repose in some instances, and average about 1.25 Horizontal to 1 Vertical. The mine bench outslopes are very susceptible to erosion as a result of the slope gradient, slope length, high annual average precipitation and the physical characteristics of the overcast material. The Division of Minerals and Geology determined that attempting to control mine bench outslope erosion through revegetation processes was a desirable component of reclaiming this site.

Due to the size, location and volume of the mine bench outslopes, it was determined that revegetation of the slopes in place was the only practical manner in which to attempt stabilization. A number of revegetation techniques were attempted in 1995 and 1996. At one location in 1996, a simple machine was developed and used to create small shelves on the outslopes for the purpose of providing a site for seed germination. Observation and sampling of the revegetated areas in 1998 indicated that this technique, when evaluated in conjunction with the many logistical and environmental constraints of these sites, provided the best revegetation results.

A large scale revegetation effort was undertaken during the 1999 construction season utilizing the techniques demonstrated in 1996. These efforts are being combined with constructed passive treatment systems in order to minimize sedimentation from the mine bench outslopes.

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BACKGROUND

The State of Colorado, Division of Minerals and Geology (DMG) is in the process of accomplishing reclamation of a previously permitted underground coal mining complex in Pitkin County, Colorado (Figure 1). The Coal Basin Mine complex is large and diverse, with great variations in elevation, exposure, soil types, slope and topography throughout the Basin. Reclamation of the Coal Basin Mine complex has been subdivided into numerous sub-components or tasks. Generally, any one reclamation project addresses one of these sub-components. One recently completed reclamation project involved an attempt to establish vegetation on the mine bench outslopes. The primary goal of the Mine Bench Outslope Revegetation Project was to minimize erosion at these areas, and thus to minimize the resultant delivery of sediment to nearby water resources.

The original Coal Basin Mine began operations in the 1890's. Coal was mined from near the headwaters of Coal Creek as a part of the coal mining and steel empire of John Osgood. Operations ceased in the early 1900's. Mining resumed at Coal Basin in about 1953. Production continued until 1991. Metallurgical quality coal was produced from five separate underground mines located in the western portion of the Basin (Figure 1). The mine entries are located high in the Basin at elevations of about 10,000 feet.

In the early 1980's, a mining permit was issued to the operator of the facility under the terms of the Colorado Surface Coal Mining and Reclamation Act. This permit outlined the operating parameters for the mine, and described the reclamation requirements for the site. Included in the permit was the requirement to revegetate such disturbances as the fill slopes located below the mine entries. These slopes had been created as a result of mine development in the 1950's.

Mining continued until 1991 when operations ceased. The operator of the facility tried to sell the operation for over a year, but ultimately these efforts proved to be unsuccessful. The mining permit was revoked and the reclamation bond forfeited by the State of Colorado. In 1992 the company filed for Chapter 11 bankruptcy protection. The State of Colorado, Mined Land Reclamation Board, was a secured creditor in the bankruptcy proceedings. The State eventually received three million dollars in cash and services to satisfy its claims in bankruptcy. The cash proceeds have been used to finance the on-going reclamation projects at the site.

ENVIRONMENTAL SETTING

The Coal Basin Mine is located within a topographic feature known as Coal Basin. Coal Basin is a large erosional feature situated on the flank of the Grand Hogback, just north of the West Elk Mountains. Coal Creek and Dutch Creek drain Coal Basin. These streams are confluent near the eastern margin of Coal Basin. Coal Creek is confluent with the Crystal River near Redstone, Colorado, four miles downstream from the mine site. The Crystal is confluent with the Roaring Fork River at Carbondale, Colorado, approximately eighteen miles downstream of Redstone.

Coal Basin is located in a sub-alpine environment. Plant communities are predominately aspen at lower elevations and Engelmann spruce at the mine entry areas. Average annual precipitation within the Basin is thirty-one inches.

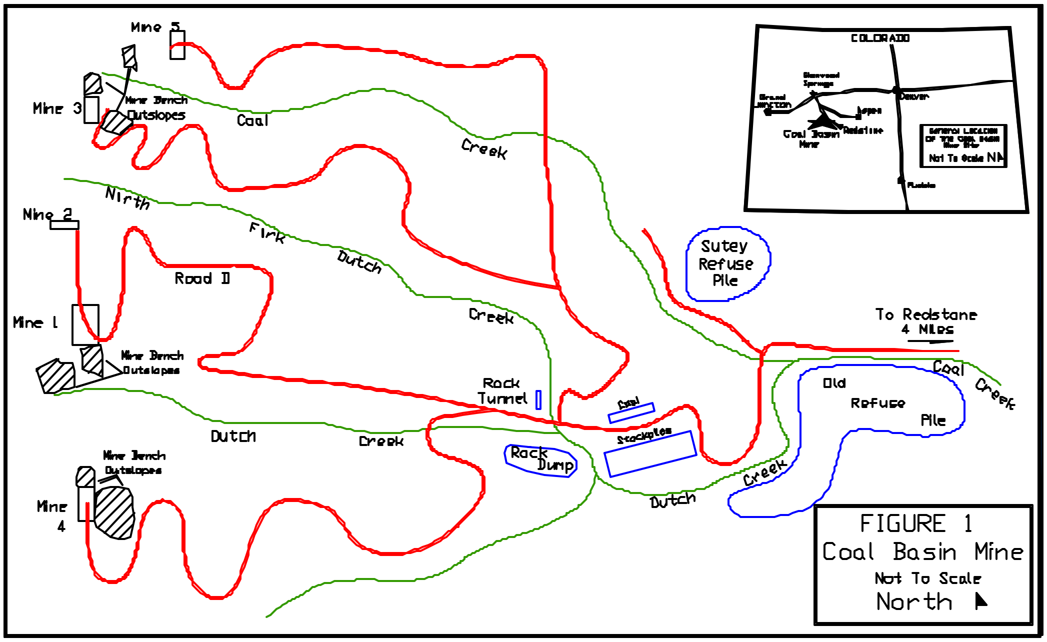

FIGURE 1
Coal Basin Mine
Not To Scale
North

Coal Basin is characterized by unique geologic conditions. Cretaceous Mancos Shale, a deep marine grey to black silty shale, predominates within the Basin up to an elevation of about 9,800 feet above mean sea level. The Mancos Shale forms steep slopes throughout the region. Slopes approaching 0.75H: 1V are not uncommon for Mancos Shale hill sides.

Conformably overlying the Mancos Shale is the upper Cretaceous Mesaverde Formation. The Mesaverde is a thick sequence of interbedded sandstones, shales and minable coal units. The Mesaverde Formation is a steep cliff-forming unit, with sandstone members forming the vertical walls of Huntsman Ridge at the western margin of the Basin.

Due in large part to the relatively high annual average precipitation and the great exposures of the erosive Mancos Shale and Mesaverde Formation, the Basin experiences a very high degree of erosion annually. Because of the high natural erosion rates, Coal and Dutch Creeks transport large volumes of sediment annually. The mining permit application estimates that 15,225 tons of sediment per year is generated due to naturally occurring processes within Coal Basin.

MINE BENCH OUTSLOPES

The five underground mines are generally located on the nose of easterly trending ridges, which descend from the north-to-south trending Huntsman Ridge. In order to develop the mines, highwalls were excavated in the ridges at each face up area. Excavation continued until a nearly vertical highwall was created. The highwalls vary in height from twenty feet (20') to about one hundred feet (100'). In order to create the highwalls, large quantities of earth were excavated from the ridgelines. In conjunction with the highwall development, large flat benches were created. These benches served as the initial coal processing areas, supported offices, warehouses, shops, and truck loading facilities and served as the mine staging areas. The excavated material was cast over the side of the ridges, down the steep slopes. This overcast material formed large fills of unconsolidated shale and sandstone debris. In some cases, trommel reject was added to the downslope area, creating layers of coarse coal, sandstone and shale materials within the upper twenty five percent of these long fill slopes.

Commonly the outslopes are over 550 feet in length and reside at or near the angle of repose. The slopes are generally devoid of vegetation and are subject to significant erosion, as evidenced by the well developed gullies, which are common on each slope. Soil is essentially non-existent on the outslopes.

The outslopes are predominately composed of dark, generally fine-grained sandstone and shale materials. The fine-grained, clay like surficial outslope material tends to form a surface crust on the slopes. Field measurements indicate that the slopes vary in size from between 2.1 and 7.8 acres. Overall slope angles vary from between 72% and 80%. Vegetative cover on the unreclaimed slopes varies from zero to two percent. Table 1 summarizes the physical characteristics of each mine bench outslope.

Observations indicate that the mine bench outslopes are significant areas of sediment generation. It is apparent that the timing of sediment delivery from the outslopes to the adjacent streams is coincident with spring snow melt and runoff from summer rain events.

Sediment loading within Coal Creek and Dutch Creek may be detrimental to macroinvertebrate species populations. A loss of macroinvertebrate species, in turn, could impact local fisheries.

The reclamation challenge presented to Minerals and Geology was to minimize the delivery of sediment to Coal and Dutch Creeks as a result of erosion on the mine bench outslopes. This goal is to be attained by the establishment of an effective, diverse and long lasting vegetative cover on the mine bench outslopes. The constraints of elevation, access and steepness of the mine bench outslopes, as well as the sheer volume of material contained on the slopes required that they be stabilized in place. Therefore, one or more methods of revegetating the mine bench outslopes had to be developed.

REVEGETATION EFFORTS

Development of a large scale steep slope revegetation project would be dependent upon experience gained from initial, small scale revegetation efforts at various locations in Coal Basin. An effort to revegetate the north and south facing slopes of Mine 3 was made in 1995. Observations indicated that seed would bounce off the outslopes unless the surficial crusting was broken. To accomplish this, a steel I-Beam was suspended by cable from a light dozer. The dozer traversed the crest of the outslope, dragging the I-Beam across the surface of the slopes. The action of the I-Beam and cable on the slope served to greatly disrupt the surficial crusting, thus scarifying the outslope for a distance of approximately two hundred feet (200') downslope. A Hydro-mulcher was used to seed, fertilize and mulch the scarified slopes.

Immediately subsequent to this effort, an intense summer thunder shower developed, with torrential rains falling on the south facing outslope. Revegetation efforts were largely unsuccessful in this location, presumably because the seed was washed off of the scarified slope during this event. Interestingly, the north facing slope did not experience the severity of the storm event. The treated portion of the north facing slope did not lose its seed, and was successfully revegetated. The loss of the seed from the south facing outslope highlighted the need to not only scarify the slope, but to provide for small slope breaks in order that seed can accumulate in various niches when, and if, it becomes mobile prior to germination.

Following the experience at Mine 3, a small scale revegetation effort was undertaken at Mine 4. Shelves were constructed on the southeast facing slope of Mine 4 for the purpose of accomplishing scarification of the clay-like surface while providing for seed holding capabilities and moisture retention. The shelves were constructed by placing six to eight feet (6' – 8') long aspen poles perpendicular to the slope, and securing them in place using rebar driven into the slope surface. The slope behind the aspen poles was dug out to create a dirt shelf about ten to twelve inches (10" – 12") wide.

The shelves were seeded, fertilized and mulched using three techniques: hand broadcast, hydro-seed / mulch and hand broadcast in conjunction with an application of a Bonded Fiber Matrix (BFM). The initial results were promising. The hand broadcast and hydro-seeded areas displayed a relatively consistent cover after one year of growth. The area treated with BFM exhibited a greater cover than either of the other two treatment areas.

A problem developed the summer following seeding, however. Snowmelt on the constructed shelves and from the inter-shelf areas tended to collect on the shelves. Due to the coarseness of the dirt particles and due to the lack of soil cohesion, the accumulated water tended to cause the edges of the shelves to fail. Eventually, the shelf sides eroded toward the middle, resulting in loss of many of the shelves over the next two years. It was observed, however, that the inter-shelf areas in the BFM treated areas displayed an effective vegetative cover. However, the use of BFM and hydro mulch at locations other than Mine 4 was considered to be impractical due to access constraints, costs and the lack of readily available water.

Cursory observations of the 1995 revegetation efforts were made in September 1996. These observations indicated that the most successful revegetation without the use of BFM was in those areas where the slope had been adequately scarified, providing sites for seed catchment. However, the impacts of erosion on the constructed shelves had to be over come.

In order to address the observed benefits and obvious limitations of the shelves, smaller, entrenched shelves were designed for construction on a small portion of the Mine 1 outslope and on the steep fill slope of a nearby haul road.

A four feet (4') diameter drum roller was fitted with steel blades welded with a twelve inch (12") spacing (horizontal and vertical) between plates. The plates, made of one half inch (1/2") steel, are twelve inches (12") in length and six inches (6") in height, and are welded to the drum perpendicular to the curvature of the roller in an alternating pattern. The roller is designed with a tongue so that it can be pulled up and down the outslopes by a cable attached to a heavy dozer. After some experimentation on the outslope of Mine 1, it was apparent that the desired effect of building numerous small shelves could be created by pulling the roller up and down the slopes.

It should be noted that the roller performs differently than an imprinter in a very important way. While an imprinter creates a depression by compressing the ground surface into a depression, in which seed, fertilizer and moisture can accumulate, the modified roller gouges a shelf in the slope. This distinction is important in that the full weight of the approximately four ton roller is applied to two or three twelve inch (12") by one half inch (1/2") plates at any one time. This pressure forces the plates into the outslope material, and creates a gouge by digging material out of the slope as the roller moves up or down the outslope. It is felt that an imprinter, with a broad, blunt projection from the barrel of the roller, would not be as effective in preparing the slope. This is because the weight of the imprinter is distributed across a larger surface area, creating a basin, rather than producing the scooping effect of the modified roller blades. Further, due to the broader surface area of the imprinter, it tends to walk over areas that contain any significant amount of surficial or near-surface rock. The modified roller, because of the limited width of the blades, was observed to wedge between rock particles, continuing to create the desired surface modifications.

Following initial tests with the roller, a larger scale demonstration was undertaken. The roller was applied to an approximately seventy five feet (75') wide (across the slope crest) by one hundred twenty five feet (125') long (down the slope) area of the Mine 1 outslope. Seed was hand broadcast at a rate of about fifteen to twenty pounds pure live seed per acre. Commercial fertilizer (18-24-0) was applied at a rate of three hundred (300) pounds per acre. Hay mulch was applied to the slopes at a rate of about two tons per acre. Slope scarification and seeding in this manner were also accomplished at this time on a steep, east facing fill slope located below Road D immediately north of Mine 1.

The use of mulch as a cover was intended to shade the seed from the sun on these dark colored slopes. The dark colored, generally south and southeast facing slopes get very hot at the Project area elevation. Therefore, the use of the mulch as a shade mechanism was thought to be beneficial to the germination potential of the seed.

INITIAL REVEGETATION RESULTS

Initial observations of the slope in 1997 were encouraging. Visually, vegetative cover at Mine 1 was estimated to be about fifteen percent (15%) to twenty percent (20%). In 1998, representative transects were evaluated for cover and species composition. The results of this analysis are presented in Table 2, 1998 Vegetative Cover Estimates.

The preliminary sampling results obtained after two growing seasons indicated that the technique of seeding many small shelves and shading the seed with straw mulch was reasonably successful at establishing an effective vegetative cover on the outslopes. Careful observation of the vegetated portions of Mine 1 outslope also clearly showed that soil particles tended to migrate down the slopes until they reached an establishing plant. When the migrating soil particles intercept an establishing plant, they collect on the uphill side of the plant. This action results in the formation of a deltaic build up of dirt on the upslope side of the plant. This pattern suggests that the outslope particles are mobile between plants, but tend to become immobile when they come into contact with a plant. It is postulated that these small flat areas of recently deposited dirt will provide sites for seed to accumulate and germinate as the establishing plants mature.

During the early stages of developing a revegetation procedure for the mine bench outslopes, it was observed that a native grass species, purple reedgrass (*Calamagrostis purpurascens)* was growing on the outslopes and on adjacent, undisturbed steep slopes. Seed from the plant was harvested in the early fall of 1996 and 1997. The seed was cleaned by hand, and broadcast onto the scarified outslopes in conjunction with the commercial seed mixture used during the revegetation efforts at Mine 1 and Road D.

An effort to establish a stand of *Calamagrostis* separate from the commercial species being used was undertaken near Mine 1 in 1996. Cleaned *Calamagrostis* seed was distributed at a north facing disturbed hillside. A portion of the area was covered by hay mulch, and a portion was not mulched. No germination was detected until the summer of 1998, when *Calamagrostis* seedlings were observed to be growing on the site. Visual estimations indicate a cover of zero to fifteen percent has been established. It is postulated that the disparity in germination success is related to variations in the percentages of coarse trommel reject material and finer grained, decomposing shales across this slope area.

In an effort to promulgate a seed source for this material, DMG entered into a contract with the Upper Colorado Environmental Plant Center (UCEPC), located near Meeker, Colorado. UCEPC agreed to accept some of the Calamagrostis seed, to clean it, conduct germination tests and attempt to cultivate it on a limited scale. Germination tests had a positive result, with a 48% to 50% of the seed tested germinating. Cultivation, however, proved to be difficult, with field plantings bearing few seedlings. Greenhouse germination was more successful. UCEPC delivered to the DMG over one thousand seedlings suitable for transplanting in the summer of 1999.

1999 OUTSLOPE REVEGETATION PROJECT

Due to the success observed as a result of the demonstrations conducted at Mine 1 and at Road D, DMG decided to undertake revegetation of the remaining mine bench outslopes.

DMG was interested in replicating the hill slope scarification and shelf construction, accomplished in 1996. However, it was recognized that, for the most part, the slopes which needed to be treated and seeded were much more remote, and provided much greater access challenges than the relatively accessible upper reaches of the Mine 1 outslope. Therefore, an invitation for bid was issued which did not specify the mechanisms of shelf construction to be employed. Rather, the invitation specified minimum dimensions of shelves, shelf spacing and the minimum number of shelves per acre to be established.

The invitation specified that shelves would be no less than twelve inches (12") in width and eight-inches (8") deep. The spacing was to be three feet (3') horizontally (perpendicular to the fall of the slope) and five feet (5') vertically (parallel to the fall of the slope). However, field modifications to the contract specifications decreased the shelf size to ten inches (10") in width, and decreased the spacing interval to three feet (3') horizontally and three feet (3') feet vertically. This change resulted in a net increase in the number of shelves from 2,184 per acre to 3,588 per acre. Construction of the shelves to this specification would result in the creation of approximately 1,596 square feet of flat surface per acre on the steep mine bench outslopes.

Because the goal of the revegetation effort is to minimize sediment delivery to adjacent streams through stabilization of the slopes, the invitation for bid provided for planting shrubs at the base of the slopes to act as natural sediment barriers as the shrubs mature. The invitation also specified the planting of seedling trees at the crests of the outslopes. It is postulated that the establishment of trees along the crests will help to slow the melting of avalanches that accumulate at the crests, and to disperse the outflow from the avalanches as they melt in the spring.

Due to litigation associated with Coal Basin reclamation that was pending during the summer of 1998, the Project was delayed until 1999. In the interim, DMG applied for, and eventually received, a non-point source grant (Clean Water Act, Section 319) through the Colorado Department of Public Health and Environment. The grant provided DMG with the unique opportunity to enhance the scope of the Project by providing the financial ability to contract for the increased density of shelves on the slope, to purchase and apply a slow release fertilizer, and to increase the number and variety of shrubs to be planted at the base of the outslopes.

The goals of the non-point source grant are to:
- Stabilize the mine bench outslopes through revegetation processes;
- Control sediment migration through the establishment of vegetative barriers;
- Control sediment migration through the use of constructed wetlands or other barriers as site conditions allow;
- Monitor slope erosion by establishing gully monitoring points at each outslope;

- Monitor sediment loads in Coal Creek, Dutch Creek and their tributaries;
- Provide opportunities for public involvement in revegetation efforts.

To accomplish these goals, numerous tasks were undertaken in 1999 as part of the mine bench outslope revegetation project. Tasks included measuring the degree of current sedimentation, accomplishing seeding of the outslopes, planting of containerized shrubs, construction of sediment traps and other sediment barriers at appropriate locations, and establishment of a stream monitoring network. Public involvement will be solicited in 2000 to help plant shrubs and increase the number of vegetative sediment barriers.

In early September 1999, Dirt-N-Iron, the Project contractor, began work as crews were brought onto the site. Using Macleod Fire Rake / Hoe, the shelves were dug into the slopes. The Macleod Fire Rake / Hoe is a rake-like tool that is composed of a steel plate fastened perpendicularly to the base of a four and a half-foot (4.5') wood handle. One side of the steel plate is a sharpened flat blade, measuring about ten inches (10") across. The opposite end is a four pronged rake, also measuring about ten inches (10") across the outside of the rake.

The crew members worked ten to fifteen feet (10' to 15') distant from each other, spread horizontally across the slope. The crew worked from the top to the bottom of each slope. It is estimated that perhaps twenty five percent (25%) more shelves than was specified were actually created, yielding approximately 4,448 shelves per acre, representing up to 1,958 square feet of flat area per acre of mine bench outslope.

While the hand crew was creating the shelves, a second crew was collecting and cleaning *Calamagrostis* seed. In addition, seed from a locally occurring aster (tentatively identified as *Aster glaucodes*) was collected and cleaned.

Seeding was accomplished as the crew worked down the slopes. The commercially obtained seed (Table 3) was distributed with a hand held seeding machine. The seed from the two native species, including the *Calamagrostis* chaff, was distributed on the slope by hand broadcast methods.

Biosol 7-2-3, a slow release fertilizer, was applied by helicopter at a rate of 1,800 pounds per acre. Certified weed free straw mulch was applied at a rate of 2,000 pounds per acre. At four of the five outslopes, the mulch was also applied by helicopter.

Approximately twenty-four (24) acres of steep mine bench outslopes were scarified, seeded fertilized and mulched during performance of this Project. Due to the steepness of the slopes and because of the density and depth of the gullies present on the slopes, a precise measurement of the acreage involved is extremely difficult. Acreage estimations were made using aerial photos, topographic maps, real-time Global Positioning System (GPS) mapping and through the use of a range finder.

Using the *Calamagrostis* seedlings provided by the UCEPC, approximately two hundred (200) tublings were planted across each of the five mine bench outslopes at mid-slope. The mid-slope area was chosen for planting, as it is anticipated that seed produced from the plants will have an equal chance of being distributed either up- or down-slope by winds.

A variety of containerized shrubs (Table 4) were planted at the base of each slope. Approximately 540 shrubs were planted at the base of each slope. The purpose of this planting was to begin the establishment of vegetative sediment barriers. This planting effort will be followed up in 2000 by planting large volumes of willow cuttings at the base of some of the mine bench outslopes. The 2000 planting will establish a shrub layering affect in the target areas. It is anticipated that this follow-up planting will largely be accomplished with the help and assistance of volunteers.

In order to help control sediment at the base of three of the slopes which were relatively accessible, sediment traps were constructed. In one instance, this required the excavation of existing, but non-functional, sediment traps. These broad shallow traps were excavated so that runoff from a portion of Mines 1 and 2, as well as runout from a large avalanche, would pass through this sequence of three traps, allowing water to stand for a short period of time, permitting sediment to drop out of suspension. Locally obtained willow cuttings were planted around the perimeter of these sediment traps in order to further slow water as it exits the traps.

In some areas, adequate room to construct sediment traps does not exist. At one such location, logs and timber were placed into semi-concentric arrangements along the length of the slope base. This approach is a short term sediment control measure, due primarily to the limited detention time afforded by the logs and timber. Intensive shrub planting will occur at this location in 2000 to provide for a greater degree of sediment control.

Measurement of the project success will be accomplished not only in terms of vegetative cover, but also in terms of erosion control and sediment retention. In order to help assess sediment retention, staff gauges were placed within each sediment trap in order to measure sediment accumulation over time.

In an effort to indirectly measure the relative success of the revegetation effort as it relates to erosion and sediment delivery from the outslopes to the adjacent water resources, gully monitoring points were established within representative gullies on each of the treated slopes. Parameters such as gully width, depth, steepness, soil characteristics and relative percent vegetative cover within each gully contributing area were recorded.

A stream monitoring network has been established on Coal and Dutch Creeks. Parameters monitored include discharge and suspended solids. This network is designed to isolate the mine bench outslope contributions from naturally occurring sediment so that an analysis of the relative success of the mine bench outslope revegetation effort can be made as vegetation matures.

SUMMARY

DMG has applied vegetative stabilization treatments to the long, erosive outslopes located below the mine entry benches at Coal Basin. Various revegetation techniques were evaluated following test plot establishment in 1995 and 1996. The test plots represent an effort to find reasonable, economic methods that demonstrate an acceptable degree of success. Selected technologies with the highest potential for success were implemented on a large scale in 1999.

Revegetation of steep features such as the mine bench outslopes in a difficult environment is challenging at best. Initial efforts appear to be successful in the short term. It is anticipated that, baring unforeseen environmental circumstances, the large scale revegetation effort undertaken in 1999 should be equally successful to that of earlier efforts. It is thought that success of the 1999 revegetation and sediment retention project will be measured by a reduction in sediment production from the mine bench outslopes. Monitoring of the outslopes and receiving streams will help to determine the degree of success over time.

TABLE 1. OUTSLOPE MEASUREMENTS

	Mine 1	Mine 1 West	Mine 3 North	Mine 3 South	Mine 5 Fan
Slope Angle	72 %	75 - 80 %	70 %	83%	72 %
Vegetative Cover *	1 %	0 –2 %	0 – 1 %	0 % - 1 %	0 %
Slope Length (Ft.)	670	800	415	400	550
Fill Depth (Ft.) *	4 - 20	10 - 15	10 - 20	7 - 15	12 - 15
Slope Size (Ac.)	2.2	7.8	2.2	3.7	2.4
Particle Size	90 % < 1”	90% < 1”	80 % < 1”	50 % < 1”	50 % < 1”
Cohesion Estimate	Poor	Poor to Fair	Poor	Fair	Poor to Fair

- * Estimated

TABLE 2. 1998 VEGETATIVE COVER ESTIMATES

	Mine 4 Outslope [1]	Mine 1 Outslope [2]	Mine 3 North Outslope [1]	Road D Outslope [2]
Vegetative Cover (%)	20 - 25	25	25	20 – 25
Predominate Species	Agropyron trachycaulum, Bromus inermis, Phleum pratense, Agropyron intermedium, Festuca ovina, Dactylis glomerata, Agropyron smithii, Poa pratensis, Achillea millifolium, Penstemon strictus	Agropyron trachycaulum, Bromus inermis, Festuca ovina, Poa pratensis, Achillea millifolium, Penstemon strictus, Linum lewisii, Astragalus cicer	Agropyron trachycaulum, Festuca ovina, Dactylis glomerata, Deschampsia caespitosa, Penstemon strictus, Poa pratensis	Bromus inermis, Agropyron trachycaulum, Phleum pratense, Festuca ovina, Achillea millifolium, Penstemon strictus, Linum lewisii, Astragalus cicer

[1] Seeded September, 1995
[2] Seeded September, 1996

TABLE 3. OUTSLOPE SEED MIXTURE

SPECIES	SCIENTIFIC NAME	VARIETY	LBS/Acre PLS
Kentucky Bluegrass	Poa pratensis	Banff	0.25
Slender Wheatgrass	Agropyron trachycaulum	Primar	4.00
Mountain Brome	Bromus arginatus	Bromar	4.00
Sheep Fescue	Festuca ovina	Covar	1.50
Timothy	Phleum pratense	Climax	0.25
Orchardgrass	Dactylis glomerata	Latar	0.50
Smooth Brome	Bromus inermis	Manchar	1.00
White Dutch Clover	Trifolium repens	Ladino	0.50
Cicer Milkvetch	Astragalus cicer	Monarch	1.00
Blue Flax	Linum lewisii	Appar	1.00
Yarrow	Achillea millifolium	VNS	0.10
Rocky Mountain Penstemon	Penstemon strictus	Bandera	0.50

TABLE 4. SHRUBS PLANTED AT THE BASE OF THE MINE BENCH OUTSLOPES

Serviceberry	(Amelanchier alnifolia)
Mountain Big Sagebrush	(Artemisia tridentata vaseyana)
Mountain Mahogany	(Cercocarpus montanus)
Shrubby Cinquefoil	(Potetilla fruticosa)
Chokecherry	(Prunus virginiana)
Wax Currant	(Ribes inerme)
Woods Rose	(Rosa woodsii)
Mountain Snowberry	(Symphoricarpos oreophilas)

2000 Billings Land Reclamation Symposium

EFFECT OF SLOPE GRADIENT AND PLANT GROWTH ON SOIL LOSS ON RECONSTRUCTED HIGH ALTITUDE SLOPES

N.M. Kapolka[1] and D.J. Dollhopf[2]

ABSTRACT

The objectives of this study were to 1) evaluate effect of slope gradient and plant growth on soil loss on high altitude (2590 meters) sites, 2) evaluate effect of coversoil thickness on plant growth, and 3) determine if the Revised Universal Soil Loss Equation (RUSLE) version 1.06 computer model could predict the quantity of soil loss in a high altitude steep slope environment.

Four slopes each with a different gradient (25%, 33%, 40%, and 50%) were constructed and each slope was divided into four plots with different coversoil thicknesses (0 cm, 15 cm, 30 cm, and 45 cm). These sixteen plots received an identical seed mixture and fertilizer application.

Soil loss increased with slope gradients up to 40% and then decreased as slope gradient increased to 50%. First year mean soil loss was 16.38 Mg/ha and decreased to 1.01 Mg/ha during the second season. Soil loss rates the second year approached those on undisturbed lands. Plots without coversoil had the lowest soil loss which was attributed to high rock cover on the soil surface. Plots with coversoil had more plant growth than plots without coversoil. There was a significant correlation during the first and second years ($r = 0.65$ and 0.70, respectively) between coversoil thickness and plant production. Increased plant production on plots with thicker coversoil, however, did not reduce soil loss.

The RUSLE computer model underestimated soil loss by 15 +/- 17 Mg/ha during the first year following slope construction. During the second year, predicted soil loss was, on average, 0.4 +/- 0.6 Mg/ha lower than measured soil loss rates. Results from this study indicated that RUSLE v. 1.06 is an effective long-term planning tool to use on steep slopes at high altitudes.

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INTRODUCTION

Hard rock mines in the Western United States often have to reclaim steep slopes. One of the most important concerns with respect to steep slope reclamation is soil erosion. Soil loss can have a negative effect on plant establishment and is a potential source of down gradient watershed degradation. One of the primary challenges when reclaiming these slopes is to control soil loss. To reconstruct slopes in an environmentally sound and cost effective manner, mining companies need to maximize slope gradient, have adequate coversoil to support vegetation, and minimize soil erosion rates.

Sediment yields tend to increase roughly linearly with slope gradient (Hahn, 1985; Hartley and Schuman, 1984; Liu et al., 1994; McIssac, 1987; Schroeder, 1987). The ease with which soil particles are detached appears to increase with slope gradient. Rainsplash, which provides most of the energy for detachment of soil particles, is more active on steeper slopes (Mathier et al., 1989). The influence of gravity increases with gradient and may cause aggregates to break loose more easily (Grosh, 1994). There is evidence, however, that suggests as slope gradients become more steep than 35 - 40%, soil loss may stabilize or decrease (Bradford and Foster, 1996; Singer & Blackard, 1982). On very steep slopes, direct raindrop impact on a given area of soil surface is reduced, thereby reducing the likelihood of detachment of soil particles (Bradford and Foster, 1996; Singer & Blackard, 1982).

Rill erosion increases on steep slopes (Hahn, 1985; Hartley & Schuman, 1984; McCool, 1987). Once a slope exceeds a critical steepness, rill erosion causes sediment yields to increase rapidly with slope gradient (McCool et al., 1987). McCool et al (1987) found that rills usually formed on slopes with gradients steeper than 30%. Hahn (1985) showed a linear relationship between length of rills and slope gradient and stated that it was likely that soil loss and rill formation are related to and are dependent on slope steepness.

There is an inverse relationship between soil loss and rock cover (Ashby et al., 1984; McIssac, 1987; Sidle and Brown, 1993; Simanton et al., 1984). High rock content increases infiltration rates and surface roughness decreasing runoff and soil loss. In addition, the higher the rock content, the less soil available for soil loss (Ashby et al., 1984; Sidle and Brown, 1993). As erosion occurs on rocky soils, rock cover increases as the coarse fragments below the surface are exposed. This armoring of the soil can further help to reduce soil erosion (Box and Meyer, 1984).

Investigators have found soil erosion decreases as plant growth increased (Hartley & Schuman, 1984; Kirkby, 1980). Vegetation intercepts precipitation and reduces the energy of the raindrops thereby decreasing soil detachment. Vegetation also increases the infiltration capacity of the soil which decreases runoff and increases soil roughness which reduces runoff velocity and encourages deposition of soil particles. Soil structual stability is also increased due to an increase in soil organic matter.

Investigators have reported that plant growth increases significantly with increased coversoil depths up to about 50 cm (Barth & Martin, 1982; McGinnies and Nicholas, 1980; Power et al., 1981; Redente & Hargis, 1985). Redente et al. (1997) studied the long-term effects of coversoil thickness on plant growth. While results from this study show that plant growth increases with increased coversoil depth it also suggests that shallow coversoil depths can support productive plant communities. Redente et al. suggested that 15 cm of coversoil over non-toxic spoil is sufficient for the establishment and continued productivity of rangeland vegetation.

The Revised Universal Soil Loss Equation (RUSLE) Version 1.06 on Mined Lands, Construction Sites, and Reclaimed Lands is a computer model developed by the Office of Surface Mining and Reclamation in Denver, Colorado (Galetovic, 1998). This model was designed to estimate the long-term soil erosion rates based on site-specific environmental conditions for disturbed lands.

Research was conducted at the Treasure Mine to (i) evaluate the effect of slope gradient and plant growth on soil loss; (ii) evaluate the effect of coversoil thickness of plant growth; and (iii) determine if the Revised Universal Soil Loss Equation (RUSLE) version 1.06 can predict soil loss in a high altitude steep slope environment.

METHODOLOGY

Research was conducted at the Barretts Minerals Inc, Treasure Mine, an open-pit talc mine, located about 15 miles east northeast of Dillon, Montana. Elevation is approximately 2590 meters and average annual precipitation is 26 cm. The mine has a snowpack for about half of the year.

The experimental design consisted of four slopes, each with a different slope gradient: 25%, 33%, 40%, and 50%. Each slope was divided into four plots, each with a different coversoil depth: 0 centimeters, 15 centimeters, 30 centimeters, and 45 centimeters of coversoil. In total, there were sixteen plots, each measuring 3.1 x 30.5 meters. At the base of each plot was a trough designed to capture runoff and sediment.

Coversoil and subsoil were analyzed for organic matter percentage using the Walkey Black method. Electrical conductivity, pH, Na, Ca, and Mg levels were determined using a saturated paste extract. Coarse fragment percentage was determined by seiving the 2 mm fraction and then volumetrically analyzing the coarse fragments. Soil texture was determined using the hydrometer method.

All plots were broadcast seeded by hand with an identical seed mixture in November 1997. *Triticum aestivum* and *Hordeum vulgare* were planted as cover crops for the first season. Cover crops grow quickly and provide short-term protection against erosion before perennial vegetation is established.

Precipitation was measured using a rain gauge, and a solar powered datalogger recorded precipitation data on an hourly basis. Sediment accumulated in collection troughs and was measured every two weeks in the late spring and summer months. Sediment was removed from the troughs, dried at 41°C, weighed, and calculated on a Mg/ha basis. Rills that formed on the plots were described quantitatively using the Erosion Condition Classification System Montana Revised Method (Clark, 1980). This method classifies rills based on depth and frequency of rills. Plant canopy cover, basal cover, rock cover, and aboveground production were estimated using 10 systematically placed quadrants on a transect on each plot during 1998 and 1999. These variables were analyzed by lifeform (i.e. grass, forb). Canopy cover, basal cover, and rock cover were estimated visually and on a percent cover basis. Production was measured by clipping vegetation 2 cm above the ground, oven-drying at 21°C to a constant weight, and then weighing.

RUSLE version 1.06 was used to calculate predicted soil loss rates. Various input variables were required for each factor in the RUSLE model. Input values were obtained from field data, from Renard et al. (1987), or from the United States Department of Agriculture Natural Resource Conservation Service State Agronomist (Fasching, 1999).

RESULTS AND DISCUSSION

Coversoil and subsoil material had a sandy loam texture. Coarse fragment percentage by volume was 33% for the coversoil and 52% for the subsoil. EC, pH, Na, Ca, and Mg levels were all considered suitable by current reclamation standards (Munshower, 1994).

Soil loss rates decreased from the first year to the second year of the study (Figure 1). Normal soil loss rates for undisturbed lands are about 0.2 – 0.5 Mg/ha (Mg/ha = 0.45 tons/acre) (Brady and Weil, 1996). Soil erosion rates for the first year (mean = 16.38 Mg/ha) were much greater than these normal rates. Soil loss decreased dramatically during the second year (mean = 1.01 Mg/ha). After just one year soil loss rates loss rates on these reconstructed slopes were similar to undisturbed slopes. This decrease in soil loss may be attributed to increased vegetative cover the second year. Plots had no vegetation for the first two months of data collection the first year. During this time precipitation was high and very high soil loss occurred. During the second year vegetative litter increased from 0% to 12% and perennial grasses and forbs continued to develop on all plots providing additional cover and slope stability.

In 1998 precipitation was about average but precipitation was below average (-6.46 cm) in 1999. Greater total precipitation in 1998 may have increased soil loss compared to 1999; however, it was more likely that the intensity of the precipitation events had a greater effect on soil loss. Soil loss is dominated by high-intensity storms (Larson, 1997; McCool, 1984). Both years had seven storms when greater than 2.5 cm of precipitation fell in one hour, but in 1998 several of these storms occurred when the soil was bare of vegetation. High intensity storms that occurred while soil was bare may have been responsible for the high soil loss rates in 1998.

As slope gradient increased from 25% to 40% soil loss increased; however as slope gradient increased to 50% soil loss decreased (Table 1). Both years the 40% slope had the highest soil erosion rate and the 50% slope had less soil loss than the 40% slope (Figure 1).

This nonlinear relationship between soil loss and slope gradients has been reported by other investigators (Bradford and Foster, 1996; Singer and Blackard, 1982). Rainsplash provides the energy for detaching soil particles that are then transported downslope. As slope gradient increases rainsplash becomes more active increasing soil loss (Mathier et al., 1989), but as slope gradients become very steep (approximately 35 – 40%) there is less direct rainsplash impact on the surface, thereby reducing detachment of soil particles and decreasing soil loss (Bradford and Foster, 1996; Singer and Blackard, 1982).

Rill severity increased with slope gradients up to 40%. Rills were more severe on the 40% slope than the 50% slope, reflecting the fact that the 40% slope yielded the greatest soil loss. Rills did not form on the plots without coversoil due to high rock cover (86%). On plots with coversoil rill severity was least on plots with 15 cm of coversoil and was greatest on plots with 30 cm of coversoil. These plots with 30 cm of coversoil also had the highest soil loss rates (Figure 1).

When sediment was collected from troughs it was often concentrated directly below rills present on these plots. Soil loss was correlated significantly with rill formation in 1998 ($r = 0.88$) and in 1999 ($r = 0.65$) at this site. In 1998 large quantities of soil were eroded as the rills formed, but in 1999 the rills acted mainly as conduits for sediment transport. Data in this study suggest that soil loss and rill formation are related to one another and depend on slope gradient.

Plots without coversoil had a mean of 86% rock cover whereas plots with coversoil had a mean of 39% rock cover. Plots with high rock cover had less soil loss and less severe

Figure 1. Comparison of total annual soil loss from all test plots in 1998 and 1999.

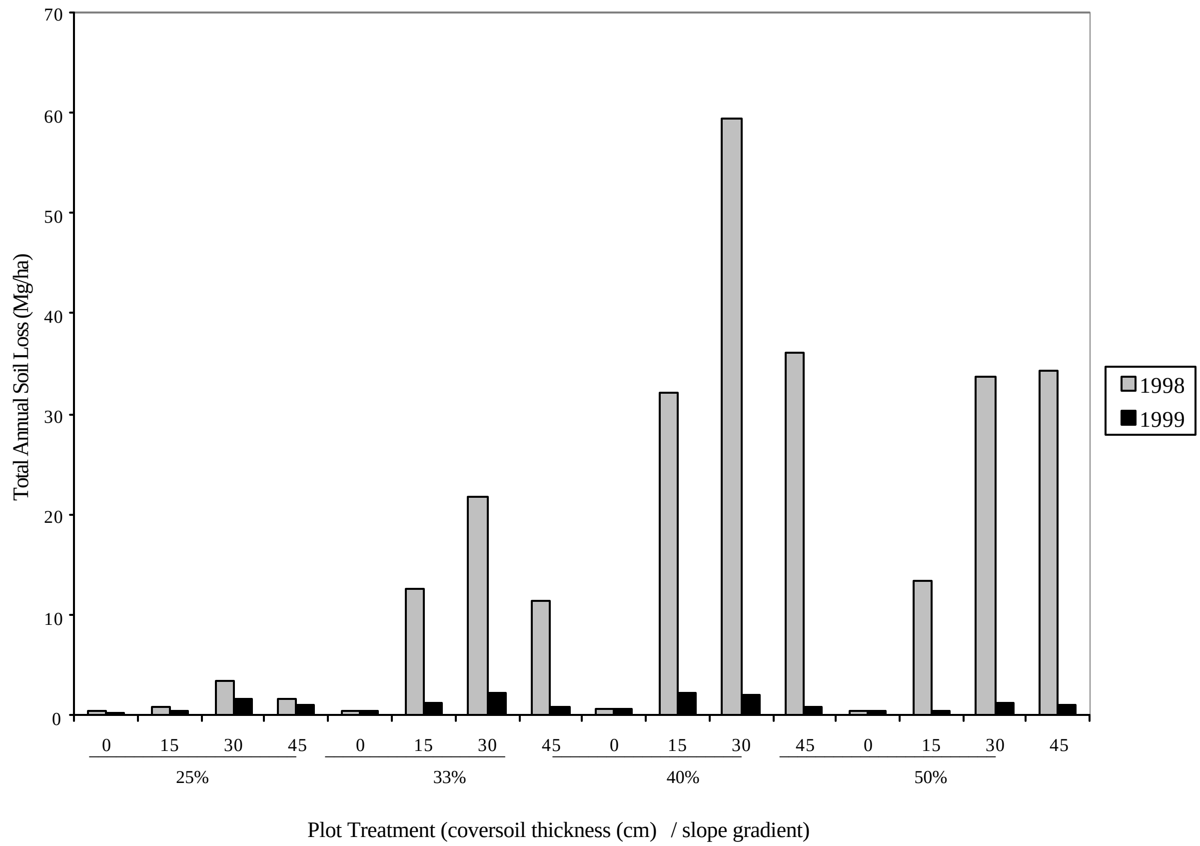

Table 1. Effect of slope gradient on total annual soil loss (Mg/ha).

	Slope Gradient			
Year	25%	33%	40%	50%
1998	6.32	46.16	128.08	81.56
1999	3.08	4.48	5.64	2.92

rills. There was a significant negative correlation between soil loss and rock cover during the first (r = -0.66) and the second (r = -0.61) year. Plots without coversoil had very little soil loss (Figure 1). Although general principles of soil reconstruction recommend that coarse fragment percentage by volume be less than 20%, on high elevation steep slopes it is appropriate to exceed this criterion to reduce soil loss rates.

In general, plant canopy cover, basal cover, and production increased with increased coversoil thickness (Table 2). During the first year there was a significant correlation between coversoil thickness and canopy cover (r = 0.58) and basal cover (r = 0.48). During the second year correlations between coversoil thickness and canopy cover (r = 0.49) and basal cover (r = 0.36) were not as strong, and only the correlation for canopy cover and coversoil thickness was significant. Production and coversoil thickness were significantly correlated in 1998 (r = 0.65) and in 1999 (r = 0.70). Results from this study indicated that

Table 2. Effect of coversoil thickness on mean* plant growth characteristics.

Plant Characteristic	Coversoil Thickness 0 cm	15 cm	30 cm	45cm
		1998		
Canopy cover (%)	30.0	47.3	45.5	47.3
Basal cover (%)	24.0	34.0	31.5	33.0
Production (kg/ha)	597	1795	1522	2858
		1999		
Canopy cover (%)	23.3	26.3	27.8	30.8
Basal cover (%)	21.8	22.0	22.8	24.8
Production (kg/ha)	775	1233	1369	1613

* n = 160

vegetation increased with increased coversoil depths. There were no significant correlations between plant growth characteristics and slope gradient indicating that slope gradient did not have an effect on plant growth. Total vegetative canopy cover, basal cover, and production values decreased from 1998 to 1999, however, perennial grass cover, forb cover, and production all increased after the first year. Decreases in total vegetative canopy and production were due to the absence of the cover crop during the second year.

On plots without coversoil, rock cover was very high (86%), and, as a result, both plant growth and soil loss rates were low (Figure 1). Increasing the coversoil depth resulted in increased plant production, however increased plant production did not result in decreased soil loss rates. Results from 1998 may not have shown a relationship between plant growth and soil loss since most soil loss occurred before the plant community established. An inverse relationship between plant growth and soil loss would have been more likely during 1999, but did not occur. Results from this study indicated that although increased coversoil depths yielded increased plant production, these increases in plant production were not sufficient to minimize soil losses.

The RUSLE version 1.06 computer model was used to calculate annual soil loss values for both years of this study. On average, predicted values for 1998 underestimated the rate of soil loss by 15 +/- 17 Mg/ha. RUSLE predicted soil loss rates for 1999 more accurately than for 1998. In 1999, RULSE, on average, underestimated soil loss by 0.4 +/- 0.6 Mg/ha. Although the RUSLE model accounts for rill and interrill erosion, data suggested that RUSLE was not able to account for the extreme quantity of soil loss during the first season as rills formed.

To account for the inaccuracy of soil loss prediction by RUSLE in the first year a rill formation factor was determined. Plots were divided into three groups based on the average rill severity rating for each plot: plots with stable to slight rill erosion, plots with slight to moderate rill erosion, and plots with moderate to critical rill erosion. Using nonlinear variable estimation (Wraith and Or, 1999), a rill formation factor was determined for plots with slight to moderate rill severity and for plots with moderate to critical rill severity. The rill formation factor (F) was multiplied by the soil erodibility factor (K) to generate a new soil erodibility factor (K1). This new soil erodibility factor (K1) was then used to generate optimized soil loss values. Using the new soil erodibility factor the optimized soil losses were closer to the measured soil losses. On average, the optimized soil losses were 1.4 +/- 8.5 Mg/ha lower than measured soil losses. These rill formation factors were generated from a small sample size and are not necessarily applicable to other sites.

There may be other reasons why the RUSLE model predicted soil loss rates notably low on many of the plots in 1998; however, if the reason for underestimation is due to the formation of rills it would be useful to incorporate this factor into RUSLE v. 1.06. This computer model was designed for mined sites, reclaimed lands, and construction sites. First year rill formation is likely to occur on these newly constructed steep slopes. Hopefully, future research will serve to corroborate the need for a special rill formation factor when using RUSLE v. 1.06 on newly constructed steep slopes.

CONCLUSIONS

As slope gradient increased to 40% soil loss increased; but as slope gradient increased to 50% soil loss decreased. Although soil loss generally increased with slope gradient, soil loss after the second year was less than 2.5 Mg/ha regardless of slope gradient or coversoil thickness. These soil loss rates are considered stable. Soil losses the first year following reclamation were higher for all slope gradients. To protect downgradient water quality during the first year following reclamation, a support practice (i.e., mulching, constructing sediments basins) should be considered.

Soil loss was least on the plots without coversoil, but this treatment is not recommended. Use of coversoil is recommended as a best management practice for land reclamation. All plots with coversoil, regardless of thickness, had more plant growth than plots without coversoil. Plant growth increased with increasing coversoil thickness. Although increased coversoil thickness yielded increased plant cover and plant production, these increases in plant growth did not have the effect of reducing soil loss. At least 15 cm of coversoil should be applied to reconstructed slopes, however, long term monitoring of a site may show that increased coversoil thicknesses have a greater effect on vegetation and subsequent soil loss as the plant community matures.

RUSLE v. 1.06 underestimated soil loss during the first year by 14.98 +/- 17.35 Mg/ha, but predictions for the second year underestimated soil losses by only 0.38 +/- 0.59 Mg/ha. Although RUSLE is designed to account for rill and interrill erosion, results from this study indicated that it was not able to account for the severe erosion that occurred as rills formed. Based on results of this study RUSLE is an effective tool to use for long term planning on reconstructed high altitude steep slopes.

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SUCCESSFUL TECHNIQUES FOR HIGH ALTITUDE STEEP SLOPE REVEGETATION

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ABSTRACT

The Molycorp, Inc. Questa mine is located in northern New Mexico in an area of steep topography. Dump construction during the open pit operation utilized steep canyons to create the dumps. The resulting overburden slopes are relatively shallow, steep and high (over 500 feet). A state highway and river, located near the toe of the slopes preclude reshaping of the piles. The angle (steepness) of the slopes is similar to the natural topography, which supports primarily a mixed conifer ecosystem. Development of a self-sustaining ecosystem appropriate to the site is the underlying goal of the revegetation program. The relatively rapid physical weathering of the waste rock creates a suitable planting medium for the seedlings. An *in situ* method for reclamation was developed based on over 20 years of research and planting programs. Both the fast growing early successional overstory species (*Populus angustifolia, Quercus gambelii, Robinia neomexicana,* etc.) and the slower growing, later successional overstory species (*Pinus ponderosa, P. flexilis, Abies concolor,* etc.) are planted simultaneously along with appropriate understory species. The differential growth of the two types of overstory species is intended to shorten the time frame to achieve a more stable, later successional plant community. Standard forestry techniques were adapted for the reclamation program. In general, seedlings of the overstory and shrub species are hand planted on the slopes using hoedads and grasses and forbs are established using direct seeding techniques. First year survival for transplants has averaged 80%. This survival rate has been attributed to three main features of the program: 1) using site adapted (genetic) stock; 2) planting pre-conditioned container grown stock; and 3) proper planting techniques. The expanded revegetation program is in its fourth year with over 130,000 seedlings planted.

Additional Key Words: reforestation, reclamation.

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INTRODUCTION

The Molycorp Inc., Questa Molybdenum Mine has been in operation since 1921. The mine is located in an area of steep, mountainous topography in narrow canyons adjacent to the Red River five miles east of the town of Questa, New Mexico in Taos County. Underground mining occurred from 1921 to the early 1960s when open pit development of the ore body began. The open pit mine operated from 1965 through 1983. From 1983 to the present mining is an underground block caving operation.

The open pit period of extraction generated 328 million tons of overburden. Deposition of this overburden material utilized the natural steep, long slopes and narrow canyons for the development of the overburden piles. Today, the overburden pile surfaces are steep and long, in some cases exceeding 500 feet in length. Unlike other mining operations where overburden piles are situated on relatively flat ground and the height of the piles is indicative of pile depth, the depth of the overburden piles at Molycorp range from 60 to 125 feet in thickness (depth) (Robertson GeoConsultants, Inc. 1999). The resulting overburden depth was a function of several factors including underlying topographic features including slope, slope length and overburden structural composition and its influence on angle of repose. The resultant surface of the overburden piles has similar slope intensity to the adjacent natural topography.

The terrain surrounding the mine supports primarily coniferous ecosystems with riparian ecosystems in the bottoms of many canyons having perennial streams or rivers. The conifer dominated ecosystems range from ponderosa pine (*Pinus ponderosa*), mixed conifer (*P. flexilis*, *Pseudotsuga menziesii*, *Abies concolor*) to spruce-fir (*Picea engelmannii* and *Abies concolor*) stands. Topographic features, specifically elevation and aspect strongly influence species distribution (Wagner and Harrington, 1994). Areas in which the coniferous overstory have been disturbed, various shrub (*Quercus* spp., *Cercocarpus montanus*, *Ribes* spp.), aspen (*Populus tremuloides*) and narrowleaf cottonwood (*P. angustifolia*) dominated communities occur. Again, the distribution of these various communities is strongly influenced by topographic features and most likely edaphic features that impact rooting mantle thickness and water holding capacity.

The other natural feature which appears to strongly influence vegetation distribution in this region are hydrothermal scars. These naturally occurring areas have highly erodible, and acidic "soils" (Meyer and Leonardson 1990). During the open pit-mining operations, hydrothermal scars were excavated along with intervening areas of more neutral geologic materials. Heterogeneous overburden piles resulted with a wide range of particle sizes, and chemistries (specifically pH).

Through the influence of overburden management and natural variability in the area, the piles represent a broad array of planting sites with a wide range of attributes which can influence revegetation success. Elevation ranges from 8,000 feet to 10,000 feet and almost every aspect occurs. In addition to the variability in the overburden thickness, overburden particle size ranges from clay sized fines to large cobble and overburden pH ranges from neutral (pH 7.0) to very acidic (pH < 3.0). In short, the overall site provides an ideal laboratory to evaluate the robustness of different revegetation treatments.

Traditional approaches to revegetation of overburden materials often involves drastic recontouring and capping with various materials to support plant growth, and in several cases manipulate water movement. However, many features of this site indicate that developing new revegetation techniques and technologies or modifying existing ones would be more advantageous to both Molycorp and the overall watershed. Some of the technologies and techniques developed from the *in situ* revegetation of the overburden would be applicable to other, natural areas in the watershed which are actively eroding.

REVEGETATION RESEARCH

Beginning in the mid-1970s Molycorp has been actively funding revegetation research at their Questa mine. Initially, this research effort began with the then Soil Conservation Service Plant Materials Center in Los Lunas, New Mexico (currently, the Natural Resource Conservation Service, Los Lunas Plant Materials Center (NRCS-LL-PMC). This research effort continues today. In 1992, Molycorp expanded this effort by expanding funding to include New Mexico State University researchers at the Mora Research Center (NMSU-MRC). This research effort also continues today. This report will summarize the accomplishments of several of these research projects. For sake of brevity, only those studies or portions of studies relating to the development of the revegetation project will be presented in this manuscript. Also, discussed will be the results of initial plantings associated with the operational revegetation plantings that began in fall 1996. Most data presented will be first year survival data or survival data after one growing season unless otherwise noted.

MATERIALS AND METHODS

The plants used in these studies and the operational program are container grown seedlings produced in greenhouses. The NMSU-MRC and NRCS-LL-PMC facilities have produced the plant materials used in these studies and operational plantings under appropriate production regimes. Seed or cutting sources are identified in each respective study. When possible and depending on the purpose of the study, local seed sources have been used. Planting of seedlings involved using traditional container planting techniques (dibble bars, hoedads, etc.) adjusted to accommodate unique site features such as rockiness and steep slopes.

Study A. Fertilization Effects on Early Survival and Vigor of Shrub Seedlings Planted on Neutral Overburden.

The purpose of this study was to evaluate the effects of fertilizer incorporation at planting on the survival and vigor of 24 shrub species.

Twenty-four species and ecotypes were evaluated in this study. Seedlings were grown in Supercells (10 in ^{3}). Seedlings were planted at the end of July 1994 on a ripped bench plot (ripped to an average depth of 10 inches). Plots were watered before or after planting. Two planting locations on the overburden piles were used in this study. Replications varied from five to seven seedlings per source with fourteen rows per treatment replication. Half of the Super Cells were fertilized at planting with the other half receiving no fertilizer (control). Fertilizer treatment consisted of 6 grams/seedling of 17-6-23 3-4 month controlled release fertilizer. All plots were top dressed with 17-17-17 fertilizer in July 1996 and 1997. The plots were evaluated in September 1995 and 1997. Individual seedlings were classified with numeric vigor ratings of 4 = excellent, 3 = good, 2 = fair, 1 = poor, and 0 = dead.

RESULTS

Initial fertilizer application effects on survival was species and ecotype specific (Table 1). Ten of the 24 sources evaluated had pronounced (>10%) reductions in first year survival with the fertilizer treatment. By the 1997 survival evaluation only two sources, one *Artemesia frigida* and one *Rosa woodsii* source, appeared to have been negatively influenced by initial fertilization beyond the initial first year effects. Overall, three year survival was influenced by source rather than initial fertilization treatment. This trend is indicated by similar shifts in survival rates regardless of fertilization treatment from the 1995 to the 1997 evaluation (Table 1).

Seedling vigor after one year was impacted the fertilizer treatment, with those plants fertilized initially, in general showing higher vigor ratings. By the 1997 evaluation, this difference had become less pronounced (Table 1).

Study B. Grass Species Trial.

The purpose of this study was to evaluate grass species and varieties on overburden when planted as transplants. The influence of fertilization at time of planting and fertilization after two growing seasons was also evaluated.

Grass seedlings were grown in horticultural six-pack containers, placed outside for hardening and fertilized with soluble fertilizer prior to transplanting. Sixty species and varieties (sources) were used in this study. Transplants were planted in two locations in ripped (to 10 inches) bench plots. Six plots were used with two plots receiving fertilizer (6 grams/seedling of 17-6-12, 3-4 month controlled release fertilizer) and four plots without fertilizer at planting. Seedlings were transplanted August 8 and 9, 1994 and plots were watered before and immediately after planting. All plots received fertilizer (17-17-17) in July 1995 and 1997. The plantings were evaluated September 1995 and 1997 for vigor and survival. Vigor was rated as described above.

RESULTS

Only data from 18 of the 60 cultivars/species are shown, including the best performing grasses and those with Molycorp accesssions. The best performing grasses are listed below. In general, vigor was improved by fertilizer treatment (Figure 1). The average vigor rating for best performing species were greater than 3.25 in the fertilizer treatment and greater than 1.5 in the control. In general, survival was not affected by initial fertilizer treatment (Figure 2).

Native cool season grasses:	Canada Wildrye, Streambank Wheatgrass, Western Wheatgrass, Reed Canarygrass
Native warm season grasses:	Spike Muhly
Introduced cool season grasses:	Orchardgrass, Tall Fescue, Timothy

Table 1. Survival and mean vigor ratings for shrubs planted in 1994 and evaluated in 1995 and 1997. Fertilizer treatment was applied at initial planting.

Species	1995 Survival		1997 Survival		1995 Vigor		1997 Vigor	
	Cont	Fertil.	Cont	Fertil.	Cont	Fert	Cont	Fertil.
Achillea spp.	98	98	97	100	1.89	3.58	3.80	3.40
Artemesia frigida	98	94	62	66	1.81	3.19	3.39	3.41
Artemesia frigida	97	83	76	28	1.62	2.93	3.83	3.77
Artemesia frigida	100	82	48	40	1.85	3.11	3.56	2.80
Artemesia spp.	96	91	87	88	1.60	3.08	3.45	3.43
Artemesia tridentata	80	58	56	47	1.53	2.49	2.25	1.0
Atriplex canescens	93	88	33	32	1.14	1.75	2.38	2.38
Berberis fendleri	--	84	--	92	--	2.75	--	2.22
Cercocarpus montanus	95	81	82	69	1.73	2.58	3.21	3.41
Chrysothamnus nauseosus	95	89	87	89	2.11	2.55	3.73	3.55
Chrysothamnus nauseosus	95	91	82	93	2.00	2.45	3.44	3.58
Eriogonum spp.	97	77	95	76	2.08	3.11	3.72	3.47
Eriogonum spp.	94	81	95	77	2.20	3.64	3.66	3.59
Jamesia americana	88	70	80	62	1.07	2.42	2.49	3.31
Prunus virginiana	93	82	96	82	2.47	2.83	3.43	3.13
Prunus virginiana	86	69	86	69	2.34	2.44	3.04	3.28
Ribes cereum	81	82	81	79	1.08	1.55	3.23	2.94
Ribes spp. (spiny)	93	84	78	78	1.09	1.52	3.33	2.59
Ribes spp. (spiny)	95	93	78	89	1.14	1.78	3.15	2.49
Robinia neomexicana	74	81	27	17	3.00	2.78	3.17	2.33
Robinia fertilis	82	86	70	67	3.29	2.83	3.19	2.43
Rosa woodsii	99	100	95	98	2.07	2.34	3.18	3.38
Rosa woodsii	96	87	95	71	2.00	2.26	2.99	2.76
Rubus spp.	100	51	93	68	1.64	2.90	3.88	3.36

Study C. Effects of Seed Source and Container Size on the Survival of Ponderosa Pine Seedlings.

The objectives for this study were to evaluate the effect of seed source and container size on the survival of ponderosa pine (*Pinus ponderosa*) seedlings planted on steep overburden slopes.

The study used seedlings from four ponderosa pine seed sources. The sources were from throughout New Mexico representing 4 USDA Forest Service seed zones including the mine's seed zone (USDA Forest Service seed zone 710), one adjacent to the mine's seed zone to the west (620), and two southern seed zones (170 and 840).

Seedlings from each of the four seed sources tested were produced in one of three growing containers. Sizes evaluated included 1 in^3, 7 in^3, and 10 in^3 containers. Seedlings were produced at the NMSU-MRC facility using a standard production regime.

Table 2. Species shown in Figures 1 and 2 listed below:

NUMBER	SCIENTIFIC NAME	COMMON NAME	SOURCE/VARIETY
1	*Dactylis glomerata*	Orchardgrass	Paiute
2	*Festuca arundinacea*	Tall Fescue	Fawn
3	*Festuca ovina*	Sheep Fescue	Covar
4	*Festuca ovina*	Sheep Fescue	Molycorp H
5	*Festuca ovina*	Sheep Fescue	Molycorp LS
6	*Festuca ovina*	Sheep Fescue	Molycorp LT
7	*Schizachyrium scoparium*	Little Bluestem	Molycorp GHS
8	*Schizachyrium scoparium*	Little Bluestem	Pastura
9	*Bouteloua gracilis*	Blue Grama	Alma
10	*Bouteloua gracilis*	Blue Grama	Willis
11	*Elymus canadensis*	Canada Wildrye	
12	*Elymus lanceolatus*	Thickspike Wheatgrass	Critana
13	*Elymus lanceolatus*	Streambank Wheatgrass	Sodar
14	*Muhlenbergia wrightii*	Spike Muhly	El Vado
15	*Pascopyrum smithii*	Western Wheatgrass	Arriba
16	*Pascopyrum smithii*	Western Wheatgrass	Rosanna
17	*Phalaris arundinacea*	Reed Canarygrass	
18	*Phleum pratense*	Timothy	Climax

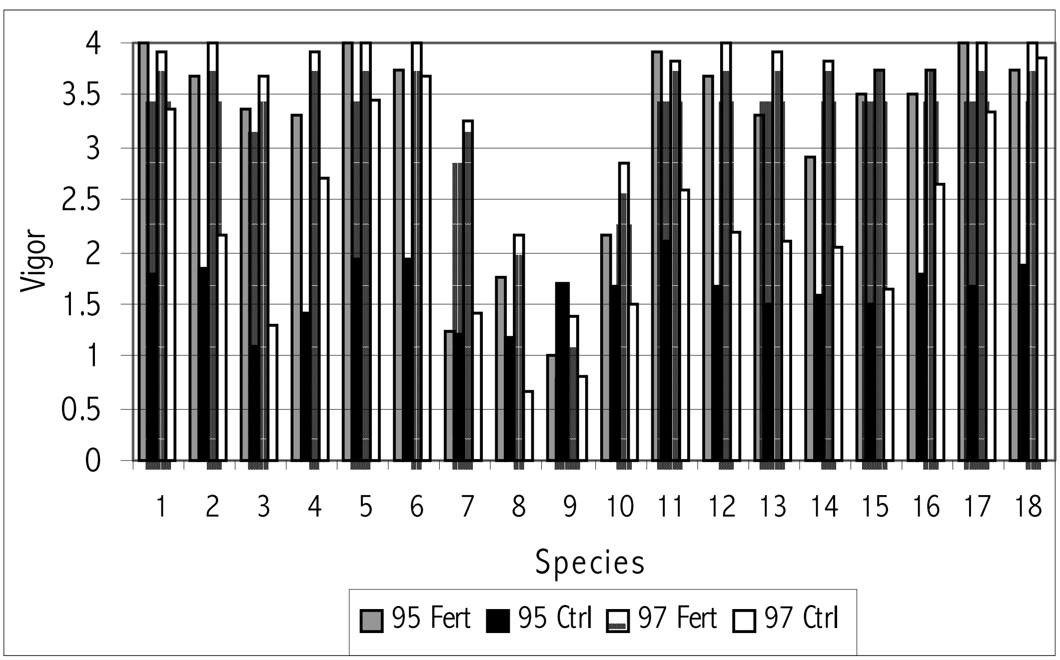

Figure 1. Effect of fertilizer at planting on vigor of grass transplants, with planting occurring in 1994. See Table 2 for species codes.

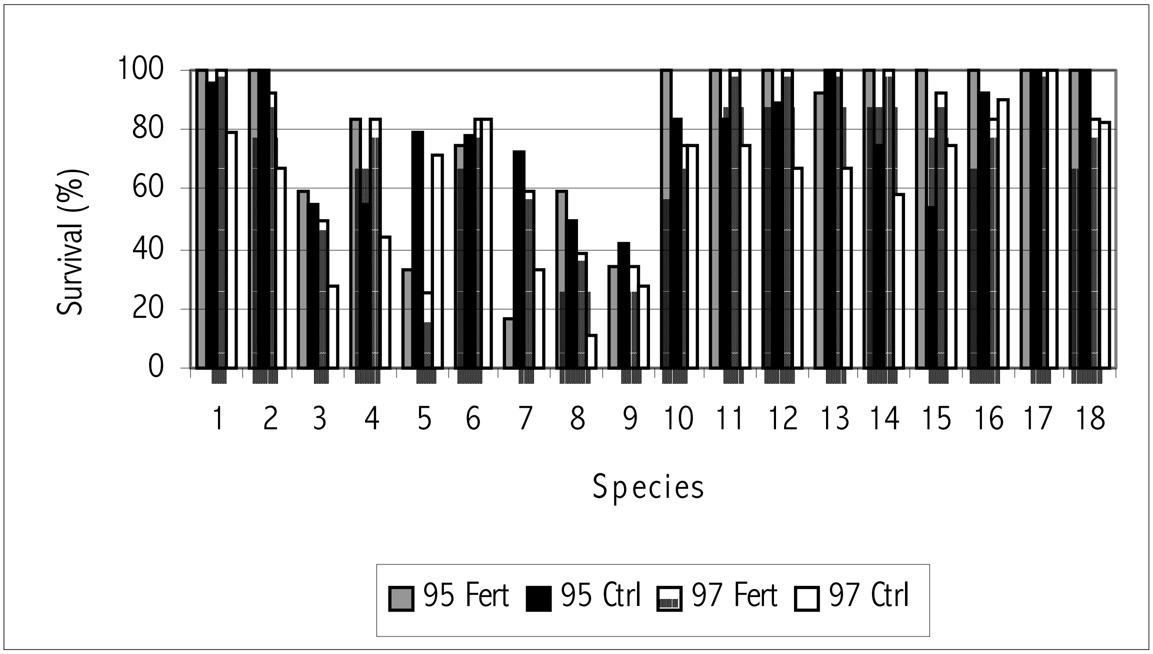

Figure 2. Effect of fertilizer at planting on survival of grass transplants, planting occurred in 1994. See Table 2 for species codes.

The seedlings were planted September 13-16, 1993. Dibble bars were used for the larger containers and a sharpshooter shovel for the 1 inch^3 container. Treatments, seed source and container size, were randomly allocated in each planting block. Two planting sites were used in the study. Both sites were near the base of the slopes.

The treatment design was a factorial design of seed source (four), and container size (three) for 12 treatments. The outplanting design was a split plot design with the two main plots being the planting sites. Each main plot consisted of six randomized complete blocks. Each treatment was represented in each block by a 10 tree row plot.

The response unit was the average of the 10 tree row plot of each treatment within each block. Because the plots were installed at the base of slopes some areas were lost by covering by overburden material. Survival values were adjusted to be a percentage of the number of living seedlings based on total number of non-covered seedlings.

RESULTS

Smaller seedlings were more prone to covering than were larger stock types (39% compared to 30%). Survival was greater for the largest two stock types, 10 in^3 and 7 in^3 (Figure 3). Some treatments had 90% survival. The smaller stock type, 1 in^3, had a survival rate of 5%. The poorest performing seed source was the southern seed source (seed zone 170). The three other seed sources performed comparably, with an average survival of 24% (Figure 4).

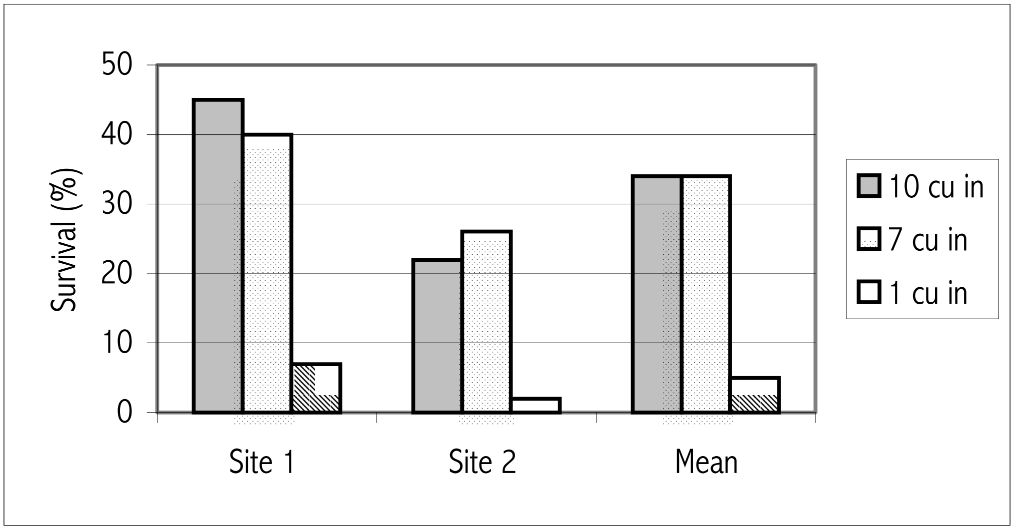

Figure 3. Effect of container size on transplanted ponderosa pine seedling survival.

Figure 4. Effect of seed source on transplanted ponderosa pine seedling survival.

Study F. Effects of Planting Site Aspect, Elevation and Substrate Chemistry on Survival of Spring and Fall Planting Conifer Seedlings.

The objectives of this study were to survey effects of aspect and elevation on conifer transplant survival for spring and late summer planted seedlings and to examine the impact of substrate chemistry on conifer transplant survival for spring and late summer planted material.

This study utilized seedlings generated from two ponderosa pine (Pinus ponderosa) seed sources, one seed source of Douglas fir (*Pseudotsuga menziesii*) and one seed source of Englemann spruce (*Picea engelmannii*). All seedlings were greenhouse grown in 9 in^3 containers. Seedlings were removed from their containers, bagged, boxed and refrigerated (34^{o}F) until planted. All seedlings were dormant when planted.

Seven planting sites were evaluated providing a range of aspects, elevations and substrate chemistry (see Table 3). Planting dates were early June and late August 1994. Only ponderosa pine was planted in June, and all four sources were planted in August.

Treatments evaluated were species and seed sources and planting date. Other factors examined were elevation, aspect and substrate chemistry. The treatment design was an incomplete factorial design with main factors being species – seed source and planting date. The outplanting study design was a randomized complete block. The seven planting sites served as complete blocks.

Each seed source by planting date combination was represented in each block by 10, 10-tree row plots. The response unit was the average of the 10-tree row plot of each treatment within each block. The survival response is as described above in Study E.

Table 3: Elevation, aspect, field pH and field conductivity for planting sites.

Site Number	Elevation (feet)	Aspect	Field pH	Field Conductivity
A	9200	South	2.9	2900 µS
B	9000	Southwest	5.0	110 µS
C	9000	South	5.5	70 µS
D	9000	Southeast	--	--
E	9400	South	3.7	720 µS
F	9400	East	2.8	1450 µS
G	8550	East	6.5	40 µS

The overall adjusted survival of this study was 44% with spring planted seedlings having an average survival of 68% (Table 4). On four sites, spring planted ponderosa pine seedlings had survival rates of 80%, with two sites in excess of 90%. Fall planted material from the same seed sources did not perform as well, with one site having a decline in survival from over 80% to 11%. Englemann spruce, planted only in the fall, had a survival rate of 65%. It was the only species to do well with the late summer planting.

Average survival by planting site ranged from 20% to 65% with all plantings having some replications with 0% and 100% survival. Planting sites A and F were acidic sites and had similar survival of approximately 47%. Species seed source and planting date trends of reduced survival and overall ranking were similar for both sites with the exception of late summer planting of one source of ponderosa. This seed source had almost no survival at planting site F while planting site A had survival of over 33% (Table 4). The somewhat less acidic site, planting site E, also had good spring ponderosa pine survival (91%), however fall planting performance was significantly reduced. The only trend in survival for neutral planting sites was the better performance for spring planted ponderosa pine.

First Year Survival of a Fall Operational Planting

In September of 1996, a trial operational planting was conducted on the top portion of one of the lower (elevation) overburden piles. The planting was done by hand using a contract planting crew. The plant material, consisted of a wide range of plant species. In general the relative proportion of plant forms was 35% deciduous trees; 40% coniferous trees; and, 25% shrubs. All plant materials were grown in reforestation containers

Table 4. Effect of planting location, species and planting date on seedling survival.

	Mean Survival (%)						
Treatment	Plot A	Plot B	Plot C	Plot D	Plot E	Plot F	Plot G
Spring ponderosa (1)	76	37	39	75	84	90	86
Spring ponderosa (2)	56	23	22	86	97	84	96
Fall ponderosa (1)	45	38	2	17	12	39	70
Fall ponderosa (2)	33	5	5	42	9	3	34
Fall Englemann spruce	42	74	48	67	52	76	99
Fall Douglas fir	21	13	8	5	0	19	9

(Supercells or Styro77 Styroblocks) at the NMSU-MRC Research Nursery. Planting crews were told to select plant materials to maximize diversity at the planting site. (Note: some members of the planting crew were better at this than others.) The planting crews were given instructions to plant seedlings four feet apart within rows and the rows were to be 4 feet apart.

In August of 1997, nine 100m^2 (50m x 2m) transects in the planting area were randomly selected and measured. Species composition and frequency were recorded. Status categories included: living, dead, living and partially buried, dead and partially buried. No interpretations of the vigor of the seedlings were made. For ease of installation and consistency, all transects were placed perpendicular to the slope direction.

RESULTS

Overall, survival ranged from 89% to 69%. The plot containing the 31% mortality was unique in that large portions of this transect (in excess of 35%) were covered by cobble sized material and those areas were not planted. The majority of the mortality was observed immediately adjacent to these cobble areas. Therefore, this plot was eliminated from the summary analysis (Table 5). The next highest mortality level was 24%. When separated by life form (conifer tree, deciduous tree, shrub) the deciduous tree, primarily narrowleaf cottonwood (*Populus angustifolia*) had the lowest survival rate of 62% (live and buried live). Coniferous trees had a survival rate of 88% of which 9% were partially buried. Shrubs had the highest survival rate of 92% (Table 5).

Partially buried seedling frequency ranged from none to 19% with an average of 9% (Table 5). Shrubs had the highest frequency of partial burying at 14% while the coniferous and deciduous trees had partial burying rates of 9% and 5% respectively.

Species diversity across the plots ranged from 10 to 16 species per plot averaging 11 species per plot. All life forms were represented in each plot. Plant density ranged from 6.700 plants per hectare (2,735 plants per acre) to 10,500 plants per hectare (4,286 plants per acre) and averaging 8,838 plants per hectare (3,648 plants per acre).

Table 5. Summary survival and partially buried responses of the 1996 Fall Operational Planting. Evaluation occurred late August 1997.

Life form	**Total percent survival (%)**	**Percent Non-Buried Alive (Mean ± SE)**	**Percent Non-Buried Dead (Mean ± SE)**	**Percent Buried Alive (Mean ± SE)**	**Percent Buried Dead (Mean ± SE)**
Conifers	88	78 ± 4	9 ± 3	9 ± 3	<1
Deciduous Trees	62	58 ± 4	36 ± 4	4 ± 1	1 ± 0.5
Shrubs	92	78 ± 8	8 ± 4	14 ± 5	0
Total	81 ± 2				

Total Buried = 9% ± 3%; Number of Species per Plot = 11 ± 1

SUMMARY

The results from these studies and others have indicated that traditional forest artificial regeneration techniques could provide a feasible means for revegetation of the overburden piles at the Molycorp Questa Mine. These studies have illustrated that there appear to be a wide array of plant species which can survive the various planting sites these piles provide. From these studies several general conclusions can be deduced. First, regarding seedling stock size, bigger is better. This is evident in the problem of seedlings being covered on some of the planting sites. In Study E, the smaller seedlings had shoot sizes generally less than three inches. These smaller seedlings were easily laid over and buried by the slightest surface movement. Other studies not reported here also had some partial losses due to seedlings being buried following planting. This is even more important when planting occurs near the base of the slope.

The second general conclusion is that species and seed sources must be carefully evaluated when selecting material for sites. This is probably most pronounced when considering substrate pH. Several studies have shown that several species can withstand the lower pH of some portions of the overburden piles indicating that there are seed sources of several species suitable to the various planting sites in the overburden piles.

The third general conclusion is that planting earlier in the growing season can improve survival. It should be noted here, that as subsequent studies and operational planting have been installed, overall survival, independent of planting date, has improved. The difficulty at this particular mine is that the initiation of the frost free period precedes the summer moisture by about 6 weeks. We have found that planting dormant stock immediately after snow melt when the overburden is generally at field capacity we obtain our highest rates of first year survival. This planting window precedes the last spring frost by two to four weeks.

The final general conclusion which can be drawn from these studies, is that further work needs to be performed on fertilizer applications. It appears that adding fertilizer at the time of planting may improve first year vigor but it also increases first year mortality rates. However, in all the studies conducted thus far, the plant material was transplanted towards the end of the growing season. This may have caused unnecessary shoot growth late in the growing season. Further work will need to be done on the timing of fertilization treatments.

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2000 Billings Land Reclamation Symposium

RESTORATION WITH NATIVE INDIGENOUS PLANTS IN YELLOWSTONE AND GLACIER NATIONAL PARKS

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ABSTRACT

The U.S. Department of Interior National Park Service has adopted a policy of 'restoration' with native indigenous plants on all disturbances related to road construction, visitor impact, and facility maintenance. The National Park Service is committed to maintaining the genetic integrity of the, often, unique native flora, with secondary goals of erosion control, competition with exotic and noxious invasive plants, and improved aesthetics. Since 1986, Yellowstone and Glacier National Parks have been working cooperatively with the USDA-NRCS Plant Materials Center in Bridger, Montana to determine which native plant species can be readily collected, increased, and successfully reestablished on disturbed sites. To maximize species diversity and compatibility, plant mixtures are designed to minimize competitive interactions. Seed mixtures are a combination of short-lived perennials (early colonizers) and long-lived perennials (late seral dominants). To capture the genetic diversity of early successional (primarily selfed) plants, seed is collected from several populations within a project area. However, with the late seral dominants (primarily outcrossed) the number of populations needed to harvest is significantly less. Early colonizing species usually have abundant and consistent seed production, effective seed dissemination, higher germination percentages, and broad tolerances of disturbed sites. Late seral dominants are found on older, less severely impacted areas. They are included in mixtures to accelerate succession, but they may not always be suited to the edaphic conditions of a severely impacted site. The production of seed and/or plants of native species at a site remote to the Parks had been found to be possible with minimal genetic drift or natural selection. With topsoil salvage and utilizing native indigenous plant material, Yellowstone and Glacier National Parks have developed very successful restoration programs.

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INTRODUCTION

Revegetation, reclamation, and restoration--all imply the reestablishment of plant cover on a disturbed site, but if taken literally may imply three levels or intensities of site mitigation. 'Revegetation' is simply the re-establishment of a plant cover, often a monoculture of an introduced plant species. Although relatively inexpensive, revegetation may not offer permanence or ecological stability. 'Reclamation' has been defined historically as the process of returning disturbed land to a condition that approximates the original site conditions and is habitable by the same or similar plants and animals which existed on the site before disturbance (Redente et. al 1994). 'Restoration' strives to emulate the structure, function, diversity, and dynamics of a specific ecosystem. Topsoil salvage can preserve the soil biota along with viable propagules of indigenous plant materials. By utilizing native indigenous plant material (seed, cuttings, transplants), the genetic integrity and diversity of the native plant communities will be maintained. Even with soil salvage and the use of native indigenous plant materials, restoration must not be interpreted as a discrete event, but rather as an ongoing process involving the reestablishment of nutrient cycling, plant succession, and plant community dynamics.

The U.S. Department of Interior National Park Service (NPS) has adopted a policy of 'restoration' of all disturbed sites related to road construction, visitor impact, and facility maintenance. The NPS is committed to maintaining the genetic integrity of the, often, unique native flora, with secondary goals of erosion control, competition with exotic and noxious invasive plants, and improved overall aesthetics of disturbed sites. In 1985, with financial support from the Federal Highway Administration, both Yellowstone National Park (northwestern Wyoming) and Glacier National Park (northwestern Montana) initiated a restoration program that involved topsoil and plant salvage, native indigenous seed collection and production, plant propagation from seed and cuttings, and extensive seeding and planting of disturbed sites. A nationwide cooperative agreement between the National Park Service and the U.S. Department of Agriculture--Natural Resources Conservation Service Plant Materials Centers (PMCs) was established in 1986 to assist in the determination of which native species could be readily collected, increased, and successfully reestablished on disturbed sites. The decision by the NPS to adopt a restoration policy has generated many unanswered questions and much controversy concerning the protection and preservation of the indigenous gene pools, e.g.,

- +What plant species can be considered indigenous to an open disturbance in a forest community?
- +What constitutes the limits of a genotype? How far away from the project area can plant propagules be collected and still be within these limits?
- +What species can be readily collected and produced using standard agricultural techniques?
- +By taking seed outside of the park to a dissimilar environment to increase seed or plants, is genetic drift or natural selection going to impact the genetic integrity of the plant material?
- +What plant species will be compatible in mixtures and what type of plant community is an acceptable restoration goal?

SPECIES SELECTION

Once the NPS made the decision to utilize native indigenous plant materials in its restoration efforts, its next decision was to determine what species would naturally colonize on open disturbances within forest communities. In Yellowstone National Park, the first road project was through lodgepole pine (*Pinus contorta*) habitat types, whereas in Glacier National Park, the first project was along Lake McDonald through a cedar-hemlock (*Thuja plicata/Tsuga heterophylla*) habitat type. It was assumed that the understory species of the adjacent forest communities would not be adapted for use on the open road corridors. By examining abandoned roads, burns, old disturbance areas (both manmade and natural) the early colonizing species were identified and by examining open parks and meadows the late seral dominants were identified. Chambers et al. (1984), working in the alpine zone of the Beartooth Mountains of South-Central Montana, found early colonizing species to have characteristics most desirable for reclamation of alpine disturbances. These species exhibited an ability to establish and grow on harsh phytotoxic sites, frequently have larger ecological amplitudes, and are distributed over wide geographic areas. Harper (1977) stated that early colonizing species usually had abundant and consistent seed production, effective seed dissemination, higher germination percentages, and broad tolerance for establishment on disturbed sites. Late seral dominants, on the other hand, as defined by Johnson and Billings (1962), are found on older and less severely disturbed sites. These species are often included in seed mixtures to accelerate succession, but may not be completely successful because of competition from early colonizers, or simply may not be suited to the edaphic conditions of the disturbed site. Both Yellowstone and Glacier Parks are creating mixtures for each specific project that include both early colonizing and late seral dominant species (table 1). Mixtures are relatively simple, relying somewhat on existing propagules in the salvaged topsoil and seed rain from adjacent areas to compliment the seeded material.

Table 1. Native plant species found to reestablish naturally on disturbed sites in Yellowstone and Glacier Parks.

COLONIZERS			
Short-lived Perennial Grasses		Perennial Forbs	
Elymus trachycaulus	slender wheatgrass	*Achillea millefolium*	western yarrow
Bromus marginatus	mountain brome	*Anaphalis margaritacea*	pearlyeverlasting
Elymus elymoides	bottlebrush squirreltail	*Phacelia hastata*	silverleaf phacelia
Elymus glaucus	blue wildlrye	*Aster integrifolius*	thickstem aster
		Solidago canadensis	goldenrod
		Viguiera multiflora	showy goldeneye
LATE SERAL DOMINANTS			
Long-lived Perennial Grasses		Perennial Forbs	
Poa ampla	big bluegrass	*Lupinus argenteus*	silvery lupine
Deschampsia cespitosa	tufted hairgrass	*Eriogonum umbellatum*	sulfur eriogonum
Pseudoroegneria spicata		bluebunch wheatgrass	*Penstemon confertus*
	yellow penstemon		
Festuca idahoensis	Idaho fescue	*Geranium viscosissimum*	sticky geranium
Poa alpina	alpine bluegrass	*Potentilla gracilis*	cinquifoil

Phleum alpinum	alpine timothy
Agrostis scabra	rough bentgrass

GENOTYPE DETERMINATION

The genetic variability within and among plant populations vary by species as a function of geographic range, reproduction mode, mating system, seed dispersal mechanism, and stage of succession (Hamrick 1983). Whether a species is self-pollinating or outcrossing makes a difference in genetic variability. The selfing mode of reproduction limits the movement of alleles from one population to another, so these species are found in small disjunct populations with little variation within a population, but distinct variation among populations. Outbreeding plants have widely dispersed pollen and seed, and tend to exhibit significant variation among individuals but less variation among populations. Species with winged or plumose seeds have the greatest potential for gene movement and subsequently have less variability among populations.

To capture the genetic diversity of early successional stage (primarily selfed) plants, seed would have to be sampled from several populations within a project area. However, with late seral dominants (primarily outcrossed), the number of populations that would need to be harvested is significantly less.

When a disturbed site is planted with seed from an adjacent or close proximity site there is a possibility that a distinct, new genotype may develop. Jain and Bradshaw (1966) found that those species that evolve on a disturbed site may actually be genetically different than individuals of the same species on adjacent undisturbed sites. Antonovics (1968) found that on harsh sites characterized by low pH and heavy metals, grass species had the ability to change from an outcrossing to a self-pollinating mode of reproduction in order to prevent dilution of the gene pool by adjacent unadapted populations. This raises the question of the need to harvest from many sites if a new distinct genotype will evolve on disturbed sites as influenced by the harshness and edaphic conditions of the site.

At this point, what actually constitutes a genotype is more theory than fact. Presently, some national parks have self-imposed collection restrictions of 5 km for short-lived, self-pollinating species, 8 km for short-lived outcrossing species, and up to 16 km for long-lived outcrossing species. These distances may be smaller if there are major changes in geography and plant community types within the project area. Yellowstone Park has adhered to these collection radiuses, while Glacier Park is collecting in close proximity of the projects sites in the alpine region (Logan Pass) and the fescue grasslands (east slope of Continental Divide), but have gone outside the park to burned areas and forest clearcuts to meet the needs for colonizing species to use along road corridors through the dense Cedar\Hemlock habitat types west of the Continental Divide.

SEED AND PLANT PRODUCTION

There is some question as to how much natural selection and genetic drift will occur when seed is grown at a site remote from the original source. Merrell (1981) stated that individuals developing at the same time, but under different environmental regimes, may have different phenotypes develop, even though their genotype is essentially the same. Seed production at a site remote from and dissimilar to the original collection site, has the potential for natural selection and genetic drift. There is a potential for a decrease in genetic diversity at several stages of production, i.e., the sizing nature of the cleaning process may exclude the largest and smallest seeds, harsh conditions at the time of germination and emergence may limit the survival to only the most viable seeds, as individual plants compete for space and nutrients in the seed production field some individuals may succumb to others, and during the harvesting process only those seeds that are mature at the time of harvest will be represented--early and late maturing individuals will be excluded. Samples of three generations of mountain brome were evaluated both phenotypically and genotypically by Dr. Thomas Mitchell-Olds and Dianne Pavek at the University of Montana-Missoula. The original collection (G_0) was collected in the Dickie Creek drainage at the southern border of Glacier Park (1987), the second generation (G_1) was produced at the Bridger PMC (1990) in a field established with G_0 seed, and the third generation (G_2) was produced at the Bridger PMC (1992) from a stand established with G_1 seed. Mitchell-Olds (1993) found the phenotypic variation (comparing morphological characteristics at three common garden sites in GNP) and genotypic variation (isozyme electrophoretic analysis utilizing 25 scorable bands) was non-significant among the three generations of mountain brome. The distance coefficients (after Johnson and Wischern 1982) and the similarity coefficients (after Gottlieb 1977) indicated that there was very little difference among the original mountain brome collection and the two subsequent generations grown at the Bridger PMC. Although this data is for only one species, it supports the potential for producing native indigenous plant materials at sites remote from their source with minimum impact on the genetic integrity of the original gene pool.

If commercially produced native seed is to be used in restoration projects, the planning process must allow at least three years; the first to collect seed, the second to plant and establish a seed production field, and the third to make the first seed harvest. Three to four harvests can be taken from a field before production drops to an uneconomical level. The cost of producing seed under commercial conditions varies greatly with species, size of field, yearly environmental conditions, and the timing of harvest. Seed production under cultivated conditions, however, produces a more reliable quantity and quality of seed than under natural conditions. Both Yellowstone and Glacier National Parks utilize multiple sources of plant material for their restoration projects. Salvaged plant material is either directly transplanted or potted for later use. Seed of native indigenous plants is collected for direct seeding, seeding of flats or containers, or for seed increase at the Bridger Plant Materials Center; cuttings are propagated at each Park's own nursery facilities, and containerized material is grown at their nurseries or contracted to commercial nurseries.

To date, there are only a few private growers that are attempting to grow native indigenous ecotypes under contract with the National Park Service and the U.S. Forest Service. Contracts with private growers include stipulations to guarantee genetic purity, and usually a set price and maximum/minimum amount of seed that will be purchased. Many of the native species of grasses and forbs that are under consideration for use in restoration projects have not been grown commercially—leaving questions about germination and dormancy problems, establishment techniques, cultural management, and harvest. The cost of production is dependent on the size of the production field, difficulty in maintaining a clean pure stand, uniformity of ripening, ease of harvesting, and ease of cleaning (table 2).

Table 2. Average cost of production of seed production of native plants based on field size, ease of production, and ease of cleaning. Average of several Plant Materials Centers involved in National Park Restoration Projects.

	Ease of Production and Cleaning		
	Easy	Moderate	Difficult
GRASSES			
Small amount (0.1 acre or less)	$35/lb	$50/lb	$100/lb
Medium amount (0.1 to 0.25 acres)	$25/lb	$40/lb	$ 75/lb
Large amounts (0.25 + acres)	$15/lb	$30/lb	$ 60/lb
FORBS	$50-$100/lb	$100-$300/lb	$300+/lb

The cost of production varies drastically among different native species. Grasses such as mountain brome and slender wheatgrass are relatively easy to grow and are very productive under cultivated conditions. Species like needlegrasses and bottlebrush squirreltail are difficult to harvest and process because of awns, while some sedges, junegrass (*Koeleria macrantha)*, and reedgrasses/hairgrasses (*Calamagrostis/Deschampsia)* are notoriously poor seed producers. Seed of the forbs are relatively difficult to produce because stands are often difficult to establish by direct seeding and control of broadleaf weeds is limited to hand rogueing and a few agricultural chemicals.

The production of large quantities of seed of a few collections is far more cost-affective than the production of small quantities of several collections. More work needs to be done to determine what constitutes a genotype or how broad of an area can a specific collection be used and still protect the genetic integrity of the indigenous plant material.

PLANTING AND MONITORING

To maximize species diversity and compatibility, plant mixtures are designed to minimize competitive interactions. The goal of the restoration effort is to produce a plant community that is as stable as the adjacent undisturbed area, which can sustain itself while progressing through successional stages. The nature of the disturbance may place constraints on both the ability to restore the site and the subsequent success that occurs on that site (Chambers et al. 1990). To minimize competition, seed mixtures should not be too complex. With linear disturbances, in particular, seed rain from adjacent areas will provide added species diversity to a seeded plant community.

Restoration within Yellowstone and Glacier National Parks begins with the salvage of topsoil. The topsoil is carefully stripped and stored in windrows along the upper edge of the road project and redistributed on the prepared cuts and fills during the same growing season. The surface is left rough and downfall logs and rock are strategically placed to create micro-niches. Most of the seeding is done by hand broadcasting, followed by hand-raking or dragging the surface to bury seed and improve seed-soil contact. Mulching with wood chips, extruded aspen fiber, or straw is done on most projects to protect against surface soil erosion and reduce soil surface drying during germination and emergence. Seed mixtures are a combination of short-lived perennials (colonizers) and long-lived perennials (late seral dominants). The seed mixtures are relatively simple, consisting of four to six grasses and three to five forbs (table 3). Shrubs and some forbs are planted as transplants, containerized material or as bareroot stock.

Table 3. Basic seed mixtures developed for different vegetation types in Glacier and Yellowstone National Parks (other species are used as available).

GNP--Alpine	GNP--Fescue Grassland	GNP--Cedar\Hemlock
*Poa alpina**	*Bromus marginatus**	*Bromus marginatus**
*Phleum alpinum**	*Pseudoroegneria spicata**	*Elymus glaucus**
*Poa gracillima**	*Festuca idahoensis**	*Deschampsia cespitosa**
*Deschampsia atropurpurea**	*Festuca campestris**	*Calamagrostis rubescens*
*Carex hoodii**	*Koeleria macrantha**	
	*Elymus trachycaulus**	*Achillea millefolium**
Aster laevis		*Penstemon confertus*
Sibbaldia procumbens	*Gaillardia aristata**	*Penstemon albertinus*
Senecio triangularis	*Hedysarum boreale**	*Aster laevis*
Epilobium alpinum	*Geranium viscosissimum*	*Antennaria neglecta*
Hypericum formosum	*Heuchera cylindrica*	
	*Potentilla gracilis**	

YNP--Lodgepole Pine Forest	YNP--Northern Grasslands	YNP--Wetlands
*Bromus marginatus**	*Stipa comata**	*Deschampsia cespitosa**
*Elymus trachycaulus**	*Pascopyrum smithii**	*Agrostis scabra**
*Elymus elymoides**	*Leymus cinereus**	*Elymus trachycaulus**
*Agrostis scabra**	*Nassella viridula**	
*Poa ampla**	*Bromus anomalus**	*Pedicularis groenlandica*
		Gentiana detonsa
*Achillea millefolium**	*Achillea millefolium**	
*Lupinus sericeus**	*Linum lewisii**	
*Phacelia hastata**	*Potentilla fruticosa*	
*Potentilla gracilis**		
*Eriogonum umbellatum**		
*Viguiera multiflora**		

* Species of which seed or plants have successfully been produced at the Bridger Plant Materials Center.

Monitoring is an integral part of the restoration process; providing information on the success of establishment techniques, individual species establishment and survival, species compatibility, and the long range stability of the established plant communities. Glacier National Park's monitoring program is loosely based on the U.S. Forest Service ECODATA (Jensen et al. 1992) ocular plot methodology. This technique utilizes both microplot and ocular surveys of ground cover, species cover, species composition, erosion status, plant mortality, plant growth, and invasion of exotics. Both Parks utilize varying intensities of monitoring: Level I is basic documentation of ground cover and the presence of exotics (often used to document conditions on small backcountry projects); Level II is a general evaluation of surface status and total vegetation cover including species lists, mortality, plant density and overall plant vigor (most commonly used along road shoulders); Level III involves microplots and shrub transects to collect data suitable for statistical analysis (utilized on large obliterated turnouts and larger cut and fill slopes); and Level IV utilizes replicated plot designs to evaluate the effectiveness of various combinations of restoration treatments (seeded vs. unseeded, mulching vs. unmulched, fertilized vs. unfertilized, chemical control of weeds and exotics, nurse/cover crop alternatives).

The restoration attempts in Yellowstone and Glacier National Parks have made every effort to maintain the genetic integrity of the plant material, to salvage and protect the viability of the soil biota (micro-organisms, mycorrhizae, and plant propagules), and to create stable, self-sustaining plant communities on disturbed sites. These new plant communities continue to change as some of the colonizer species give way to the late seral species and as additional species appear as a result of seed rain from adjacent sites and topsoil borne plant propagules. Research results indicate that seeding and associated mulching practices provide erosion control, but do not totally restrict the encroachment of exotics without additional weed control measures.

Glacier Park has seeded the entire road-cut/fill, the barrow-ditch, and the road-edge. Much of the road-edge is periodically mowed. This mowing has had a significant impact on native species, reducing the stand density and cover. Most of the native species indigenous the higher elevations are bunchgrasses and many of the species used for restoration are short-lived perennials (pioneer-early colonizers). The bunchgrasses do not tolerate mowing and the short-lived perennials rely on seed shatter and reestablishment to maintain themselves in a plant community. Rhizomatous species would better tolerate mowing, but these species may not be indigenous to these sites.

Both Parks are satisfied that the seeding and planting of native indigenous plant material on major disturbances, rather than letting nature take its course, is the proper procedure for the preservation and protection of the native gene pools.

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THE USE OF LOCAL ECOTYPES FOR THE REVEGETATION OF ACID/HEAVY METAL CONTAMINATED LANDS IN WESTERN MONTANA

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ABSTRACT

Current reclamation efforts to revegetate abandoned mine sites in western Montana rely primarily on commercial seed sources and limited native seed collection. Very few species of commercially available seeds are adapted to acid/metalliferrous soil, or to western Montana. The Development of Acid Tolerant Plant Cultivars project seeks to address this problem by selecting plant ecotypes from western Montana that demonstrate superior tolerance to acid/heavy metal soil conditions. In 1995, two initial evaluation plots were constructed on the Anaconda Smelter Superfund Site in southwestern Montana. Plant materials in this study were assembled from wildland collections on degraded sites throughout western Montana and from commercial seed sources. The plots were replicated three times in a randomized complete block design and collectively tested 95 species consisting of 51 grass, 29 forb, 14 shrub, and 1 tree species. The entries were evaluated for percent survival, vigor, height, and seedhead production. After three growing seasons, the superior performing entries were identified. The best performing collections are presently being tested in a comparative evaluation planting near Anaconda with comparisons to other accessions and cultivars of the same species. Concurrently, 13 grass, 6 forb, and 7 shrub species are being grown at the Bridger Plant Material Center (BPMC) to determine cultural techniques and to increase seed. The results of the comparative evaluation planting and the success of seed production will provide valuable information for the selection of plant materials. Releases will be made through the Pre-Varietal Release process at the "Source-Identified" and "Selected" level. Foundation seed for the releases will be maintained at the BPMC for distribution through the Montana and Wyoming Crop Improvement Association to commercial seed producers.

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INTRODUCTION

The legacy of Montana's mining past has left a wide range of problems and challenges for those charged with reclamation and associated activities in the next century. There are an estimated 6,000 abandoned hardrock and milling sites in Montana (Montana Department of State Lands 1994). Serious environmental and safety issues have been identified at 286 of these sites (Montana Department of State Lands 1995). Additionally, Montana has the largest Superfund site in the United States. The Upper Clark Fork Basin Superfund complex extends 225 km (140 mi) from Silver Bow Creek north of Butte to the Milltown Dam near Missoula. In the Clark Fork Basin alone, there are approximately 51.8 km^2 (20 mi^2) of tailing ponds; more than 453.2 km^2 (175 mi^2) of soils and vegetation contaminated by air pollution from smelting operations; at least 77.7 km^2 (30 mi^2) of unproductive agricultural land; over 241 km (150 mi) of contaminated river bed and riparian habitat; and millions of gallons of contaminated groundwater (Johnson and Schmidt 1988; Moore and Luoma 1990).

Metal mine and mill wastes are the most difficult and highly visible reclamation problems facing land rehabilitation specialists today (Munshower 1994, Neuman et al. 1993). At the Anaconda smelter site, 40 km (25 mi) northwest of Butte, copper ore milling, smelting, and refining operations took place between 1884 and 1980. Today, this 777 km^2 (300 mi^2) site contains large volumes of wastes, debris, and contaminated soil. Re-entrainment of these wastes continues to be a problem. Release mechanisms include air dispersion, surface water runoff, and wind erosion, resulting in secondary contaminant sources in surface and subsurface soils, sediments, surface water, and fugitive dust (CDM Federal 1997).

As global populations grow, the demand for natural resources accelerates. New mining and mineral extraction technology also has spurred a resurgence in the mining industry. Such developments can create severe disturbances that potentially threaten the integrity of watersheds including water quality, wildlife habitat, aesthetic resources, and other environmental concerns. These severe disturbances often suspend succession and thus intensify contamination problems. The resulting loss of vegetation decreases soil stability, soil shading, organic matter, nutrient cycling, and in turn, degrades wildlife habitat.

The arid and semi-arid climate prevalent in the Intermountain and Northern Great Plains region increases the time required for disturbances to rehabilitate naturally. Depending on soil conditions (rootzone characteristics), drastic disturbances may require hundreds or thousands of years to achieve functional plant communities. Hardrock minelands pose additional problems for revegetation, primarily: steep slopes; unfertile soil media (low cation exchange capacity, low water holding capacity, low organic matter); extreme moisture, temperature, and wind fluctuations; acidic soils; and heavy metal contamination. To accelerate rehabilitation, proper plant selection on these harsh sites is crucial.

Although the Surface Mining Control and Reclamation Act of 1977 allows the use of introduced species, State and Federal regulatory agencies recognizing the importance of adaptation and biological diversity, frequently require the re-establishment of a permanent vegetative cover of the same variety native to the area (Roundy et al. 1997). Scientists contend it is essential that indigenous native plant species be selected that are evolutionary products of that environment. Native indigenous species have a long history of genetic sorting and natural selection by the local environment. Over the long-term, these plants are often better able to survive, grow and reproduce under the environmental extremes of the local area than introduced plants originating in other environments (Brown 1997, Munshower 1994).

The utilization of tolerant races, even on amended or topsoiled sites, is suggested because the subsoil is often a major portion of the rootzone materials. Species exhibiting acid/heavy metal tolerances may also reduce the need for lime and are a precaution against poor mixing of amendments with acidic wastes. Populations of acid and metal-tolerant vegetation have been successfully selected, propagated and established on abandoned mine sites in Europe and Africa. Tolerant populations have been identified in North America but none have been propagated for seed production.

Improving the metal tolerance of plants is of interest to scientists internationally. Many papers have recently been published on developing transgenic metal tolerance (Hasegawa et al. 1997, Manual de la Fuente et al. 1997, Vatamaniuk et al. 1999). However, the biology is complex, poorly understood, and the technology needed to transfer genes to wildland plants is not well developed. Ethical and biological questions related to releasing genetically engineered organisms into the environment are also pertinent. Traditional plant breeding (plant selection) seems to be the best approach at present.

Except when extensive amelioration has been employed, reclamation efforts on hardrock minelands in western Montana have met with limited success. At the Anaconda Superfund Site, for example, the region's plant cover and diversity remains low although revegetation efforts began in the 1940s (RRU 1993). The majority of native seed currently being used on metal mine reclamation projects in Montana were developed for coal strip-mine reclamation and range renovation in the dry, saline soils of eastern Montana. The few cultivars adapted to western Montana, where the bulk of reclamation occurs, were not selected for acid or heavy metal tolerance. The Development of Acid/Heavy Metal-Tolerant Cultivars (DATC) project seeks to identify, select and release naturally occurring acid/heavy metal-tolerant plant ecotypes desirable for reclamation and commercial seed production.

The project objective is to develop plants for use on lands where ameliorative and adaptive revegetation methods are implemented. In an agricultural approach the contaminated soil media is removed and replaced with hauled topsoil and typically planted using highly productive exotic species. The ameliorative/adaptive approach, in contrast, involves amending/shaping the soil in-situ, and identifying, specifying, and establishing plants that are ecotypically differentiated, or adapted, and tolerant of the site conditions. Although, this approach has been used in Europe since the 1960s, its use in the United States is relatively new (Morrey 1996). The ameliorative/adaptive reclamation method may be the preferred approach in the future due to diminishing economical topsoil resources, and available land for repositories. This approach also addresses concerns regarding biodiversity, self-sustaining plant communities, and the need for an alternative method on steep slopes.

METHODS AND MATERIALS

The project design is based on the assumption that the best plants for acid/heavy metal contaminated soils would be those found growing at such sites. Plants that are able to survive in nutrient poor, acidic rooting media contaminated with heavy metals such as copper, zinc, lead, cadmium, and arsenic are thought to possess inheritable genetic traits for tolerance to those conditions. This assumption is based on numerous studies. Jain et al. (1966) documented the existence of localized races or ecotypes each adapted to the particular environment conditions of its habitat. The study concluded that distances as low as 1-2 meters are sufficient to permit populations of certain species occupying contrasting habitats to become very distinct from one another. Bradshaw et al. 1965 found that *Agrostis tenuis*, a common perennial grass in temperate climates, evolved unique populations in old mine workings that exhibited tolerances to various heavy metals. Furthermore, these tolerances were not lost in cultivation in the absence of the metal, and were heritable. Surbrugg (1982) reported two cool season grass species growing on copper tailings at Anaconda that possessed tolerances to elevated levels of copper and zinc. Chambers et al. (1984) working in the Beartooth Mountains of southcentral Montana found that species colonizing severe disturbances exhibited an ability to establish on phytotoxic sites. Additionally, there is evidence that metal tolerant strains tend to be more drought tolerant and translocate fewer contaminates to their aerial portions than non-tolerant plants (Smith and Bradshaw 1972).

The process of developing plants for mineland revegetation encompasses a number of stages: 1) seed/plant collection from affected sites and assemblage of commercially available plant material, 2) initial evaluation of assembled germplasm, 3) secondary large-scale seed collection of better performing germplasm, 4) seed increase of superior collections, 5) field testing of superior germplasm, and 6) release of foundation quality seed to commercial seed producers. The project has concentrated on collecting and testing plant materials at the Anaconda Smelter Superfund site because of the extent of contamination, elevation, varied terrain, and cool, semi-arid climate.

Initial Evaluation Planting

The project was initiated in 1995 with 124 collections made at 26 mine impacted sites throughout western Montana. Seed and occasionally plants were collected from a range of elevations, precipitation zones, aspects, contamination types and concentrations, soil and plant community types. In addition, released cultivars and other commercially available plant materials were assembled. Three initial evaluation plantings (IEPs) were established - one plot near East Helena and two plots near Anaconda, Montana. The plots collectively tested 95 species (220 accessions). Only data from the Anaconda sites (Site 1 and Site 2) are presented, however, due to subsequent burial of the East Helena plot.

The soil at Site 1, located near the junction of Highways 1 and 48, has been impacted by aerial fallout from smelter emissions and the ongoing re-deposition of exposed hazardous substances. The site was sparsely vegetated and mostly devoid of topsoil due to severe wind and water erosion. Prior to plowing, the site had an average pH of 5.5. The plot site was deep plowed, cultivated with sweeps, and roller packed. After plowing, the pH increased due to a calcareous layer in the top 30 cm (1 ft) of the soil profile. Composite samples from the top 25.4 cm (0.83 ft) of the profiles indicated levels of cadmium, copper and zinc that exceeded the upper limits for phytotoxicity established by the EPA. The surface soil samples had metal concentrations several times greater in magnitude than the composite samples. Surface water runoff during storm events, soil crusting and stoniness were other factors observed at the site.

Site 2 is located on the Opportunity Ponds about 3 km (2 mi) northeast of Site 1. The Opportunity Ponds were used as a disposal site for mill tailings. During active disposal of smelter wastes, a portion of the ponds was covered with water, but has since been allowed to dewater. Very high levels of copper, lead, and zinc, in combination with extremely poor fertility, low pH and organic matter characterize Site 2. The site was devoid of vegetation except for sparse patches of *Agrostis gigantea*. The average pH prior to plowing was 3.0. Quick lime was incorporated at this site at three different rates: 0, 11, and 22 metric tons per ha (0, 30, and 60 tons per ac). The composite soil samples at the site contained extremely high levels of cadmium, copper and zinc. One sample contained cadmium concentrations 21 times, copper 53 times, and zinc 266 times greater than the upper limits established for phytotoxicity. Other growth factors include a hard surface crust, high winds and subsequent particle movement that can sand blast, bury, and defoliate plants. The site's total exposure to incoming solar radiation and associated high ground surface temperatures and reflectance also influences plant growth.

The sites were planted with a push type, single-row, belt seeder in rows 9 m (30 ft) long, with 0.45 m (1.5 ft) row spacing, approximately 1 cm (0.5 in) deep. Both sites were a randomized complete block design replicated 3 times. Of the 220 entries tested, 80 were released cultivars and 140 were wildland collections or common sources. Distribution of cultivar lifeforms was 59 grasses, 18 forbs, and 3 shrubs. Distribution of wildland collections and common sources was 69 grasses, 26 forbs, 35 shrubs, and 8 trees.

Comparative Evaluation Planting

A Comparative Evaluation Planting (CEP) was installed to test the wildland plant material that performed well in the IEP. The CEP is located on the Willow Glenn Road, approximately 3 km (2 mi) east of Anaconda. Soil contamination in this area is concentrated in the upper few centimeters of the profile and is the result of past stack emission fallout and the ongoing re-deposition of fugitive dust. The plot site is approximately 0.2 ha (0.5 acres) and had an average pH of 4.5 [0-15 cm (0-6 in) composite samples] after tillage to a depth of 15 cm (6 in). Most soil samples contained arsenic and copper concentrations exceeding EPAs upper range for phytotoxicity. Some samples had phytotoxic levels of zinc.

The CEP is testing multiple accessions of 6 forb species, 13 grass species and 6 forb/grass mixes. The plot contains 84 entries in a randomized complete block design, replicated 4 times. The entries were planted in May 1999, using a single row, push-type belt seeder based on a seeding rate of 82 PLS per m (25 PLS per ft). During the unusually dry growing season of 1999, the CEP was evaluated twice.

RESULTS AND DISCUSSION

Initial Evaluation Planting

The IEP plots have been evaluated annually since 1996 for height, integrated vigor (incorporates assessment of leafiness, basal area, tillering, and color), and percent stand/survival. The results are from 1999 at Site 1 and 1998 at Site 2, the fourth and third growing seasons, respectively. The entries were ranked using the scores for vigor and percent stand weighted equally. The top performing entries (up to the fifteenth rank if applicable) from each lifeform from Site 1 and Site 2 are listed below in tables 1 and 2.

None of the forbs, trees or shrubs planted at Site 2 survived. At both sites potted woody material was transplanted in early July during particularly hot weather. Transplant timing may have contributed to the mortality of the woody material at Site 2. The more sheltered position of Site 1 may have enabled the woody material to survive there. *Leymus racemosus* ND-691, which performed the best at Site 2, was not included in the entries at Site 1. Second ranking, *Leymus racemosus* 'Volga' ranked in the middle of the field at Site 1. *Pseudoroegneria* ssp. *inermis* 'Whitmar' performed very well at both sites. Other grasses that performed well at both sites include *Elymus lanceolatus* 'Sodar', *Elymus lanceolatus* ssp. *lanceolatus* 'Schwendimar', *Pseudoroegneria spicata* ssp. *spicata* 'Goldar', *Leymus angustus* 'Prairieland', and *Pascopyrum smithii* 'Rosana'. *Deschampsia cespitosa* performed well at both sites although the two high ranking entries were different accessions. Both accessions outperformed *Deschampsia cespitosa* 'Peru Creek', a released cultivar. *Elytrigia repens* X *Pseudoroegneria spicata* 'Newhy' was a top performer at Site 2 and also performed fairly well at Site 1, although not a top performer. *Poa alpina* 9016273 and *Festuca rubra* 'Penlawn' that were top performers at Site 2 did not fare well at Site 1.

Table 1. Anaconda Initial Evaluation Planting Site 1 Top Performing Species.

LIFEFORM	SPECIES	ACCESSION/ CULTIVAR	RANK	ORIGIN
Forb	*Potentilla hippiana*	9076289	1	Native
Forb	*Epilobium angustifolium*	9076267	2	Native
Forb	*Penstemon strictus*	Bandera	3	Native
Forb	*Heuchera parviflora*	9076279	4	Native
Forb	*Coronilla varia*	Chemung	4	Introduced
Forb	*Lotus corniculatus*	Kalo	5	Introduced
Forb	*Sphaeralcea coccinea*	9076283	6	Native
Forb	*Dalea purpurea*	Keneb	7	Native
Forb	*Lotus corniculatus*	Norcen	7	Introduced
Forb	*Aster chilensis*	9078675	8	Native
Forb	*Medicago sativa*	Spredor-3	8	Introduced
Forb	*Phacelia hastata*	9058019	9	Native
Forb	*Lathyrus sylvestris*	Lathco	10	Introduced
Grass	*Pseudoroegneria spicata* ssp. *spicata*	Secar	1	Native
Grass	*Pseudoroegneria spicata* ssp. *inermis*	Whitmar	2	Native
Grass	*Psathyrostachys juncea*	Bozoisky-Select	3	Introduced
Grass	*Elymus lanceolatus*	Sodar	4	Native
Grass	*Deschampsia cespitosa*	9076290	5	Native
Grass	*Psathyrostachys juncea*	Mankota	6	Introduced
Grass	*Leymus cinereus*	Magnar	7	Native
Grass	*Leymus cinereus*	Trailhead	8	Native
Grass	*Elymus lanceolatus* ssp. *lanceolatus*	Schwendimar	9	Native
Grass	*Pseudoroegneria spicata* ssp. *spicata*	Goldar	10	Native
Grass	*Elymus trachycaulus* ssp. *trachycaulus*	Pryor	11	Native
Grass	*Pascopyrum smithii*	Rodan	12	Native
Grass	*Elymus elymoides*	9040189	13	Native
Grass	*Leymus angustus*	Prairieland	14	Native
Grass	*Pascopyrum smithii*	Rosana	15	Native
Shrub	*Salix alba*	9078386	1	Introduced
Shrub	*Rosa woodsii*	9078385	2	Native
Shrub	*Lonicera* spp.	9081306	3	Native
Shrub	*Artemisia longifolia*	9076289	4	Native
Shrub	*Caragana* spp.	9078379	5	Introduced
Shrub	*Symphoricarpos albus*	9078388	6	Native
Shrub	*Shepherdia argentea*	9081334	7	Native
Shrub	*Atriplex canescens*	Rincon	8	Native
Shrub	*Rhus trilobata*	Bighorn	9	Native
Shrub	*Atriplex* X *aptera*	Wytana	10	Native
Tree	*Populus deltoides* ssp. *monilifera*	9078382	1	Native

Table 2. Anaconda Initial Evaluation Planting Site 2 Top Performing Species.

LIFEFORM	SPECIES	ACCESSION/ CULIVAR	RANK	ORIGIN
Grass	*Leymus racemosus*	ND-691	1	Introduced
Grass	*Leymus racemosus*	Volga	2	Introduced
Grass	*Pseudoroegneria spicata* ssp. *inermis*	Whitmar	3	Native
Grass	*Poa alpina*	9016273	4	Native
Grass	*Festuca rubra*	Pennlawn	5	Introduced
Grass	*Leymus arenarius*	ND-2100	6	Introduced
Grass	*Elytrigia repens* X *Pseudoroegneria spicata*	Newhy	7	Native
Grass	*Leymus angustus*	Prairieland	8	Unknown
Grass	*Deschampsia cespitosa*	9076280	9	Native
Grass	*Elymus lanceolatus* ssp. *lanceolatus*	Critana	10	Native
Grass	*Pseudoroegneria spicata* ssp. *spicata*	Goldar	11	Native
Grass	*Elymus lanceolatus* ssp. *lanceolatus*	Schwendimar	12	Native
Grass	*Pascopyrum smithii*	Rosana	13	Native
Grass	*Elymus lanceolatus*	Sodar	14	Native
Grass	*Poa secunda*	Canbar	15	Native

At both sites, cultivars, both native and introduced, overwhelmingly outperformed wildland collections. This may be due to the higher pure live seed (PLS) content of the cultivar seed. The wildland seed was not tested for viability or purity. All seed was sown at 25 PLS per ft when PLS was known. When unknown, the seed was sown at 25 seeds per foot. This variance may account for the seemingly superior performance of cultivars.

In general, grasses seemed to outperform forb, shrub and tree lifeforms. The wildryes and wheatgrasses, known for their drought tolerance, were the best performing grasses. Many of the best performing forbs were legumes and many also pioneering species

Comparative Evaluation Planting

The emergence rates in the CEP was extremely low. Less than half (42%) the entries emerged. The highest emergence rate was 15.7% for *Oryzopsis hymenoides* 'Nezpar'. A month later seedling survival had declined greatly and only 9% of the entries (table 3) contained live seedlings. In early November, the CEP was replanted in hopes that a more favorable growing season would result in better plant establishment. The pH of the site may prove to be too acidic for plant establishment unless plowed to a greater depth and/or amended.

Table 3. Anaconda Comparative Evaluation Planting Results. Planted May, 1999.

LIFEFORM	SPECIES	ACCESSION/CULTIVAR	% SURVIVAL
Grass	*Elymus trachycaulus*	9081620	0.33
Grass	*Elymus trachycaulus*	Pryor	0.33
Grass	*Oryzopsis hymenoides*	Nezpar	0.33
Grass	*Psuedorogeneria spicata*	Secar	0.33
Grass/Forb	Cultivated Plains	Seed Mix	0.17
Grass	*Agrostis gigantea*	9076266	0.05
Grass	*Agrostis gigantea*	9076276	0.05

Seed Increase

Seed increase of the promising collections has been initiated at the USDA NRCS Plant Materials Center at Bridger, Montana. The objective of seed production is to provide foundation seed and cultural information to commercial growers. Currently, there are approximately 1.4 ha (3.5 ac) of promising acid/heavy metal-tolerant plant materials in seed increase including 6 forb species, 13 grass species and 7 shrub species (table 4). Some of these native species have not previously been cultivated.

Table 4. Ecotypes in Production at the Bridger Plant Materials Center

LIFEFORM	SPECIES	COMMON NAME	ELEVATION*	ORIGIN
Forb	*Aster chilensis*	creeping aster	foothills to subalpine	Native
Forb	*Heuchera parviflora*	littleflower alumroot	montane to alpine	Native
Forb	*Penstemon eriantherus*	fuzzy-tongued penstemon	plains to montane	Native
Forb	*Phacelia hastata*	silverleaf phacelia	plains to alpine	Native
Forb	*Potentilla hippiana*	woolly cinquefoil	Foothills	Native
Forb	*Sphaeralcea coccinea*	scarlet globemallow	plains to montane	Native
Grass	*Agrostis gigantea*	redtop	plains to montane	Introduced
Grass	*Carex paysonis*	Payson's sedge	foothills to alpine	Native
Grass	*Deschampsia cespitosa*	tufted hairgrass	foothills to alpine	Native
Grass	*Elymus trachycaulus*	slender wheatgrass	plains to alpine	Native
Grass	*Juncus balticus*	Baltic rush	plains to subalpine	Native
Grass	*Leymus cinereus*	basin wildrye	plains to montane	Native
Grass	*Oryzopsis hymenoides*	Indian ricegrass	plains to foothills	Native
Grass	*Pascopyrum smithii*	western wheatgrass	plains to subalpine	Native
Grass	*Poa alpina*	alpine bluegrass	subalpine to alpine	Native
Grass	*Poa ampla*	big bluegrass	plains to montane	Native
Grass	*Poa compressa*	Canada bluegrass	plains to montane	Naturalized
Grass	*Poa* species	bluegrass species	foothills	Native
Grass	*Pseudoroegneria spicata*	bluebunch wheatgrass	plains to foothills	Native
Shrub	*Juniperus horizontalis*	creeping juniper	plains to subalpine	Native
Shrub	*Purshia tridentata*	antelope bitterbrush	plains to foothills	Native
Shrub	*Rosa woodsii*	Prairie rose	plains to subalpine	Native
Shrub	*Shepherdia argentea*	silver buffaloberry	plains to foothills	Native
Shrub	*Symphoricarpos albus*	common snowberry	plains to subalpine	Native
Shrub	*Symphoricarpos occidentalis*	western snowberry	foothills to montane	Native
Shrub	*Ribes* species	currant species	foothills to alpine	Native

* Kershaw et al. 1998

Planting begins with seedbed preparation that includes the isolation of accessions of the same or similar species to protect the genetic integrity of the accessions. Seed production fields are commonly established by seeding 1 m (3 ft) rows at 90 PLS per m (30 PLS per ft). Many of the forb and woody species require pre-treatments to break dormancy. In some cases, hard seeded species can be dormant fall planted without pretreatment. In the establishment year, weed control is difficult due to the generally slow establishment of native species. Weeds are controlled by timely mowing, tilling, and spraying with herbicides formulated for seedlings. Fields are fall fertilized to insure the slow release of nutrients and to initiate development of seedhead primordia.

Seed production usually begins in the second growing season. Many native grass species can be combine harvested. The forbs are often harvested using a swather equipped with a canvas catch basin. The woody species are usually hand stripped. To optimize seed yields, the harvested plant material is often left to afterripen and dry on tarps for 1-2 weeks. Specialized equipment is then utilized to clean the seed. Cleaning methods vary depending on the type, size, shape, and amount of debris in each harvest. Most commonly, the plant material is processed by running it through a hammermill, which liberates the seed by flailing the material. Next, the material is run over a seed mill which uses wind and vibrating screens to further separate the good seed from the chaff.

The end product of the project will be the release of indigenous, native plant materials that demonstrate superior tolerance to acidic conditions and heavy metal contamination. In addition, the plant material chosen for release will consider the following criteria: commercial production potential, heavy metal uptake in aerial plant tissues, and the ability to add to the ecosystem's resilience by initiating and/or accelerating the process of succession. Releases will be made through the Pre-Varietal Release certification process at the "Selected" and "Source-Identified" levels. The foundation seed will be maintained at the BPMC and distributed to commercial seed producers through the Montana and Wyoming Crop Improvement Association. Each release will have a companion Planting Guide that provides information such as plant adaptation, uses, compatibility, growing techniques, etc. Plant releases are anticipated to begin in 2001.

CONCLUSION

The results of the IEP suggest that there are a number of species that have not been released for revegetation purposes but have reclamation potential. These species include *Aster chilensis*, *Epilobium angustifolium, Heuchera parviflora, Potentilla hippiana, Sphaeralcea coccinea, Artemisia longifolia, Populus deltoides* ssp. *monilifera, Rosa woodsii*, *Symphoricarpos albus*, and *Symphoricarpos occidentalis*. Many of the cultivars that performed well originated from other regions. New ecotypic releases of these species may be of value. *Deschampsis cespitosa* Peru Creek, for example, is a cultivar originating from Colorado, however, at the IEP two collections from mine affected sites in western Montana outperformed Peru Creek. Some species that merit further investigation include *Deschampsia cespitosa*, *Elymus lanceolatus, Elymus trachycaulus*, *Leymus cinereus, Pascopyrum smithii*, *Poa alpina* and *Pseudoroegneria spicata*.

Many cultivars on the market performed well. The outstanding forb cultivars included *Penstemon strictus* 'Bandera', *Coronilla varia* 'Chemung' and *Lotus corniculatus* 'Kalo'. The outstanding grass cultivars include *Pseudoroegneria spicata* ssp. *inermis* Whitmar, *Elymus lanceolatus* Sodar, *Elymus lanceolatus* ssp. *lanceolatus* Schwendimar, and *Pseudoroegneria spicata* ssp. *spicata* Goldar. Although only a small sampling of shrub cultivars were tested, the best performers were *Atriplex canescens* 'Rincon', *Rhus trilobata* 'Bighorn' and *Atriplex* X *aptera* 'Wytana'.

Information on the performance of the entries at the CEP is forthcoming. Until more data from the CEP is collected it is impossible to make any conclusions on the performance of local ecotypes versus broadly adapted cultivars. The success of seed increase efforts at the BPMC will also help determine the potential of future releases.

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