Striving for Restoration, Fostering Technology and Policy for Reestablishing Ecological Function

March 20 - 24, 2000 - Sheraton Billings Hotel
Billings, Montana

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2000 Billings
Land Reclamation Symposium

Striving for Restoration,
Fostering Technology and Policy for Reestablishing
Ecological Function

Sheraton Billings Hotel
Billings, Montana
March 20 - 24, 2000

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2000 Billings Land Reclamation Symposium

THE ECOLOGICAL BASIS FOR RECLAMATION SUCCESS CRITERIA

Frank F. Munshower, Ph.D.

ABSTRACT

Reclamation success criteria were incorporated into federal and state coal strip mining laws or regulations of the 1970's. Other surface disturbing agencies, following the lead of the Office of Surface Mining, have attempted to develop similar reclamation success criteria. State hardrock mining and sand and gravel regulatory agencies, highway departments, the Forest Service, the Bureau of Land Management, and the Environmental Protection Agency have attempted to clarify what they consider successful reclamation efforts. Final determination of reclamation success for these groups has always been based on the appearance and production of vegetation but plants are very opportunistic and resilient. They mask deficiencies of reclamation for years but will eventually fail if the soil resource is not rehabilitated sufficiently to insure the perpetuation of the plants. That is the reclaimed plant community must be enhancing the soil, it must be increasing the quality and quantity of the resource in which it is growing or natural loss of the soil will eventually contribute to the destruction of vegetation on the reclaimed site. It seems reasonable, therefore, that the soil resource is the criteria that should be evaluated for final bond release rather than the vegetation covering the soil.

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INTRODUCTION

The question - to reclaim or not - is no longer relevant. Every reputable mining company, the EPA, state highway departments, and other industries or government agencies attempt to rehabilitate to some extent the lands they disturb or the lands within their jurisdiction. The question today is what is adequate reclamation.

A definition of reclamation is appropriate at this point. Reclamation is the goal of returning the soil and the plant community it supports to conditions in which the stability and productivity of the site are comparable to that of the site prior to disturbance. Reclamation includes components of hydrology, soils and vegetation. Arguments that disturbed sites should be returned to pre disturbance conditions aren't relevant because it is not possible to do so.

We cannot restore a site even after an action as simple as plowing because of all of the changes produced in the soil physical, chemical, and biological properties by the action of turning over or mixing the top six inches of the profile. However, we can revegetate the site to some or most of the plant species found on the site prior to disturbance by very careful and selective reclamation. Whether this is called restoration or reclamation is not relevant, it is simply academic and I prefer to use the term reclamation. Many researchers call this type of reclamation restoration but as Allen (1995) pointed out, "...even the best examples of restoration have been able to reintroduce only a fraction of the plant species richness and natural recolonization is slow at best."

In the late 1960's and early 1970's western coal mining was bursting out of the constraints imposed by transportation costs and cheap eastern coal because of the growing demand for energy and air pollution awareness. The Arab oil embargo simply exacerbated the demand for western coal. At that time the potential for returning livestock to range sites after they had been surface mined was not considered good. Curry (1975) for example was quite skeptical that Great Plains minesoils would ever be productive after stripmining. Today we know that livestock gain weight and reproduce as well on reclaimed mined lands as they do on native range. We know that the land can be as stable as it was before disturbance and that wildlife invade the land even before mining is finished. These generalizations pertain to reclaimed mountain soils as well as reclaimed soils on the plains.

We now have thousands of acres of western land that was disturbed by surface mining in various stages of reclamation. Some of this land has been supporting crops or livestock since before the Surface Mining Control and Reclamation Act was enacted in 1977 but little of this land has received approval as successfully reclaimed. If the soils and vegetation were considered successful, then one would assume that final and complete bond release would be authorized. This has rarely been the case on coal mines in our region and I do not know of any superfund sites that have met with widespread approval after rehabilitation. Therefore I must assume that the reclamation of these sites is lacking in some quality.

THE QUESTION

The big question today at mines, superfund sites, linear rights-of-way, and other disturbances is, are the results of reclamation good enough for final approval be it as full bond release on coal mine sites or some other criteria that signifies adequacy at a superfund site or along a highway right-of-way. For various reasons many agencies (e.g. EPA), advocacy groups, and others are attempting to apply the final bond release criteria of SMCRA to disturbances of interest to the group, therefore, I shall use the success criteria of this law as the basis for my discussion. But, please be aware that what I am about to say pertains to the determination of reclamation success on all forms of surface disturbances in the semiarid west.

In an attempt to answer this question of successful or unsuccessful reclamation a group of terms were introduced into the Surface Mining Control and Reclamation Act of 1977 (Public Law 95-87). These include diversity, production, self perpetuating, native, and succession among others. All of these terms pertain to the plant community growing on the disturbed site and all have shortcomings that lessen their ability to quantify successful reclamation. This I believe is the cause of our inability to document successful reclamation. Our definition of successful reclamation is based on ambiguous terms or on ideas and concepts that we have not fully considered. I will attempt to illustrate this.

Diversity

The first of these terms was 'diversity'. As several authors have pointed out this term has almost as many definitions as individuals attempting to define it (Chambers 1983, Whittaker 1975, McIntosh 1967). It definitely is not species richness, or simply the number of species within a predetermined area because diversity includes some intangible reference to the distribution and number of each species. This is what makes it so hard to quantify, these intangibles. In addition to this weakness if we carefully inspect undisturbed environments we find that in areas of uniform soil, slope, aspect, and exposure the number of species is surprisingly small. The reports of large numbers of species are always from more mesic areas to the east or if from our region then they are from disturbed sites, grazed sites, or landscapes of diverse soils, slopes, aspect, exposure, etc. But, both federal and state law or regulation require that those disturbing a site reconstruct a uniform soil of relatively constant slope on the site after the disturbance. How can the individual responsible for reclamation produce a diverse plant community on a disturbed site, even if we could define it, when they are restricted to a uniform environment? As Prodgers and Keck (1996) so apply pointed out habitat is one of the critical keys to vegetational diversity.

Production

Production was the second term I mentioned. In every instance in which a report describes the production measured on a disturbance the parameter measured was actually standing crop not production. Production is the amount of tissue produced by the plant not the amount of above ground biomass that was measured after a number of herbivores have chewed on the vegetation. Production should include the underground component of the plant. This is rarely measured. But in terms of site

stability it is probably more important that above ground biomass. Several years ago Rich Prodgers carried out a vegetation study in the area of a proposed coal mine near Circle, Montana. In one year of sampling he recorded between 10 and 20 lb/a of standing crop. On the same transects he recorded almost 2,000 lb/a the next year. A plant parameter that varies over two orders of magnitude from one year to the next is not a reliable interpreter of revegetation success.

Self Perpetuating

Many groups and individuals ask if the vegetation growing on a disturbance is self perpetuating. Federal and state laws or regulations state that vegetation on coal minesoils must be 'self perpetuating' or 'self regenerating'. I presume this means the plants must be reproducing themselves. This can not be addressed other then stating that the plants are forming seedheads because there are no safe sites for new plants to develop on young minesoils for many years after the original seeding. The following example illustrates this principle.

Area to be reclaimed: One acre

Seed Mix:

	Rate (PLS)	
Grasses	Seeds/ft^2	lb/a
Western wheatgrass	4	1.5
Blue bunch wheatgrass	4	1.5
Needle-and-thread	4	1.5
Forbs		
Purple prairie clover	2	0.3
Prairie coneflower	2	0.1
Black sampson	2	0.6

If we assume that half of the seed germinates and establishes there remain nine plants on each square foot of soil. There are neither adequate nutrients nor sufficient water to support that number of rapidly growing plants. By the time of review for determination of adequacy of reclamation there are probably only one or two plants surviving on this foot of minesoil. Which plant will it be. Probably the one with the genetic constituents that enable it to utilize the resources of the site rapidly before another plant can absorb them and the plant lucky enough to find these nutrients and moisture. That is, the most competitive and tolerant of the seeded species. We are selecting cultivars for exactly those reasons. We want the new plants to be rapid growing and tolerant of the cold and drought of our prairies and mountains. They do this so well they absorb most of the nutrients and moisture in the soil and leave little for most other plants of the system.

What is the life expectancy of these plant on the Great Plains? We do not know exactly but we know that it is 10 years for some of these species and probably much longer than that, possibly several

decades, for many of the perennial grasses. Since our seeded area has produced the maximum number of plants permitted by the soil and climate of the area there are no safe sites for seeds to germinate and establish. How then can the investigator state that new plants are establishing on the site. The new plants cannot enter the ecosystem until one of the older plants dies and this will not occur for many years. The investigator can state that the plants growing on the disturbed site are setting seed and there may be a young plant or two but it is rare that it can be definitely stated that new plants have established from seed produced by the plants growing on the reclaimed site.

Native

Vegetation seeded on disturbed sites is to be composed predominately of native species. The reason given for this regulation is that natives are better adapted to the rigors of our soils and climate than introduced species. That isn't necessarily true and is becoming less so each day as more and more exotic plants invade our native grasslands. If it were true we would not have so many noxious weeds and few plants are as well adapted to the west as Crested wheatgrass (Walker et al. 1995). Introduced species may be undesirable but lack of adaptation to the site, low forage production, or lack of palatability can not be used as rejection criteria.

Succession

Finally, new plant communities growing on disturbed sites are supposed to be undergoing succession. Succession is defined as the progressive changes in vegetation and animal life that culminate in the climax plant community. Succession is readily observable during the first few years of plant growth on disturbed sites. Let us say three to five growing seasons as the annual weedy species that rapidly invaded the new plant community during its first growing season are replaced by the very aggressive, perennial, stress tolerant cultivars in the seed mix. During the next undetermined number of years very few changes occur in the plant community. Possibly a few tough weeds invade it, possibly two or more seeded species disappear from the community but the anticipated invasion of the site by propagules from adjacent rangeland does not occur in any great amount during anything close to the bonding period. Observations have not shown a return to anything like original vegetation on semiarid grasslands even when grazing is excluded (Laycock 1991, Allen 1988).

Successional concepts as developed in the more mesic coniferous forest of the west or in the more mesic east occur at such a slow rate on the plains that the changes cannot be measured in a few decades. We have no idea what final climax vegetation would look like on the Northern Great Plains and the foothills of the Rockies. What European man found when he arrived in the west was an ecosystem maintained by burning and grazing. This system was never allowed to develop to a climatic climax but was maintained in a fire climax. Lewis and Clark (Ambrose 1996) noted the large fires used by the native Americans to mark the flotillas progress westward and fire was also used by the American Indians to remove vegetation surrounding winter villages. As early as 1793 fires on the Northern Great Plains were noted. Fidler (1793) said, "These large plains either in one place or another is constantly on fire..." He further noted that, "The lightning in the spring and fall frequently lights the grass, and in winter it is done by the Indians." These were not small fires. Haley (1929) gave an account of a fire in

1885 that started in the Arkansas River country of western Kansas and burned 175 miles to the Canadian River Breaks of Texas. He also gave accounts of several large fires of 20 by 60 miles.

Clearly fire and climate are the major factors controlling vegetation on the Great Plains (Wright and Bailey 1980) and many authors maintain that fire is the reason why the Great Plains are treeless (Stewart 1953). Which stage of succession are the reclamation programs of the Great Plains to strive to create - the unknown climax, a forested stage, some seral grassland stage, or none at all. Many say establish what was there prior to disturbance. With the exception of plowed crop land most of the acreage disturbed by mining and linear rights-of-way on the Great Plains is native rangeland. But, this vegetation is a midseral stage of succession, a disclimax maintained by burning and grazing. If this is what we want than we in fact do not want succession to take place.

Clearly we need better criteria for reclamation success or final bond will never be released on many acres of western surface mined land. Reference areas or technical standards have value and should be incorporated into these new criteria but the terms mentioned above have serious shortcomings.

A POSSIBLE SOLUTION

If the soils, land forms, and hydrologic balance of the disturbed site have been rehabilitated and an approved seeding and planting has taken place what final criteria should be evaluated to determine reclamation success. Obviously, a thousand years of stable soil and vegetation production would be a good answer but not a realistic one. Some set of parameters must be defined to answer this question and they must be applicable within a reasonable amount of time. In our region the ten year bonding period of SMCRA is a reasonable starting point for a reclamation time frame.

For all disturbances from highway meridians and shoulders, through all types of mining, to hazardous and non hazardous waste disposal sites vegetation cover has been the parameter evaluated for determination of final reclamation success. At best this analysis has been a contentious determiner of reclamation success and in the worse case vegetation is simply not acceptable as the determiner. The best case occurs on surface coal minesoils with all of the problems noted above obstructing a clear definition of reclamation success. The worse case occurs on hazardous waste sites on which vegetation can be readily grown but is of questionable longevity. Rather than placing total confidence in plant performance I would like to propose that we give a better look at the soil profile than is presently advocated. The rootzone is less influenced by perturbations in the weather and several characteristics of this soil layer may be more clearly defined and evaluated than vegetative parameters. If the surface soil horizons express certain characteristics vegetation will develop on and in it whether intentionally seeded or not. Vegetation is in reality a visible reflection of the attributes of the rootzone. I shall discuss several attributes of soil on a disturbed site which might be evaluated to determine reclamation success.

Topsoil

Coal mine regulations necessitate that topsoil be salvaged and saved for application to recontoured minesoils, but, both the quality and quantity of this material are important to a functioning soil system. Stored topsoil may be degraded and require some type of rejuvenation after application to the disturbed landscape to quickly regain its predisturbance plant supporting capacity. The coal industry has rapidly learned how to maximize recovery and minimize destruction of this valuable resource. Highway departments have been slow to maximize recovery of better surface soils and still often spread poor quality material for topsoil along meridians or shoulders. The EPA, Forest Service, Bureau of Land Management, and state Abandoned Mines Programs often find themselves without any topsoil at disturbed sites under their jurisdiction. At these sites the construction of good quality topsoil may be accomplished but it is expensive and time consuming. Nevertheless, the importance of this soil layer to the performance of vegetation cannot be overstated. The quality and quantity of topsoil directly influence the germination, growth, production and reproduction of plants (Barth and Martin 1982, Doll et al. 1984). The quality of topsoil can be defined by determination of the chemical, physical, and biological characteristics of the material.

Biological System in the Soil

Organisms within and on the soil represent an integral component of a functioning soil system. While concentrated in the topsoil cover they also extend in limited quantity into lower horizons. They range from the small bacteria to animals as large as earthworms and small rodents. The major types and ranges of their numbers are available. The larger animals initiate the decomposition of plant and animal tissues by pulverizing, granulating and incorporating these materials within the soil. The smaller invertebrates and worms continue the process by degrading large organic materials to smaller pieces. Finally bacteria, fungi, and actinomycetes complete the conversion of large organic molecules to carbon dioxide, water and nutrients. All of these organisms are, therefore, indispensable in a healthy soil. Trends in the populations and species of these organisms can or already have been established. Decreases in the number of species precede degradation of plant communities. On coal mine sites when direct haul topsoil in applied to recontoured minesoils populations of these organisms are maintained or recover rapidly. When stored topsoil is spread on a site these numbers have been reduced. On polluted soils of many superfund sites the number of species are markedly reduced (Hartmen 1973) but construction of a new topsoil may raise their numbers.

Chemical System in the Soil

The enumeration of all of the chemical reactions in the soil is impossible but several major components of these reactions may be measured and serve to indicate that the disturbed soil has or is in the process of recovering from disturbance. Like the biological components of the soil system these reactions are concentrated in topsoil but they also occur to greater or lesser degrees in lower horizons. Parameters such as the infiltration rate and water holding capacity, cation exchange capacity, organic matter content, and concentrations of the major and minor nutrients are of major importance to a healthy soil system.

On coal minesoils the characteristics of materials in the top four feet of the profile are carefully regulated but such is not the case on superfund sites or hardrock mine wastes. At these latter sites the presence of materials with low water holding capacity or elevated levels of alkaline, saline, or acid generating materials within the top four feet of the soil profile are common. It may be as subtle as sandy materials with inadequate number of exchange sites to prevent leaching of nutrients or selenium leaching into ground water from surface layers; it may be an obvious problem such as acid generation in the cap on a tailings pond. These soil deficiencies may not even pose a problem within a reasonable amount of time (10 years). They may not be detectable without special studies but preliminary determinations can indicate their possibility and prevent construction of soils possessing these attributes. The presence of low cation exchange capacity and coarse textured materials or detrimental soluble trace element concentrations should be enough to prevent declaration of reclamation success even though plant growth on the soil surface may meet all success criteria as defined by pre-reclamation agreements.

Depth of the Rootzone

The Office of Surface Mining has already addressed this problem. Federal and most state regulations clearly state that a non-toxic layer of soil at least four feet thick must be laid over recontoured coal mine disturbances. Montana requires eight feet of this non-toxic material. Numerous range plants and many woody species commonly develop roots deeper than four feet. A toxic layer at four feet hinders the establishment or presents an obstruction to the long term persistence of these species on prairie or mountain soils.

The depth of non-toxic material is especially important at numerous superfund and abandoned mine sites across the west. The use of an 18 inch coversoil over toxic material has been demonstrated at Butte and a few other locations with phytotoxic surface materials. The limitations of this type of reclamation are obvious: few species composing the plant community and a continuing maintenance problem. The more subtle problems with this reclamation are not so obvious. Is the development of new soil on these sites compensating for soil loss? Is this what we want to call successful reclamation?

SUMMARY

This discussion was not intended to be a condemnation of any existing system of reclamation success determination but simply a suggestion that looking at other facets of the reclaimed landscape might provide a faster and better determinant of final reclamation success. Obviously, something is wrong. At one of the few coal sites approved for final bond release in Colorado a massive land slide wiped out many years of excellent plant growth. On the other hand many acres of livestock supporting minesoils in Montana have been awaiting final bond release for over a decade because they do not meet some minor determinate of reclamation success. At superfund sites the growth of three or four acid and metal tolerant species on 18 inches of coversoil over toxic wastes is considered successful reclamation despite the lack of topsoil and an adequate root zone. We should reevaluate present success criteria and develop a realistic set of parameters to be measured for final determination of reclamation success.

The vegetation growing on our prairie and mountain soils are the result of centuries of slow weathering, plant growth, grazing, regrowth, fire, and again regrowth. Every time they are disturbed they change. If you drive a vehicle across the prairie during the wet season the tracks of the vehicle are visible for many years. Plowed fields returned to grazing in the 1930's still do to support vegetation comparable to that found on adjoining non disturbed areas. Yet, we expect a minesoil to support vegetation comparable to that on the site prior to disturbance. At the same time in our haste to cover the scars of past mineral exploitation in our mountains we pull a few inches of non-toxic material over the disturbance and call it reclaimed. Somehow these two extremes do not mesh. There should be some middle ground, some criteria that indicate that in the long run things will continue to improve even though the site will never get back to what it was before disturbance. Yellowstone National Park will never be the same as it was before 1988 but it is improving daily. The vegetation and soils along many of our highways, on numerous minesoils, and around some superfund sites are also improving daily. We should be able to distinguish those that are improving, those that are successfully reclaimed, or those changing in a manner that suggests that they are successfully reclaimed and separate them from those sites that are destined to fail. I believe that looking into the soil profile is a step in the right direction.

REFERENCES

Allen, E.B. 1988. Some trajectories of succession in Wyoming sagebrush grassland, pp 89-112 In: Allen, E.B. (ed.) The Reconstruction of Disturbed Arid Ecosystems. Westview Press, Boulder, CO.

Allen, E.B. 1995. Restoration Ecology: Limits and possibilities in arid and semiarid lands, pp 5-13 in: Proc. Wildland Shrub and Arid Land Restoration Symposium. USDA For. Serv. Gen. Tech. Rpt. INT-GTR-315. Intermt. Resch. Sta., Ogden, UT.

Ambrose, S.E. 1996. Undaunted Courage. Simon and Schuster Inc., New York. 474 p.

Barth, R.C. and B.K. Martin. 1982. Soil-Depth Requirements to Reclaim Surface-mined Areas in the Northern Great Plains. A mining research contract report. CO School of Mines, Environ. Tech. Div., Golden, CO. 182 p.

Chambers, J. 1983. Measuring Species Diversity on Revegetated Surface Mines: An Evaluation of Techniques. USDA For. Serv. Resch. Pap. INT-322.

Curry, R.R. 1975. Biogeochemical Limitations on Western Reclamation. Paper presented at the Symposium Sponsored by U.S. Dept Interior, Bureau of Mines and Univ of ND. Grand Forks, ND.

Doll, E.C., S.D. Merrill, and G.A. Halvorson. 1984. Soil Replacement for Reclamation of Stripmined Lands in North Dakota. Bull. 514, Agric. Exp. Sta. ND State Univ., Fargo, ND 24 p.

Fidler, P. 1793. Diary of Peter Fidler for the period 1792-93. Glenbow-Alberta Inst. Calgary.

Haley, J.E. 1929. Grass fires of southern Great Plains. West Texas Hist. Year Book 5:23-42.

Hartman, L.M. 1976. Fungal Flora of the Soil as Conditioned by Varying Concentrations of Heavy Metals. Ph.D. Dissertation. Univ. Montana, Missoula, MT.

Laycock, W.A. 1991. Stable states and thresholds of range condition on North American rangelands: a viewpoint. J. Range Mngt. 44:427-433.

McIntosh, R.P. 1967. An index of diversity and the relation of certain concepts to diversity. Ecol. 48:392-404.

Prodgers, R.A. and T.J. Keck. 1996. Vegetational diversity concepts and strategies for reclamation, pp.141-157 in: Proc. of the Billings Symposium. Reclamation Research Unit, Montana State Univ. Publ. No. 9603. Bozeman, MT.

Stewart, O.C. 1953. Why the Great Plains are treeless. Univ. CO. CO Quart. 1:40-50.

Whittaker, R.H. 1975. Communities and Ecosystems. Macmillan Publishing Co., Inc. New York. 387 p.

Wright, H.A. and A.W. Bailey. 1980. USDA For. Serv. Gen. Tech. Rpt. INT-77. Intermt. For. and Range Exp. Sta., Ogden, UT. 60 p.

2000 Billings Land Reclamation Symposium

REFERENCE AREA REALITY CHECK

Michael S. Savage[1]

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

Location	Total Cover	Relative Cover				Herbaceous Production			Number of Species			
		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

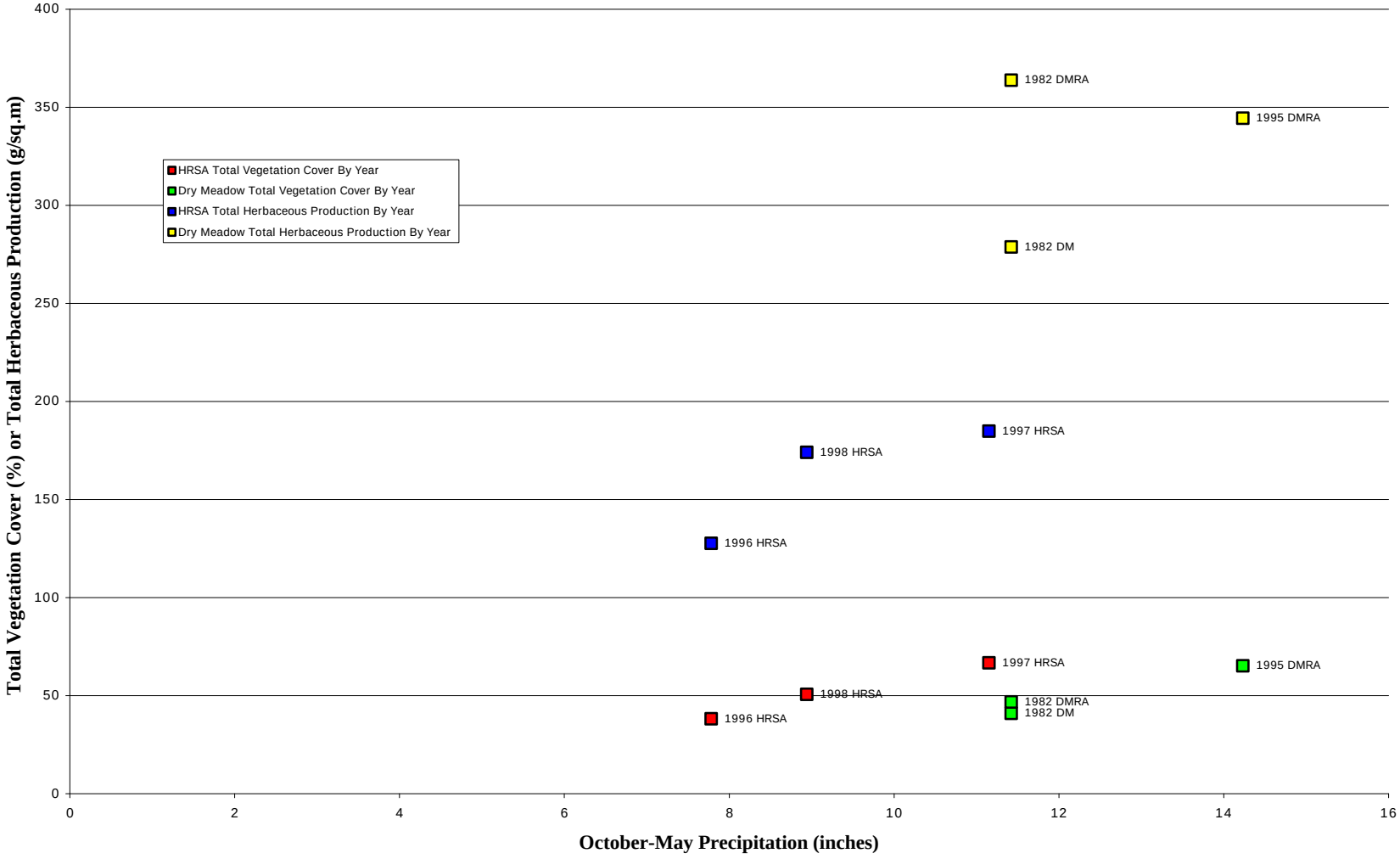

Table 2. Comparison of Vegetation Parameters in Graminoid Communities at the West Elk Mine

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.

REFERENCES

CEC. 1998. Coors Energy Company Keenesburg Mine 1998 Annual Hydrologic Report

Federal Register. 1979. Department of the Interior, Office of Surface Mining Reclamation and Enforcement. Surface Coal Mining and Reclamation Operations: Permanent Regulatory Program. Vol.44-No.50. 3-13-79. Book 2: Pages 14901-15309

MCC. 1997. West Elk Mine Mining and Reclamation Plan. CDMG File C-80-007

Olson, J.S. 1958. Rates of succession and soil changes on southern Lake Michigan sand dunes. Bot. Gaz. 119: 125-170

Oosting, H.J. 1942. An ecological analysis of the plant communities of Piedmont, North Carolina. Amer. Midl. Nat. 28: 1-126

Rickliefs, R.E. 1973. Ecology. Chiron Press.861 p.

Savage and Savage, Inc. 1994. Grassy Creek Reclaimed Area Quantitative Vegetation Study (1994), Final Bond Release, Meadows No. 1 Mine, Milner, Colorado

Savage and Savage, Inc. 1994a.1994 Vegetation Monitoring: Coors Energy Company, Keenesburg Mine, Keenesburg, Colorado

Savage and Savage, Inc. 1995. 1995 Vegetation Monitoring: Coors Energy Company, Keenesburg Mine, Keenesburg, Colorado

Savage and Savage, Inc. 1995a. 1995 Dry Meadow Reference Area Vegetation Monitoring, West Elk Mine, Somerset, Colorado

Savage and Savage, Inc. 1996. Grassy Creek Reclaimed Area Quantitative Vegetation Study (1995), Final Bond Release, Meadows No. 1 Mine, Milner, Colorado

Savage and Savage, Inc. 1996a. 1996 Quantitative Vegetation Study, Phase II Bond Release: Coors Energy Company, Keenesburg Mine, Keenesburg, Colorado

Savage and Savage, Inc. 1996b. Historic Record Study Area Baseline Characterization (1996): Precipitation Soils, Vegetation, West Elk Mine, Somerset, Colorado

Savage and Savage, Inc. 1997. 1997 Vegetation Monitoring: Coors Energy Company, Keenesburg Mine, Keenesburg, Colorado

Savage and Savage, Inc. 1997a. Historic Record Study Area, Vegetation and Precipitation Characterization (1997), West Elk Mine, Somerset, Colorado

Savage and Savage, Inc. 1998. 1998 Vegetation Sampling, Blue Grama Reference Area and Reclaimed Areas, Capstan Mining Company Bacon Mine, Colorado Springs, Colorado

Savage and Savage, Inc. 1998a. 1998 Vegetation Monitoring: Coors Energy Company, Keenesburg Mine, Keenesburg, Colorado

Savage and Savage, Inc. 1998b. Historic Record Study Area, Vegetation and Precipitation Characterization (1998), West Elk Mine, Somerset, Colorado

Savage and Savage, Inc. 1999. 1999 Vegetation Sampling, Blue Grama Reference Area and Reclaimed Areas, Capstan Mining Company Bacon Mine, Colorado Springs, Colorado

Shantz, H.L. 1917. Plant succession on abandoned roads in eastern Colorado. J. Ecol. 5: 19-42

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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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REFERENCES

North Dakota State Program. 1998. Standards for Evaluation of Revegetation Success and Recommended Procedures for Pre- and Postmining Vegetation Assessments. North Dakota Public Service Commission, Bismarck.

Ries, R. E. and L. Hofmann. 1984. Pasture and hayland: measures of reclamation success. Minerals and the Environment 6:85-90.

Soil Conservation Service. 1987. Soil series - range yield data (Tech. Notes, Sec. VI). USDA NRCS (North Dakota State Office, Bismarck). Soil Tech. Note No. HD-4, 430-VI.

Soil Conservation Service. 1975. Range Sites (Range and Native Grass Interpretations, Sec. II-E). USDA NRCS (North Dakota State Office, Bismarck). Tech. Guide.

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 4ºC 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 goal of 1 shrub m^{-2} on 10% of the affected lands. Lands disturbed after August 6, 1996 have a shrub density standard 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.

References

Final bond release criteria to Permit 376-T3. 1995. Temporary File Number 3 4/107.

Rosebud Coal Sales Company (RCSC). Rosebud Mine. 1994. Reclamation Plan. Volume 11. Permit 376-T3.

Rosebud Coal Sales Co. (RCSC). Rosebud Mine. 1998/99. Bond Release Information. Full/partial volume 2 of 2. Start Aug.1999. Permit 376-T3.

WYDEQ, LQD, 1994. Guideline No. 1. Topsoil and overburden. Wyoming Department of Environmental Quality. Land Quality Division. pp. 40

WYDEQ, LQD, 1996. Guideline No. 17. Permanent postmine impoundments. Wyoming Department of Environmental Quality. Land Quality Division. pp.18

WYDEQ, LQD, 1998 a. How to Handle Bond Release on Coal Mined Lands Affected During Various Regulatory Time Frames? Wyoming Department of Environmental Quality, Land Quality Division. pp.27

WYDEQ, LQD, 1998 b. Coal Rules and Regulations. Wyoming Department of Environmental Quality, Land Quality Division.

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.

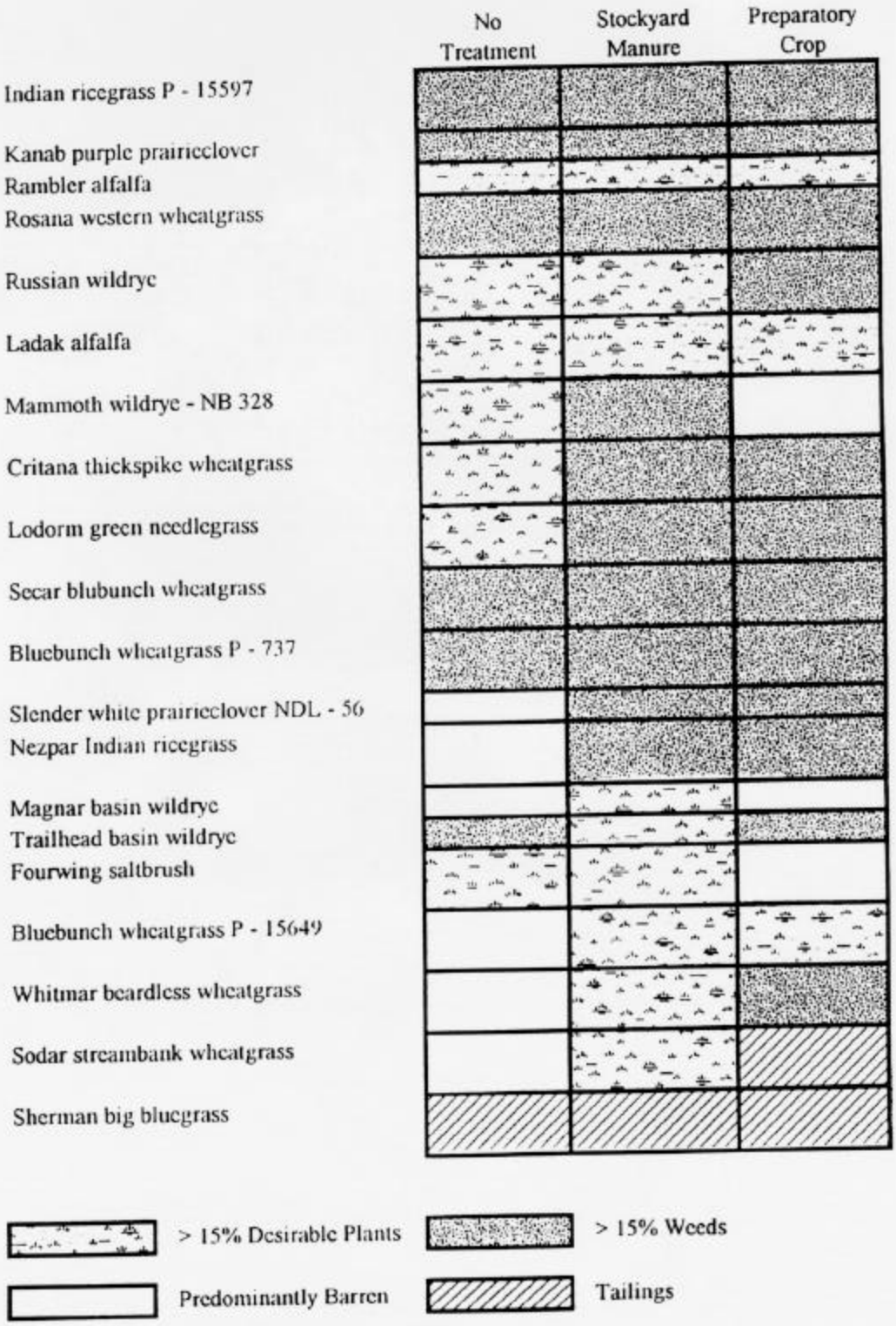

FIGURE 1. Treatment and Planting Layout at the Texas Avenue Test Plots.

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				PREP. CROP TREATMENT				MANURE TREATMENT			
	YEAR											
	2	6	11	15	2	6	11	15	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

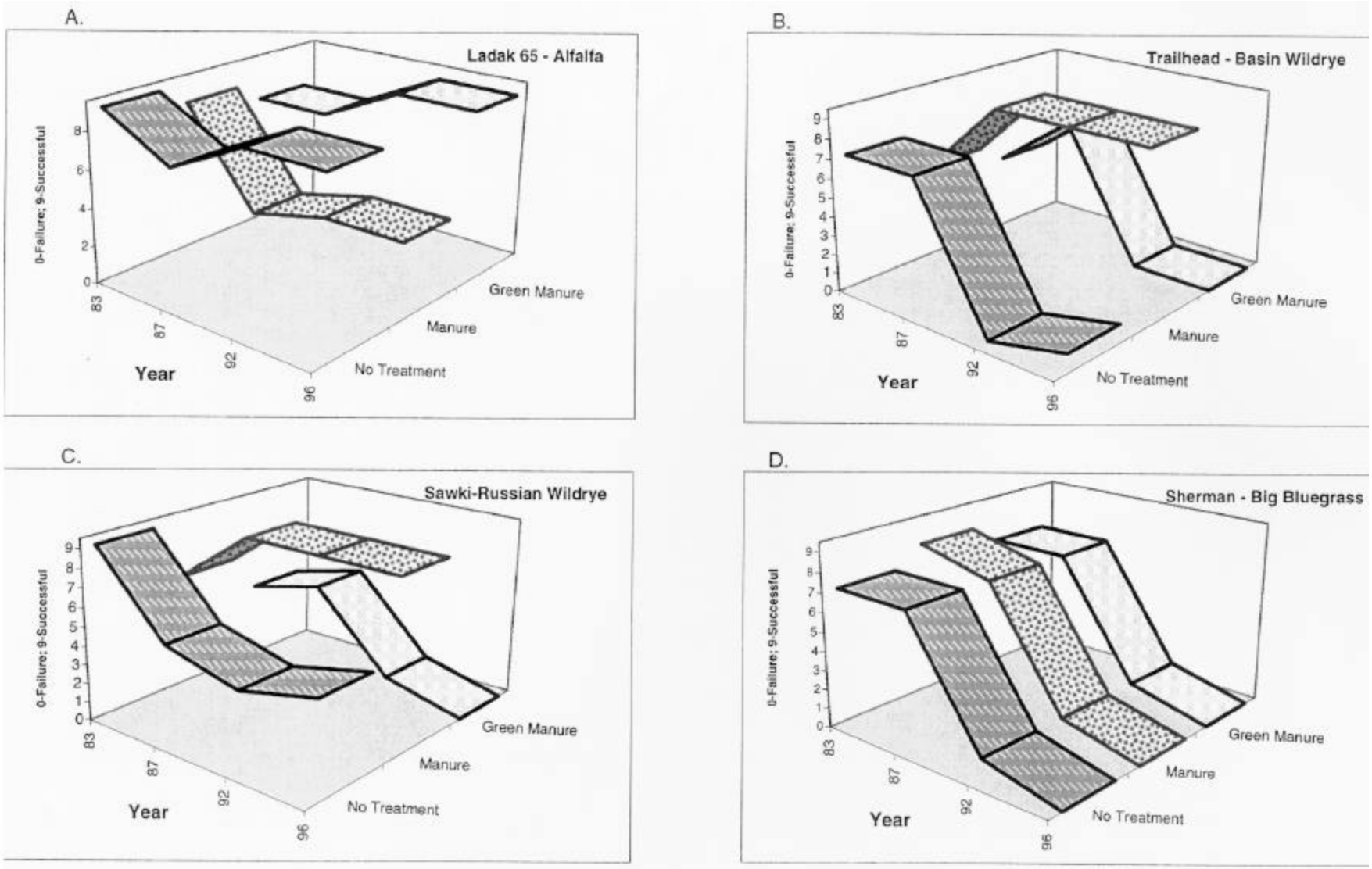

FIGURE 2. Three classes of plant performance. Alfalfa (A) was the only satisfactory seeded species on non-manured substrates 15 years after planting. Basin wildrye (B) and Russian wildrye (C) established slowly and persisted only on the manured coversoil. Big bluegrass (D) established strongly but did 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.

REFERENCES

Alexander, M. 1991. Introduction to Soil Microbiology. Second ed. Krieger Pub. Co., Malabar, FL. 467 pp.

Briggs, M., Roundy, B., and W. Shaw. 1995. Trial and error. Restoration and Management Notes 12: 160-166.

Daubenmire, R. 1959. A canopy-coverage method of vegetational analysis. Northwest Sci. 33(1): 43-64.

Grime, J. 1979. Plant Strategies and Vegetation Processes. Wiley, N.Y.

Heady, H. 1952. Reseeding, fertilizing, and renovating an ungrazed mixed prairie. J. Range Mgt. 5:144-149.

Houston, D. 1982. The Northern Yellowstone Elk: Ecology and Management. Macmillan Pub. Co., NY. 474 pp.

Josselyn, M., Chamberlain, S., Goodnight, K., Hopkins, H., and A. Fiorillo. 1993. Evaluation of coastal conservancy enhancement projects, 1978-1992. San Francisco State Univ., Tiburon, Ca.

McIntosh, R. 1980. The relationship between succession and the recovery process in ecosystems. pp. 11-62 *In:* J. Cains (ed.) The recovery process in damaged ecosystems. Ann Arbor Sci. Pub. 167 pp.

Michener, W. 1997. Quantitatively evaluating restoration experiments: research design, statistical analysis, and data management considerations. Ecol. Restoration 5(4):324-337.

Ziemkiewicz, P., and S. Takyi. 1990. Organic matter dynamics on reclaimed coal mines in the Canadian Rockies. pp. 127-133 *In*: Proc. of the 1990 Mining and Reclamation Conference and Exhibition, Vol. I. Charleston, W. Va. 319 pp.

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.

CITATIONS

Josselyn, M., Chamberlain, S., Goodnight, K., Hopkins, H., and A. Fiorillo. 1993. Evaluation of coastal conservancy enhancement projects, 1978-1992. San Francisco State Univ., Tiburon, Ca.

Munshower, F. 1994. Practical handbook of disturbed land revegetation. Lewis Pub, CRC Press, Boca Raton, FL. 265 pp.

Ryerson, D., and J. Taylor. 1974. Rangeland fertilization in Montana - a literature review. pp. 1-19 IN: Proc. Range Fertilization Symposium, Havre, MT. July. Mt. Ag. Expt. Sta. Res. Rep. 70. Pages not consecutively numbered.

2000 Billings Land Reclamation Symposium

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.

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REFERENCES

Agronomic Interpretations Working Group. 1995. Land suitability rating system for agricultural crops: 1. Spring-seeded small grains. W.W. Pettapiece (ed.). Tech. Bull. 1995-6E. Center for Land and Biological Resources Research, Agriculture and Agri-Food Canada, Ottawa. 90 p. 2 maps.

Alberta Environmental Protection. 1994. Guide for pipelines pursuant to the Environmental Protection and Enhancement Act and Regulations. Alberta Environmental Protection, Land Reclamation Division. Edmonton, Alberta.

Brocke, L. 1988. Alberta legislation as it relates to soil reclamation and energy extraction. In: Energy Extraction: Concerns and Issues Related to Soil Reclamation. Partial Proceedings of the 34th Annual CSSS/AIC Meeting. University of Calgary, Calgary, Alberta. pp. 1-7.

Landsburg, S. and Fedkenheuer, A.W. 1990. Pipeline construction in NOVA's Alberta Gas Transmission Division. In: Proceedings of Planning, Rehabilitation and Treatment of Disturbed Lands Billings Symposium. Billings, Montana. March 25-30, 1990. Reclamation Research Unit Publication No. 9002, Montana State University, Bozeman. Vol. II, 9 pp.

Mahnic, R.J. and J.A. Toogood, J.A. 1992. Proceedings of the Industry/Government Pipeline Success Measurement Workshop. Alberta Land Conservation and Reclamation Council Report No. RRTAC 92-3. ISBN 0-7732-0886-0. 75 pp.

Mutrie, D.F. and Gilmore, K.B. 1995. Pipelining in Canada and the U.S.: an environmental comparison. In: Proceedings of the 5th International Symposium on

Environmental Concerns in Rights-of-Way Management, Montreal, Quebec, Sept. 19-22, 1993.

NGTL External Advisory Board. 1999. Alberta landowner pipeline reclamation assessment manual. A.W. Fedkenheuer (ed.). TransCanada Transmission, Calgary, Alberta. 8 p.

NGTL External Advisory Board. 1999. Alberta pipeline reclamation assessment manual. A.W. Fedkenheuer and W.W. Pettapiece (eds.). TransCanada Transmission, Calgary, Alberta. 126 p.

Powter, C.B. (compiler). 1998. Glossary of reclamation terms used in Alberta. (5th ed.). Alberta Conservation and Reclamation Management Group Report No. RRTAC OF-1A. Alberta Conservation and Reclamation Management Group, Alberta Environmental Protection. Edmonton, Alberta.

Wellsite Criteria Working Group. 1995. Reclamation criteria for wellsites and associated facilities. Alberta Environmental Protection, Land Reclamation Division, Edmonton.

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

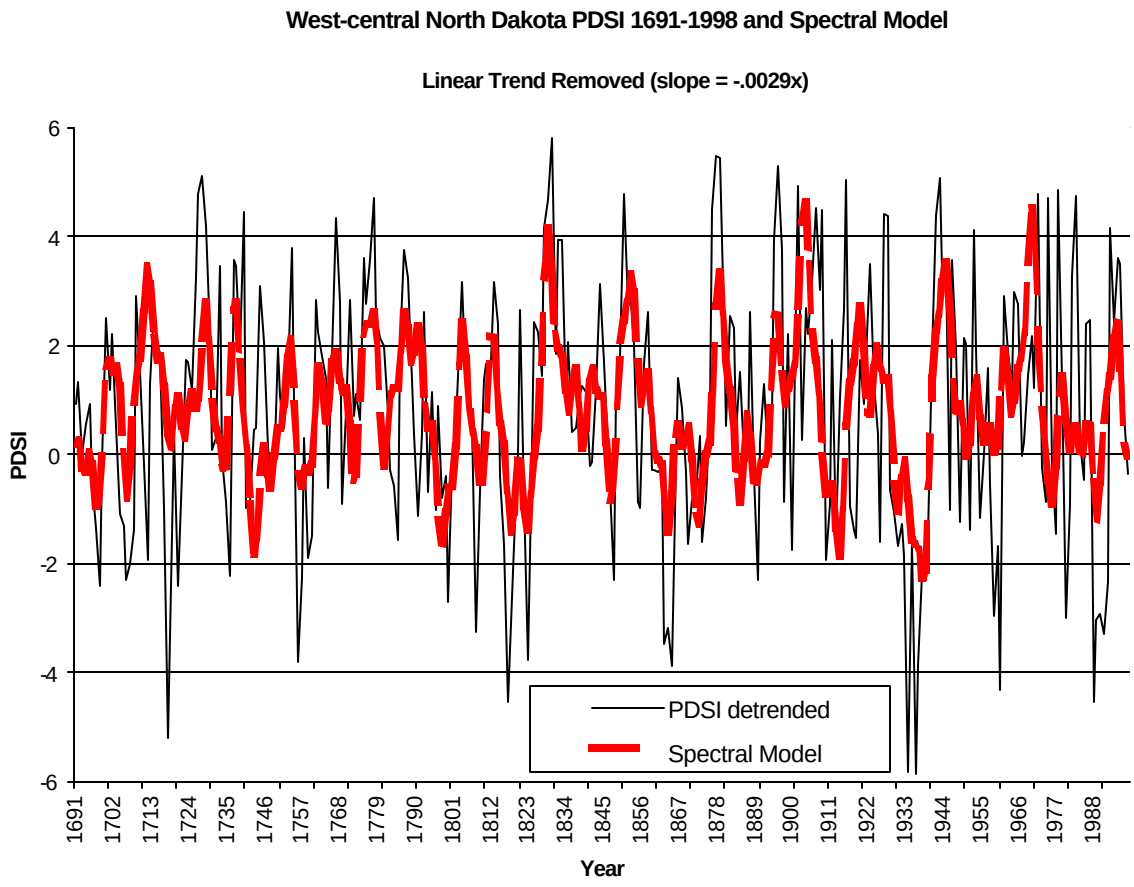
Table 1

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

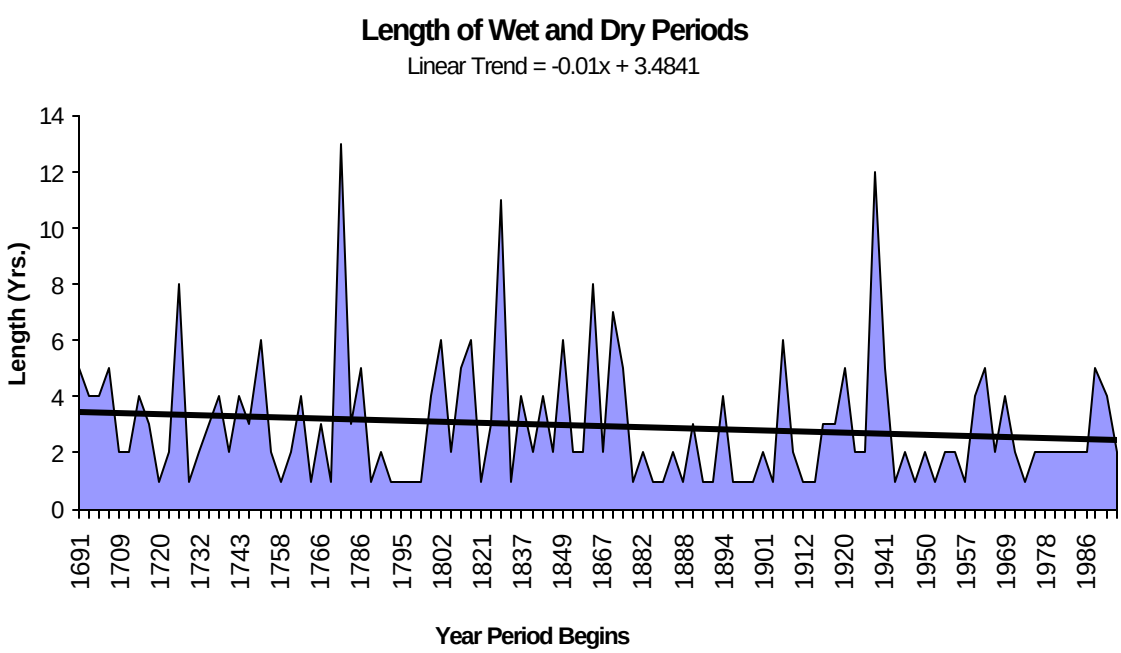
Correlation (.40-.78) of 1979-98 with 20-year intervals beginning:	Visual Curve Matching: 1979-98 with 20-yr. intervals beginning:	Periods of 5 or more Wet Years	Periods of 5 or more Dry Years	Severe Wet Years	Severe Dry Years
		1691-95			
			1704-08		
1709	1711				1718
1723		1723-30		1726-29, 33, 37-38, 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.

REFERENCES

Cook, E. R., D. M. Meko, D. W. Stahle and M. K. Cleaveland. 1996. Tree-ring reconstructions of past drought across the coterminous United States: Tests of a regression method and calibration/verification results. Radiocarbon 1966:155-169.

Cook, E. R., D. M. Meko and C. W. Stockton. 1997. A new assessment of possible solar and lunar forcing of the bidecadal drought rhythm in the western United States. Jour. Climate 10:1343-1356.

Guttman, N. 1991. Sensitivity of the Palmer Hydrologic Drought Index to temperature and precipitation departures from average conditions. Water Resources Res. 27:797-807.

Hayes, M. J. 1999. Drought Indices. National Drought Mitigation Center, URL: http://enso.unl.edu/ndmc/enigma/indices.htm

Mann, M. E., R. S. Bradley and M. K. Hughes. 1998. Global-scale temperature patterns and climate forcing over the past six centuries. Nature 392:779-787.

Michaelsen, J. 1989. Long-period fluctuations in El Niño amplitude and frequency reconstructed from tree-rings. Amer. Geophys. Union Geophys. Monogr. 55:69-74.

Mock, C. J. 1991. Drought and precipitation fluctuations in the Great Plains during the late Nineteenth Century. Great Plains Res. 1(1):26-57.

Palmer, W. C. 1965. Meteorological drought. U.S. Weather Bureau Res. Paper 45, 58p.

Sieg, C. H., D. Meko, A. T. DeGaetano and W. Ni. 1966. Dendroclimatic potential in the Northern Great Plains. Radiocarbon 1996:295-302.

Woodhouse, C. A. and J. T. Overpeck. 1998. 2000 years of drought variability in the central United States. Bull. Amer. Meteorol. Soc. 79(12):2693-2714

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 precipation 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.

References

Halvorson, G.A., 1996, "Comparative Evaluation of Productivity of Prime and Nonprime Land," Final Status Report, Contract No. LRC-XVIII-58, North Dakota State University, Land Reclamation Research Center, Mandan, ND.

Halvorson, G.A., and Nathan, M.V., 1993, "Research on the Reclamation of Prime Farmland in North Dakota," Report to the ND Legislative Council pursuant to Section 5 of H.B. 1005 of the 52nd Legislative Session, North Dakota State University, Land Reclamation Research Center, Mandan, ND.

Halvorson, G.A., and Nathan, M.V., 1995, "Reclamation of Prime and Nonprime Soils," Mineland Reclamation Review, March 29, 1995, North Dakota State University, Land Reclamation Research Center, Mandan, ND.

North Dakota Public Service Commission, 1997, "Rules Governing Surface Mining and Reclamation Operations, June 1, 1997," Bismarck, ND.

North Dakota Public Service Commission, 1995, "Standards for Evaluation of Revegetation Success and Recommended Procedures for Pre- and Postmining Assessments, Revised May 1995,"Bismarck, ND.

Richardson, J.L., and Wollenhaupt, N.C., 1983, "Natural Soil and Landscape Development," Can Mined Land Be Made Better Than Before Mining? Conference Proceedings, November 7, 1982, Stronghold Press, pp. 95-96.

Schroeder, S.A., 1991, "Topographic Position Effects on Soil Water and Wheat Yields on Reclaimed Minelands," North Dakota Farm Research, Vol. 48, No. 5, pp. 3-5.

Schroeder, S.A., and Doll, E.C., 1984, "Productivity of Prime, Nonprime, and Reclaimed Soils in Western North Dakota," North Dakota Farm Research, Vol. 41, No. 5, pp. 3-6, 31.

Soil Conservation Service, 1984, "North Dakota Important Farmlands," Bismarck, ND.

Stomberg, A., 1985, "Prime Soils Handling in North Dakota," Proceedings of the 1985 Annual Meeting of American Institute of Mining Engineers, Albuquerque, NM, pp. 1-3.

The Falkirk Mining Company, 1995, "Surface Coal Mining Permit No. NAFK-9503," The Falkirk Mining Company, Underwood, ND.

Wollenhaupt, N.C. and Richardson, J.L., 1982, "The Role of Topography in Revegetation of Disturbed Lands," Symposium on Surface Coal Mining and Reclamation in the Northern Great Plains Proceedings, March 8-9, 1982, pp. C.2.1-C.2.11.

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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
Native Mix 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
Precrop Mix 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.

	Year of Data								
Tillage	**1989**[1]	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**Mean**
				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.

	Year of Data							
Location	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**
	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.

REFERENCES

Barnhisel, R.I., J.L. Powell and W.O. Thom. 1988a. Use of soft red winter wheat for reclamation of surface-mined lands in western Kentucky. I. Effects of cultivar selection, soil depth and ripping. J. Prod Agric. 1:304-308.

Barnhisel, R.I., J.L. Powell, J.R. Armstrong, M.L. Ellis and F.A. Craig. 1988b. Effect of soil depth, liming, and subsoiling of reconstructed prime farmland on alfalfa production. Pp. 266-273. *In*: 1988 Mine Drainage and Surface Mine Reclamation Conference Proceedings. Am. Soc. Surface Mining and Reclamation, USDI, Pittsburgh, PA. April 17-22, 1988.

Brenneman, W.S. 1991. Soil compaction. J. Soil and Water Conserv. 45(1):3.

Materechera, S.A., A.M. Alston, J.M. Kirby, and A.R. Dexter. 1992. Influence of root diameter on the penetration of seminal roots into a compacted subsoil. Plant and Soil 144:297-303.

Meek, B.D., E.A. Rechel, L.M. Carter, and W.R. Detar. 1988. Soil compaction and its effect on alfalfa in zone production systems. Soil Sci. Soc. Am. J. 52:232-236.

Phillips, R.E. and D. Kirkham. 1962. Mechanical impedance and corn seedling root growth. Soil Sci. Soc. Am. Proc. 26:319-322.

Pikul, J.L. and J.K. Aase. 1999. Wheat response and residual soil properties following subsoiling of a sandy loam in eastern Montana. Soil and Tillage Res. 51(1-2):61-70.

Thompson, P.J., I.J. Jansen, and C.L. Hooks. 1987. Penetrometer resistance and bulk density procedures for predicting root system performance in minesoils. Soil Sci. Soc. Am. J. 51:1288-1293.

Voorhees, W. 1990. Winters can't undo modern compaction. J. Soil and Water Conserv. 45(6):632.

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.

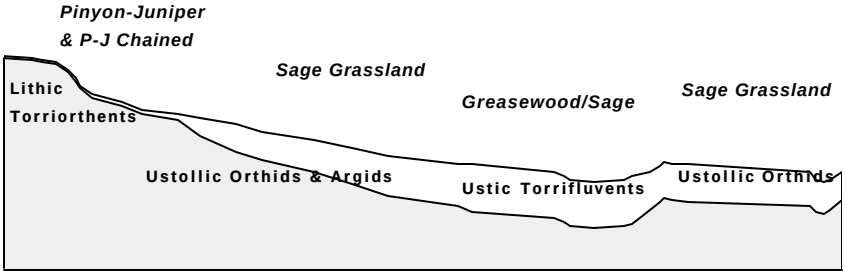

Figure 1: Toposequence of premine soils and associated plant communities in NW New Mexico. Genetic soil (A & B horizons) are indicated by clear portion of the figure

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.

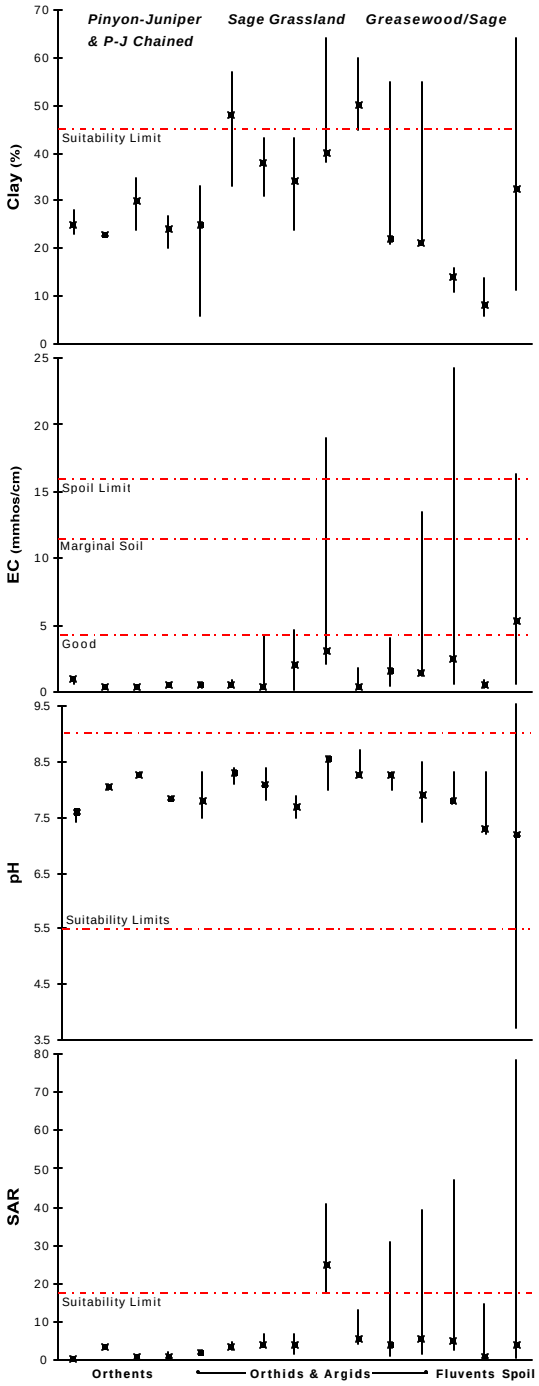

Figure 2: Physio-chemical variability of selected soils along a premine toposequence. Weighted average for salvageable topsoil indicated by marker; lines show variability within soil profile. Expected spoil variability on far right from premine

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.

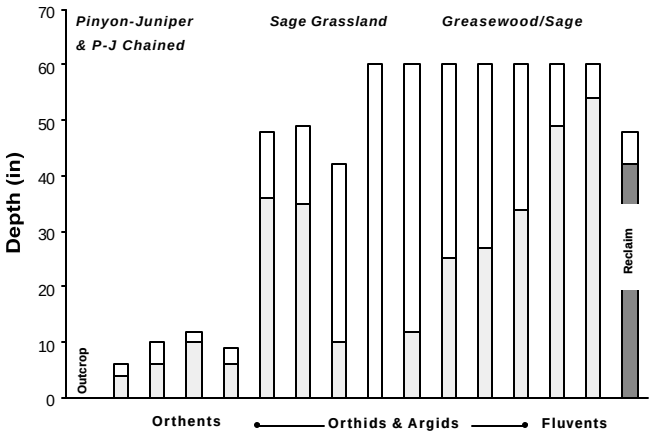

Figure 3: Soil depth along a topographic gradient in NW New Mexico. Genetic (A & B) horizons are clear portion of bars. Shaded portion is the effective depth of the profile. Typical reclaimed soil on

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.

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.

REFERENCES

Barth, R.C. and B.K. Martin. 1984. Soil depth requirements for vegetation of surface-mined areas in Wyoming, Montana and North Dakota. JEQ 13:399-404.

Biondini, M.E., and E.F. Redente. 1986. Interactive effect of stimulus and stress on plant community diversity in reclaimed lands. Reclamation & Reveg. Res. 4:211-222.

Buchanan, B., T Ramsey and D. Romig. 1999. Building a foundation for diversity. Paper presented at the OSM Interactive Forum: Approaching bond release. Sept. 1999. Flagstaff, AZ.

DePuit, E. J. 1984. Potential topsoiling strategies for enhancement of vegetation diversity on mined lands. *In* F.F. Munshower and S.E. Fischer (eds.) Third Biennial Symp. on Surface Coal Mine Reclamation on the Great Plains. Billings, MT

Franco-Vizcaino, E., R. Graham and E. Alexander. 1993. Plant species diversity and chemical properties of soils in the central desert of Baja California, Mexico. Soil Sci 155:406-416.

Gates, D.H., L.A. Stoddart and C.W. Cook. 1956. Soil as a factor influencing plant distribution on salt deserts of Utah. Ecol. Mono. 26:155-175.

Keck, T.J. and J.M. Wraith. 1996. Variations among different reclamation materials ar Western Energy's Rosebud Mine. *In* F.F. Munshower and S.E. Fischer (eds.) Planning, Rehabilitation and Treatment of Disturbed Lands, 7th Billings Symp., Billings, MT.

Keck, T.J. W.F. Quimby and G.A. Nielsen. 1993. Spatial distribution of soil attributes on reconstructed minesoils. Soil. Sci. Soc. Am. J. 57:782-786.

Merrill, S.D., R.F. Ries and J.D. Power. 1998. Subsoil characteristics and landscape position affect productivity of reconstructed mine soils. Soil Sci. Soc. Am. J. 62:263-271.

Merrill, S.D., S.J. Smith and J.D. Power. 1985. Effect of disturbed soil thickness on soil water use and movement under perennial grass. Soil Sci. Soc. Am. J. 49:196-202.

Munk, L.P. 1996. Sodicity and salinity in mined land reclamation. *In* F.F. Munshower and S.E. Fischer (eds.) Planning, Rehabilitation and Treatment of Disturbed Lands, 7th Billings Symp., Billings, MT.

Munk, L.P., D.E. Romig, and M.D. Coates. 1999. Spoil sodicity standards: Reconciling science and regulation. *In* Proc. Am. Soc. Surface Mining Reclamation 16th Annual Mtg. Scotsdale, AZ.

Power, J.D., F.M. Sandoval, R.F. Ries and S.D. Merrill. 1981. Effect of topsoil and subsoil thickness on soil water content and crop production on a disturbed soil. Soil Sci. Soc. Am. J. 45:124-129.

Prodgers, R.A. and T.J. Keck. 1996. Vegetation diversity concepts and strategies for reclamation. *In* F.F. Munshower and S.E. Fischer (eds.) Planning, Rehabilitation and Treatment of Disturbed Lands, 7th Billings Symp., Billings, MT.

Schafer, W.M. 1979 Variability of minesoils and natural soils in SE Montana. Soil Sci. Soc. Am. J. 43:1207-1212.

Sorenson, T. 1948. A method for establishing groups of equal amplitude. I. Plant sociology based on similarity of species content. Det. Kong. Danske Vidensk. Selsk Biol. Skr. 5:1-24.

Stark, J.M., and E.F. Redente. 1985. Soil-plant diversity relationships on a disturbed site in northwestern Colorado. Soil Sci. Soc. Am. J. 49:1028-1034.

Wallace, A., E.M. Romney and V.Q. Hale. 1973. Sodium relations in desert plants: I. Cation contents of some plant species from the Mojave and Great Basin deserts. Soil Sci. 115:284-287.

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.

REFERENCES

DePuit, E.J. 1984. Potential Topsoiling Strategies for Enhancement of Vegetation Diversity on Mined Lands. Proc. of the 3rd Billings Symposium on Surface Coal Mine Reclamation in the Great Plains, Billings, MT.

Doll, E.C., S.D. Merrill, and G.A. Halvorson. 1984. Soil Replacement for Reclamation of Stripmined Lands in North Dakota. North Dakota State Agricultural Experiment Station Bulletin 514, Fargo, ND. 23 p.

Faught, C.K. 1989. Effects of Selectively Handling Topsoil on Edaphic Conditions for Revegetation. University of Wyoming, Department of Plant, Soil and Insect Sciences, MS Thesis.

Fox, D. 1993. Soil Depth and Herbaceous Yield Relationships on Reclaimed Surface Mined Lands in North Dakota. North Dakota State University, Department Animal and Range Sciences, MS Thesis.

Halvorson, G.A. and et al. 1986. Topsoil and subsoil thickness requirements for reclamation of nonsodic mined-land. Soil Sci. Soc. Am. 50 (Mar/Apr):419-422.

Oddie, T.A. and A.W. Bailey. 1988. Subsoil Thickness Effects on Yield and Soil Water when Reclaiming Sodic Minespoil. J. Environ. Qual. 17(4):623-627.

Schuman, G.E., E.M. Taylor, Jr., F. Rauzi and B.A. Pinchak. 1985. Revegetation of Mined Land: Influence of Topsoil Depth and Mulching Method. J. of Soil and Water Conser. (March-April):249-252.

Wyoming Department of Environmental Quality-Land Quality Division. 1994c. Guidelines 1, 2, and 14.

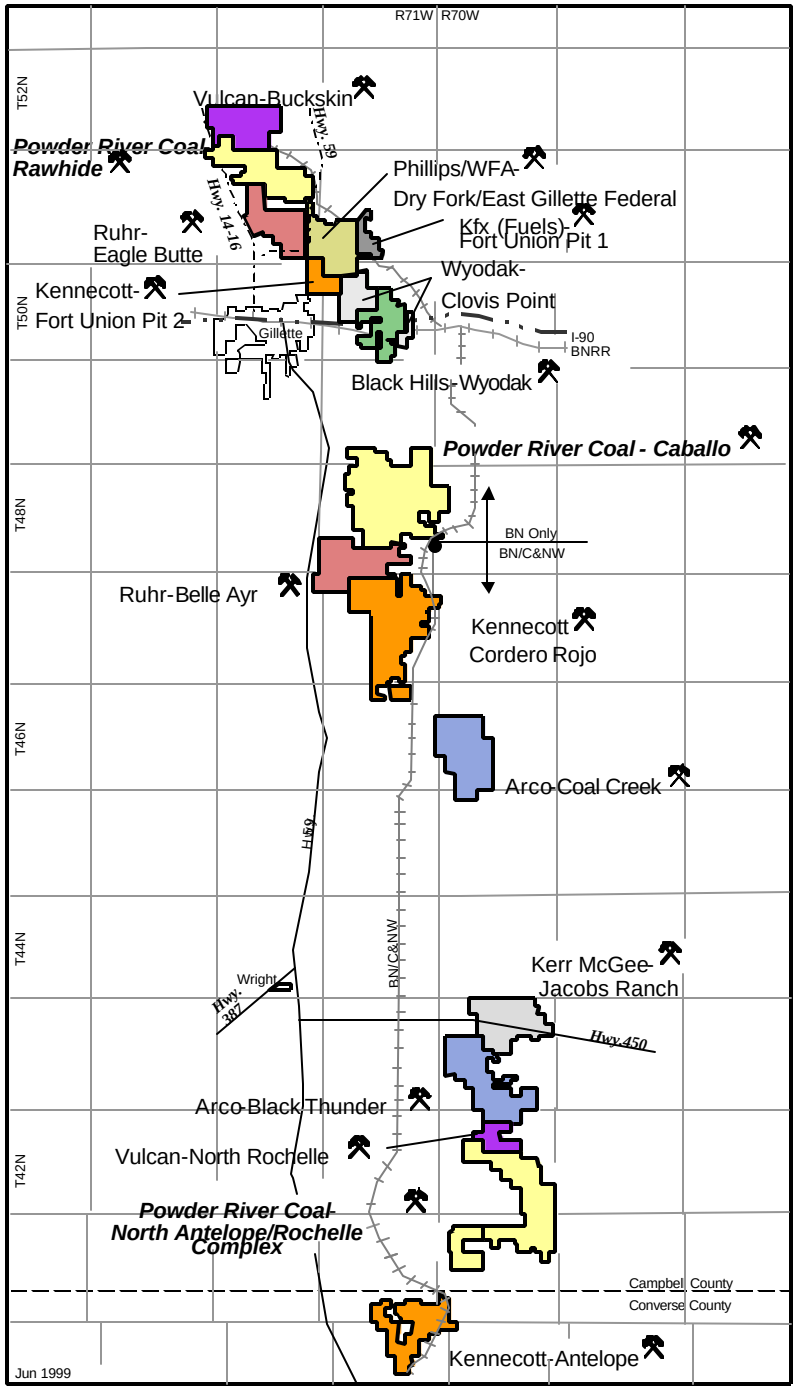
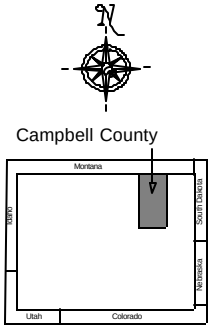


FIGURE 1. LOCATION OF NORTH ANTELOPE/ROCHELLE PERMIT AREA WITHIN EASTERN POWDER RIVER BASIN



Denotes Active Mine

FIGURE 2. SOIL SAMPLE LOCATIONS WITHIN TREATMENTS.

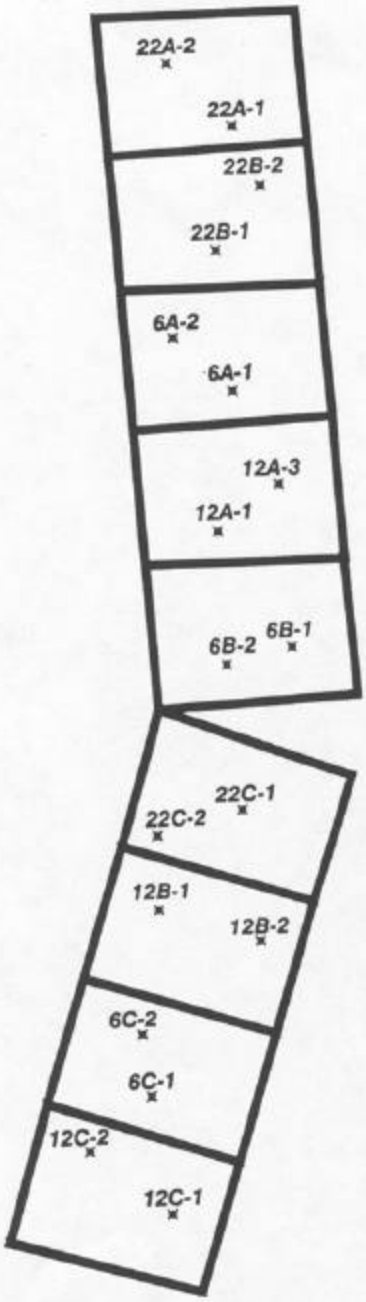


Table 1. 1998 Backfill Suitability Analysis in the Vicinity of the AML Variable Topsoil Study (WDEQ-LQD Guideline 1, 1994).

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.

REFERENCES

Blomquist, K. W. and G. E. Lyon. 1993. Effects of soil quality and depth on seed germination and seedling survival at the Nevada Test Site. Wildland Shrub and Arid Land Restoration Symposium, Las Vegas, NV, USDA Intermountain Research Station.

Brown, R. W., R. C. Sidle, et al. 1991. Reclamation Research Results on the Borealis Mine: Progress Report 1987-1990. Logan, UT, USDA Forest Service Intermountain Research Station Forestry Sciences Laboratory: 69.

Chambers, J. C., R. W. Brown, et al. 1994. "An evaluation of reclamation success on Idaho's phosphate mines." Restoration Ecology 2(1): 4-16.

Hoffman, T. L. and C. L. Wambolt. 1996. Growth response of Wyoming big sagebrush to heavy browsing by wild ungulates. Proceedings: Shrubland Ecosystem Dynamics in a Changing Environment, Las Cruces, NM, USDA Forest Service Intermountain Research Station.

Mathews, D. T. and M. S. Savage. 1990. Revegetation observations at surface coal mines in the Axial Basin, Yampa River Basin, and North Park, Colorado. Fifth Billings Symposium on Disturbed Land Rehabilitation, Billings, MT, Montana State University.

McLendon, T. and E. F. Redente. 1992. "Effects of nitrogen limitation on species replacement dynamics during early secondary succession on a semiarid sagebrush site." Oecologia 91: 312-317.

Pendleton, R. L., S. D. Nelson, et al. 1996. Do soil factors determine the distribution of spineless hopsage (*Grayia brandegei*)? Proceedings: Shrubland Ecosystem Dynamics in a Changing Environment, Las Cruces, NM, USDA Intermountain Research Station.

Tilman, D. and D. Wedin. 1991. "Dynamics of nitrogen competition between successional grasses." Ecology 72: 1038-1049.

USDA. 1988. Range Plant Handbook. Mineola, NY, Dover Publishing.

Wilson, J. B. 1999. Assembly rules in plant communities. Ecological Assembly Rules. E. Weiher and P. Keddy. New York, Cambridge University Press: 130-164.

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MIXED SHRUB RECLAMATION: THE RECLAMATION OF AN IMPORTANT HABITAT

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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 <u>completely</u> 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
Species	**Life Form**	**No. of Plants by Life Stage**					**Total**	**Total**
		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**

REFERENCES

Econ, Inc. 1983. Vegetation Report for the Mining Area C. Prepared for Western Energy Company, Project 295-83-A, Helena, Montana, February 15, 1983.

Harju, H.J. 1980. Reclamation for Wildlife – The Wyoming Viewpoint, Presentation at Soil Conservation Society of America Symposium, March 26, 1980.

Laycock, W.A. 1980. What Is Successful Reclamation? – A Look At the Concepts of Adaptability, Productivity, Cover, and Diversity of Seeded Species, USDA, SEA-AR, Forage and Range Management Research, Crops Research Laboratory, Colorado State University, Fort Collins, Colorado, 1980.

Mackie, R.J. 1991. Big Game Historical Perspective. Abst. Livestock – Big Game Symposium, Reno, Nevada, September 18-20, 1991.

Regele, S.M., and L. Reichert. 1997. Vegetation at a Glance, GIS approach to Ecology. Presentation at U.S.DI., O.S.M. Interactive Forum on Computer Applications for Electronic Permitting, Denver CO. June, 1997.

Steele, B.B., and C.V. Grant. 1982. Topographic Diversity and Islands of Natural Vegetation: Aids in Re-establishing Bird and Mammal Communities on Reclaimed Mines," Reclamation and Revegetation Research, Vol. 1, 1982, pp. 376-381.

Viert, S.R. 1999. Rosebud Mine Revegetation Monitoring Report Cedar Creek Associates, Inc. Fort Collins, CO. November 1999.

Wendtland, K.J.1992. Regulatory Directives and Reclamation Strategies in the Development of Ecologically Diverse Post-Mined Landscape, Presentation at June 14, 1992 meeting for Society for Surface Mining and Reclamation, Duluth, Minnesota.

Wollenhaupt, N.C., and J. L. Richardson. 1982. The Role of Topography in Revegetation of Disturbed Land, Symposium on Surface Coal Mining and Reclamation in the Northern Great Plains.

Wood, A.K., and K. Hamlin. 1989. Ecology of Sympatric Mule and White-tailed Deer Populations in a Prairie Environment. Tech Bull. Montana Department of Fish, Wildlife and parks, Helena, Montana. 98 pp.

Yde, C. 1999. Build It and They Will Come: Successful Bond Release Begins With the PMT. Office of Surface Mining, Symposium Reclamation Issues, and Surface Coal Mining Applications in the Arid, Semi-arid West, September 21-24, 1999 Flagstaff, Arizona.

Zacek, J.C., H.E. Hunter., T.A. Bown., and R.L. Ross, 1977, U.S.D.A. Soil Conservation Service Montana Grazing Guides

2000 Billings Land Reclamation Symposium

THE TOPSOIL DILEMMA

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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.

LITERATURE CITED

Environmental Quality Council. 1997. Smith vs. State of Wyoming, Department of Environmental Quality, Docket No. 2749-96.

Laramie Boomerang. 1998. Court rules against mine's definition of topsoil. Nov. 8, 1998. Laramie, WY.

Munshower, F.F. 1994. Practical Handbook of Disturbed Land Revegetation. CRC Press, Inc. Boca Raton, FL.

Wyoming Department of Environmental Quality-Land Quality Division (WDEQ-LQD). 1984. Guideline No. 1, Cheyenne, WY.

Wyoming Statutes. 1998. Wyoming Environmental Quality Act and Industrial Development Information and Siting Act, Annotated and Supplement. WDEQ, Cheyenne, WY.

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 35ºC (95ºF) to lows less than -18ºC (0ºF) 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.

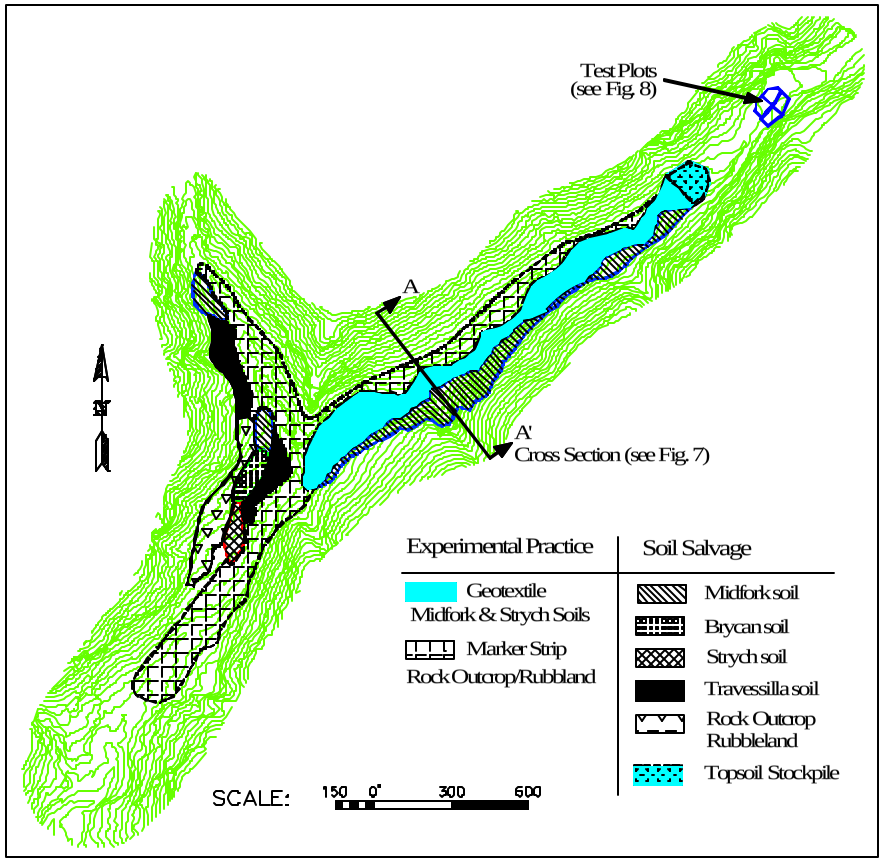

Figure 3. Mine site soils map

•€ 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 $kg \cdot ha^{-1}$ (2,000 pounds per acre) of straw and 561 $kg \cdot ha^{-1}$ (500 pounds per acre) of wood fiber hydromulch with a tackifier (in addition to the hay worked into the soil).

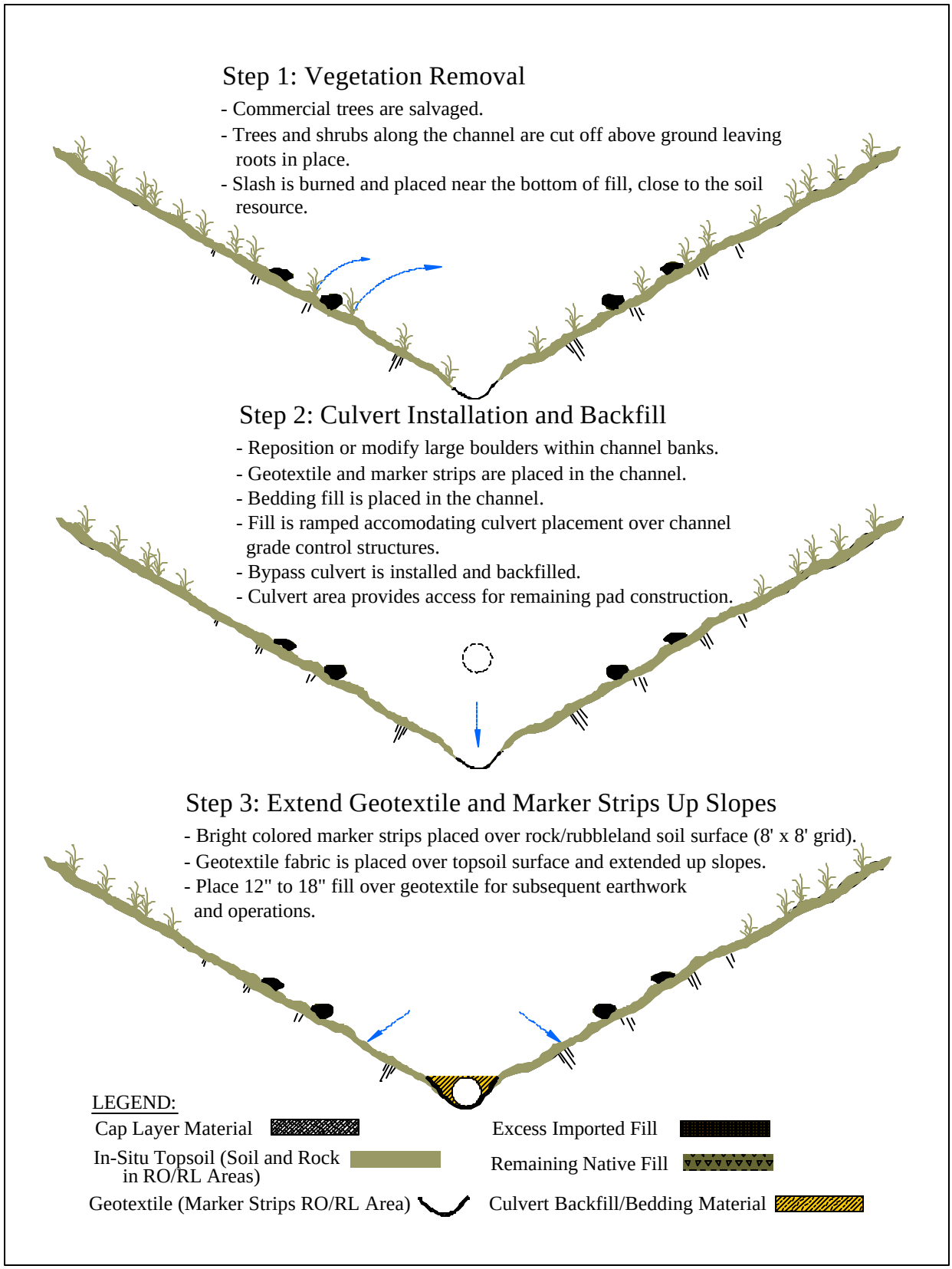

Figure 4. Construction sequence.

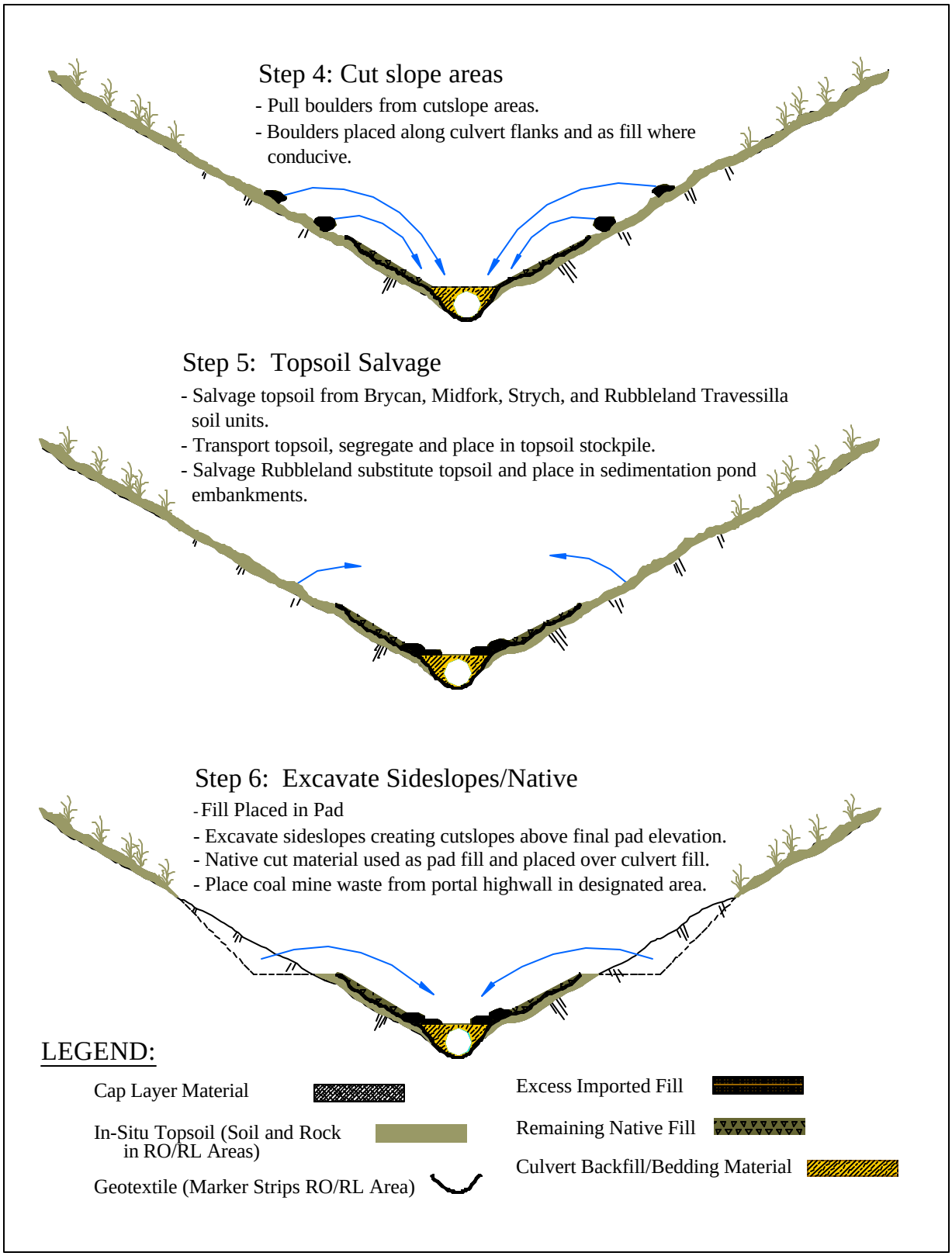

Figure 4. Construction sequence (continued).

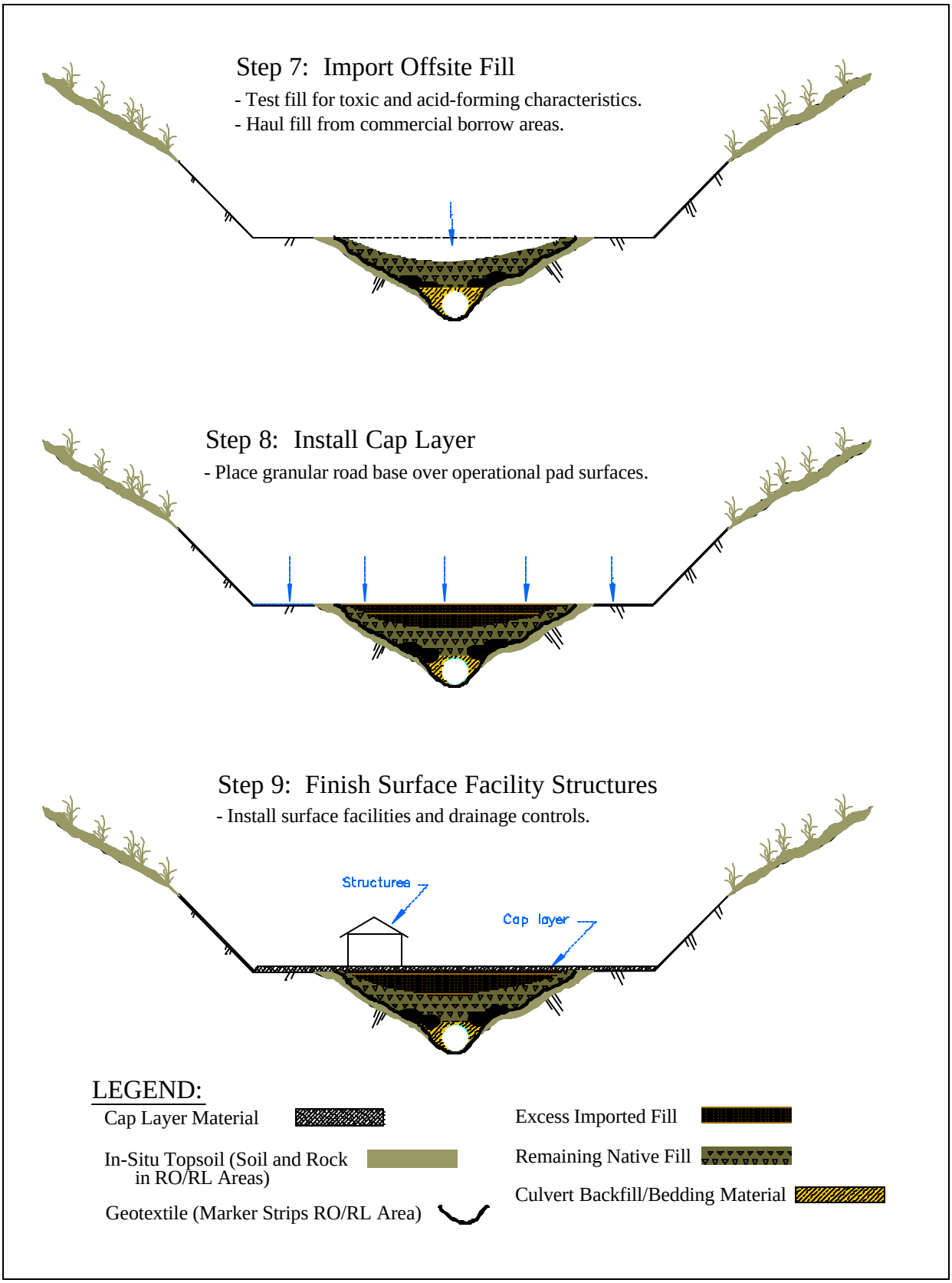

Figure 4. Construction sequence (continued).

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

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

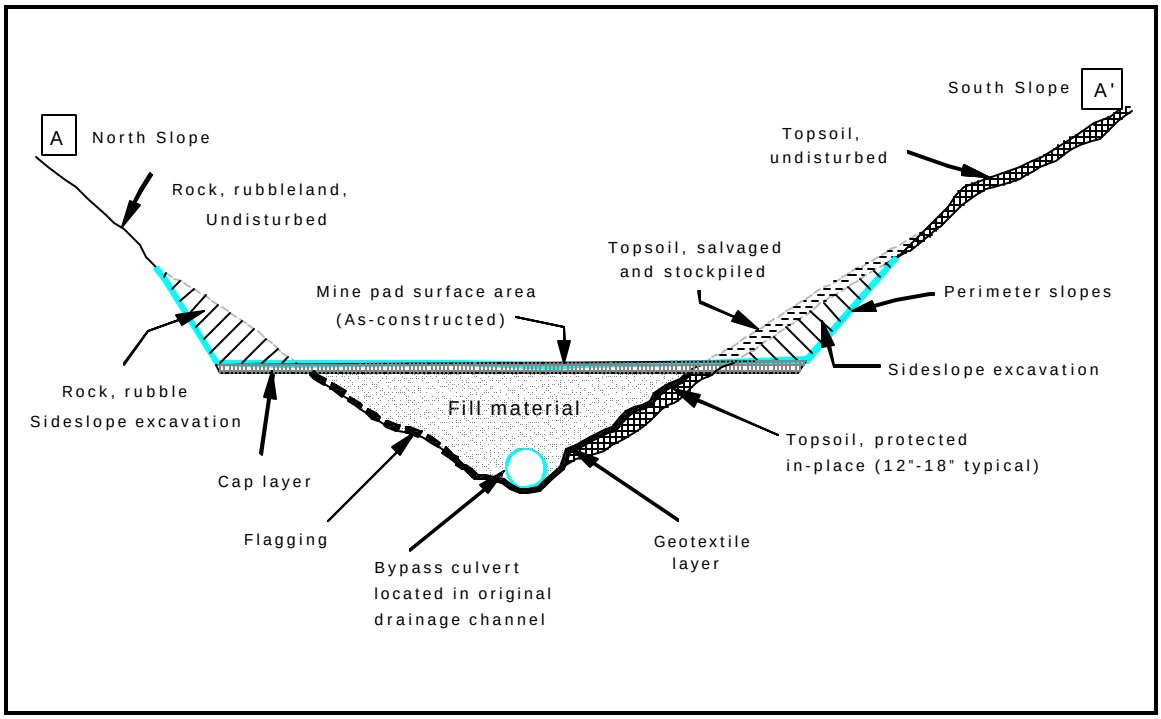

Figure 7. Generalized cross section.

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

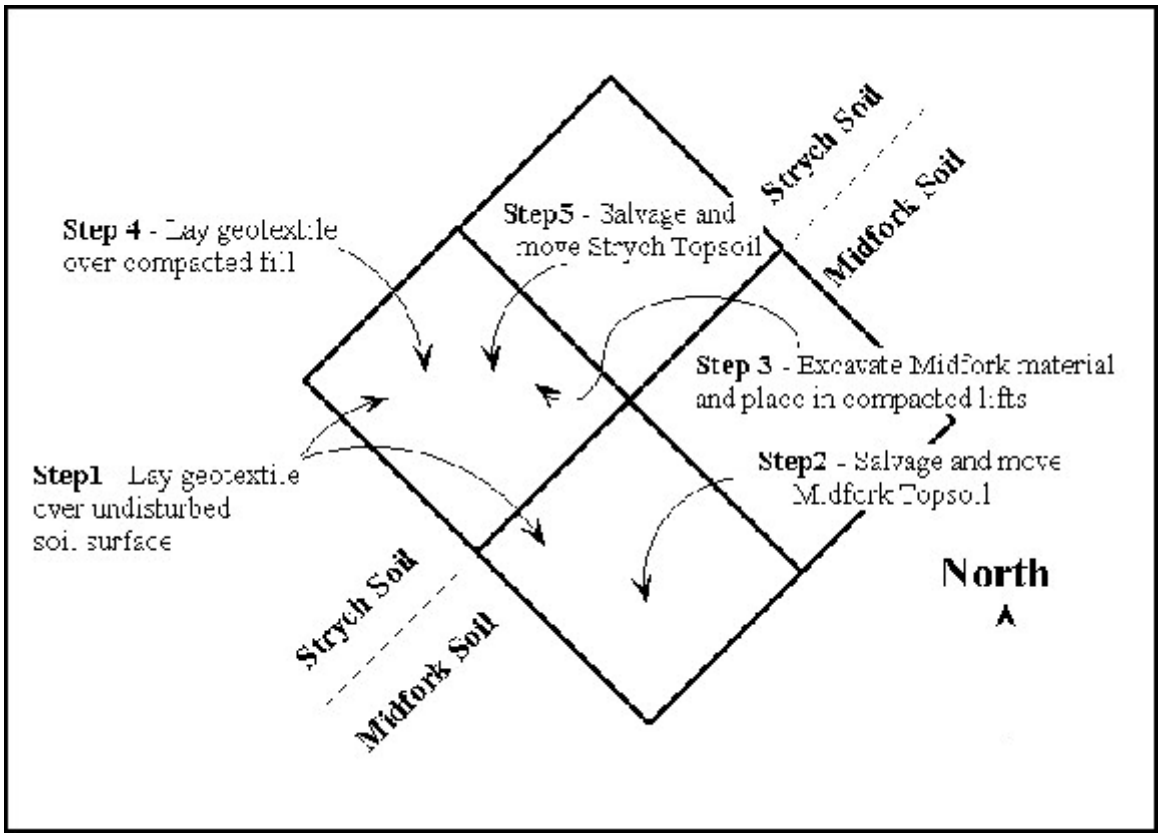

Figure 8. Test plot diagram.

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

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REFERENCES

Cundell, A. M. 1977. The role of microorganisms in the revegetation of strip-mined land in the western United States. J. Range Manage. 30: 299-305.

Fresquez, P. R., W. C. Lindemann, and D. L. Lindsey. 1982. Soil biota in southwestern coal strip-mine spoils. In: E. F. Aldon and W. R. Oaks (eds.) Reclamation of mined lands in the southwest: a symposium. Soil Conservation Society of America New Mexico Chapter. 218 pp.

Jensen, E. H. and J. W. Borchert. 1988. Soil survey of Carbon area, Utah. U. S. D. A. Soil Conservation Service. U. S. Government Printing Office 1988 0-183-510:QL3. 294 pp.

Nyenhuis, J. H. 1997. Soil resource assessment West Ridge Mine area, Carbon County, Utah. In: West Ridge Mine permit application package. West Ridge Resources, Inc., Price Utah.

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

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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-

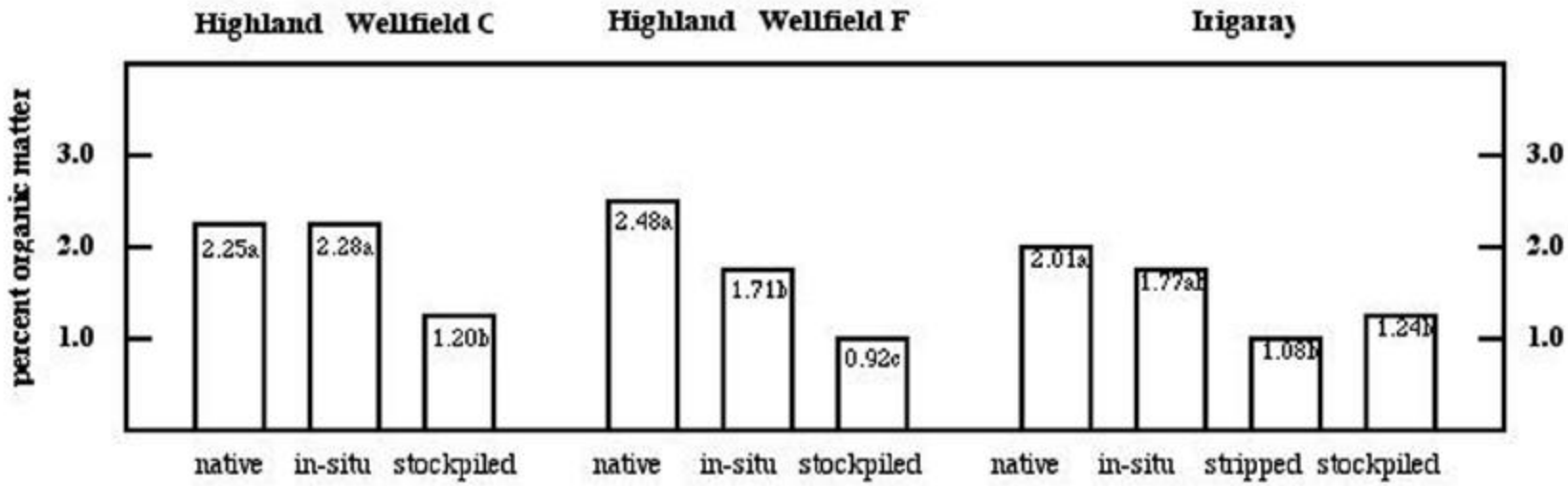

Figure 1. Soil organic matter contents

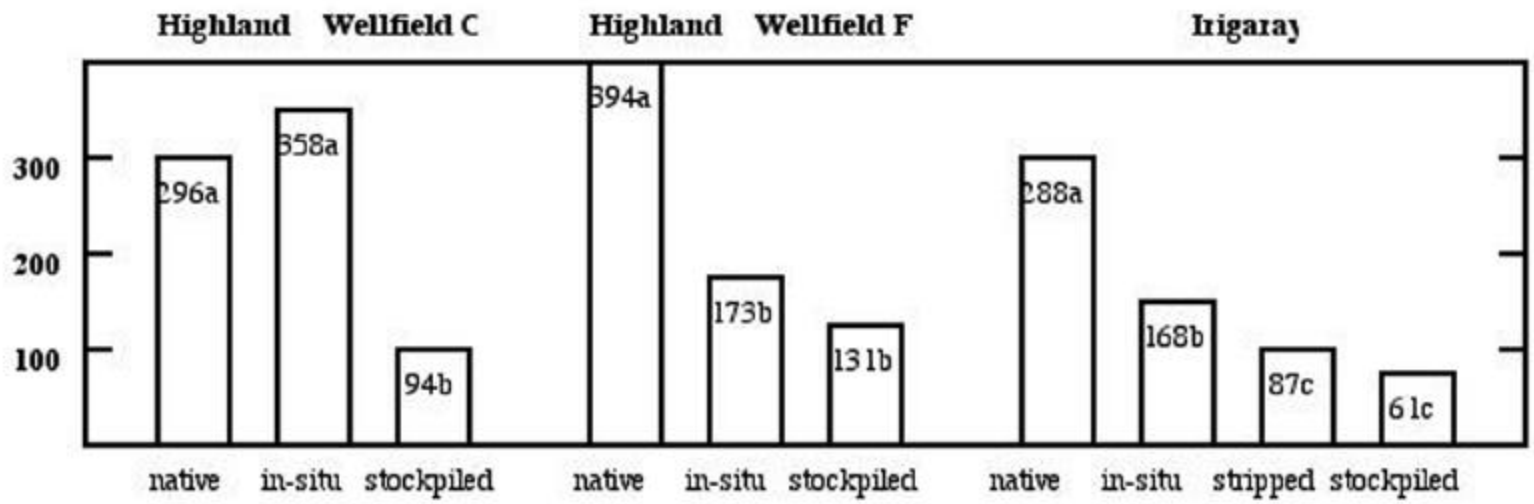

Figure 2. Arbuscular mycorrhizal spore numbers

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.

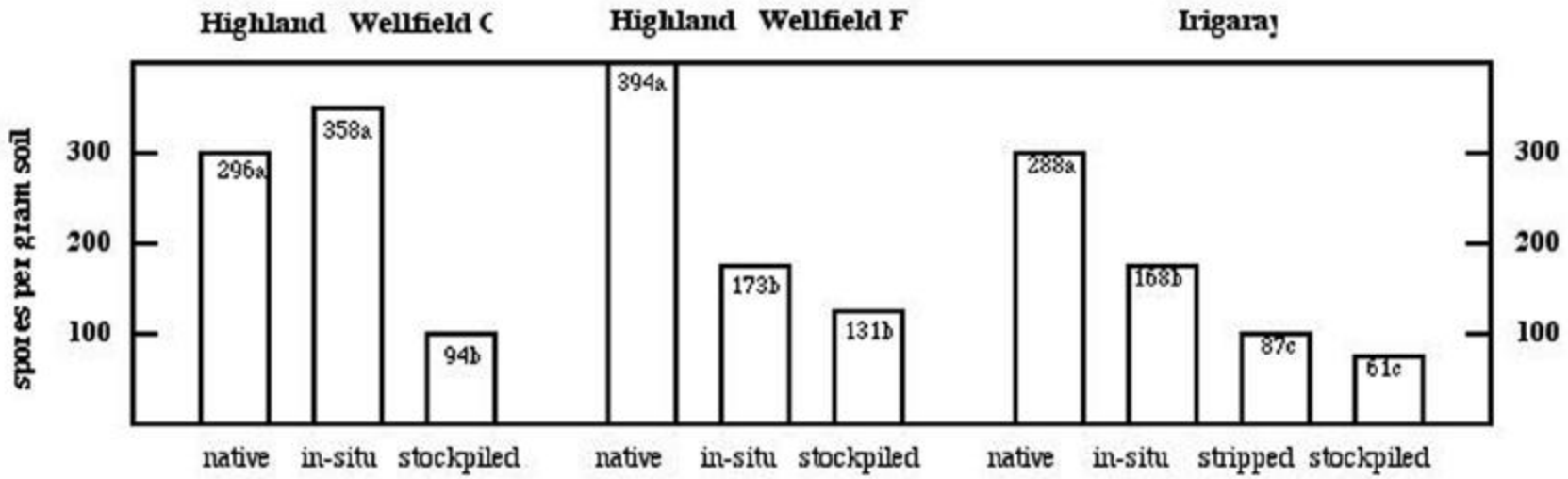

Figure 3. Arbuscular mycorrhizal spore numbers

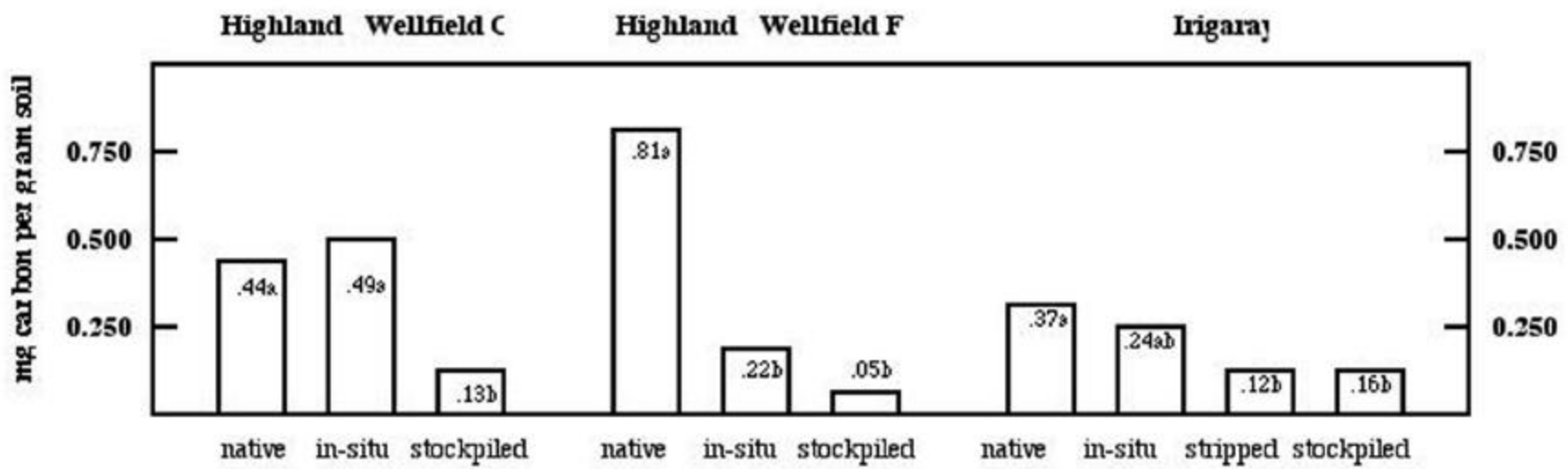

Figure 4. Soil microbial biomass carbon

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.

References

Ankeny, M. D., T. C. Kaspar, and R. Horton. 1990. Characterization of tillage and traffic effects on unconfined infiltration measurements. Soil Sci. Soc. Am. J. 54:837-840.

Bertrand, A.R. 1965. Rate of water intake in the field. Pages 197-209 in C.A. Black, D.D. Evans, J.L. White, L.E. Ensminger, and F.E. Clark, editors. Methods of Soil Analysis, Part 1: Physical and Mineralogical Properties. Soil Science Society of America, Madison, WI.

Blake, G.R. and Hartge, K.H. 1986. Bulk density. Pages 363-375 in A. Klute, editor. Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods. Soil Science Society of America, Madison, WI.

Brady, N.C. 1990. The Nature and Properties of Soils. MacMillan, New York.

Foster, R. C. 1988. Microenvironments and soil microorganisms. Biol. Fertil. Soils 6:189-203.

Heady, H.F. and Rader, L. 1958. Modifications of the point frame. J. Range Manage. 11:96-99.

Horwath, W.R. and Paul, E.A. 1994. Microbial Biomass. Pages 753-773 in Weaver, R.W., Angle, S., Bottomley, P., Bezdicek, D., Smith, S., Tabatabai, A., Wollum, A., editors. Methods of Soil Analysis, Part 2: Microbiological and Biochemical Properties. Soil Science Society of America, Madison, WI.

Huysman, F., W.M.I.S. Gunasekara, Y. Avnimelech, and W. Vestraete. 1989. Hydrogen consumption rate in a soil as an indicator of compaction and gas diffusion status. Biol. Fertil. Soils 8: 231-234.

Kaiser, E.-A., G. Walenzik, and O. Heinemeyer. 1991. The influence of soil compaction on the decomposition of plant residues and on microbial biomass. Pages 207-216 in W.S. Wilson, editor. Advances in Soil Organic Matter Research: The Impact on Agriculture and the Environment. Royal Soc. Chem., Cambridge, U.K.

Klute, A. 1986. Water retention: laboratory methods. Pages 635-662 in A. Klute, editor. Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods. Soil Science Society of America, Madison, WI.

Mueller-Dombois, D. and Ellenberg, H. 1974. Aims and methods of vegetation ecology. John Wiley & Sons, New York. 547 p.

Plaster, E. J. 1997. Soil Science and Management. Delmar Publishers, Albany, N.Y.

Pederson, T. A., A. S. Rogowski and R. Pennock. 1978. Comparison of morphological and chemical characteristics of some soils and minesoils. Recl. Rev. 1: 143-156.

Severson, R. C. and L. P. Gough. 1983. Rehabilitation materials from surface coal mines in the western U.S.A. I. Chemical characteristics of spoil and replaced cover soil. Recl. and Reveg. Res. 2: 83-102.

Visser, S., J. Fujikawa, C. L. Griffiths and D. Parkinson. 1984. Effect of topsoil storage on microbial activity, primary production and decomposition potential. Plant and Soil 82: 41-50.

2000 Billings Land Reclamation Symposium

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.

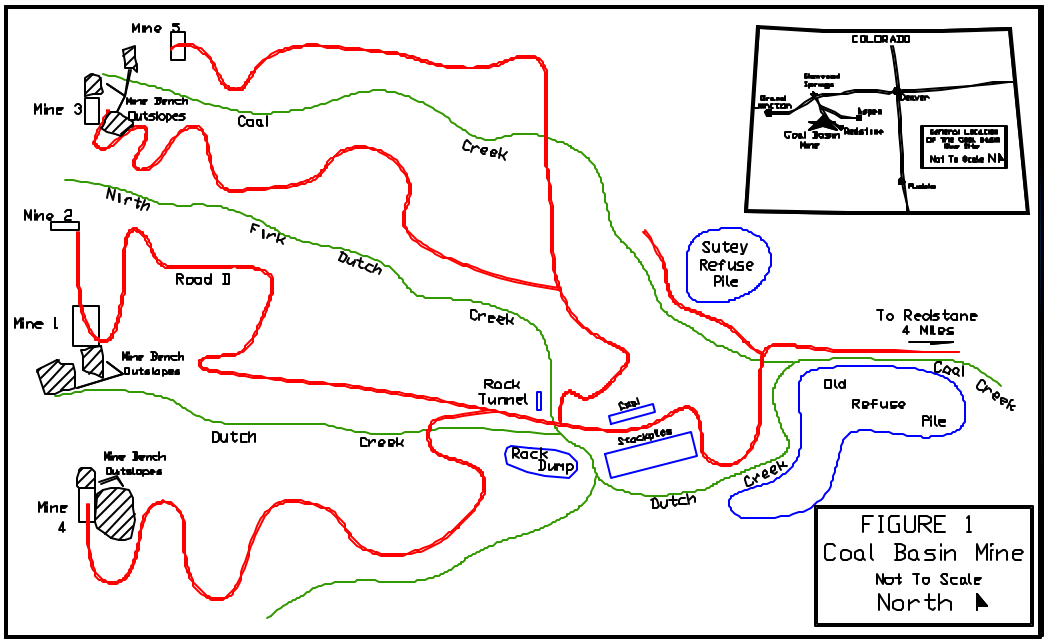
In the early 1980's, a mining permit was issued to the operator of the facility under the terms of the Colorado Surface Coal Mining and Reclamation Act. This permit outlined the operating parameters for the mine, and described the reclamation requirements for the site. Included in the permit was the 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.


Mine 5
Mine 3
Mine Bench Outslopes
Coal
Creek
North
Fork
Dutch
Mine 2
Road II
Mine 1
Mine Bench Outslopes
Creek
Rock Tunnel
Coal Stockpiles
Sutey Refuse Pile
To Redstone 4 Miles
Coal Creek
Old Refuse Pile
Dutch
Creek
Mine Bench Outslopes
Mine 4
Rock Dump
Dutch
Creek
COLORADO
Denver
Not To Scale NA
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)

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

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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.

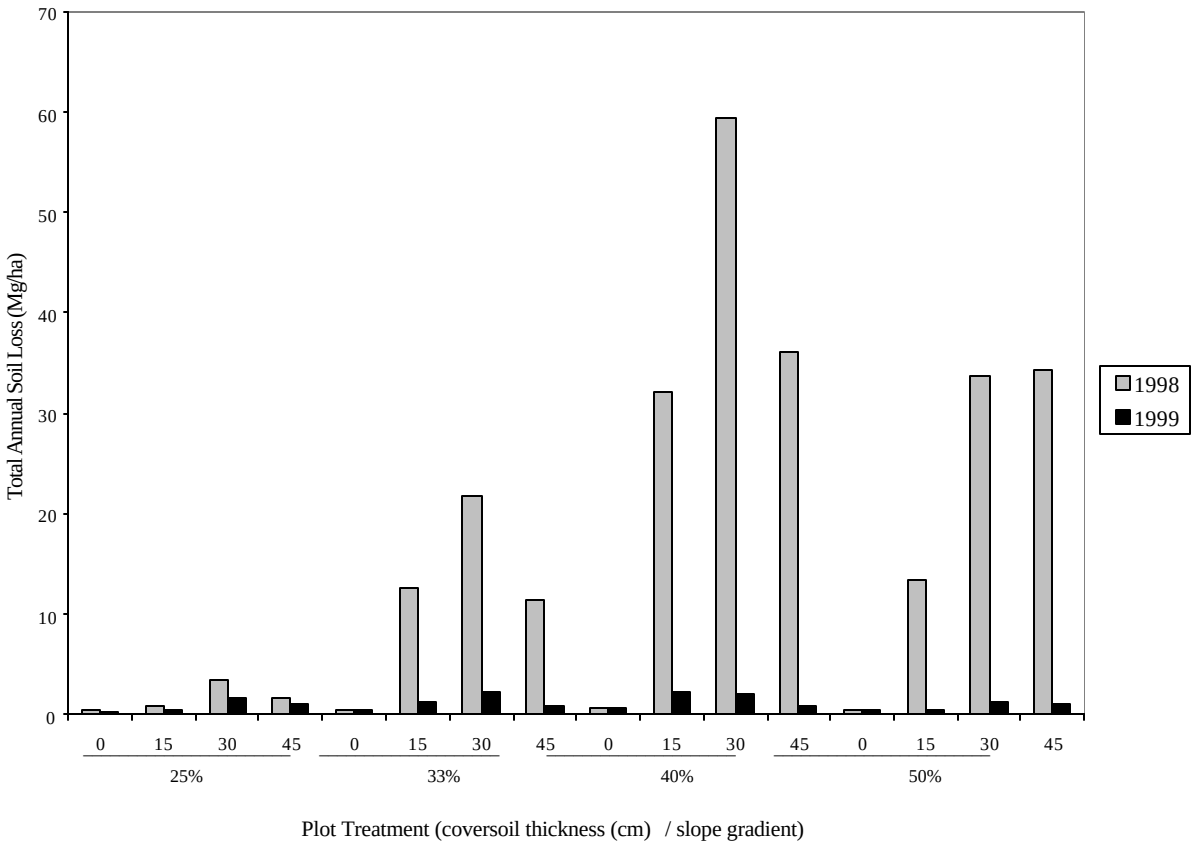

Table 1. Effect of slope gradient on total annual soil loss (Mg/ha).

	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.

REFERENCES

Ashby, W.C., W.G. Vogel, C.A. Kolar, and G.R. Philo. 1984. Productivity of stony soils on strip mines. In Soil Erosion: Prediction and Control. Soil Conservation Society of America, Ankeny, IA. pp. 31-43.

Barth, R.C. and B.K. Martin. 1982. Soil-depth requirements to reclaim surface-mined areas in the Northern Great Plains. Restoration Institute, Colorado School of Mines, Golden, CO. 11p.

Box, J.E. Jr., and L.D. Meyer. 1984. Adjustment of the universal soil loss equation for cropland soils containing coarse fragment. In Soil Erosion: Prediction and Control. Soil Conservation Society of America, Ankeny, IA. pp. 31-43.

Bradford, J.M. and G.R. Foster. 1996. Interrill soil erosion and slope steepness factors. Soil Science Society of America Journal. 60:909-915.

Brady, Nyle C. and R.R. Weil. 1996. The Nature and Properties of Soils. Eleventh Edition. Prentice Hall. Upper Saddle River, NJ.

Clark, Ronnie. 1980. Erosion condition classification system. Determination of soil erosion condition Montana revised method. US Department of the Interior, Bureau of Land Management Technical Note #346.

Fasching, Richard A. USDA NRCS State Agronomist. Bozeman, MT. Personal communication. July, 1999.

Galetovic, Joesph R., 1998. Guidelines for the use of the revised universal soil loss equation (RUSLE) version 1.06 on mined lands, construction sites, and reclaimed lands. Office of Surface Mining, Denver, CO.

Grosh J.L. and A.R. Jarrett. 1994. Interrill erosion and runoff on very steep slopes. Transactions of the ASAE. 37:1127-1133.

Hahn, D.T., W. Moldenhauer, and C.B. Roth. 1985. Slope gradient effect on erosion of reclaimed soil. Transactions of the ASAE. 28:805-808.

Hartley, D.M., G.E. Schuman. 1984. Soil erosion potential of reclaimed mined lands. Transactions of the ASAE. 27:1067-1073

Kirkby, M.J. and R.P.C. Morgan. 1980. Soil Erosion. John Wiley & Sons, New York, NY.

Larson, W.E., M.J. Lindstrom, and T.E. Schumacher. 1997. The role of severe storms in soil erosion: A problem needing consideration. Journal of Soil and Water Conservation. 5:90-95.

Liu, B.Y., M.A. Nearing, and L.M Risse. 1994. Slope gradient effects on soil loss for steep slopes. Transactions of the ASAE. 37:1835-1839.

Mathier, L.A. G. Roy, and J.P. Pare. 1989. The effect of slope gradient and length on the variables of a sediment transport equation for sheetwash. Catena. 16:545-558.

McCool, D.K. and K.G. Renard. 1990. Water erosion and quality. Advances in Soil Sciences. 13:175-185.

McCool, D.K., L.C. Brown, G.R. Foster, C.K. Mutchler and L.D. Meyer. 1987. Revised slope steepness factor for the Universal Soil Loss Equation. Transactions of the ASAE. 30:1387-1396.

McGinnies, W.J. and P.J. Nicholas. 1980. Effects of topsoil thickness and nitrogen fertilizer on the revegetation of coal mine spoils. J. Environmental Quality. 4: 681-685.

McIssac, G.F., J.K. Mitchell and M.C. Hirschi. 1987. Slope steepness effects on soil loss from disturbed lands. Transactions of the ASAE. 30:1005-1013.

Munshower, Frank F. 1994. Practical Handbook of Disturbed Land Revegetation. Lewis Publishers, Boca Raton, FL. 265p.

Power, J.F., F.M. Sanduval, R.E. Ries, and S.D. Merrill. 1981. Effects of topsoil and subsoil thickness on soil water content and crop production on a disturbed soil. Soil Science Society of America Journal. 45:124-129.

Redente, E.F., and H.E. Hargis. 1985. An evaluation of soil thickness and manipulation of soil and spoil for reclaiming mined land in northwestern Colorado. Reclamation and Revegetation Research. 4: 1729-1732.

Redente, E.F., T. McLendon, W. Agnew. 1997. Influence of topsoil depth on plant community dynamics of a seeded site in Northwest Colorado. Arid Soil Research Land Rehabilitation. 11:139-149.

Renard, K.G., G.R. Foster, G.A. Weesies, D.K. McCool, D.C. Yoder. January 1997. Predicting soil erosion by water: a guide to conservation planning with the revised universal soil loss equation (RUSLE). USDA ARS Agricultural Handbook 703.

Schroeder, S.A. 1987. Slope gradient effect on erosion of reshaped spoil. Soil Science Society of America Journal. 51:405-409.

Sidle, Roy C., R.W. Brown, and B.D. Williams. 1993. Erosion processes on arid minespoil slopes. Soil Science Society of America Journal. 57:1341-1347.

Simanton, J.R., E. Rawitz, and E.D. Shirley. 1984. Effects of rock fragments on erosion of semiarid rangeland soils. In Soil Erosion: Prediction and Control. Soil Conservation Society of America, Ankeny, IA. pp. 65-72.

Singer, Micheal J., and J. Blackard. 1982. Slope angle – Interrill soil loss relationships for slopes up to 50%. Soil Science Society of America Journal. 46:1270 – 1273.

Toy, Terrence J. 1989. Geomorphic responses of natural and reclaimed hillslopes to precipitation events in Wyoming. In: Proceedings of the American Society for Surface Mining and Reclamation 6th Annual National Meeting. Calgary, Alberta. 219-228.

Wraith, Jon M. and Dani Or. 1998. Nonlinear variable estimation using spreadsheet software. Journal of Natural Resources, Life Science and Education. 27. pp. 13-19

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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

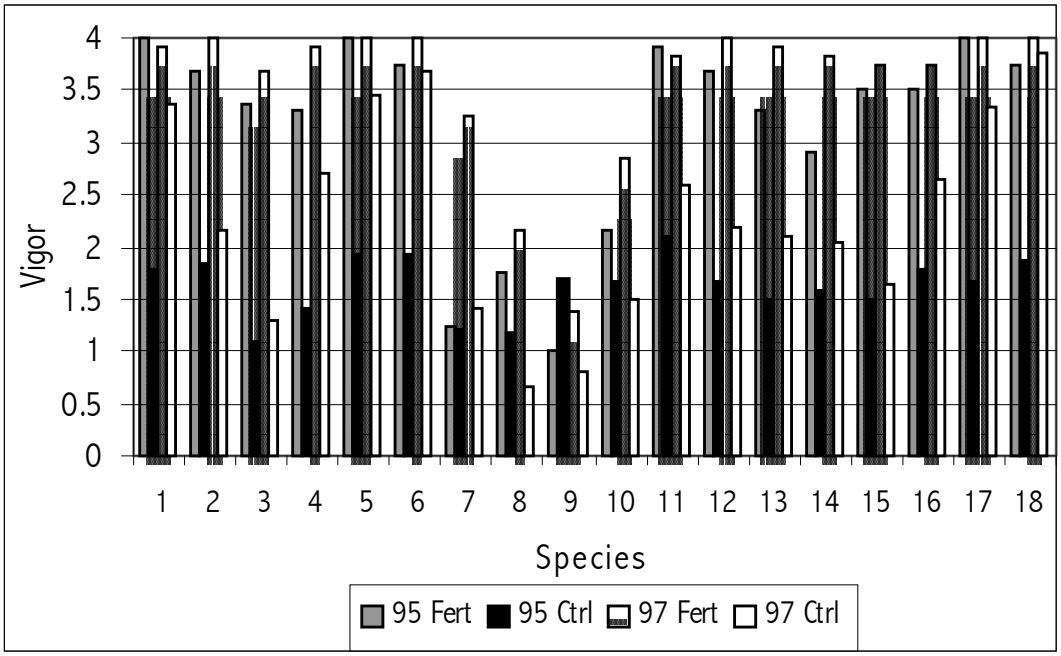

Figure 1. Effect of fertilizer at planting on vigor of grass transplants, with planting occurring in 1994. See Table 2 for species codes.

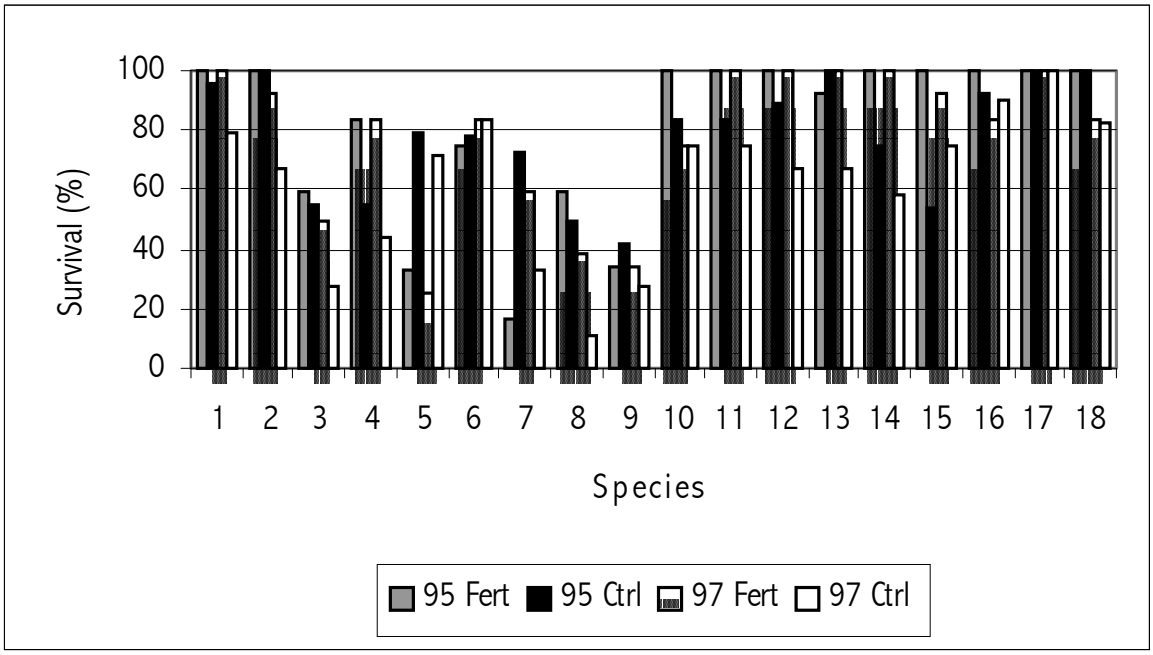

Figure 2. Effect of fertilizer at planting on survival of grass transplants, planting occurred in 1994. See Table 2 for species codes.

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).

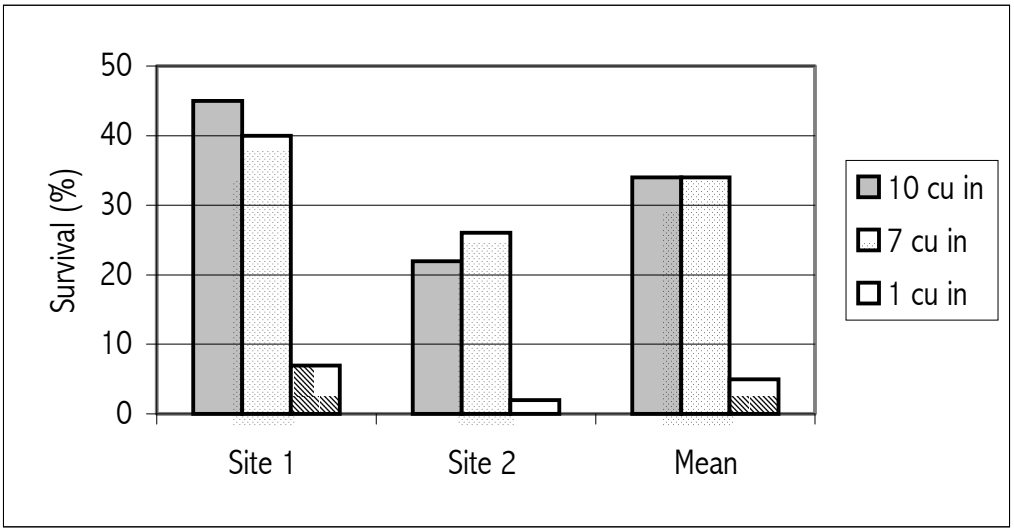

Figure 3. Effect of container size on transplanted ponderosa pine seedling survival.

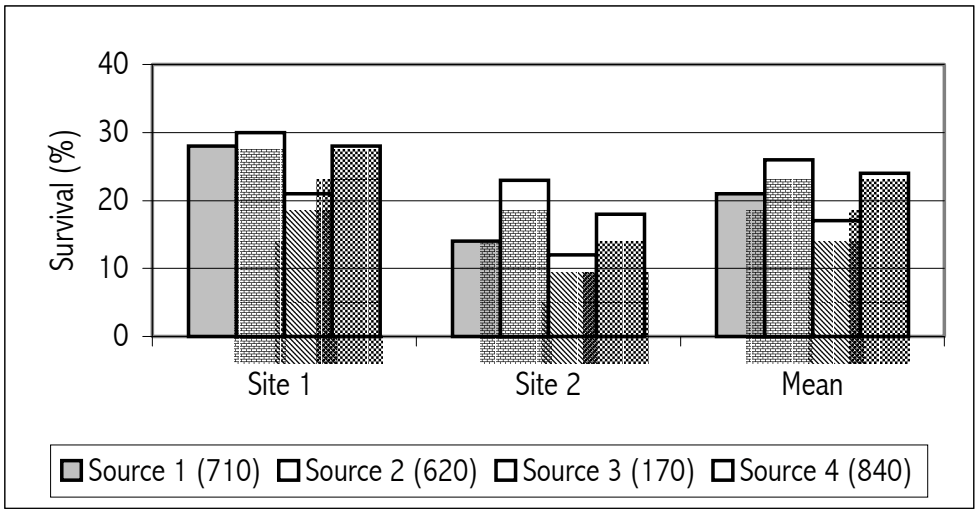

Figure 4. Effect of seed source on transplanted ponderosa pine seedling survival.

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^oF) 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.

REFERENCES

Meyer, J. and R. Leonardson. 1990. Tectonic, Hydrothermal and Geomorphic Controls on Alteration Scar Formation near Questa, New Mexico. New Mexico Geological Society Guidebook, 41st Field Conference, Southern Sangre de Cristo Mountains, New Mexico, 1990.

Robertson GeoConsultants, Inc. 1999. Interim Report: Questa Waste Rock Pile Drilling, Instrumentation and Characterization Study. Interim Report 052007/1. Prepared for Molycorp, Inc. September 6, 1999.

Wagner, A. M. and J. T. Harrington. 1994. Revegetation Report for Molycorp, Inc. Report prepared for Molycorp, Inc. – New Mexico Mine Permit TA001RE.

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.

REFERENCES

Antonovics, J., 1968. Evolution in closely adjacent plant populations. V. Evolution of Self-Fertility. Heredity, London. 23:219-238.

Chambers, J. C., R. W. Brown, and R. S. Johnston. 1984. Examination of plant successional stages in disturbed alpine ecosystems: A method of selecting revegetation species. *In* Colbert, T. A. and R. L. Cuany (eds) Proceedings: High

Altitude Revegetation Workshop, No. 6, Water Resources Research Institute, Colorado State University, Information Series, No. 53, pp. 215-224.

Chambers, J. C., J. A. McMahon, and G. L. Wade. 1990. Difference in successional processes among biomes: Importance in obtaining and evaluating reclamation success. *In* J. C. Chambers and G.L. Wade (eds) Evaluating Reclamation Success: The Ecological Consideration--Proceedings of a Symposium. Charleston, West Virginia. April 23-26, 1990. USDA-Forest Service General Technical Report NE-164.

Hamrick, J. L., 1983. The distribution of genetic variation within and among natural plant populations. pp. 335-348, *In* C. M. Schonewald-Cox, S. M. Chambers, G. MacBryde, and L. Thomas (eds), Genetics and Conservation--A reference for managing wild animals and plant populations. Benjamin Cummings Publishing Co., Inc., Menlo Park, CA.

Harper, J. L. 1977. Population Biology of Plants. Academic Press, New York

Jain, S. K., and A. D. Bradshaw. 1966. Evolutionary divergence among adjacent plant populations. I. The Evidence and Its Theoretical Analysis. Heredity 21: 407-441.

Jensen, M.E., W. Hann, and R.E. Keane. 1992. Ecosytem Inventory and Analysis Guide. USDA Forest Service, Northern Region, Missoula, MT.

Johnson, P. L., and W. D. Billings. 1962. The alpine vegetation of the Beartooth Plateau in relation to cryopedogenic processes and patterns. Ecological Monographs 32: 105-135.

Johnson, R. A., and D. W. Wischern. 1982. Applied Multivariate Statistical Analysis. Englewood Cliffs, MJ:Prentice Hall, Inc.

Gottlieb, L. 1977. Electrophoretic evidence and applied systematics. Annals of the Missouri Botanical Garden 64: 161-180.

Mitchell-Olds, T. 1993. Genetic diversity of plant species in Glacier National Park: Implications in Management. Annual Report--National Park Service Contract No. CA-1463-5-0001.

Merrell, D. 1981. Ecological Genetics. University of Minnesota, Minneapolis.

2000 Billings Land Reclamation Symposium

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.

REFERENCES

Bradshaw, A.D.; McNeilly, T.S.; Gregory, R.P.G. 1965. Industrialization, evolution and the development of heavy metal tolerance in plants. British Ecological Society Symposium 6: 327-343.

Brown, R.W.; Amacher, M.C. 1997. Selecting plant species for ecological restoration: a perspective for land managers. Revegetation with native species, pp.1-16 In: Proceedings, 1997 Society for Ecological Restoration Annual Meeting. U.S.D.A. Forest Service Rocky Mountain Research Station. Proceedings RMRS-P-8.

CDM Federal. 1997. Final baseline ecological risk assessment. Anaconda regional water, waste, and soil operable unit; Anaconda Smelter NPL Site, Anaconda, Montana, Vol. 1. Prepared for EPA, Region VIII, Montana Office. (October).

Chambers, J.C.; Brown, R.W.; Johnston, R.S. 1984. Examination of plant successional stages in disturbed alpine ecosystems: a method of selecting revegetation species. In: Proceedings: High Altitude Revegetation Workshop. No. 6 Information Series: 215-224.

Hasegawa, I.; Terada, E.; Sunairi, M.; Walota, H.; Shinmachi, F.; Noguchi, A.; Nakajima, M.; Yazaki, J. 1997. Genetic improvement of heavy metal tolerance in plants by transfer of the yeast metallothionein gene (CUP1). In: Plant and Soil 196: 277-281.

Jain, S.K.; Bradshaw, A.D. 1966. Evolutionary divergence among adjacent plant populations. Heredity, 21: 407-441.

Johnson, H.E.; Schmidt, C.L. 1988. Clark Fork Basin Project: status report and action plan. Prepared for the Office of the Governor, Helena, MT.

Kershaw, L; MacKinnon, A; Pojar, J. 1998. Plants of the Rocky Mountains. Lone Pine Publishing. 384 p.

Manual de la Fuente, J.; Ramires-Redriguez, V.; Cabrera-Ponce, J.L.; Herrera-Estrella, L. 1997. Aluminum tolerance in transgenic plants by alteration of citrate synthesis. Science Magazine Vol. 276 June 6, 1997:1566-1568.

Montana Department of State Lands, Abandoned Mine Reclamation Bureau. 1994. 1994 Summary report. (December).

Montana Department of State Lands, Abandoned Mine Reclamation Bureau. 1995. 1995 Summary report.

Moore, J.N.; Luoma, S. N. 1990. Hazardous waste from large-scale metal extraction: The Clark Fork Waste Complex, Montana. Prepared by the University of Montana, Missoula, MT, and the U.S. Geological Survey. 34 p.

Morrey, D. 1996. Vegetation on Barren Mining Land. Land and Water: 41-44.

Munshower, F.F. 1994. Practical handbook of disturbed land revegetation. CRC Press, Inc. 265 p.

Neuman, D.R.; Munshower, F. F.; and Dollhopf, D. J. 1993. Revegetation of mining wastes in Montana. Montana AgReseach Vol.1, Issue 1: 3-7.

Reclamation Research Unit (RRU). 1993. Arts Phase I Report. Anaconda Revegetation Treatability Studies Phase I: Literature Review, Reclamation Assessments, And Demonstration Site Selection. 28 P. Document No.: Asss-Arts-I-Fr-R1-102293.

Roundy, B.A.; Shaw, N.L.; Booth, D.T. 1997. Lessons from historical rangeland revegetation for today's restoration:1-8. In Proceedings: Using Seeds of Native Species on Rangelands. Society of Range Management 50th Annual Meeting. U.S.D.A. Forest Service Intermountain Research Station. General Tech. Report INT-GTR-372.

Smith R. A. H.; Bradshaw, A. D. 1972. Stabilization of toxic mine wastes by the use of tolerant plant populations. Trans. Inst. Min. Metall. 81 (A): 230-237.

Surbrugg, J.E. 1982. Copper and zinc tolerance in two Montana grass species growing on copper mill tailings. Montana State University master's thesis.

Vatamaniuk, O.K.; Mari, S.; Lu, Y.; Rea, P. 1999. AtPCS1, phytochelatin synthase from *Arabidopsis*: isolation and *in vitro* reconstitution. In: Proceedings of the National Academy of Science, Vol. 96, June, 1999: 7110-7115.

Hydrologic Issues Associated with Coal-Bed Methane Development in Montana

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Coal-bed methane exists in coal seams in portions of southeastern Montana and is now beginning to be developed. The gas, held by water pressure on the cleat and in micro pores in the coal, is produced by dewatering the coal seams. Water production should last many years, as experienced in Wyoming. Several hundred gas wells over an area of several townships are currently planned in Montana. Production from 11 exploration and test wells from December, 1998 through March, 1999 averaged 17 gallons per minute causing water-level declines approaching 10 feet in coal-mine monitoring wells. Under conditions of commercial production, the potential exists for creating water-level drawdown far exceeding that created by mining. Recovery will presumably require years, similar to that required for large mined areas.

Produced water will be held temporarily in ponds, discharged to surface water channels, and lost to evaporation. Coal-aquifer water in the Decker area is high in sodium, and discharge water will have very high sodium adsorption ratio (SAR) values potentially causing some soils impacts. Some increase in salt load in the Tongue River will also occur, however dilution may mask this increase. Increased erosion and scouring in otherwise ephemeral stream channels is possible.

Target areas for gas production are generally adjacent to active coal mines, which are currently causing water-level declines in coal-bed aquifers. The mining companies are responsible for re-establishing hydrologic balance within their area of influence in order to receive permit closure and bond release. Distinguishing the impacts of mining and coal-bed methane development will be a major challenge and will effect mine bond release, future resource development, and land owners. Land owners are concerned that a lack of monitoring related to coal-bed methane may lead to long term loss of water in wells and springs that supply agricultural needs.

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2000 Billings Land Reclamation Symposium

GEO-CHEMICAL TRANSFORMATIONS AND HYDROLOGIC RECOVERY OBSERVED IN A COAL-STRIP-MINE-SPOILS AQUIFER

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ABSTRACT

Ground-water recovery trends and geo-chemical transformations observed over the past 25 years in the Rosebud Coal spoils aquifer at the Rosebud Mine southeast of Colstrip, Montana may provide valuable insight into developing proactive hydrologic reclamation strategies. Ground-water recovery in the spoils aquifer appears to be controlled by several predominant factors including regional ground-water recharge, former pit floor surface elevations, and the timing and progression of pit backfilling, while spoil aquifer water quality appears largely controlled by the rate and trend of ground-water recovery. Spatial analysis of spoils aquifer water quality data indicates that major element concentrations generally increase with residence time, and hence with distance away from recharge sources. These data suggest that the detailed evaluation of operational and/or pre-mine ground-water monitoring data, projected pit floor elevations, recharge zones, and sensitive downgradient aquifers can yield reasonable predictions regarding ground-water quantity and/or quality problems which may then be amenable to mitigation early in the reclamation process.

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INTRODUCTION

Between 1924 and 1958, Northern Pacific Railroad mined coal for steam locomotive use, disturbing approximately 1,800 acres of land southeast of Colstrip around what is now Western Energy Company (WECo) Pit 6 and Area E (Figure 1). WECo resumed mining coal in Pit 6 and Area E from 1968 to 1986 for energy production. To date more than 2,500 acres of Rosebud Coal aquifer has been replaced with overburden spoils along the one to one-and-one-half mile wide southeast trending band of predominantly reclaimed strip mine area located southeast of Colstrip, northeast of Highway 39, and north of Cow Creek Road (project area). The northeastern portion of the project area is bounded by coal and clinker outcrop. This report evaluates water-level recovery and water quality trends observed in the spoils aquifer over the past 25 years in the project area, identifies potential adverse impacts to ground-water quantity and quality, and proposes alternative reclamation strategies that could be applied in other strip-mine areas to minimize related impacts to the hydrologic balance.

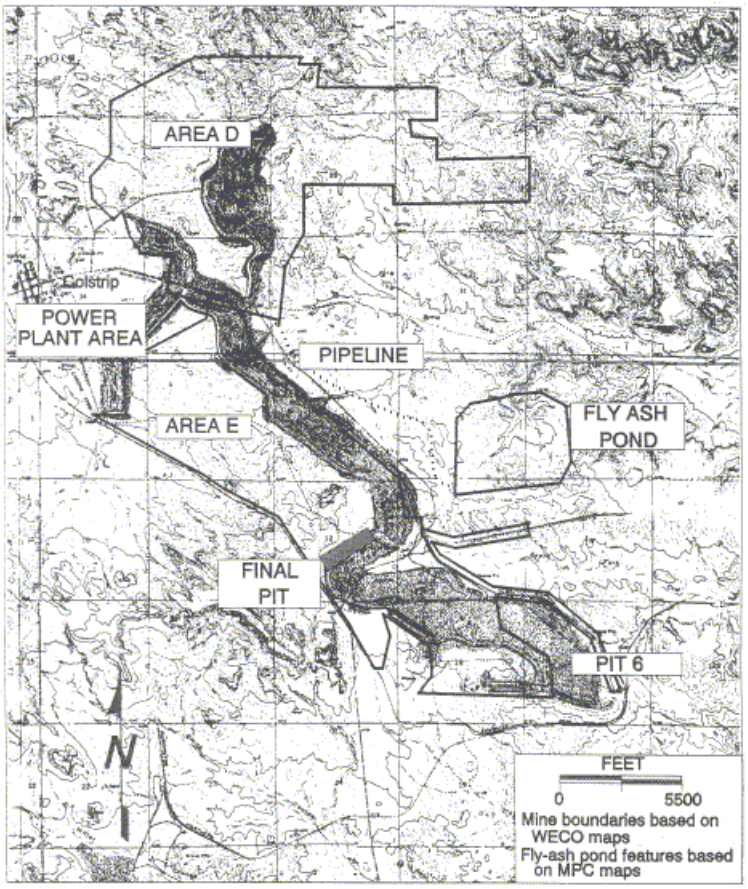

Figure 1. Mine, power plant, and fly-ash pond features near Colstrip, Montana (after MBMG 1994).

HYDROGEOLOGIC SETTING

Quaternary deposits outside the project area consist of weathered bedrock, colluvium and unconsolidated clay, silt and sand alluvium. The Tongue River Member of the Fort Union Formation is the only rock outcropping in the Rosebud Mine area. That member is predominantly a fine- to medium-grained silty sandstone with interbedded siltstone, silty

shale, and carbonaceous shale, localized clinker zones, and coal beds (DSL/OSM 1983). The total thickness of the Fort Union Formation at Colstrip is less than 500 feet, with the Tongue River Member comprising approximately 350 feet. In this area, the three coal seams identified in the Tongue River Member, in descending stratigraphic order, are the Rosebud, McKay, and Stocker. The coal seams dip generally one to two degrees southerly, with many local variations in the project area as a result of small-scale folding, faulting, and localized thinning and thickening of coal seams and related interburden.

The 25-foot-thick Rosebud Coal seam was the only seam mined in the project area. Overburden, comprising interbedded sandstone, siltstone and shale resided over the Rosebud Coal in the project area prior to mining. Overburden thickness ranged from zero to approximately 150 feet prior to mining. Regraded Rosebud spoils thickness ranges from less than 25 feet near the cropline to over 100 feet. The interburden unit situated between the Rosebud and McKay Coal seams ranges in thickness from 5 to 25 feet over the project area.

Based on conditions observed in undisturbed aquifers up-gradient of the project area, the overburden aquifer was predominantly unconfined prior to mining, while the Rosebud Coal aquifer was more or less confined. The Rosebud/McKay Coal interburden which lies beneath the Rosebud Coal spoils throughout the project area is considered to be an aquitard based on the relative mean transmissivities of 2,000 gallons/day/ft (gpd/ft) and 43 gpd/ft measured for the Rosebud spoils aquifer and the interburden, respectively (DSL/OSM 1983). The Rosebud spoils aquifer is unconfined.

HYDROLOGIC EVALUATION

Spoil Aquifer Recovery

Ground-water recovery in the Rosebud spoils aquifer within the project area appears to be controlled by several factors including regional ground-water recharge, former pit floor elevations, and the timing and progression of pit backfill. Potentiometric surface elevations inferred from Rosebud Coal and coal spoils wells located within and adjacent to the project area indicate that the regional ground-water system likely recharges the project area from the west, while recharge from East Fork Armells Creek (EFAC) alluvium and Montana Power Company (MPC) facility ponds near the town of Colstrip source the project area from the north. Precipitation in the area, which is around 15 inches/year, supplies a small component of direct recharge to the project area. Upon entering the spoils, ground-water flow appears to be controlled by pit floor surface elevations. The pit floor (base of Rosebud Coal) iso-elevation surface tends to decrease in elevation to the northwest and southeast of a divide created by what appears to be a northeast plunging anticlinal feature located along the northwest Pit 6 boundary. The spoils aquifer potentiometric surface decreases in elevation to the north and east of that divide. Near the northern boundary of the project area, the spoil aquifer potentiometric surface decreases in elevation to the south into a shallow trough created by an apparent southwest plunging synclinal feature which trends through the center of Area E.

The amount of ground-water recovery recorded in project-area spoils wells ranges from zero to more than 30 feet. As would be expected, low spoils saturation is observed proximal to the bedrock divide situated along the northwest Pit 6 boundary, while increasing

spoils saturation is observed northwest and southeast of that divide. Areas of low saturation also correspond to the former final pit location at the south end of Area E.

Spoil Aquifer Water Quality

WECo and the Montana Bureau of Mines and Geology (MBMG) collectively monitor several wells completed within the Rosebud spoils aquifer. Total dissolved solids (TDS) levels from the most recent analytical data available for spoils wells within the project area range from 1,200 to 5,500 milligrams per liter (mg/l). Iso-concentration contours inferred from these data indicate that TDS appears to generally increase from southwest to northeast across the project area. This distribution likely relates to the reaction of regional recharge from the Rosebud Coal aquifer (entering from the west) with spoils material in the project area.

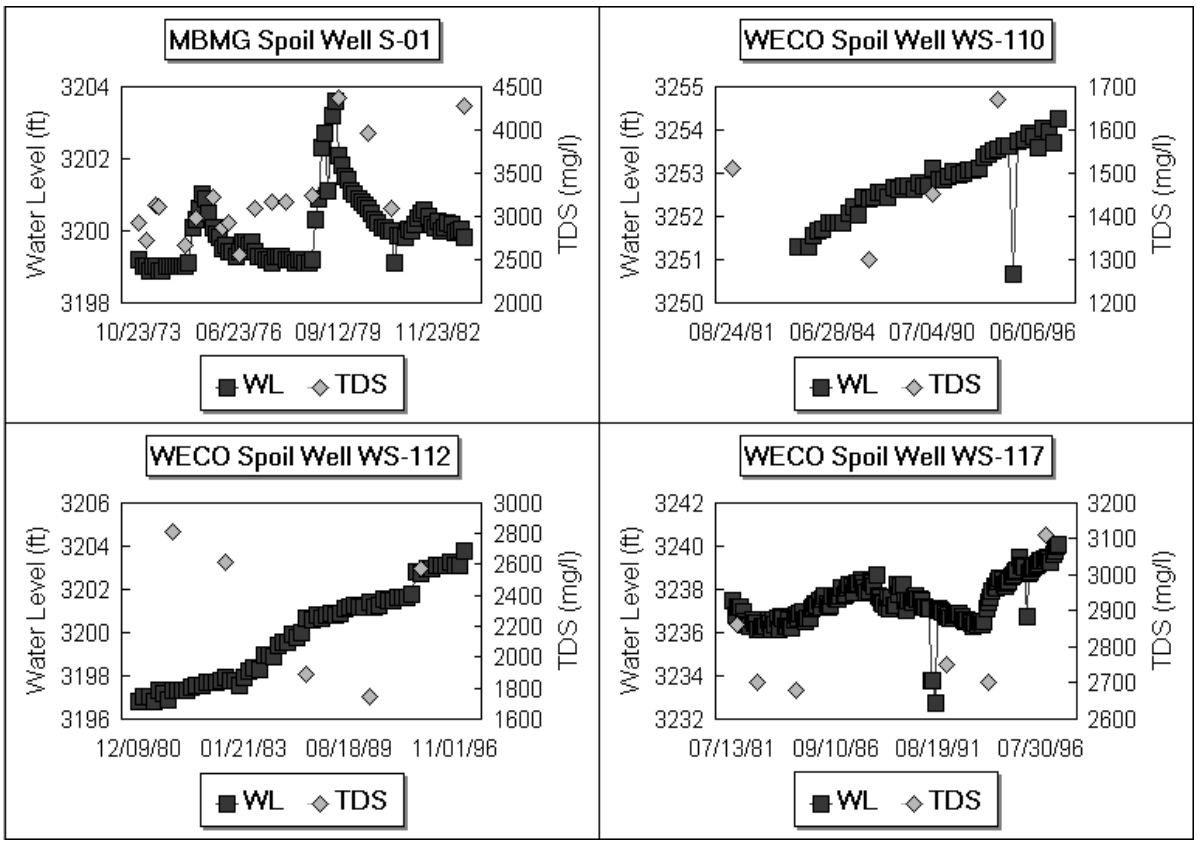

Figure 2. Temporal relationship between selected spoils well water-levels and TDS.

Poor spoils water quality (TDS >3,000 mg/l) appears to correspond with areas of low (<10 feet) saturation, suggesting that spoils water quality may increase with saturation. Poor spoils water quality is also observed proximal to power plant facility ponds near the town of Colstrip to the north and possibly the fly ash ponds located east of the project area. Temporal relationships between spoils well water quality and water levels (see Figure 2) indicate that sharp increases in water level correlate with sharp rises in TDS, gradual increases in water level correlate with stable or decreasing TDS, and decreasing water levels correspond with decreasing TDS.

HYDROLOGIC MITIGATION

Some of the trends observed in the hydrologic and geo-chemical data collected from the project area over the past 25 years could be used to support predictions regarding post-mine spoils water quantity and quality at other active or proposed coal-strip-mine areas. The detailed evaluation of operational and/or pre-mine ground-water monitoring data, anticipated pit floor elevations, recharge zones, and sensitive downgradient aquifers could yield valuable information regarding where water will be in deficit in the future, and likewise where future water quality problems could be anticipated. Based on these predictions, proactive measures could be employed early on in the mining process to minimize impacts to the hydrologic balance. For example, spoil aquifer zones residing over high spots in the proposed pit floor and/or away from viable recharge sources, where slow recovery would be anticipated, could be recharged artificially with pit water surpluses, where available. Spreading basins could be strategically placed in the spoils over these anticipated slow recovery zones prior to final regrading and supplied with water that would otherwise be released outside the permit area. Such artificial recharge would not only conserve water and enhance hydrologic recovery within the permit area, but it could help flush reactive spoils material ahead of schedule.

To mitigate potential water quality impacts outside the permit area, an appropriate width of undisturbed coal seam could be left down-slope of mining where proposed pit floor contours and distance from recharge sources indicate that poor quality spoils water could accumulate and discharge to critical alluvial or clinker aquifers. Field data collected by the USGS at the West Decker Mine indicate that water quality may improve as ground water flows from a spoil aquifer to a coal aquifer (Clark 1995). Leaving an undisturbed "buffer zone" of relatively low permeability coal (relative to spoil) could also help regulate the rate at which lower quality spoils aquifer discharges are released to critical alluvial or clinker aquifers.

REFERENCES CITED

Clark, David W. 1995. Geochemical Processes in Ground Water Resulting from Surface Mining of Coal at the Big Sky and West Decker Mine Areas, Southeastern Montana. U.S. Geological Survey Water-Resources Investigations Report 95-4097, 80 p.

DSL/OSM. 1983. Final Comprehensive Environmental Impact Study, Western Energy Company's Rosebud Mine. Montana Department of State Lands and the U.S. Office of Surface Mining Report OSM 83-10, 306 p.

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Cumulative Hydrologic Response of Ground Water to Strip Mining at the Decker and Spring Creek Mines, 1972 – 1998, Decker, Montana

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ABSTRACT

Large scale coal mining in the Decker area became active in the 1970's with the opening of the East Decker, West Decker and Spring Creek mines. The three mines occupy approximately 22 square miles of adjacent permit area. At the end of 1998, the mines had removed a cumulative total of 377 million tons of coal from five coal seams. As the shallow coal seams are the primary aquifers in the Decker area, mining has resulted in declines in ground water levels in the aquifers removed by mining as well as a deeper aquifer that is not mined.

The mines have installed and currently monitor a network of approximately 200 monitoring wells within and outside the permit areas. Additional wells installed by the Montana Bureau of Mines and Geology extend the monitoring coverage to approximately 230 wells. More than 20 years of monitoring data have charted ground water changes associated with mining in the Decker area. Drawdown is detectable approximately five miles west of the West Decker Mine and 3 miles east of the East Decker Mine. Maximum measured drawdown is 135 feet in a coal seam mined at East Decker. At the end of the 1998 water year, water level hydrographs suggested that drawdown near pit areas as well as locations distant from the pit had reached or were approaching steady state. At locations where drawdown is still increasing, rates generally appear to be slowing in most aquifers. Estimates of future drawdown attributable to mining over the next twenty years were made based on drawdown rates at the end of the 1998 water year.

At the end of the 1998 water year, all drawdown in the area was associated with mining activity. In late 1998, production of coal bed methane and associated dewatering of the coal aquifers began to strongly influence the rate and location of drawdown. As the mines have a permit obligation to restore ground water to pre-mining levels, distinguishing between mine and coal bed methane impacts to ground water will be an important aspect of future monitoring and will indicate whether or not sufficient water will be available to meet ground water reclamation obligations.

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INTRODUCTION

Three large coal-strip mines are currently in production in the Decker area of southeast Montana (Figure 1). West Decker Mine opened in 1972, followed by East Decker Mine in 1977 and Spring Creek Mine in 1979. A cumulative total of more than 377 million tons of coal had been removed from these three mines by the end of 1998. All three mines are projected to have approximately twenty years of production remaining.

As coal seams are the principle aquifers in the area, water level declines in the shallow coal aquifers have been recorded in the vicinity of the mines. At the close of the 1998 water year, all ground-water drawdown could be attributed to mining, with cones of depression clearly centered over pit areas. In late 1998 and early 1999 two events were initiated that will change drawdown and recharge rates in the Decker area and may influence the mines' ability to meet reclamation obligations to restore ground water to pre-mine levels. Coal bed methane production began in December 1998 and immediately began to strongly affect drawdown rates south of the West Decker Mine. Raising of the Tongue River Reservoir stage by more than four feet in the spring of 1999 created additional recharge to open and reclaimed mine pit areas adjacent to the reservoir. This paper documents drawdown levels and rates attributable to more than twenty years of mining prior to changes in ground-water levels that will result from more recent, non-mining influences.

HYDROGEOLOGY OF THE DECKER AREA

Coal seams in the Decker area are part of the Tongue River Member of the Eocene age Fort Union Formation. Mining impacts six coal seam aquifers. At East Decker Mine (East Decker), the coal seams locally designated as the D1 Upper (D1U), D1 Lower (D1L), and D2 are being mined. The D1U and D1L seams converge west of East Decker to form a single seam known as the D1 at West Decker Mine (West Decker). The D1 and D2 seams are mined at West Decker, although both are not mined in every West Decker pit. The D1 and D2 seams converge north and west of West Decker to form a single 80-foot thick seam mined at the Spring Creek Mine (Spring Creek). This seam is known as the Anderson-Dietz . A seam known as the D3 at the Decker mines and the Canyon seam at Spring Creek is approximately 100 feet below the deepest coal seam mined but is also experiencing drawdown.

With the exception of the Anderson-Dietz seam, the coal seams range in thickness between 15 and 50 feet and are separated by as little as a few feet up to 100 feet of clayey siltstones and silty sandstones. Although coal depth and thickness and overburden thickness are highly variable, the top of the D1 seam averages about 150 feet below ground surface and the top of the D2 seam averages approximately 230 feet below ground surface. The top of the D3 seam ranges from 300 to 500 feet deep. At Spring Creek, the top of the Anderson-Dietz seam typically lies between 100 feet and 150 feet deep.

Except for the pits and areas immediately adjacent to the pits, aquifers that were confined prior to mining remain confined. In some areas of East Decker and West Decker, prehistoric burning in parts of the D1U and D1 baked, fused and fractured adjoining siltstones and sandstones, producing a reddish rock known as

clinker. These clinker zones are typically thinly saturated and unconfined. Baseline studies (Spring Creek Coal Company, 1980) indicate that the Anderson-Dietz aquifer was not confined within the Spring Creek permit boundary, but was confined west and south of the permit area. Large bodies of clinker that formed during burning of the Anderson-Dietz seam lie to the east and north of the mine and are generally dry.

The strata that contain the coal beds form a shallow syncline that plunges gently to the south, with the syncline axis roughly coincident with the Tongue River Reservoir. The coal aquifers are recharged in the highlands east and west of the Decker area and discharge to the Tongue River. Numerous northeast-trending normal faults locally act as low-flow or no-flow boundaries and appear to strongly influence the location and amount of drawdown. A fault less than a mile south and east of East Decker pits acts as a hydrologic barrier inhibiting drawdown on the south, down-dropped side of the fault. A parallel fault, less than two miles west of the above described fault, also appears to form a hydrologic barrier. The result is the formation of a fault-bounded block approximately five miles long characterized by steep drawdown. A normal fault near the north permit boundary of Spring Creek appears to be restricting drawdown to the south, down-dropped, side of the fault.

MINING INFLUENCES ON GROUND-WATER LEVELS

A network of 230 monitoring wells is used to measure changes in ground-water levels within and outside the mine permit boundaries. The mines and the Montana Bureau of Mines and Geology (MBMG) have collected more than 20 years of monitoring data. Monitoring data collected through the end of the 1998 water year (October 1998) (Decker Coal Company, 1999) is used in this study. Mining in the Decker area affects the aquifers by causing ground water to drain into the open pits. The collected water is subsequently removed from the pits and pumped to ponds for use inside the mine area or for eventual release into the Tongue River. Mining rates and location influence the location, depth and rate of drawdown. Well hydrographs clearly reflect the changes in the mining operations over time. In general, aquifers affected by mining at the Decker mines have shown greater drawdown south and southwest of the pit areas than north and east of the pit areas.

D1 Upper and D1 Lower

At East Decker, the D1U seam is burned in the north and northeast part of the permit area. At this location, the aquifer is unconfined and contains only a small amount of water. One mile north of pit 14, cumulative drawdown in the D1U measures between two and four feet. Drawdown in this aquifer is not detectable a mile and a half northeast of pit 14. A mile south of pit 13, water levels have declined 51 feet, with 50 feet of confining pressure head remaining.

In the D1L aquifer at East Decker, 76 feet of drawdown has been recorded approximately a half-mile southwest of pit 13. A mile south of pit 13, 58 feet of drawdown has been recorded and 72 feet of pressure head remains. Approximately 3,500 feet north and northeast of pit 14, drawdown has been less than 12 feet. Two feet of drawdown has been measured two-and-a-half miles east

of pit 14. Current drawdown rate three-and-a-half miles southwest of pit 13 is less than one foot a year.

There are no plans at this time to remove additional coal from the north pit area of East Decker. Hydrographs of water level trends in the D1U and D1L aquifers north and east of pit 14 suggest continued drawdown will be negligible or cease. Drawdown is not expected to advance beyond current limits. Current drawdown limits are approximately a mile east of pit 14 in the D1U and two-and-a-half miles east of pit 14 in the D1L.

Drawdown southwest of the pit is expected to continue as mining progresses south and east. At current rates, another 40 feet of drawdown in the D1U is expected near pit 13 and up to 20 feet of drawdown in both the D1U and D1L is expected three-and-a-half miles southwest of pit 13. The drawdown limit to the southwest is estimated to increase by approximately two miles.

D1 Aquifer

At West Decker, the D1 seam has been burned northeast of pit 12 and is almost completely burned in the pit 16 area. In the burned area northeast of pit 12, water levels appear strongly influenced by reservoir levels and drawdown is minimal. Immediately south of pit 11, a monitoring well measured 32 feet of drawdown and was essentially dry when it was removed in 1995. A half-mile west of pit 11, 26 feet of decline in the D1 had been measured, leaving 34 feet of water remaining in the monitoring well under water table conditions. The D1 aquifer combines with the D2 aquifer approximately a mile-and-a-half due west of West Decker and the D1 diverges to form the D1U and D1L one to two miles south of pit 11, depending on location. At West Decker, drawdown in the D1 influences water levels in the D1U and D1L south of the convergence-divergence line. At least 17 feet of drawdown has been recorded in the D1 west of pit 16.

D1 drawdown at West Decker appears to have slowed considerably. Three miles southwest of pit 11, drawdown is approximately one foot per year. If this rate continues, approximately 20 feet of additional drawdown is expected here. Mining is complete in the southernmost part of pit 11 and much of the area has been reclaimed. Current drawdown extends more than three miles southwest of pit 11 and is not expected to increase appreciably under current mining plans.

D2 Aquifer

Drawdown in the D2 aquifer is steeper and more extensive than in any other aquifer locally affected by mining. As in the D1U and D1L aquifers, the rate of drawdown is extremely low to absent north and east of East Decker but southwest of the mine, drawdown is steeper and the rate is greater as drawdown is concentrated in the fault block southwest of pit 13. Maximum recorded drawdown comes from a monitoring well located approximately a half-mile southwest of pit 13 where the water level has declined 135 feet. The aquifer remains barely confined at this location. Approximately a mile southwest of pit 13, water level dropped 25 feet in the last six years. The rate of water level decline at this location has averaged three feet per year during the last two years, suggesting that the rate of decline may be slowing somewhat. At the current rate,

approximately 60 more feet of decline could take place during the remaining mine life.

Drawdown has decreased from 8 feet per year to 4 feet per year in the past four years immediately southwest of pit 13, again suggesting that drawdown is slowing. Three-and-a-half miles southwest of the mine, the drawdown rate averages a half-foot per year. At this rate, drawdown is expected to increase approximately 10 feet over the remaining mine life.

North and northeast of pit 14 at East Decker, drawdown has been more conservative, ranging from 49 feet at a location less than a half-mile east of the pit to 8 feet at a location two-and-a-half miles east of the pit. The rate of water level decline has ceased at most locations north and northeast of pit 14. Twenty to 70 feet of confining pressure remains in the D2 aquifer north and east of pit 14. As mining is not currently active in pit 14, no further decreases in water level are expected.

Mining in pit 16 at West Decker began in 1991 and subsequent drawdown in the area has been slight. Most of the D1 seam and some of the D2 seam has been burned in this area. Up to nine feet of drawdown in the D2 aquifer has been measured immediately north of pit 16. A monitoring well less than a mile north of the pit has measured no drawdown.

At West Decker, D2 coal is being removed only from pit 12. Measurements made immediately north of pit 12 indicate that the water level has dropped 86 feet, leaving approximately 27 feet of confining head. Approximately 31 feet of drawdown has been measured about a mile west of pit 11, leaving 66 feet of confining pressure close to the location where the D1 and D2 seams merge.

Combined D1/D2 or Anderson-Dietz Aquifer

Approximately two-and-a-half miles west of pit 11 at West Decker, 28 feet of drawdown has been recorded and 18 feet of confining pressure remains in the combined D1 and D2 seams. Seven feet of drawdown has been measured in the combined seam approximately four-and-a-half miles west of pit 11. Five feet of drawdown has been measured in an unconfined part of the aquifer two miles south of pit 2 at Spring Creek and two miles west of pit 16 at West Decker. One mile west and three miles southwest of the pit 16 area, the aquifer retains approximately 30 feet of pressure head.

Forty feet of drawdown is the greatest water level decline measured in the Anderson/Dietz aquifer at Spring Creek. Three feet to 10 feet of drawdown has been measured less than a half-mile outside the south permit boundary.

D3 Aquifer

Although the D3/Canyon seam is not being mined and lies 100 feet below the deepest coal seam mined, drawdown in the D3/Canyon has been documented at each of the mines. Explanations for the decline in head within the D3/Canyon aquifer include reduction in confining pressure due to the removal of overlying coal seam aquifers and overburden, inadequately sealed drill hoes, and fracturing of overburden caused by blasting at the mine site (Reiten and Wheaton, 1993). The mines also maintain water supply wells with multiple aquifer completions

that typically include the D3/Canyon aquifer. However, drawdown in the D3/Canyon aquifer is not centered at these well sites, but closely mimics the drawdown pattern of the shallower aquifers. Maximum measured drawdown in the D3/Canyon aquifer is 37 feet approximately 1,500 feet west of pit 13 at East Decker. Eight feet of drawdown in the D3/Canyon aquifer is detectable up to two-and-a-half miles east of pit 14 at East Decker and five feet of drawdown is detectable two miles west of pit 11 at West Decker. Recent water level measurements in the vicinity of pit 16 recorded a drawdown rate of as much as a foot a month. At Spring Creek, 21 feet of drawdown has been measured near the pits and approximately 8 feet of drawdown has been measured a mile away from the permit area. Drawdown rates in the D3 remain relatively high and variable from location to location, making it difficult to make life-of-mine estimates of the amount and extent of drawdown.

Spoils Aquifer

Upon reestablishment of recharge to backfilled pit areas, the backfilled material or spoils is expected to saturate and form an aquifer that will store and transmit groundwater and reestablish flow between upgradient and downgradient coal aquifers. Currrent water levels and recharge rates are important indicators of how quickly the spoils aquifers will establish. Many of the pits remain partially or wholly cut-off from upgradient recharge and a final evaluation of spoils aquifer recovery awaits completion of mining and reclamation. A recovery of between 85 and 110 feet in water level has been recorded in reclamation in the west part of East Decker. Resaturation and water level in the spoils at this location is strongly influenced by the stage of the Tongue River Reservoir. Water levels throughout reclaimed pit areas at East Decker are rising between one-and-a-half and three feet a year.

Water levels in spoils at West Decker appear controlled more by mining operations than by recharge from the reservoir. Water levels in spoils monitoring wells at West Decker typically are static or declining. At Spring Creek, recently installed monitoring wells indicate that between 9 and 15 feet of water has reentered reclaimed spoils.

NON-MINING INFLUENCES ON GROUND-WATER LEVELS

Two recent events may cause significant changes to the hydrologic system in the Decker area and will affect drawdown and recharge in the vicinity of the mines. The first was the initiation of coal bed methane production in late 1998 near the Decker town site, less than two miles south of West Decker. The second hydrologic event was the raising of the Tongue River Reservoir stage in the spring of 1999. This event will tend to supply more recharge to the reclaimed and open pit areas adjacent to the reservoir.

Coal Bed Methane Production

Coal bed methane production requires reduction of pressure head in the coal seams. To facilitate the reduction in pressure head, ground water is pumped from the targeted coal seams (D1 Upper, D1 Lower, D2, and D3 aquifers) at an

average pumping rate of approximately 17 gallons per minute (data from reports submitted to the Board of Oil and Gas Conservation). Coal bed methane wells have also been permitted near the East Decker mine and further expansion of methane production in the area is anticipated. Methane production is estimated to continue for 20 years. Although ground water pumping should decrease with time once pressure head is adequately reduced to allow the gas to escape, significant and steep drawdown is expected in the affected aquifers. Approximately 80 feet of drawdown was measured between December 1998 and December 1999 in a Decker Coal Company monitoring well (Decker Coal Company, 2000) located immediately south of the Decker town site and less than two miles south southwest of pit 11. Previously, drawdown measured by this well was attributed to mining. At the end of the 1998 water year, total drawdown at this well was 19 feet with a rate of approximately one foot per year. Drawdown from mining and coal bed methane production will have additive affects in areas near the mine, although drawdown associated with methane production is expected to be much greater than that from mining. Widespread and steep aquifer drawdown due to coal bed methane production may significantly slow the recovery of water levels in the mine areas once mining and reclamation are complete.

Tongue River Reservoir

Reconstruction of the Tongue River dam spillway completed in early 1999 resulted in an increase in the maximum pool level of the reservoir from 3424.8 feet to 3428.8 feet. Due to damage sustained by the dam and spillway during a 1978 flood, reservoir water levels usually were maintained well below the previous spillway height of 3424.8 feet. Subsequent to the 1978 flood, average reservoir levels from August to April were below 3,410 feet, and average peak water levels of 3,420 feet typically occurred for two weeks in June (Montana Department of Natural Resources and Conservation and others, 1996). Since reconstruction of the spillway, the average expected increase in reservoir level is uncertain and will depend largely on whether water allocated to holders of water rights is used or stored. During the spring and summer months of high water demand, the water level likely will be close to spillway elevation. During the summer of 1999, West Decker experienced inflow into the West Decker pits of up to 20,000 gallons per minute (Decker Coal Company, personal communication). The long-term results of a sustained increase in reservoir level is unknown. However, an increase in reservoir level is expected to increase recharge to reclaimed pits that are adjacent to the reservoir at the Decker mines. Due to an increase in local base level, increases in reservoir levels may also mitigate local ground-water drawdown.

REFERENCES

Decker Coal Company, 1999, Annual Hydrologic Permit Report, 1998 Water Year.

Decker Coal Company, 2000, Annual Hydrologic Permit Report, 1999 Water Year.

Montana Department of Natural Resources and Conservation, Northern Cheyenne Tribe, and United States Bureau of Reclamation, 1996, Tongue River Basin Project Final Environmental Impact Statement.

Reiten, J. and Wheaton, J., 1993, Unexpected impacts to unmined aquifers near coal mines, Proceedings of the Billlings Symposium, Vol. 2, p. 134-142.

Spring Creek Coal Company, 1980, Spring Creek Mine application, environmental baseline study, Vol. 2, prepared by Environmental Consultants.

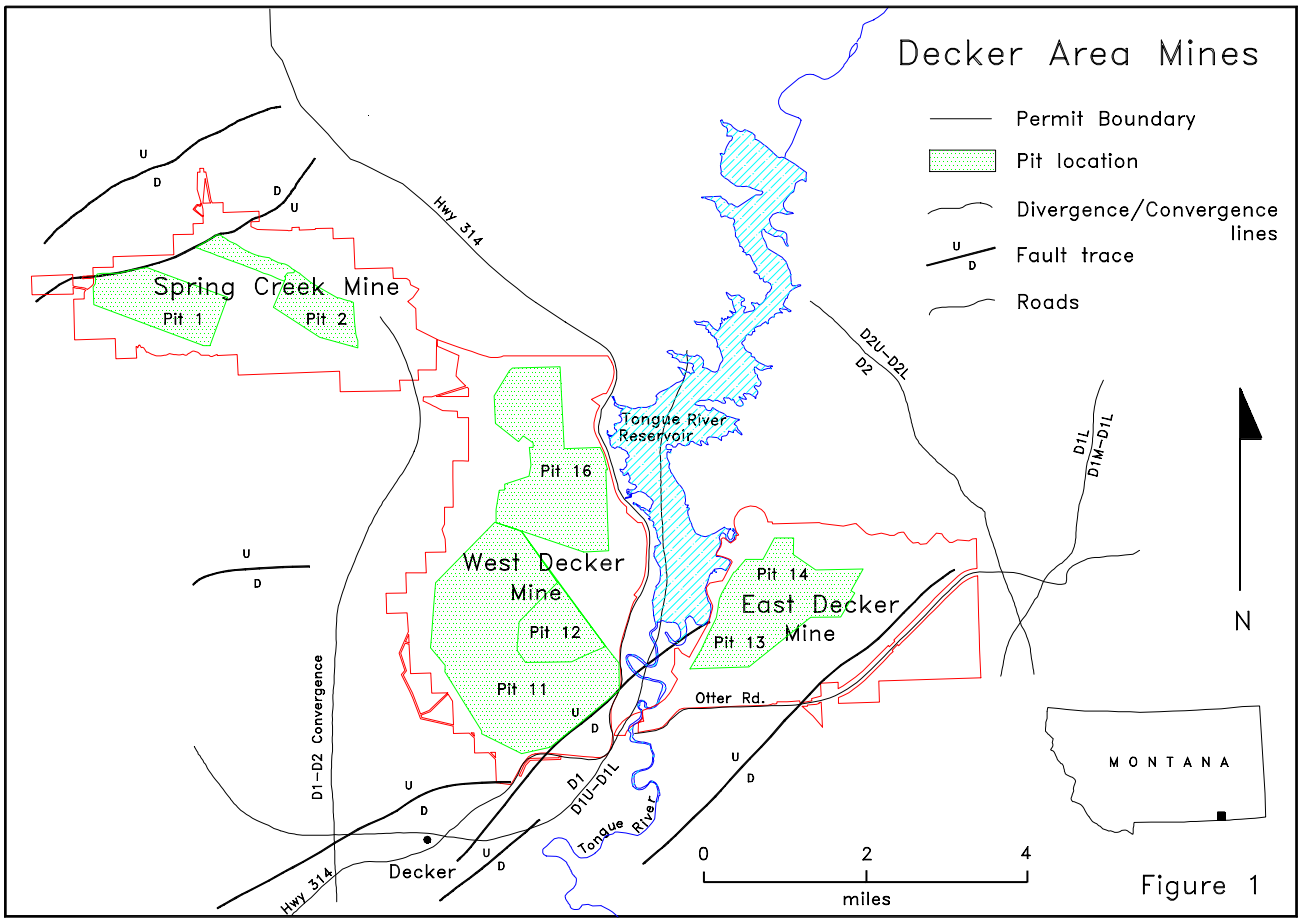
Decker Area Mines
Permit Boundary
Pit location
Divergence/Convergence lines
Fault trace
Roads
Spring Creek Mine
Pit 1
Pit 2
Hwy 314
Tongue River Reservoir
Pit 16
West Decker Mine
Pit 12
Pit 11
Pit 14
East Decker Mine
Pit 13
Otter Rd.
D2U-D2L
D2
D1L
D1M-D1L
D1-D2 Convergence
D1
D1U-D1L
Tongue River
Decker
Hwy 314
N
MONTANA
0
2
4
miles

Figure 1

2000 Billings Land Reclamation Symposium

UTILIZATION OF A REGIONAL GROUND-WATER MODEL TO PREDICT RELATIVE IMPACTS TO LIFE OF MINE PLANS FOR AREA C NEAR COLSTRIP, MONTANA

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ABSTRACT

Western Energy Company (WECO) has been conducting coal mining activity in Area C west of Colstrip, Montana since 1982 and a long-term ground-water monitoring database has evolved. This database provided an opportunity to quantify "cause-and-effect" relationships between historic mining and ground-water system responses, and to assess relative impacts of two different plans of mining operation designated respectively as the Existing Life of Mine Plan (Existing Plan) and a Proposed Plan. The State of Montana Department of Environmental Quality (DEQ) and WECO agreed that WECO would utilize the existing data and create a three-dimensional ground-water model to assist in comparing long-term ground-water system responses associated with each plan.

The data were evaluated, a conceptual model created, a ground-water model constructed, and it was calibrated to steady-state and transient conditions. Once the calibration effort satisfactorily matched the historic database, the model was used to predict future ground-water system responses associated with the plans. An unusual consideration from a ground-water modeling perspective is that the mining process involves replacing native formations with mining spoils possessing different hydraulic characteristics. Most model tools are not well suited to directly incorporate such formation parameter transitions. A procedure termed "adaptive parameterization" was used to address this issue.

The model effort predicted western portions of Area C would see about 15 meters more drawdown but that central portions would see about 7 meters less drawdown at Year 2019 by imposing the Proposed Plan versus the Existing Plan. Any drawdown differences were predicted to become inconsequential by 50 years after mining. Relative differences in dewatering discharges for the plans were evaluated. A net discharge increase of 340-600 cubic meter/day was predicted for the Proposed Plan.

INTRODUCTION

This paper presents the approach and results for a ground-water model effort developed by Nicklin Earth & Water, Inc. for Western Energy Company (WECO). The effort was used to

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compare potential differences in impacts to the ground-water system outside Area C related to proposed mine changes to the existing Area C Life of Mine Plan. Area C is located to the west of Colstrip, Montana. The existing Area C Life of Mine Plan shall be referred to as the Existing Plan. The proposed mine changes will hereinafter be referred to as the Proposed Plan. The main difference in the two plans involve mining slightly different areas and different sequencing. In addition, the Proposed Plan would leave longer high wall exposure times and longer high wall lengths during mining activity. The Montana Department of Environmental Quality requested that these issues be evaluated further by WECO. Hence, a ground-water model was created for this purpose. The modeling effort included meetings with the Montana Department of Environmental Quality (DEQ) at the beginning and end of each phase in order to attain DEQ's preliminary concurrence with the modeling approach and the interim modeling results.

GROUND-WATER MODEL PROGRAM OBJECTIVES

The modeling program objectives described in the Phase 1 report were the following:

- **Objective 1:** To summarize the conceptual understanding of the hydrogeologic regime in the vicinity of Area C for purposes of constructing a ground-water model.
- **Objective 2:** To develop a calibrated model which has reliable predictive capability.
- **Objective 3:** To predict temporal and long-term hydraulic/hydrologic responses associated with the mining activity in Area C. The primary focus will be to evaluate the responses that would be created by both the Proposed Plan and the Existing Plan.
- **Objective 4:** To predict and compare the level of potential impacts associated with the two plans.

KEY HYDROLOGIC ELEMENTS REQUIRING REPRESENTATION

The numerical model was designed to emulate key hydrologic features and factors inferred to impact ground-water flow within or proximate to areas that are to be mined. These features/factors include the following:

- Certain geologic units containing/transmitting ground water will be mined. The units of primary interest are the Rosebud Coal, Rosebud Coal Overburden and units immediately underlying or lying adjacent to mined areas.
- Dewatering occurs during the mining process. The dewatering activity moves with the mine progression. In essence, the model must be capable of emulating the temporal and spatial variations in hydraulic stress.
- The mining process transforms geologic formations to a material of different characteristics. In essence, Rosebud Overburden and Rosebud Coal are mined with spoils being returned in their place. The net result is formation material possessing different hydraulic properties including the following:

- The spoils would have relatively uniform vertical to horizontal hydraulic conductivity ratios compared to the much lower vertical to horizontal conductivity ratios for the native formations.
- The porosity of the spoils is much higher than the porosity of the native materials. Hence, the spoils are anticipated to possess higher storage coefficients than the native formations.

- The mining activity may also impact the net recharge in the vicinity of mined areas.

SIMULATION TOOLS

The modeling effort was conducted using the following numerical simulation tool MODFLOW - A modular three-dimensional finite difference ground-water flow model developed by the United States Geological Survey [USGS] (McDonald and Harbaugh, 1988).

Graphical User Interfaces (GUIs) were applied extensively in the Area C modeling effort. The two primary GUIs used in the modeling effort were Groundwater Modeling System (GMS) and Groundwater Vistas (GV). GMS was developed by the Engineering Computer Graphics Laboratory of Brigham Young University for the U.S. Army Engineer Waterways Experiment Station. It is primarily an interface for conducting ground-water simulations using a variety of analysis codes including MODFLOW. Groundwater Vistas was developed by Environmental Simulations, Inc. of Herndon, Virginia. It also serves as an interface for conducting ground-water simulations including MODFLOW.

Each GUI possessed relative advantages over the other GUI for certain elements of the WECO modeling effort. The modeling effort was greatly facilitated by applying these GUIs in tandem as one was better suited for model calibration whereas the other was better for developing the series of cascading models which could be used to better represent the mining process in the application phase.

MODEL CONSTRUCTION/MODEL DOMAIN

The model domain boundaries were placed significantly beyond Area C to reduce the likelihood that impacts from model boundary conditions would negatively impact the simulation of the mine dewatering process. The closest boundary is to the south and it generally conforms to a ridge located just south of Area B Extension (alternatively designated as Area C South). The model boundary was extended to the south-southwest or to the Little Wolf Mountains.

The hydrogeology was represented in the model using a three-layer model with each layer being assumed as constant saturated thickness (confined). A limiting factor in selecting the most applicable criterion (confined versus unconfined) is the fact that some areas of the aquifer

system in the vicinity of Area C may be confined and others unconfined. Assuming either a confined or unconfined model involve idealizations which are not often attained in real world situations, particularly when hydrogeologic conditions are complex. Assuming a transmissivity based model greatly simplifies the model construction process and reduces the likelihood of numerical convergence problems. The results tend to be conservative or such models tend to over-predict the degree of drawdown and the rate of extraction assuming all other factors are equal.

Three model layers were established to represent the geologic features. The model grid structure consists of 96 rows and 192 columns and it is variably spaced. The model cells are uniformly spaced over Area C using 90 meter spacings. Those model cells on the periphery of the model domain were of variable spacing.

STEADY-STATE MODEL CALIBRATION

The following summarizes the steady-state model calibration process:

Step 1: The initial model structure was defined using GMS.
Step 2: The model structure from GMS was imported into GV.
Step 3: The initial model parameters were iteratively modified within the realm of the given database until a reasonable model fit was achieved. The main variable of concern was transmissivity and it was altered significantly throughout the model calibration process via trial-and-error. Recharge and vertical leakance were also altered during the model calibration process but to a much less significant degree.
Step 4: The model fits were evaluated using the statistical evaluation packages contained in GV. Ninety-six monitoring wells were used to conduct the statistical evaluations. Water levels preceding mining were chosen for the steady-state calibration. Most of these water levels were from July, 1983.

The primary focus during the model calibration process was defining the magnitude of transmissivity of the model layer which represented the Rosebud Coal. In addition, a focus was made on using recharge values consistent with the literature estimates defined in an Environmental Impact Statement that was prepared in 1982.

The calibrated matched water levels except for a small portion of the model domain for all formations represented in the model. Low recharge rates were applied in the model area and they ranged from about 0.2 to 0.8 centimeters per year. Generally, relatively lower recharge rates were applied to portions of the model area which possessed greater topographic relief. The recharge rates used were generally consistent with the predictions made in an Environmental Impact Statement (EIS) completed in 1982.

The model calibration effort also included extensive sensitivity analysis with respect to transmissivity, vertical leakance and recharge.

TRANSIENT CALIBRATION/MODEL APPLICATION PROCEDURE

Once the steady-state model calibration was completed using GV, the MODFLOW data set was imported into GMS for the model application effort whereby GMS was used to create a series of cascading models to represent these mining phases:

- Historical mining activity to 1996;
- Existing Plan mining activity from 1997 through 2019; and
- Proposed Plan mining activity from 1997 through 2019.

In addition, a series of models were constructed to emulate a period of recovery following the cessation of mining activity in 2019.

The impacts of the mine dewatering process were represented by using the Drain Package of MODFLOW. In essence, the mining activity was discretized into a series of sections or mining steps. Drains were added and removed from each section in accordance with mining activity progression. The GUI GMS greatly assisted in this effort as conceptual features could be added as necessary and then a new input file was automatically generated.

The formation parameters for spoils returned in place of native formations were adjusted to values conceived to be more representative of spoils. In essence, a cascading series of flow modules were created with the only difference being the formation parameters that had been updated in accordance with the mining activity progress. The updated parameters included replacing the mined native formation parameters as follows:

- Transmissivity of spoils was assumed as 3.0 cubic meter/day being subdivided as 1.5 cubic meter/day in Layers 1 and 2 as mining steps progressed.
- The relative vertical to horizontal hydraulic conductivity ratio associated with Layer 1 and 2 was increased to 0.1.
- The storage coefficient for the spoils was increased to 0.1.

The model cascade included simplication of the mining process into a 5 historic periods. Following the historic representation, 5 additional models were developed to represent future mining for each the Proposed Plan and the Existing Plan to represent future mining to the end of 2019. Finally, two models were developed to represent recovery periods for each plan and they included 10 year stress periods with 5 year time steps extending from 2020 to 2120. In essence, predicted potentiometric head and drawdown plots were created at 5-year increments in time during the period of recovery.

The procedure used above was first applied to the historic mining activity before it was applied to the Existing Plan and Proposed Plan.

The primary aquifer of interest in Area C is the Rosebud Coal. The EIS indicated storage coefficient (S_c) for the Rosebud Coal was 0.000015. However, it was deemed that such a

value would unlikely be indicative of water being derived from the Rosebud Coal during the mining operation. The first transient model calibration efforts tested an S_c value of 0.002. However, this value proved to produce significant over-predictions of drawdown when compared to actual observations. For instance, it was observed that the initial simulations were projecting significant drawdowns into western portions of Area C in contradiction with the existing database whereby little response was actually being observed. Hence, the use of S_c = 0.002 was deemed to produce excessively conservative results from a drawdown perspective. Another attempt for conducting the transient calibration was to apply storage coefficients of 0.02 and 0.05. The net results were much more adequate fits with the existing water level database.

The value of S_c = 0.02 was ultimately selected for model application purposes for the Existing and Proposed Plans.

DISCUSSION

In general, the predicted drawdown results appear to conform reasonably well with observations to date which show that drawdown impacts are localized to historic and active mining portions in Area C.

Drain flow predictions using a Flow Budget algorithm in GMS were made at the juncture with E. Fork Armells Creek for historical mining periods 4 and 5 where relatively high rates of discharge were observed during mining. The main discharge source was the alluvial aquifer. Those predictions indicated flows from mine pit dewatering would be about 3.2 cubic meter/min during the historical mining periods. Communications with WECO staff indicate that visually observed flow rates associated with pit dewatering in this portion of Area C during active mining were more likely about 1.8 to 2 cubic meter/min. Hence, based upon the visual observations of WECO staff, the model over-predicted flow rates there. There are two potential reasons for the difference in flow rate extraction estimates and they are the following:

1) Higher flow rate estimates result at sinks when a confined model is used to represent localized conditions that are more likely to be unconfined.
2) The model simplification assumes all portions of the drains in each portion of the historic model stress period and historic area are activated simultaneously. The actual mining dewatering process as mining proceeds is more gradual.

The net result is a series of models that produced conservative flow rate predictions. A test was conducted to predict the likely conservativeness of the model by simulation using simplified/ idealized conditions with characteristics of the mining process. The results predicted that the model would overestimate actual discharges by about 1.74 times. When the results are adjusted using this factor the flow extraction rates would equate to about:

$$3.2/1.74 = 1.8\ m^3/min$$

Such an adjusted flow rate is in reasonable conformance with visual observations of WECO staff during pit dewatering activity performed near E. Fork Armells Creek.

A review of the results for the two plans indicates the following relative to potentiometric head:

1) The most significant differences in the potentiometric head predictions are associated with the Overburden.
2) One of the main differences in potentiometric head predictions between the two plans correlate with slightly different mining areas.
3) The overall predicted long-term drawdown is relatively greater near the western-most portions of Area C for the Proposed Plan in comparison to the Existing Plan. This is likely due to the fact that mining activity in this portion is projected to begin ten years earlier for the Proposed Plan than for the Existing Plan.

Drawdowns and differences in drawdown between the two plans were examined up to 100 years in the future.

Mass balance results for the series of models were compared in an attempt to predict/distinguish the differences in the amount of water that would be extracted for the Proposed Plan in comparison to the Existing Plan. The net projected flow increase for the Proposed Plan is about 340 to 600 cubic meter per day during the active mining operation.

Sensitivity analysis was also conducted on the transient calibration and predictive phases of the modeling effort for the following:

Storage coefficient for spoils; and
Net recharge over spoils.

LIMITING ASSUMPTIONS OF MODELING EFFORT

There are limiting assumptions that should be noted when applying this flow model including the following

- The model assumes each saturated zone is of constant thickness. The actual saturated zones are of variable thickness spatially and temporally.
- The mine stress periods assume continuous drain dewatering over time. Mine dewatering activity actually varies in time during the mine stress periods.
- There is considerable uncertainty about the magnitude of various formation parameters including hydraulic conductivity (transmissivity), vertical hydraulic conductivity ratios, storativity, and recharge rates.

- The nature of the hydrologic flow regime outside Area C, particularly that to the southwest of Area C is unknown. The degree that ground water flows toward or away from Area C will impact the rate of hydrologic recovery in Area C.
- There is no unique solution to a complex natural system. In essence, there are alternative conceptual and hydraulic models which could be applied to Area C.
- Models are predictive tools and they represent simplifications of complex systems.

SUMMARY AND CONCLUSIONS

The following summarizes the results of this ground-water modeling effort:

- The model provides a conservative and consistent basis for comparing the hydrologic responses of the Proposed Plan and the Existing Plan;
- The steady-state calibrated model utilizes hydraulic parameters, namely transmissivity values, that correspond well with the existing database.
- A transient model was developed and the results of the model were compared to historical water level observations in the vicinity of mining activity. The results of that comparison indicate that selection of relatively high storage coefficients values for native formations yields results more consistent with monitoring well observations. The transient model results were also compared to estimated pit dewatering extraction rates. The tendency of the model was to over-predict flows.
- The Proposed Plan and Existing Plan dewatering activities were simulated. The results of the simulations predict that a majority of the differences between the plan potentiometric heads and hydrologic balances will occur during mining.
- Any differences in potentiometric heads predicted to arise during the Life of Mine Plans diminishes after mining until those differences are relatively inconsequential by 50 years. Differences in hydrologic balance are predicted to be relatively inconsequential immediately following mining activity.

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Soil-Water Modeling for Reclamation Covers in the Southwestern United States

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ABSTRACT

Given the performance limitations of many conventional RCRA covers in arid regions, the development of effective alternatives using locally available materials is integral to the efficient reclamation of mine sites. We used the UNSAT-H water balance model to evaluate the effectiveness of various soil cover designs at limiting water movement from the covers under vegetative and climatic conditions found in the semi-arid Southwest United States. We simulated water movement past the base of soil covers with diverse hydraulic characteristics. Saturated hydraulic conductivity varied from 2×10^{-5} to 6×10^{-3} cm/s and available water capacities varied from 0.03 to 0.26 units. The soil covers ranged from 15 to 75 cm thick overlying materials with divergent hydrologic properties ($K = 1.0 \times 10^{-1}$ cm/s and $K = 5.0 \times 10^{-7}$ cm/s). The leaf area index (LAI) function was varied seasonally to mimic the growth response of vegetation to temperature and rainfall distribution patterns. The LAI ranged from 0.012 to 0.5 m^2 m^{-2} with the maximum occurring during the summer monsoon period. The root length density function simulated a 40-30-20-10 root distribution pattern restricted to the cover soils. Climate was simulated using daily precipitation and temperature data from a 10-year period of record that includes extremely wet winters and summers. The simulated annual precipitation ranged from 8 to 26 inches with 60 percent of the years being above the long-term average (16 inches). We selected materials with moderate to high infiltrability to minimize model-generated run-off.

The simulation results indicated that percolation of water was effectively eliminated (<1 percent of mean annual precipitation) with soil covers ranging from 15 to 75 cm thick. The effectiveness of the cover thickness treatments varied in response to hydraulic conductivity and water storage capacity. Soil covers with 6 to 7 cm of profile available water capacity effectively eliminated drainage in most years. In general, compacted clay layers below the soil cover provided no apparent benefits since the post-evapotranspirative drainage from the soil cover was minimal.

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2000 Billings Land Reclamation Symposium

Water Budget for a Coal-Mine-Pit Lake in Southeastern Montana

John R. Wheaton, Warren P. Phillips, and Terry H. Brown

Leaving portions of the final pits of coal mines as water impoundments can, in some situations, benefit both mining companies and those who use the land after reclamation. The water resource is valuable, especially in semi-arid southeastern Montana, but it must be designed with the local water balance in mind. In this site study, the water budget of two final-mine pit lakes are being quantified and related to calculated pre-mining conditions. One impoundment is 120-feet wide, 1,800 feet long and less than 18 feet deep. It is steep sided and protected by a highwall along the west edge. Water in the lake comes from a combination of ground-water discharge from an adjacent coal seam, and from surface runoff during precipitation events. The second site is an oval pond ranging from 320 to 460 feet wide, 1,650 feet long and less than 11 feet deep. Water in the lake comes almost entirely from surface runoff and direct precipitation. Annual precipitation in the area is about 14 inches. All stream channels are ephemeral. Losses from both ponds include ground-water outflow to the mine spoils, evaporation, and transpiration from plants. Water levels in one impoundment have been stable for nearly 20 years, with annual fluctuations of less than 2 feet. The second lake is less than 10 years old, and has water-level fluctuations that exceed 2 feet due to the lack of ground-water inflow. Net radiation and temperature data from adjacent vegetated sites provides free-water evaporation estimates that compare favorably with floating evaporation pan data from the impoundments.

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2000 Billings Land Reclamation Symposium

Geochemical Modeling of a Coal-Mine-Pit Lake in Southeastern Montana

Warren P. Phillips, John R. Wheaton and Terry H. Brown

Coal-strip-mine pits have, in some situations, been left to fill with water, forming lakes. In certain settings, these pit lakes maintain an adequate water supply, neutral pH values and low levels of dissolved metals. In these situations coal-mine-pit lakes provide a significant environmental amenity. The complex interactions between geochemical, biological and hydrological processes occurring in these lakes are not well understood. In this study, chemical and hydrological estimates of water balance components and sediment geochemistry were used to evaluate the water quality of a pit lake in southeastern Montana. Lake waters are high in SO_4 (~1500ppm), Mg (~300ppm), Ca (~125ppm) and Na (~100ppm) and represent a combination of ground-water discharge from an adjacent coal seam, and surface runoff. The lack of metals and high pH (~7.5) in the lake are due to the high alkalinity and natural buffering capacity of the carbonate-cemented Fort Union Formation sediments. Preliminary mass balances of both conservative and reactive chemicals indicate that observed improvements in pit-lake chemistry relative to recharging coal seam waters are a result of dilution by runoff, microbial action, and solution and redox reactions occurring in the lake. Elements acting conservatively in the lake (Mg, SO_4, Cl, Na and Li) indicate that recharging ground water is, on average, being diluted approximately 25% by surface runoff.

The potential toxicity of lake bed sediments to benthic organisms was evaluated by performing both a "total" sediment digest using a microwave aqua regia method and by analyzing anoxic sediment cores for acid volatile sulfides (AVS) and simultaneously extracted metals (SEM). ICP analyses indicate that concentrations of metals in the lake bed sediments are less than those reported for the surrounding spoils and coal-bearing formations. Further, the ratio of AVS to SEM measured in lake sediments indicate that a sufficient amount of AVS is present to effectively bind heavy metals as metal sulfides; this presumably renders them unavailable to sediment-dwelling organisms.

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BIG SAGEBRUSH (*ARTEMISIA TRIDENTATA*) COMMUNITIES - ECOLOGY, IMPORTANCE AND RESTORATION POTENTIAL

Stephen B. Monsen and Nancy L. Shaw

Abstract

Big sagebrush (*Artemisia tridentata* Nutt.) is the most common and widespread sagebrush species in the Intermountain region. Climatic patterns, elevation gradients, soil characteristics and fire are among the factors regulating the distribution of its three major subspecies. Each of these subspecies is considered a topographic climax dominant. Reproductive strategies of big sagebrush subspecies have evolved that favor the development of both regional and localized populations.

Sagebrush communities are extremely valuable natural resources. They provide ground cover and soil stability as well as habitat for various ungulates, birds, reptiles and invertebrates. Species composition of these communities is quite complex and includes plants that interface with more arid and more mesic environments.

Large areas of big sagebrush rangelands have been altered by destructive grazing, conversion to introduced perennial grasses through artificial seeding and invasion of annual weeds, principally cheatgrass (*Bromus tectorum* L.). Dried cheatgrass forms continuous mats of fine fuels that ignite and burn more frequently than native herbs. As a result, extensive tracts of sagebrush between the Sierra Nevada and Rocky Mountains are rapidly being converted to annual grasslands. In some areas recent introductions of perennial weeds are now displacing the annuals. The current weed invasions and their impacts on native ecosystems are recent ecological events of unprecedented magnitude.

Restoration of degraded big sagebrush communities and reduction of further losses pose major challenges to land managers. Loss of wildlife habitat and recent invasion of perennial weeds into seedings of introduced species highlight the need to stem losses and restore native vegetation where possible. Initial efforts to stabilize degraded sagebrush communities relied upon the use of introduced grasses. It is now generally recognized that restoration of the structure, functions and values of sagebrush ecosystems requires the use of site adapted species, subspecies and ecotypes. Our ability to accomplish this goal is improving with the use of an increasing numbers of native species and development of seed production and seeding practices for each.

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INTRODUCTION

Big sagebrush (*Artemisia tridentata* Nutt.), the most widely distributed of the 11 sagebrush species in the Intermountain region, also occurs on the western Great Plains in western Montana, Wyoming and Colorado. Seasonal precipitation patterns, elevation gradients and soil conditions regulate the distribution of the three major subspecies of this landscape-dominating shrub.

Basin big sagebrush (*A. t*. Nutt. ssp. *tridentata*), once the most widespread of the three subspecies, is a tall, erect, heavily branched shrub growing 1 to 3 m in height with trunklike main stems (Cronquist 1994). Plant crowns and heights of the broad panicles are uneven, giving the shrub a ragged appearance. Persistent leaves are narrowly lanceolate and apically 3-toothed. When crushed they emit a pungent, spicy odor (Blaisdell et al. 1982). Basin big sagebrush flowers from late August to October and seeds mature from October to November (McArthur et al. 1979).

This subspecies is common to dominant on plains, in valleys and canyon bottoms and along ditch banks and fence rows in areas below 2,500 m elevation that receive 32 to 36 cm of annual precipitation (Cronquist 1994, Goodrich and Neese 1986, Goodrich et al. 1999, Monsen and McArthur 1984). It normally occurs in sagebrush, rabbitbrush (*Chrysothamnus* Nutt. spp.), juniper (*Juniperus* L.) and pinyon (*Pinus* L.)-juniper communities on deep, productive, well-drained, gravelly to fine sandy loams and deep alluvial soils (Welsh et al. 1987). Many of these areas have been converted to agricultural uses. Some basin big sagebrush populations occur on alkaline soils and form mosaics with salt desert shrubs (McArthur et al. 1979).

Wyoming big sagebrush (*A. t*. Nutt. ssp. *wyomingensis* Beetle & Young) is the most xeric subspecies of big sagebrush, generally growing on shallow, gravelly soil on sites receiving 20 to 30 cm of annual precipitation (Cronquist 1994, Goodrich et al. 1999, Monsen and McArthur 1984). It exhibits a ragged growth habit, similar to that of basin big sagebrush, but most plants are less than 1 m in height. The main stems branch at or near ground level. Persistent leaves are narrowly cuneate to cuneate and emit a pungent odor when crushed (McArthur et al. 1979). Panicles are narrower than those of basin big sagebrush. Flowering occurs from late July to September and seeds mature in October and November.

Common throughout much of the Intermountain area, Wyoming big sagebrush also occurs east of the Continental Divide in Montana, Wyoming, and Colorado. It is most abundant at low to moderate elevations, but may be found at elevations up to 2,700 m in sagebrush, rabbitbrush, salt desert shrub, juniper and bitterbrush (*Purshia tridentata* [Pursh] D.C.) communities (Cronquist 1994, Welsh 1987).

Mountain big sagebrush (*Artemisia tridentata* Nutt. ssp. *vaseyana* [Rydb.] Beetle), like Wyoming big sagebrush, is normally less than 1 m in height, but some low elevation plants may be 2 m tall. Main branches divide near the ground and sometimes layer. Unlike the other two subspecies, the crown and inflorescence branches of Wyoming big sagebrush are of uniform height, giving the plant a spreading to rounded outline. Persistent leaves are broadly cuneate and spatulate and emit a sweet, camphor or mintlike odor (McArthur et al. 1979). Panicles are narrow and dense. Plants bloom in July and seeds mature from September through October (McArthur et al. 1979). Mountain big sagebrush occurs at elevations from 800 to 3,200 m on sites receiving more than 30 cm of annual precipitation (Cronquist 1994, Goodrich 1999, Monsen and McArthur 1984). It grows on well-drained, slightly alkaline to

slightly acid soils in plant communities ranging from sagebrush-grass to aspen (*Populus tremuloides* Michx.) to spruce (*Picea* Link.)-fir (*Abies* Hill.) (Sampson and Jesperson 1963, Welsh 1987).

All subspecies of big sagebrush are considered topographic and edaphic climax dominants. Their ability to differentiate and adapt to the widely varying and continuously changing habitats of the Intermountain region is attributed, at least partially, to development of polyploid populations capable of surviving in drier habitats (McArthur 2000). In addition, hybridization between overlapping taxa and populations of this wind pollinated species produces new genetic combinations, thus expediting the occupation of available niches.

Several adaptive features influence the distribution and persistence of big sagebrush subspecies. These include variation in growth habit, root system development, response to fire, the ability to conduct photosynthesis at low temperatures and the production of allelopathic substances in roots and leaves that decrease the respiration of associated species and provide a chemical defense against herbivory (Blaisdell et al. 1982, Kelsey 1986a, Kelsey 1986b, Petersen 1995). Additional adaptive features include seed germination capabilities over a wide range of temperatures, unusual seed dispersal strategies, seed size and structure and timing of seed maturation (Blaisdell et al. 1982, Kelsey 1986a, Kelsey 1986b, Meyer and Monsen 1992, Petersen 1995).

PRIOR USE AND STATUS OF BIG SAGEBRUSH COMMUNITIES IN THE WEST

Extensive disturbances have occurred throughout big sagebrush communities of the western United States. Degradation began soon after domestic livestock were introduced into the region beginning in the 1840s (Young et al. 1979). Grazing occurred throughout a wide range of plant associations at various elevations and in areas characterized by differing climatic regimes. Grazing was particularly disruptive in big sagebrush communities as use was imposed during spring and fall periods when forage quality and accessibility of these communities are generally greater than for upland communities, but when plants are most susceptible to damage. Consequently, herbaceous understory species associated with big sagebrush vegetation received concentrated and repeated heavy use which reduced their vigor and ability to recover (Houston 1961). The duration of favorable temperature and soil water conditions for growth in spring is highly variable in sagebrush communities (Hanson et al. 1986). Thus in dry years, grazed plants were often further stressed, hastening the decline of the more palatable species

Grazing also disrupted ecological processes associated with natural succession (Blaisdell et al. 1982), facilitating the invasion of annual weeds (Billings 1994, Mack 1981). Weed infestations, in turn, dramatically increased the frequency of wildfires and further reduced the vitality and integrity of the remaining native communities (Whisenant 1990). Increased fire frequency and aggressive annual weeds combined to displace big sagebrush with the ultimate result that extensive areas of shrub and perennial grass communities were converted to annual grasses (Allen 1990, Bunting 1985, Piemeisel 1951). Pellant and Hall (1994) reported that more than 1.3 million hectares in Nevada, Oregon, Utah, Washington, and Idaho were occupied by cheatgrass (*Bromus tectorum* L.) and medusahead wildrye (*Taeniatherm caput-medusae* L.), while another 30.8 million hectares were classified as infested with susceptible to invasion by these two annual grasses.

Serious disturbances were created by livestock grazing in numerous other western plant communities at the same time big sagebrush sites were being impacted. Numerous high elevation watersheds were severely degraded by grazing as early as 1880 (Ellison 1960). This created such serious downstream problems that attention became focused on the restoration of aspen and mountain herbland communities. The importance of stabilizing high elevation watersheds prompted the selection of species that could provide immediate and permanent protective ground cover (Sampson 1921). As might be expected, the native species tested exhibited erratic establishment, due, in part, to inexperience and inappropriate planting techniques. Scientists and land managers discovered that various introduced perennial species, principally grasses, established quickly and provided uniform ground cover on exposed soils as well as palatable forage for livestock (Forsling and Dayton 1931).

Based on successes in high elevation watersheds, land managers accepted and began to use a number of introduced perennial grasses to stabilize disturbances in other plant communities (Meeuwig 1965). The introduction of exotic forage species to replace understory bunchgrasses on low elevation shrublands quickly became a common practice (Hull and Holmgren 1964, Plummer et al. 1955). In addition, a number of early surveys and inventories of western lands recommended conversion of shrub communities to introduced forage species (Williams 1898).

Many native plant communities, principally big sagebrush types, were converted to introduced perennial grasses and managed specifically for seasonal grazing by livestock (Hull 1971, Pechanec et al. 1944, Plummer et al. 1955). Land managers and private land owners accepted the concept that conversion of big sagebrush communities to introduced grasses would not only provide persistent cover, acceptable forage yields, and improved seasonal forage quality and availability, but would also control weeds and enhance wildlife habitat and watershed quality. Breeding and plant selection programs were instigated to develop introduced species as forage plants for big sagebrush communities (Johnson 1980, Johnson et al. 1981).

Later observations and studies of seeded watersheds and rangelands, including big sagebrush sites, began to indicate that introduced grasses were not compatible with native communities (Walker 1999). Their presence reduced the survival of remnant native species, restricted natural recruitment and changed the composition of entire communities. Seeding crested wheatgrass *(Agroypron cristatum* [L.] Gaertner), intermediate wheatgrass (*Elymus hispidus* [Opis] Meld) and smooth brome (*Bromus inermis* Leysser) directly with big sagebrush has prevented shrub seedlings from establishing (Richardson et al. 1986). Mature stands of these grasses also prevented natural recruitment of antelope bitterbrush (Monsen and Shaw 1982) and big sagebrush (Meyer 1994). Frischknecht and Bleak (1957) reported that seeded bluebunch wheatgrass (*Elymus spicatas* [Pursh] Gould) stands were more likely to permit sagebrush seedling recruitment than were crested wheatgrass stands. Seeding introduced grasses on big sagebrush sites occupied with some native perennial herbs and shrubs has resulted in the conversion of a mixed assemblages of species to a predominance of introduced species. This conversion process has continued over a nearly 30-year period in some areas (Walker 1999). Its progress is influenced by climatic conditions as well as by livestock and wildlife use.

Livestock grazing, weed invasion, wildfires, and plant conversion projects have all negatively impacted wildlife habitat in big sagebrush communities (Dobler 1994; Workman and Low 1976). The high nutritional quality and variety of forbs and shrubs present in native communities is vital for maintaining wildlife diversity (Dietz and Negy 1976, Yoakum 1978). Many

important shrubs, suffrutescent species, and broadleaf herbs that were critical to wildlife, particularly during winter periods were reduced (Updike et al. 1990) or lost. Declines or losses of species that furnish habitat for numerous wildlife species occurred throughout the sagebrush zone (Monsen and Shaw 1984, Peterson 1987, Shaw et al. 1999, Workman and Low 1976). A rapid and continued decline in populations of small mammals, raptors, sage grouse (*Centrocercus urophasianus*) (Connelly and Braun 1997), songbirds (Saab and Rich 1997), and other vertebrates and invertebrates has also occurred throughout big sagebrush communities of the West, particularly in the past 20 to 40 years.

The use of woody and herbaceous plants to restore wildlife habitat began prior to 1930 in several western states (Brown and Martinsen 1959, Holmgren 1954, Hubbard et al. 1959). By 1950 native species were being used to revegetate mined sites, roadway disturbances, parks and natural areas. The demand for site-adapted material prompted the collection and planting of some native species, but demands were small compared to those for seeds of introduced species used for rangeland and watershed seedings. During the 1950s the demand for native species for a wide range of sites grew rapidly.

A major increase in mining activities occurred in the western United States beginning in the mid 1960s. Open pit mining for coal provided a major source of income from areas previously used primarily for grazing. At the same time, public demand for revegetation of human-caused disturbances began increasing (Monsen and Plummer 1978, Wieland et al. 1971). Regulations were adapted to insure that disturbances were regraded, topsoiled and planted to a mixture of species that existed on the site prior to mining. Concern for proper revegetation of mined sites soon expanded to include roadways, pipelines and related disturbances (Megahan 1974). Native species were now considered valuable for providing ecologically stable communities.

In 1958 the Utah Fish and Game Department began funding a cooperative study with the USDA Forest Service to develop the ecological database and technology required to improve big game habitats in Utah. The initial emphasis was on pinyon-juniper woodlands and big sagebrush communities (Plummer and Jensen 1957). Major objectives were to reestablish shrub and forb communities, thus emphasis was shifted to a new suite of species. Reliance upon introduced grasses was reduced, and research was directed toward the development of technology required to harvest, process and plant native shrubs and forbs. This project ultimately provided the scientific basis and methodology for revegetating shrub dominated communities in Utah and surrounding states (McArthur 1988). Large acreage of private, state and federal lands were planted with site-adapted species, and the work is ongoing. Based on demands for seeds of native species generated by this and other public and private revegetation efforts, the native seed industry underwent rapid growth (McArthur and Young 1999).

Perhaps the single most important issue that has emerged to promote the re-establishment of native communities, particularly big sagebrush sites, has been the spread of weeds throughout the West. One of the most troublesome species is cheatgrass *(Bromus tectorum* L.), a cool season annual grass. Cheatgrass and several other annual weeds were first reported in about 1900, but spread rapidly and occupied large areas within 10 to 30 years (Platt and Jackman 1946). Other equally troublesome weeds, including numerous perennials, were introduced later, but now present serious problems (Roche and Roche 1988). Many disturbances were initially planted to introduced perennial grasses as they developed rapidly and were able to compete with the annual weeds (Monsen 1994). Seeding exotic perennials to contain exotic annuals proved

successful initially, but the resulting stands did not provide the structure, functions, resilience or values of the native communities.

A new generation of weeds is now emerging; some are capable of invading existing stands of exotic perennial grasses (Sheley and Petroff 1999) as well as some native communities (Sheley and Petroff 1999). This new group includes such aggressive weeds as the knapweeds *(Centaurea* L. spp.) and rush skeletonweed (*Chondrilla juncea* L.), some of which are capable of invading and displacing annual weeds, including cheatgrass. Reestablishing communities of native species appears to be the most ecologically sound means of containing these weeds.

ADVANCEMENT OF NATIVE PLANTS

Acceptance

The evolution of the native seed and plant industry has obviously been totally dependent upon the demand for these species. Some native species have been planted for over 50 years, but only a fraction of all native species are currently in use. Sufficient amounts of big sagebrush seeds are collected annually from wildland stands to plant many large disturbances, including portions of the 0.6 million hectares that burned in Nevada and other western states in 1999. However, only small quantities of many other species are collected each year. Nonetheless, a number of additional species native to big sagebrush communities are becoming more available (McArthur and Young 1999).

Land managers have recognized the need for locally adapted species and ecotypes and appropriate planting technology for each. Studies of ecotypic variation have provided site requirement data and facilitated the development of seed transfer guidelines for some commonly collected shrub and herb ecotypes (Shaw and Roundy 1997). Research has also provided a better understanding of the seedbed conditions required to establish big sagebrush and other species, thus increasing the opportunity to create seedbed microenvironments and devise seeding schedules that maximize the opportunity for establishment of uniform stands (Boltz 1994, Meyer 1994, Roundy 1994). Although an increasing number of native species are being used, many species needed for the restoration of entire communities have only rarely, or more often, never been planted. In addition, our understanding of species relationships and planting practices required to restore communities to a complete assemblage of adapted species at ecologically compatible densities and patterns is poorly developed.

Seed prices are generally quite high as species first come into use. Suppliers realize that extremely expensive seed lots will likely not be purchased. Consequently they tend to provide species that can be sold, yet provide a satisfactory profit. Obviously, costs to collect or produce and clean many species may remain quite high, due to unusual seed characteristics. However, as demand grows, increased emphasis is generally given to the development of improved collection, production, and cleaning techniques, often resulting in increased availability, higher quality, and lower prices (Stevens et al. 1996). Many native species that are urgently needed to restore shrublands are not available in sufficient amounts from wildland collections, consequently field production protocols are being developed to grow the required quantities of seed.

Research and Development

Various federal and state agencies have organized projects to study the ecology and seed and seedling biology of selected native species in order to develop guidelines for their use in revegetation projects (Shaw and Roundy 1997). Research conducted to facilitate the initial use of many native species on mined sites, roadways, recreation sites, and similar disturbances has ultimately benefited many other users.

Cooperative research has been conducted by the USDA Forest Service, Shrub Sciences Laboratory and the Utah Division of Wildlife Resources for more than 40 years. Efforts have centered the studying ecology and use of native shrubs and herbs to for revegetating range and wildlife habitats. The long-term commitment to this effort has resulted in the release of over a dozen native cultivars and the development of data required to make over 100 species available for use by the commercial seed industry (McArthur and Young 1999).

State and federally funded research has been instrumental in encouraging the collection and study of native species. Research has been directed toward defining the areas of adaptation of populations or ecotypes within individual species. Plant materials have been assembled to better define the adaptive characteristics that may limit species or ecotypes to specific sites, climatic regions, or soil conditions (Monaco 1996). Sufficient differences have been noted among populations or ecotypes of individual species that users should be cautioned against moving plant materials outside their area of adaptation.

A limited number of studies have been conducted to determine the genetic relationships among species, subspecies, and populations and the nature of genetically controlled characteristics. Collections of selected species have been assembled to permit comparisons of specific characteristics such as herbage production, drought tolerance, seedling vigor and related attributes that may enhance their use. A principal concern is the maintenance of genetic diversity within a population when seeds are grown under cultivation. Guidelines for retaining genetic integrity must be developed for native species grown in seed fields to avoid shifts in genetic characteristics if some plants may be favored or eliminated during field production.

Research has also been conducted to determine the agronomic characteristics of potential revegetation species and ecotypes. Of greatest concern are the germination and seedling establishment characteristics of each plant. Considerable variation has been found to occur in seed dormancy, germination patterns, and growth characteristics among different collections and populations (Meyer and Monsen 1990, Shaw 1994). Germination patterns are genetically regulated and have evolved to enhance survival under different climatic regimes (Meyer and Monsen 1992). Seeds of different species and populations require specific microenvironmental seedbed conditions for germination and establishment. Determining specific requirements for individual species and populations is essential for developing appropriate seedbed preparation and planting techniques and equipment (Monsen and Meyer 1990).

A site-identified certification program to verify and certify the origin of wildland collected seeds was recently developed and accepted by the Association of Official Seed Certifying Agencies (Young 1994). This program provides a system for inspection, labeling, and certification of specific collections. Seed collections are inspected in the field by qualified state seed certification agency personnel who tag individual seed lots and maintain records to assure that seeds are sold with proper data on the site of origin.

Development of Wildland Harvesting, Cleaning, and Storage Practices

Although the development of technology to harvest, clean, and plant the seeds of species native to sagebrush communities is often not recognized as a major issue, development of this information is extremely critical. Most conventional seed harvesting equipment is not capable of harvesting many native species. In addition, existing seed cleaning equipment used for agronomic species has not been completely satisfactory for cleaning some native seeds. Consequently, funding by federal and state agencies has been required to develop new equipment or modify existing equipment for harvesting and cleaning wildland seeds. Competition for seed sales has compelled native seed collectors and growers to assume a role in these endeavors. Although the costs required to develop new harvesting and cleaning equipment often exceed the capabilities of individual companies, modifications and improvements of existing equipment have considerably streamlined harvesting and improved the quality of the seed lots marketed.

Research has been conducted to develop safe and effective techniques for cleaning and planting seeds of species that present unusual difficulties. Some seed lots are difficult and costly to clean; others are easily damaged during the cleaning process. Removal of seed coats or other appendages from seeds of some species may decrease seed germinability and seedling survival. The condition of individual seed lots directly affects the metering of seeds through conventional drills and seeders. Consequently, safe and efficient techniques must be developed for cleaning each species

Development of Seed Germination and Quality Standards

Development of seed germination and quality standards is essential for the marketing of native seeds. Standard testing procedures are essential to aid buyers in determining the quality and value of individual lots. Federal and state agencies have conducted studies to develop germination procedures for individual species for use by state seed testing laboratories. Purity and other tests of seed quality are also being standardized.

Seed Warehousing

A high percentage of native seed sales are made to either state or federal agencies. Sales of some species are dependent on annual collections from wildland stands, consequently their availability varies considerably. To reduce this uncertainty in seed supply, the Utah State Division of Wildlife Resources (Utah DWR) and the USDI Bureau of Land Management in Idaho (Idaho BLM) have each constructed and manage seed warehouses. The BLM warehouse handles seeds for plantings in much of the western United States. At each location, seeds are acquired in advance to assure their availability when planting begins. The DWR distributes a list of seeds and seed sources required on an annual basis.

Advanced seed purchasing and warehousing has added stability to the native seed industry as collectors are aware of the species and amounts of seeds required at the beginning of the field season and can plan their harvesting accordingly. Many other agencies, private companies, and contractors who enter into cooperative plantings with the Utah DWR and Idaho BLM also benefit from the seed warehousing program. In addition, these programs have improved the availability of numerous species, making them available for other buyers. The result has been a much more rapid advancement of the native species program than would otherwise have been expected. The use of adapted ecotypes has increased, and in some cases seed prices have been reduced.

Both the Utah DWR and Idaho BLM have hired and trained individuals to manage their facilities. These individuals are involved in the development and execution of revegetation projects and monitoring programs to assess planting success. This combined responsibility has greatly increased the tracking of seed quality, improved of seed storage techniques, and increased the use of adapted species and ecotypes. More thorough monitoring of seeding success permits feedback to improve the success of future plantings.

The DWR has developed seed quality standards and they set maximum acceptable seed prices for individual species each year. Seeds are often stockpiled during good harvest years. Seed companies quickly recognized that seeds of some species harvested from wildland stands were costly and supplies often unreliable, consequently some progressive companies began raising seeds under cultivation, thus improving seed availability and reducing prices.

Development of Site Preparation and Planting Practices

A primary challenge to the use of native seeds was the development and use of successful planting practices. This required the development of equipment to seed trashy seeds and seeds with unusual morphological characteristics. Private contractors and companies normally do not have the resources to research and develop suitable equipment. A concentrated effort has been required to address these problems. The development of seeding and related equipment for range and wildlands use is often not attractive to large equipment companies as equipment sales are normally quite low compared with sales of conventional agricultural equipment. However, small machinery companies have often been instrumental in developing and modifying equipment to solve specific problems. A small Utah company, for example, developed the “Hansen Seed Dribbler” which permitted planting seeds of different shapes and sizes. This machine completely revolutionized shrub seedings.

The Range Technology and Equipment Committee

An independent committee was organized in 1944 to help advance the development of equipment needed to revegetate rangelands. This organization, now known as the Range Technology and Equipment Committee (RTEC) has been successful in soliciting funds from state and federal agencies to develop and construct harvesting, cleaning and seeding equipment. In addition, the group has published and distributed proceedings, manuals and reports to advance revegetation technology.

REFERENCES

Billings, W.D. 1994. Ecological impacts of cheatgrass and resultant fire on ecosystems in the western Great Basin, pp. 22-30. In: Proceedings: Ecology and Management of Annual Rangelands. S.B. Monsen and S.G. Kitchen (comps.). USDA, Forest Service, Intermountain Research Station. Gen. Tech. Rep. INT-GTR-313. Ogden, UT.

Blaisdell, J.P., R.B. Murray and E.D. McArthur. 1982. Managing Intermountain rangelands-sagebrush-grass ranges. USDA, Forest Service, Intermountain Forest and Range Research Station. Gen. Tech. Rep. INT-134. Ogden, UT. 41 p.

Boltz, M. 1994. Factors influencing postfire sagebrush regeneration in south-central Idaho, pp. 281-290. In: Proceedings: Ecology and Management of Annual Rangelands. S.B. Monsen and S.G. Kitchen (comps.). USDA Forest Service, Intermountain Research Station. Gen. Tech. Rep. INT-GTR-313. Ogden, UT.

Brown, E.R., C.F. Martinsen. 1959. Browse planting for big game in the state of Washington. Washington State Game Department Biol. Bull. 12. Olympia, Washington. 63 p.

Bunting, S.C. 1985. Fire in sagebrush-grass ecosystems: successional changes, pp. 7-11. In: Rangeland Fire Effects. K. Sanders and J. Durham (eds.). Symposium sponsored by USDI Bureau of Land Management and University of Idaho. USDI, Bureau of Land Management, Boise, ID.

Connelly, J.S. and C.E. Braun. 1997. Long-term changes in sage grouse (*Centrocercus urophasianus* populations in western North America. Wildlife Biology 3:123-128.

Cronquist, A. 1994. Vol. Five. Asterales. In: A. Cronquist, A.H. Holmgren, N.H. Holmgren, J.L. Reveal and P.K. Holmgren. Intermountain Flora. The New York Botanical Garden, Bronx, NY.

Deitz, D.R and J.G. Negy. 1976. Mule deer nutrition and plant utilization, pp. 71-78. In: Mule Deer Decline in the West--A Symposium. G.W. Workman and J.B. Low (eds.). Utah State University, College of Natural Resources, Utah Agricultural Experiment Station, Logan, UT.

Dobler, F.C. 1994. Washington state shrub-steppe ecosystem studies with emphasis on the relationship between nongame birds and shrub and grass cover densities, pp. 149-161. In: Proceedings-- Ecology and Management of Annual Rangelands. In: S.B. Monsen and S.G. Kitchen (comps). USDA, Forest Service, Intermountain Research Station. Gen. Tech. Rep. INT-GTR-313. Ogden, UT.

Ellison, L. 1960. Influence of grazing on plant succession of rangelands. Bot. Rev. 26:1-78.

Forsling, C.L. and W.A. Dayton. 1931. Artificial reseeding on western mountain range lands. USDA Circ. 178. Washington, DC. 48 p.

Frischknecht, N.C. and A.T. Bleak. 1957. Encroachment of big sagebrush on seeded range in north-eastern Nevada. J. Range Manage. 10:165-170.

Goodrich, S. and E. Neese. 1986. Uinta Basin Flora. USDA Forest Service, Intermountain Region and Ashley National Forest and USDI Bureau of Land Management, Vernal District, Ogden, UT. 319 p.

Goodrich, S., E.D. McArthur and A.H. Winward. 1999. Sagebrush ecotones and average annual precipitation. In: E.D. McArthur, W.K. Ostler and C.L. Wambolt (comps.). Proceedings: Shrubland Ecotones. USDA Forest Service, Rocky Mountain Research Station. RMRS-P-11. Ogden, UT.

Hanson, C.L., H.G. Fisser and J.R. Wight. 1986. Biology and ecology of sagebrush in Wyoming: V. Herbage yield dynamics and seasonal precipitation patterns, pp. 326-330. In: Proceedings--Symposium on the Biology of *Artemisia* and *Chrysothamnus*. E.D. McArthur and B.L. Welch (comps.). USDA, Forest Service, Intermountain Research Station. Gen. Tech. Rep. INT-200. Ogden, UT.

Holmgren, R.C. 1954. A comparison of browse species for revegetation of big game winter ranges in southwestern Idaho. USDA, Forest Service, Intermountain Forest and Range Experiment Station. Res. Pap. 33. Ogden, UT. 12 p.

Houston, W.R. 1961. Some interrelations of sagebrush, soils, and grazing intensity in the Northern Great Plains. Ecol. 42:31-38.

Hubbard, R.L, E.C. Nord and L.L. Brown. 1959. Bitterbrush reseeding--a tool for the game manager. Misc. Paper 39. USDA, Forest Service, Pacific Southwest Forest and Range Experiment Station. Misc. Paper 39. Berkeley, CA. 14 p.

Hull, A.C., Jr. 1971. Grass mixtures for seeding sagebrush lands. J. Range Manage. 24:150-152.

Hull, A.C., Jr. and R.C. Holmgren. 1964. Seeding southern Idaho rangelands. USDA Forest Service, Intermountain Forest and Range Experiment Station. Res. Pap. INT-10. Ogden, UT. 31 p.

Johnson, D.A. 1980. Improvement of herbaceous plants for drought-stressed western rangelands, pp. 419-433. In: Adaptation of Perennial Herbaceous Plants for Drought-stressed Western Rangelands. N.C. Turner and P.J. Kramer (eds.). John Wiley and Sons, New York.

Johnson, D.A., M.D. Rumbaugh and K.H. Asay. 1981. Plant improvement for semiarid rangelands: possibilities for drought resistance and nitrogen fixation. Plant and Soil 58: 279-303.

Kelsey, RG. 1986a. Emergence, seedling growth, and crude terpenoid concentrations in a sagebrush garden, pp. 358-365. In: McArthur, E.D. and B.L. Welch, comps. Proceedings—symposium on the biology of *Artemisia* and *Chrysothamnus*; 1984 July 9-13; Provo, UT. U.S. Department of Agriculture, Forest Service, Intermountain Research Station. Gen. Tech. Rep. INT-200. Ogden, UT.

Kelsey, R.G. 1986b. Foliage biomass and crude terpenoid productivity of big sagebrush (*Artemisia tridentata*), pp. 375-388. In: McArthur, E.D. and B.L. Welch, comps. Proceedings—symposium on the biology of *Artemisia* and *Chrysothamnus*; 1984 July 9-13; Provo, UT. U.S. Department of Agriculture, Forest Service, Intermountain Research Station. Gen. Tech. Rep. INT-200. Ogden, UT.

Liao, J. 1996. Phenological development and seed germination characteristics of rush skeletonweed in southwestern Idaho. Brigham Young University, Provo, UT. 57 p. M.S. Thesis.

Mack, R.N. 1981. Invasion of *Bromus tectorum* L. into western North America: an ecological chronicle. Agro-Ecosystems 7:145-165.

McArthur, E.D. 1988. New plant development for range management, pp. 81-112. In: Vegetation Science Application for Rangeland Analysis and Management. P.T. Tueller (ed.). Kluwer Academic Publishers, Dordrecht, Netherlands.

McArthur, E.D. 2000. Sagebrush systematics and distribution, pp. 9-14. Entwistle, P.G., A.M. DeBolt, J.H. Kaltenecker and K. Steenhof (comps.). Proceedings: Sagebrush Steppe Ecosystem Symposium. USDI Bureau of Land Management. BLM Pub. BLM/ID/PT-001001 + 1/50. Boise, ID.

McArthur, E.D. and S.A. Young. 1999. Development of native seed supplies to support restoration of pinyon-juniper sites, pp. 327-330. In: Proceedings: Ecology and Management of Pinyon-Juniper Communities within the Interior West. S.B. Monsen and R. Stevens (comps.). USDA Forest Service, Rocky Mountain Research Station. Proc. RMRS-P-9. Ogden, UT.

McArthur, E.D., A.C. Blauer, A.P. Plummer, and R. Stevens. 1979. Characteristics and hybridization of important intermountain shrubs. III. Sunflower family. USDA Forest Service, Intermountain Forest and Range Experiment Station. Res. Pap. INT-220. Ogden, UT.

Meyer, S.E. 1994. Germination and establishment ecology of big sagebrush: Implications for community restoration, pp. 244-251. In: Proceedings-Ecology and Management of Annual Rangelands. S.B. Monsen and S.G. Kitchen (comps.). USDA, Forest Service, Intermountain Research Station. Gen. Tech. Rep. INT-GTR-313. Ogden, UT.

Meyer, S.E. and S.B.Monsen. 1990. Seed-source differences in initial establishment for big sagebrush and rubber rabbitbrush, pp. 200-208. In: Proceedings--Symposium on Cheatgrass Invasion, Shrub Die-off, and Other Aspects of Shrub Biology and Management. E.D. McArthur et al. (comps.). USDA, Forest Service, Intermountain Research Station. Gen. Tech. Rep. INT-276. Ogden, UT.

Meyer, S.E. and S.B. Monsen. 1992. Big sagebrush germination patterns: subspecies and population differences. J. Range Manage. 45:87-93.

Meeuwig, R.O. 1965. Effects of seeding and grazing on infiltration capacity and soil stabilization of a subalpine range in central Utah. J. Range Manage. 18:173-180.

Megahan, W.F. 1974. Deep-rooted plants for erosion control on granitic road fills in the Idaho Batholith. USDA, Forest Service, Intermountain Forest and Range Experiment Station. Res. Pap. INT-161. Ogden, UT.

Memmott, K.L. 1995. Seasonal dynamics of forage shrub nutrients and seasonal grazing impacts on cryptogamic crusts. Brigham Young University, Provo, UT. 42 p. M.S. Thesis.

Monaco, T.A. 1996. Use of dark respiration to determine optimal adaptation in native Great Basin plant species. Brigham Young University, Provo, UT. 74 p. M.S. Thesis.

Monsen, S.B. 1989. Shrub selection for pinyon-juniper plantings, pp. 326-329. In: Proceedings--Pinyon-juniper Conference. R.L. Everett (comp.). USDA, Forest Service, Intermountain Research Station. Gen. Tech. Rep. INT-215. Ogden, UT.

Monsen, S.B. 1994. The competitive influence of cheatgrass (*Bromus tectorum*) on site restoration, pp. 43-50. In: Proceedings--Ecology and Management of Annual Rangelands. S.B. Monsen and S.G. Kitchen (comps.). USDA, Forest Service, Intermountain Research Station. Gen. Tech. Rep. INT-GTR-313. Ogden, UT.

Monsen, S.B. and E.D. McArthur, 1984. Factors influencing establishment of seeded broadleaf herbs and shrubs following fire, p. 112-124. In: K. Sanders and J. Durham (eds.). Rangeland Fire Effects, a Symposium. USDI, Bureau of land Management, Idaho State Office, Boise, ID.

Monsen, S.B. and S.E. Meyer. 1990. Seeding equipment effects on establishment of big sagebrush on mine disturbances, pp. 192-199. In: Fifth Billings Symposium on Disturbed Land Rehabilitation. Vol. I. Hardrock Waste, Analytical, and Revegetation. Reclamation Research. Montana State University. Unit Pub. 9003. Bozeman, MT.

Monsen, S.B. and A.P. Plummer. 1978. Plants and treatment for revegetation of disturbed sites in the Intermountain area, pp 155-173. In: The Reclamation of Disturbed Arid Lands. R.A. Wright (ed.). University of New Mexico Press, Albuquerque, NM.

Monsen, S.B. and N.L. Shaw. 1982. Seeding antelope bitterbrush with grass on south-central Idaho rangelands–a 39-year response, pp. 126-136. In: Proceedings-- Research and Management of Bitterbrush and Cliffrose in Western North America. A.R. Tiedemann and K.L. Johnson (comps.). USDA, Forest Service, Intermountain Forest and Range Experiment Station. Gen. Tech. Rep. INT-152. Ogden, UT.

Monsen, S.B. and N.L. Shaw. 1984. Response of an alkali sagebrush/fescue site to restoration treatments, pp. 126-133. In: Proceedings--Symposium on the Biology of *Artemisia* and *Chrysothamnus*. E.D. McArthur and B.L. Welch (comps.). USDA, Forest Service, Intermountain Research Station. Gen. Tech. Rep. INT-200. Ogden, UT.

Pechanec, J.F., A.P. Plummer, J.H. Robertson and A.C. Hull, Jr. 1944. Eradication of big sagebrush (*Artemisia tridentata*). USDA, Forest Service, Intermountain Forest and Range Experiment Station. Res. Pap.10. Ogden, UT. 23 p.

Pellant, M. and C. Hall. 1994. Distribution of two exotic grasses on Intermountain rangelands: status in 1992, pp 109-112. In: Proceedings--Ecology and Management of Annual Rangelands. S.B. Monsen and S.G. Kitchen (comps.). USDA, Forest Service, Intermountain Research Station. Gen. Tech. Rep. INT-GTR-313. Ogden, UT.

Petersen, K.L. 1987. Effects of prescribed burning on nongame birds in a sagebrush community. Wildlife Soc. Bull. 15:317-329.

Peterson, J.G. 1995. Ecological implications of sagebrush manipulation. Montana Fish, Wildlife and Parks, Wildlife Management Division. Federal Aid in Wildlife Restoration Project W-101-R-2. Helena, MT. 49 p.

Piemeisel, R.L. 1951. Causes affecting changes and rate of change in vegetation of annuals in Idaho. Ecol. 32:53-72.

Platt, K. and D.R. Jackman. 1946. The cheatgrass problem in Oregon. Oregon Agriculture Experiment Station. Bull. 668. Corvallis, OR. 48 p.

Plummer, A.P. and R.L. Jensen. 1957. Job completion report for artificial revegetation studies on big game ranges in Utah. Information Bull. 1955-56. Utah State Department of Fish and Game, Salt Lake City, UT. 26 p.

Plummer, A.P, A.C. Hull, Jr, G. Stewart and J.H. Robertson. 1955. Seeding rangelands in Utah, Nevada, southern Idaho, and western Wyoming. USDA Handbook 71. Washington, DC. 73 p.

Richardson, B.Z., S.B. Monsen and D.M.Bowers. 1986. Interseeding selected shrubs and herbs on mine disturbances in southeastern Idaho, pp 134- 139. Proceedings-- Symposium on the Biology of *Artemisia* and *Chrysothamnus*. In: E.D. McArthur and B.L. Welch (eds.). USDA, Forest Service, Intermountain Research Station. Gen. Tech. Rep. INT-200. Ogden, UT.

Roche, C.T. and B.F Roche, Jr. 1988. Distribution and amount of four knapweed (*Centaurea* L.) species in eastern Washington. Northwest Sci. 62:242-251.

Roundy, B.A. 1994. Relating seedbed environmental conditions to seedling establishment, pp 295-299. In: Proceedings--Ecology and Management of Annual Rangelands. S.B. Monsen and S.G. Kitchen (comps.). USDA, Forest Service, Intermountain Research Station. Gen. Tech. Rep. INT-GTR-313. Ogden, UT.

Saab, V.A. and T. C. Rich. 1997. Large-scale conservation assessment for Neotropical migratory land birds in the interior Columbia River Basin. PNW-GTR-399. USDA-FS, Portland, Oregon.

Sampson, A.W. 1921. Reseeding the range. National Wool Grower 11:11-13.

Sampson, A.W. and B.S. Jespersen. 1963. California range brushlands and browse plants. Calif. Agric. Exp. Stn. Ext. Serv. Man. 33. Berkeley, CA. 162 p.

Shaw, N.L. 1993. Germination and seedling establishment of spiny hopsage in response to planting date and seedbed environment. J. Range Manage. 47:165-174.

Shaw, N.L. and B.A. Roundy. 1997. Proceedings: Using Seeds of Native Species on Rangelands. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station Gen. Tech. Rep. INT-GTR-372. Ogden, UT. 30 p.

Shaw, N.L., V.A. Saab, S.B. Monsen and T.D. Rich. 1999. *Bromus tectorum* expansion and biodiversity loss on the Snake River Plain, southern Idaho, USA. VI International Rangeland Congress, Aitkenvale, Queensland, Australia. 2:586-588.

Sheley, R.L. and J.K. Petroff. 1999. Biology and management of noxious rangeland weeds. Oregon State University Press. Corvallis, OR. 438 p.

Sparks, S.R., N.E. West and E.D. Allen. 1990. Changes in vegetation and land use at two townships in Skull Valley, western Utah, pp 26-36. Proceedings--Symposium on Cheatgrass Invasion, Shrub Die-off, and Other Aspects of Shrub Biology and Management. In: E.D. McArthur et al. (comps.). USDA, Forest Service, Intermountain Research Station. Gen. Tech. Rep. INT-276. Ogden, UT.

Stevens, R., K.R. Jorgensen, S.A. Young and S.B. Monsen. 1996. Forb and shrub seed production guide for Utah. Utah State University Extension Service, Logan, UT. 51 p.

Updike, D.R, E.R. Loft and F.A. Hall. 1990. Wildfires on big sagebrush/antelope bitterbrush range in northeastern California: Implications for deer populations, pp 41-46. Proceedings--Symposium on Cheatgrass Invasion, Shrub Die-off, and Other Aspects of Shrub Biology and Management. In: E.D. McArthur et al. (comps.). USDA, Forest Service, Intermountain Research Station. Gen. Tech. Rep. INT-276. Ogden, UT.

Walker, S.C. 1999. Species compatibility and successional processes affecting seeding of pinyon-juniper types, pp. 331-337. In: Proceedings: Ecology and Management of Pinyon-Juniper

Communities within the Interior West. S.B. Monsen and S.G. Kitchen (comps.). USDA, Forest Service, Rocky Mountain Research Station. RMRS-P-9. Ogden, UT.

Welsh, S.L., N.D. Atwood, S. Goodrich, and L.C. Higgins (eds.). 1987. A Utah Flora. Great Basin Naturalist Memoirs 9. Brigham Young University, Provo, UT. 894 p.

Wieland, P.A. T., E.R. Frolich and A. Wallace. 1971. Vegetation propagation of woody shrub species from the Northern Mojave and southern Great Basin deserts. Madrono 21:149-152.

Workman, G.W. and J.B. Low. 1976. Mule deer decline in the West - a symposium. Utah State University, College of Natural Resources, Utah Agricultural Experiment Station, Logan, UT. 134 p.

Whisenant, S.G. 1990. Changing fire frequencies on Idaho's Snake River Plain: ecology and management implications, pp. 4- 10. In: Proceedings-Symposium on Cheatgrass Invasion, Shrub Die-off, and Other Aspects of Shrub Biology and Management. E.D. McArthur et al. (comps.). USDA, Forest Service, Intermountain Research Station. Gen. Tech. Rep. INT-276. Ogden, UT.

Williams, T.A. 1898. A report upon the grasses and forage plants and forage conditions of the Rocky Mountain Region. USDA, Division of Agrostology. Bull. 12. Washington, DC.

Yoakum, J.D. 1978. Pronghorn, pp 103-121. In: Big Game of North America. J.L. Schmidt and D.L. Gilbert (eds.). Stackpole Books, Harrisburg, PA.

Young, J.A., R.E. Eckert, Jr. and R.A. Evans. 1979. Historical perspectives regarding the sagebrush ecosystem, pp. 1-13. In: The Sagebrush Ecosystem; A Symposium. Utah State University, College of Natural Resources, Logan, UT.

Young, S.A. 1994. The (certified) seeds of revegetation, pp 271-272. In: Proceedings--Ecology and Management of Annual Rangelands. S.B. Monsen and S.G. Kitchen (comps.). USDA, Forest Service, Intermountain Research Station. Gen. Tech. Rep. INT-GTR-313. Ogden, UT.

2000 Billings Land Reclamation Symposium

DERIVATION AND INTERPRETATION OF WYOMING'S POSTMINING SHRUB DENSITY AND COMPOSITION STANDARDS FOR COAL MINE LANDS

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ABSTRACT

Since its approval in 1980, the Wyoming Coal Program has been graced by a variety of postmining shrub density/compositional standards for coal mine lands. This paper briefly traces the history of the appearance (and disappearance) of various goals and standards. This segment briefly outlines the components of the current density/compositional ***goal*** for lands affected prior to 8/6/96 and the ***performance standard*** for lands affected after 8/6/96.

The paper presents actual premining baseline data to illustrate the mechanics (and quirks) of the formulae which establish the current goal and standard for each individual mine site.

The paper concludes with presentation and discussion of select data addressing achievement of the goal and standard. Apparent reasons for achievement of (or lack of achievement of) the goal and standard will be discussed.

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INTRODUCTION

The history of shrub restoration requirements for Wyoming coal mine lands is checkered and complex. The general topic of shrub restoration has all too often devolved to haggling over the contribution of one or more of the three varieties of big sagebrush (Artemisia tridentata). The emotionally charged opinions about big sagebrush confound and do not help elucidate the more general topic of the restoration of shrub habitat and shrub composition. Readers of this paper should understand that use of the term shrub includes a variety of shrub species, including all shrubs and subshrubs which were identified in baseline vegetation surveys. Readers should not equate shrub exclusively with Big sagebrush.

HISTORICAL PERSPECTIVES

The 1973 Wyoming Legislature promulgated the Wyoming Environmental Quality Act (Wyo. EQA) which held that lands affected by mining operations should be reclaimed to the highest previous use of the affected lands. The Wyo. EQA uses words such as "surrounding terrain and natural vegetation", "wildlife and aquatic habitat and resources" and the "utility and capacity of the reclaimed lands to support such (highest previous) uses". The Wyo. EQA has never detailed shrub restoration requirements, but it does establish a requirement to consider habitat when reclaiming mined lands.

The 1973 Wyo. EQA directed the establishment of rules and regulations for reclamation standards. By November 1975, the Wyoming Department of Environmental Quality, Land Quality Division (LQD) had published a set of Rules and Regulations which required permittees to restore the land to a condition equal to or greater than its highest previous use and required permittees to restore wildlife habitat commensurate with or superior to premining habitat.

The United States Congress promulgated the Surface Mining Control and Reclamation Act (SMCRA) and thereby established the Office of Surface Mining Reclamation and Enforcement (OSM) in 1977. SMCRA included a quantitative postmining shrub density standard for coal mine lands. Perhaps more importantly SMCRA provided a mechanism by which states could assume primacy for implementation of SMCRA.

After lengthy negotiations, the OSM approved the Wyoming State Coal Program (Wyoming Coal Program) in November 1980. On this date, the LQD Rules and Regulations required that operators restore postmining shrub density ***equal to*** premining shrub density.

Since November 1980, a very complex and at times chaotic drama has unfolded. The cast of players in everchanging combinations have included:

- the Wyoming State Legislature
- the Wyoming Department of Environmental Quality/LQD

- the Wyoming Game and Fish Department (Wyo. Game and Fish)
- the OSM, Denver and Casper offices
- the LQD Advisory Board, a citizens' board appointed by the Governor which has consultative and advisory oversight of the LQD
- the Wyoming Environmental Quality Council (Wyo. EQC), a citizens' body appointed by the Governor which acts as the hearing examiner for all cases contesting the administration or enforcement of all actions of the Wyo. Department of Environmental Quality
- other interested (and invited) organizations

An example of these entangled interactions is the historical group of 12 persons which met 10 times from May through August 1994 to draft new LQD Rules and Regulations on shrub restoration. This working group comprised representatives of the LQD, the Wyo. Game and Fish, the Wyoming Mining Association and several environmental groups. In order that each person would "buy into" their final product (which would be forwarded to the LQD Advisory Board, then the Wyo. EQC and then the OSM), each person's concerns required full resolution.

The regular recasting of Wyoming state laws and federal laws and LQD Rules and Regulations created a wide variety of shrub restoration goals and standards between 1980 and 1996. The last major act of this morality play occurred on August 6, 1996 when OSM approval inserted the new shrub restoration standard into the LQD Rules and Regulations and thereby created a shrub restoration goal and a shrub restoration standard. The key distinctions between a goal and a standard will be discussed later.

These shrub restoration revisions were not the only revisions to the Wyo. EQA and LQD Rules and Regulations over these years. The cumulative effect of all revisions created a great deal of uncertainty concerning what goal or standard applied to specific affected land units. On October 31, 1998, the LQD Administrator published a document entitled "How To Handle Bond Release On Coal Mined Lands Affected During Various Regulatory Time Frames". This document was also the product of extensive interaction between LQD staff and members of the Wyoming coal industry.

APPLICATION OF CURRENT LQD RULES AND REGULATIONS

The LQD Administrator's October 1998 statement of policy outlined the following time periods which help frame application of the LQD Rules and Regulations.

This paper compresses and rearranges the five temporal categories outlined in the original document and addresses only the shrub restoration topic. This compression is not appropriate for other postmining topics.

Lands Affected After June 30, 1973 And Prior To March 26, 1981

The Wyo. EQA (effective July 1, 1973) and OSM approval of the 1981 LQD Rules and Regulations (effective March 26, 1981) frame this period. If these affected lands were not used after March 26, 1981 in support of continuing mining operations, these lands have no shrub restoration goal or standard. Note that the date the land was affected, not the date of permanent reclamation, establishes the applicable trigger date.

Lands Affected After March 26, 1981 And Prior To August 6, 1996

The OSM's August 6, 1996 approval of revised LQD Rules and Regulations established a ***shrub restoration goal*** for lands affected in this temporal category and where those affected lands have not been used after August 6, 1996 in support of continuing mining operations.

The shrub restoration goal holds that when wildlife use is part of the postmining land use, the coal permittee should:

- restore a set percentage of the reclaimed lands to a mosaic of shrub patches. The percentage and distribution shall be determined from premining data.
- restore an average density of one shrub per square meter in the shrub patches.
- seed approved shrub species on all other reclaimed lands used jointly by livestock and wildlife.
- apply best technology currently available in all efforts to achieve the goal.

The shrub restoration goal is not an absolute, statutory requirement which must be unambiguously achieved in all reclamation. Rather, the goal implies that the coal permittee will consistently use sound, widely accepted reclamation practices to attempt to attain the target. The permittees' final results will be subjectively judged at final Incremental Bond release (Phase 3 bond release) using a combination of qualitative and quantitative data.

Lands Affected After August 6, 1996

The OSM's August 6, 1996 approval establishes a ***shrub restoration standard*** for lands in this category and for all lands which were affected earlier but which have been used after 8/6/96 in support of continuing mining operations. The shrub restoration standard applies to all reclaimed lands which have the designated land uses of grazingland and fish and wildlife habitat.

Appendix A of the LQD Coal Rules and Regulations holds that coal permittees shall:

- except where a lesser density is justified by premining conditions, restore at least 20% of eligible lands to shrub patches supporting an average density of one shrub per square meter.

- ensure that shrub patches are no smaller than 0.5 acres each and are arranged in a mosaic that will optimize habitat interspersion and edge effect.

- use plant community-specific, premining shrub density and shrub composition data to determine the postmining areal extent of shrub patches and their specific postmining density and composition.

- choose one of four calculation options for all eligible land within each permit area or amendment area.

- ensure that the average postmining total and species-specific shrub densities are at least 90% of the calculated densities at the time of final Incremental Bond release (Phase 3 bond release).

The shrub restoration standard is an absolute, statutory requirement which must be unambiguously achieved on all eligible lands at the time of final Incremental Bond (Phase 3) release. Simply trying to attain the performance standard is not adequate.

Appendix A of the LQD Rules and Regulations details the four options and calculation procedures for the shrub restoration standard. The calculation procedures are complex and use premining baseline data. The working group which developed these procedures recognized that premining data sets were as old as 25 years, that they were gathered by many different consultants and that the data sets were seldom developed with the detail required in Appendix A calculations. Table 1 is a brief summary of the four possible options. To date, most coal permittees in the Wyoming Powder River Basin have chosen Option II or III. Table 2 is an example using data from the Jacobs Ranch Mine in Campbell County, WY. Table 3 is an example using data from the Caballo Rojo Mine in Campbell County, WY.

Option	Distinguishing Characteristics
I	Postmining standard is not community-specific, but is based upon the premining density of only full shrubs; reductions in premining shrub density are possible if any premining community has a shrub density greater than one per square meter and is less than 20% of the eligible lands.
II	Postmining standard is not community-specific, but is based upon the premining density of only full shrubs; the postmining shrub density is set at one per square meter.
III	Postmining standard is community-specific and is based upon the premining density of only full shrubs; each eligible premining community contributes to the calculation of postmining density and areal extent of community-specific shrub patches.
IV	Postmining standard is community specific, but is based upon the premining density of full and subshrubs; each eligible premining community contributes to the calculation of postmining density and areal extent of community- specific shrub patches.

Table 1. Characteristics of Options I through IV for a postmining shrub restoration standard

Eligible Premining Vegetation Community	Acres Affected after April 6, 1996	% Eligible Acreage	Density Premining Full Shrubs (no./m^2)	Adjusted Density Postmining Total Shrubs (no./m^2)	Number Premining Full Shrubs w/Relative Density $0.1	Dominant Premining and Postmining Full Shrub	(2)Density Postmining Dominant Shrub (no./m^2)	(3)Density Postmining Residual Shrubs (no./m^2)	(4)Density Postmining Approved Subshrub (no./m^2)	(5)Acres in Shrub Patches
Big sagebrush	825	31.7	5.24	1.0 (1)	1	Big sagebrush	0.5	0.25	0.25	165
Upland grassland	1544	59.3	0.15	0.15	1	same	0.075	0.038	0.038	308.8
Bottomland grassland	15	0.6	0.08	0.08	1	same	0.04	0.02	0.02	3.0
Playa-Dry	158	6.1	0.04	0.04	1	same	0.02	0.01	0.01	31.6
Playa-Wet	60	2.3	0.0	0.0	0	none	0.0	0.0	0.0	12.0
TOTAL	2602	100	–	–	–	–	–	–	–	520.4

Table 2. Example of calculations and actual target values for Option III (community-specific shrub density standard) for the Jacobs Ranch Mine, Campbell County, Wyoming

Notes:

(1) The maximum postmining density for any community-specific shrub patch is one per square meter.

(2) Density Postmining Dominant Shrub = [density of premining total shrub] multiplied by the factor of [1.0 divided by the total number of full shrubs with Relative Density $ 0.1 plus 1.0] e.g. for the Big sagebrush community 0.5 = [1.0] x [1.0/1+1.0]

(3) Residual Shrubs are all premining full shrubs (other than the premining dominant) and other approved subshrubs which have a Relative Density $0.1.

(4) Approved Subshrubs are *Artemisia frigida, Atriplex gardneri, Ceratoides lanata, Artemisia pedatifida* and *Artemisia spinescens*.

(5) Postmining acreage for each community equals 20% of the acres affected after April 6, 1996.

Eligible Premining Vegetation Community	Acres Affected after April 6, 1996	% Eligible Acreage	Density Premining Full Shrubs (no./m^2)	[1]Density Postmining Total Shrubs (no./m^2)	Number Premining Full Shrubs w/Relative Density $0.	Dominant Premining and Postmining Full Shrub	[1] Density Postmining Dominant Shrub (no./m^2)	[1] Density Postmining Residual Shrubs (no./m^2)	[3] Density Postmining Approved Subshrub (no./m^2)	Acres in Shrub Patches
Sagebrush Shrubland	869.5	33.4	2.46	N/A	1	big sagebrush	N/A	N/A	N/A	N/A
Rough Breaks	211.3	8.1	1.96	N/A	1	same	N/A	N/A	N/A	N/A
Mixed Grass Prairie	1,460.2	56.2	0.4	N/A	1	same	N/A	N/A	N/A	N/A
Bunchgrass	4.4	0.2	0.24	N/A	1	same	N/A	N/A	N/A	N/A
Lowland Prairie	29.5	1.1	0.08	N/A	1	same	N/A	N/A	N/A	N/A
Playa Grassland	25.8	1.0	0.0	N/A	0	none	N/A	N/A	N/A	N/A
TOTAL	2600.7	100.0	__	1.0	__	big sagebrush	0.5 [2]	0.25	0.25	520.1 [4]

Table 3. Example of calculations and actual target values for Option II (permit-wide shrub density standard) for the Caballo Rojo Mine, Campbell County, Wyoming

Notes: [1] N/A appears in these cells because Option II does not require community-specific density calculations.

[2] Density Postmining Dominant Shrub = [density of premining total shrub] multiplied by the factor of [1.0 divided by the total number of full shrubs with Relative Density $0.1 plus 1.0] e.g., for the big sagebrush community 0.5 = [1.0] x [1.0/1+1.0].

[3] Approved Subshrubs are same as on Table 2.

[4] Postmining acreage equals 20% of the eligible acres affected after August 6, 1996.

ACHIEVEMENT OF SHRUB RESTORATION GOAL AND STANDARD

The LQD has at least four information sources to evaluate a permittee's progress toward and final achievement of the applicable goal and standard. The first source contains the only data which will be used to make a final determination that the goal and standard were achieved. The other three sources will provide some insight that the permittee is trending toward achievement. The four data sources are:

- formal data submitted in support of final Incremental Bond (Phase 3) release. These data derive from detailed quantitative field sampling regimes and rigorous statistical tests of sample adequacy.

- formal data submitted in fulfillment of Interim Vegetation Monitoring (IVM) programs. These data derive from moderately detailed quantitative field sampling regimes, but are without rigorous tests of sample adequacy.

- limited data from qualitative and semi-quantitative field surveys conducted by LQD staff. These field surveys are moderately detailed, but are without any tests of sample adequacy.

- other observations or data submitted by coal permittees or their consultants.

In relation to achievement of the shrub restoration goal, the LQD has received no requests for final Incremental (Phase 3) Bond release; thus, no rigorous quantitative data are available. However, all coal permittees in the Wyoming Powder River Basin have approved IVM programs; some data are available from most of those IVM programs. Table 4 presents a select summary of a partial survey of data from IVM program data as presented in LQD Annual Reports. These data suggest that coal permittees may attain the shrub restoration goal when they selectively seed and specifically map and sample defined shrub patches. Secondly, these data also suggest that coal permittees will not attain the shrub restoration goal if they do not selectively seed shrub patches; the general, background plant communities are not showing adequately dense patches even when reclamation is as old as 16 years. Thirdly, data are not available to clearly assess whether shrub patches cover 10% of the reclaimed goal lands.

Mine	Field Sample Year	Reclamation Sampled		Age Of Reclamation At Sample Year	Range Of Full And Subshrub Density (no./m^2)
		Seeded Shrub Patch	General Plant Community		
Belle Ayr	1995	X	X	10-16	0.001 - 0.5
	1998			12-14	0.3
Wyodak	1994		X	3	0.8 - 3.0
	1997	X		7	2.0
	1998		X	6-16	0.01 - 0.9
Black Thunder	1993		X	1-3	0.2 - 5.8
	1995		X	2-4	0.4 - 1.3
	1997		X	2-6	0.003 - 1.6
	1998		X	1-7	0.005 - 2.7
Cordero	1995	X (?)		?	0.0 - 2.4
	1998		X	4-12	0.0 - 0.5
Rawhide	1994	X		3-8	0.1 - 12.1
	1995		X	7-16	0.01 - 0.5
	1995	X		6-8	0.2 - 4.2
	1996		X	4	0.02 - 0.1
	1996	X		4-10	0.03 - 3.5
	1997		X	3	0.1 - 0.4
	1997	X		3-10	0.01 - 5.4
	1998		X	4-20	0.01 - 0.6

Table 4. Total (full plus subshrubs) shrub density data from permanently reclaimed lands covered by the shrub restoration goal for select coal mines in Campbell County, WY

The first two conclusions are generally supported by semi-quantitative surveys conducted by Richard Vincent of the LQD on five mines in the Powder River Basin in 1999. Coal permittees or their consultants have not submitted other observations or field data which would alter these conclusions concerning attainment of the shrub restoration goal.

There are very few hard data (but many opinions) available to determine whether coal permittees are achieving the shrub restoration standard, primarily because there is limited acreage of lands affected after August 6, 1996 and now permanently reclaimed. This acreage is progressively increasing, but the authors found only one IVM program data set which addresses lands reclaimed under the standard. A portion of the Black Thunder Mine's 1998 IVM program sampled one-year old shrub patches and recorded total shrub densities ranging from 0.5 - 2.3 shrubs per square meter. The data were not presented in a format suitable to assess the shrub composition element of the shrub

restoration standard.

No other specific data have been presented to the LQD in support of attainment of the shrub restoration standard.

The authors opine that to unambiguously achieve the shrub restoration standard, coal permittees must diligently:

- choose and apply the best available technology for establishing diverse (as approved) mixtures in distinct shrub patches.

- regularly observe and quantitatively sample the established shrub patches to evaluate the areal extent component and the compositional element and the density elements of the shrub standard.

- conduct best available husbandry practices to protect and encourage shrub establishment and survival in the shrub patches.

2000 Billings Land Reclamation Symposium

SEEDS AND SEEDLING ESTABLISHMENT OF WYOMING BIG SAGEBRUSH

D.T. Booth[1] and Y. Bai[2]

ABSTRACT

Success with sagebrush depends on good seed vigor, and rapid seedling development. These characteristics are influenced by harvesting, processing, storing, and sowing. In this paper we discuss research findings related to those activities: (1) It appears that Wyoming big sagebrush growing on the western edge of the Great Plains might hold viable seed longer into the winter, and might have greater seed dormancy than do other habitat types. (2) Tests of debearder-processed seeds indicate the procedure does not degrade seed quality. (3) Sagebrush seeds in storage often show unexpected, and seemingly random viability losses. We need research to define the interactions of seed physiology and storage conditions and to predict seed shelf life. (4) Temperature has a measurable influence on water absorption by sagebrush seeds, but the rate and extent of water absorption does not appear to influence germination or seedling vigor. (5) Moisture stress will affect germination and an increase in moisture stress from 0.00 to -0.50 MPa will result in approximately half of germinable seeds remaining ungerminated. (6) Heavy seeds germinate better. We recommend seed buyers select seed lots with less than 3500 seeds/g to obtain high-vigor seeds; also, that seed lots be monitored using inexpensive in-the-office tests of germination. (7) We recommend sagebrush seeding rates of 1000 seeds/m^2. Lower seeding rates reduce stand density but heavier rates do not give a corresponding density increase. High seeding rates are consistent with sagebrush ecology.

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INTRODUCTION

The reestablishment of diverse, self-sustaining plant communities that include native shrubs is a prerequisite for bond release to mining companies extracting mineral resources in Wyoming and other western states (Federal Register 1996). Shrub reestablishment in general, and sagebrush restoration in particular, have presented continuing challenges that only recently have met with some consistency and predictability. Where the 1986 Wyoming coal mining rules stated a **goal** of 1 shrub /m^2 on 10% of the affected area, the 1996 rule **requires** 1 shrub /m^2 on 20% of the affected area (Federal Register 1996, Booth et al. 1999). Success with sagebrush, perhaps more than with other native shrubs, depends on a properly prepared seedbed, good seed vigor, and rapid seedling development. Sagebrush seed biology is influenced by harvesting, processing, storing, and sowing. In this paper we review some fundamentals for successful Wyoming big sagebrush revegetation.

BIG SAGEBRUSH SEEDS

Big sagebrush seeds are shiny achenes, about 2 mm long and enclosed in a papery pericarp that is often removed during seed cleaning (Booth et al. 1997). The pericarp can influence seed water uptake; although, differences in water uptake among naked and pericarp-covered achenes are small and probably not biologically significant (Bai et al. 1999). The achenes contain mucilaginous materials that may aid adhesion to the soil surface during radicle penetration (Walton et al. 1986); and, residual endosperm that is formed as a membrane fused to the inner wall of the seed coat (Atwater 1980, Meyer, in press). The cotyledons are large, thickened and dominate the axis. Young and Young (1992) reported Wyoming big sagebrush has 3500-3800 seeds/g and Bai et al. (1997) reported 3100-4500 seeds/g for five Wyoming collections harvested in February. Most sagebrush seeds used in reclamation are collected from native stands where seed production and quality vary from site to site, reflecting ecotypical influences, and from year to year as a result of weather and parental conditions. Seed quantity and quality varies, but reclamation continues. This, and the late seed-ripening dates mean that reclamation depends on seeds stored from previous year's harvests. Thus seed quality changes during storage, and the frustratingly short shelf-lives of some seed lots, are important revegetation issues.

HARVESTING, PROCESSING, AND STORING SEEDS

Sagebrush blooms in late summer and early fall and seeds mature October through December. Young and Young (1992) cautioned that seeds need to be harvested quickly after maturity to avoid losses and storm damage associated with the late season and Walton et al. (1986) report that viable seeds are dispersed during the first seven days after seed-ripe. Most sagebrush seed harvesting occurs in late fall or early winter, but significant amounts of Wyoming big sagebrush in Wyoming can be harvested in February (Bai et al. 1997) or later, indicating ripe seeds are held longer than seven days and that dispersion is spread over a greater time. Whether this is a characteristic of the subspecies, or a characteristic correlated to the more eastern part of sagebrush distribution is not known (see Meyer and Monsen 1992 for a discussion of habitat-correlated characteristics of sagebrush seeds).

Seed harvesting produces a mixture of seed stalks, flower parts, and seeds which is usually processed with debearders (a machine originally designed to remove the beard or awn from barley). Booth et al. (1997) found that debearder processing resulted in significant increases in the temperature and relative humidity of the material being processed (Fig. 1), but the transient (<10 min.) conditions had no effect on seed quality as measured by percent germination, germination rate, and seedling vigor. Even running a large load for 20 min. did not damage seeds nor decrease quality factors. Debearders do remove the pericarp from a fraction of the seeds and the longer seeds are in the machine, the greater the percentage with pericarp removed (Fig. 2). However, pericarp removal had no effect on seed germination percentage or rate, nor was there any evidence that it affected seed shelf life (Booth et al. 1997).

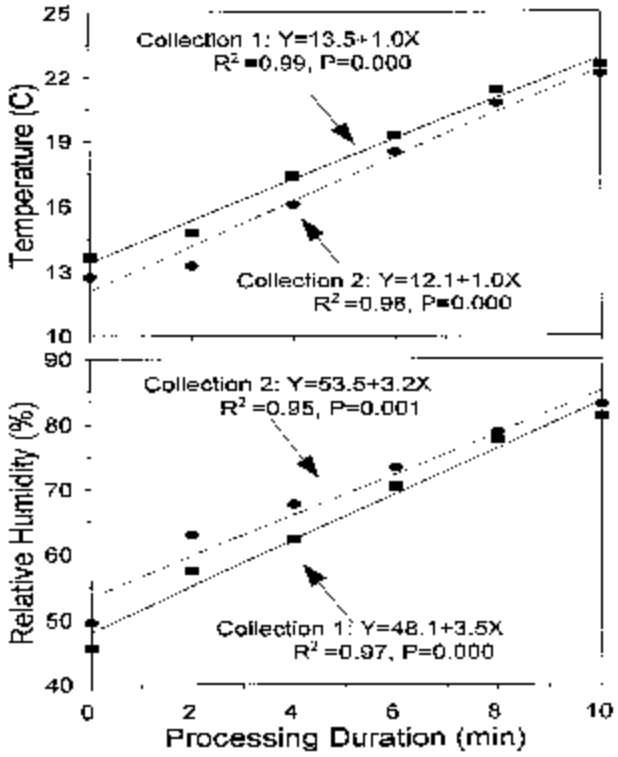

Fig. 1. Changes in temperature and relative humidity inside a debearder while processing Wyoming big sagebrush seeds (Booth et al. 1997).

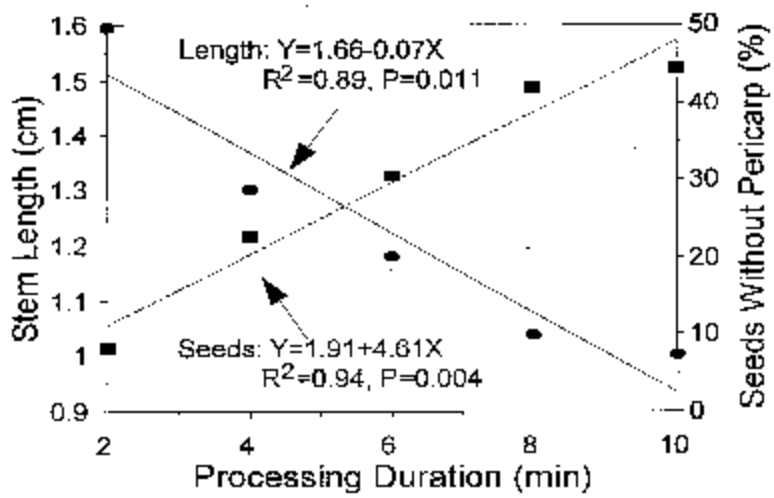

Fig. 2. Stem length and percent of Wyoming big sagebrush seed without pericarp after processing with a debearder (Booth et al. 1997). Stem length refers the effect of the debearder on stems contained in material collected at seed harvest.

Some Wyoming big sagebrush seed lots undergo costly, untimely decreases in germination percentage during storage. Bai et al. (1997) made five collections from Wyoming, stored them for 24 months at room temperature, and found that germination increased for one collection, decreased for two collections, and did not change for two collections. Booth and Shaw (in review) stored two lots of Idaho-collected Wyoming big sagebrush seeds for 15 months at -22°C and at room temperature, then tested the two seed storage conditions using two germination protocols. Both lots experienced significant reductions in germination percentage after six months regardless of storage conditions. After 15 months one protocol indicated cold storage preserved viability but the other protocol indicated decreased viability with no difference among storage conditions. Such results emphasize our need to understand environmental interactions with seed aging - particularly as it relates to accurate seed testing.

DORMANCY AND GERMINATION CHARACTERISTICS

Atwater (1980) has noted that seed dormancy in nonendospermic seeds is due to impermeable seed coats or to germination inhibitors contained within the seed. Sagebrush does not have impermeable seed coats and no germination inhibitors have been identified. However, Wyoming big sagebrush seed lots are known to contain some viable seeds that are not readily germinable after harvest (McDonough and Harniss 1974, Meyer and Monsen 1992, Bai et al. 1997, Booth et al. 1997). Meyer and Monsen (1992) reported that Wyoming big sagebrush seeds from 21 collections were largely nondormant when germinated at 15°C in light. The maximum percentage of dormant seeds in these collections was 11%. All of their collections were from west of the 110th meridian and whether

or how the geographic range influenced their results is unknown. Booth et al. (1997) studied two commercial seed lots and found that germination percentage increased by 15 to 20% after 4.5 months of storage, indicating an afterripening effect. Afterripening is post-harvest embryo maturation measured as the time required for seeds to become germinable. True dormancy may also affect a fraction of Wyoming sagebrush seeds (Booth et al. 1999). Seeds collected from and sown in the Powder River Basin produced seedlings during three post-sowing growing seasons (Schuman and Booth (1998), Schuman et al. (1998), and Schuman et al. (this proceedings)). This was also observed in an adjacent study in which annual photographs were used to record the appearance of new seedlings in permanent plots (data on file). The photographic data extrapolated to large areas imply 2 to 7 thousand seedlings/ha may appear the third growing season after seeds are sown, thus distributing Wyoming big sagebrush emergence from a single seed lot through at least 3 years.

WATER RELATIONS AND GERMINATION

Seed germination and germination rate of Wyoming big sagebrush are limited by water stress - similar to basin big sagebrush (Sabo et al. 1979, Walton et al. 1986) and fringed sagebrush (Bai et al. 1995). An increase in moisture stress from 0.00 to -0.50 MPa will result in approximately half of germinable seeds remaining ungerminated and those that do germinate will take twice as long as for seeds with no stress (Fig. 3).

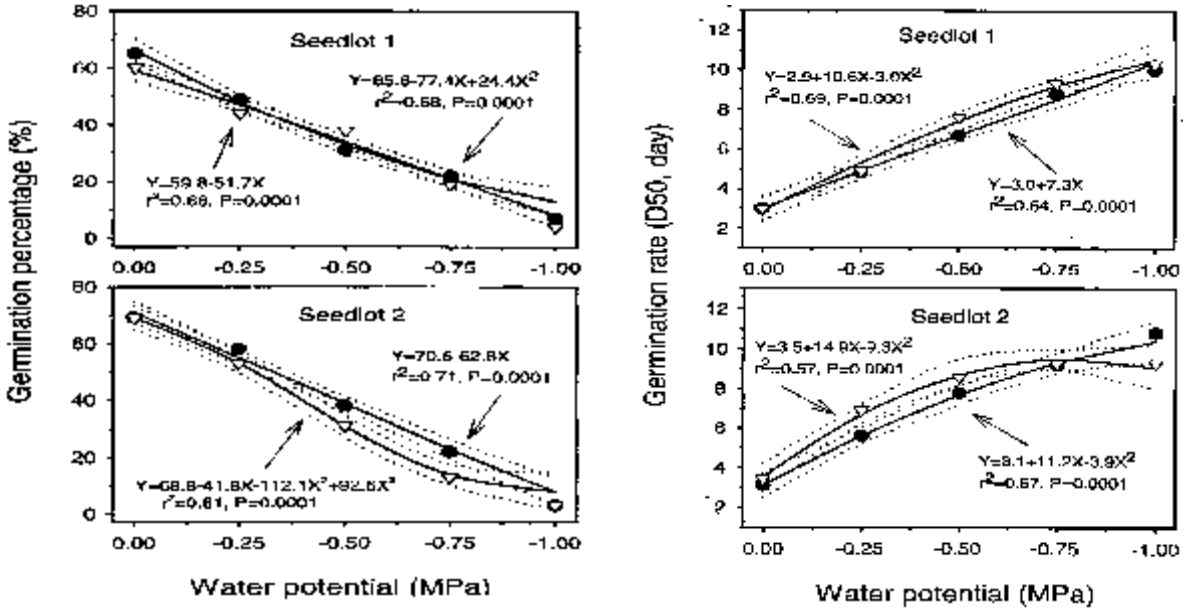

Fig. 3. Predicted germination percentage (solid line at left) and rate (D50, solid line at right) with 95% confidence bands (dotted line) of Wyoming big sagebrush seeds with (filled circles) or without (open triangles) pericarp as a function of water potential (Bai et al. 1999). Symbols indicate actual values.

Orthodox seeds like sagebrush are dispersed as desiccated micro-plants. How rehydration occurs - the rate, temperature, and extent - often has a lasting influence on germination and seedling performance (see Booth 1993 for a review). Managed rehydration, known as "seed priming", has enhanced field performance of a variety of agricultural seeds (Taylor and Harmon 1990). Bai et al. (1997) tested the interactions of temperature and time on seed water uptake of Wyoming big sagebrush under humid conditions. Significant moisture increases occurred after; 16 hours at 2ºC, 4 hours at 5ºC, and 2 hours at 10 and 15ºC (Figure 4). Seed moisture equilibrated with the humidity and reached the greatest concentration under the 10ºC regime. Surprisingly, no differences were detected in germination percentage, germination rate, or seedling vigor that could be related to moisture uptake. Neither did imbibition under wet (as contrasted to humid) conditions appear to have any significant influence on these processes. Thus, priming appears unlikely to enhance field performance of Wyoming big sagebrush.

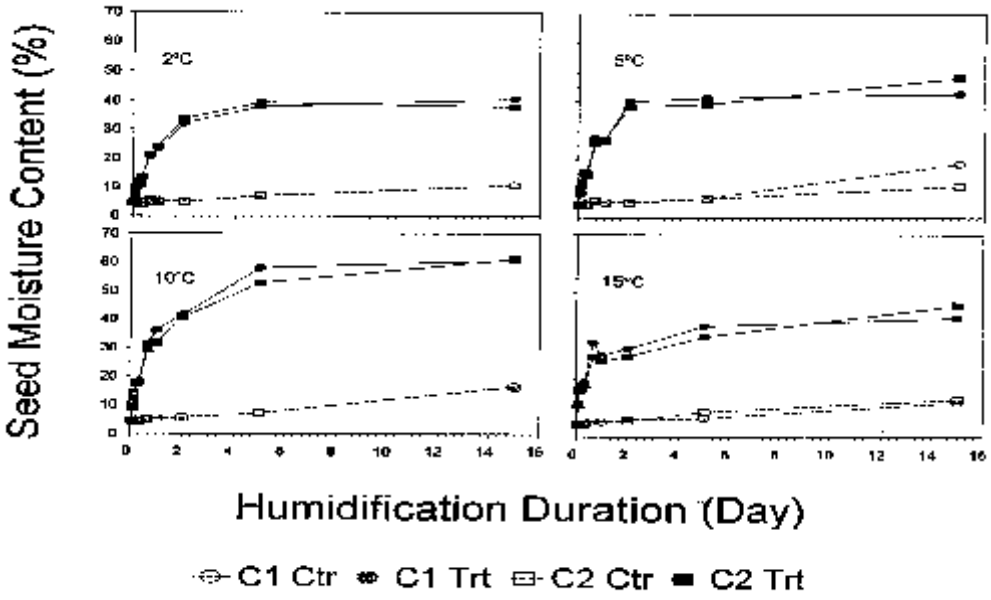

Fig. 4. Seed moisture content of humidified (Trt) and non-humidified (Ctr) Wyoming big sagebrush seeds at different temperatures and treatment durations (Bai et al. 1997).

SEED SIZE / TESTING / SEEDING RATES

Heavy Wyoming big sagebrush seeds are likely to germinate more quickly and to a greater extent than lighter seeds (Bai et al. 1997). We advise sagebrush seed buyers to pay attention to seed weight and look for lots with less than 3500 seeds/g (remembering that heavier seeds mean fewer seeds per gram). Our selection of 3500 seeds/g is arbitrary and based only on the range in seed weight reported in this paper and our findings that the heavier seed lots performed better than light seed lots.

Seed testing must be an ongoing exercise for sagebrush and can be conducted in the office at low-cost. In addition, seed lots older than six months from harvest should always be evaluated within a month of sowing. [See Bai et al. 1997 for our method of testing Wyoming big sagebrush seeds.]

Germination and seedling establishment are rapid under optimum temperature and moisture conditions when seeds are physiologically ready. However, the co-incidence of germinable seeds and optimum conditions in the field is unpredictable and random and the source of episodic "pulses" in seedling recruitment (Lommasson 1948, Walton et al. 1986, Schuman et al. 1998, Booth et al. 1999). Numerous agronomic practices have been developed to enhance establishment and these are discussed elsewhere in these proceedings. Regardless of these practices, the variability of weather and biological systems make optimum field conditions hard to predict and unlikely to be arranged. Older reclaimed sites with sagebrush have been found to have a shrub density directly correlated to the number of seeds dispersed up to about 1000 seeds/m^2 (Figure 5)(Booth et al. (1999).

The sagebrush diaspore is simple in construction and functions. The reproductive strategy is small seed size, high seed numbers, and distribution near the mother plant (Walton et al. 1986). High seeding rates are therefore consistent with sagebrush ecology. As with other species "good management requires an understanding of the mysteries of specific seedbed ecologies and innovation in adapting methods of seed distribution and fixation that will complement, rather than contradict, those diaspore functions most critical to seed success" (Booth 1987).

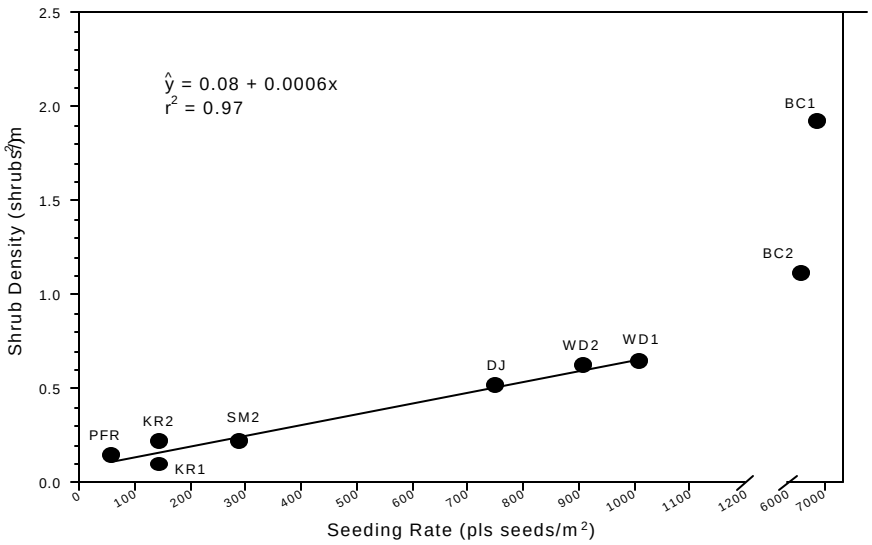

Fig. 5. Shrub density as influenced by the number of pure live seeds sown. The regression equation does not include data from the BC1 & 2 sites. Note the break in the x axis between 1200 and 6000 seeds/m^2. Letter symbols indicate different mines. Figure is from Booth et al. 1999.

REFERENCES

Atwater, B.R. 1980. Germination, dormancy and morphology of the seeds of herbaceous ornamental plants. Seed Sci. Technol. 8:523-573.

Bai, Y., J.T. Romo, and J.A. Young. 1995. Influences of temperature, light and water stress on germination of fringed sagebrush (*Artemisia frigida*). J. Range Manage. 48:219-225.

Bai, Y., S.P. Hardegree, D.T. Booth, and E.E. Roos. 1999. Technical note: Pericarp removal has little effect on sagebrush seeds. J. Range Manage. 52:384-386.

Bai, Y. 1997. Effect of seed moisture on Wyoming big sagebrush seed quality. J. Range Managment. 50:419-422.

Booth, D.T. 1987. Diaspores of rangeland plants: ecology and management. pp. 202-211. In: G.W. Frasier and R.A. Evans (eds) Proc. Symp. Seed and Seedbed Ecology of Rangeland Plants. Nat'l. Tech. Info. Serv., 5285 Port Royal Rd., Springfield, VA.

Booth, D.T. 1993. Can we improve shrub seedling vigor by managing seed imbibition? pp. 47-58. In: Planning, Rehabilitation and Treatment of Disturbed Lands - Sixth Bill. Symp. Recl., Res. Unit Publ. No. 9301, Montana State Univ., Billings, MT.

Booth, D.T., Y. Bai, and E.E. Roos. 1997. Preparing sagebrush seed for the market: Effects of debearder processing. J. Range Manage. 50:51-54.

Booth, D.T., J.K. Gores, G.E. Schuman, and R.A. Olson. 1999. Shrub densities on pre-1985 reclaimed mine lands in Wyoming. Restoration Ecology 7:1-9.

Booth, D.T. and N.L. Shaw. (in review). Technical Note on germinating and storing Wyoming big sagebrush seeds. J. Range Manage.

Federal Register. 1996. Office of Surface Mining and Enforcement. 30 CFR Part 950. Wyoming Regulator Program, final rule; approval of amendment. 61(152):40735.

Lommasson, 1948. Succession in sagebrush. J. Range Mange. 1:19-21 (reprinted in 1993, Rangelands 15:109-110).

McDonough, W.T. and R.O. Harniss. 1974. Effect of temperature on germination in three subspecies of big sagebrush. J. Range manage. 27:204-205.

Meyer, S.E. (in press). *Artemisia*. Woody Plant Seed Manual, USDA Forest Service.

Meyer, S.E. and S.B. Monsen 1992. Big sagebrush germination patterns: Subspecies and population differences. J Range Manage. 45:87-93.

Sabo, D.G., D.V. Johnson, W.E. Martin, and E.F. Aldon. 1979. Germination requirement of 19 species of arid plants. Res. Paper PM-210, USDA Forest Service, Rocky Mountain Forest and Range Exp. Sta., Fort Collins, CO.

Schuman, G.E. and D.T. Booth.1998. Strategies for establishment of big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) on Wyoming mined lands. Final Report, Aband. Coal Mine Land Res. Prog., Office of Res., Univ. Wyo., Laramie and Wyo. Dept. Envir. Quality, Aband. Mine Land Prog. Cheyenne, WY.

Schuman, G.E., D.T. Booth, J.R. Cockrell. 1998. Cultural methods for establishing Wyoming big sagebrush on mined lands. J Range Manage. 51:223-230.

Schuman, G.E., D.T. Booth, and R.A. Olson. 2000. Enhancing Wyoming big sagebrush establishment with cultural practices. (this proceedings).

Taylor, A.G. and G.E. Harmon. 1990. Concepts and technologies of selected seed treatments. Annu.

Rev. Phytopathol. 28:321-339.
Walton, T.P., R.S. White, and C.L. Wambolt. 1986. *Artemisia* reproductive strategies: a review with emphasis on plains silver sagebrush. pp. 67-74. In: D.E. McArthur and B.L. Welch (compliers), Proc. symp. on the biology of *Artemisia* and *Chrysothamnus*. Intermountain Res. Sta. Gen. Tech. Report INT-200, USDA Forest Service, Ogden, UT.
Young, J.A. and C.G. Young. 1992. Seeds of woody plants in North America. Dioscorides Press, Portland, OR.

2000 Billings Land Reclamation Symposium

ENHANCING WYOMING BIG SAGEBRUSH ESTABLISHMENT WITH CULTURAL PRACTICES

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ABSTRACT

Wyoming big sagebrush has proven difficult to re-establish by direct seeding on mined lands in the western U.S. This paper reviews research accomplishments over the last decade that address ecological and cultural practices to enhance big sagebrush establishment. Direct-placed topsoil, mulching and arbuscular mycorrhizae have been shown to positively influence seedling establishment of this species on mined land. Direct-placed topsoil possesses better biological, physical, and chemical characteristics that are conducive to plant establishment. Direct-placed topsoil has greater water storage capacity, better soil physical properties, and higher levels of mycorrhizal inoculum. Mycorrhizae has in turn been shown to give the seedlings greater drought stress tolerance. Forty-five day old sagebrush seedlings that were mycorrhizal were able to survive in soils at -3.2 MPa of moisture stress compared to -2.8 MPa for those that were not infected. Regardless of sagebrush seedling age, no non-mycorrhizal seedlings survived in soils with water potentials less than -3.3 MPa compared with mycorrhizal seedlings that survived in soils as dry as -3.7 MPa. Mulch is believed to produce micro-climate changes in the seedbed area that provides "safe-sites" that result in more optimum conditions for sagebrush germination and establishment. Grass seeded concurrently with sagebrush creates significant competition and has reduced sagebrush seedling establishment. The use of a more easily established shrub species (*Atriplex cansescens*) as a "pioneer" plant has not shown any beneficial or "exclusionary" effects on Wyoming big sagebrush establishment. Direct-placed topsoil has not shown benefits as a source of sagebrush propagules. Ten-year old reclaimed lands seeded with multiple shrub species had higher canopy cover, density, and diversity than sites where the seed mixture included only a single shrub species. These recent findings are being incorporated into direct seeding technology by the mining industry; however, some questions remain unanswered. These technology advances will not ensure seedling establishment but will greatly enhance the probability of success in arid and semiarid environments.

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INTRODUCTION

Xerophytic shrubs are a significant component of rangelands throughout much of the arid/semiarid West and provide many benefits to the function and utility of rangeland ecosystems (McKell and Goodin 1973). Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) is one of the most widely distributed and adapted shrub species in Wyoming and the region (Beetle and Johnson 1982). However, its re-establishment on mined lands has generally proven difficult because of low seedling vigor, an inability to compete with herbaceous species, and altered edaphic conditions (Harniss and McDonough 1976, Young and Evans 1989, Schuman et al. 1998). Reduced levels of arbuscular mycorrhizae (AM) in the disturbed soils have also been postulated as a factor limiting the success of re-establishment of big sagebrush on disturbed lands (Call and McKell 1982, Stahl et al. 1988). Arbuscular mycorrhizae can improve the host plant's ability to extract nutrients and water from soil (Stahl et al. 1988). Indirect evidence has indicated that water availability is one of the key factors involved in big sagebrush seedling establishment success (Jones 1991). Allen (1984) reported that sagebrush is particularly dependent upon mycorrhizal symbiosis to reach full growth potential. Use of "pioneer" plants to improve soil conditions, including mycorrhizal levels, of disturbed lands for later seral species has also been postulated as a means to enhance re-establishment of big sagebrush (Booth 1985, Meyer 1990). It is evident from this brief review of the literature that much additional information was needed to enhance our understanding of big sagebrush seedbed ecology and to develop a seeding technology that would result in successful re-establishment of this species.

Recent Findings

Schuman and Booth (1998), Stahl et al. (1998), Schuman et al. (1998), and Booth et al. (1999) reported on recent research evaluating the effects of historic reclamation practices, soil management, mulching, competition, and arbuscular mycorrhizal on big sagebrush establishment. Schuman and Booth (1998) and Schuman et al. (1998) in a study to evaluate the effect of topsoil management (stockpiling vs direct placement), mulching (stubble, surface, stubble + surface, and no mulch), and competition (three grass seeding rates) found that all three variables affected big sagebrush seedling establishment in an interactive manner. Sagebrush seedling densities responded differently to the treatments during the first year (1992) after seeding and the following spring than they did in the fall of 1993 and 1994 (Table 1-3). The largest increase in sagebrush seedlings were observed between the spring 1993 and fall 1993 due to the wet and cool conditions during that period. Big sagebrush seedling densities observed in 1992 on the direct placed topsoil-no competition-mulched treatments (Table 1) exceeded the shrub density standard (1 shrub m^{-2}) adopted in Wyoming (Federal Register 1996). If we use Kriger et al. (1987) findings that 32% of the big sagebrush established the first year will survive after 11 years we still have adequate seedling densities for the stubble and surface mulch treatments to achieve this standard. This emphasizes the importance of good cultural practices in establishing big sagebrush since 1992 was a below

Table 1. Sagebrush seedling density as affected by topsoil management, mulch type, and grass seeding rate, 1992. (Schuman et al. 1998)

	Topsoil Management					
	Fresh			Stockpiled		
Competition (kgPLS ha^{-1})	0	16	32	0	16	32
Mulch Type	plants m^{-2}					
Spring 1992						
stubble	5.78	1.11	0.04	0.11	0	0
surface	7.37	0.07	0	0.04	0	0
stubble + surface	1.59	1.56	0.63	0.11	0	0.04
control	0	0	0.04	0	0	0

$LSD_{0.10}$=2.48, within a mulch type with a topsoil management;
$LSD_{0.10}$=2.51 within a topsoil management with a seeding rate;
$LSD_{0.10}$=2.71 within a mulch type within a seeding rate.

Fall 1992						
stubble	5.15	0.52	0.07	0	0	0.04
surface	6.07	0	0.15	0	0	0
stubble + surface	1.41	1.11	0.37	0.30	0.04	0
control	0	0	0	0	0	0

$LSD_{0.10}$=2.13 within a mulch type within a topsoil management;
$LSD_{0.10}$=2.16 within a topsoil management within a seeding rate;
$LSD_{0.10}$=2.30 within a mulch type within a seeding rate.

Table 2. Sagebrush seedling density as affected by topsoil management, mulch type, and grass seeding rate, 1993. (Schuman et al. 1998)

	Topsoil Management					
	Fresh			Stockpiled		
Competition (kgPLS ha^{-1})	0	16	32	0	16	32
Mulch Type	plants m^{-2}					
	Spring 1993					
stubble	6.30	2.04	1.81	1.63	0.04	0.15
surface	8.74	0.30	0.89	0.44	0.04	0.93
stubble + surface	4.07	2.48	1.52	1.56	0.33	0.11
control	1.26	0.56	0.22	0.37	0.14	0.04

$LSD_{0.10}$=2.01 within a mulch type within a topsoil management;
$LSD_{0.10}$=2.07 within a topsoil management within a seeding rate;
$LSD_{0.10}$=2.73 within a mulch type within a seeding rate.

	Fall 1993					
stubble	9.67	3.93	2.93	5.41	2.11	1.93
surface	13.48	1.00	1.22	2.74	1.81	2.18
stubble + surface	8.04	2.89	1.63	4.59	2.15	1.70
control	7.52	1.37	0.52	1.81	0.52	0.19

$LSD_{0.10}$=2.59 within a mulch type within a topsoil management;
$LSD_{0.10}$=2.89 within a topsoil management within a seeding rate;
$LSD_{0.10}$=3.91 within a mulch type within a seeding rate.

Table 3. Sagebrush seedling density as affected by topsoil management, mulch type, and grass competition, Fall 1994. (Schuman et al. 1998)

	Topsoil Management					
	Fresh			Stockpiled		
Competition (kgPLS ha^{-1})	0	16	32	0	16	32
Mulch Type	plants m^{-2}					
stubble	8.15	9.82	7.11	3.44	2.78	3.26
surface	12.11	4.63	5.33	2.40	3.52	5.07
stubble + surface	9.11	3.78	4.26	3.30	3.85	2.52
control	7.22	5.88	4.56	4.48	2.52	1.70

$LSD_{0.10}$=3.00 within a mulch type within a topsoil management;
$LSD_{0.10}$=3.79 within a topsoil management within a seeding rate;
$LSD_{0.10}$=3.99 within a mulch type within a seeding rate.

average (87%) precipitation year. Direct-placed topsoil resulted in 40% more sagebrush seedlings than the stockpiled topsoil treatment, and in 1992 and the spring of 1993, differences were 1-2 orders of magnitude greater for direct-placed topsoil. Soil moisture content of the surface 7.5 cm of direct-placed topsoil was always higher than that observed in the stockpiled topsoil treatment in 1992. This observed greater soil moisture undoubtedly improved sagebrush germination and establishment on direct-placed topsoil in 1992. The benefits of direct-placed topsoil were only observed in treatments where no grass was seeded. No differences in sagebrush seedling densities were evident between the 16 and 32 kg PLS ha^{-1} grass seeding rates. However, even the lowest seeding rate is slightly above the maximum used by the industry in their reclamation programs (further discussion of grass seeding rate will be covered later in the paper).

Benefits of topsoil management are evident in the initial year of establishment; however, this study did not clearly delineate some of the benefits expected. Unseeded control plots in an adjacent study did not have any sagebrush seedlings present after 4 yrs; therefore, direct-placed topsoil did not act as a seedbank for sagebrush nor was natural recruitment occurring (Schuman and Booth 1998).

Even though the arbuscular mycorrhizal (AM) fungal spore counts were significantly different between the two topsoil management treatments (3088/g stockpiled vs 4500/g direct-placed) no differences in sagebrush seedling infection was observed in the seedlings excavated in

June 1993., (Schuman et al. 1998). Root segments examined from the study showed an infection rate of 66-76%. They believe that the time between topsoil placement (late summer 1990) and June 1993 was more than adequate for reinoculation of the stockpiled topsoil. Loree and Williams (1984) found that native grasses became infected with AM within a year of establishment on long-term stockpiled topsoil indicating inoculum is spread quite readily under natural conditions. However, this finding should not diminish the importance of topsoil management for AM concerns. Stahl et al. (1998), in a greenhouse study, found that the sagebrush seedling age groups of 30 to 150-days old that were mycorrhizal were able to tolerate greater drought stress (moisture tension) before dying than non-mycorrhizal seedlings. Non-mycorrhizal, 45-day-old sagebrush seedlings died when the moisture stress level was -2.8 MPa compared to the mycorrhizal seedlings which tolerated soil moisture tensions of -3.2 MPa before dying (Figure 1). Sagebrush seedling age and mycorrhizae treatment interacted, such that as sagebrush seedlings aged the beneficial influence of AM on soil moisture stress tolerance increased (Figure 2). Those seedlings $\geq$120 days of age that were non-mycorrhizal were much less tolerant of soil moisture stress than younger non-mycorrhizal seedlings (Figure 1) indicating that sagebrush seedlings become more dependent upon the benefits of mycorrhizae as they age. This phenomena could partially explain the lack of infection differences observed by Schuman et al. (1998) in seedlings grown on direct-placed vs stockpiled topsoil. Those seedlings growing in stockpiled topsoil failing to form AM early in their development may have not tolerated repeated drying cycles experienced in a typical spring-summer period in a semiarid climate. Hence, seedlings sampled a year later may not have been representative of the seedling population that originally germinated and emerged because non-mycorrhizal seedlings may have died early in their development.

The presence of mulch also greatly affected sagebrush seedling establishment in 1992 (Schuman and Booth 1998, Schuman et al. 1998). No seedlings were evident in the first year where mulch was not applied (Table 1). Both stubble and surface mulch treatments had similar or greater seedling establishment than the stubble + surface mulch treatment. Soil moisture content of the surface 7.5 cm was greater under all mulch treatments compared to the no-mulch treatment. Schuman et al. (1980) demonstrated that stubble mulch enhanced grass seedling establishment through reduced diurnal temperature fluctuations and increased soil moisture.

Grass competition reduced sagebrush seedling densities throughout the duration of the study on direct-placed topsoil treatment where stubble or straw mulch was used (Schuman and Booth 1998, Schuman et al. 1998). They reported grass seedling densities of 0, 196, and 250 grass seedlings m^{-2} for the 0, 16, and 32 kg PLS ha^{-1} grass seeding rates, respectively. No differences in grass seedling density among topsoil management treatments were observed. They concluded that successful establishment of big sagebrush on mined lands might require seeding in the absence of any grass or perhaps at very low grass seeding rates. These findings have led to further research by Fortier et al. (2000) evaluating effects of grass competition and big sagebrush seeding rates on sagebrush seedling establishment reported at this conference.

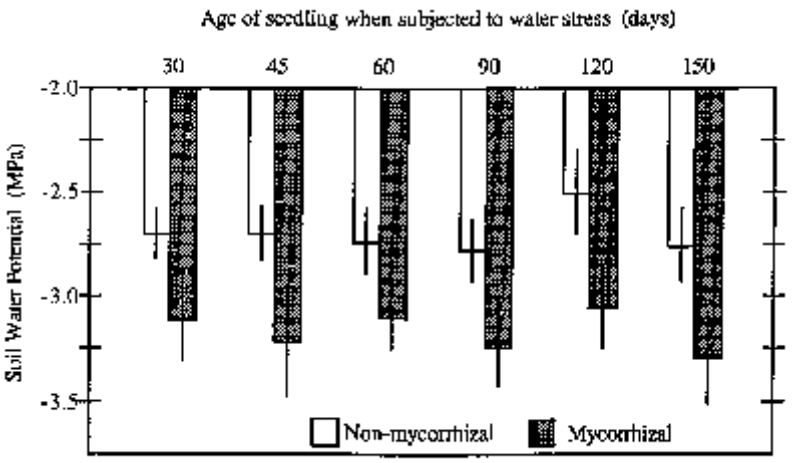

Figure 1. Average soil water potentials resulting in death of mycorrhizal and non-mycorrhizal sagebrush seedlings. Vertical bars on each column represent 1 standard deviation. Differences between mycorrhizal and non-mycorrhizal treatments were statistically significant at $P \leq 0.01$ for each age group. (Stahl et al. 1998)

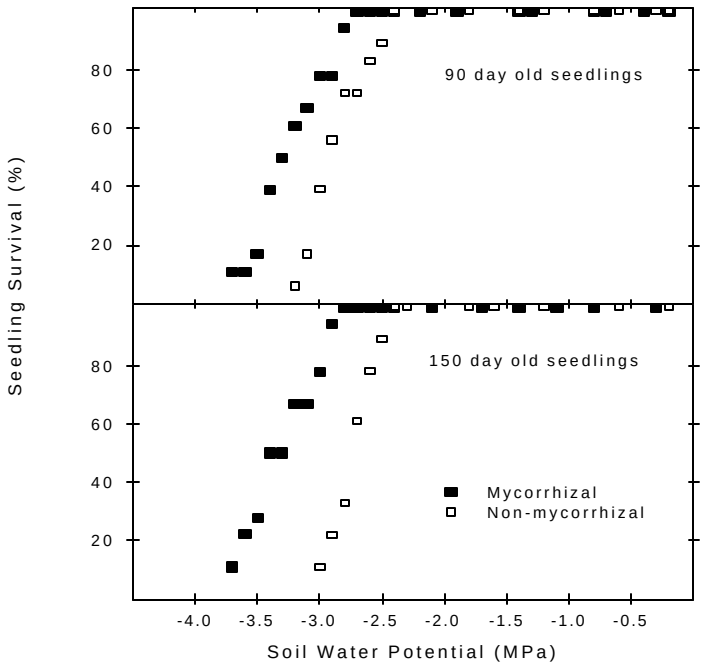

Figure 2. Survival rates for 90 and 150 day old mycorrhizal and non-mycorrhizal sagebrush seedlings at different levels of soil dryness. (Stahl et al. 1998)

A research study aimed at assessing the role of fourwing saltbush (*Atriplex canescens* ssp. *aptera*) as a "pioneer" plant to enhance the later establishment of big sagebrush and to evaluate the role of this plant in excluding big sagebrush when seeded at rates in excess of 2.2 kg PLS ha^{-1} was reported by Schuman and Booth (1998). Grass competition was not evaluated in this study; hence, the only herbaceous plant competition that existed was from plants that became established naturally through the topsoil seedbank or other means of recruitment. The entire study area had a stubble mulch. They found that fourwing saltbush neither improved nor restricted sagebrush establishment; however, they did report greater total shrub densities where fourwing saltbush was over-seeded a year later with big sagebrush. Big sagebrush represented 42% of the shrub density and the seeding strategy produced about 10,000 more total shrub seedlings per hectare than other seeding strategies. Gores (1995), Booth et al. (1999), and Olson et al. (2000) also reported that shrub densities were greater when more than one shrub species is included in the reclamation seed mixture.

Schuman et al. (1998) and Schuman and Booth (1998) showed that big sagebrush seed maintains its viability for much longer than thought (Young and Evans 1989) because new seedlings were noted 3-5 years after the initial seeding of big sagebrush in the research they reported. Wyoming big sagebrush has been shown to have some seed dormancy (McDonough and Harniss 1974, Booth et al. 1997); therefore, Schuman et al. (1998) and Schuman and Booth (1998) believe that continued germination and establishment of big sagebrush for several years was related to seed dormancy, the continual development of "safe sites" for seed germination and establishment (Harper 1977) and improved climatic conditions (precipitation and temperature) in subsequent years.

Research has also shown that seeding a mixture of shrub species also results in greater overall density, species diversity, and structural diversity than is achieved by a single shrub species (Gores 1995, Booth et al. 1999 and Olson et al. 2000). Gores (1995) and Olson et al. (2000) also reported that sites seeded to several shrub species resulted in higher diversity indices of reclaimed sites compared to those where only fourwing saltbush was seeded (Figure 3). Greater species and structural diversity greatly enhance wildlife habitat quality.

Conclusions/Summary

Research reviewed in this paper has answered many questions related to establishment of Wyoming big sagebrush on mined lands; however, not all of the issues/concerns have been fully addressed. Current research is assessing the effects of sagebrush seeding rates and multiple levels of grass competition on sagebrush establishment should further aid in defining and developing a big sagebrush establishment technology. The fact that big sagebrush has exhibited some seed dormancy and has been shown to retain seed viability for several years after being seeded greatly increases the probability of a good "precipitation and temperature year" occurring while the seed is still viable. This fact alone may make it desirable to seed big sagebrush at a higher rate than previously recommended to ensure an adequate seed bank for germination and establishment over several years. Even though big sagebrush seed is relatively expensive, this cost would be much lower than having to mobilize equipment and a contractor a second year to ensure adequate and desired sagebrush densities are achieved.

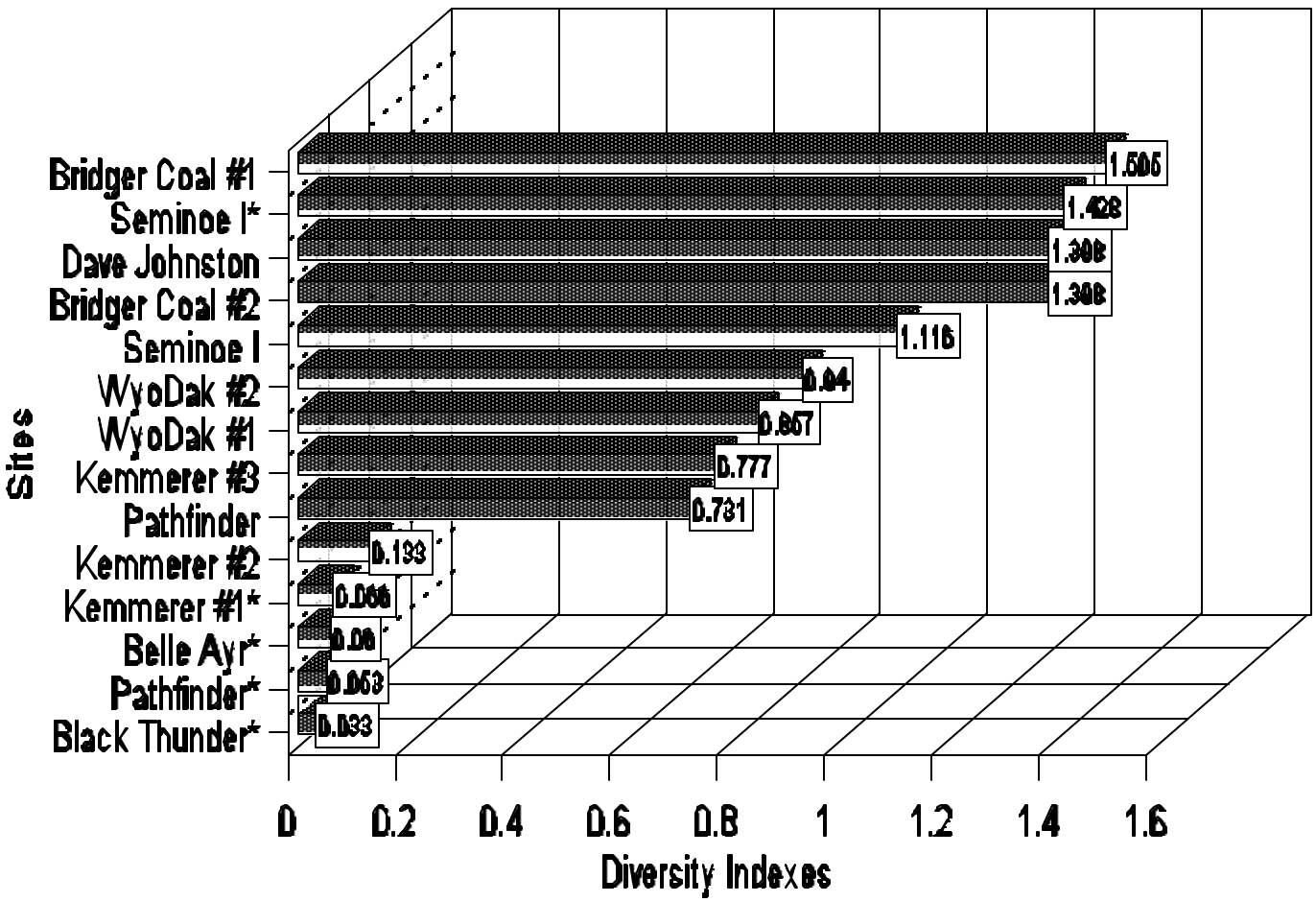

Figure 3. Diversity indexes for fourwing saltbush/grass (denoted by *) and fourwing saltbush/big sagebrush/grass sites. Refer to Booth et al. 1997 for a list of seeding mixture used at each site. (Olson et al. 2000)

Evidence also does not seem to support the fact that more easily established shrubs, such as fourwing saltbush, enhance establishment of other shrubs such as big sagebrush; however, inclusion of multiple shrub species in the seed mixture has been shown to increase total shrub seedling density and greater plant community diversity.

Research has repeatedly highlighted the many benefits of direct-placed topsoil, such as AM inoculum, better soil physical characteristics, seedbank of native species, healthy microbial populations that ensure good nutrient cycling, and enhanced water infiltration and water storage capacity. Enhanced drought stress tolerance of big sagebrush seedlings when AM associations are present highlights an important factor in improving seedling survival in an arid/semiarid environment where soil moisture levels fluctuate dramatically in the surface few centimeters of the soil.

Mulch has also been shown to be critical to formation of "safe sites" for big sagebrush germination and establishment through microclimate modification. Stubble mulching is a desired practice over the use of straw mulch which is more costly, more labor intensive and has a greater potential to introduce non-desired and noxious weed species into reclaimed lands. Use of a stubble mulch has also been shown to have long-term benefits for water infiltration into the reconstructed soil profile (Schuman et al. 1980).

Reclamationists have recommended and in some instances planted big sagebrush in small islands with the intention that these islands serve as seed banks for further spread of the species into the revegetated areas. However, data by Gores (1995) and Lyford (1995) showed that natural recruitment of big sagebrush into revegetated mine lands from native stands of big sagebrush was generally limited to a few meters after 10-15 years. Lyford (1995) stated that natural recruitment decreased 50-fold when distance to the seed source exceeded 100 m. Therefore, this approach to aiding establishment of big sagebrush will probably not be effective within the bonding time frame.

Research within the last decade has produced a much better understanding of seedbed ecology of big sagebrush. Research is leading toward development of a seeding strategy for big sagebrush that should also benefit establishment of other native shrub species as well.

References

Allen, E.B. 1984. Vesicular-arbuscular mycorrhizae and colonizing annuals: Implications for growth, competition and succession. p. 41-51. In: S.E. Williams and M.F. Allen (eds). VA Mycorrhizae and Reclamation of Arid and Semiarid Lands. August 17-19, 1982, Dubois, WY. Wyoming Agr. Exp. Stn. Rpt. No. SA1261, Laramie.

Beetle, A.A. and K.L. Johnson. 1982. Sagebrush in Wyoming. Wyoming Agr. Exp. Stn. Bull. 779. University of Wyoming, Laramie.

Booth, D.T. 1985. The role of fourwing saltbush in mined land reclamation: A viewpoint. J. Range Manage. 38:562-565

Booth, D.T., Y. Bai, and E.E. Roos. 1997. Preparing sagebrush seed for market: Effects of debearder processing. J. Range Manage. 50:562-565.

Booth, D.T., J.K. Gores, G.E. Schuman, and R.A. Olson. 1999. Shrub densities on pre-1985 reclaimed mine lands in Wyoming. J. Restoration Ecology. 7:1-9.

Call, C.A. and C.M. McKell. 1982. Vesicular-arbuscular mycorrhizae-a natural revegetation

strategy for disposed oil shale. Reclamation and Revegetation Res. 1:337-347.
Federal Register. 1996. Office of Surface Mining and Enforcement. 30 CFR Part 950. Wyoming Regulatory Program-final rule; approval of amendment. Vol. 61: (152):40735.
Fortier, M.I., G.E. Schuman, and A.L. Hild and L.E. Vicklund. 2000.Effects of seeding rates and competition on sagebrush establishment on mined lands. In: Proc., 2000 Billings Land Reclamation Symposium, March 20-24, 2000, Billings, MT. Reclamation Research Unit, Montana State University, Bozeman. (In press)
Gores, J.K. 1995. The evaluation of big sagebrush and fourwing saltbush establishment on pre-1985 Wyoming reclaimed mine sites. M.S. Thesis, University of Wyoming, Laramie.
Harniss, R.O. and W.T. McDonough. 1976. Yearly variation in germination in three subspecies of big sagebrush. J. Range Manage. 29:167-168.
Harper, J.L. 1977. The recruitment of seedling populations. p. 111-147. In: Population Biology of Plants. Academic Press, New York.
Jones, G.P. 1991. Seedling survival and adult plant water relations of black sagebrush and big sagebrush in the Laramie Basin. Ph.D. Dissertation, Dept. of Botany, University of Wyoming, Laramie.
Kriger, J.A., W.A. Berg, J.T. Herron, C.M. Phillips, and R.G. Atkinson. 1987. Shrub establishment in the mountain shrub zone. p. L-3-1 through L-3-6. In: Proc., 4th Biennial Symposium on Surface Mining and Reclamation of the Great Plains and 4th Annual Meeting of the American Society of Surface Mining and Reclamation, March 16-20, 1987, Billings, MT. Reclamation Research Unit Rpt. 8704, Montana State University, Bozeman.
Loree, M.A.J. and S.E. Williams. 1984. Vesicular-arbuscular mycorrhizae and severe land disturbance . p. 1-14. In: Proc., VA Mycorrhizae and Reclamation of Arid and Semiarid Lands. August 17-19, 1982, Dubois, WY. Wyoming Agric. Exp. Stn. Sci. Rpt. No. SA1261, Laramie.
Lyford, M.E. 1995. Shrub establishment on drastically disturbed lands. M.S. Thesis, University of Wyoming, Laramie.
McDonough, W.T. and R.O. Harrniss. 1974. Effects of temperature on germination in three subspecies of big sagebrush. J. Range Manage. 27:204-205.
McKell, C.M. and J.R. Goodin. 1973. United States arid shrublands in perspective. p. 12-18. In: Proc., Third Workshop of U.S./Australia Rangelands Panel, Tucson, AZ. Society for Range Management, Denver, CO.
Meyer, S.E. 1990. Shrubland restoration-an ecologist's perspective. Handout: Workshop on Plant Species and Wildlife Habitat Establishment Successes and Failures. Billings, MT. Intermountain Research Station, Shrub Sciences Laboratory, USDA, FS, Provo, UT.
Olson, R.A., J.K. Gores, D.T. Booth, and G.E. Schuman. 2000. Suitability of shrub establishment on Wyoming mined lands reclaimed for wildlife habitat. Western North American Naturalist. (In Press)

Schuman, G.E. and D.T. Booth. 1998. Strategies for establishment of big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) on Wyoming mined lands. Final Report, Abandoned Coal Mine Land Research Program, Office of Research, University of Wyoming, Laramie and Wyoming Department of Environmental Quality, Abandoned Mine Land Program,

Cheyenne, WY.
Schuman, G.E., D.T. Booth, and J.R. Cockrell. 1998. Cultural methods for establishing Wyoming big sagebrush on mined lands. J. Range Manage. 51:223-230.
Schuman, G.E., E.M. Taylor, Jr., F. Rauzi and G.S. Howard. 1980. Standing stubble versus crimped straw mulch for establishing grass cover on mined lands. J. Soil and Water Conservation. 35:25-27.
Stahl, P.D., G.E. Schuman, S.M. Frost, and S.E. Williams. 1998. Interaction of arbuscular mycorrhiza and seedling age on water stress tolerance of *Artemisia tridentata* ssp. *wyomingensis*. Soil Sci. Soc. Am. J. 62: 1309-1313.
Stahl, P.D., S.E. Williams, and M. Christensen. 1988. Efficacy of native vesicular-arbuscular mycorrhizal fungi after severe soil disturbance. New Phytol. 110:347-354.
Young, J.A. and R. Evans. 1989. Dispersal and germination of big sagebrush (*Artemisia tridentata*) seeds. Weed Sci. 37:201-206.

2000 Billings Land Reclamation Symposium

EFFECTS OF SEEDING RATES AND COMPETITION ON SAGEBRUSH ESTABLISHMENT ON MINED LANDS

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ABSTRACT

Shrub establishment on reclaimed coal mines of the Powder River Basin in Wyoming is a vital and required component in reclamation. Efforts to revegetate using xerophytic shrubs have been unsuccessful due to competition for moisture, poor seedling vigor, and altered edaphic conditions. As a result, methods to re-establish Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) are needed to meet shrub density standards. This study examines effects of grass competition and sagebrush seeding rate upon establishment of big sagebrush seedlings at the Belle Ayr Coal Mine near Gillette, Wyoming. Experimental plots seeded with three sagebrush rates (1, 2, and 4 PLS kg/ha) and seven rates of a grass mixture (0, 2, 4, 6, 8, 10, and 14 PLS kg/ha) were used to assess effects of sagebrush seeding rate and grass competition on seedling density and survival. Data from four sagebrush seedling counts (June 30, August 3, August 31, and October 25, 1999) show a decline in sagebrush seedlings at higher grass seeding rates, although not statistically significant. Sagebrush seedling density differed among sagebrush seeding rates. On all four sampling dates, sagebrush seedling density was greater in the 4 kg/ha rate than the 2 and 1 kg/ha rates. Mean seedling counts on June 30 differed among all three sagebrush rates whereas on August 3, 31, and October 25 the 2 and 1 kg/ha rates had similar seedling densities. Sagebrush seedling density and grass and forb production determined in 2000 will provide us with further information about treatment effects on sagebrush seedling establishment and survival. We anticipate that this study and other recent research on the effects of other cultural practices on sagebrush establishment will enable proposal of a seeding strategy for Wyoming big sagebush.

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INTRODUCTION

In arid and semiarid rangelands, where mining has occurred, re-establishment of key vegetative species is critical to maintain function, structure, diversity, and stability of the landscape. Key shrub species have evolved to exploit the limited resources of these regions, and are a vital component of rangeland function. Shrubs provide many benefits to humans and animals including erosion control, industrial products, ornamentals, medicine, functionality of rangeland ecosystems, and wildlife browse and cover (McKell 1989). Precipitation and available soil moisture dictate the distribution of xeriphytic shrub communities across North America (McKell 1989), and their drought tolerance make them well-suited to dominate arid and semiarid regions. As a result, shrub communities are found in saline valleys, dry deserts, broad valleys, and on xeric slopes. Shrub restoration is an important science across the western United States because of recent attention and heightened ecological awareness paid to surface mine reclamation.

Efforts to re-establish shrubs on coal mined lands was heightened upon adoption of a specific shrub density standard, 1 shrub/m^2 on 20 percent of reclaimed lands, by the Wyoming Department of Environmental Quality (Wyoming DEQ 1996). Attaining shrub density standards for Wyoming big sagebrush (*Artemisia tridentata ssp. wyomingensis* Beetle & Young) in the Powder River Basin of Wyoming have proven difficult to achieve. Problems encountered with sagebrush re-establishment include low seedling vigor, slow growth habits, poor seed viability, disease, injury or excessive browse from livestock and wildlife, and competition from herbaceous species (Harniss and McDonough 1976, DePuit 1988, Young and Evans 1989, Schuman et al. 1998).

Past studies have shown that sagebrush seedling establishment is dependent upon moisture availability (Jones 1991), arbuscular mycorrhizal infection (Allen 1984, Stahl et al. 1998), and herbaceous competition (Schuman et al. 1998). There are a number of approaches to resolve competition and water stress in shrub seedlings. For example, straw mulch can be applied prior to seeding to enhance soil water retention, regulate temperatures, increase microbial activity, and reduce competition (Schuman et al. 1980, 1998). Practices such as mowing, excavation of herbaceous species, interseeding, and two-phase seeding can alleviate competitive pressures on shrub seedlings (DePuit 1988). The rate and time of seeding can also influence shrub seedling survival. Although rate of seeding can be manipulated to reduce environmental and competitive stresses; successful guidelines have not been established for mined lands. Successful reclamation techniques require proper and effective seeding rates to accelerate and direct plant succession toward desired conditions.

Research Objectives

This study examines sagebrush seeding rate and grass competition treatment effects on Wyoming big sagebrush establishment. Guidelines for proper seeding rates of native shrubs, especially Wyoming big sagebrush, are vital management strategies for mined lands of the Powder River Basin.

The objectives of this study are to investigate three factors affecting sagebrush seedling establishment on mined lands: 1) influence of grass competition on Wyoming big sagebrush germination, emergence and establishment 2) effects of sagebrush seeding rates on sagebrush seedling density and survival, and 3) the interaction of sagebrush seeding rate and grass competition on sagebrush seedling establishment and survival.

MATERIALS AND METHODS

The study area is located at the Belle Ayr Coal Mine, RAG Coal West, Inc., 29 km southeast of Gillette, Wyoming. The Powder River Basin is situated between the Black Hills and Big Horn Mountains in northeastern Wyoming. This area has a continental, temperate, semiarid climate. The landscape is characterized by rolling plains and divides with steep escarpments separating plain-like areas from dissected areas with terraces and sloping alluvial fans along streams. Average annual precipitation at the Belle Ayr Mine is 380 mm and average temperature is 7.2^{o}C (Vicklund 1998). Snowfall averages 132 cm, most of which falls between October and April. Fifty percent of the precipitation occurs between April and July (Bjugstad 1978).

Pre-mining vegetation of the Powder River Basin is northern mixed-grass prairie, which includes localized concentrations of big sagebrush in a matrix of cool- and warm-season perennial grasses. Black sagebrush (*Artemisia nova*) is common to shallow soils while big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) is commonly found on well-drained uplands. Plains cottonwood (*Populus sargentii*) and willow species (*Salix* sp.) surround larger streams in the Powder River Basin. Greasewood (*Sarcobatus vermiculatus*) and salt-tolerant grasses are limited to broad drainage bottoms and some playas in the area. Local soils formed either from Tertiary and Upper Cretaceous aged shale, sandstone, and limestone or from alluvial terraces and fans. Most soils have a carbonate horizon 40-76 cm deep in the soil profile (Glassey et al. 1955).

Experimental units of the study are located on a 36-ha reclaimed site at Belle Ayr Mine. During December 1997 and January 1998, topsoil was spread from a stockpile at 56 cm in depth over spoil material (70 m deep). In April 1998 the study area was seeded to 'Steptoe' barley (*Hordeum vulgare*) at the rate of 22.4 kg/ha. Barley was mowed in late summer and again in early fall 1998 to provide a 15 cm high stubble mulch.

Experimental Design

The experimental design was a randomized block design with four replicate blocks (27 x 45.5 m). Grass seeding rate treatments of 0, 2, 4, 6, 8, 10, and 14 kg PLS/ha were randomly applied within each block (6.5 x 27 m) and seeded in early December 1998. Three species of grasses, western wheatgrass (*Pascopyrum smithii*), slender wheatgrass (*Elymus trachycaulus*), and thickspike wheatgrass (*Elymus lanceolatus*) were mixed on an equal seed number basis to form a cool-season perennial grass mixture. In December 1998, this mixture was seeded at the seven rates described earlier to provide a variety of grass competition levels. Grass treatments were seeded using a 1.5 m wide double disk drill and seeded about 1.5 to 2.0 cm deep. Each grass treatment plot was divided into 6.5 by 9 m randomly assigned subplots for sagebrush seeding rate

treatments. Sagebrush seed collected near Gillette in the fall 1998 was broadcast seeded at 1, 2, and 4 kg PLS/ha in March 1999 within each subplot.

Sampling Methods

Six 1-m^2 permanent quadrats were established within each sagebrush by grass treatment subplot (6.5 x 9 m) to assess sagebrush seedling densities during two summer seasons, 1999 and 2000. Sagebrush seedlings were counted on June 30, August 3, August 31, and October 25, 1999 within each quadrat. Sagebrush density will be determined in June, August, and October of 2000 and cover and production of grasses and forbs will be evaluated in July 2000.

Soil moisture content was determined biweekly at 0-5 cm and 5-15 cm depths from June 17 through August 30. Soil core samples were taken in seven random subplots within two replications. Soil temperature was recorded at 5 cm and 15 cm soil depths at the site. In addition, minimum/maximum air temperature and precipitation were recorded on a weekly basis. Soil temperature, air temperature and precipitation were monitored April through October, 1999, and will be monitored again in 2000. Soil samples taken in seven locations at three depths (0-15 cm, 15-30 cm, and 30-46 cm) will be analyzed for soil pH, electrical conductivity, particle size separation, cation concentration (potassium, calcium, sodium, and magnesium), organic carbon, total nitrogen, and phosphorus concentration.

Data Analysis

Analysis of variance was accomplished using a split-plot, randomized block design to assess sagebrush seedling establishment relative to grass and sagebrush seeding rate treatments on each sampling date and across sampling dates. Grass seeding rates are main plot treatments while sagebrush seeding rates are subplot treatments. Least significant difference (LSD) mean separation was used to indicate differences in sagebrush seedling density among the sagebrush and grass seeding rates. Repeated measures analysis of variance was used to determine differences within sagebrush and grass seeding rate treatments. Comparison of October 1999 seedling densities with June 2000 densities will be used to evaluate seedling survival. Soil moisture data for six sampling dates were analyzed to determine significance between grass seeding rate and soil water content during the 1999 growing season. Treatment effects and mean separations were evaluated at $P \leq 0.05$.

RESULTS

Above normal precipitation during spring and early summer of 1999 resulted in an abundance of volunteer species, and as a result the study area was mowed in late July to aid in the assessment of sagebrush seedlings and to mimic the management practices used on adjacent reclaimed lands. Mowing was maintained at 10-15 cm in height to prevent sagebrush seedling damage.

Soil moisture content declined from June to late July with further declines in late August (Table 1). At 0-5 cm soil depths, soil moisture content differed among sampling

dates, irrespective of grass seeding rates. June 17 and August 13 exhibited higher soil moisture content than all other sampling dates. Soil moisture content at 5-15 cm soil depth differed among grass seeding rates, depending on sampling date. Differences in soil moisture were observed on July 1 and August 13 within the grass seeding rates; however, there are no consistent trends with respect to grass seeding rate.

Table 1. Soil Moisture (%) at 0-5 cm and 5-15 cm depths in seven grass seeding rates during summer 1999 at Belle Ayr Mine.

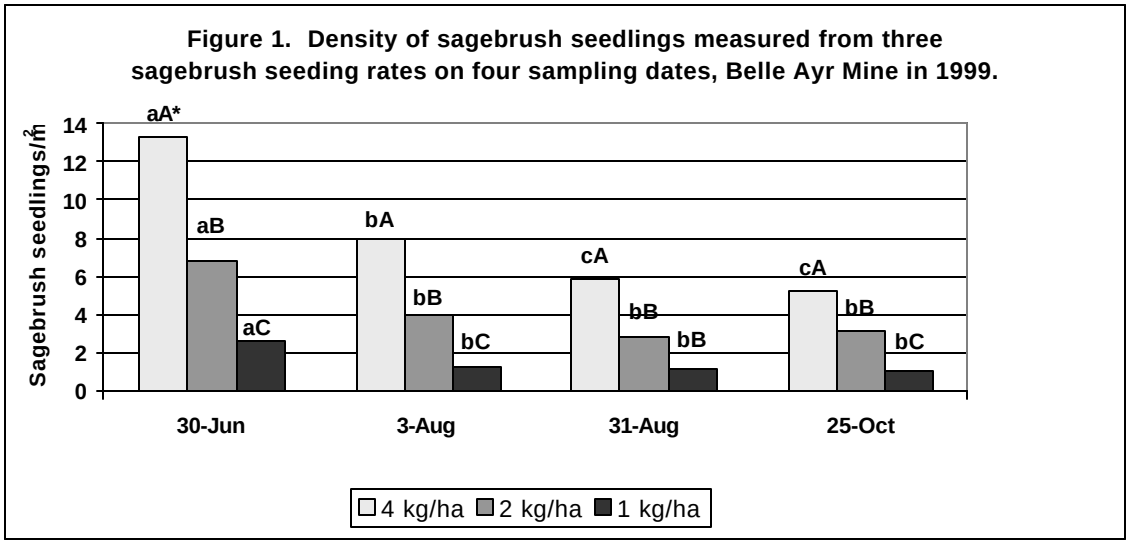
	June 17		July 1		July 15		July 29		August 13		August 30	
Soil Depth (cm)	0-5*	5-15**	0-5	5-15	0-5	5-15	0-5	5-15	0-5	5-15	0-5	5-15
Grass rate (kg/ha)												
0	12.7	15.0 Aa	8.80	9.9 ABbc	6.2	10.5 Ab	5.1	8.9 Abc	18.4	16.9 Aa	4.8	6.6 Ac
2	15.6	18.5 Aa	11.1	12.9 Ab	5.9	8.90 Acd	6.3	9.9 Abc	14.0	11.5 Bbc	5.7	6.2 Ad
4	14.8	16.2 Aa	7.90	8.60 Bb	7.4	8.30 Ab	5.6	9.9 Ab	16.1	15.4 Aa	5.2	7.0 Ab
6	14.6	17.7 Aa	8.70	11.6 ABb	7.1	10.6 Abc	5.8	9.4 Abc	12.1	10.0 Bbc	5.5	7.7 Ac
8	14.6	15.4 Aa	10.9	12.4 Aab	6.2	10.1 Abc	6.9	8.4 Ac	15.1	11.9 Bab	5.7	8.3 Ac
10	14.6	17.7 Aa	9.30	11.3 ABb	7.3	9.50 Abc	4.9	7.3 Ac	17.0	12.1 Bb	5.8	7.2 Ac
14	14.1	16.9 Aa	9.20	12.9 Ab	6.7	8.80 Ac	5.1	8.4 Ac	14.9	10.0 Bbc	6.4	8.7 Ac
Date Mean	14.4 x		9.40 y		6.7 z		5.6 z		15.4 x		5.6 z	

*Within 0-5cm soil depth dates differ; means with the same letter (x, y, z) are not significantly different.
**Within 5-15cm soil depth, grass means within a date with same uppercase letters do not differ; within a grass seeding rate, dates with same lowercase letters do not differ, P > 0.05 LSD.

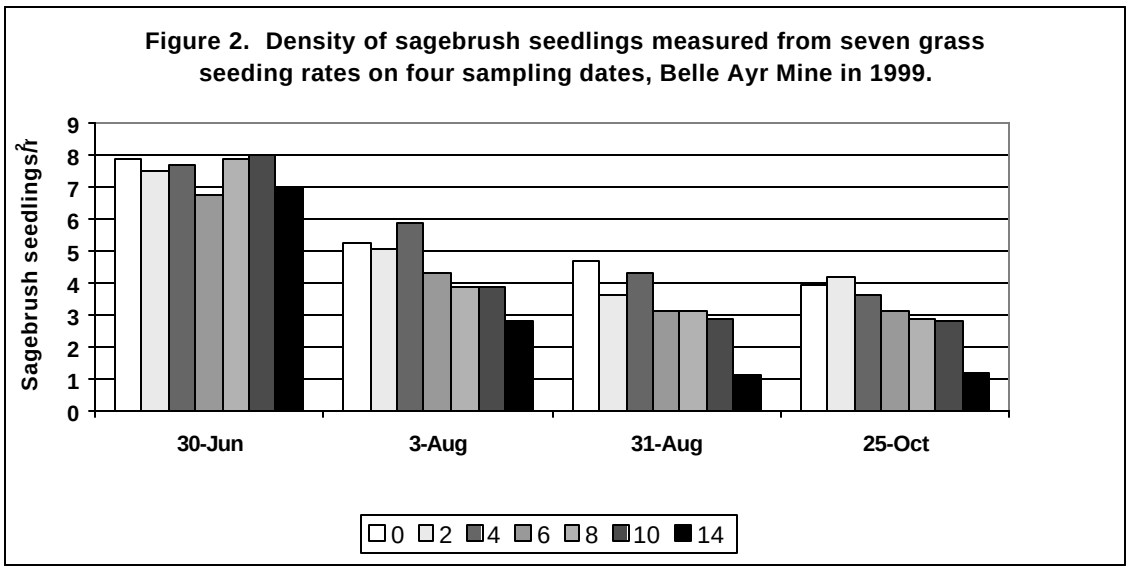
Sagebrush seedling density differed among the three sagebrush seeding rates (Figure 1); seedling density at 4 kg/ha sagebrush seeding rate was greater than the 2 and 1 kg/ha rates on all four sampling dates in 1999. The number of sagebrush seedlings declined during the first growing season in all sagebrush seeding rates. When averaged across sagebrush seeding rates, fewer sagebrush seedlings were observed in the higher grass seeding rates; however, this effect was not statistically significant (Figure 2).

DISCUSSION

Results from the first growing season suggest limited effects of grass competition on sagebrush establishment in the 1999 growing season. Since precipitation was above normal for spring and early summer months this moisture availability may explain the lack of significant differences in sagebrush seedling densities among grass seeding rates. Soil moisture data at 5-15 cm does show an interaction between grass seeding rate and date, which suggests that grass has a greater influence on soil moisture at deeper soil depths. The 0-5 cm soil samples were more variable in soil moisture over time, as we would expect.



*Uppercase letters indicate mean separation among sagebrush rates within a date. Lowercase letters indicate mean separation among dates within a specific sagebrush rate. Means with the same letter are not statistically different, LSD.



Higher sagebrush seedling density was achieved using 4 kg PLS/ha, although all three rates resulted in sagebrush seedling densities of $\geq 1/m^2$ in the first growing season. In addition, the highest sagebrush seeding rate, 4 kg/ha, had the highest mortality of seedlings over the growing season. Mortality of sagebrush seedlings over the growing season could be attributed to lower soil moisture content in late summer.

We anticipate that normal or below normal precipitation and the development of the grass community will cause greater effects of grass seeding rates on sagebrush seedling survival in the next growing season. Furthermore, mortality of sagebrush seedlings over the winter may also significantly alter sagebrush seedling density. It appears that with any over-winter mortality the 1 kg/ha sagebrush seeding rate will result in a seedling density $< 1/m^2$ unless further germination and establishment occurs in 2000. Schuman (1999) suggest that higher sagebrush seeding rates, than are normally recommended, be used to ensure the desired density of sagebrush since the seed has been shown to retain viability in the field for several years. He believes this would greatly increase the probability of a good/optimum "precipitation and temperature year" occurring for germination and establishment of big sagebrush without the cost of repeated seeding attempts.

The influence of grass and sagebrush seeding rates on sagebrush seedling establishment will provide us with valuable information about seeding methodology. Our evidence along with recent findings of Schuman et al. (1998) on cultural revegetation methods will furnish reclamationists with guidelines to improve shrub establishment on reclaimed mined lands.

REFERENCES

Allen, E.B. 1984. Vesicular-arbuscular mycorrhizae and colonizing annuals: Implications for growth, competition and succession, pp. 41-51 In: VA Mycorrhizae and Reclamation of Arid and Semiarid Lands, S.E. Williams and M.F. Allen (eds). Wyoming Agr. Exp. Stn. Rpt. No. SA1261, Laramie, WY.

Bjugstad, A.J. 1978. Reestablishment of woody plants on mine spoils, pp. 3-12 In: The reclamation of disturbed arid lands, R.A. Wright (ed.). Univ. Mexico Press.

DePuit, E.J. 1988. Shrub establishment on drastically disturbed lands, pp. 55-60 In: Proc., Seventeenth Wyoming Shrub Ecology Workshop. 21-22 June 1988, Jackson, Wyo.

Glassey, T.W., T.J. Dunnewald, J. Brock, H.H. Irving, N. Tippetts, and C. Rohrer. 1955. Campbell County Soil Survey, Wyoming. USDA-Soil Conservation Service. No. 22.

Harniss, R.O. and W.T. McDonough. 1976. Yearly variation in germination in three subspecies of big sagebrush. J. Range Manage. 29:167-168.

Jones, G.P. 1991. Seedling survival and adult plant water relations of black sagebrush and big sagebrush in the Laramie Basin. Ph.D. Diss., University of Wyoming, Laramie.

McKell, C.M. 1989. The Biology and Utilization of Shrubs. Academic Press, San Diego California.

Schuman, G.E. 1999. Direct seeding establishment of Wyoming big sagebrush: Research Advances. In: Proc. Interactive Forum Approaching Bond Release: Revegetation, Reclamation Issues, and Surface Mining Applications in the Arid, Semi-Arid West, September 20-24, 1999, Flagstaff, AZ. Office of Surface Mining, Denver, CO.

Schuman, G.E., E.M. Taylor, Jr., F. Rauzi, and G.S. Howard. 1980. Standing stubble versus crimped straw mulch for establishing grass cover on mined lands. J. Soil and Water Cons. 35:25-27.

Schuman, G.E., D.T. Booth, and J.R. Cockrell. 1998. Cultural methods for establishing Wyoming big sagebrush on mined lands. J. Range Manage. 51:223-230.

Stahl, P.D., G.E. Schuman, S.M. Frost, and S.E. Williams. 1998. Arbuscular mycorrhizae and water stress tolerance of Wyoming big sagebrush seedlings. Soil Sci. Soc. Am. J. 62:1309-1313.

Vicklund, L. 1998. Personal communication: Belle Ayr Mine precipitation and temperature data.

Wyoming Department of Environmental Quality, Land Quality Division. 1996. Coal rules and regulations, Chapter 4, Appendix A, State of Wyoming, Cheyenne, WY.

Young, J.A. and R.A. Evans. 1989. Dispersal and germination of big sagebrush (*Artemisia tridentata*) seeds. Weed Sci. 37:201-2

2000 Billings Land Reclamation Symposium

A DESIGN SOLUTION TO BIG SAGE ESTABLISHMENT: SEED PRODUCTION PLOTS AND FACILITATION BEDS

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ABSTRACT

Big Sage (*Artemisia tridentata v. Wyomingensis*) has proven difficult to re-establish in the Powder River Basin of Wyoming due to drought, plant competition, economics, and other factors. Planting unit design that takes into consideration the natural reproductive strategy of big sage could have a substantial impact on the economics and success of sage establishment. In general, the reproductive strategy of sage is to produce a large amount of short-lived seed with highly variable viability over a long life span. Actual establishment of seedlings results from infrequent stochastic events that create favorable conditions for germination and growth. Thus, the concept of direct-seeding sage as a one-time event is contradictory to the reproductive strategy of sage. In addition, studies have been conducted which demonstrate that large edge-to-area ratios result in increased invasion by species into otherwise stable habitats. A reinterpretation of this concept suggests that species with invasive qualities (i.e. – big sage) and high seed production may benefit from long-linear populations and adjacent disturbed habitats. Bitterroot Restoration proposes a design solution that emulates the natural strategy of sage reproduction. The proposed design solution would utilize the planting of containerized sage into linear "seed production plots" and adjacent "facilitation beds" which receive an annual seed rain. The proposed solution is supported by both field data from an existing replicated study in Wyoming and case studies of similar projects on high cost reclamation projects. We hypothesize that this long-term view of shrub establishment based upon species reproductive strategy will result in sage stands capable of achieving bond release.

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INTRODUCTION

Restoration of big sagebrush (*Artemisia tridentata v. wyomingensis*) to mined lands in Wyoming is mandated by both the Wyoming Department of Environmental Quality and the Office of Surface Mining. Current regulations require a post-mining shrub density of 1 shrub per meter^2 on 20% of the affected mining area. This requirement has stimulated substantial research into establishment techniques based upon the use of seed as the main propagule source (Meyer 1992; Schuman and Booth 1998). Historically, establishment techniques based upon the use of seed have been largely unsuccessful (Chambers, Brown et al. 1994; Booth, Gores et al. 1999). Although recent advances in seed quality and seeding technology have furthered the successful use of seed in reclamation, they have not produced results that will meet bond release. A second, but less publicized method with substantially higher success is the use of containerized live plant materials. By industry standards this method is generally considered to be economically prohibitive. The purpose of this paper is to contrast seeding versus outplanting of containerized materials and to propose a hybrid establishment system which will potentially result in greater success than either of the present methodologies.

SEEDING AS A RESTORATION TECHNIQUE

Seeding of big sagebrush has generally resulted in marginal establishment rates (Meyer 1990; Brown, Sidle et al. 1991; Chambers, Brown et al. 1994; Booth, Gores et al. 1999). Booth and others reviewed pre-1985 reclaimed lands seeded with big sagebrush in Wyoming and found that none would meet the 1996 shrub requirement (Booth, Gores et al. 1999). Brown et al conducted a Nevada study comparing various reclamation techniques which resulted in no establishment of sage seedlings after three years of monitoring (Brown, Sidle et al. 1991). In a Wyoming comparison of seeding rates and live planting, Meikle et al. also failed to establish sagebrush from seed (Meikle, Ballek et al. 1995). Failure of seeding is due to many reasons including improper matching of genetics (Meyer 1990), depauperate mycorrhizal populations (Schuman and Booth 1998), variable seed quality (Meyer 1992), plant competition (Cockrell, Schuman et al. 1995), browse damage (Hoffman and Wambolt 1996), as well as the commonly accepted influence of droughty weather during the time of seedling establishment (several authors). The main reason for seeding failure may not be a misunderstanding of seeding strategies, but rather a lack of understanding of the reproductive biology of sagebrush.

Meyer and Mozingo both provide excellent reviews of sagebrush reproductive biology (Mozingo 1987) (Meyer 1992). Big sagebrush is a small-seeded species with seeds typically 1.0 mm X 0.7 mm in size. As with most small seeded species, big sagebrush produces an abundant quantity of seed. It has been estimated that a single shrub with a 1 meter crown will produce 450 flowering branches and at least 350,000 seeds. In a good year, seed production can exceed 1,000,000 on an individual plant. Seed production is subject to annual differences in moisture, frost events, intra-specific competition, and other factors. Xeric upland Wyoming big sagebrush is noted as not setting seed except in wet years. Being self-fertile, individual plants can set seed regardless of the distance to their nearest neighbor. In general, flowering occurs between August and October with subsequent seed dispersal occurring from October through January. Seed dispersal is accomplished via animals and the wind. Sage seed is generally short-lived although this has been questioned by some researchers (Cockrell, Schuman et al. 1995). A majority of seed planted or produced in a given year is gone from the seed bank by the following spring (Meyer 1992). Seed is generally lost through germination in winter or spring. The fraction of the seed that enters the seed bank is less than 1% (Meyer 1992). Thus, seeding of sage in a given year is likely to fail unless weather conditions and seed viability are conducive to immediate establishment.

Recruitment of sagebrush seedlings is strongly limited by abiotic and biotic factors. Newly emerged seedlings are susceptible to frost damage, drought, and damping off disease. Some factors such as snow cover can effectively increase establishment success. In one study seedling emergence was increased substantially over controls with placement of a snow fence to capture moisture (Meyer 1992). In addition, companion plants have been demonstrated to ameliorate site conditions and allow for greater survival of seedlings and establishment (MacArthur, Stevens et al. 1995). Surviving seedlings begin to flower at about 4 years of age. Big sagebrush in southeastern Idaho on average survives to 4 years of age but commonly exceeds 40 years with some specimens surviving for more than 100 years (West 1988).

Ultimately, planting of big sage via seeding has failed to produce consistent stand establishment. These failures are understandable and predictable in light of the natural history of the species, however.

OUTPLANTING AS A RESTORATION TECHNIQUE

Outplanting of containerized big sage has generally resulted in high establishment rates although studies and actual monitoring data are few and far between. Fall planted seedlings have resulted in plant survival in excess of 90% over six years monitoring on one southeastern Montana mine site (Martin 1999). Survival of

late spring planted seedlings on a particularly harsh Wyoming site resulted in 23% survival over five years monitoring(Meikle 1999).

Several variables that are not easily controlled in seeding operations can be controlled under greenhouse production. Plant materials produced for outplanting procedures are grown under greenhouse conditions in conical 10 cubic inch containers that promote deep-rooted seedlings. Growth in such containers bypasses the vulnerable seedling stage which seeded materials must pass prior to becoming drought and frost hardy. Small quantities of appropriate seed sources can yield large quantities of plant materials which allow for the exact matching of site genetics. In addition, vesicular-arbuscular-mycorrhizal inoculants (VAM) are currently available from several companies and can be applied to plant materials prior to or at the time of outplanting thus mediating low nutrient and soil moisture conditions. Furthermore, plants can be placed in appropriate microsites during hand outplanting operations.

Despite high survival rates, outplanting of big sagebrush is not without problems. Outplanting remains a labor intensive and costly enterprise. Although it is long-lived, it is apparent that true restoration of sage will require continual recruitment within a suitable seedbed in order to persist and dominate a site over a period of time. Thus, even though sage may be successfully planted on a site, their long-term existence is not guaranteed unless an appropriate vegetation surrounds stands and allows for continual colonization and recruitment of new individuals. Shrub densities that could potentially meet bond release within short time periods offset these barriers, however.

PROPOSED DESIGN SOLUTION

Our proposed strategy is based both on species biology and design of planting units. This strategy recognizes that seeding efforts are contradictory to the reproductive strategy of big sagebrush and that long-term establishment requires continual recruitment into the existing population. BRI proposes a design solution to facilitate the establishment of sagebrush from propagules using a series of "Seed Production Plots" which act as a propagule sources and "Facilitation Beds" which as propagule acceptors.

The proposed planting unit design would be designed with two components: 1) Seed Production Plots and 2) Facilitation Beds. The purpose of the Seed Production Plots would be to provide a continuous source of propagules and microbial inoculum for the planting unit. Seed Production Plots would consist of live-planted containerized sagebrush seedlings that are inoculated with mycorrhizal fungi. Within plots, big sagebrush would be planted in linear strips similar to shelterbelts in the western United States in order to maximize the potential spread of seedrain within the planting unit. Facilitation beds will consist

of specially prepared and planted spaces between the seed production plots. The purpose of these beds will be to provide an area conducive to sage establishment for an extended period of time. Facilitation beds will be prepared with a shallow topsoil layer and planted to vegetation that is characteristically susceptible to invasion by big sagebrush. For example, bunch grasses are far less aggressive than cool season grasses and will allow open soil microsites that will facilitate sage establishment from wind blown seed provided by the linear sage plantings.

The impacts of seed rain and other dispersal mechanisms have been evaluated in other biomes with generally positive results(Myster and Sarmiento 1998; Urbanska, Erdt et al. 1998; Toh, Gillespie et al. 1999). Where large areas are to be revegetated, scattered plantings rather than large-scale and intensive plantings may represent an economically attractive option. This approach has been demonstrated successfully in Queensland, Australia through the use of clumped perch trees that act to attract frugiverous birds which subsequently seed tree species into previously forested areas (Toh, Gillespie et al. 1999).

In the western US, several big sage researchers have recommend the planting of small islands of sage surrounded without any grass seeding on relatively flat grounds in order to facilitate establishment from seed rain (Schuman and Booth 1998) (Meyer 1992). Dispersion of big sagebrush seed has been quantified with dispersal by wind reaching up to 30 meters (Meyer 1992). Recruitment, consequently, tends to be greater on the windward side of the plant due to the prevailing wind direction on seed dispersal. Several authors have witnessed recruitment over time. Brown et al. conducted a study an extensive study on a Nevada waste dump site which evaluated several reclamation treatments including topsoil application, mulch application, various seeding rates, and various fertilization rates (Brown, Sidle et al. 1991). Of several species planted by seed, only big sage and black sage failed to appear in test plots during three years of monitoring. During the final year of monitoring, big sage seedlings were noted in depressions adjacent to the study site and were assumed to be the result of seed rain on adjacent native shrublands. Similarly, Meikle et al. established test plots on a northern Nevada site and located volunteer sage seedlings within two years after establishment of a planted bunchgrass community on waste rock. Schuman and Meyer note similar findings in Wyoming (Meyer 1992; Schuman and Booth 1998).

The use of companion vegetation which is conducive to invasion by sage has also been recognized by others. Rubber rabbitbrush (*Chrysothamnus nauseousus*) has been noted as compatible with sage establishment (MacArthur, Stevens et al. 1995). Early successional grass species such as squirreltail grass (*Sitanion hystrix*) and saltbush (*Atriplex* sp.) have been noted as compatible as well. Big sagebrush colonized a matrix of dryland bunchgrasses dominated by bluebunch wheatgrass, basin wildrye, and Sandberg bluegrass in Nevada (Meikle and Lu 1997). In general, seedling survival is a function of both light availability, plant size and gap size. Big sagebrush seed requires light for germination and plant

canopies which allow for greater penetration of light increase the potential for invasion. Subsequently, shelter from adult plants increases plant survival as long as sufficient gap space existed.

Cheatgrass and high fertility agronomic grasses tend to eliminate entirely the recruitment or establishment from seeds. Chambers states that highly competitive forage species have resulted in limited establishment of native species on reclaimed lands (Chambers, Brown et al. 1994). The result is that 14 years after reclamation on their southeast Idaho study site, big sagebrush had not re-invaded the study plots. This may have been aggravated by addition of legumes such as alfalfa and sweet clover which increase soil nitrogen levels. In addition, litter cover on sites excludes the invasion of certain species. This may be particularly relavent to sage invasion onto sites. Chambers conclusion is that changes to current reclamation methods will need to be made to facilitate natural successional processes which encourage establishment of native species. Particularly those later successional species which require disturbance and open space for establishment.

CONCLUSION

Successful sage restoration will require an understanding of the reproductive biology of big sagebrush, a planting strategy which reflects this, and an appropriate understanding of "ecological time". The proposed design approach uses containerized plantings as a source of continuous seed rain into adjacent facilitation beds that contain companion plants with growth characteristics conducive to big sage establishment. Given the large areas areas to be restored, highly designed scattered plantings relying upon containerized plant materials rather than large-scale and intensive plantings may represent an economically attractive option to reclamationists in the western US.

REFERENCES

Booth, D. T., J. K. Gores, et al. 1999. "Shrub densities on pre-1985 reclaimed mine lands in Wyoming." Restoration Ecology **7**(1): 24-32.

Brown, R. W., R. C. Sidle, et al. 1991. Reclamation Research Results on the Borealis Mine: Progress Report 1987-1990. Logan, UT, USDA Forest Service Intermountain Research Station Forestry Sciences Laboratory**:** 69.

Chambers, J. C., R. W. Brown, et al. 1994. "An evaluation of reclamation success on Idaho's phosphate mines." Restoration Ecology **2**(1): 4-16.

Cockrell, J. R., G. E. Schuman, et al. 1995. Evaluation of cultural methods for establishing wyoming big sagebrush on mined lands. 1995 National Meeting of the American Society for Surface Mining and Reclamation, Gillette, WY, ASSMR.

Hoffman, T. L. and C. L. Wambolt 1996. Growth response of Wyoming big sagebrush to heavy browsing by wild ungulates. Proceedings: shrubland ecosystem dynamics in a changing environment, Las Cruces, NM, USDA Forest Service Intermountain Research Station.

MacArthur, E. D., R. Stevens, et al. 1995. Adaptation and success of big sagebrush and rubber rabbitbrush on disturbed sites. 1995 National Meeting of the American Society for Surface Mining and Reclamation, Gillette, WY, ASSMR.

Martin, P. (1999). Personal communication.

Meikle, T. W. (1999). Shrub Establishment Plot Monitoring at Triton Coal. Gillette, WY, Triton Coal Corporation**:** 1.

Meikle, T. W., L. Ballek, et al. 1995. Big sage: an initial comparison of seedling survival between direct seeding and planting containerized stock. 1995 National Meeting of the American Society for Surface Mining and Reclamation, Gillette, WY, ASSMR.

Meikle, T. W. and S. Lu 1997. Report for the grassland establishment study. Golconda, NV, Getchell Gold Corporation**:** 13.

Meyer, S. E. 1990. Seed source differences in germination under snowpack in northern Utah. Fifth Billings Symposium on Disturbed Land Rehabilitation, Billings, MT, MSU - Reclamation Research Unit.

Meyer, S. E. 1992. Germination and establishment ecology of big sagebrush: implications for community restoration. Symposium on Ecology, Management, and Restoration of Intermountain Annual Rangelands, Boise, ID, USDA Forest Service Intermountain Research Station.

Mozingo, H. 1987. Shrubs of the Great Basin. Reno, Unversity of Nevada Press.

Myster, R. W. and F. O. Sarmiento 1998. "Seed inputs to microsite patch recovery on two tropandean landslides in Ecuador." Restoration Ecology **6**(1): 35-43.

Schuman, G. E. and D. T. Booth 1998. Strategies for Establishment of Big Sagebrush (Artemisia tridentata ssp. wyomingensis) on Wyoming mined lands. Cheyenne, WY, High Plains Grasslands Research Station**:** 53.

Toh, I., M. Gillespie, et al. 1999. "The role of isolated trees in facilitating tree seedling recruitment at a degraded sub-tropical rainforest site." Restoration Ecology **7**(3): 288-297.

Urbanska, K. M., S. Erdt, et al. 1998. "Seed rain in natural grassland and adjacent ski run in the swiss alps: a preliminary report." Restoration Ecology **6**(2): 159-165.

West, N. E. 1988. Intermountain Deserts, Shrub Steppes, and Woodlands. North American Terrestrial Vegetation. M. G. Barbour and W. D. Billings. New York, Cambridge University Press.

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DEMOGRAPHIC CHARACTERISTICS OF THREE *ARTEMISIA TRIDENTATA* SUBSPECIES

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ABSTRACT

Previous research suggested that woody plant recruitment may occur in pulses in semi-arid areas. In 1997, approximately 75 stem cross sections were collected from 9 stands of each of 3 subspecies of big sagebrush in Wyoming along elevation and climatic gradients. Annual growth-rings were used to identify year of establishment and demographic characteristics were analyzed from age-class frequencies. Mean stand ages of the 3 subspecies were different (P=0.002), and subsequent analysis revealed that Wyoming and mountain big sagebrush stand ages (32 $\pm$ 9 and 26 $\pm$ 9 respectively) were significantly older than basin big sagebrush (17 $\pm$ 3) stand ages (LSD, "=0.05). Mean recruitment intervals (years) were shorter for basin (1.6) than for Wyoming (2.3) and mountain (2.2) sagebrush (P=0.01). The number of cohorts did not differ among the subspecies (P=0.11), however, the percent of years with recruitment was significantly higher for basin (59%) compared to Wyoming (37%) and mountain (39%) big sagebrush (P<0.0001). Age-class frequency distributions of each stand and regional stand combination were assessed for dispersion across each associated period of record. Chi-square goodness-of-fit tests were performed for the negative binomial distribution. All stands (with one exception) and all three regional stand combinations fit the negative binomial distribution. Age-class frequency patterns of all subspecies indicate that recruitment is clustered or aggregated across each period of record. Recruitment in big sagebrush stands occurs in pulses throughout Wyoming.

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INTRODUCTION

All 3 subspecies of big sagebrush, basin (*Artemisia tridentata* Nutt. ssp. *tridentata*), mountain (*A. tridentata* ssp. *vaseyana* [Rydb.] Beetle), and Wyoming (*A. tridentata* ssp. *wyomingensis* Beetle and Young) are dominant constituents of many rangeland communities, occupying approximately 150,800 square kilometers of rangelands in Wyoming (Beetle and Johnson 1982). Big sagebrush has a wide ecological range and occupies a diversity of habitats (Beetle 1960), playing crucial roles in reducing erosion potential, providing wildlife habitat, and improving rangeland aesthetics (Vale 1974).

Big sagebrush subspecies identification is based on leaf morphology, growth form, and geographic location (Beetle and Johnson 1982). Distribution is related to elevation, temperature, and soil moisture (Cawker 1980). Wyoming sagebrush occurs at low to mid elevations on fine-textured soils. Basin sagebrush is also found at low to mid elevations but on deep, well-developed soils. Mountain sagebrush is distributed from mid to high elevations where cooler temperatures, higher precipitation, and developed soils are prevalent (Beetle 1960).

West et al. (1979) concluded that threetip sagebrush (*Artemisia tripartita* Rydb.), and granite pricklygilia (*Leptodactylon pungens* [Torr.] Nutt.) age-class frequency distributions do not usually deviate from the log-normal model, however high recruitment rates were observed in certain years. Pulses of recruitment in desert plant communities were suggested by Went (1955) and demonstrated for creosote bush (*Larrea tridentata* [DC.] Cov.) (Chew and Chew 1965; Barbour 1969). Unusual climatic events and high soil moisture conditions are suggested as major contributing factors (Noy-Meir 1973; Cawker 1980). A pulse is an infrequent recruitment of large numbers of individuals into a population. Cawker (1980) demonstrated evidence of climatic control of big sagebrush survival in British Columbia. If rare or infrequent climatic events control pulses of big sagebrush recruitment, these events should be evident within the population age structure as variations in age class frequency. Demography patterns of big sagebrush in Wyoming have not been assessed. This project was conducted to examine the age structure of 9 stands of each of the 3 subspecies on 27 native sites within 3 geographic areas of Wyoming.

Specific objectives were to: 1) determine plant and stand ages; 2) compare stand ages, periods of record, number of cohorts, percent of years with recruitment, and recruitment intervals between subspecies; and 3) assess the dispersion of age-class frequencies through time.

MATERIALS AND METHODS

Big sagebrush stands having a variety of cohorts, similar soil characteristics and topography, and minimal herbivory disturbance were selected for this study. Sites were selected to minimize microsite effects that increase or decrease supplemental moisture conditions, thereby minimizing potential variations in recruitment and survival rates between sites (Roughton 1972; Bonham et al. 1991).

Stem sections for *wyomingensis* were collected from 3 stands in northeast Wyoming near Rochelle; 3 stands in the South Fork of the Powder River watershed, northwest of Casper in central Wyoming; and 3 stands in southwest Wyoming near Pinedale. Stem sections for *tridentata* were collected from 3 stands near Pinedale; 3 stands near Worland, on the west slope of the Bighorn Mountains; and 3 stands near Farson, in southwest Wyoming. Stem sections for *vaseyana* were collected from 3 stands near Pinedale; 3 stands near Buffalo, on the east slope of the Bighorn

Mountains; and 3 stands west of Laramie, near Elk Mountain in south central Wyoming. The 3 stands in each regional grouping were located within a 15 mile radius. All stand locations were permanently recorded with a Global Positioning System, and latitude/longitude coordinates and elevations are published in Perryman and Olson (2000).

A stratified, random sampling method was used to collect stem cross-sections from each stand. A permanent 100 m baseline transect was located within each stand, and 10, 100 m perpendicular transects were established at randomly selected points along the baseline transect. Along each perpendicular transect, 8 random points were selected, and the closest individual big sagebrush plant was sampled. If the closest individual was not suitable for accurate age determination (e.g., damaged stem), another random point was selected until a suitable individual was found.

Stem cross-sections were obtained by sawing the plant below ground level (Ferguson 1964) to ensure that the pith and first annual growth ring were included. The stem was then cut approximately 10 cm from the bottom, providing a 10 cm long stem section. Sampling was conducted during the summer of 1997. Between 75 and 80 stem sections were collected from each stand (Cawker 1980).

In the laboratory, the bottom portion of each stem section was sanded sequentially with 60, 80, 320, and 400 grit sanding belts. Annual growth-rings were examined using a 10 power stereo microscope, and enumerated once by 2 different technicians for a total of 2 observations per sample.

Annual growth-rings are formed when the secondary xylem forms concentric rings around the stem during the growing season. Rings are easily distinguishable from one another by a distinct cork layer 8-18 cells wide (Ferguson 1964). This layer is produced throughout the growing season between the old and new xylem.

Inter-annual or false rings have not been encountered in big sagebrush at northern latitudes and higher elevations (Diettert 1938, Moss 1940, Ferguson 1964, Perryman and Olson 2000). Global positions and elevation of sites in Wyoming fulfill both of these criteria. Locally absent rings do occur, however complete absence of rings are almost never encountered due to the unique nature of annual growth-ring formation in big sagebrush (Ferguson 1964, Perryman and Olson 2000).

Many older stems are “lobed” or “rosette” in form and lack radial symmetry. Often the decumbent and decadent form of older stems leads to open pith exposure and loss. Accurate age assessments are not possible when the pith is absent. Our sampling was biased for single-stemmed plants with intact
piths over individuals without radial symmetry. As a result, some older plants with decadent stems were excluded.

Mean recruitment intervals, period of record, number of cohorts, and percent of years with recruitment were calculated for each subspecies. Age-class frequency distributions were constructed for each subspecies at 2 geographic scales, stand and regional stand combination. Age-class frequency dispersion through time was assessed by chi-square goodness-of-fit tests for both Poisson and negative binomial distributions (Ludwig and Reynolds 1988; Zar 1999).

RESULTS AND DISCUSSION

Individual plants and stands were generally younger than those found in previous big sagebrush dendrochronologic studies (Ferguson 1964, Roughton 1972, Cawker 1980). Prior research indicated that individual big sagebrush plant age often exceeds 100 years (Blaisdell 1953, Ferguson 1964) in the southwestern U.S. The oldest plant (81 years) in this study was a mountain sagebrush plant located in the Bighorn Mountains. The oldest Wyoming sagebrush plant (75 years) was from the Powder River Basin, and the oldest basin sagebrush plant (55 years) was found near Pinedale, WY. Young seedlings, 5-10 years old, were common in all stands.

Analysis of variance indicated that mean stand ages of the 3 subspecies were different (P= 0.002), and subsequent analysis revealed that Wyoming and mountain sagebrush stand ages (32, $\pm$ 9 and 26, $\pm$ 9 years respectively) were older than basin sagebrush (17, $\pm$ 3) stand age (LSD, "=0.05). Mean and median ages for stands and geographic stand combinations by subspecies are listed in Table 1. Analysis of variance indicated no difference in stand ages between geographic region (P=0.60).

Analysis of variance results for recruitment intervals, period of record, number of cohorts, and percent of years with recruitment are in Table 2. Recruitment intervals (by stand) ranged from 1.9 to 2.7 years for Wyoming sagebrush; 1.3 to 2.7 for basin sagebrush; and 1.2 to 2.9 for mountain sagebrush. Mean recruitment intervals were shorter for basin sagebrush (1.6) than for Wyoming (2.3) and mountain (2.2) sagebrush (P= 0.01). Years with high age-class frequencies occurred at irregular intervals. This supports the hypotheses by Went (1955) and West et al. (1979) that successful recruitment in arid and semi-arid plant communities occurs in pulses, often with many years of no seedling survival between successful years. Shorter intervals reflect more frequent, favorable recruitment conditions and higher rates of seedling survival. Less favorable climatic conditions may lengthen intervals in regions where Wyoming and mountain sagebrush plants occur (West 1978, Cawker 1980).

The number of cohorts did not differ among the subspecies (P= 0.11), however, the percent of successful recruitment years was significantly higher for basin sagebrush (59%) than for the Wyoming (37%) and mountain (39%) subspecies (P< 0.0001). A shorter mean period of record for basin sagebrush may explain the higher recruitment rate and shorter recruitment intervals. However, big sagebrush recruitment is episodic, and our data suggest that for Wyoming sagebrush, statewide recruitment occurred in only 33 of the past 75 years.

Age-class frequency distributions of each stand and regional stand combination were assessed for dispersion across each associated period of record. Chi-square goodness-of-fit tests were performed for both the Poisson and negative binomial distributions (Table 3). No stands or regional stand combinations fit the Poisson distribution and all variances were greater than the mean, indicating that recruitment is not random, but clustered, aggregated, or contagious (Zar 1999) across a period of record. All stands (with the exception of 1 mountain sagebrush stand) and all three regional stand combinations fit the negative binomial distribution. Means were different for each stand and stand combination so *k*-exponent values were different for each goodness-of-fit test (Table 3).

Cohort or age-class negative binomial distribution patterns were characterized by a relatively large number of years with no recruitment, a moderate number of years with minimal recruitment, and relatively few years with relatively high recruitment. Graphs of actual frequency probabilities for a representative stand and regional stand combination are displayed in Fig. 1.

CONCLUSION

These results suggest that big sagebrush plants that dominate much of the current vertical structure of plant communities in Wyoming are relatively young. However, mean stand ages of Wyoming sagebrush in northeast and central Wyoming are approximately 3 to 4 times older than the mean fire-free interval (8 years) for the area (Perryman 1996). Fire suppression activities are often associated with woody plant invasion of northern mixed-grasslands (Kucera 1981; Fisher et al. 1987; Steinaur and Bragg 1987).

Irregular pulses of recruitment are characteristic of big sagebrush stands in Wyoming. These results support hypotheses by Went (1955), West et al. (1979), and Cawker (1980), that recruitment in semi-arid regions occur only in years with favorable climate. Age-class frequency of big sagebrush stands follow the negative binomial distribution. Characteristically, there are a large number of years of no recruitment, an intermediate number of years with some recruitment, and a few years of high recruitment. Recruitment intervals are longer for Wyoming and mountain sagebrush than for basin sagebrush. We believe these results reflect general trends of demography in other big sagebrush communities in Wyoming. The large sample size (approximately 2200 individual plants) and regional consistency of results support our conclusion.

Future research must address mortality and survivorship curves of big sagebrush to fully understand the demography of this species. However, this study describes age frequency distributions and pulse recruitment phenomena of big sagebrush in Wyoming.

REFERENCES

Barbour, M.G. 1969. Age and space distribution of the desert shrub *Larrea divaricata*. Ecology, 50:679-685.

Beetle, A. A. 1960. A study of sagebrush, the section *Tridentatae* of *Artemisia*. Wyo. Agr. Exp. Sta. Bull. No. 368, Laramie, WY.

Beetle, A. A. and K. L. Johnson. 1982. Sagebrush in Wyoming. University of Wyo. Agr. Exp. Sta., Laramie, WY.

Blaisdell, J.P. 1953. Ecological effects of planned burning of sagebrush-grass range on the Upper Snake River Plains. U.S. Dept. of Agr. Tech. Rep. No. 1075.

Bonham, C.D., T.R. Cottrell, and J.F. Mitchell. 1991. Inferences for life history strategies of *Artemisia tridentata* subspecies. J. of Veg. Sci. 2:339-344.

Cawker, K.B. 1980. Evidence of climatic control from population age structure of *Artemisia tridentata* Nutt. in southern British Columbia. J. of Biogeogr. 7:237-248.

Chew, R.M. and A.E. Chew. 1965. The primary productivity of a desert shrub (*Larrea tridentata*) community. Ecol. Monogr., 35:355-375.

Diettert, R.A. 1938. The morphology of *Artemisia tridentata* Nutt. Lloydata, 1:3-74.

Ferguson, C. W. 1964. Annual rings in big sagebrush. Papers of the Laboratory of Tree-Ring Research No. 1. The University of Arizona Press, Tucson, A.Z.

Fisher, R.F., J.J. Jenkins, and W.F. Fisher. 1987. Fire and the prairie-forest mosaic of Devil's Tower National Monument. Am. Mid. Nat., 117:250-257.

Kucera, C.L. 1981. Grasslands and fire. *In*: Fire Regimes and Ecosystem Properties. USDA For. Serv. Gen. Tech. Rep. WO-26, 594p.

Ludwig, J.A. and J.F. Reynolds. 1988. Statistical Ecology: A Primer on Methods and Computing. John Wiley & Sons, New York.

Moss, E.H. 1940. Interxylary cork in *Artemisia* with reference to its taxonomic significance. Am. J. Bot., 27:762-768.

Noy-Meir, I. 1973. Desert ecosystems: environment and producers. Annual Review of Ecology and Systematics, 4:25-51.

Perryman, B.L. 1996. Fire history of the Rochelle Hills area of Thunder Basin National Grasslands. Ph.D. Dissertation, Univ. of Wyoming, Laramie.

Perryman, B.L. and R.A. Olson. 2000(in press). Age-stem diameter relationships of big sagebrush and their management implications. J. Range. Manage.

Roughton, R.D. 1972. Shrub age structures on a mule deer winter range in Colorado. Ecology, 53:615-625.

Steinauer, E.M. and T.B. Bragg. 1987. Ponderosa pine (*Pinus ponderosa*) invasion of Nebraska Sandhills prairie. Am. Mid. Nat. 118:358-365

Vale, T.R. 1974. Sagebrush conversion projects: An element of contemporary environmental change in the western United States. Biol. Conserv., 6:274-284.

Went, R.W. 1955. The ecology of desert plants. Sci. Amer. 192:68-75.

West, N.E. 1978. Basic synecological relationships of sagebrush dominated lands in the Great Basin and Colorado plateau. *In* The sagebrush ecosystem, A symposium, Logan, UT, College of Natural Resources, Utah State Univ., Logan.

West, N.E., K.H. Rea, and R.O. Harniss. 1979. Plant demographic studies in sagebrush-grass communities of southeastern Idaho. Ecology 60:376-388.

Zar, J.H. 1999. Biostatistical Analysis, 4th Ed. Prentice Hall, Upper Saddle River, New Jersey

Table 1. Mean and median stand and regional stand combination ages (years) by subspecies.

Subspecies, Stand, and Regional Combination	Mean	Median	n
wyomingensis			
R1	28	25	78
R2	23	19	73
R3	26	28	73
Northeast WY	26	25	224
TT1	32	33	61
TT2	30	29	58
TT3	21	16	59
Central WY	27	29	178
MW1	45	46	69
MW2	50	50	65
MW3	39	39	67
Southwest WY	45	46	201
vaseyana			
EM1	19	19	67
EM2	21	17	69
EM3	26	18	69
Southcentral WY	22	18	205
ES1	23	19	67
ES2	15	16	81
ES3	17	17	76
Central WY	18	17	224
P1	44	47	60
P2	34	35	57
P3	31	25	67
Southwest WY	36	35	184
tridentata			
WS1	22	21	76
WS2	22	21	70
WS3	14	13	78
Central WY	19	21	224
BS1	20	20	70
BS2	15	14	73
BS3	14	12	68
Southwest WY[1]	17	14	211
BP1	14	13	74
BP2	17	17	76
BP3	16	16	72
Southwest WY[2]	16	16	222

[1]West slope of the Green River Basin
[2]East slope of the Green River Basin

Table 2. Analysis of variance for mean recruitment intervals (years), mean number of cohorts in the period of record, mean percent of recruitment years in the period of record, and mean period of record (years).

Subspecies	Interval (yr)[1]	SE	# of Cohorts	SE	% Recruitment Years	SE	Period of Record	SE
wyomingensis	2.3[a]	± 0.7	23[a]	± 1.9	37[a]	± 5	62	± 6
vaseyana	2.2[a]	± 0.7	21[a]	± 4.1	39[a]	± 6	54	± 14
tridentata	1.6[b]	± 0.6	20[a]	± 2.4	59[b]	± 9	34	± 8

[1] Means with the same superscript within a column are not significantly different (P>0.05, LSD).

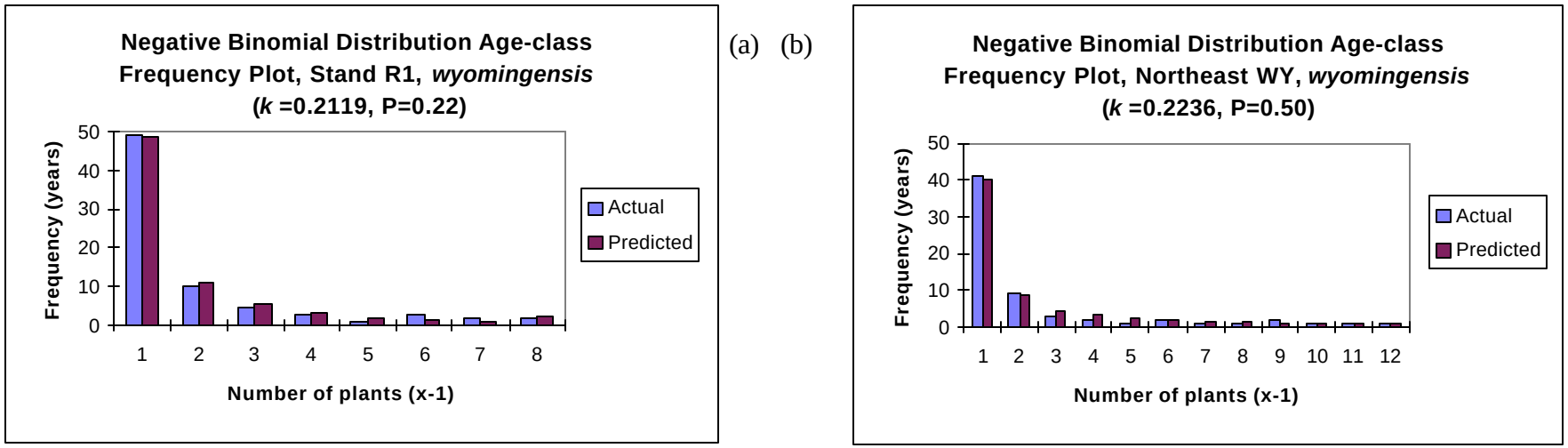

Fig. 1. Representative negative binomial age-class frequency plots from Chi-square goodness-of-fit tests of (a) a stand and (b) a regional stand combination for Wyoming sagebrush.

Table 3. Results of chi-square goodness-of-fit tests for Poisson (p-value) and negative binomial (p-value and *k*-exponent value) distributions for individual stands and regional stand combinations.

Stand, and Regional Combination	Poisson	Negative Binomial	*k*
wyomingensis			
R1	0.0001	0.22	0.2387
R2	0.0001	0.83	0.2119
R3	0.0001	0.64	0.2145
Northeast WY	0.0001	0.50	0.2236
TT1	0.0001	0.19	0.3612
TT2	0.0001	0.23	0.5818
TT3	0.0001	0.44	0.3962
Central WY	0.0001	0.35	0.5377
MW1	0.0001	0.75	0.2499
MW2	0.0001	0.32	0.3043
MW3	0.0001	0.56	0.3218
Southwest WY	0.0001	0.71	0.3667
vaseyana			
EM1	0.0001	0.56	0.4662
EM2	0.0001	0.99	0.3052
EM3	0.0001	0.32	0.2348
Southcentral WY	0.0001	0.67	0.2674
ES1	0.0001	0.23	0.3029
ES2	0.0001	0.59	0.1538
ES3	0.0001	0.84	0.2509
Central WY	0.0001	0.45	0.1659
P1	0.0001	0.91	0.2337
P2	0.0001	0.81	0.3322
P3	0.0001	0.009*	0.3480
Southwest WY	0.0001	0.34	0.3698
tridentata			
WS1	0.0001	0.31	0.4497
WS2	0.0001	0.51	0.4889
WS3	0.0001	0.54	0.4069
Central WY	0.0001	0.11	0.4111
BS1	0.0001	0.14	1.2299
BS2	0.0001	0.76	0.3408
BS3	0.0001	0.68	0.6599
Southwest WY[1]	0.0001	0.31	0.6838
BP1	0.0001	0.40	0.6382
BP2	0.0001	0.69	0.4016
BP3	0.0001	0.79	0.2247
Southwest WY[2]	0.0001	0.87	0.2403

[1]West slope of the Green River Basin

[2]East slope of the Green River Basin

*Only stand or stand combination that did not fit the negative binomial distribution.

2000 Billings Land Reclamation Symposium

HISTORICAL SAGEBRUSH ESTABLISHMENT PRACTICES IN THE POWDER RIVER BASIN

Laurel E. Vicklund[1]

ABSTRACT

The Powder River Basin of Wyoming is a semi-arid area dominated by sagebrush grassland vegetation communities. This region includes 15 surface coal mines. Reclamation of mined lands requires reestablishment of native species and post mine land use. The Wyoming Department of Environmental Quality (WDEQ) serves as the regulatory authority for the State's surface coal mines. Wyoming statutes require that the disturbance from surface coal mining activities be reclaimed to a condition at least equal to the premining condition.

Big sagebrush (*Artemisia tridentata)* is one of the major shrub components of premining vegetation communities. Because of sagebrush's dominance in various portions of the basin, shrub density requirements were developed by the state and have evolved to a current shrub density standard. The evolution of the shrub density requirements has been paralleled by development of myriad shrub establishment techniques.

Successful shrub establishment is vital for final bond release. Most final reclamation will be evaluated for a shrub density standard on twenty percent of the post-mined surface. The most successful techniques should be evaluated from the over 20 years of shrub establishment experience. To see where we are going, we need to look at where we've been.

—

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INTRODUCTION

The Powder River Basin of Northeast Wyoming includes 15 surface coal mines. Surface coal mining expanded significantly in the early 1970's. The volume of coal shipped rose steadily through the 1980s to a current total of approximately 317 million tons shipped in 1999. (Wyoming Mining Association 1999).

The national Surface Mining Control and Reclamation Act (SMCRA) of 1977 regulates the reclamation of mined lands. The Wyoming Environmental Quality Act (WEQA) defined Wyoming's program and the Wyoming Department of Environmental Quality (WDEQ) serves as the regulatory authority for the State's surface coal mines. Wyoming statutes require mined land disturbances be reclaimed to a condition equal to the premine condition and require demonstration that the land is capable of sustaining premine land use (SMCRA 1977; WEQA 1973).

Premining land use in northeastern Wyoming is primarily grazing and wildlife habitat. The wildlife habitat portion of the land use dictates the reestablishment of the premine shrub component that in this area, is Wyoming big sagebrush (*Artemesia tridentata ssp. wyomingensis).*

The purpose of this report is to present a brief history of regulations, planting techniques, and research in shrub reestablishment in Wyoming with particular emphasis on the Powder River Basin. Mines within the Powder River Basin were surveyed to obtain information regarding their sagebrush reclamation efforts. This history is divided into the following periods:

Pre - 1980
1980 - 1989
1990 - 1999
2000 and Beyond

HISTORICAL SUMMARY

Pre- 1980, Before the State Program Approval

Regulation

Prior to 1980, the federal program required surface coal mine operators to restore shrubs and trees to an average density of 450 stems per acre (Code of Federal Regulations 30CFR 816.116). The original WEQA required operators to reclaim shrubs and trees to a density equal to the density premining. On average, this is a difference of about nine times the stems per acre. Such a large difference in regulatory requirements caused much discussion and regulatory action after 1980 between the operators and the agencies.

Techniques

Of the mines surveyed, three were built prior to 1980. None of those mines built before 1980 reported planting any sagebrush in reclamation conducted before 1980.

Research
Research before 1980 on establishing sagebrush, discussed seedling ability to compete for moisture (Cook and Lewis 1963). McDonough and Harniss (1974) theorized sagebrush was difficult to establish due to then current methods used to harvest seed, seed microclimate, and seed dormancy. Harniss and McDonough (1976) hypothesize that poor establishment from direct seeding resulted from poor seed viability. Research by Howard et al. (1979) showed that woody plants may have surviveed the climate and soil conditions of Wyoming and Colorado, but growth was slowed by wildlife predation. These early research topics form the basis for future papers.

1980 – 1989

Regulation
In 1983 the Federal Office of Surface Mining Reclamation and Enforcement (OSMRE) adopted regulations requiring minimum shrub and tree stocking and planting arrangements for areas to be developed for fish and wildlife habitat. The planting rates were to be specified by the regulatory authorities based on local and regional conditions after consultation with State agencies responsible for the administration of the forestry and wildlife programs. Several environmental groups and the coal industry promptly sued OSMRE. A court ruling was completed in 1987 and OSMRE revised the federal rules.

During the four years of court proceedings, Governor Herschler appointed a Task Force on Regulatory Reform. One of the subcommittees was charged with developing an alternative to the 100 percent shrub replacement requirement. The WDEQ Land Quality Division (LQD) Rules and Regulations proposed operators meet a 10 percent shrub goal of the premining density. This goal is one shrub per square meter on 10 percent of the affected area. The regulation was promulgated in 1986 with OSMRE's approval before final court ruling.

The Wyoming Game and Fish Department (WGFD) petitioned WDEQ/LQD for a new shrub density standard in 1989 that would increase the density rate and specify the composition of shrubs to be used. The proposal would change the 10 percent goal to a 20 percent standard and address the premining shrub community composition. The 20 percent standard was defined as one shrub per square meter.

The 20 percent standard was debated before the Land Quality Advisory Board (LQAB) several times during 1989. Subsequently the LQAB requested a committee be formed consisting of LQD, WGFD, and coal industry personnel to negotiate a compromise.

Techniques
In 1980, two mines started to incorporate big sagebrush into the permanent reclamation seed mix. Initial seed rates in 1980 through 1983 varied from 0.1 to 20 pounds of sagebrush seed per acre. The seed was broadcast with a Brillion drill and drill seeded

with a Truax drill and another unknown type of drill. Vegetation sampling from one site indicated that drill seeding obtained a shrub density of 0.02 shrubs per square meter.

From 1980 to 1983 at the above-mentioned mines, grass hay mulch was applied at the rate of 2 tons per acre and 10 pounds of winter wheat per acre was used as a cover crop. One mine applied fertilizer regularly at the rate of 20 pounds of nitrogen and 20 pounds of potassium per acre. Vegetation sampling reported no sagebrush established at these sites.

By 1985 more mines included big sagebrush with the permanent reclamation seed mix. By 1989, all mines surveyed had included sagebrush into the permanent reclamation seed mix. Seeding rates were less varied and ranged from 1 to 6 pounds per acre. Fertilizers were no longer used. The technique of using stubble mulch and interseeding sagebrush was common at the majority of mines surveyed. Vegetation sampling of the sites planted during this time frame show sagebrush establishment rates of 0.16, 0.46 and 1.06 shrubs per square meter.

Other methods were also being utilized to establish big sagebrush during the 1980's. Some mines purchased and planted sagebrush tublings. One mine built a range pad cutter and harvested pads of native rangeland with mature, established sagebrush plants for placement in reclaimed areas. Vegetation sampling showed little or no recorded success. No documentation described any special considerations regarding seed procurement or seed treatment.

Research

Research during the 1980's began to look at sagebrush issues in greater detail, paralleling the trend of in-depth research of disturbed lands issues. Williams et al. in 1981 added to the pool of research by identifying vesicular-arbuscular mycorrhizae (VAM) as a factor affecting sagebrush seedling establishment. Their work specifically studied VAM inoculum in long-term topsoil stockpile storage.

In 1984, Pfannensteil and Wendt studied enhancing the establishment of sagebrush on reclamation in Colorado by direct haul placement of topsoil. By 1988, C. Wayne Cook was reviewing the then-present body of reclamation research. Cook observed that current research was not widely available and in particular, stated that some shrubs were still difficult to establish. His ultimate question was, "Has research contributed significantly to mined land reclamation." By 1989 other researchers were debating the proposed shrub density increase regulation (Tessmann and Kleinman 1989). The Tessmann and Kleinman point/counterpoint debate echoed some of the same issues discussed by Colbert and Colbert in 1983 about the validity of using sagebrush for revegetation.

1990 – 1999

Regulation

The joint shrub committee consisting of WGFD, LQD, industry personnel and special interest groups held work sessions in 1990, 1991, and 1992 on the 20 percent standard issue. Finally, the Environmental Quality Council (EQC) approved a proposal for shrub density standard of one shrub per square meter on 20 percent of the affected area. The State rule submitted in October 1992 was filed and submitted to OSMRE for public comment. The federal public comment period ran through April of 1993.

Meanwhile, the 1993 Wyoming Legislature passed and made law Enrolled Act No. 86 without the Governor's signature. Enrolled Act No. 86 inserted several paragraphs. That basically required operators who reclaim grazingland to reestablish shrubs on 10 percent of the affected surface to a density of one shrub per nine square meters or to a premining density, whichever is less. Shrubs stipulated for use in reclamation consisted of native shrubs from the general area identified in premining surveys, but the dominant premining shrub need not be the dominate postmining shrub.

Enrolled Act No. 86 was submitted to OSMRE as a formal program amendment. After the extended the public comment period, OSMRE requested that the State clarify the conflicting rule and statutory language. Wyoming responded by outlining the conflicting portions of the rule and statute and requested that OSMRE determine whether the amended statute was as effective as the Federal law.

By January 1994, OSMRE rejected the State rule and the State statute and required six amendments be added to Wyoming's program. The legislature responded by drafting proposed changes in Enrolled Act 86. Governor Sullivan signed Enrolled Act No. 24 (1994) that fulfilled part of OSMRE's requirements and the State requested a time extension to address the remainder of amendments.

Additional draft legislation was proposed to satisfy the remainder of OSMRE's required amendments. The changes were signed into law, in February 1995, by Governor Geringer as Enrolled Act No. 8. This Act changed the definition of critical and crucial fish and wildlife habitat and resulted in subsequent changes to the vegetation related rules and regulations. Reestablishment of shrubs basically required operators who reclaim mined lands to reestablish shrubs on 20 percent of the affected surface to a density of one shrub per one square meter. Three other variations on this shrub density requirement allow operators to develop site specific shrub reclamation bond release commitments to reflect the premining shrub vegetation community.

Operators were required to delineated the land currently affected as of August 6, 1996 that would still be regulated by the old 1980-1989 regulation of one shrub per square meter on 10 percent of the affected lands. Lands affected after that date would be subject to the new 20 percent shrub density rule.

Techniques

While mail between Wyoming and OSMRE was flying fast and furious, operators continued to plant sagebrush. Rates of pure live seed in approved mixes varied between the mines surveyed from 10 pounds per acre to 0.5 pound per acre. The majority of sagebrush was seed that was planted by seeding, broadcast through a drill or by hand, and one mine still applied small amounts of sagebrush seed by hydroseeding. One mine planted a few small areas with sagebrush tublings. None of the surveyed mines were applying nitrogen any more, although a few occasionally applied potassium.

All were using a stubble mulch or cover crop to assist in sagebrush establishment. By 1995, most were showing results in sagebrush density through vegetation surveys. Many operators established and monitored permanent shrub transects.

Densities reported from these surveys ranged from 0.01 sagebrush per square meter to 2.72 sagebrush per square meter. One mine showed slightly elevated densities in areas where topsoil was directly placed. Some transects showed increasing density trends; some showed declining trends, and die-off of previously established sagebrush.

More mines showed seed origin as Wyoming instead of unknown, indicating the increased awareness of obtaining more locally grown seed. The above planting techniques also indicate that these operators were incorporating the state-of-the-art technology into their shrub reclamation programs.

Research

In the 1990's, research seemed to become further focused. Cockrell et al. (1995) conducted extensive field research on the effect of topsoil management, mulching practices, and plant competition on initial sagebrush seedling establishment. McArthur et al. (1995) reviewed establishment attributes of big sagebrush and rubber rabbitbrush (*Chrysothamnus nauseosus*) and their use and performance in reclamation plantings.

The Wyoming Abandoned Coal Mine Land Research Program (AML) has provided funds and a platform for many reclamation research projects. Through the AML program, Schuman et al. (1998) examined effective strategies to establish big sagebrush on mined lands in the Powder River Basin. Booth et al. (1996) added to available information on post-harvest and pre-planting seed treatment on sagebrush seedling vigor. One of the most recent AML studies still in progress is research to identify the seeding rate of cool season grasses and competition effect on sagebrush seedlings. (Fortier et al. work in progress)

2000 and Beyond

Several things became noticeable during the review of the history of the shrub establishment regulations, the individual mine sagebrush establishment techniques, and sagebrush related research. It appeared that mines incorporated actual sagebrush seeding and establishment techniques from the wealth of successful research results and that sagebrush is beginning to successfully establish in reclaimed areas.

Sagebrush reclamation, success and research showed a consistent and smoothly increasing trend. By comparison, the step-like function of increasing shrub regulations was erratic. This might suggest that the attention focused on the increasing regulations, not the presence of the regulations themselves, lead to the increased focus on sagebrush establishment research.

Future issues in sagebrush establishment might include; techniques to ensure long term viability of plants after initial establishment; and development of other vital wildlife habitat features. As stated in the beginning of this paper, not only is industry required to reclaim mined land disturbances to a condition equal to the premine condition; they are also required to demonstration that the land is capable of sustaining the premine land use. Reclamation of wildlife habitat consists of more components than big sagebrush. However, regulations and rules, from the early 1980 to present, have focused on sagebrush establishment. Perhaps it is time, with out extensive regulations and rule making that accompanied sagebrush, to expand reclamation efforts to include other components of wildlife habitat.

Acknowledgement

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The references listed represent only a small portion of the wealth of research that has been and is currently being conducted on sagebrush.

References

Booth, D. T., and E. E. Roos. AML project work in progess. The influence of post-harvest and pre-planting seed treatment on sagebrush seedling vigor.

Code of Federal Regulations. Title 30, Chapter VII, Subchapter K, § 816.

Cockrell, J. R., G. E. Schuman, and D. T. Booth. 1995. Evaluation of cultural methods for establishing Wyoming big sagebrush on mined lands. In: Proceedings for 1995 National Meeting of the American Society for Surface Mining and Reclamation, 12th Annual Meeting. June 5-8, 1995, Gillette, WY.

Colbert, T. A. and M. A. Colbert. 1983. Revegetating with sagebrush, who's right? Rangelands 5: 33-35.

Cook, C. W. and C. E. Lewis. 1963. Competition between big sagebrush and seeded grasses on foothill ranges in Utah. J. Range Manage. 16: 245-250.

Cook, C. W. 1988. Has research contributed significantly to mined land reclamation? Proceeding: High Altitude Revegetation Workshop No. 8. Information Series No. 59: 230-239. Water Resources Research Institute. Colo. State University.

Fortier, M. I., G. E. Schuman, A. L. Hild, and L. E. Vicklund. AML work in progress. Effects of seeding rates and competition on sagebrush establishment on mined lands.

Harniss, R. O. and W. T. McDonough. 1974. Yearly variation in germination in three subspecies of big sagebrush. J. Range Manage. 29: 167-168.

Howard, G. S., F. Rauzi, and G. E. Schuman. 1979. Woody plant trials at six mine reclamation sites in Wyoming and Colorado. U.S. Depart. of Ag. Production Research Report No. 177.

McArthur, E., Durant, Richard Stevens, and Steven B. Monsen. 1995. Adaptation and success of big sagebrush and rubber rabbitbrush on disturbed sites. In: Proceedings for 1995 National Meeting of the Amer. Society for Surface Mining and Reclamation, 12th Annual Meeting. June 5-8, 1995, Gillette, WY.

McDonough, W. T. and R. O. Harniss. 1974. Effects of temperature on germination in three subspecies of big sagebrush. J. Range Manage. 27: 204-205.

Pfannensteil V. R. and G. W. Wendt. 1984. Enhancing shrub establishment by utilizing direct haul topsoil on mine spoils in western Colorado. IN: Symposium on the Reclamation of Lands Disturbed by Surface Mining. Amer. Society of Surface Mining and Reclamation. July 13-14, 1984. Owenberg, KY.

Schuman, G. E., D. T. Booth, and J. R. Cockrell. 1998. Cultural methods for establishing Wyoming big sagebrush on mined lands. J. Range Manage. 51: 223-230.

Tessmann, S. A. and L. H. Kleinman. 1989. Should the mining industry be required to increase the amount of sagebrush planted at reclaimed sites—point/counterpoint. The Wyoming Mining Claim. 15(2): 8-11.

U. S. Congress. 1977. Surface Mining Control and Reclamation Act (SMCRA). 1977 Public Law (30 USC 1201 et seq.). Washington, D. C.

Williams, S. E., M. A. J. Loree and P. C. Singleton. 1981. The effects of long term storage on fertility and biological activity of topsoil. Abstract. In: Proceedings of the Fifth North American Conference on Mycorrhizae. August 1981, Quebec City, Quebec, Canada.

Wyoming Environmental Quality Act (WEQA). 1973. Wyoming Statute.

Wyoming Mining Association. 2000. 1999 Coal Production Report.

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SAGEBRUSH AND MINE RECLAMATION: WHAT'S NEEDED FROM HERE?

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ABSTRACT

The Wyoming Environmental Quality Act requires coal mines to include shrubs in the reclamation revegetation species mix and further specifies planting patterns and density required for full reclamation bond release. Wyoming big sagebrush (*Artemesia tridentata* ssp. *wyomingensis*) is a principal shrub component in many of the vegetative communities found in the coal mining districts of Wyoming and elsewhere in the western United States. Efforts to establish Wyoming big sagebrush on reclaimed areas by the coal mining companies in Wyoming have met with mixed success. The University of Wyoming, through its Abandoned Coal Mine Lands Research Program funded by the Abandoned Mine Land Program of the Wyoming Department of Environmental Quality, has sponsored several research projects beginning in 1993 to better understand the requirements of Wyoming big sagebrush revegetation and to find more cost effective and dependable methodologies for meeting the legislative and regulatory requirements. The research to date has been less than conclusive; seed is germinating, but seedlings seldom reach a mature, dominant, or co-dominant position on reclaimed sites. One study found natural sagebrush stands are even-aged, suggesting only certain, unique climatic or weather conditions may be a requisite for stand establishment, or perhaps some catastrophic event such as fire, may be required. Further research is needed to find economic methods for Wyoming big sagebrush establishment and survival. Current seeding methodologies may add as much as five cents to the cost of producing one ton of coal. Coal contracts are won or lost by as little as five cents subtracted or added to the cost per ton of coal. What are the economic cut-offs for "transplanting and seeding"? What types of cultural practices will ensure seed germination and seedling survival each year, instead of just when climatic conditions are ideal? Cultural practices may include, but are not limited to soil chemical and physical characteristics, surface manipulation, mulches, cover crops and heavy livestock grazing. This information is needed before the mining industry can satisfy the regulatory requirements in a cost-effective manner.

Additional Key Words: shrubs, revegetation, regeneration

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INTRODUCTION

The Wyoming Environmental Quality Act at § 35-11-415(b)(vii) requires mine operators to "Replace as nearly as possible, native or superior self regenerating vegetation on land affected, as may be required in the approved reclamation plan" (WEQA 1998). The Land Quality Division of the Wyoming Department of Environmental Quality promulgated rules and regulations in 1996 specifying a shrub standard to be achieved as part of the revegetation success requirements for coal mines seeking reclamation bond release. Chapter 4 of the Rules and Regulations, "Environmental Protection Performance Standards for Surface Coal Mining Operations," at Section 2 (d)(i) requires the operator to "…establish on all affected lands a diverse, permanent vegetative cover of the same seasonal variety native to the area or a mixture of species that will support the approved postmining land use in a manner consistent with the approved reclamation plan. The cover shall be self renewing and capable of stabilizing the soil." Section 2 (d)(x)(E) further requires "The post mining density, composition, and distribution of shrubs shall be based upon site specific evaluation of premining vegetation and wildlife use. Shrub reclamation procedures shall be conducted through the application of best technology currently available." Finally, Subsection 2 (d)(x)(E)(I) states "Except where a lesser density is justified from premining conditions in accordance with Appendix A, at least 20% of the eligible lands shall be restored to shrub patches supporting an average density of one shrub per square meter. Patches shall be no less than .05 acres each and shall be arranged in a mosaic that will optimize habitat interspersion and edge effect….This standard shall apply to all lands affected after August 6, 1996" (LQD 1998). Although big sagebrush (*Artemesia tridentata*) and its subspecies are not specifically mentioned in the above cited requirements, because of the requirements to replace or restore the vegetation existing prior to the mining disturbance, the replacement of big sagebrush is specified by default.

The coal mining industry has included sagebrush in its revegetation efforts for the past decade with mixed success. Schuman and Booth (1998) and others have suggested the cause for the mixed results may be low seedling vigor, competition from herbaceous species, altered soil conditions, and reduced levels of arbuscular mycorrhizae in the reclaimed mine soils.

RECENT BIG SAGEBRUSH ESTABLISHMENT RESEARCH

The Abandoned Coal Mine Land Research Program (ACMLRP), administered by the University of Wyoming and funded by the Abandoned Mine Land Program of the Wyoming Department of Environmental Quality, was established in 1991 to sponsor research for abandoned and active coal mine reclamation. The ACMLRP has funded four research projects on big sagebrush establishment, with emphasis on the subspecies *wyomingensis*. Four major studies have been undertaken since 1993, three of which have been completed and one is still in progress.

One study, Climatic Control of Sagebrush Survival for Mined-Land Reclamation (Perryman et al. 1999), looked into climatic and environmental factor relationships with

natural sagebrush stand establishment. This study evaluated stands of the Wyoming, basin (*vaseyanna*), and mountain (*tridentata*) subspecies from locations thorough out Wyoming. Significant findings include stands are generally even-aged and establishment is episodic. Mean stand ages of Wyoming big sagebrush in northeast and central Wyoming are approximately 26 to 32 years. This is 3 to 4 times older than the mean fire-free interval of 8 years for these areas. Irregular pulses of recruitment appear to be characteristic of big sagebrush stands in Wyoming.

This study further found that above average December and January precipitation following initial establishment of Wyoming big sagebrush seedlings was a common occurrence associated with stand establishment. It would appear that the deeper snow cover associated with the above-average precipitation at that time of year provides protection from winter desiccation as well as additional soil moisture during the spring growing season. For basin big sagebrush, there was higher recruitment in those years with higher than average June precipitation during the first growing season, followed by higher than average precipitation in March, May and June of the second growing season. Mountain big sagebrush did not follow this pattern as precipitation in the higher mountain environments means lower temperatures, not conducive to germination and growth at those times of the year.

Perryman et al. (1999) further found that big sagebrush stand age might be estimated by stem diameter measurements of the larger plants within the stand with reasonable accuracy. They obtained good correlation with approximately 1 mm of diameter per year.

A second study, <u>The Influence of Post-harvest and Pre-planting Seed Treatment on Sagebrush Seedling Vigor</u>, was initiated in 1993 (Booth et al. 1996). Analyses were performed on big sagebrush seeds collected from several locations during the late winter. Processing through a 48-inch commercial debearder did not appear to reduce seed quality. Moisture percentages in the seed ranged from 2.3 to 9.0% and seed weights ranged from 0.022 to 0.032 g/100 seeds. Germination percentages were highest, and germination most rapid, from the heavier seeds.

This study also evaluated moisture uptake (hydration) by big sagebrush seed in storage during a 15-day period at 2°, 5°, 10°, and 15°C. Hydration occurred slowly at the cooler temperatures while the maximum rate of hydration occurred at 10°C. The differences in hydration rates did not appear to influence germination or seedling vigor in laboratory tests.

Big sagebrush seeds, when exposed to seven water potentials ranging from 0.00 to –1.5 MPa, exhibited greatest germination at 0.00 Mpa. The authors also observed that the pericarp reduces water uptake and that pericarp removal enhanced germination between –0.50 and –1.00 Mpa. Booth et al. (1996) recommended, however, not to remove the pericarp, as they believed it is important in retaining seed viability in the soil until more favorable soil moisture conditions occur. They implied normal seed

processing would result in an adequate quantity of naked seed without the need for further pericarp removal.

As an extension to the previous study, Booth et al. (1998) in Wyoming Big Sagebrush Seed Production from Mined Lands and Adjacent Unmined Rangelands, evaluated big sagebrush seed production from reclaimed coal mine lands and undisturbed, native ground. This study was done at the Dave Johnson Coal Mine in central Wyoming from July 1995 through October 1998. Big sagebrush plants observed ranged in age from 10 to 20 years. They found the number of seed stalks per plant, seed quantities, and seed weights were greater from plants on reclaimed mine land than from companion plants on adjacent undisturbed sites. Some plants had been fenced to observe the effects of wildlife browsing. It was observed the unfenced plants produced lighter and drier seeds than the plants that were fenced. It was also observed, unexpectedly, that the fences apparently provided some environmental modification comparable to the effects of mulch and wind protection treatments applied as part of the study. Soil moisture conditions varied considerably from year to year. However, when averaged across all variables, soil moistures on reclaimed and mulched native sites was higher than on no-mulch reclaimed and no-mulch undisturbed sites.

In the study Strategies for Establishment of Big Sagebrush (*Artemesia Tridentata* ssp *Wyomingensis*) on Wyoming Mined Land (Schuman and Booth 1998), looked at coal mine reclamation practices and their relationships with big sagebrush establishment. They found that direct placed topsoil did not act as a seed bank for big sagebrush as compared to stockpiled topsoil. They did find, however, that direct placed topsoil consistently had higher soil moisture and greater arbuscular mycorrhizae spore counts than did stockpiled topsoil. As a result, the direct placed topsoil sites had 40% more big sagebrush seedlings than stockpiled topsoil sites the first season of establishment and from one to two orders of magnitude more the following season.

Schuman and Booth (1998) looked at the differences in mycorrhizal infection between direct placed topsoil and stockpiled topsoil. In spite of a nearly 33% greater spore count in direct placed topsoil, there was no apparent difference in the number of mycorrhizal infected big sagebrush seedlings between the two soil treatments. The authors note this may be because the non-infected seedlings had already died prior to the observations. There did seem to be a positive effect of mycorrhizae on drought stress tolerance by big sagebrush seedlings.

Stubble mulch and crimped straw mulch were found to provide greater big sagebrush seedling establishment than was no mulch or stubble and straw mulch together. Grass competition was further observed to have reduced big sagebrush seedling density throughout the duration of the Schuman and Booth study.

A final aspect of the Strategies for Establishment of Big Sagebrush study was the relationship and effect of seeding big sagebrush with fourwing saltbush (*Atriplex canescens*) as a pioneer species for later big sagebrush establishment. There were no effects, either positive or negative, shown by this phase of the study. It was observed,

however, that the increase in total shrub density was favorable in helping to meet the shrub density regulatory standard for reclamation bond release.

An important finding from the Schuman and Booth study is big sagebrush seed apparently maintains its viability for a much longer time than previously thought. New seedlings were noted three and five years after the initial seeding.

The study Grass Competition and Sagebrush Seeding Rates: Influence on Sagebrush Seedling Establishment (Fortier et al. 1999) is in its first year and only preliminary results are reported. First growing season data for big sagebrush seedling performance under three sagebrush seeding rates and seven grass seeding rates were mixed. Heavy spring and early summer precipitation masked the expected effects of increasing grass competition. However, big sagebrush seedling density did show a direct relationship with seeding rates, and big sagebrush seedling density was lower at the higher grass seeding rates. Big sagebrush seedling density declined with decreasing precipitation and soil moisture content through the summer for all seeding rates, and the greatest seedling loss was seen in the highest big sagebrush seeding rates. All three big sagebrush seeding rates of 1 kg/ha, 2 kg/ha, and 4 kg/ha met the regulatory required density of 1 shrub per square meter at the end of the first growing season.

SUMMARY

The research conducted under the Wyoming ACMLRP has shown that the establishment of natural big sagebrush stands is episodic and appears to be dependent upon winter and early spring precipitation patterns immediately following seedling establishment. Other findings of significance are:

1. Big sagebrush seedlings are sensitive and susceptible to winter desiccation.
2. Big sagebrush seedlings are sensitive to late growing season moisture stress.
3. Big sagebrush seedlings are intolerant of grass and/or herbaceous competition, apparently for the above stated reasons.
4. Direct placed topsoil is not an apparent source of big sagebrush seed or propagules.
5. Mycorrhizae are important in helping big sagebrush seedlings to survive periods of moisture stress.
6. Direct placed topsoil generally has higher soil moisture content and mycorrhizal spore counts, both of which are beneficial to big sagebrush seedling establishment and survival, than does stockpiled topsoil.
7. Big sagebrush should be seeded a season or two before grass or herbaceous species to insure seedling establishment.
8. Stubble mulch or straw mulch provides protection to big sagebrush seedlings from winter desiccation and to maintain soil moisture contents for longer periods of time.
9. Big sagebrush seed has an apparent longer viability than previously thought, up to three to five years.

RESEARCH NEEDS

Big Sagebrush Seeding and Transplanting Costs

Further research is needed to find cost-effective methods for Wyoming big sagebrush establishment and survival. Current seeding methods, following many of the preceding recommendations, may add as much as $0.05 per ton ($0.055 per metric ton) of coal produced, which is substantial considering that Powder River Basin coal is selling on the spot market for less than $3.50 per ton ($3.85 per metric ton). Contracts are won or lost by as little as five cents per ton of coal.

Transplanting and seeding costs are a substantial part of the total reclamation costs. The cost of transplanting containerized stock can be more than $2.00 per stem. It would require 809 stems per acre (2,022/hectare) or $1,618.00 per acre ($4,045.00/ha) to meet the regulatory requirement of one shrub per square meter over 20% of the area just for planting only the big sagebrush.

Seeding costs are much less than transplanting but at a much greater risk of establishment failure. One 1999 contracted seed price for Wyoming big sagebrush was just over $32.00 per PLS pound ($70.40/kg). At a seeding rate of one-half pound PLS per acre (0.625 kg/ha), the cost for the seed alone would be $3.52 per acre ($8.80/ha) for the shrub density requirement of 20% of the area. This does not include the cost of planting, which, when including seedbed preparation, seeding, and mulching, will approach $500.00 per acre ($1,250.00/ha). Recent research has been recommending 3-8 PLS pounds per acre (3.4 – 9.1 kg/ha) seeded for best results. Six PLS pounds (6.82 kg/ha) of big sagebrush seed at the current price is $192.00 per acre ($480.00/ha) or $38.00 per acre ($96.00/ha) plus seeding costs for 20% of the area. It is clear the costs of planting materials alone for big sagebrush become quite high considering the establishment success that has been achieved. It is imperative to find more efficient and cost-effective ways of meeting the shrub density and vegetative performance requirements of the Wyoming Land Quality Division's Coal Rules and Regulations.

Next Generation of Research

Research in two basic areas is needed. Are there new cultural practices for establishing big sagebrush that have not yet been explored? What are the costs and economics of those cultural practices and methodologies that are, or will be, proven to result in big sagebrush stand establishment? How can these costs be improved?

Different types of cultural practices to ensure seed germination and seedling survival each year should be explored. Cultural practices may include, but are not limited to, soil chemical and physical characteristic modifications, surface manipulation, mulches, cover crops, and even heavy livestock grazing.

What are the soil chemical characteristics that drive big sagebrush germination and establishment? Are there nutrient characters such as organic matter or nitrogen that

aid in the growth of big sagebrush? What are the soil physical characteristics or surface manipulation that will increase water holding capacity until such a time that the seed needs it to germinate or seedlings need it to continue growth and survival? Can the use of mulches and cover crops be used more effectively to increase soil moisture and protect new seedlings? We know that heavy livestock grazing will inhibit grass growth and allow sagebrush to increase. Can grazing be utilized to speed up the process of sagebrush establishment?

Only a few ideas have been given for future research that may provide all of us in the industry with the knowledge needed to make good decisions. Western coal is a very competitive business and new and more cost-effective ways of competing must be found if that business is to survive. Finding better, more dependable, cost-effective ways to successfully establish big sagebrush is one very important way to remain competitive while maintaining compliance with the reclamation regulations.

REFERENCES

Booth, D. T., E. E. Roos, and Y. Bai. 1996. The influence of post-harvest and pre-planting seed treatment on sagebrush seedling vigor. Project Review Seminar. Abandoned Coal Mine Land Reclamation Program. November 6, 1996. Gillette, Wyoming.

Booth, D. T., Y. Bai, and E. E. Roos. 1998. Big sagebrush seed production from mined lands and adjacent unmined rangelands. Project Review Seminar. Abandoned Coal Mine Land Reclamation Program. November 5, 1998. Gillette, Wyoming.

Fortier, M. L., G. E. Schuman, A. L. Hild, and L. E. Vicklund. 1999. Grass competition and sagebrush seeding rates: influence on sagebrush seedling establishment. Project Review Seminar. Abandoned Coal Mine Land Reclamation Program. November 17, 1999. Gillette, Wyoming.

Land Quality Division. 1998. Coal rules and regulations. Wyoming Department of Environmental Quality. Cheyenne, Wyoming.

Perryman, B. L., R. A. Olson, Ann L. Hild, and A. M. Maier. 1999. Climatic control of sagebrush survival for mined-land reclamation. Project Review Seminar. Abandoned Coal Mine Land Reclamation Program. November 17, 1999. Gillette, Wyoming.

Schuman, Gerald E. and D. Terrance Booth. 1998. Strategies for establishment of big sagebrush (*Artemesia tridentata* ssp. *Wyomingensis*) on Wyoming mined lands. USDA, Agricultural Research Service. High Plains Grasslands Research Station. Cheyenne, Wyoming.

Wyoming Environmental Quality Act and Industrial Development Information and Siting Act. 1998. Wyoming Department of Environmental Quality. Cheyenne, Wyoming.

2000 Billings Land Reclamation Symposium

MATERIAL CHARACTERIZATION AND PRIORITIZATION OF REMEDIATION MEASURES AT THE ZORTMAN/LANDUSKY MINE SITES.

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ABSTRACT

Reclamation of the Zortman and Landusky gold mines in the Little Rocky Mountains of north-central Montana is currently being undertaken under the direction of the Montana Department of Environmental Quality and using the funds from the Reclamation Bond. As with many projects a balance must be found between the economics, technical, environmental and socio-economic issues at the sites. As part of the reclamation effort, a geochemical characterization program was developed which involved an intensive field geochemical assessment, supported by laboratory test work and 'historic' data. The objective of the characterization program was two-fold. Firstly, to identify the location, extent and probable contaminant loads from the sites; and secondly, to identify candidate materials for suitable cover and remediation purposes. Prioritization of remediation measures was then completed in an effort to assess and optimize the degree of remediation attainable with the limited financial resources available. This paper describes the material characterization program. It also describes the method and rationale developed to prioritize the remediation measures.

Additional Keywords: Zortman, Landusky, reclamation, geochemistry, remediation.

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INTRODUCTION

The Zortman and Landusky mines are located in Phillips County, Montana approximately 155 miles north of Billings (Figure 1). There has been mining in the area in one form or another since the first gold panner found a nugget in 1884. The first mill was built there in 1904 and mining continued underground off and on through to the 1970's ceasing intermittently during the two World Wars. Larger scale open pit mining and heap leach operations of the lower grade ore at Zortman and Landusky began in 1979 by Pegasus Gold Corporation and continued until 1995. Gold and silver were extracted by Carbon Absorption and Stripping and Merrill-Crowe precipitation. Both mines are currently closed and being reclaimed under the direction of the Montana DEQ using the Closure Bond Funds provided for by Pegasus under Montana Bonding requirements.

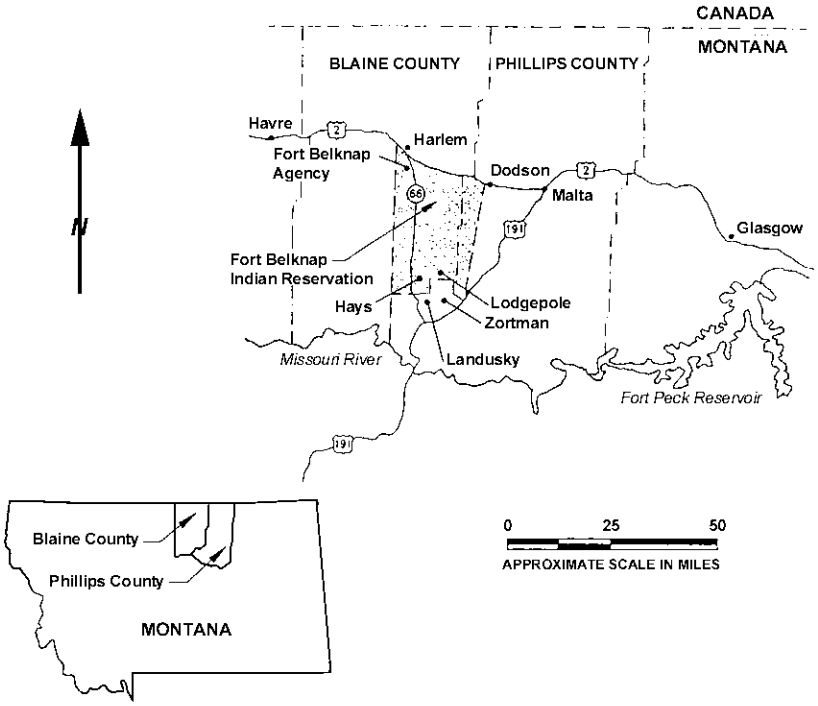

Figure 1. Location map of Zortman and Landusky Mine Sites
(after US DOI and MT DEQ, 1996)

Mine reclamation at the Zortman and Landusky mines, as with most mines, is faced with multidisciplinary issues and decisions in which compromises must be made and trade-offs evaluated. There are at least two critical issues for the Zortman/Landusky reclamation. There is (1) insufficient funding in the reclamation bond and (2) limited suitable construction material on site to complete the reclamation that was proposed in the Environmental Impact Statement (EIS) (US DOI and MT DEQ, 1996) and stipulated in the Record of Decision (ROD) (MT DEQ and US DOI, 1998) for the site. Therefore, an evaluation of the effectiveness of the specified measures and prioritization of reclamation areas and measures is being done. In order to complete this evaluation and prioritization a geochemical characterization program was undertaken.

The objective of the geochemical program was two-fold. Firstly, to identify the location, extent and probable current and future contaminant loads from the various facilities (leach pads, waste dumps and open pits) on the sites and to prioritize which areas most require a high degree of reclamation and which require less or minimal reclamation. Secondly, the program was aimed at identifying candidate materials on site for cover and remediation purposes. The characterization program was comprised of an assessment of historic information, a field reconnaissance survey and laboratory testing program. This paper presents the results of the characterization program and some discussion as to how this information will be used to prioritize remediation areas and measures.

CHARACTERIZATION PROGRAM

Historic Data

A fair amount of geochemical and geological information is available about the site, most of which was produced after 1990. In 1992, the mining company (Pegasus) filed an application for expansion of the operations. As a result, between that time and mid 1994, a number of studies were undertaken in preparation of an Environmental Impact Statement (EIS). These studies included extensive static and kinetic tests of drillcore aimed at predicting the acid generating potential of the rock mined and exposed as a result of expansion (Miller and Hertel, 1997). The mine expansion however never went forward. Therefore, the material characterized in those studies remains unmined. The vast amount of information produced in those studies is therefore of limited usefulness to the current reclamation program.

Prior to the application for expansion in the mid-1980's an extensive water monitoring program was implemented on both the Zortman and Landusky sites. As a result, a great deal of extremely valuable information has been collected on the geochemical behavior of mine elements and area, such as leach piles and mine pits. Water quality trends over time have proven very helpful in assessing the current contaminant loads from the sites and likely future water qualities. They allow trends to be established indicating the evolutionary behavior of large masses of mine disturbed materials. These results are discussed in greater detail later in the paper.

Another set of historic data that is often not fully exploited for geochemical characterization is the mined material itself. The pit walls, spent ore and waste rock materials that are currently exposed and have been for at least 5 to 10 years, since mining operations ceased, are essentially a large, 'historic' humidity cells. Simple tests such as paste pH, paste conductivity measurements and leach extraction tests on material exposed to weathering for this amount of time can provide more information than could be achieved in relatively short term laboratory tests. As a result, the field reconnaissance surveys at Zortman and Landusky were an extremely critical part of the characterization program.

Field Reconnaissance Program

The objectives of the field reconnaissance program were (1) to identify potential sources of NAG material (i.e. non-acid generating material that may be a potential source of construction and cover material) and (2) to identify and quantify potential sources of acid generating material and contaminant sources. The program consisted of paste pH and paste TDS analyses and visual identification of rock type, degree of alteration, degree of oxidation, surface precipitates and staining, presence of visible sulfides and any 'unusual' textures. Field logs (including photographs) were recorded and the sample locations were surveyed using a GPS system and plotted on a map.

The results of the field paste pH and paste TDS analyses are summarized in Table 1 organized by mine facility (or material type). As would be expected, samples with low pH values have higher TDS values (due to the presence of soluble minerals on the grain surfaces) and those samples with neutral pH results have low TDS values. The relationship between paste pH and paste TDS for the different material types on the Zortman and Landusky sites is shown in Figure 2. There is a clear trend whereby samples with pH values below approximately 5, show sharply increasing TDS concentrations. The samples that do not fall neatly within this trend are predominantly leach pad samples (designated by open circles on the figure) where the addition of lime and caustic soda in the leaching solutions account for moderate to high TDS values and still control the pH to circum-neutral values (i.e. the TDS results from alkalinity products not acidity/oxidation products).

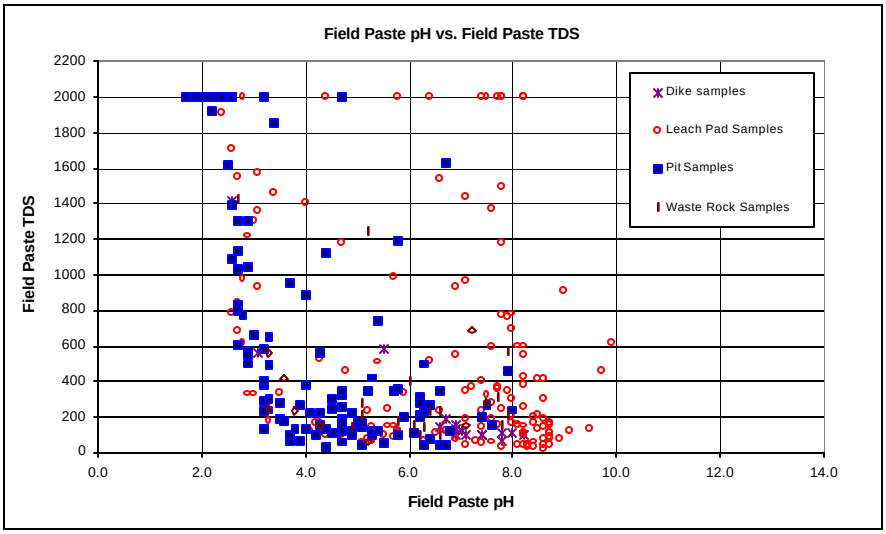

Figure 2. Paste pH versus paste TDS for Zortman and Landusky samples.

The color of the Zortman and Landusky mined material (again with the exception of the spent ore on the leach pads) is a relatively good indication of pH, or acid generating conditions. Visual inspection therefore can provide the first assessment of a material's acid generating potential. The unoxidized porphyry materials containing fresh sulfide minerals (in particular pyrite and, on Landusky, marcasite) are typically grey in color. These materials are acid generating with pH values commonly below 3 and very high TDS concentrations. The partially oxidized porphyry material was often an olive-green to

yellow color. This color is a reflection of the presence of secondary minerals produced when sulfide minerals oxidize, such as iron oxy-hydroxides and iron sulfates. These minerals are soluble and when dissolved produce acid, therefore they are sometimes referred to as 'stored acid products'. The partially oxidized material is predominantly acid generating with pH values generally less than 4.5. The oxide porphyry material contains no visible residual sulfides and typically has paste pH values in the 4.5 to 6.0 range. This material is orangey-red in color and relatively easily differentiated from the other material types on this basis.

Table 1. Summary of mean, minimum, maximum and standard deviation values for paste pH and paste TDS results by mine facility.

ZORTMAN		**MEAN**	**MIN**	**MAX**	**STD DEV**
Leach Pad Samples	pH		1.8	9.0	2.3
	TDS	597	60	>2000	641
Pit Wall and Pit Floor Samples	pH		1.7	6.7	1.4
	TDS	758	30	>2000	786
Waste Rock Samples	pH		2.7	7.1	1.4
	TDS	316	60	1430	379
Dike samples	pH		2.6	7.4	1.6
	TDS	438	100	>2000	600
Roadcut Samples	pH		3.7	6.9	1.3
	TDS	235	70	460	192
Tailings	pH		5.8	7.6	0.7
	TDS	800	70	>2000	937
Topsoil	pH		5.0	6.8	0.7
	TDS	141	50	228	64
LANDUSKY		**MEAN**	**MIN**	**MAX**	**STD DEV**
Leach Pad Samples	pH	7.1	2.5	9.9	1.8
	TDS	602	20	>2000	678
Pit Wall and Pit Floor Samples	pH	4.2	1.9	8.0	1.9
	TDS	845	40	>2000	748
Waste Rock Samples	pH	6.2	3.3	7.9	1.6
	TDS	364	140	1250	300
Stockpile Samples	pH	7.6	6.9	8.0	0.6
	TDS	130	100	170	36
Dike Samples	pH	7.2	3.7	8.2	1.7
	TDS	117	70	190	40
Topsoil	pH	7.0	3.5	8.0	1.7
	TDS	560	90	>2000	723

Although color alone is not recommended to differentiate between material types, it is a useful classification tool for the Zortman and Landusky sites. Caution should be exercised when judging leach pad material as many surface minerals precipitating from leach pad solutions have coated the surface of much of the material and the color is a less dependent characteristic of the geochemistry. Field 'clues' including paste pH, paste TDS rock type

and color description at these sites, where the material has been exposed to weathering conditions for an extended period of time, are relatively inexpensive and very valuable pieces of information. This type of survey is often not given enough credit in similar characterization programs. The outcome of the field reconnaissance survey were large maps of each site designating potentially acid generating, moderately acid generating and non-acid generating material on the sites. These maps are continually refined as new information about the sites is obtained (e.g. results of the laboratory testing program) and will be used in the prioritization of reclamation areas.

During the reconnaissance program, samples were collected for confirmatory laboratory testing. Sampling for lab testing concentrated on obtaining representative samples with respect to rock type and geochemical type (i.e. degree of oxidation, sulfide content etc.), as well as obtaining representative samples of each mine facility (i.e. each leach pad, pit, waste dump etc.). There was a slight bias in numbers of samples collected for lab testing towards both the potential NAG materials and the ARD/metal leaching materials. The lab testing program is described in detail in the Section below.

Laboratory Testing Program

All samples collected for the laboratory testing program were submitted for paste pH and paste conductivity measurements on the as-received 'fines', modified acid base accounting (ABA) tests, inorganic carbon and leach extraction analyses. Subsets of these samples were also analyzed via forward acid titration, multi-element ICP, net acid generation (NAG) tests and sieve analyses. Some of the more critical results from these tests are discussed in the following sub-sections.

Paste pH and Paste Conductivity Results

Paste pH and paste conductivity tests on the as-received 'fines' were completed for two reasons. Firstly as a quality control/quality assurance check on the paste pH and paste TDS values obtained in the field using the hand held field instruments. The paste pH and paste conductivity measurements in the lab were taken on the as received 'fines' using a 1:1 solids to distilled water ratio to mimic as close to possible the methodology used in the field. Secondly, it is believed to be a more representative result than the paste pH and paste conductivity values on the same sample prepared for Acid Base Accounting (ABA) tests, i.e. the crushed samples. In effect, this crushing liberates the alkalinity from the matrix of a sample thereby effecting the paste pH. Figure 3 is provided to show the relationship between the field and lab paste pH measurements on the as-received fines (or un-crushed samples) as compared to the field and lab paste pH measurements on the crushed split sample for ABA testing. This graph clearly shows that crushing the samples liberates more alkalinity (and therefore results in higher pH values) than is available in the field. The results serve as a caution that one cannot rely on paste pH values obtained on a crushed sample as indicative of field conditions. Measurements of field paste pH should always be done on the uncrushed fines, this an important consideration when selecting a drilling method for sample recovery in waste rock and leach piles.

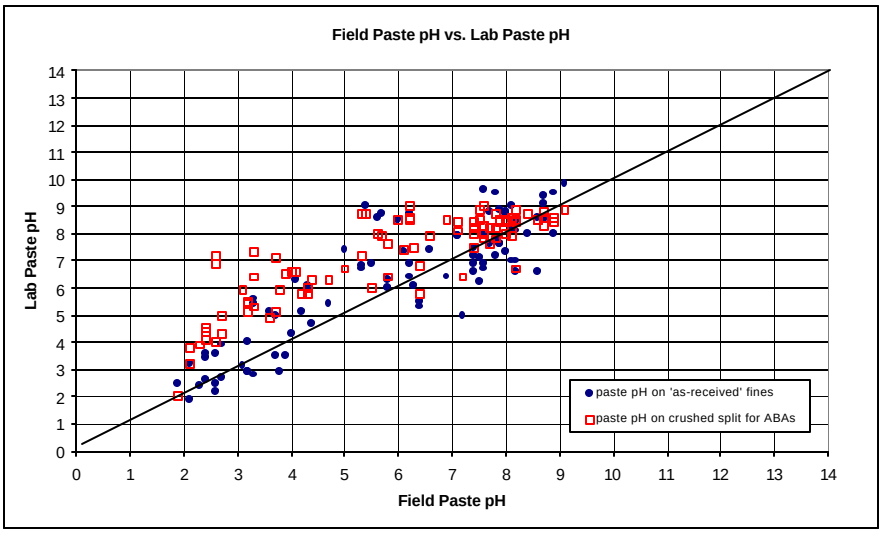

Figure 3. Field paste pH versus lab paste pH on un-crushed and crushed samples.

Modified Acid Base Accounting (ABA) and Inorganic Carbon Results

The modified ABA test is used to determine the balance between the acid producing (sulfides) and acid consuming components of a sample. The results of this test for the Zortman and Landusky samples are provided in summary form in Table 2 by material type.

A very definite trend can be seen in the samples (except for the leach pad material) with respect to the total percent sulfur and field paste pH (Figure 4). Almost all samples (excluding leach pad samples) with total sulfur contents greater than 0.2% have field paste pH values less than 5.0. This percentage of sulfur is far less than would be visible in the field. This suggests that there is very little neutralization or buffering capacity in the material except for that added to the leach pad material. It can be expected that once the alkalinity in the leach pad samples is exhausted that these samples will also plot within the dotted lines outlining the apparent natural trend of the other materials on site.

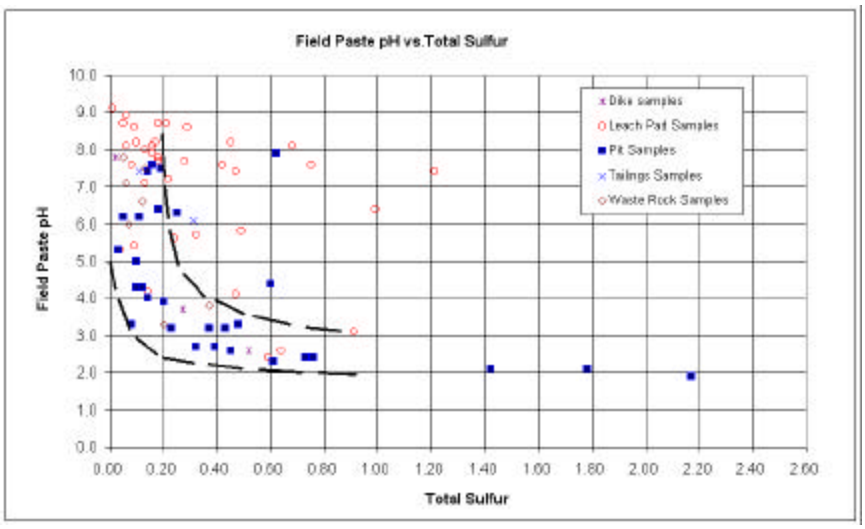

Figure 4. Field paste pH versus Percent Total Sulfur.

Table 2. Summary of modified ABA and inorganic carbon results by material type

LOCATION DESCRIPTION		PASTE pH	S(T) %	S(SO4) %	AP	NP	NET NP	NP/AP	TIC %
ZORTMAN									
Leach Pads	MIN	4.1	0.1	0.0	0.0	-1.4	-25.5	0.2	0.0
	MAX	8.7	1.0	0.4	25.6	12.1	10.8	9.7	0.1
	MEAN		0.3	0.1	6.2	3.6	-2.6	1.7	0.0
	STD DEV		0.3	0.1	6.5	2.9	7.8	2.2	0.0
Pit Wall and Pit Floor Samples	MIN	2.0	0.0	0.0	-1.3	-27.7	-59.6	0.2	0.0
	MAX	9.2	2.2	1.1	49.4	19.6	17.1	7.9	0.2
	MEAN		0.5	0.2	10.4	1.8	-8.6	2.0	0.1
	STD DEV		0.7	0.3	14.3	11.2	21.3	2.2	0.1
Roadcut & Waste Rock Samples	MIN	4.9	0.2	0.2	-1.6	-0.2	0.9	0.2	0.0
	MAX	6.3	0.3	0.3	2.8	3.7	1.3	1.3	0.0
	MEAN		0.3	0.2	0.6	1.7	1.1	0.7	0.0
	STD DEV		0.1	0.0	3.1	2.8	0.3	0.8	-
LANDUSKY									
Leach Pads	MIN	5.9	0.0	0.0	-0.9	-0.8	-26.4	0.1	0.0
	MAX	8.9	1.2	0.3	27.2	15.6	12.8	5.6	0.2
	MEAN		0.4	0.1	8.3	4.1	-4.2	1.6	0.0
	STD DEV		0.4	0.1	9.6	3.6	11.1	1.9	0.0
Pit Wall and Pit Floor Samples	MIN	3.2	0.1	0.0	0.0	-5.4	-36.3	0.2	0.0
	MAX	9.0	1.6	0.5	50.0	389.4	387.8	249.2	5.0
	MEAN		0.6	0.2	12.9	47.5	34.6	23.2	1.0
	STD DEV		0.5	0.1	14.4	99.7	95.4	71.2	1.5
Waste Rock Material	MIN	5.9	0.1	0.0	0.3	0.2	-8.9	0.4	0.0
	MAX	8.7	0.4	0.2	9.1	215.8	215.4	690.4	2.5
	MEAN		0.2	0.1	3.1	94.5	91.5	212.8	1.4
	STD DEV		0.1	0.1	3.5	97.4	99.7	323.7	1.1

Figure 5 is a plot of neutralization potential (NP) versus acid potential (AP) in kg $CaCO_3$/tonnes equivalent. This type of graph is typically used to report results of ABA testing. In general, the samples that plot above the 1:1 line (~60%) would be considered potentially acid generating, those that plot below the 3:1 line (~28%) would be considered non-acid generating and those that fall between the two lines (~12%) would be dassified as 'uncertain' with respect to acid generating potential. It takes very little sulfur content in a sample for that sample to plot below the NP/AP ratio of 1:1, this again suggests that there is very little neutralization potential in the samples to 'balance' the acid generating potential imparted by less than a quarter of a percent sulfur.

Forward Acid Titration Results

The forward acid titration test is done to determine, qualitatively, the acid neutralizing capacity of a sample by adding measured amounts of acid to the sample to lower the pH. The amount of acid required to reach each pH interval is dependent on the amount of

neutralizing material available. As the pH decreases, different minerals react to neutralize (or buffer) the added acid. Within the pH range of 5.5 to 7.0 carbonate minerals in the sample dissolve and neutralize the acidity. If there are significant carbonates present a 'step' or flattening out of the curve will occur within that pH range (i.e. 5.5 to 7.0). A few of the results are shown below in Figure 6. The leach pad sample is the only sample showing any degree of flattening in this range. This is likely a result of the added alkalinity in the leach pad solutions. Between the pH range of 3.0 to 3.7, limonite (FeOOH) will buffer acid. This may be occurring to some degree in these samples. At even lower pH values (i.e. below ~3), aluminosilicate minerals such as the feldspars in the samples will dissolve and buffer added acid. This is likely the reason that these results show a long flattening tail below pH of 2.0.

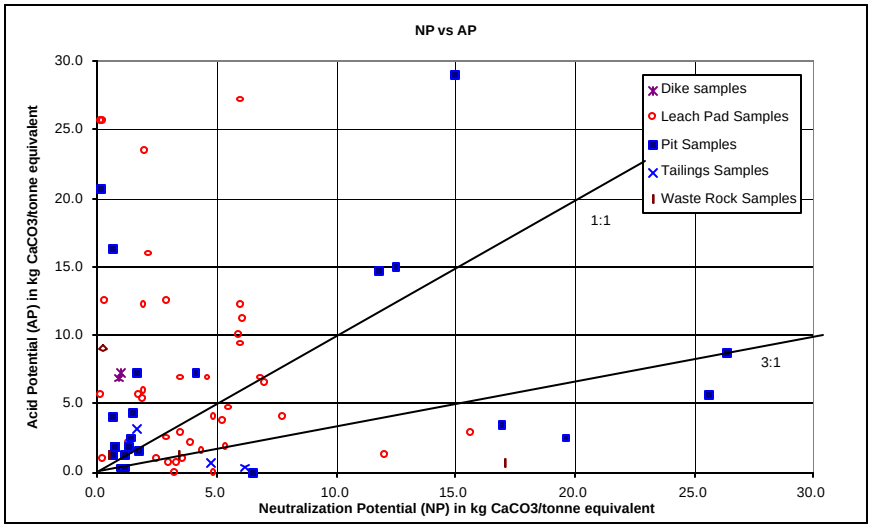

Figure 5. Neutralization Potential (NP) versus Acid Generating Potential (AP).

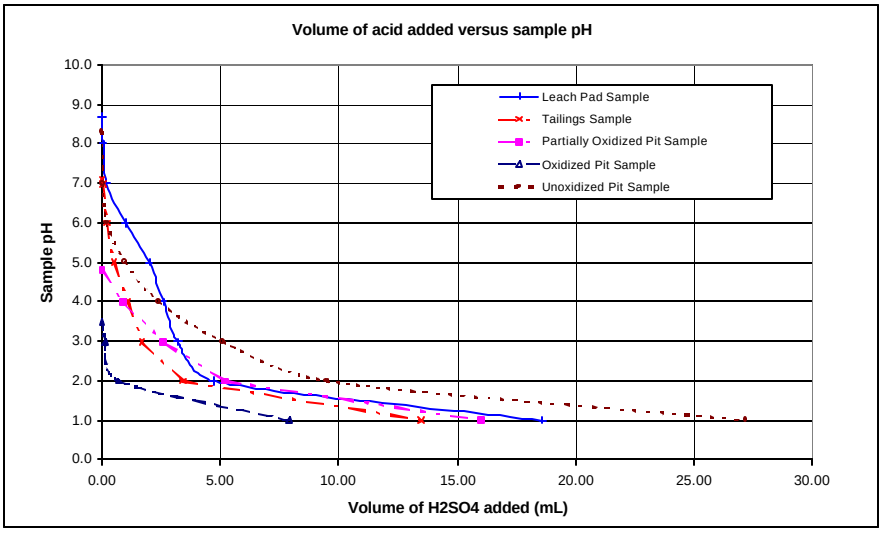

Figure 6. Forward Acid Titration Results.

Net Acid Generation (NAG) Results

The net acid generation test was used to determine the net acid remaining, if any, after complete oxidation of the materials with a strong oxidant (hydrogen peroxide) and allowing complete reaction of the acid formed with the neutralizing components of the material. The NAG test provides a direct assessment of the potential for a material to produce acid after a period of exposure and weathering and is used to refine the results of the ABA predictions. One of the great advantages of the NAG test is that it allows an assessment of the kinetics of the reactions in a sample in a relatively short period of time.

Some of the samples collected were analyzed using the NAG method with an industrial H_2O_2 reagent at a starting pH of 5.5. The experiments were run for approximately 3 days and the pH, Eh and temperatures were recorded at intervals throughout that period. The results of pH are plotted in Figure 7. The following classification criteria (Lapakko and Lauwrence, 1993) were used to assess the acid generating potential of those samples tested with the NAG method.

Final NAG_{pH} > 5.5	Non-acid generating
Final NAG_{pH} between 3.5 and 5.5	Uncertain to low risk acid generating potential
Final NAG_{pH} <3.5	High risk of acid generating potential

Therefore, based on these results, two of the samples tested (Tailings and Unoxidized Pit Samples) would be considered non acid generating (Final NAG_{pH}>5), one sample (Leach Pad Sample) would be classified as 'uncertain' (Final NAG_{pH} between 3 and 5) and two samples (Unoxidized and Partially Oxidized Pit Samples) would be considered acid generating (Final NAG_{pH} <3). After approximately 300 minutes (5 hours) the samples are at or very near their Final NAG_{pH}. The uncertain sample is "marginal" and results appear to indicate two clearly different and definable behaviors. The first three are non-acid generating (with little buffering capacity) and the latter two are clearly acid generating.

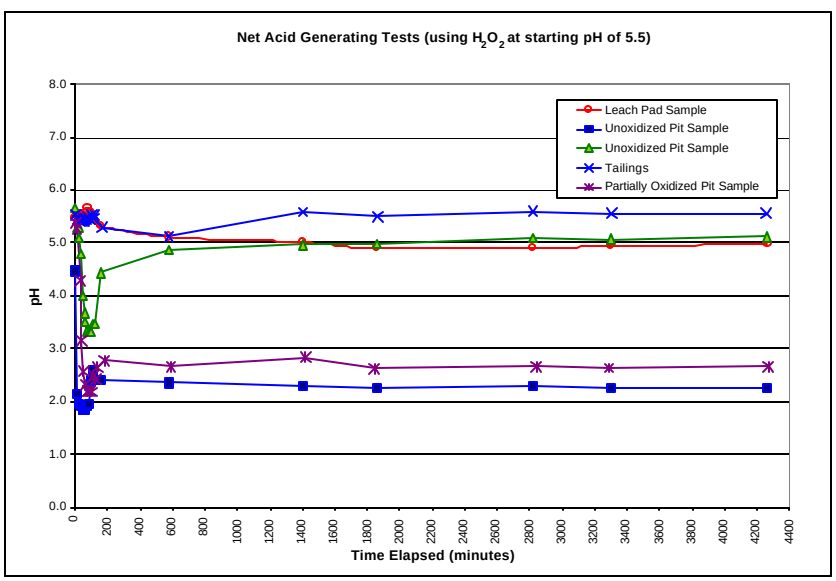

Figure 7. Net Acid Generation Tests – pH versus Time for Selected Samples.

Leach Extraction Tests

Leach extraction tests were completed in order to characterize and quantify the soluble contaminant content of a sample. The procedure used for these analyses was the EPA 1312 leach extraction test using a leachate reagent of de-ionized water acidified to a pH of 5.0 to 5.5 to represent rainwater. The procedure uses a solid to liquid ratio of 1:2. The leachate concentrations are representative of current ARD evolution state and the quantity of leach water compared with solid sample. Field conditions have much higher solid:liquid ratios and ARD conditions will mature with time. The resultant leachate concentrations therefore are not necessarily representative of what concentrations would be expected in the field. An assessment of the current field water qualities from material exposed on the surface was completed by accounting for the 'dilution' factor inherent in the leach extraction test and assuming a field moisture content of ~10% (as opposed to a moisture content of 200% used in the test). In other words, the leachate concentrations were multiplied by a factor of [10/(200+10)]. These calculated concentrations however do not yet represent field water qualities. During the leach extraction tests, the dilution of solute concentrations in the leachate can cause the dissolution of secondary mineral phases that were previously in a solid phase (i.e. oversaturated). It was therefore necessary to "re-instate" the solubility controls on the solute concentrations by modeling the calculated leachate concentrations using the geochemical equilibrium model MINTEQA2 (Allison et al., 1991). Water quality predictions were then made for the surface water runoff from the various material types. Table 3 provides the predicted water qualities from those areas considered highly acid generating, moderately acid generating and non-acid generating for both the Zortman and Landusky sites.

Table 3. Predicted water quality of material with various degrees of acid generating potential on both Zortman and Landusky.

Parameter (mg/L)	Predicted Water Quality of:					
	Highly acid generating material		Moderately acid generating material		Non acid generating material	
	ZORTMAN	LANDUSKY	ZORTMAN	LANDUSKY	ZORTMAN	LANDUSKY
pH	[< 3]	[< 3]	[3 - 5]	[3 - 5]	[> 5]	[> 5]
Al	161	925	59	87	0	0
As	1.34	6.01	0.00	0.00	0.00	0.00
Ca	40	85	154	146	10	218
Cd	0.00	0.10	0.15	0.10	0.00	0.00
CO3	0	0	8	0	26	17
Cr	4.90	0.47	0.37	0.15	0.00	0.00
Cu	1.62	1.18	0.71	0.00	0.10	0.30
Fe	0.24	2.37	0.00	0.05	0.00	0.00
K	0.0	0.0	305.0	0.0	0.0	78.7
Li	22.35	27.46	10.45	0.00	0.00	0.00
Mg	55	364	689	380	14	166
Mn	2	33	40	11	0	8
Ni	0.43	1.59	1.53	0.68	0.00	0.00
Pb	0.00	0.00	0.02	0.00	0.00	0.00
Si	0.12	0.03	0.53	0.70	0.85	0.30
SO4	3988	3245	394	494	11	148
Zn	0.77	15.48	0.72	4.66	0.06	0.23

WATER QUALITY MONITORING DATA

As mentioned above, a relatively extensive groundwater and surface water monitoring program was started at the site in the mid-1980's. Water quality trends over time have allowed us to predict apparent 'mature' water qualities. Sulfate concentrations and pH trends over time for two wells believed to be representative of the 'mature' water qualities as a result of acid generation and contaminant release on the both Zortman and Landusky are provided in Figures 8 and 9 respectively. It appears that the 'terminal' pH for ARD impacted waters on Zortman is approximately 0.5 of a pH unit lower than that on Landusky and the sulfate concentrations are also higher on Zortman (perhaps by a factor of 2).

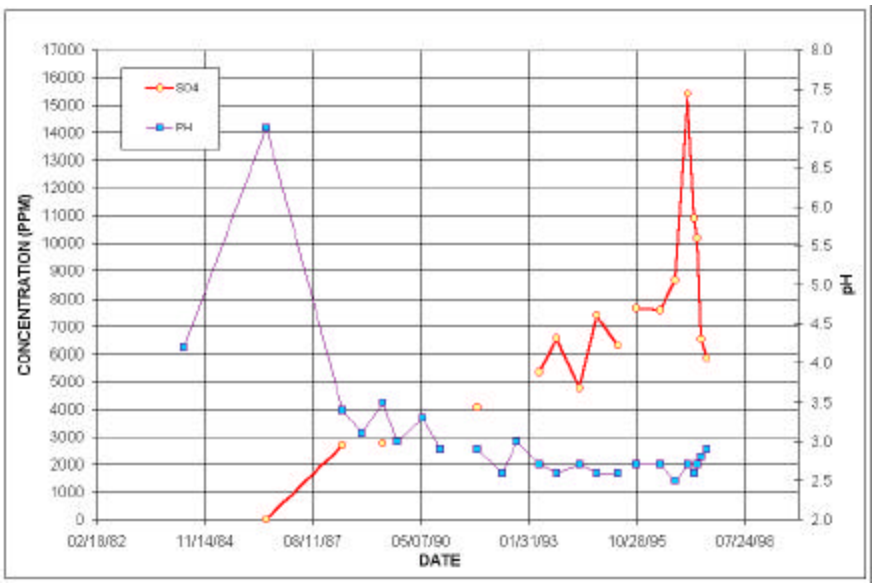

Figure 8. SO_4 conc. and pH over time at a groundwater monitoring well on Zortman.

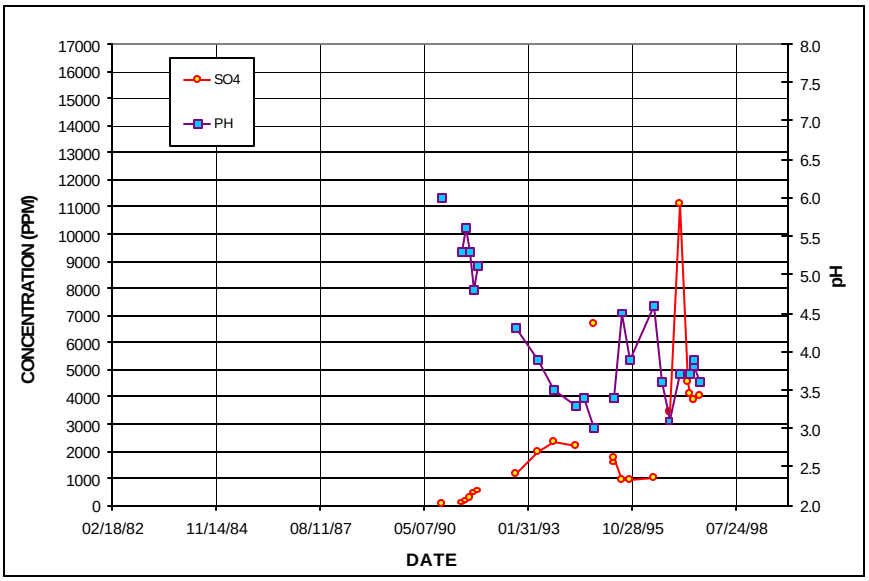

Figure 9. SO_4 conc. and pH over time at a groundwater monitoring well on Landusky.

PRIORITIZATION OF REMEDIATION AREAS AND MEASURES

The field reconnaissance results, laboratory test results, predicted surface water qualities and the data obtained from the surface and groundwater monitoring program at the sites, together with the site water balances are being used to develop current and likely future mass balance and contaminant load estimations for the sites. These estimations along with the engineering volume mass balance and material costing will be incorporated into a Multiple Accounts Analysis, or MAA, (Robertson and Shaw, 1998) decision-making tool for the prioritization and evaluation of the likely results of certain reclamation areas and measures. The MAA evaluation of the various reclamation alternatives is currently underway as a cooperative effort between ourselves, the Montana Department of Environmental Quality, the U.S. Bureau of Land Management, U.S. Environmental Protection Agency and the Fort Belknap Tribal Council. Past experience with this type of decision making has proven extremely successful for multi disciplinary projects involving multiple stakeholders such as with the Zortman and Landusky Reclamation Project.

REFERENCES

Allison, J.D., Brown, D.S., and Novo-Grada, K.J. 1991. MINTEQA2/PRODEFA2, A Geochemical Assessment Model for Environmental Systems, version 3.0, EPA/600/3-91/021, 1991, Office of Research and Development, U.S. Environmental Protection Agency, Athens GA.

Lapakko, K. and Lawrence, R.W. 1993. Modification of the Net Acid Production (NAP) Test, pp. 145-159. In: Proc. BC Mine Reclamation Symposium, Port Hardy, B.C.,.

Miller, R.A. and Hertel, T.M. 1997. Mine Rock Characterization- Zortman and Landusky Mines, Little Rocky Mountains, Phillips County, North-Central Montana, pp. 515-532. In: Proc. of the Fourth International Conference on Acid Rock Drainage, Vancouver, B.C. Canada, May 31-June 6, 1997.

Montana Department of Environmental Quality and U.S. Department of the Interior Bureau of Land Management. 1998. Record of Decision, Zortman and Landusky Mines Reclamation Plan Modifications and Mine Life Extensions. Report prepared June, 1998.

Robertson, A. MacG. and Shaw, S.C. 1998. Alternatives Analysis for Mine Development and Reclamation, pp. 51-62. In: Proceedings of the 22nd Annual BC Mine Reclamation Symposium, Penticton, BC. Canada, September 14-17, 1998.

U.S. Department of the Interior Bureau of Land Management and the State of Montana Department of Environmental Quality, Hard Rock Bureau. 1996. Final Environmental Impact Statement, Zortman and Landusky Mines Reclamation Plan Modifications and Mine Life Extensions. Report prepared March, 1996.

2000 Billings Land Reclamation Symposium

Amelioration of Sodic Spoils by Weathering in the Powder River Basin, Montana

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ABSTRACT

The coal-bearing formations in the Western United States locally contain sodic materials that have traditionally been considered unsuitable as reclamation substrates. Significant regulatory and operational resources are directed toward the avoidance of sodic materials for reclamation under the assumption that they are toxic. However, a comprehensive assessment of the physicochemical factors affecting sodium toxicity and sodicity related permeability reductions indicate that many sodic spoils are conditionally acceptable as reclamation substrates from a short-term perspective. The acceptability of these spoils is predicated on the time-transgressive reduction in sodicity associated with leaching and primary mineral weathering. Thus, the rate and trajectory of weathering in the spoils is important for determining their suitability as soil substitutes over the long-term. We will present new data from reclaimed sodic spoil test plots established at the Decker Coal Mine in the late-1970's that demonstrates the weathering related amelioration of spoil sodicity. Specifically, decreases in the spoil pH and sodium adsorption ratio (SAR) were accompanied by increases in salinity. The spoil solution chemistry is interpreted to indicate a shift from carbonate-dominated to sulfate-dominated systems. Data from the cover soils confirms that convective leaching and the relatively rapid decrease in spoil sodicity eliminates concerns associated with cover soil sodification by diffusional processes.

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2000 Billings Land Reclamation Symposium

EVALUATION OF FERRIC OXIDE FOR ADSORPTION OF ARSENIC LEACHING FROM A MINE WASTE REPOSITORY

G.S. Vandeberg[1], D.J. Dollhopf[1], J.D. Goering[1], and D.R. Neuman[1]

ABSTRACT

Modeling of leachate production through a proposed mine waste repository along Silver Bow Creek near Butte, Montana showed that arsenic levels exceeded the State of Montana standard (WQB-7) of 18 µg/L. Therefore, an investigation was conducted with ferric oxide to determine its potential in attenuating arsenic from leachate produced in an acidic-metalliferous tailings repository. Acidic-metalliferous tailings were neutralized with lime and placed in columns overlying no ferric oxide (no-treatment), ferric oxide thickness at 1.67 percent of the tailings thickness, and ferric oxide thickness at 3.33 percent of the tailings thickness. These columns produced leachates containing mean As concentrations of 323, 192, and 156 µg/L respectively. The 1.67 and 3.33 percent ferric oxide treatments reduced corresponding mean As concentrations by 41 and 52 percent. The ferric oxide layers also adsorbed large amounts of copper and zinc, significantly reducing concentrations of these metals in leachate.

Acidic-metalliferous tailings neutralized with lime were also placed in columns atop a 7.62 cm and a 15.24 cm thick layer of ferric oxide. The As concentrations in leachates were reduced 68 percent and 79 percent compared to the control, respectively.

These results indicate that when leachate As levels were in the range of 162-324 µg/L, the ferric oxide layers tested did not adsorb sufficient As to reduce the concentration to below the Montana standard (WQB-7). Using a regression model, it was estimated that the ferric oxide layer would need to be 25.4 cm thick, to remove sufficient As to meet the WQB-7 standard.

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INTRODUCTION

The Streamside Tailings Operable Unit extends for a distance of 42 km along Silver Bow Creek from west of Butte, Montana to the Warm Springs Ponds (Figure 1). The operable unit contains more than 70,000 m^3 of flood plain and channel sediments, and railroad beds which contain high levels of arsenic (As), cadmium (Cd), copper (Cu), lead (Pb), and zinc (Zn) from mining and smelting wastes (MDEQ and USEPA 1995). As part of the remedial design for the unit, tailings impacted soils which cannot be safely treated in place will be excavated along with channel sediments and railroad beds, and placed in Mine Waste Relocation Repositories (MWRR) located outside the 100 year flood plain boundary (MDEQ and USEPA, 1995). Compliance with Applicable or Relevant and Appropriate Requirements (ARARs) requires consideration of the migration of contaminants to ground water in that, (1) leachates from the MWRR must not exceed the Montana Department of Environmental Quality (MDEQ) WQB-7 standards for ground water (MDEQ, 1995), and (2) the leachate must not degrade the ground water quality. Excavated waste materials placed into the MWRRs will be limed to minimize the leaching of metals and subsequent migration of these metals to ground water.

Numerous MWRR designs were evaluated for potential leachate production by Maxim (1998). Leachate production calculated with the HELP model ranged from 0.02 cm to 5.54 cm per year for these scenarios. One alternative, (45.7 cm of cover soil over neutralized wastes at a near stream location), had a leachate production of 1.55 +/- 1.52 cm per year and was selected for the preliminary final design for reclamation of a portion of the Streamside Tailings Operable Unit.

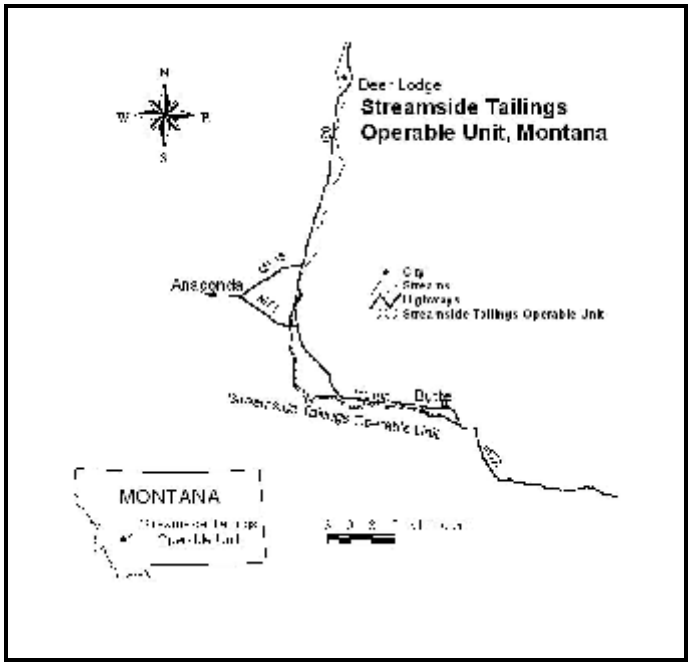

Figure 1. Streamside Tailings Operable Unit along Silver Bow Creek, near Butte, Montana.

The potential for leachate production from a MWRR raised the concern that contaminants, especially arsenic, may migrate to ground water. Therefore, Maxim (1998) evaluated the ability of arsenic to leach from lime amended wastes from the operable unit. They found that unamended wastes yielded leachate with 350 µg/L As, while lime amended wastes yielded 210 µg/L As. Both of these leachates exceeded the WQB-7 standard for As of 18 µg/L. However, continued bench top tests indicated that the geologic materials beneath the proposed MWRR location would attenuate As further to levels of 18 to 20 µg/L from an initial

concentration of 200 µg/L.

The solubility of As has been shown to be strongly controlled by adsorption onto iron oxide surfaces (Klaus et. al., 1998). For example, Woolson et al. (1971) concluded the presence of iron (Fe) in soils is the most effective factor in controlling the mobility of arsenate. The solubility product for arsenate combined with iron is 100-fold less than when combined with calcium associated with soil-clay systems.

The intent of this bench scale study was to determine if the utilization of iron oxide materials at the base of a MWRR can increase adsorption of As from leachate and hence, prevent or notably reduce potential arsenic loading to ground water.

STUDY OBJECTIVES

This investigation served to evaluate the feasibility of constructing an adsorption layer beneath the mine waste to decrease arsenic release from a MWRR. One adsorption material, ferric oxide (Fe_2O_3) having the common mineral name hematite, was tested. The material used was a commercial "natural red iron oxide" of minus 60 mesh particle size ($\leq$ 0.25 cm). Hematite is the most widely utilized iron ore mined in the United States and is the primary iron mineral in taconite which averages about 25 percent iron (Mason and Berry, 1968). Objectives of this investigation were to:

- determine the degree to which As in leachate at 200 µg/L can be adsorbed by ferric oxide; and

- evaluate the quantity of ferric oxide required in a mine waste repository to reduce As in leachates to levels that meet State ground water quality standards.

METHODS

This investigation was divided into two phases: Phase I tested the adsorption characteristics of ferric oxide alone using a synthetic arsenic solution; and Phase II simulated repository field conditions by placing ferric oxide at the bottoms of columns loaded with amended mine waste. Phase I methods and results will not be presented in this paper, but are available in Dollhopf et. al. (1999).

Ferric oxide material (natural red iron oxide) was obtained from Dyce Chemical/HCl in Billings, Montana. The material was $\leq$ 0.25 mm in particle size, and was analyzed for total Al, As, Cd, Cu, Fe, Mn, Pb, Si and Zn by XRF (Table 1). The capacity of this material to adsorb a synthetic arsenic leaching solution was examined in Phase I, and was found to reduce solutions containing 115.2 to 108.0 µg/L As to levels less than 18 µg/L (Dollhopf et. al., 1999).

Bulk tailings samples were collected from test pit locations SC-1014 (38-48 cm depth) and 1N-1088 (0-40.6 cm depth) within the Streamside Tailings Operable Unit in an attempt to duplicate the tailings samples which Maxim (1998) used in their earlier leachate tests. The tailings samples were air dried, sieved to $\leq$ 2 mm, and mixed together in the proportion of approximately 24 percent 1N-1088 and 76 percent SC-1014 to maximize arsenic content. Subsamples of the tailings were analyzed for the items listed in Table 1.

Table 1. Analytical testing methods for the Streamside tailings bulk samples.

Parameter	Constituents	Method
Preparation and Rock Content	Volumetric rock content	ASTM D421-85 and ASTM D422-63 (ASTM, 1997)
Particle Size, Soil Textural Class	Dry Sieve Analysis, weight and volumetric basis	ASTM D422-63 (ASTM, 1997), Modified Day Method 15-5 (ASA, 1986)
Percent Moisture	Gravimetric	ASA Method 21-2.2.2 (ASA, 1986)
Saturation Percent	Saturation Percent	ASA Method 21-2.2.2 (ASA, 1986)
Electrical Conductivity	Saturated Paste Extract	USDA Handbook 60, Method 3a, 4b (U.S. Salinity Lab Staff, 1954)
pH	Saturated Paste Extract	USDA Handbook 60, Method 3a, 21c (U.S. Salinity Lab Staff, 1954)
Total Lime Requirement	Modified Sobek Acid Base Account/ SMP Active Acidity	Modified Sobek-Sulfur Fractionation SMP Single Buffer (Sobek et.al., 1978)
Total As and Metals	As, Cd, Cu, Pb, and Zn	by XRF Ashe (1995)

Lime kiln dust (LKD) was collected from the same source (Continental Lime Co., Townsend, MT) that Maxim (1998) used in their study to amend the tailings. The LKD was sieved to $\leq$ 0.25 mm and analyzed for percent moisture (Method 21-2.2.2; ASA, 1986) and calcium carbonate equivalence (CCE) (ASTM C25-96a, ASTM, 1997). Equation 1 was used to calculate the lime application rate for the mixed tailings sample. The calculated rate was adjusted to account for the calcium carbonate equivalence (lime as $CaCO_3$) and percent moisture of the LKD.

$$LR = [31.25\ (HNO_3\text{-}S + \text{Residual-}S) + 23.44\ (HCl\text{-}S) + SMP]\ 1.25 \qquad [1]$$

where:

LR = Lime requirement (tons $CaCO_3$ /1000 tons),
HNO_3-S = Nitric acid soluble sulfur (%),
Residual-S = Sulfur (%) left after acid extractions,
HCl-S = Hydrochloric acid soluble sulfur (%),

SMP = SMP single buffer lime rate (tons $CaCO_3$ /1000 tons), and
1.25 = A mixing design factor to adjust for field incorporation.

Nine modified (no ceramic plates) Tempe cells were set up using 45.7 cm high and 8.2 cm diameter polycarbonate cylinders. Each column base was retained, in a downward sequence, with a number 42 Whatman filter, a fine nylon mesh with 0.0036 cm openings, and a fine (0.0127 cm openings) 304 stainless steel screen. *Treatment 1* (control) consisted of 2322 g of LKD amended tailings. *Treatment 2* consisted of 2322 g of LKD amended tailings overlying 59.26 g (1.67 % of tailings thickness) of ferric oxide. *Treatment 3* consisted of 2322 g of LKD amended tailings overlying 118.46 g (3.33 % of tailings thickness) of ferric oxide. The ferric oxide thicknesses correspond to a 7.6 cm and 15.2 cm adsorptive layer beneath a 4.6 m high MWRR. Each of the treatments was replicated three times. A second nylon screen was placed on the upper soil surface of all columns to dissipate energy from water additions and therefore prevent erosion of the surface.

Deionized water was used to leach the columns and was pushed through the material under an air pressure of 50 kPa (0.5 bars). Leachate was collected in 82 ml aliquots representing each 1.5 cm of applied water. The 1.5 cm of water represents Maxim's (1998) prediction of potential yearly leachate production based on the chosen MWRR design. A total of 4182 ml was leached from each column. The extraction time for each aliquot averaged approximately 30 minutes. The pH and electrical conductivity of each 82 ml aliquot was determined in the laboratory. The aliquot representing year one was also analyzed for total As, Cd, Cu, Pb, Mn, and Zn (Table 2). Aliquots for years 5 and 10 were analyzed for total As. The aliquot for year 50 was analyzed for total As, and dissolved As, Cd, Ca, Cu, Fe, Pb, Mg, Mn, Na, Zn, hardness and sodium adsorption ratio (Table 2).

Table 2. Tempe cell and column leachate analytical parameters.

Parameter	Analysis Method
pH	150.1 (USEPA 1979)
EC	120.1 (USEPA 1979)
As (V), As (III), As (total), Ca, Cd, Cu, Fe, Mg, Mn, Na, Pb, Zn	EPA CLP SOW 788 (USEPA 1988)

After 4182 ml of leachate was attained from each column, more ferric oxide was added to one of the *Treatment 2* columns to equal 815.67 g (7.62 cm, 22.9% of waste thickness). Furthermore, 1631.34 g (15.24 cm, 45.8 % of waste thickness) of ferric oxide was added to the bottom of one of the *Treatment 1* (no ferric oxide) columns. The two modified columns and a *Treatment 1* column were brought to saturation, and 82 ml of leachate was produced. The leachates were analyzed for dissolved As to determine if further As could be removed from the leachate with even thicker amounts of ferric oxide.

RESULTS

Ferric Oxide and Tailings

The chemical constituents of the ferric oxide material are shown in Table 3. The ferric oxide product contained approximately 77.2 percent Fe_2O_3 in combination with oxides of silica, aluminum, calcium and magnesium as well as other impurities. The oxides of Ca and Mg may serve to provide alkalinity into a leaching solution. Impurities included 55.4 to 66.6 mg/kg total As and 3250 to 3310 mg/kg total Mn. Total levels of Zn, Cu, Cd, and Pb were relatively low.

Table 3. Manufacturer's analysis and total elemental concentrations found in two samples of ferric oxide analyzed by XRF.

Constituent	Dyce Chemical/HCL Label Information	Sample A SSTAASSFE1	Sample B SSTAASFE2
Aluminum (%)	not available	1.44	1.78
Arsenic (mg/kg)	not available	66.6	55.4
Cadmium (mg/kg)	not available	none detected	none detected
CaO (%)	0.5	not available	not available
Copper (mg/kg)	not available	149	139
Iron (%)	54.0	55.0	56.5
Fe_2O_3 (%)	77.2	not available	not available
Manganese (mg/kg)	not available	3310	3250
MgO (%)	1.1	not available	not available
Lead (mg/kg)	not available	none detected	none detected
Zinc (mg/kg)	not available	67.2	72.8
Silica (%)	not available	10.78	11.65

The results of the tailings analyses are shown in Tables 4 and 5. Based on these results, the tailings have slightly lower total As levels than those used in the Maxim study (1998). However, other metals such as Cu and Zn are much higher. According to the analysis of the sulfur fractions and equation [1], 12.5 tons $CaCO_3$/1000 tons of tailings was required to neutralize the active and potential acidity. The rate was adjusted to 15 tons LKD/1000 tons to account for moisture content and calcium carbonate equivalence of the LKD.

Table 4. Physiochemical characteristics of tailings samples.

Sample	Texture	Moisture	Saturation	pH	Electrical conductivity	As	Cd	Cu	Pb	Zn	Comments
	USDA	% Mass	% Mass	su	dS/m	mg/kg					
Maxim study (1998)	Sandy Loam	NA	NA	4.5	NA	1059	22	1717	2243	3337	tailings composite
SSTAASTLS4	Sandy Loam	2.79	36.99	6.00	2.80	879	11.2	3500	4070	6350	Composited Bulk Sample 24/76 mix
SSTAASTLS5	Sandy Loam	2.81	38.77	6.06	2.81	859	10.4	3430	4070	6200	Composited Bulk Sample 24/76 mix

Table 5. Sulfur fractionation and $CaCO_3$ requirements for the tailings bulk sample.

Sample	Neut. Potential	Acid Potential	Acid/Base Potential	Non Sulfate Sulfur	Total Sulfur	H_20 Extractable Sulfur	HCl Extractable Sulfur	HNO_3 Extractable Sulfur	Residual Sulfur	SMP Buffer Lime Requirement
	tons $CaCO_3$/1000 tons			%						tons $CaCO_3$/1000 tons
Maxim (1998)	1.7	16	-15	NA	1.16	0.7	0.2	<0.1	0.4	13
SSTAASTLS-4	5	8	-3	0.26	0.63	0.37	0.06	0.14	0.06	2.4
SSTAASTLS-5	6	10	-4	0.31	0.60	0.29	0.11	0.15	0.05	1.10

Leachate Chemistry

Arsenic concentrations in leachate from the two ferric oxide treatments were, with the exception of year 10, consistently lower than leachate concentrations from the no-treatment columns (Table 6). A statistical comparison for each data set (years 1, 5, 10, and 50) indicated that the ferric oxide treatments were significantly different for year one from the untreated column As concentrations. Five and 50 year treated column As concentrations were significantly different from the no-treatment sample concentrations, and no significant differences were found for year 10 (Table 6). The latter finding is due in part to the large variation in concentrations from the no-treatment columns which produced a large standard deviation (157 µg/L) for these samples. The means of all leachate samples from the no-treatment, 1.67 percent ferric oxide, and 3.33 percent ferric oxide were 323, 192, and 156 µg/L total As respectively. The addition of further ferric oxide to two of the columns further reduced arsenic levels, but not below the target of 18 µg/L (Table 7). Leachate As concentrations suggest the ferric oxide material has a capacity to attenuate As.

In addition to arsenic, the metals Cd, Cu, Pb, Mn, and Zn were determined for year one and year 50 samples (Table 6). Cadmium values were at or below the laboratory detection level of 5 µg/L for all leachate samples. Copper values in leachate from the ferric oxide treatments were 73-75 percent lower than those in the no-treatment. Manganese levels were lower in the treated cell leachates for year 1, but all levels (treated and no-treatment) were high in year 50 leachates.

Ferric Oxide Thickness

The ferric oxide thicknesses used in the study reduced arsenic values in leachate solution, but not to the WQB-7 standard of 18 µg/L. A linear regression of the log transform of concentrations (log10) versus ferric oxide thickness suggests approximately 25.4 cm of ferric oxide would be required to meet the WQB-7 standard of 18 µg/L with an R^2 of 0.94 (Figure 2). However, the log base curve fit may not accurately represent these data when arsenic values fall below those used to predict the model. Arsenic adsorption data were also compared with Freundlich and Langmuir type adsorption curves. The arsenic data fit the Langmuir model well ($R^2 = 0.99$) and show that with increasing arsenic concentrations in equilibrium, more arsenic is adsorbed (Figure 3). However, the model has a negative slope which yields a negative adsorption maximum.

CONCLUSIONS

Ferric oxide at 1.67 percent and 3.33 percent of tailings thicknesses reduced mean arsenic levels in leachate by 41 and 52 percent compared to leachate from amended tailings and no ferric oxide layer. These results show that ferric oxide is capable of removing significant

amounts of arsenic from solution. However, the ferric oxide treated leachates still had mean arsenic levels at 192 µg/L and 156 µg/L which is above the WQB-7 standard of 18 µg/L As. The use of thicker amounts of ferric oxide (22.9% and 45.8 %) reduced arsenic values further, but not at or below the WQB-7 standard. A log regression model suggests that a ferric oxide layer at least 25.4 cm thick is required to reduce arsenic levels to 18 µg/L in leachate emanating from the columns tested.

Constituent	**Leachate Year**	**Treatment**		
		1 **No Ferric Oxide**	**2** **1.67 % Ferric Oxide Thickness**	**3** **3.33 % Ferric Oxide Thickness**
As (µg/L)	1 5 10 50	283.3a 300.67a 508.0a 202.0 (235.33)a	136.33b 169.67b 377.33a 82.67 (99.00)b	99.67c 152.33b 286.0a 109.33 (125.67)b
Cd (µg/L)	1 50	3.33a (< 5)a	< 5a (< 5)a	< 5a (< 5)a
Cu (µg/L)	1 50	400.67a (554.67)a	102.67b (108.00)b	116.33b (108.67)b
Mn (µg/L)	1 50	797a (3006.67)a	42.67b (2615.00)a	16.67c (5953.33)a
Pb (µg/L)	1 50	4.33a (0.33)a	< 1a (< 1)a	1.67a (< 1)a
Zn (µg/L)	1 50	73.33a (203.33)a	20.00a (60.00)b	33.33a (14.14)b
pH (su)	1 5 10 50	9.75 8.24 7.67 7.63	6.78 7.06 7.72 7.72	7.50 7.20 7.70 7.68
Electrical Conductivity (dS/m)	1 5 10 50	2.72 2.60 2.31 2.01	2.99 2.60 2.26 1.99	3.51 2.57 2.27 2.36

Table 6. Analytical results (means) of Tempe cell leachate from Phase II. Dissolved metal values are denoted in brackets ( ). Different letters following means indicate that they are significantly different (p = 0.05).

Parameter	No-treatment	7.62 cm Ferric oxide	15.24 cm Ferric oxide
Dissolved Arsenic (Fg/l)	242	78	51

Table 7. Dissolved arsenic concentrations in leachate from amended tailings with 0, 7.62 cm and 15.24 cm thick basal layers of ferric oxide.

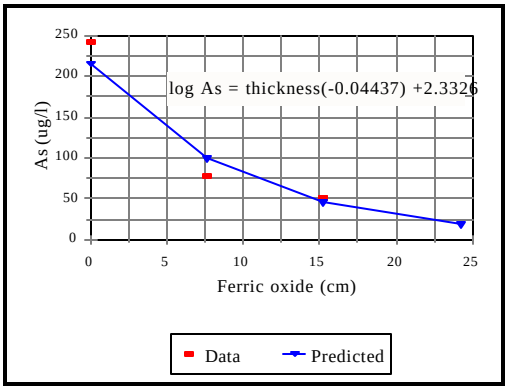

Figure 2. Log regression model for predicting ferric oxide thickness.

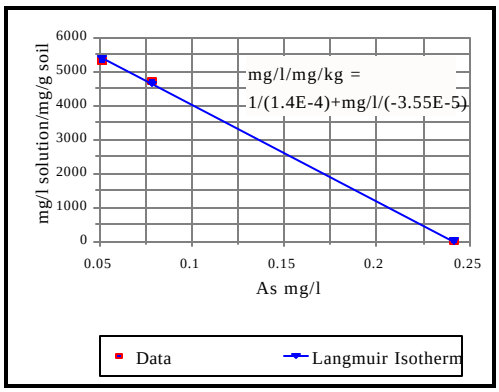

Figure 3. Langmuir isotherm model of arsenic adsorption data.

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REFERENCES

ASA. 1986. Methods of Soil Analysis, Part 1, Physical and Mineralogical methods. A. Klute (ed.). Amer. Soc. of Agron. and Soil Sci. Soc. of America, Madison, WI.

Ashe Analytics. 1995. Clark Fork River Superfund Investigations Laboratory Analytical Protocol for XRF Analysis. Ashe Analytics, Butte, MT. Prepared for ARCO.

ASTM. 1997. ASTM Book of Standards. American Society for Testing and Materials, West Conshohocken, PA.

Dollhopf, D.R., J.D. Goering, G.S. Vandeberg, and D.R. Neuman. 1999. Evaluation of Ferric Oxide for Adsorption of Arsenic Leaching From a Mine Waste Repository. Reclamation Research Unit Publication No. 9901, Reclamation Research Unit, Montana State University, Bozeman, MT.

Fetter, C. W. 1988. Applied Hydrogeology, Second Edition. Macmillan Publishing Company. New York. 592 pp.

Klaus, P., A. Jain, and R. Loeppert. 1998. Arsenite and Arsenate Adsorption on Ferrihydrite: Kinetics, Equilibrium, and Adsorption Envelopes. Environmental Science & Technology. 32: 344-349.

Mason, Brian and L.G. Berry. 1968. Elements of Mineralogy. W.H. Freeman and Company. San Francisco, CA. 550p.

Maxim Technologies. 1998. Alternatives Analysis for Mine Waste Relocation Repositories, Streamside Tailings Operable Unit, Silver Bow Creek/Butte Area NPL Site. Report prepared by Maxim Technologies, Helena, MT for Montana Department of Environmental Quality, May 1998.

MDEQ. 1995. Montana Numeric Water Quality Standards. Circular WQB-7. Montana Department of Environmental Quality, Helena, MT.

MDEQ and USEPA. 1995. Record of Decision. Streamside Tailings Operable Unit, Silver Bow Creek/ Butte Area NPL Site. Montana Department of Environmental Quality and U.S. Environmental Protection Agency, Helena, MT.

Sobek, A. A., W.A. Schuler, J.R. Freeman, and R.M. Smith. 1978. Field and Laboratory Methods Applicable to Overburdens and Mine Soils. Method 3.2.19, EPA 600/2-78-054. P95-99.

U.S. Department of Agriculture. 1954. Diagnosis and Improvement of Saline and Alkali Soils. Agriculture Handbook No. 60. U.S. Dept. of Agriculture, Washington, DC.

USEPA. 1988. Contract Laboratory Program. Statement of Work for Inorganic Analysis. SOW No. 788 or most current SOW.

USEPA. 1983. Methods for Chemical Analysis of Water and Wastes. U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Cincinnati, OH 45628. EPA-600/4-79-020.

USEPA. 1979. Methods for Chemical Analysis of Water and Wastes. EPA - 600/4-79-020.

Woolson, E. A., J. H. Axley and P. C. Kearny. 1971. The chemistry and phytotoxicity of arsenic in soils. I. Contaminated field soils. Soil Sci. Soc. Amer. Proc. 35:938-943.

Show Me the Progress!

A.k.a./Managing Hardrock AML Cleanup Projects Under the CWAP & GPRA

George M. Stone, Jr.*

Restoring watersheds can pose significant challenges due to the technological complexities of water pollution, the costs of treatment, and the time it takes to identify and clean up the contributing AML sites. The Clean Water Action Plan (CWAP) and its implementing guidance provide a framework for partnership efforts, fund leveraging, and ensuring that wherever possible those persons responsible for the pollution contribute to the cleanup. [1] In addition, today's AML project managers must fulfill the provisions of the Government Performance and Results Act (GPRA),[2] whose sponsors rally around the theme of "what gets measured gets done!" Relatively small annual appropriations add up, and agencies need to demonstrate significant achievements in shot time frames for the monies spent, or risk future funding. This presentation shares some of the successful methods used and "lessons learned" in implementing both the CWAP and GPRA under the BLM's AML program.

Where the BLM has done well, it has been able to enter into partnerships where projects have clearly defined goals, known beneficiaries of the cleanup exist, and where agency roles have been established. Risk-analysis was applied so that the most significant sites were usually addressed first. No polluted sites have been left unreclaimed. Large watersheds have been broken down into manageable segments, which enabled some small to medium size on-the-ground projects to be completed in short time frames while site characterization and other preparation work continued on the more difficult sites or the next watershed segment. Moreover, by developing ways to report progress on the number of sites in the watershed which have been initiated and completed each year, meaningful progress has been reported under the GPRA.

In contrast, there are projects which could be progressing better had certain shortcomings been identified and addressed at the outset, and new project proposals which are unlikely to be funded if corrective adjustments are not made. Examples include projects:

- With questionable objectives and unspecified benefits or beneficiaries.
- Not planned in segments.
- Where prep work or other support activities have been nebulous, not measured and difficult to assess in terms of progress.
- Too difficult technologically for a new program to handle.
- Which did not establish contingency funding to clean up all sites, including those on private lands.
- Where other kinds of pollutants are being overlooked.
-

In short, when the inevitable audit compares tomorrow's water sample against today's, will there be a meaningful improvement? Avoid the traps listed above. Report your accomplishments under GPRA. Ensure your AML program is included in your agency's strategic and annual plans. Broadcast your progress, for example, on the Internet. Get key funding and political leaders involved, or at least informed, an keep them up to date on your progress.

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George M. Stone, Jr.*, Senior Abandoned Mine Land Specialist, Bureau of Land Management, Protection & Response Group, WO-360, 1849 C St., NW, MS 504-LS, Washington, DC 20240

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[1] Under the CWAP, State government agencies take the lead to identify polluted watersheds. Next, the States, together with Federal land management agencies like BLM and the Forest Service, determine which polluted watersheds are attributable to AML sites. The government agencies prioritize the watersheds based on risk assessment, and collaborate on a comprehensive plan whereby all of the problem sites are addressed over a certain time period given an anticipated level of funding. If responsible parties can be identified or if willing third parties can contribute to the effort, those factors are taken into account as well.

[2] Briefly, under the Act and related financial management statutes and guidelines, agencies are to operate in more of a business cycle by developing strategic and annual work plans, performance measures tied to budgets, and applying program evaluation (including cost accounting) to hold managers accountable for results and, in turn, to provide input to the next round of plans.

2000 Billings Land Reclamation Symposium

BIOENGINEERED STREAMBANK STABILIZATION ON SILVER BOW CREEK, BUTTE, MONTANA

Jay Windell, Ph.D.[1] and Chuck Stilwell, P.E.[2]

ABSTRACT

A newly configured approximately 7,000-foot long (1.3 miles) meandering channel was created at the ARCO Lower Area One, Phase I, Segment II remediation site, Butte, Montana. The project goal was to reclaim and stabilize approximately14,000 lineal feet (2.6 miles) of stream bank and riparian corridor with native seed, herbaceous, shrub (willow) and tree plantings. The finished channel included a 30-45 foot average top width, 30 outside concave banks and 30 inside curve point bars. The channel decreased in elevation 19.7 feet for an average 0.31% gradient. An engineered diversion was located immediately upstream of the project site to divert portions of flows in excess of 35 cfs for a period of five years or until the 30 outside concave banks become stabilized with root structure.

This paper provides a summary of the streambank design, construction techniques and post-construction assessment of those banks. Thirteen of the 30 concave banks were treated and stabilized using eight bioengineered treatment combinations. The remaining 17 banks and point bars were stabilized using an intensive vegetative treatment (IVT) containing three staggered rows of willow cuttings at two-foot centers. Two staggered rows of IVT were installed behind the bioengineered treatments at the 13 locations. Mycorrhiza and osmocote were utilized during willow installation. Observations and quantitative monitoring including measurements of willow stem growth that provided a basis for evaluating bank stabilization with root structure and the restoration of biological function utilizing the nine bioengineered treatments. Measurements after two growing seasons indicated that plant growth and root structure met or exceeded design expectations. Information and understanding gained from the variety of bioengineering designs used on this project will be considered during potential future designs downstream of Butte.

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INTRODUCTION

The uppermost portion of Silver Bow Creek near Butte, Montana was the site of a remediation project titled Lower Area One (LAO) Phase I, Segment II. Remediation included removal of large quantities of tailings and underlying soils with elevated metals concentrations. Clean fill material was imported to construct a 200 to 400 foot wide floodplain and a low flow meandering stream channel. In addition to remediation goals, there was a desire to restore the area to a naturally functioning stream, riparian and wetland ecosystem. Hence, the project presented the need for: 1) creating a fully vegetated riparian floodplain, and 2) restoring the stream channel using a natural geomorphic design and bioengineered bank stabilization treatments.

A plan was developed to avoid subjecting the newly formed floodplain, riparian corridor and channel to the erosive overbank flows of spring snowmelt runoff and isolated storm events by taking advantage of approximately half of the old Silver Bow Creek Channel and constructing a new temporary channel for the remainder. The engineered diversion was located parallel to the project site to divert flow in excess of 35 cfs for a period of up to five years or until the streambanks became stabilized with native plant (i.e., willow) root structure. The diversion channel was sized to convey the runoff from the 10-year-24 hour storm event estimated at 477 cfs.

Project complexity dictated use of an interdisciplinary team approach including experienced professionals with expertise in civil and hydraulic engineering, hydrology, fluvial geomorphology, ecology, botany, bioengineering, habitat restoration, fisheries and other related disciplines. ESA Consultants Inc. under contract to the Atlantic Richfield Company (ARCO) developed the Work Plan; R2 Consultants Inc. produced the geomorphic stream channel design plan; Schafer & Associates Inc. developed the interim revegetation design plans, directed intensive vegetation treatment and conducted steambank oversight and monitoring; and Aquatic and Wetland Company designed and directed the installation of the bioengineered bank stabilization treatments.

The bioengineered stabilization treatments and their variations included using three types of toe material: wattling, brush layering and biologs that are fully described in the methods below. End of the first growing season monitoring during October 1998 included photography and qualitative observations. End of the second growing season monitoring during October 1999 included measurements of willow survival, density, and growth (Ave. and Max. height). The purpose of this paper is to summarize the nine bioengineered streambank designs, key construction techniques used for willow planting and to report the qualitative and quantitative findings from the initial two years monitoring.

METHODS

Species Selection

Careful consideration was given to stabilization of the streambank zone defined by the channel edge or bank toe, bank slope and floodplain terrace associated with the reconstructed channel. Five native willow species were identified for planting in the streambank zone based on their phenology-morphology, environmental tolerances and production characteristics (ARCO 1997). Three of the five species were known to be abundant within the Silver Bow Creek floodplain valley including Sandbar willow (Salix exigua), Booths willow (Salix boothii), and Yellow willow (Salix lutea) and harvest sites were selected accordingly. Other willow species played a minor role and were not considered in the monitoring results discussed below: Geyers willow (Salix geyeriana), Pacific willow (Salix lasiandra), and Bebbs willow (Salix bebbiana).

The construction work steps involved in the bioengineered bank stabilization with willows included harvesting, bundling, handling, soaking and planting willows. The project began by harvesting dormant willows during the early spring of 1998 and planting progressed thereafter during April, May and June.

Willow Preparation

Harvesting Willows. Small lightweight chain saws and heavy-duty brush cutters worked well for harvesting large numbers of willow stems in a short period. Once willows were cut near ground level, they were gathered and piled at a convenient site for processing.

Bundling. Processing willows for ease of handling included forming a bundle by gathering ten stems (plus or minus one inch in diameter). Dead stems were not included in the bundles. The stems were placed on modified "saw horses" positioned five feet apart and each end of a bundle wrapped with plastic wrap. The bundles were placed in piles of ten, loaded onto a covered trailer to keep out of the sun and prevent drying and transported to a site for soaking in water.

Soaking. All willow bundles were placed in a pond and to the extent possible, submerged for a minimum of three days or longer. Soaking willows ensures that the vascular tissue and buds are super saturated thus resulting in dissolution and leaching of an anti-root hormone located in the stems. After soaking, bundles were removed from the pond, transported to the construction site, placed in the creek's flowing water and planted the same day.

Design and Implementation

The newly configured channel extended approximately 7,000 feet (1.3 mile) with 14,000 feet (2.6 miles) of riparian streambanks that were planted with native grass species, herbaceous sedges and rushes, shrubs including willow (Salix spp.) and tree plantings. The planform of the low flow channel was designed with a sinuosity of 1.25 and typical

stream gradients from 0.2% to 0.4%. The constructed channel included a top width ranging between 30 and 45 feet, a bottom depth of 2.5 feet, 1.75:1 side slopes and a capacity to transport 270 cfs before overbanking. Observation and map analysis resulted in identification of 30 outside concave curve banks and 30 point bars or inside convex curve banks for purposes of design. Each curve was numbered beginning at the downstream project boundary (Figure 1).

Bioengineered Treatments. More intensive bioengineered bank treatments were located at 13 of the 30 outside concave bends. Eight bioengineered designs were determined necessary due to higher erosion potential. Specific treatments for the 13 banks were chosen and implemented based on the high and low risk erosion potential and named according to bank slope and toe treatment (Figures 2 to 7). Toe material was considered nonstructural/organic and included wattling (live facines or bundles of willows 6 inches in diameter), brush layering (intensive single line of willow cuttings running parallel with the water edge) and biologs constructed from biodegradable coconut fibers. Wattling was used as the protective toe at five locations for a total 680 feet. A brush layer toe was installed at three locations for a total of 513 feet. A biolog toe was installed at five locations for a total of 650 feet. Therefore, the total concave bank bioengineered treatment length was 1,843 feet (0.35 mile).

A ninth bank treatment, called Intensive Vegetation Treatment (IVT), was applied to the remaining 17 low risk erosion potential banks, point bars and straight reaches extending for 12,157 feet (Figure 8). Treatment included planting willow cuttings, other shrubs and trees above the ordinary high water mark, sedges and rushes from the water edge throughout the capillary zone, and intra-seeding and hydromulching the remaining area. IVT treated bank spacing of willows varied from one to three feet.

Willow cuttings were inserted to the ground water table after punching a three to four foot deep hole with a dibble bar attached to the bucket of a rotating trackhoe. The number of cuttings placed in each dibbled hole varied according to the diameter of the cuttings and ranged between one and three. Two staggered rows on two to three foot centers were planted behind the 13 concave bend banks and three staggered rows on two foot centers were planted along the convex banks, point bars and straight reaches. Planting distance for the first row from the water edge ranged between one-foot for concave banks to three-foot for convex banks.

RESULTS

Successful bank stabilization was judged by two criteria: 1) performance during and after an unpredicted storm flow event, and 2) quantitative measurements of willow plantings. An estimated flow of 450 cfs occurred following a severe thunderstorm on July 31,1998 or approximately three months after treatment implementation. It was estimated that 300 cfs was diverted into the alternate channel and 150 cfs remained in the new Silver Bow Creek channel. Minimal erosion damage was observed after this storm event and no repair work was required. Therefore, it was observed that the bioengineered treatments worked well at the design flow capacity.

Willow Growth (Second Year)

Quantitative measurements based on, stem survival/mortality, density, and above ground growth were taken during the second growing season. Qualitative observations of bank erosion were also made. No erosion was observed in the 17 concave bend areas treated with IVT.

Average plant height and maximum plant height measurements were made at six of the thirteen- banks treated with the different types of bioengineered treatments (Table 1). Stem height was measured within each of three randomly selected one-meter sections for each of six bank treatments for a total of 18 meters (Table 2). The amount of growth was measured from the surface of the ground to the woody-growing tip of the stem. Branches and leaves were not measured.

An overall average height for the six bank treatments ranged between 4.0 and 4.6 feet for an average of 4.2 feet by the end of the second growing season. An average 77 day growing season (range = 74 to 80 frost-free days) was used to estimate the inches of growth per day for the two growing seasons. Average growth per day ranged between 0.33 and 0.38 inches per day or a little over one-third of an inch per day.

Maximum height for the fastest growing stems ranged between 6.8 and 8.6 feet with an average of 7.8 feet for the six banks measured (Table 3). Therefore fast growing stem growth for the two growing seasons ranged between 0.57 inches and 0.72 inches for an average growth rate of nearly two thirds of an inch per day (0.65”). A number of stems achieved a height of 8.6 feet (103.2”) that translates into a growth rate of 0.72 inches per day by the end of the second growing season (77 days + 77 days = 144 days).

In summary, average willow stem growth under the conditions within the Silver Bow Creek was one-third of an inch each day over the two growing seasons and the fast growing stems averaged nearly three-fourths inch per day. Although not evaluated quantitatively, it was observed that the stabilizing underground root development was rapid and comparable to the above ground growth.

Mortality/Survival Planting Density

Interest was expressed regarding the number of willow stems planted per meter for the installed variations of brush layering, which involved dense linear planting of willow stems along a bank. Therefore, three one-meter sections were randomly selected within six of the treatment types (18 meters). The number of live stems and dead stems were counted. The number of willow stems planted per meter did not vary greatly for the six banks sampled and averaged 26 per meter. Average number of stems surviving per meter at the end of the second growing season within the six treatments was 16.3 or 64% of those planted (Table 3). Average number of dead stems counted was 9.3 (36%).

Additional Observations

Although quantitative measurements were not taken by willow species, species differences in willow phenology/morphology and production characteristics contributed greatly to bank stabilization. Sandbar, Booths and Yellow willow cuttings each formed roots within 10 to 15 days of planting. Banks were well stabilized during the first growing season and improved significantly by the end of the second growing season. It was assumed that the amount of above ground growth was reflected in the amount of below ground root growth.

Observations suggested that Booths and Yellow willow cuttings out performed Sandbar willow in terms of short and long-term above ground vegetative production. Booth and Yellow willow species showed greater above ground biomass production by the end of the second growing season than Sandbar willow and appeared to be prime candidates for future projects within the area along with the Sandbar willow.

Finally, casual observations were also made during monitoring of fish already inhabiting the new creek. Game (trout) and non-game (suckers) fish were observed in the newly created habitat consisting of stable banks and overhead cover created by the various willow treatments.

PROJECT COST

A primary interest of this project was to assess the cost/benefit of various bank stabilization designs. Costs for all project elements are summarized as follows.

Design Cost. The engineering design cost for the 13-bioengineered treatments was minimal and is not included in the implementation cost (Table 4). However, design and willow preparation cost is included for that portion of the IVT treatment involving the two staggered rows of cuttings planted behind the eight different bioengineered bank treatments (Table 1, Fig. 2-7).

Implementation Cost. Implementation costs for constructing the bioengineered treatments included toe material, willow bundles, fabric, excavator time and incidentals. Cost for incidental(s) included stakes, rebar, flags, micorrhiza, polymer, and safety related equipment. Costs for travel, lodging, per diem and oversight are not included in the following breakdown.

Labor cost for planting those treatments requiring willows (e.g., 10 of the 13 banks) required wattling and brush layering) was included in the willow harvest cost per bundle ($15). Therefore, the cost for harvesting and planting 1,020 willow bundles was $15,300 (1,020 X $15). Planting required an excavator and operator for five days to construct the four-foot deep trenches into which the willow bundle stems were placed at a cost of

$6,000 plus $500 for mobilization (total $6,500). Five different banks measuring 650 linear feet were treated with 32 biologs measuring 20 feet long and 16 inches in diameter. Log cost and installation was $280 each for a total cost of $8,960 or $14 per foot. A total of eight rolls of erosion control fabric (COIR cf #7) measuring 6.6 feet wide and 165 feet long was applied at nine of the thirteen treated banks. Fabric cost $245 per role (120 sq. yd.) delivered to the construction site and $21.32 per role for installation (0.02 cents/sq. ft) ($245 + $21.32 = $266.32/roll) for a total fabric cost of $2,130.56.

In summary, no willows were used with three of the five banks treated with biologs for a total length of 400 feet. The remaining ten banks measuring 1,143 feet were treated with wattling, brush layering or a combination. Nevertheless, the combined cost for willows ($15,300), excavator ($6,500), biologs ($8,960), and fabric ($2,131) totaled $31,890 or an approximate average cost of $17.30 per foot.

Cost of Willow Portion of IVT (at the 13 Banks)

Implementation of the entire 7,000 foot IVT treatment required an excavator with a dibble bar to poke 3 to 4 foot deep holes for inserting 2-3 stems/hole at a $3,600 cost plus $500 for mobilization for a total cost of $4,100. The 13 treated banks extended 1,843 feet or 26% of the total IVT treatment length (7,000'). The excavator/operator machine time cost was 26% of $4,100 or $1,066. A total of 614 willow bundles at $15/ bundle were required to plant the two staggered rows of cuttings behind the 13 banks receiving treatment at a total cost of $9,214 (incl. harvesting and planting). Therefore, cost of the willow portion of the IVT treatment (2 rows) was $10,280 (excavator time $1,066 + willow/planting $9,214 = $10,280) or approximately $5.58 per foot.

In summary, the overall cost for the IVT treatment ($10,280 or $5.58/ft.) and the 13 bioengineered bank treatments ($31,890 or $17.30/ft.) totaled $42,170 or an approximate average per foot cost of $22.88.

Cost per Foot

Table 4 is a cost per foot comparison of the bioengineered treatments with a riprap treatment designed for the Cashe La Poudre River, Colorado: a Corps of Engineers project. The specifications required type M riprap ten feet wide and two feet thick at $12/ton (4 tons/lf = $48/ft). The riprap was transported to the site (2 hr. @ $65/hr. = $130) with a 22 cubic yard end dump that translates into $11.81 per ton. An excavator was used to place the riprap at $4.33 per foot and eight inches of soil was placed on top (0.9 cents/sq./ft). The area was then seeded for 0.6 cents per square foot. Therefore, the cost of a typical riprap bank treatment was $65.64 per lineal foot.

Costs for both the hard and soft bank treatments assume eight to ten feet of bank coverage per lineal foot extending from the channel invert upward and the ability to withstand water velocities of 10 feet per second or greater. Costs per foot for the bioengineered treatments ranged between $14.50 (IVT only, 3 rows) and $43.00 depending on treatment complexity. Treatments requiring brush layering used one bundle

of 10 stems per foot ($15). The IVT only treatment (assuming 3 rows with 3 stems/hole) averaged one half of bundle per foot ($7.50). IVT treatment planted behind and in combination with the bioengineered treatment used one-third willow bundle per foot at a cost of $5.00. Wattling used one-third of a bundle per foot of overlapping stems at a cost of $5.00 per foot. The total individual cost per treatment can be calculated by using the total length treated (Table 1) by the total cost per foot (Table 4).

LESSONS LEARNED

Major lessons learned from this project included:

- IVT (only) as designed and constructed in this project, was very successful in stabilizing newly constructed streambanks (rapid willow growth and lower mortality that in other comparable projects in the basin).
- Use of intensive treatments (biologs, brush layering, wattles) may not be needed in conditions with controlled flood flows during the initial 2 to 5 growing seasons.
- Fabric on banks is not necessary if flood flows are controlled in the initial 2-5 post construction years.
- Willow preparation steps, as used in this project, are critical for success of rapid willow establishment.
- Given general cost/benefit assessment (cost per foot, Table 4, and bank stability using qualitative observation and quantitative measurement), no one bioengineered bank treatment is a preferentially better performer using strictly the costs per foot of each treatment, treatment 3 (wattle toe, IVT) and 9 (IVT only) appear preferred.
- Willow cuttings with diameters in excess of one inch showed higher survival rates and better growth than cuttings with diameters less than one inch.
- Brush layering appeared equally successful with or without a protective toe constructed with either wattling or biolog.

Other lessons learned.

- Wattling must be located where soil moisture is high but not flooded or submerged. When soil moisture conditions are excessively wet, willow cutting survival and growth was decreased.
- Growth rate was similar for willow cuttings used for brush layering, wattling or as willow cuttings planted in holes created with a dibble bar (IVT).

Conclusion

Second year monitoring indicated a highly successful stabilization project based on absence of erosion, vegetation survival, density, growth, and streambank stability. The design objectives have been met. The concave, convex and straight reaches of the streambanks are stable, riffle/run/pool habitat is present, several species of fish have been observed, waterfowl have become residents, and site aesthetics are developing as expected. The Lower Area One, Phase I, Segment II should be an example project of how traditional nonfunctional hard riprap stabilization approaches can be replaced by biologically functional bioengineered approaches to erosion and bank stabilization challenges. Much information on specific designs and construction techniques are

transferable to other projects, given proper caution that flood flows were controlled for up to 5-years post construction.

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LITERATURE CITED

ARCO, 1997. Interim Revegetation Design Lower Area One Phase I, Segment II. Final. 47 pages. Tables and Figures.

Windell, J. and G. Gurnee. 1999. Four Bioengineered Stabilization Treatments. Land and Water. Vol. 43(2). March/April. Pp. 54-58.

Table 1. Bank number, treatment type and length.
IVT = Intensive Vegetation Treatment

Bank Number	TREATMENT TYPE	Treatment Length ft.	Treatment Type Subtotal ft.	Toe Treatment Subtotal ft.
10	1. Wattle Toe, Brush Layer, Fabric, IVT	105	-	
12	1. Wattle Toe, Brush Layer, Fabric, IVT	205	310	
24	2. Wattle Toe, Fabric, IVT	205	-	
25	2. Wattle Toe, Fabric, IVT	65	270	
26	3. Wattle Toe, IVT	100	100	
	TOTAL	680		680
7	4. Biolog Toe, Fabric, IVT	80	380	
28	5. Biolog Toe, IVT	160	-	
30	5. Biolog Toe, IVT	160	320	
3	6. Biolog Toe, Brush Layer, Fabric, IVT	100	-	
5	6. Biolog Toe, Brush Layer, Fabric, IVT	150	250	
	TOTAL	**650**		650
22	7. Brush Layer Toe, IVT, no fabric	72	72	
23	8. Brush Layer Toe, Fabric, IVT	165	-	
29	8. Brush Layer Toe, Fabric, IVT	276	441	
		513	= 1,843 (0.35 mile)	513
Control banks	9. Intensive Vegetative Treatment only (IVT)	12,257		

Table 2 **Number of willow cuttings planted per meter and number and number and percent survival.**

Bank Number	Treatment Type	Average Live/M #/m	Average Live/M %	Average Dead/M #/m	Average Dead/M %
3	Biolog Toe, Brush Layer	17	68	8	32
5	Biolog Toe, Brush Layer	14	61	9	39
10	Wattle Toe, Brush Layer	20	65	11	35
12	Wattle Toe, Brush Layer	17	57	13	43
23	Brush Layer, Fabric	16	70	7	30
29	Brush Layer, Fabric	14	64	8	36
	AVERAGE	**16.3**	**64**	**9.3**	**36**

Table 3 **Willow cutting growth at end of second growing season.**

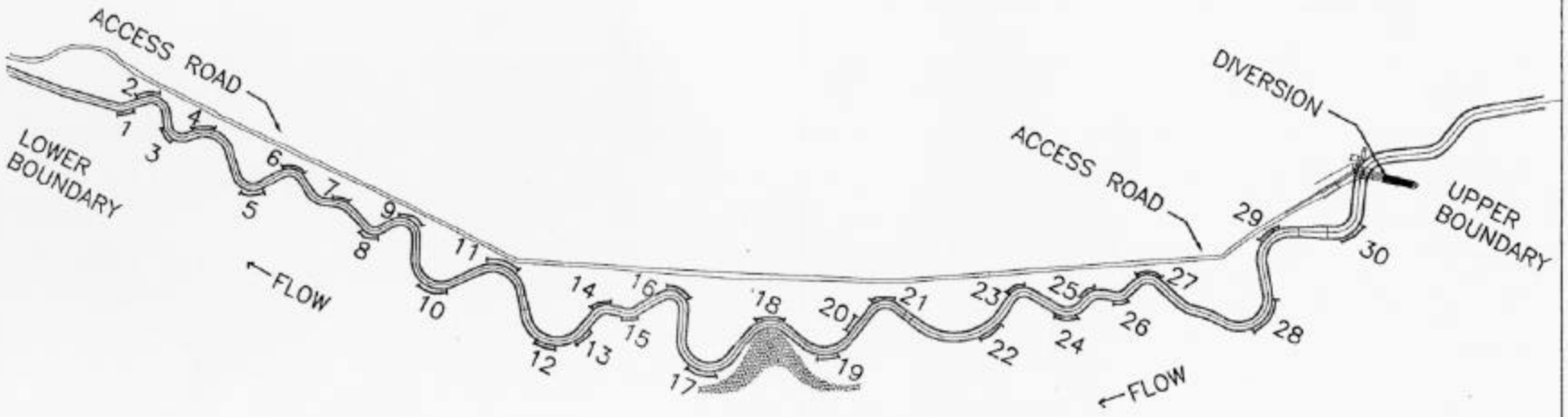
Bank Number	Treatment Type	Average Height ft.	Maximum Height ft.
2	Intensive	4.2	8.2
3	Biolog Toe, Brush Layer	4.6	7.4
5	Biolog Toe, Brush Layer	4.1	7.7
10	Wattle Toe, Brush Layer	4.4	7.8
23	No Toe, Brush Layer	4.0	8.6
29	No Toe, Brush Layer	4.1	6.8
	AVERAGE	**4.2**	**7.8**

Table 4: Cost per lineal foot comparison of bioengineered and riprap treatments. Costs assume completion of bank shaping/grading; all treatments extend 8-10 lf up the bank. Water velocities are assumed to be 10ft./sec. IVT=2 rows unless indicated otherwise and one-third bundle per foot at $5.00.

Treatment Type	Toe Material $	Willow Bundle $	Fabric[2] $	Excavator[5] Time $	Incidentals[6] $	Total $
1. Wattle Toe[1], Brush Layer, Fabric[2], IVT	5.00	20.00	2.00	4.00	3.00	34.00
2. Wattle Toe, Fabric, IVT	5.00	5.00	2.00	4.00	3.00	19.00
3. Wattle Toe, IVT	5.00	5.00	0.00	4.00	3.00	17.00
4. Biolog Toe[3], Fabric[2], IVT	14.00	5.00	2.00	4.00	3.00	28.00
5. Biolog Toe, IVT	14.00	5.00	0.00	4.00	3.00	26.00
6. Biolog Toe, Brush Layer, Fabric, IVT	14.00	20.00	2.00	4.00	3.00	43.00
7. Brush Layer Toe, IVT	15.00	5.00	0.00	4.00	3.00	27.00
8. Brush Layer Toe, Fabric, IVT	15.00	5.00	2.00	4.00	3.00	29.00
9. IVT only[7] (3 rows)	0.00	7.50	0.00	4.00	3.00	14.50
Riprap[8]	-	-	-	-	-	$65.64 lf

Footnotes
1. Wattling = overlapping cuttings tied and wired together: eight inches in diameter
2. Fabric = 6.5 feet wide and 165 feet long, material and installation
3. Biologs were 16" in dia. and 20' long
4. Brush layering equal one cutting per inch i.e., or one bundle per foot
5. Excavator time = $4.00 per lineal foot
6. Incidentals = micorrhiza, polymer, osmocote, stakes, wire, rebar, etc.
7. IVT @ 2' centers requires 1/2 bundle per lineal foot.
8. See text.

SILVER BOW CREEK



NUMBERS INDICATE LOCATIONS OF
BIOENGINEERED STABILIZATION TREATMENTS

FIGURE 1

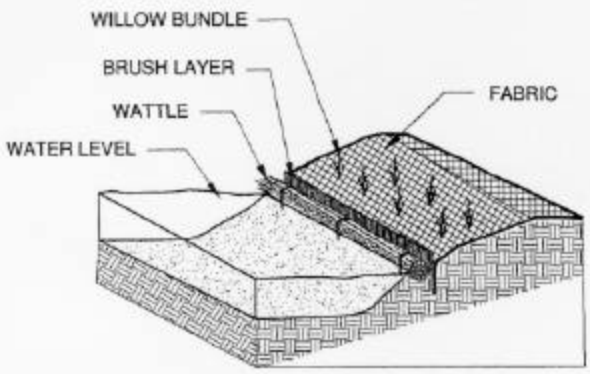


FIGURE 2. WATTLE TOE, BRUSH LAYER, FABRIC, IVT (TREATMENT 1)

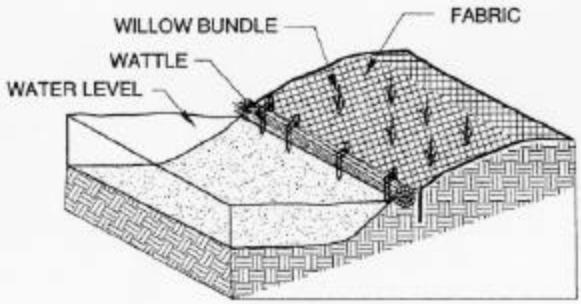


FIGURE 3. WATTLE TOE, IVT, FABRIC (TREATMENT 2)

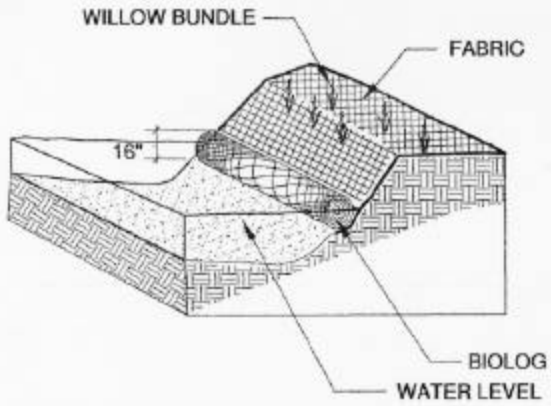


FIGURE 4. BIOLOG TOE, IVT, FABRIC (TREATMENT 4)

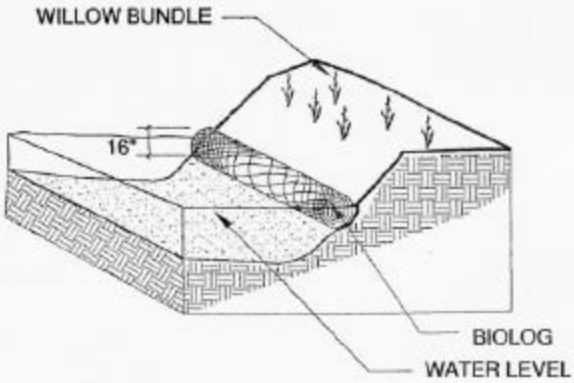


FIGURE 5. BIOLOG TOE, IVT (TREATMENT 5)

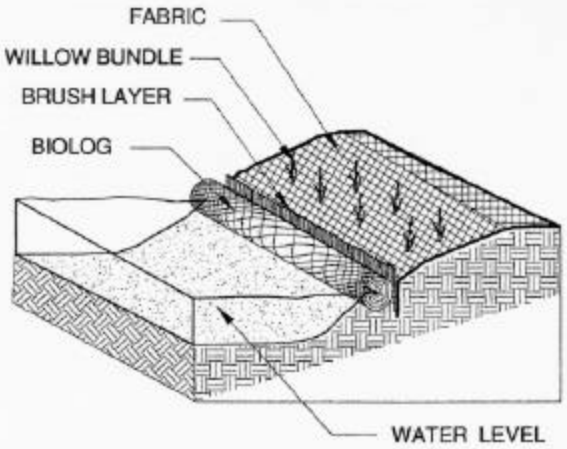


FIGURE 6. BIOLOG TOE, BRUSH LAYER, FABRIC, IVT (TREATMENT 6)

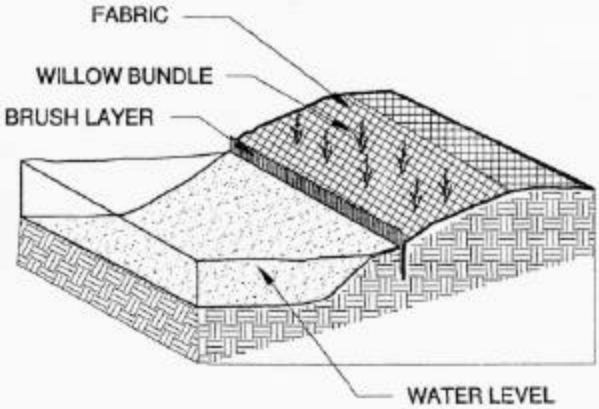


FIGURE 7. BRUSH LAYER TOE, IVT, FABRIC (TREATMENT 8)

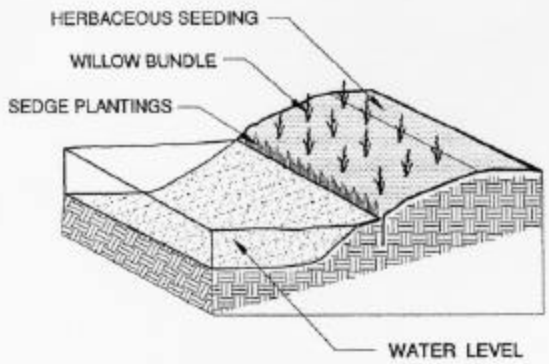


FIGURE 8. IVT (TREATMENT 9)

2000 Billings Land Reclamation Symposium

An Evaluation of Revegetation Success Within a Floodplain System Impaired by Sulfide Mine Waste

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Abstract

The long-term reclamation success of the stream portion of the LAO Operable Unit (LAO OU), a riparian system impaired by mining and development activity downstream of Butte, Montana, depends on vegetation to minimize floodplain erosion and stabilize streambanks. Another key objective of the LAO project is restoring the area to a naturally functioning riparian habitat. Reclamation activities at LAO entailed mine tailings removal, backfilling with unimpacted material, construction of a meandering stream channel and 100-year floodplain, and revegetation of the reconstructed floodplain. As part of the revegetation design process, LAO was divided into four hydrologic zones, streambank, wetland, subirrigated, and upland. Species selection and placement was based primarily on these zones.

Revegetation efforts initiated in October 1997 and completed in October 1998 consisted of seeding herbaceous species; planting dormant cuttings and containerized woody and wetland species; and transplanting trees and large willow shrubs. Silver Bow Creek streambanks were stabilized with cuttings planted at high densities and bioengineered streambank stabilization treatments.

The site was monitored qualitatively in 1998 and 1999 to provide data to support post-construction management decisions and to determine the success of the planting effort. With few exceptions, estimated cover values in 1999 ranged from 55% to 75% on upland zones and 75% to 95% on subirrigated, streambank and wetland zones. The diversity and seedhead production of seeded species increased notably from 1998 to 1999. Few areas of erosion or weed infestations were observed. The major concern in the initial post-construction phase is weed invasion. Weed control measures consisting of manual pulling and spot spraying were effective in minimizing the spread of invasive species. The majority of containerized plants exhibited good vigor and low mortality. Greater than 90% of several thousand cutting planted along streambanks have survived to date, exhibiting excellent growth and vigor and extensive root systems.

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INTRODUCTION

Between 1881 and 1910, eight ore-processing plants flourished in Butte, Montana, including the Butte Reduction Works and the Colorado Smelter. Tailings, a byproduct of the historic smelting processes, were deposited along a stretch of Silver Bow Creek (SBC) between the Reduction Works and Colorado Smelter. The tailings wastes led to the loss of vegetation and wildlife, leaving roughly 43 acres barren and sterile for over 80 years. This barren area, Lower Area One (LAO) is shown below.

Lower Area One (before tailings removal) looking east

After eight years of study, a cleanup plan was developed for LAO that divided the project into two phases. The first phase, completed between 1993 and 1998, entailed removal of approximately 1.2 million cubic yards of tailings, reconstruction of the SBC channel and floodplain, and restoration of the reconstructed riparian system. Once the tailings were removed, the excavated areas were backfilled with soil from borrow sources located near Butte. A meandering stream channel and 100-year floodplain were subsequently constructed and revegetated, essentially completing reclamation of the southern portion of LAO. The second phase of the project addressing reclamation of the northern portion of LAO is expected to be completed at a future date (2002-2004). It is not part of this paper.

Revegetation of the SBC streambanks and floodplain was integral to the long-term objectives of the project; specifically, floodplain erosion control, streambank stabilization, and restoration of the site to a naturally functioning riparian habitat. This paper describes the revegetation design and implementation process used at LAO, beginning in 1996 and ending in October 1998. The paper summarizes post-construction qualitative monitoring results collected in 1998 and 1999, concluding with an assessment of the selected revegetation methods and the applicability of the methods to other sites. Design and implementation details are presented in the Interim Revegetation Design for LAO, Phase I, Segment II (ARCO 1997); Draft Post-Construction Summary Report for LAO Revegetation (ARCO 1998a); and Draft LAO 1998 and 1999 Qualitative Vegetation Monitoring Reports (ARCO 1998b and 1999).

REVEGETATION DESIGN APPROACH

The revegetation design approach was based on a combination of principles from reclamation science, direct experience gained from various demonstration projects in the Butte/Anaconda region (ARCO 1989, 1994, 1996), and indirect experience of revegetation experts. The first step in the revegetation design process was characterization of the site's post-construction soil, topography, and hydrology. Design elements addressed site-specific physiographic and hydrologic conditions and soil substrate characteristics of the borrow material, forming the basis for selection of plant species and materials best suited to LAO.

The physiographic location of a particular plant species depends, in part, on its tolerance to inundation, saturation, and desiccation, which is related to the duration of low and high flows of surface water and groundwater. The reconstructed stream channel, streambanks, floodplain, and dike areas of the SBC corridor differed in hydrologic and topographic setting. For design purposes, the floodplain corridor was divided into four revegetation zones according to hydrologic regime. Wetland, subirrigated, and upland zones were delineated according to groundwater depth thresholds. The streambank zone was defined on the basis of proximity to the stream channel where vegetation was subject to extended periods of inundation.

The revegetation zone descriptions incorporated definitions of duration and frequency for inundation and saturation from various literature sources (National Research Council 1995; Hansen et al 1995). Establishing minimum thresholds for groundwater depth based on existing data provided a means to delineate planting zones onsite within a relatively short time period. Groundwater thresholds specified in Table 1 were assumed to occur for one to two weeks or more in May through June (high water flow conditions) at a frequency of one out of every two years.

Table 1-LAO Revegetation Zone Descriptions

Zone	Description
Streambank	Areas with nominal bank heights associated with a bankfull level of an instantaneous 2-year peak flow of 270 cfs in SBC. Incorporates bank toe, slope and top. The streambank zone encompassed approximately 1 acre.
Wetland	Areas saturated to a depth of 1 foot or less below the ground surface (bgs). The wetland zone encompassed approximately 9 acres.
Subirrigated	Areas saturated to a depth greater than 1 foot to 3.5 feet bgs. The subirrigated zone encompassed approximately 17 acres.
Upland	Areas saturated at depths greater than 3.5 feet bgs. The upland zone encompassed approximately 11 acres.

The revegetation zone boundaries were drawn on design maps according to the best available groundwater monitoring data. The zone boundaries incorporated construction specifications for backfill elevations. A minimum of 18 inches of finer-grained topsoil was placed in the streambank and upland zones. A minimum of 6 inches of topsoil material was placed where groundwater elevations were expected to be within 0 to 18 inches of the ground surface. A minimum of 12 inches of topsoil material was placed where groundwater was expected to be 12 to 36 inches bgs.

Plant Species Selection

The inherent heterogeneity of the SBC floodplain corridor was addressed by using different seed mixes, plant materials, and planting strategies for each vegetation zone. The goal of revegetating LAO according to four zones was to maximize the success of vegetation establishment given the anticipated post-construction soil and water conditions and to incorporate a diversity of vegetation typically found in a natural riparian area.

Species lists were formulated from several sources of information: existing or neighboring plant communities (survey of SBC by Bitterroot Native Growers); species performance on other reclamation projects; and consultation with Dr. Paul Hansen (University of Montana), Dr. Warren Keammerer (Keammerer Ecological Consultants), Dr. Chris Hoag (NRCS), Dr. Frank Munshower (Montana State University), Schafer and Associates, Aquatic and Wetland Consultants, Western Reclamation, and Circle S Seed.

Critical factors considered for development of herbaceous and woody species lists were adaptability to the defined hydrologic regime; ability to establish easily and quickly to facilitate soil stabilization and deter the initial invasion of undesirable volunteer species; and ability to minimize

weed competition. Cover soil characteristics, species diversity, and aesthetics were also considered. Selected plants were comprised primarily of native species. Naturalized species such as White Dutch clover and strawberry clover were used when availability of native species was limited.

Plant selection for the **streambank zone** focused on quick-establishing herbaceous species with a dense root mass that would aid in soil stabilization such as slender wheatgrass, Canby bluegrass, and strawberry clover. Woody species such as Bebb willow, Booth willow, sandbar willow, yellow willow, and red-osier dogwood were selected for ease of propagation and extensive root systems. Rhizomatous wetland species such as beaked sedge, Nebraska sedge, and hardstem bulrush were planted to facilitate erosion control at the base of the bank of the water's edge.

The **wetland zone** seed mix was a combination of species suited to temporarily and semi-permanently flooded soil conditions. The herbaceous species included fowl bluegrass, fowl mannagrass, ticklegrass, tufted hairgrass, and Baltic rush.

The **subirrigated zone** herbaceous species mix was designed to provide a broad range of adaptation for variable groundwater conditions. The list contained a range of grasses able to tolerate higher groundwater depths such as tufted hairgrass and alkali grass. Canby bluegrass, Great Basin wildrye, and Western wheatgrass were selected for adaptation to drier conditions. Woody species included plants suited to moist environments such as Booth and Bebb willow and plants adapted to drier environments such as Woods rose, Western serviceberry, golden currant, and common chokecherry. Quaking aspen and black cottonwood were designated for transitional areas between subirrigated and upland zones.

The **upland zone** herbaceous mix was designed with species that tolerate drought and reduce weed competition by establishing quickly and by developing rhizomatous root systems. The species included sheep fescue, bluebunch wheatgrass, Indian ricegrass, and white yarrow.

Plant Material Selection

A variety of plant materials were utilized to better ensure vegetation success within each zone. Species, plant location, availability, and cost dictated the material used. An important component of the planning process was the identification of sources, availability, and costs of the various seed mixes and plant materials in order to procure the required materials prior to construction.

Direct seeding was implemented sitewide using seed mixes customized to each zone. Some of the wetland species for the floodplain wetlands were direct seeded with a specialized mix tested in similar climates. **Cuttings** were used extensively to establish woody species on streambanks and to provide long-term bank stabilization. Additional

stability on outside curves was provided by planting multiple cuttings per hole with the holes placed at high densities. Cuttings provide several advantages as a plant source including a high concentration of root primordia, a large size that out-competes other species, minimal disturbance to soil during installation, a means of reaching the water table on steep and high bank slopes, and use of native genetic plant material. The success of the cuttings was optimized by using specific harvesting and planting procedures such as collecting select species and sizes, utilizing healthy stock material, storing harvested cuttings in oxygenated water, and properly timing harvesting and planting. **Containerized species** were used to add immediate visual impact, an established root system, aboveground growth, and carbohydrate reserves that enhance survival. The revegetation design specified the use of tubelings and 1- and 5-gallon containerized plants. **Transplants** were to be used on a limited basis in the original design. One of the changes made prior to planting was to increase the number of large containerized plants (10- and 15-gallon) and transplants to provide seral variability, quick maturity, and aesthetic enhancement.

REVEGETATION IMPLEMENTATION

Planning

Final design maps delineated the revegetation zones, plant clusters, and associated seed mixes, seeding methods, and plant materials. Live plant material clusters were numbered on the maps and identified according to plant community type. Streambank curves were also numbered and designated as straight reaches, inside curves, or outside curves depending on planform position. Once the design maps were completed, the revegetation zones and cluster locations were staked in the field prior to seeding and planting.

The SBC channel was reconstructed in Fall 1997 followed by seeding of the majority of the site in November 1997 and March and May 1998. The cuttings were harvested in early April 1998. Cuttings and the majority of containerized plants were planted from late April to early May. Wetland and woody tubelings and 1-gallon willows were planted in mid-May.

Installation

Seeding

Drill seeded areas were fertilized and chisel plowed before seeding. Seed for the upland, subirrigated, and wetland zones was applied with a custom drill seeder. The seeded areas were mulched and crimped with weed-free wheat straw mulch at a rate of approximately 3,000 pounds per acre. To minimize erosion, most of the streambanks were hydroseeded with a mixture of seed, mulch, and tackifier. Steep upland slopes and wet areas were hand-broadcasted.

Cuttings Harvest and Installation

The design for streambank revegetation, willow wattles (willow bundles laid at bank toe), and brush layering (intensive planting of cuttings at the bank toe) required a total of 20,000 willow cuttings. The criteria for selection of the cuttings specified collection of the stems from healthy stands in the spring before bud break. Willow stems were 1 to 2 inches in diameter and 5 to 7 feet long. Once harvested, the cuttings were stored in oxygenated water for 7 to 10 days to remove anti-rooting hormones. Cuttings were planted to base flow groundwater depths with the aid of a dibble bar mounted on a trackhoe. After insertion, fertilizer pellets and sand were added to the holes. The sand was compacted to ensure adequate soil/stem contact. Each hole was watered thoroughly after planting.

Containerized Plants and Transplants

The holes for the containerized plants were dug manually as a result of restricted equipment access. Fertilizer pellets were added to containerized plant materials. Approximately 1,213 woody tubelings, 5,700 wetland tubelings, and 1,270 1-gallon, 270 5-gallon, and 36 15-gallon containerized plants were installed. Access restrictions limited the number of transplants installed. A tree-spade was used to harvest and plant approximately 40 black cottonwood, quaking aspen, and Booth, Bebb, Geyer, and sandbar willow transplants.

ONGOING SITE MANAGEMENT

Ongoing monitoring and maintenance of vegetation after planting is critical to the success of the planting effort. Temporary irrigation was used at LAO to aid the establishment of containerized and tranplanted woody plants located on the floodplain and upper streambanks. Portable pumps and hoses were used to irrigate portions of the site during the first two growing seasons. The condition of the containerized plants and transplants will be assessed in the third season to determine if additional irrigation is needed. Onsite noxious weeds have been controlled using a combination of manual removal and chemical spraying. Areas adjacent to LAO were blanket sprayed to limit the migration of weed seeds to the site. The site was fertilized in late August 1998 and again in November 1999.

QUALITATIVE MONITORING RESULTS

Qualitative monitoring was conducted at LAO in 1998 and 1999 to evaluate general site conditions, uniformity of vegetation cover, presence of bare or chlorotic zones, evidence of reproduction, weed infestations, and erosive areas. Permanent cover transects, belt transects, and monitoring sites (plant clusters) were established within representative zones, streambank curves , and plant cluster types across the site. Each transect and monitoring site has been photodocumented. Cover for seeded species was estimated visually along each monitoring transect. Survival rates for

cuttings and containerized species were estimated based on individual plant counts within plant clusters and belt transects. Counts were completed immediately following construction and in the two subsequent growing seasons. Quantitative monitoring will be completed in year 3 using appropriate statistical methods to ensure data usability. Site-specific performance standards will be developed for LAO that will be closely tied to management objectives and proposed land uses.

1998 Qualitative Monitoring Results

First year qualitative monitoring was conducted in late August 1998. With few exceptions, estimated cover values on monitored wetland sites ranged from 75 percent to 90 percent. Cover on subirrigated sites was estimated at 60 percent to 90 percent and on upland sites, at 35 percent to 60 percent. In general, areas that were drill seeded in fall 1997 exhibited higher cover values and greater diversity than areas drill seeded in spring 1998. Cover in the wetland and subirrigated zones was typically higher, likely the result of greater groundwater availability. The upland areas at LAO are primarily located on steep slopes that do not retain moisture as well as flat terrain. Streambanks that were hydroseeded in March 1998 exhibited excellent growth by August with estimated cover values ranging from 80 to 90 percent. Diversity was reduced on hand-seeded banks, likely the result of inadequate mixing of the seed mix. Few areas of erosion or weed infestations were noted. Small infestations of spotted knapweed were observed particularly on the streambanks in the east portion of the site. Isolated areas of erosion were observed in areas where seeding was delayed. No erosion rills or gullies were observed on upland slopes.

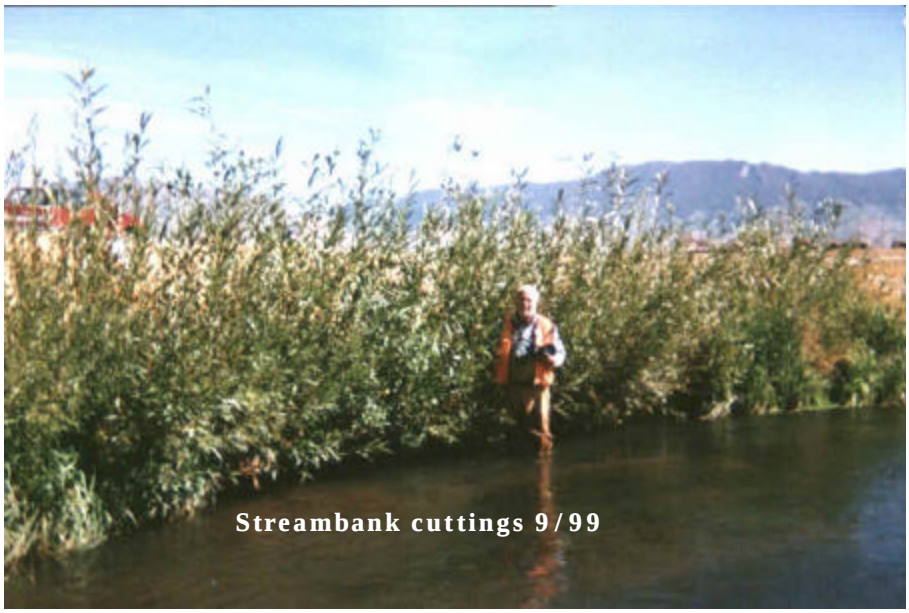
Throughout the site, the cuttings exhibited excellent growth and survival reaching heights of up to three feet by August 1998. Yellow willow species appeared to be the most successful of the species propagated. The majority of containerized plants exhibited good vigor and low mortality within the belt transects monitored. Some mortality was noted in the large containerized and transplanted black cottonwood and quaking aspen trees. Wetland tubelings planted on the streambanks showed excellent growth and vigor throughout the site.

1999 Qualitative Monitoring Results

Qualitative monitoring was conducted for the second year in mid-August, 1999. Second year monitoring results indicated higher species richness sitewide, particularly in areas seeded by fall 1997 and spring 1998. Species such as Indian ricegrass, Western wheatgrass, fringed sagebrush, white yarrow, sheep fescue, cicer milkvetch, sloughgrass, bluebunch wheatgrass, yellow sweet clover, mannagrass and rush species were either observed for the first time or occurred at a higher frequency. Sitewide cover improved notably from the first to second year of monitoring. Seeded plants displayed excellent vigor and seedhead production. Wheatgrass species were 3 to 4 feet high. Estimated cover contributed by volunteer wheat

introduced with the straw mulch decreased in 1999. Cover range estimates reported for 1999 included results for areas seeded in late fall 1998 that were not monitored in August 1998.

Streambank cuttings just after planting 5/98



Streambank cuttings 9/99

Planted and seeded wetland species in inundated or saturated wetland perimeters were robust, especially hardstem bulrush, Baltic rush, Nebraska and beaked sedge, common rush, and creeping spikerush. Containerized willows and volunteer cattails exhibited good growth and vigor. Vegetation was slow to establish in drier areas of the wetland seeded in October 1998. Estimated cover ranged from 90 percent on wetland areas

seeded in November 1997 and March 1998 to 35 percent on the area seeded in October 1998. Cover on subirrigated sites was estimated at 60 percent to 90 percent. Cover on upland sites ranged from 55 percent to 70 percent, slightly higher than in 1998. Species in the subirrigated zone were dominated by slender and thickspike wheatgrass, Canby bluegrass, tufted hairgrass, meadow foxtail, Western wheatgrass, and alkali sacaton. Dominant upland species included streambank wheatgrass, Canada bluegrass, sheep fescue, Great Basin wildrye, bluebunch and Western wheatgrass, white yarrow, Indian ricegrass, blue flax and fringed sagebrush. No signs of erosion were observed in 1999. Several isolated areas of spotted knapweed were noted. The cuttings continued to exhibit excellent growth, vigor, and extensive root systems as evidenced by hundreds of new willow shoots at the root stem. Survival rates for cuttings planted using a dibble bar on monitored streambank sites were greater than 90 percent. The majority of cuttings were 4 to 7 feet high. Yellow willow, Booth willow, and sandbar willow appeared to be the most successful species based on height, vigor, and aboveground biomass.

The majority of containerized plants exhibited good vigor although some mortality was observed in 1999, particularly in the east end of the site where soil clay content was higher and ponded groundwater was observed. Seventeen 5-gallon and 15-gallon quaking aspen, red-osier dogwood, common chokecherry and black cottonwood plants died within the sites monitored. Approximate mortality rates for containerized plants were 10 to 15 percent. Approximately 3 to 5 transplants out of the 40 planted did not survive.

CONCLUSIONS

The revegetation design strategy for LAO was unique, driven by LAO's high-profile location and the goal of establishing a restored floodplain and recreational end land use. Although there was no regulatory incentive, several components of the LAO design exceeded standard reclamation practices and tended toward habitat restoration. Long-term bank stabilization and vegetation growth were facilitated by diversion of peak flows from the SBC channel for 5 years, which was unique to this site. The backfill material met strict soil criteria standards for growth media. The revegetation design accounted for varying hydrologic and topographic conditions by delineating four revegetation zones and by tailoring species and and plant material selection to these four zones. Containerized plant materials and transplants were used extensively to provide more immediate visual impact and diversity.

Facets of the LAO revegetation design may have limited applicability to other reclamation sites, primarily when considering the cost versus benefit. Labor costs for implementation alone (excluding design costs) were approximately $5580 per acre. Plant materials and seed mixes were approximately $1160 per acre. Although the containerized plants were visually effective, material and labor costs may be prohibitive on a larger

scale. Temporary irrigation is often necessary for optimum survival of containerized plants in southwest Montana, which can be extremely expensive and impractical in areas with limited water and access. Cuttings were planted at high densities at LAO to stabilize the banks and to ensure the establishment of streambank vegetation. Without flood diversion, the success of the cuttings observed to date may not have been feasible without erosion control fabric or bank toe treatments. The option of diverting flows is not available at most sites.

The implementation of the revegetation strategies at LAO provided important information that can be applied to other sites. The project demonstrated that the logistics of seeding and planting for four different revegetation zones was manageable and effective on a relatively large scale. Two years of qualitative monitoring indicate that selected herbaceous and woody species appear to be well-adapted to the respective hydrologic regimes. Based on floodplain and streambank vegetation maturity after two years of growth, the SBC channel may be able to withstand flood flows by the third year. Containerized material sizes should be streamlined to the extent possible. Planting would have been facilitated by limiting the number of sizes of containerized plants to either 1- or 5-gallon and 10- or 15-gallon sizes. Although woody tubelings are relatively inexpensive, their use complicated the planting effort. They were difficult to identify before and after planting and highly susceptible to damage. Wetland tubelings provided the only material source for several wetland species, and consequently, were a necessary part of the design.

The most notable success to date in terms of plant growth has been the cuttings planted on the streambanks. The design called for approximately 20,000 cuttings, which necessitated implementation of a well-defined plan for harvesting, transporting, storing, and planting the willow stems. The technical specifications were followed carefully with the exception that some of the cuttings planted at a later date were soaked in water for up to three weeks or stored under cold, wet conditions. This did not appear to compromise success. Cuttings were planted at especially high densities on the streambanks to allow for anticipated mortality rates of up to 50-70% estimated for cuttings subject to normal flood flow conditions. Actual mortality rates were closer to 10-15%. Planting cuttings at lesser densities would likely have been equally successful, given the fact that flood flows were being diverted.

Estimated cover percentages contributed by wheat during the first year of monitoring indicated that the mulch contained more cereal seed than recommended. Annual species tend to compete with seeded species for limited water and nutrient sources. Mulch should be certified weed-free with less than 5 percent cereal seed. Mulch stems should be 8 to 10 inches long to allow for a single crimping pass.

Weed control measures consisting of annual hand-pulling and spraying have been effective to date although manual removal would

become impractical on a large scale. It is important to note that regardless of the initial success of a diverse vegetation community, non-weedy volunteer species such as red top may eventually invade the site.

The long-term success of revegetation at LAO in achieving reclamation goals will be determined through continued qualitative and quantitative monitoring evaluated in the context of site-specific performance standards. The LAO SBC Revegetation Design implemented several innovative alternatives to standard reclamation practices in order to achieve project objectives. As discussed above, most were successful, some were not, while some were excessive when the cost was weighed against the benefit. The information gained on this project was valuable and can be used to facilitate the success of other stream reconstruction projects.

REFERENCES

ARCO 1989. Streambank Tailings and Revegetation Study. Streambank Tailings Operable Unit, Silver Bow Creek/Butte Area NPL Site, Anaconda, Montana.

ARCO 1994. Silver Bow Creek Remediation Demonstration Project I, II, and III. Streambank Tailings Treatability, Remedial Investigation/Feasibility Study, Streambank Tailings Operable Unit Silver Bow Creek/Butte Area NPL Site, Anaconda, Montana.

ARCO 1996. Clark Fork River Governor's Demonstration Project 1993-1995 Monitoring Report., Milltown Reservoir Operable Unit, Silver Bow Creek/Butte Area NPL Site, Anaconda, Montana.

ARCO 1997. Interim Revegetation Design for LAO, Phase I, Segment II, Butte Priority Operable Unit, Silver Bow Creek/Butte Area NPL Site, Anaconda, Montana.

ARCO 1998a. Post-Construction Summary Report for LAO Revegetation, Butte Priority Operable Unit, Silver Bow Creek/Butte Area NPL Site, Anaconda, Montana.

ARCO 1998b. 1998 Qualitative Vegetation Monitoring Report. Butte Priority Operable Unit. Silver Bow Creek/Butte Area NPL Site. Anaconda, Montana.

ARCO 1999. 1999 Qualitative Vegetation Monitoring Report. Butte Priority Operable Unit. Silver Bow Creek/Butte Area NPL Site. Anaconda, Montana.

Hansen, P.L., RD Pfister, K. Boggs, BJ Cook, J. Joy, and DK Hinkley 1995. Classification and Management of Montana's Riparian and Wetland Sites. Montana Forest and Conservation Experiment Station- School of Forestry. University of Montana. Missoula, Montana.

National Research Council 1995. Wetlands: Characteristics and Boundaries. US Department of Commerce. NTIS. National Academy Press. Washington D.C.

2000 Billings Land Reclamation Symposium

CHARACTERIZATION OF MYCORRHIZAE AND SEED BANK COMPOSITION IN AN EASTERN MONTANA WETLAND

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ABSTRACT

The majority of soil survey work in the context of mine reclamation has focused on the physico-chemical quality of soil, with little attention to biological properties. This study characterizes the mycorrhizal colonization levels in wetland plants, mycorrhizal infectivity potential of wetland soils, and seed bank composition. The work took place in a portion of a drainage bottom that is classified as jurisdictional wetland at the Absaloka Mine (Westmoreland Resources, Inc.), Big Horn County, Montana. The hydric soil was moderately alkaline, non-saline, and rich in total nitrogen and phosphorus. Soil samples were collected along bank-to-bank transects across the wetland and analyzed for mycorrhizal inoculation potential and seed bank composition. Hydrophytic plants, including *Spartina pectinata*, *Carex nebraskensis*, and *Carex lanuginosa*, were analyzed for mycorrhizal colonization level. Mycorrhizal colonization levels were high in *S. pectinata* and *C. nebraskensis*. Mycorrhizal inoculation potential was also high, but decreased at the center of the wetland. The density of seeds in the seed bank did not differ between sites within the wetland. There was a high proportion of weed species found throughout the wetland. Understanding the role of AM fungi in wetland plant establishment will contribute to wetland soil handling and revegetation efforts. An assessment of the seed bank is also important prior to management decisions about using wetland soils as a source of seeds for restored wetland sites.

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INTRODUCTION

Despite the ecological significance of wetland ecosystems, our understanding of the ecological restoration of wetlands is at a rudimentary stage. Soil survey work in wetland reclamation on mine sites has focused primarily on the physico-chemical quality of soil, with little attention to biological properties. This study focuses on two biotic components of the soils: mycorrhizal fungi and the soil seed bank.

Vesicular arbuscular mycorrhizae (AM), otherwise known as endomycorrhizae, are a plant-fungal symbiosis, where the fungus (Endogonaceae) colonizes plant roots. The effect of AM on the host plant varies depending on environmental conditions, and ranges from mutualistic to parasitic (Johnson et al. 1997). The plant provides the fungus with a carbon source, while the fungus benefits the plant by increasing the uptake of nutrients (especially phosphorus) and water (Stahl 1998), and protecting the plant from pathogens (Newsham 1995).

Mycorrhizae may be especially important for plant success in disturbed areas (Allen 1989), and restoration ecologists have focused on methods to reintroduce mycorrhizal fungi to restoration projects, in an effort to speed succession on disturbed sites. The ecological role of mycorrhizae in wetlands and in wetland restoration has not been well investigated (Turner and Friese 1998). This study was undertaken to look for the presence or absence of mycorrhizal fungi along a wetland cross-section.

The seed source for revegetation of many wetlands comes from either the natural seed bank (Galatowitsch and van der Valk 1996), or propagule inflow (Mitsch et al. 1998). Because recommendations for wetland restoration include the use of intact wetland soils to serve as a source of native seeds (Galatowitsch and van der Valk 1994; Brown and Bedford 1997), it is important to assess the composition of wetland seed banks. This is especially true of wetlands that border on weed-infested land, since the establishment of unwanted, invasive species is a major problem for wetland restoration (Galatowitsch and van der Valk 1994).

Our research objectives were: 1) to measure the presence of mycorrhizal fungi in the wetland soils; 2) to assess whether there were significant differences in the occurrence of mycorrhizal fungi that correlated with a gradient across the wetland; and 3) to determine the density and composition of the wetland soil seed bank.

METHODS

Soil and plant samples were collected in May of 1998 from a wetland located on the Absaloka Mine, of Westmoreland Resources, Inc., east of Hardin in Big Horn County, Montana. The study site was located in Drainage 25 (T1N, R38E, sw quarter of Section 29). This segment (304 m) was located between an active stripping limit and a county road, and was scheduled to be disturbed in 1998.

The wetland occurred on a ½ percent slope, with an east aspect. It was a subirrigated upland drainage bottom with a trapezoidal shape. Mean annual precipitation at the mine is 343 mm, mean annual air temperature is 10°C, and the elevation is 1061 m. Soils were and hydric, with the following redoximorphic characteristics: H_2S present near the surface, matrix chroma # 2, oxidized and precipitated Fe or Mn, prominent

mottling below 6 inches of sediment, and prolonged ponding at localized depressions. Soil chemistry data are summarized in Table 1. The study area contained a mixture of native wetland plant species and exotic species including Kentucky bluegrass (*Poa pratensis*), Canada thistle (*Cirsium arvense*), and marsh sow-thistle (*Sonchus uligonosa*).

Plant and soil samples were collected from five sites along each of three transects that crossed the wetland, from N to S, for a total of 15 collection points. The transects were approximately 41 m apart. The five sites represented 2 bank midslopes (Sites 1 and 5), two edges of drainage bottom (Sites 2 and 4), and the center of drainage bottom (Site 3). The bank-to-bank distance ranged 41 to 51 m. The presence of mycorrhizae in the wetland soils was determined through two methods: direct assessment of colonization levels of plants found in the wetland, and inoculation potential of wetland soils.

Table 1. Drainage 25 soil chemistry data*.

Depth (m)	pH	Electrical Conductivity (dS/m)	Total Kjeldahl N (*u*g/g)	Total Olsen P (*u*g/g)	Organic Matter (%)	Texture
0-0.15	7.8	2.1	4983	8.6	11.6	L
0.15-0.3	8.1	1.0	2053	1.6	3.6	SiL
0.3-0.6	8.2	0.8	1163	1.2	1.8	L
0.6-1.2	8.2	0.8	477	<1	0.6	SL
1.2-1.5+	8.2	0.9	497	1	0.8	L

* Values represent the average of three profiles located at the center of the transects.

Mycorrhizal Colonization Levels

Nineteen plants were collected for determination of mycorrhizal colonization levels in the field. Plants were collected from the center of the wetland. Thirteen of the plants collected were from the genus *Carex*, and 6 plants were *Spartina pectinata. Carex* spp. A and B were not positively identified, because of the lack of reproductive structures available for species identification. They could be the young of the two identified species, or possibly *C. praegracilis*, which was identified in the mine vegetation baseline data.

Fine roots were randomly selected from each individual plant and prepared according to a modified Phillips and Hayman (1970) method. Root samples were soaked in 2.5% KOH for 48 hours, rinsed with distilled water, soaked in 3% HCl for 12 hours, and soaked in Trypan Blue stain for 24 hours. Mycorrhizal structures were quantified according to the magnified intersections method detailed by McGonigle, et al. (1990). Up to 151 intersections of root tissue were assessed per individual for presence of fungal hyphae, vesicles or arbuscules. Data were arc-sine transformed, and analyzed with two-way ANOVA, to test for effects of species or site effects on colonization levels. Post hoc LSD tests, alpha=0.05, were used to test for significant differences between samples.

Mycorrhizal Inoculation Potential

Mycorrhizal inoculation potential is a relative measure of the number of AM fungal propagules in the soil. Soil samples were placed in 750 ml pots, 12 cm dia x 12

cm high, and planted with Sudan grass (*Sorghastrum sudanese*) as a bait plant. After eight weeks plants were harvested, cleared and stained, and mycorrhizal colonization levels were quantified, as described above. A total of 96 intersections was assayed for each individual. Data was arc-sine transformed, and analyzed with a two-way ANOVA to test whether there were transect or site effects on colonization levels. Post hoc LSD tests, alpha=0.05, were used to test for differences between samples.

Seed Bank Analysis

Seed bank density and composition was determined by seedling emergence—soil samples are brought into the greenhouse and the quantity and identity of germinating seedlings is monitored. Seedling emergence is one of the most accurate measures for assessing community-level studies of seed banks (Gross 1990), including wetland seed bank studies (Poiani and Johnson 1988).

Two soil cores, 5.6 cm in diameter and 5 cm deep, were extracted from each of the 15 sample sites in May, 1998. Each core was split length-wise, and root segments were removed. Samples of soil were spread in small trays (17cm x 25cm x 8cm deep) on top of greenhouse potting soil and subjected to one of two treatments: moist soil or inundated soil with the water level 1 cm above the surface of the soil. Previous research has shown an increase in the number of germinants when both a moist and an inundated treatment are used (Bliss and Zedler 1998). Inundated pots were maintained for 6 months, during which time seedling emergence was negligible (2 graminoids total), so pots were allowed to dry, and kept moist to monitor subsequent germination. Pots were monitored weekly for number and identity of seedlings. Seedlings were grown until identification was possible, or until the end of this study, which lasted 15 months. Two way ANOVA was used to test that there were transect or site differences in the total number of seeds/m^2 and total weed seeds.

RESULTS

Plants collected from the field were mycorrhizal, with an average colonization level of 58%. Many of the fungal hyphae present in the roots were in small fragments, and not necessarily functional. This may be due to the timing of sampling, since AM activity is known to fluctuate seasonally (Koide and Schreiner 1992). Two-way ANOVA on the mycorrhizal data showed that there was a significant species effect on mycorrhizal colonization levels ($F_{4,19}$=6.27, P=0.007), but site was not significant ($F_{1,19}$=0.46, P=0.51). Colonization levels were significantly higher in *C. nebraskensis* and *S. pectinata* than in the other species of Carex (Figure 1).

Mycorrhizal infectivity potential was also high across soil samples. Between 53% and 86% of all root intersections had a fungal hypha, vesicle or arbuscule present. There was not a significant transect effect on inoculation potential of the soils ($F_{2,29}$=1.55, P=0.246), but there was a significant site effect ($F_{4,29}$=8.21, P=0.001). Site 3, which represented the wettest portion of the wetland, had the lowest level colonization, significantly lower than levels at Sites 1, 4 and 5 (Figure 2).

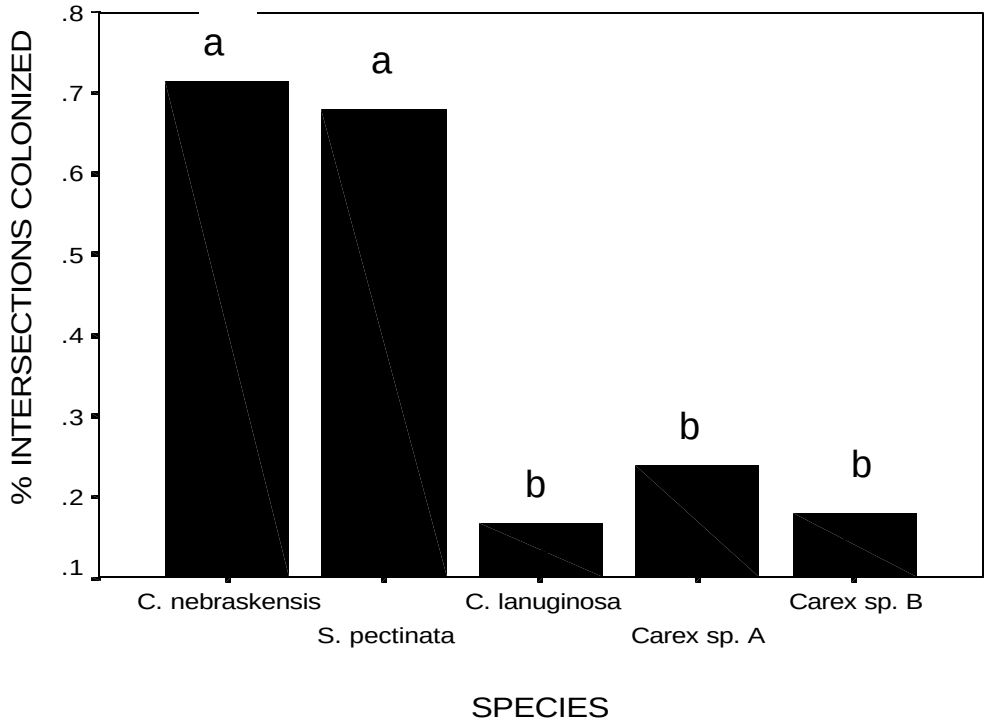

Figure 1. AM Colonization Level of Wetland Plants. Similar letters above bars indicate values that do not differ significantly.

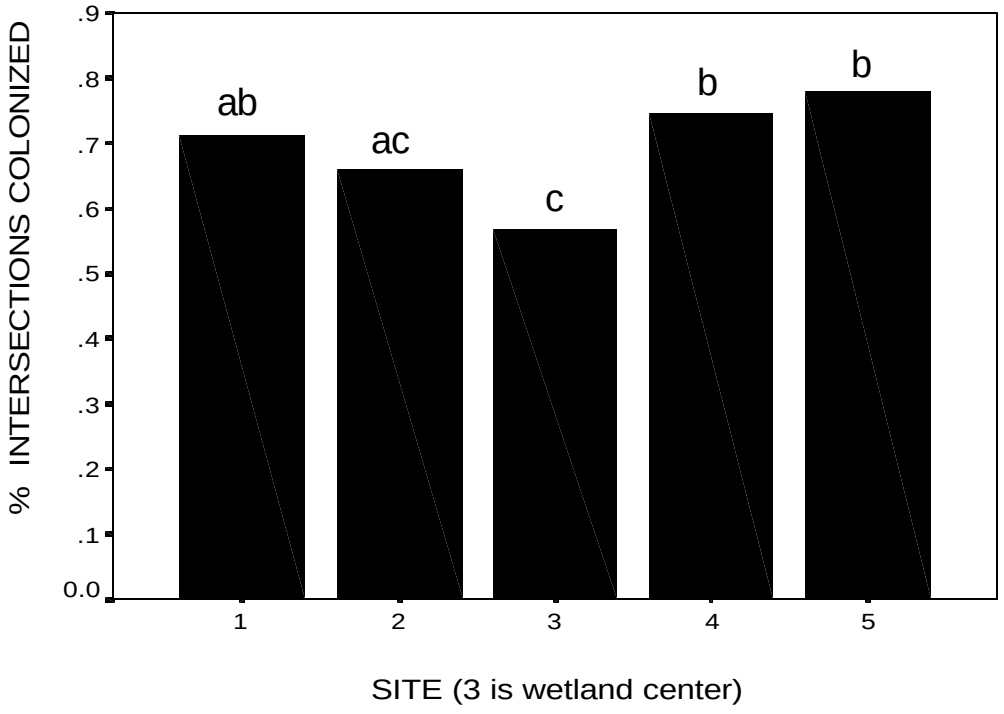

Figure 2. Mycorrhizal infectivity potential as measured by AM colonization level in bait plants. Similar letters above bars indicate values that do not differ significantly.

Seed bank density was 45,000 seeds/m^2. This estimate is high, but fits within the range found in other studies (Leck 1989). It should also be noted that this density estimate is based on a smaller than recommended number of cores used for the analysis (Brock et al. 1994). Density did not differ either across transects ($F_{2,14}$=0.05, P=0.95) or sites throughout the wetland ($F_{4,14}$=1.12, P=0.37; Figure 3).

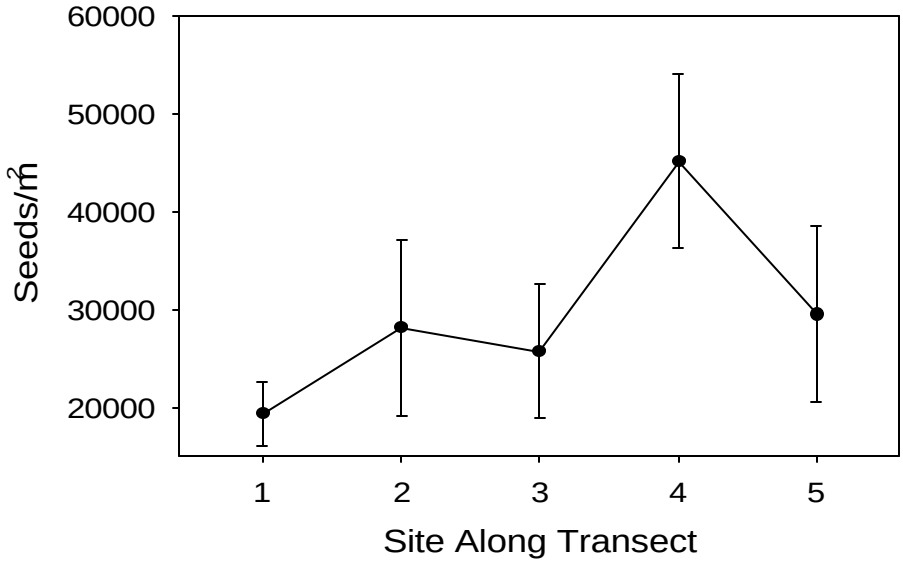

Figure 3. Seed bank density across wetland transects. Error bars represent the standard error of the mean. Site 3 is the center of the wetland.

There were a total of 18 taxa which emerged in this study (Table 2). Of the 10 taxa identified to species, 9 were non-native. The single native species was *Rumex salicifolius*, which occurred in 3 samples. The genus of *Carex*, not identified to species, also occurred in 3 samples. Unknowns E, J and N were relatively uncommon. Unknown K, tentatively identified as *Antennaria* sp., was a small rosette, with dark green, hirsute leaves. Graminoids were a large category that included a mixture of species, many of which germinated, produced one or two leaves, and then died. *Bromus tectorum* flowered, and *Poa pratensis* was identified by leaf traits. The category "seedlings" consists of individuals that germinated but did not attain a size that could allow for them to be categorized or identified.

Table 2. Number of seedlings emerged from 6 cores extracted from each site type (combined across transects). Total area sampled for each site type was 0.0015 m^2.

Species	Site 1	Site 2	Site 3	Site 4	Site 5
			Non-native forbs		
Chenopodium album	0	1	0	0	0
Cirsium arvense	1	0	4	8	0
Medicago sativa	0	0	0	0	1
Melilotus officinalis	0	11	1	4	3
Sonchus uligonosa	8	11	16	28	20
Taraxacum officinale	0	0	0	3	1
Thlaspi arvense	0	15	0	7	11
			Non-native graminoids		
Bromus tectorum	2	0	0	0	2
Poa pratensis	0	10	16	0	0
			Native forbs		
Rumex salicifolius	0	1	4	0	1
			Native graminoids		
Carex species	0	0	3	1	0
			Unknowns		
Unknown E	0	0	0	2	1
Unknown J	0	1	0	0	0
Unknown K	2	0	4	7	4
Unknown N	1	0	0	0	7
Graminoids	50	55	56	128	61
Seedlings	10	20	12	12	7

DISCUSSION

This study has shown two things that are relevant to mycorrhizae in wetland restoration. The first is that there is a fairly high concentration of mycorrhizal propagules present in the soil. The water table at this site was 48 inches below the surface, and while the soils are classified as hydric, the standing water may occur in relatively discrete patches, leaving much of the soil available to AM fungal colonization. And the second finding is that two of the dominant species in this wetland have a high level of mycorrhizal colonization.

While these results are of interest, especially in light of the increasing role of mycorrhizal fungi in restoration programs, it should be noted that we still have a very poor understanding of the functional role of mycorrhizal fungi in wetland ecosystems (Turner and Friese 1998). Future work should address the role of AM fungi in the establishment of wetland sites on recently restored sites. Sampling across time and with changing reproductive status of the host plant would help us to understand seasonal and phenological effects on mycorrhizal colonization (Koide and Schreiner 1992, Lu and Koide 1994). For example, AM may be more important during flowering and seed

production than during seedling establishment. This kind of information would be very important for restoration ecologists.

The potential for the seed bank to contribute to wetland revegetation has been shown in a number of studies (van der Valk and Pederson 1989), as has the effect of seeding on species diversity and richness of native wetland species (Reinartz and Warne 1993). A caveat added to recommendations for the use of "donor seed banks" is that they should be checked for problematic species (Galatowitsch and van der Valk 1994).

While the results of the seed bank study should be interpreted cautiously, because of the small sample size and the low success rate for growing species until they reproduced for positive identification, there are several points that can be gleaned from the data. The first is that there is a high percentage of weed species present in the seed bank. This suggests that the seed bank in this wetland is not a good source of native wetland species, but instead a source for non-native propagules. The high proportion of weedy species may be due to past grazing and the adjacent grazing-impacted land, which has a high proportion of non-native species. However, there may also be a potential for greater native species representation in the soils with the inclusion of root fragments. Native perennial vegetation may be most likely to propagate from root fragments as opposed to seeds.

While this study was small in scale, and covered only one site, the results underscore the importance of studying wetlands in their landscape context. Mycorrhizal fungi and seeds stored in the soil will be influenced by vegetation adjacent to the wetland. Studies that include gradients across the landscape will give us better information on how adjacent land use practices affect the soil biota of wetland fragments.

Finally, at this site, wetland soil was dewatered and salvaged in July 1998 and stockpiled to be used for wetland reconstruction at the end of mine life. While the practice of direct hauling of soil is preferred by Montana coal mines, the results of this study show there are pros and cons to the stockpiling approach. Long-term storage might diminish the reserve of weed seed over the next 10-20 years; it would certainly also destroy the integrity of the soil biota. Setting aside the wetland soil now, however, means that the mine will have the appropriate volume, texture and biological remnants at the end of mining to initiate wetland reclamation. If the wetland soil had been direct-hauled to reclaim a drainage bottom, it is likely that mycorrhizal propagules would survive the mechanical disturbance, but the weeds could outcompete the seeded native perennial species. Therefore, in the case of wetland replacement, the pros and cons of different soil handling options must be weighed by site-specific factors.

Because we did not identify the species of the mycorrhizae present in the wetland, we do not know if there were mycorrhizae that were unique to plants and soils that occupied the wet parts of the wetland. If such special adaptation exists, then a strong argument for using only the original soil for wetland reconstruction could be made, in hope of recovering the plant species which existed prior to disturbance. This concept then suggests the need for future studies to measure the survival and distribution of mycorrhizae in native soil, in soil stockpiles, and in reclamation.

REFERENCES

Allen, E.B. 1989. The restoration of disturbed arid landscapes with special reference to mycorrhizal fungi. J. of Arid Env. 17:279-286.

Bliss, Shannon A. and Paul H. Zedler. 1998. The germination process in vernal pools: sensitivity to environmental conditions and effects on community structure. Oecologia. 113: 67-73.

Brock, Margaret A., Kevin Theodore, and Laurie O'Donnell. 1994. Seed-bank methods for Australian wetlands. Austr. J. of Mar. and Freshwater Res. 45: 483-93.

Brown, Stephen C. and Barbara L. Bedford. 1997. Restoration of wetland vegetation with transplanted wetland soil: an experimental study. Wetlands. 17: 424-37.

Galatowitsch, Susan M. and Arnold G. van der Valk. 1994. Restoring Prairie Wetlands: An Ecological Approach. Iowa State University, Ames. 246 pp.

Galatowitsch, S. M. and A. G. van der Valk. 1996. The vegetation of restored prairie wetlands. Ecol. Appl. 6: 109-19.

Gross, Kay L. 1990. A comparison of methods for estimating seed numbers in the soil. J. of Ecol. 78: 1079-83.

Johnson, N.C. J. H. Graham, and F. A. Smith. 1997. Functioning of mycorrhizal associations along the mutualism-parastism continuum. New Phyt. 135:575-585.

Koide R. T. and R. P. Schreiner. 1992. Regulation of the vesicular-arbuscular mycorrhizal symbiosis. Ann. Rev. Plant Phys. and Plant Mol. Biol. 43: 557-581.

Leck, Mary Allessio. 1989. Wetland seed banks, pp. 283-305, *In* Mary Allesio Leck, V. Thomas Parker, and Robert L. Simpson [eds.], Ecology of Soil Seed Banks, Academic Press, Inc. San Diego. 462 pp.

Lu X, and R. T. Koide. 1994. The effects of mycorrhizal infection on components of plant growth and reproduction. New Phyt. 128: 211-218.

McGonigle, T. P., M. H. Miller, D.G. Evans, G. L. Fairchild, and J. A. Swan. 1990. A new methiod which gives an objective measure of colonization of roots by vesicular-arbuscular mycorrhizal fungi. New Phytol. 115: 495-501.

Mitsch, William J., Xinyuan Wu, Robert W. Nairn, Paul E. Weihe, Naiming Want, Robert Deal, and Charles E. Boucher. 1998. Creating and restoring wetlands: a whole-ecosystem experiment in self-design. Bioscience. 48: 1019-1030.

Newsham, K.K., Fitter, A.H., and Watkinson, A.R. 1995. Multi-functionality and biodiversity in arbuscular mycorrhizas. Tree, 10: 407-411.

Phillips, J. M. and D. S. Hayman. 1970. Improved procedure for clearing and staining parasitic and vesicular-arbuscular mycorrhizal fungi for rapid assessment of infection. Trans. Br. Mycol. Soc. 55:158-161.

Poiani, Karen A. and W. Carter Johnson. 1988. Evaluation of the emergence method in estimating seed bank composition of prairie wetlands. Aquatic Bot. 32: 91-7.

Reinartz, James A. and Elizabeth L. Warne. 1993. Development of vegetation in small created wetlands in southeastern Wisconsin. Wetlands. 13: 153-164.

Stahl, P.D., Williams, S.E., and Christensen, M. 1988. Efficacy of native vesicular-arbuscular mycorrhizal fungi after severe soil disturbance. New Phyt. 110:347-54.

Turner, Stephen D. and Carl F. Friese. 1998. Plant-mycorrhizal community dynamics associated with a moisture gradient within a rehabilitated prairie fen. Res. Ecol. 6: 44-51.

Van der Valk, A. G., and Roger L. Pederson. 1989. Seed banks and the management and restoration of natural vegetation, pp 329-346, *In* Mary Allesio Leck, V. Thomas Parker, and Robert L. Simpson [eds.], Ecology of Soil Seed Banks, Academic Press, Inc. San Diego. 462 pp.

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A HYDROLOGIC APPROACH TO WETLAND DELINEATION

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ABSTRACT

Wetland accounting is required to prevent their loss, and the hydrologic regimes of altered riparian areas must be predicted for revegetation planning. Both conditions applied to our study area along Silver Bow Creek, Montana. Reclamation of this riparian zone involves removing metal-contaminated sediment and replacing it with clean borrow, generally lowering the floodplain, and relocating the stream channel. A temporary diversion ditch will temporarily carry high stream flows away from the reconstructed stream channel.

Standard jurisdictional wetland delineation procedures are inappropriate for drastically disturbed areas such as Silver Bow Creek. With adequate data, hydrologic parameters can be used to delineate wetlands better than procedures requiring edaphic and vegetational indicators. In a fluvial setting where the hydrologic regime is determined predominantly by groundwater, we delineated wetlands based solely on application of jurisdictional hydrologic criteria (Env. Lab., 1987, as further elaborated by NRC, 1995). Based on the water table, wetlands were defined as:

> Those areas inundated with less than two meters of water or saturated within one-third meter of the surface for two or more consecutive weeks during the plant growing season approximately every other year.

Using a set of shallow wells, drive points, and seasonal observations, a groundwater contour map was constructed by hand and digitized into a geographic information system (GIS). By combining this with a very accurate topographic map, a computer-generated depth-to-groundwater map portrayed wetlands and other hydrologic zones. This map was field verified and as a result slightly modified. For the designed postremediation topography, another depth-to-groundwater map was constructed and used to predict the location and extent of wetlands and for revegetation planning.

Key Words: wetland hydrology, jurisdictional wetland delineations, groundwater contours, depth-to-water maps, revegetation planning.

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"The long-term success of any wetland restoration or creation project is, to a very large extent, dependent upon restoring, establishing, or developing and managing the appropriate hydrology."

D. Hammer (1997)

INTRODUCTION

Wetlands that fall under the provisions of the Clean Water Act (CWA) and Executive Order 11990 ("no net loss") are called "jurisdictional wetlands." They are identified using procedures described in a federal delineation manual (Env. Lab. 1987, herein called the 1987 Manual). Wetland delineation is the process by which the investigator identifies and locates wetlands, typically through consideration of hydrological field indicators, soil profiles, and vegetation sampling and inventory (Tammi 1994).

Positive indicators of wetland hydrology, hydric soils, and hydrophytic vegetation are required for an area to be a jurisdictional wetland. But although soils and vegetation may be given weight equal to hydrology in a delineation procedure, they are mere indicators. Hydrology is the force that creates wetlands. Unfortunately, in the delineation procedure it often is impossible to place current hydrologic conditions into a temporal context. Since many delineations are based on brief visits to the site, hydrology often is inferred from other evidence as a practical necessity. This is not strictly allowed. Although "hydrology is often the least exact of the parameters, and indicators of wetland hydrology are sometimes difficult to find in the field" (Env. Lab. 1987, p. 34), proof of wetland hydrology is required. "It is essential to establish that a wetland area is periodically inundated or has saturated soils during the growing season" (Env. Lab. 1987, p. 34).

In some contaminated environments, soils and plants don't reliably reflect the hydrologic regime, and hydrology assumes preeminence when identifying wetlands. In restoring wetlands, understanding hydrology is likely to be the most important consideration (Hammer 1997, p. 152).

At a fluvial riparian Superfund site near Butte, Montana, an alternative approach to wetland delineation was more reliable for two reasons relating to the reliability of vegetation and soils as wetland indicators:

1. Plants were absent from some areas that consisted of phytotoxic, metal-contaminated tailings. Elsewhere, some vascular plant species rated as obligate (e.g., Baltic rush, sandbar willow) or facultative (e.g., tufted hairgrass) wetland species in Region 9 (Reed 1988) can occur locally as dominants over a range of soil moisture regimes, including habitats much drier than wetlands. The dominant streamside grasses (two introduced *Agrostis* species), while the sole dominants in some saturated or vernally inundated streambank wetlands, are rated as neutral wetland indicators or not listed (Reed 1988). In the case of the

streambank grasses, metal tolerance and fertile stream water probably account for their occurrence in otherwise atypical hydrologic zones.

2. Hydric soils were more difficult than usual to identify because:

a) Tailings in the soil profile may appear as mottles (i.e., colors that result from alternating oxidation and reduction of that part of the soil profile). This could lead to identification of a hydric soil where none existed.

b) Gley colors, indicating the prevalence of a low redox potential, are often less distinct in coarse sediments, such as those found in upper Silver Bow Creek, than in loamy or heavier textured soils. Soil color is a poor indicator of hydric conditions in sandy soils, where long-term saturation and anaerobic conditions may not result in colors corresponding to gley soils (Tammi 1994, p. 45). This could lead to identification of nonhydric soil where the soil was hydric.

In this environment, a rather rigorous body of hydrologic information can provide a more appropriate basis for wetland delineation than edaphic and vegetational inference.

STUDY AREA AND ENVIRONMENT

Silver Bow Creek originates at a copper mine in Butte, Montana, at latitude 45.95, longitude 111.05. Elevation ranges from about 1,676 meters (5,500') at Butte to 1,493 m (4,900') 43 km (27 stream miles) downstream where Silver Bow Creek enters a series of settling ponds before joining Warm Springs Creek to form the Clark Fork River. The entire length of Silver Bow Creek and its floodplain is a Superfund site, but only the uppermost 2 km (1.2 mi.) comprises the study area for this investigation. The floodplain is relatively narrow there, ranging from 120 to 200 meters wide. Climate is cool and dry. Average annual precipitation in Butte between 1964-1998 was 32.5 cm (12.8 inches). During that period, precipitation exceeded 46 cm (18 inches) in four years, but in six years it was less than 23 cm (9 inches).

Silver Bow Creek is predominantly a gaining stream. In the past century, it has aggraded with mine tailings combined with granitic alluvium. The uncontaminated alluvium largely consists of pea gravel, sand and silt typically with little clay. Tailing deposits in the upper reaches of the site average between 0.2 to 0.5 m (0.5 to 1.5 feet) in depth with a maximum of 1.2 m (4 feet). During low flows, surface water discharge in the creek at the upper end of the operable unit averages about 21 cfs, but more than 250 cfs has been recorded. Surface water has elevated concentrations of copper, lead, cadmium, mercury and zinc, especially following intense runoff events.

The Superfund remedy calls for removing tailings and contaminated soil and backfilling with clean borrow. In the process, the stream will be relocated and the surface elevation lowered. For purposes of preliminary wetland accounting and revegetation planning, the location and extent of

preremediation wetlands first had to be quantified, and then postremediation wetlands had to be predicted.

Groundwater levels in the study area respond to precipitation/snowmelt and changes in stream stage. Groundwater levels close to the creek respond more quickly to changes in stream stage and precipitation/snowmelt events than on the fringes of the floodplain (Abdo 1994). Groundwater ranges in depth from above-surface to 0.9 meters (3 feet) belowground within Reach A, the focus of this report. Seasonal groundwater fluctuations in Reach A range from about 0.2 to 0.6 meters (0.7 to 2.0 feet).

WETLANDS DEFINED

The National Research Council (1995) provided the following reference definition of wetlands, which clearly distinguishes between the functional role of hydrology and indicator values of soils and vegetation:

saturation at or near the surface of the substrate. The minimum essential characteristics of a wetland are recurrent, sustained inundation or saturation at or near the surface and the presence of physical, chemical, and biological features reflective of recurrent, sustained inundation or saturation. Common diagnostic features of wetlands are hydric soils and hydrophytic vegetation. **These features will be present except where specific physiochemical, biotic, or anthropogenic factors have removed them or prevented their development.** (Emphasis added.)

The Environmental Protection Agency (EPA) and U.S. Army Corps of Engineers (USACE) define wetlands this way (Env. Lab. 1987):

> Wetlands are areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that **under normal circumstances** do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas. (Emphasis added.)

The phrase “under normal circumstances” was included in the definition because there are circumstances in which the vegetation in a wetland has been altered as a result of human activity, and vegetational or edaphic indicators may be misleading. “In such cases, an alternative method must be employed in making wetland delineations” (Env. Lab. 1987, p. 8). Our alternative method of identifying wetlands is based solely on hydrology.

Our working definition of wetland hydrology comes from National Research Council (NRC 1995), which lists on p. 93 four criteria for wetlands. These are: 1) depth of inundation or saturation in relation to the water table, 2) timing of inundation/saturation, 3) frequency of saturation or flooding, and 4) duration of saturation or inundation. Thresholds are needed for each criterion because thresholds define boundaries, and wetland delineation is largely a matter of identifying boundaries.

1. DEPTH. With occasional exception, wetlands are inundated with less than two meters of water, above which an aquatic habitat is indicated. At the lower threshold, wetlands should be inundated or saturated to the soil surface (Env. Lab. 1987). However, in making jurisdictional wetland delineations, soil profiles must be examined at least 0.4 meters (16 inches) deep, and observation are made just below the A horizon or at 0.25 meters (10 inches).
NRC (1995, p. 104) concurred that seasonal saturation should be near the ground surface, interpreting it as the upper 30 cm (one foot) of soil, which corresponds to the control zone for very poorly drained soils in Natural Resource Conservation Service terminology. In defining hydric soils, the Soil Conservation Service (1991) includes all Aquic suborders and subgroups that are somewhat poorly drained and have a "frequently occurring water table less than one-half foot from the surface for a significant period (usually more than two weeks) during the growing season" for very sandy soils, or at a depth of one foot (0.3 m) for less permeable soils.
Most soils in the study area are coarse to very coarse, and coversoils (transported fill) will be predominantly sandy loams with <10% clay. Capillary rise is not expected to be significant in this environment. The saturation zone was assumed to be the elevation of the groundwater surface.

Considering these factors, we set the threshold for seasonal saturation at 15 cm (six inches).

2. TIMING. Hydrology during the growing season is the critical factor for vegetation. In saturated/inundated soils, vascular plants and soil microbes quickly deplete free oxygen during the growing season, while at the same time sulfur compounds and other plant toxins accumulate. We assume that late May to mid-September inclusive is the effective growing season, and that high groundwater is most likely to occur during spring runoff (May-June).

3. FREQUENCY. Since it is rarely measured, either in reference wetlands or jurisdictional candidates, frequency is imprecisely addressed, e.g., wetlands must be inundated/ saturated "periodically" (Env. Lab. 1987) or "recurrently" (NRC 1995). A minimum frequency of one out of two years seems to be the consensus (NRC 1995, pp. 5,107), so yearly frequency of inundation/saturation should be >50%.

4. DURATION. Environmental Laboratory (1987, Table 5, p. 36) lists 12.5% of the growing season as the minimal duration for wetlands. Based on a 120-day growing season, this equals 15 days of inundation or saturation. (See also U.S. Army Corps of Engineers 1992, 15 consecutive days of saturation or 7 consecutive days of flooding.) The definition of hydric soils also specifies a criterion of "usually more than 2 weeks" of saturation (SCS 1991). The Comprehensive Wetlands Conservation and Management Act of 1995, passed by the House but not the Senate, specifies that wetlands must have water present at the land surface for 21 consecutive days during the growing season.

For saturation to exert a major influence on soils and plants, the minimum duration must be consecutive. While we are aware that anaerobic conditions will develop more quickly in saturated soils at the end of June than at the beginning of May, we assume that two or more weeks of consecutive saturation in May-June is an acceptable threshold in our area.

Summing up: wetlands were defined hydrologically as those areas inundated with less than two meters of water or saturated within 15 cm (0.5 feet) of the surface for two or more consecutive weeks in the plant growing season at least every other year (NRC 1995, p. 5). Wetlands were identified through the relation of water table and ground surface elevations. We further distinguished inundated wetlands (those usually covered by water for more than two weeks during the growing season) from those usually saturated but less commonly and more briefly inundated. This distinction allows tailoring revegetation strategies to two classes of wetlands that differ significantly in redox potential and plant suitability.

METHODS

Due to the time constraints associated remedy design, groundwater levels during a single growing season were used in delineating wetlands for Reach A. We could have extrapolated from historic stream gauge data. That approach would involve numerous assumptions without necessarily providing more accurate wetland delineations. As remediation design efforts progress downstream, hydrology from multiple growing seasons will be factored into delineations.

This wetland delineation procedure was predicated on accurate topographic maps derived from recent aerial photography and ground-truthing. In application, the scale was 1":100' with two-foot contour intervals. Maps of equal accuracy depicted the postremediation topography.

Delineating Existing Wetlands

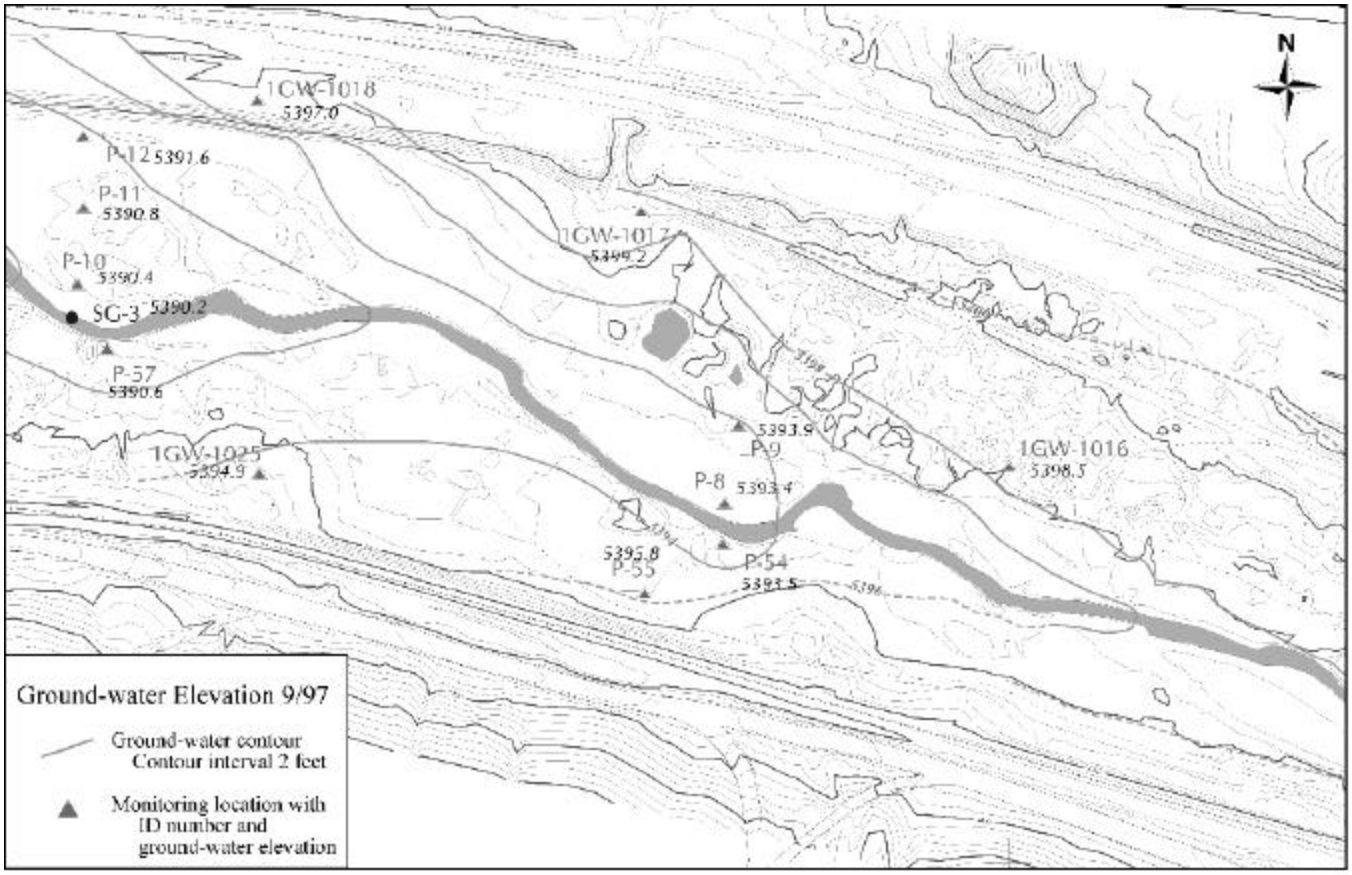
Existing wetland areas were delineated through the following series of steps:

1. Preparing groundwater contour maps based on a set of 38 well/drive points and three surface water staff gages within a 2 km (1.2 mile) stretch of Silver Bow Creek (Figure 1) using September 1997 data. Wetlands were identified where groundwater was less than 46 cm (1.5 feet) below the ground surface (rather than 15 cm, see wetland definition) because groundwater levels in September are usually about one foot lower than during the height of the growing season (May – June). Our data suggest that a one-foot seasonal variation in groundwater depth was representative for Reach A, given variations among wells and drive points.

2. Generating depth-to-water maps based on the groundwater contour maps,

3. Verifying wetland delineations based on previous experience (e.g., observations of seasonal inundation) and several dozen shallow holes power augered to the water table or a depth of two feet,

4. Editing the groundwater contour maps, then producing revised jurisdictional wetland maps, and



Scale in feet

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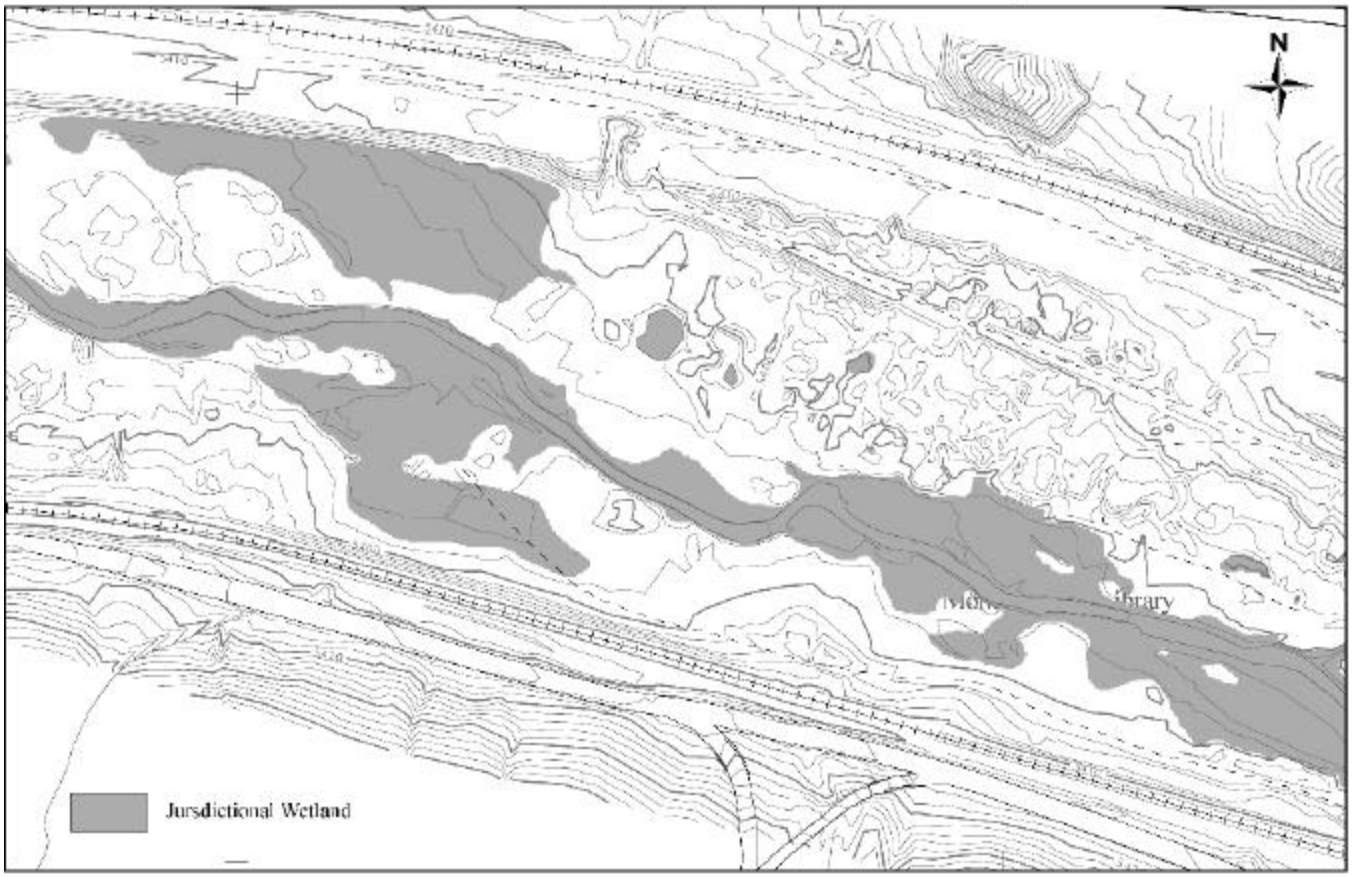


Figure 1. Ground-water contour map (above) and jurisdicitonal wetlands (pre-remediation).

5. Correcting the depth-to-water maps by hand where ground-truthing conflicted with the wetland map, but further changes to the groundwater contour map seemed unjustified.

Topographic information came from the Arc/Info TOPOGRID module. The Montana Natural Resource Information System compiled the depth-to-groundwater maps by subtracting surface elevations from groundwater elevation contours. Projections of postremediation wetlands were similarly compiled from design plans (topographic model) and predicted groundwater contour maps, which incorporated the effects of a temporary diversion channel.

Depth-to-water was mapped in three increments based on two-week seasonal highs:

1. Groundwater above the land surface (inundated wetlands, always less than two meters deep),

2. 0-0.5 feet below land surface (saturated wetlands),

3. >0.5 feet below land surface (nonwetlands, further divided into three subcategories).

Predicting Wetlands for Reclamation Planning

Because this segment of Silver Bow Creek has aggraded, it was possible to lower the stream and floodplain elevations during construction subject to some vertical controls. This obviously would create more wetlands. However, constructing a temporary diversion ditch to handle high stream flows was found to be cheaper than armoring streambanks to withstand very high flows that are unlikely in the short-term, but which pose considerable risk if they did occur. In places, this ditch is expected to sometimes intercept groundwater, acting as a drain. A final complication was that the stream channel was relocated away from horizontal controls.

The first step in predicting the location of jurisdictional wetlands in the postremediation landscape was to create a groundwater contour map. Control points used to construct this map included existing groundwater levels in several wells/drive farthest from Silver Bow Creek and those up-gradient from the diversion ditch. In addition, surface water elevations were incorporated from a projected flow of 30 cfs in the reconstructed stream channel and about 10 cfs in diversion ditch.

Once the groundwater surface was approximated, a GIS procedure combined groundwater and surface elevation information to provide a depth-to-groundwater map. The same hydrologic definition of wetlands was used.

RESULTS

Existing Wetlands

Existing jurisdictional wetlands are shown on Figure 1. The initial wetland maps constructed from the preliminary groundwater contour maps indicated 9.6 ha (23.7 acres) of wetlands, including the riverine component. With final revisions, the final map indicated 9.9 ha (24.6 acres) of wetlands, a relative difference of just 4 %.

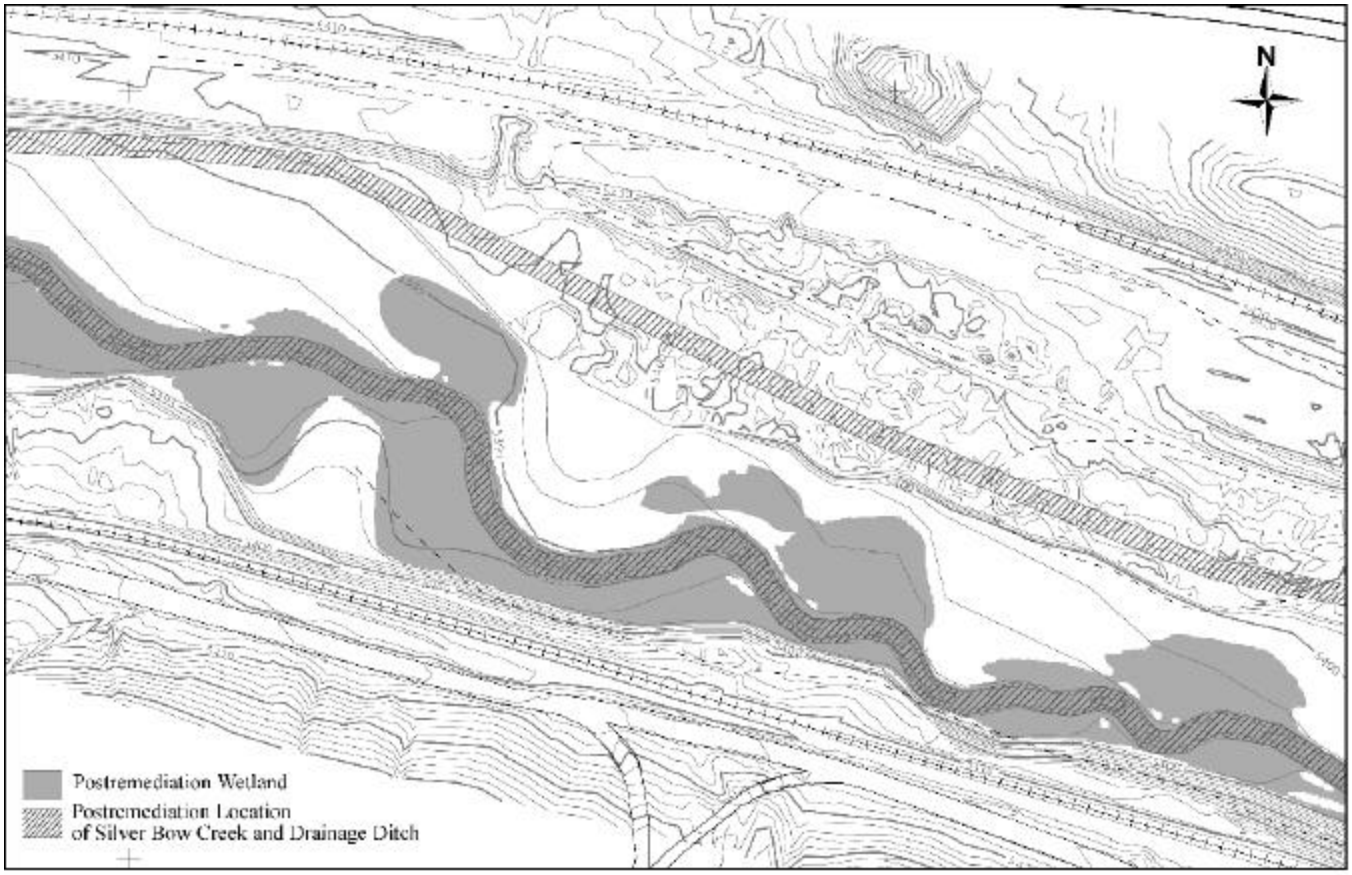
Predicted Wetlands

Since the floodplain elevation will be lowered when tailings are removed, one would expect more wetland acreage following remediation. However, the stream elevation as well as the floodplain elevation are being lowered, so the postremediation wetland acreage is similar to the current one (Figure 2). In the short term, however, the diversion ditch will intercept the water table, resulting in drier hydrologic conditions (Figure 2). The map of hydrologic regimes will be field-verified following construction.

With the diversion channel, postremediated wetlands are projected to cover approximately 4.9 ha (12.2 acres). Once the ditch is removed, wetland acreage is anticipated to be nine hectares (22.3 acres, Figure 2), indicating a net loss of 0.9 wetland hectares (2.3 acres) from the baseline condition (Figure 1). In wetland accounting, wetland functions and values, while more often guessed than measured, are considered along with wetland acreage. Since restored wetlands are expected to function better than the existing ones, a net gain in wetlands is anticipated.

DISCUSSION

While based on the 1987 Manual and NRC (1995), our hydrologic definition of wetlands was tailored to the study area. With a few modifications, it may be appropriate for other groundwater discharge wetlands with a sound groundwater database. Duration of inundation/saturation may be modified for longer or shorter growing seasons. Where capillary rise is significant, an increment would have to be added to the water table elevation. There are a great variety of wetland types (Cowardin and others 1979). Our approach would be inappropriate for wetlands resulting from perched water tables, tides, and some other conditions.



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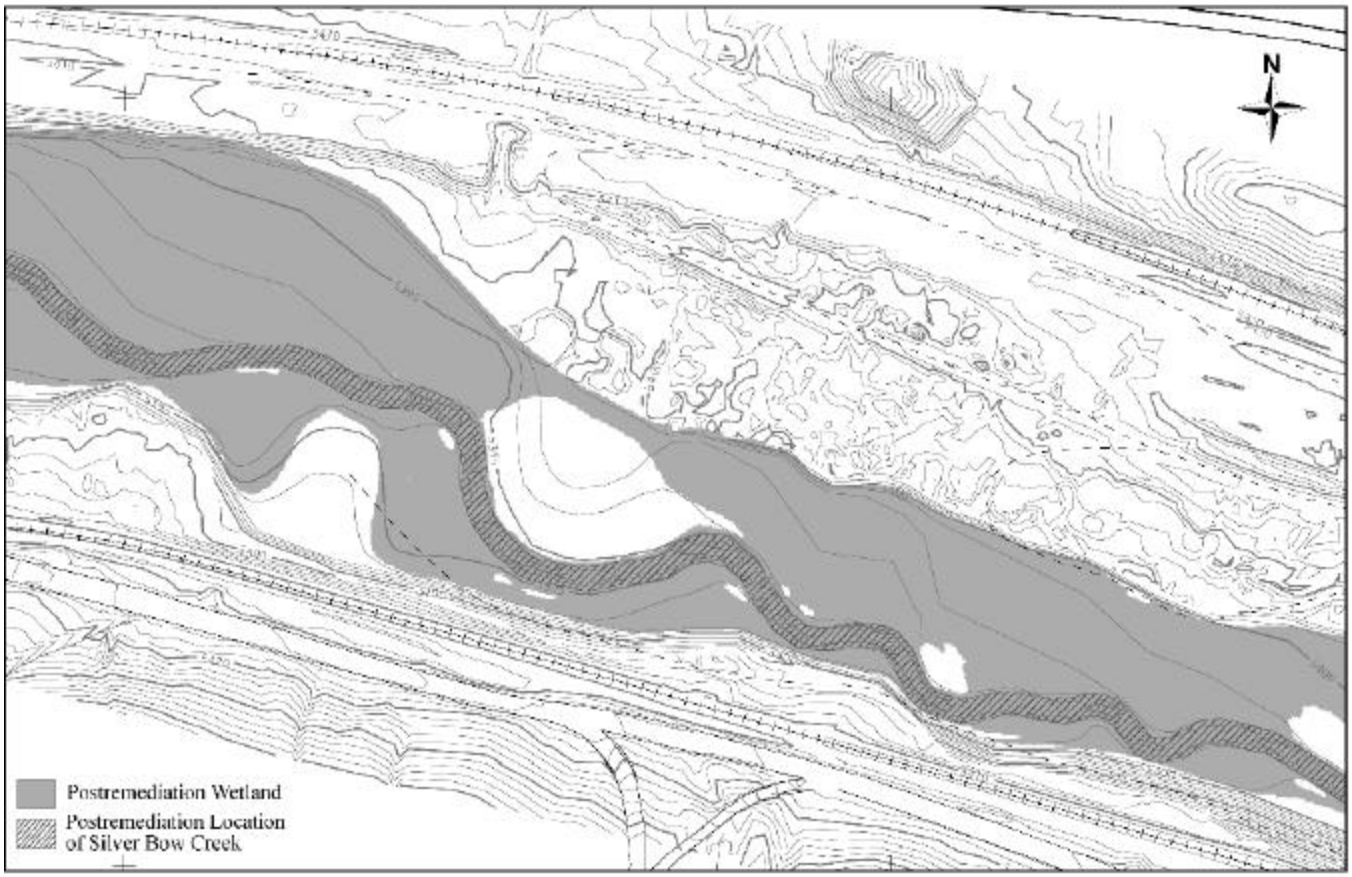

Figure 2. Area of postremediation wetlands with and without drainage ditch.

REFERENCES

Abdo, G. 1994. Final Report, Results of the Town Pump Aquifer Test. Montana Bureau of Mines and Geology. Submitted to the Montana Department of Environmental Quality, Helena, Montana.

Cowardin, L., Carter, V., Golet, F., and E. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Fish and Wildlife Service, DOI, Washington, D.C. FWS/OBS-79/31. 35 pp. + appendices (103 total pp.).

Environmental Laboratory. 1987. Corps of Engineers wetlands delineation manual. Tech. Rept. Y-87-1. U.S. Army Engineer Waterways Expt. Sta. Vicksburg, Miss. 100 pp. + appendices.

Federal Interagency Committee for Wetland Delineation. 1989. Federal Manual for Identifying and Delineating Jurisdictional Wetlands. U.S. Army Corps of Engineers, U.S. Environmental Protection Agency, U.S. Fish and Wildlife Agency, and USDA Soil Conservation Service. Washington, D.C.

Hammer, D. 1997. Creating freshwater wetlands (second ed.). CRC Press/Lewis Publishers, Boca Raton, FL. 406 pp.

National Research Council. 1995. Wetlands, characteristics and boundaries. W. Lewis Chair. National Academy Press (National Academy of Sciences). 307 pp.

Reed, P. 1988. National list of plant species that occur in wetlands: Montana. NERC-88/18.26. USFWS, St. Petersburg, FL. 101 pp.

Soil Conservation Service (SCS, now the Natural Resource Conservation Service). 1991. Hydric soils of the United States. USDA SCS Misc. Pub. 1491. Pages unnumbered.

Tammi, C. 1994. Onsite identification of wetlands. Pp. 35-54 *In:* D. M. Kent ed. Applied Wetland Science and Technology. Lewis Publishers, Boca Raton, FL. 436 pp.

2000 Billings Land Reclamation Symposium

Effects of Riparian Resource Gradients on the Establishment of Native and Invasive Plants

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ABSTRACT

Successful revegetation of disturbed stream-side lands is central to rehabilitating watersheds and creating healthy ecosystems. Of particular concern is the role disturbed riparian areas can play in the spread of noxious weeds. This greenhouse study investigated the influences of depth to water table and plant available nitrogen on the seedling establishment of four native species and two invasive weeds. The objective was to investigate the influence of soil resources on establishment of early successional, late successional and invasive weedy species. Three upland species (annual sunflower-*Helianthus annuus*, bluebunch wheatgrass-*Agropyron spicatum*, and spotted knapweed-*Centaurea maculosa*) and three wetland species (American sloughgrass- *Beckmannia syzigachne*, tufted hairgrass-*Deschamspia cespitosa* and Canada thistle-*Cirsium arvense*) were broadcast seeded in separate pots filled with a uniform soil. Treatments consisted of factorial combinations of seven depth to water table and three nitrogen treatments (6 species x 7 water levels x 3 nitrogen treatments x 2 replications=252 pots). The seven water levels ranged from "dry" with no sub-irrigation to saturated with water at or above the soil surface. Nitrogen treatments included: a control, high nitrogen addition (100 Kg N/Ha) and a nitrogen depletion through the addition of sucrose (1000 Kg C/Ha). Emergence was counted 70 days after seeding. At this point, plants were thinned to one individual per pot. Plants were harvested 60 days later and final, above ground biomass was measured. Depth to water table significantly influenced seedling emergence of *A. spicatum*, *C. maculosa*, *D. cespitosa* and *B. syzigachne* ($P<0.10$) with highest emergence occurring with a water table from 10 cm to 30 cm below the soil surface. In addition, nitrogen treatments significantly effected emergence of *B.syzigachne* with highest emergence occurring with the high nitrogen addition. Depth to water table was also found to significantly influence biomass of *A. spicatum*, *C. maculosa* and *D. cespitosa* with highest biomass with water tables 10 cm to 30 cm below the soil surface. Nitrogen treatments influenced biomass for *A. spicatum* and *C. maculosa*. In addition, *C. maculosa* growth was greatly inhibited by sucrose additions. Biomass of both these species increased in the high Nitrogen treatments, but this effect was much more pronounced in *C. maculosa*. These results suggest that disturbed riparian areas may be restored to a healthy, weed-free condition through the appropriate selection of species for a given hydrologic setting, and the management of plant available soil nitrogen at relatively low levels. Additionally, results suggest that sub-irrigated sites are most favorable for revegetation, but are also most vulnerable to weed invasion.

INTRODUCTION

Riparian areas provide many ecological and hydrologic benefits. Healthy riparian vegetation can stabilize banks, improve fisheries habitat and provide depositional buffer zones for pollutants carried in surface runoff (Satterlund and Adams 1992, Osborne and Koviac 1993). Streams passing through riparian areas can also serve as dispersal agents for native and exotic plant species (Pysek and Prach 1993). This seed transport mechanism, coupled with disturbances associated with seasonal flooding or land use, provides opportunities for the establishment of non-indigenous species. As a result riparian areas may be vulnerable to weed invasions and may also serve as beachheads for invasions of the surrounding landscape (Pysek and Prach 1993).

Weed invasions are of particular concern in restoration efforts involving disturbed riparian sites and adjacent uplands. Weeds can prevent the successful establishment of desirable vegetation. Successful establishment of stands of desirable vegetation from seed is a pre-requisite to the development of viable, weed-free plant communities (Sheley and Petroff 1999). Because plant species respond differently to environmental conditions, information on the interactive influences of soils and hydrology on seedling establishment is necessary for the restoration of riparian areas.

The effects of hydroperiod and nutrient concentration on plant competition have been investigated by Grace, Newman and Koebel (1996) who found these factors interact to create species specific advantages for *Typha domigenesis, Cladium jamaicense* and *Eleocharis interstincta* in the Everglades ecosystem. They suggested that the responses of these species are associated with species growth rate, tissue concentrations of P, and response to contrasting environmental conditions. In upland ecosystems, species with early successional characteristics or traits (rapid growth rates, high tissue nutrient concentrations, annual life cycles and rapid nutrient uptake rates) have been found to be significantly favored by high levels of soil nitrogen (Tilman & Wedin 1991, McLendon & Redente 1991, Redente et al. 1992). Conversely low levels of available nitrogen favor late successional species.

Plant community research directed at understanding general effects of resources has largely focused on survival and competition of established plants with less attention to emergence and early establishment of seedlings. This seedling establishment phase is a bottleneck that restoration ecologists struggle with in the development of healthy, native plant communities (R. Sheley, *personal communication* 1998). While much research has been conducted on the influences of nitrogen on successional dynamics, particularly in uplands, little information is available on the effects of hydrology on succession in non-forested riparian systems.

The overall objectives of this study, and a companion field study, were to determine the influences of hydrologic setting and nutrient availability on seedling establishment and early successional trajectories in a rangeland, riparian ecosystem. This paper explores initial results of the greenhouse study. There were two specific objectives:

I. <u>To determine the influence of a hydrologic gradient on the seedling establishment of early successional, late successional and invasive weedy species</u>. We hypothesized that highest seedling establishment and growth for all species would occur in aerobic conditions with high soil water

availability. Such environments are present in intermediate locations along gradients from streams to upland range where a shallow water table maintains ample soil water by sub-irrigation but is not high enough to induce prolonged, waterlogged, anaerobic conditions.

II. To investigate the influences of plant available nitrogen on the seedling establishment of early successional, late successional and invasive weedy species along a hydrologic gradient. Following Tilman and Redente we hypothesized that early successional and weedy species would respond strongly to nitrogen availability with greatly enhanced seedling establishment and growth in a high nitrogen environment and inhibited establishment and growth in low nitrogen environments. By comparison, late successional species would have smaller positive responses to high Nitrogen and smaller negative responses to low N. Consequently they would have relatively high seedling establishment and growth in low nitrogen environments compared to early successional species and weeds.

METHODS

Species

Six species common to the Northern Rocky Mountains were selected for their contrasting, life history characteristics (Tables 1 & 2). Two upland, native species were selected to represent early and late successional species (Stubbendieck, Hatch and Butterfield 1991, R. Sheley and J. Jacobs *personal communication* 1998). In addition an upland, perennial noxious weed was selected (Sheley and Petroff, 1999).

Table One: Characteristics of selected upland species

	Life Cycle	Growth Form	Characteristic Successional Stage
Agropyron spicatum	Perennial	Grass	Late
Centaurea maculosa	Perennial	Invasive Forb	Early (Invasive Weed)
Helianthus annuus	Annual	Forb	Early

Two wetland native species were selected to represent species with high short term revegetation potential and high long term revegetation potential (Hansen et al. 1997) and annual and perennial life cycles (Cooper & Meirings 1989). These criteria were used rather than successional status as the utility of classical concepts of succession for wetland plant communities has been questioned (P. Lesica, *personal communication* 1998). Life cycle and short term versus long term revegetation potential may correlate with successional status or with the ability to exploit resource rich

Table Two: Characteristics of selected wetland species

	Life Cycle	Growth Form	Characteristic Successional Stage	Short Term Revegetation Potential	Long Term Revegetation Potential
Deschampsia cespitosa	Perennial	Grass	Late	Low	High
Cirsium arvense	Perennial	Invasive Forb	Early (Invasive Weed)		
Beckmannia syzigachne	Annual	Grass	Early	Moderate	Low

sites versus the ability to survive and compete in resource poor, highly competitive environments. A perennial, invasive weed common in riparian areas was also selected (Sheley and Petroff 1999, J. Klausman, *personal communication* 1998).

Water Treatment

A depth-to-water-table gradient was created using 42 plastic tubs (40 cm deep by 40 cm wide by 50 cm long) maintained at one of seven, randomly assigned, water levels. Water levels were maintained at a depth of 0 and 2 cm above the soil surface and 5, 10, 20 and 30 cm below the soil surface with an automatic, drip irrigation system. In addition, a "dry" treatment was maintained with no sub-irrigation. Six, 10 cm by 10 cm by 36 cm tapered tree pots packed with a sandy, clay loam soil were placed in each tub. Pots were left open at the bottom to allow water flow into and out of the soil column. To account for fluctuations in water levels due to soil swelling and shrinkage actual water levels in each pot were measured weekly for the first four weeks of the experiment. All pots were watered from above weekly with 155 ml of deionized water to simulate rain. Each pot was planted with one of six selected species at a rate of 3000 seeds/square meter.

Nitrogen Treatments

One of three nutrient treatments was randomly assigned to each tub: a control hereafter referred to as OO, a high nitrogen addition hereafter referred to as N2 (100 Kg N/ha) and a nutrient depletion through the addition of sucrose hereafter referred to as CO (1000 Kg C/ha). Sucrose provides a carbon source for microbes leading to increased immobilization of nitrogen. These treatments were applied through weekly additions of 155 ml of deionized water, ammonium chloride solution or sucrose solution. This volume of solution was selected to simulate average spring precipitation for Norris, MT, the location of the accompanying field study. Each combination of species, nitrogen treatment, and water level was replicated twice yielding 252 pots in 42 tubs.

Data collection

Emergent seedlings were counted 70 days after planting. At this time plants were thinned to a single individual per pot. Above ground biomass was harvested 130 days after planting then dried to a constant weight and weighed.

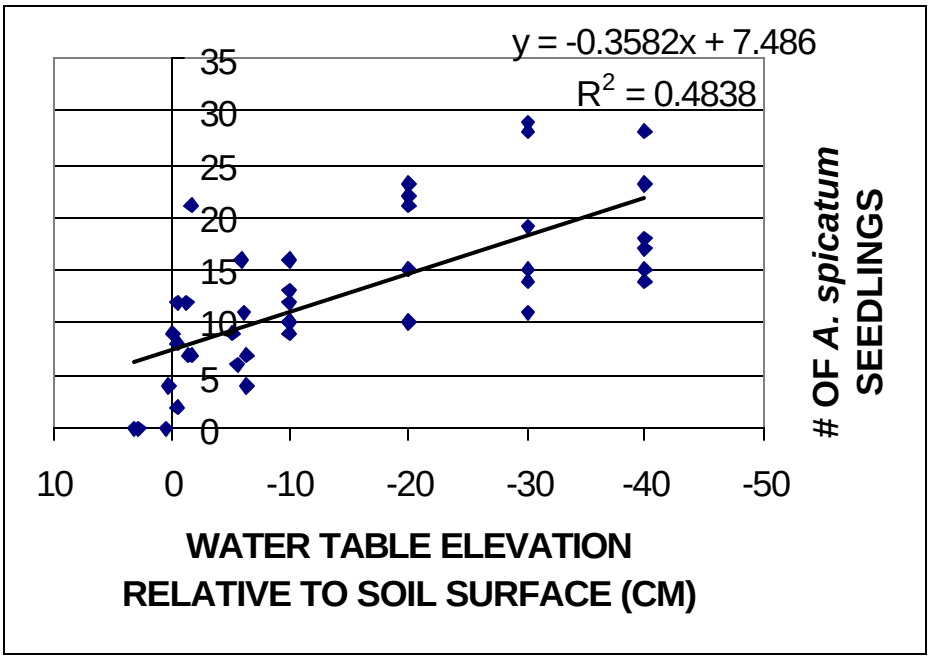
Multiple, linear regression analysis was used to assess the effects of treatments on seedling establishment and final biomass. The initial models tested included depth to water table, nitrogen treatments, and location in the greenhouse as independent variables and either seedling emergence or final biomass as the dependent variables. Independent variables were tested at the 0.10 level of significance. The final models presented were constructed by a step wise elimination of insignificant, independent variables; they do not include nonlinear models that may better describe results.

RESULTS AND DISCUSSION

Seedling Emergence

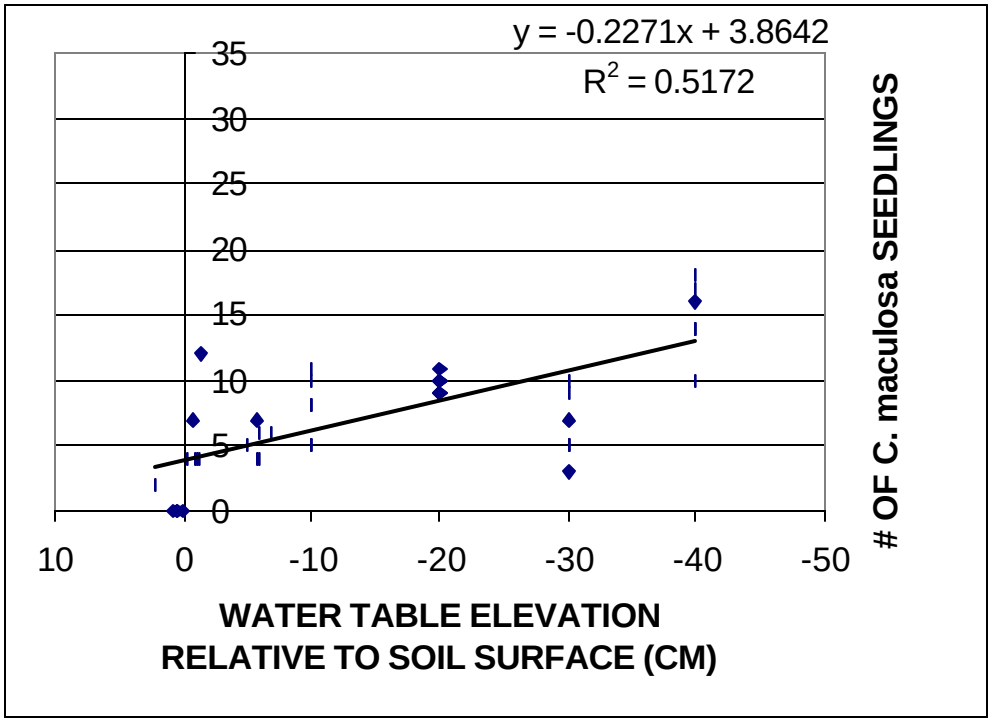
Analysis of seedling emergence of upland species found no significant relationship between seedling emergence, depth to water table and nitrogen treatments for *H. Annuus* ($P<0.10$). Analysis of seedling emergence of *A. spicatum* and *C. maculosa* yielded a single linear regression models with depth to water table predicting seedling emergence (Figures 1 & 2).

The model explained 48% and 52% of seedling emergence for *A. spicatum* and *C. maculosa,* respectively, with water table elevation (Table 3). No significant relation was found between nitrogen treatments and seedling emergence for these species. Both *A. spicatum* and *C. maculosa* had highest emergence in relatively dry pots and responded negatively to increased wetness. *Agropyron spicatum* emergence was high in dry pots and with deeper sub-irrigation (-20 cm and -30 cm). *Centuarea maculosa* emergence tended to be higher in dry pots than all other treatments (Figures 1 & 2). The only water input to "dry" pots came from weekly applications of 155 ml of water, nitrogen solution or sucrose solution, which was designed to simulate spring rainfall. These results contradict the hypothesis that emergence is optimized by sub-irrigation because emergence of *A. spicatum* and *C. maculosa* was as high or higher in pots with no sub-irrigation. Neither species tolerated even moderate flooding stress well, but *C. maculosa* was less able to tolerate sub-irrigation than *A. spicatum*. *Centuarea maculosa* emergence appeared to be inhibited even by relatively deep sub-irrigation (-30 cm) while *A. spicatum* appeared to be inhibited by water levels of 10 cm or less from the surface. It is notable, however, that C. maculosa may be able to occupy all locations along an upland-wetland gradient short of actual flooding. There is little prior research on upland weeds to support this concept, although research on obligate wetland plants indicates species specific responses to hydrology (Grace, Newman and Koebel 1996) with some invasive species enjoying a competitive advantage on wetter sites (David 1999).



Note: -40= "dry" treatment with no sub-irrigation

Figure One: *A. spicatum* seedling emergence in response to water table elevation.



Note: -40= "dry" treatment with no sub-irrigation

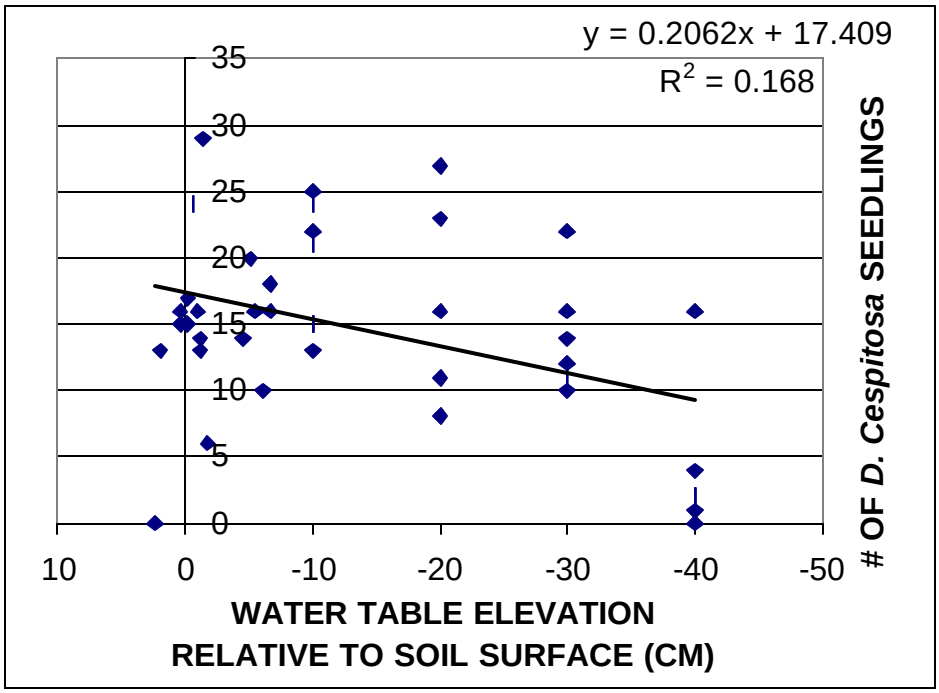
Figure Two: *C. maculosa* seedling emergence in response to water table elevation

Table Three: Regression coefficients, P values and R squares for seedling emergence.

species	Beta 0	Beta 1 depth	Beta 2 N treatment	P value depth	P value N treatment	R square
A. spicatum	7.49	-0.36	*NS	0.00	*NS	0.48
C. maculosa	3.86	-0.23	*NS	0.00	*NS	0.52
H. annuus	*NS	*NS	*NS	*NS	*NS	*NS
D. cespitosa	17.41	0.21	*NS	0.01	*NS	0.17
B. Syzigachne	17.74	0.1536	-2.83	0.00	0.00	0.33

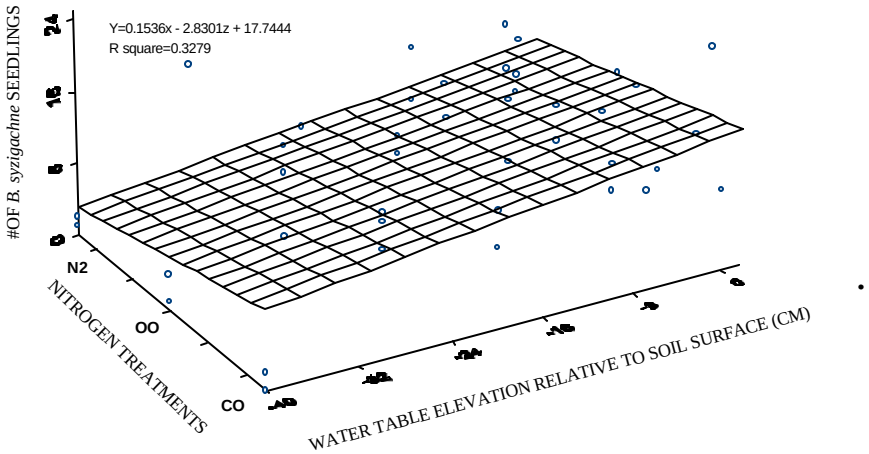
*NS=Not Significant

Among the wetland plants, species specific responses to hydrology were demonstrated by *D. cespitosa* and *B. syzigachne* which, in contrast to upland species, had highest emergence with water at or near the soil surface (Figures 3 & 4). Both these species, though, had successful seedling establishment in all but the driest tubs. Indeed, with *D. cespitosa* only 17% of the variability in emergence was explained by water table elevation. The multiple, linear regression model for *B. syzigachne* yielded a better fit with 33% of variability explained by depth to water and nitrogen treatments (Table 3).



Note: -40= "dry" treatment with no sub-irrigation

Figure Three: *D. cespitosa* seedling emergence in response to water table elevation



Note: -40= "dry" treatment with no sub-irrigation

Figure Four: *B. syzigachne* seedling emergence in response to nitrogen treatments and depth of water table below the soil surface in centimeters.

Results for *B. syzigachne* support the hypothesis that emergence of this rapidly establishing species is favored by high nitrogen, but other species showed no significant effect of Nitrogen on emergence. Controls on emergence of *C. arvense* were not analyzed because germination was very poor. This was surprising considering the prevalence of this weed in riparian areas. Further investigation of establishment requirements for *C. arvense* would aid interpretation of these results.

Biomass

Analysis of biomass for upland species indicated that both depth to water table and nitrogen treatments significantly affected biomass of *A. spicatum* and *C. maculosa* ($P<0.10$) (Table Four). Neither variable affected biomass of *H. Annuus*. The multiple linear regression models for *A. spicatum* and *C. maculosa* indicated highest biomass with a water table 40 cm below the soil surface in tubs with nitrogen added (Figure 5 and 6). Both *A. spicatum* (a late successional, perennial grass) and *C. maculosa* (an invasive weed) were favored by added Nitrogen, but response to Nitrogen was much more pronounced in *C. maculosa*. The coefficient for nitrogen's effect in the multiple, linear regression model for *C. maculosa* is over twice that of *A spicatum's* (1.90 and .72 respectively) demonstrating that, in this experiment, nitrogen had a much greater influence on *C. maculosa* growth. The strong,

positive response of *C. maculosa* to high nitrogen environments is supported by earlier research by Herron (1999). Similar responses to high nitrogen environments have been seen with early seral species (Tilman and Wedin 1991, McLendon and Redente 1991, Redente et al. 1992). It should be noted, though, that both the *A. spicatum* and the *C. maculosa* models accounted for only slightly more than 20% of the variability in biomass. In other words, approximately 80% of the variability in biomass is due to factors not investigated in this experiment or is associated with nonlinear responses to Nitrogen and water level treatments.

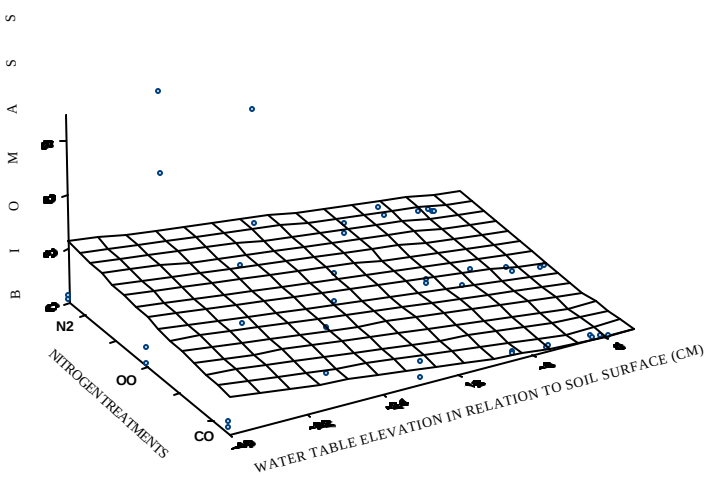
The only other species to show a significant growth response to Nitrogen treatments was *D. cespitosa*. The regression model for this species (Figure 7) showed biomass to increase with increasing nitrogen, but the Nitrogen treatments only explained 12% of the variability in biomass.

Seedling emergence and growth results for *C. maculosa* may have important management implications. In our experiment this aggressive, noxious weed established in many upland and intermediate locations along the hydrologic gradient. This suggests that disturbance of riparian areas, with a wide range of hydrologic conditions, may place them at high risk for weed invasion. This risk may be moderated by low ambient nitrogen availability or by the addition of a carbon source (McLendon and Redente 1991, Redente et al. 1992). Alternatively, the planting of an ephemeral cover crop with high Nitrogen uptake rates may favor desirable natives over invasive species (Herron 1999). Reductions in plant available Nitrogen may also significantly reduce biomass accumulation in desirable, perennial grasses, but this modest tradeoff should be preferable compared to the impacts of noxious weeds.

Table Four: Regression coefficients, P values and R squares for biomass of final harvest.

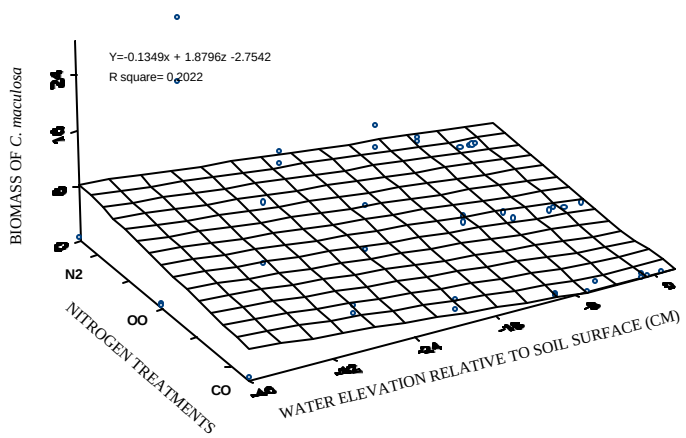
species	Beta 0	Beta 1 depth	Beta 2 N treatment	P value depth	P value N treatment	R square
A. spicatum	-1.00	-0.06	0.72	0.01	0.07	0.21
C. maculosa	-2.75	-0.13	1.88	0.02	0.06	0.20
H. annuus	*NS	*NS	*NS	*NS	*NS	*NS
D. cespitosa	0.99	*NS	1.81	*NS	0.02	0.12
B. Syzigachne	*NS	*NS	*NS	*NS	*NS	*NS

*NS=Not Significant



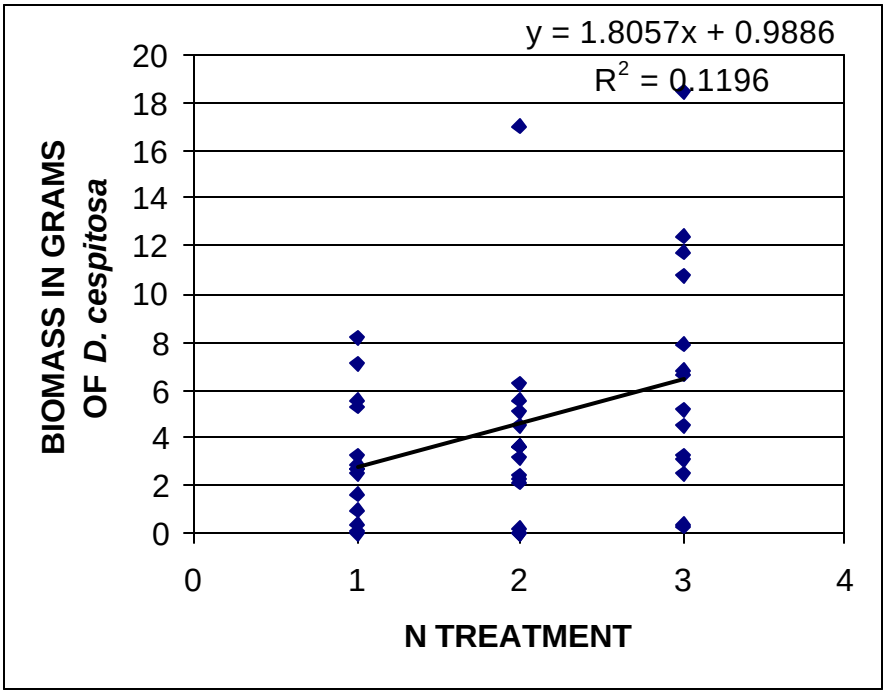
Note: -40= “dry” treatment with no sub-irrigation

Figure Five: *A spicatum* biomass seedling emergence in response to nitrogen treatments and depth of water table below the soil surface in centimeters.



Note: -40= “dry” treatment with no sub-irrigation

Figure Six: *C. maculosa* biomass in response to nitrogen treatments and depth of water table below the soil surface in cm.



Note:1=CO, 2=OO, 3=N2

Figure Seven: *D. cespitosa* biomass in response to nitrogen treatments

REFERENCES

Aguilera, M.O., and Lauenroth, W.K. 1995. Influence of gap disturbances and type of micro sites on seedling establishment in Bouteloua gracilis. Journal of Ecology 83:87-97.

Burke, I.C., Lauenroth, W.K., Vinton, M.A., Hook, P.B., Kelly, R.H., Epstein, H.E., Aguir, M.R., Robles, M.D., Aguilera, M.O., Murphy, K.L., and Gill, R.A. 1998. Plant-Soil interactions in temperate grasslands. Unpublished Manuscript.

Cooper, D.J., and Meiring, K. 1989. A Handbook of Wetland Plants of the Rocky Mountain Region. 1-124. EPA publication, region VIII:1-124.

David, P.G. 1999Response of exotics to restored hydroperiod at Dupuis Reserve, Florida. Restoration Ecology 7 (4):407-410.

Day, F.P. 1982. Litter decomposition in the seasonally flooded Great Dismal Swamp. Ecology 63(3): 670-678.

Grace, J.B. 1987. The impact of preemption of the zonation of two *Typha* species along lake shores. Ecological Monographs 57(4): 283-303.

Hansen, P.L., Pfister, R.D., Boggs, K., Cook.1997. Classification and management of Montana's riparian and wetland sites. Publication of University of Montana School of Forestry:1-485

Herron, G. 1999. Directing succession by altering nutrient availability. Unpublished thesis, Montana State University:1-53.

Hook, P.B., Burke, I.C., and Lauenroth, W.K. 1991. Heterogeneity of soil and plant N and C associated with individual plants and openings in North American shortgrass steppe. Plant and Soil 138: 247-256.

Hunt, H.W., Ingham, E.R., Coleman, D.C., Elliott, E.T., and Reid, C.P.P. 1988. Nitrogen limitation of production and decomposition in prairie, mountain meadow, and pine forest. Ecology 69(4): 1009-1016.

Lockaby, B.G., Murphy, A.L., and Somers, G. L. 1996. Hydroperiod influence on nutrient dynamics in decomposing litter of a floodplain forest. Soil Science Society of America Journal 60: 1267-1272.

Lockaby, B.G., Wheat, R.S., and Clawson, R.G. 1996.Influence of hydroperiod on litter conversion to soil organic matter in a floodplain forest. Soil Science Society of America Journal 60: 1989-1993.

McLendon, T. and Redente, E.F. 1991. Nitrogen and phosphorous effects on secondary succession dynamics on a semi-arid sagebrush site. Ecology 72(6): 2016-2024.

Newman, S., Grace, J.B., and Koeble, J.W. 1996. Effects of nutrient and hydroperiod on Typha, Cladium and elocharis: implications for Everglades restoration. Ecological Applications 6: 774-783.

Osborne, L.L., Koviac, D.A. 1993. Riparian vegetated buffer strips in water-quality restoration and management. Freshwater Biology 29:243-258.

Pysek, P., and Prach, K. 1993. Plant invasions and the role of riparian habitats: a comparison of four species alien to central Europe. Journal of Biogeography 20: 413-420.

Redente, E.F., Friedlander, J.E., and McLendon, T. 1992. Response of early and late semiarid seral species to nitrogen and phosphorus gradients. Plant and Soil 140: 127-135.

Satterlund, D.R., and Adams, P.W. 1992. Wildland Watershed Managment. John Wiley & Sons. Inc., New York, New York, USA.

Sheley, R.L., and Petroff, J.K. 1999. Biology and Managment of Noxious Rangeland Weeds. Oregon State University Press.

Stubbendieck, J., Hatch, S.L., and Butterfield, C.H. 1991. North American Range Plants. University of Nebraska Press.

Tilman, D., and Wedin, D. 1991. Plant traits and resource reduction for five grasses growing on a nitrogen gradient. Ecology 72(2):685-700.

Vinton, M.A., and Burke, I.C. 1995. Interactions between individual plant species and soil nutrient status in shortgrass steppe. Ecology 76(4): 1116-1133.

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TOOLS FOR THE RAPID SCREENING AND CHARACTERIZATION OF HISTORICAL METAL-MINING WASTE DUMPS

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ABSTRACT

Assessment of metal mobility, acid-drainage production, and toxic effects from the weathering of historical mine-waste dumps is an area of growing need as the environmental effects of inactive mine-waste sites across the country are being evaluated and mitigated. The U.S. Geological Survey Mine Waste Characterization Project has taken a multidisciplinary approach to assemble, develop, and refine methods and tools for characterizing and screening weathered solid-mine wastes. Researchers from a variety of disciplines, including geophysics, geochemistry, analytical chemistry, geology, mineralogy, geomicrobiology, remote sensing, spatial modeling, and aquatic toxicology, have worked together at several metal mining waste sites to develop an integrated "tool kit" for the rapid screening and characterization of historical mine-waste sites. This paper provides a brief overview of some of these tools.

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INTRODUCTION

There are thousands of historical mine-waste dumps present on inactive metal-mining sites, some of which are on Federal lands and have been abandoned. Since these are historical dumps, generally they are relatively small. However, the potential release of dissolved metals, acidity, or suspended particulates from mine-waste dumps can be a serious and long-lasting problem. Assessment of the potential environmental effects of historical mine-waste dumps is an area of growing need. The U.S. Geological Survey Mine Waste Characterization Project has taken a multidisciplinary approach to assemble, develop, and refine methods and tools for characterizing and screening weathered solid-mine wastes. Researchers from a variety of disciplines have worked together at several metal-mining waste sites in Colorado and New Mexico to develop an integrated "tool kit" for the rapid screening and characterization of historical mine-waste sites. Tools developed from this work can be used in ranking and prioritizing historical mine-waste dumps. A brief overview of several of these tools is given below.

SCREENING TOOLS

Sampling Strategy

We sought to develop a statistically based, cost-effective sampling strategy that could provide the foundation for screening and prioritizing mine-waste dumps on a regional or watershed basis. Because we are concerned with average properties, our sampling strategy entails collection of a composite sample from each waste dump. When more detailed site characterization is required, other sampling strategies might be employed, depending on the objectives of the work. A detailed discussion of our sampling strategy is given in K.S. Smith et al. (2000). In order to minimize sampling errors, our strategy requires that a composite sample consist of at least 30 increments (subsamples). Hence, we divide a mine dump into at least 30 cells of roughly equal surface area. Multiple surficial samples of roughly equal mass are collected from each cell with a trowel, successively placed in a bucket, and mixed to create a mine-dump composite sample. The sample is air-dried and dry-sieved to < 2 mm. The resulting < 2 mm mine-dump composite sample should weigh at least one kilogram. For screening and prioritizing historical mine-waste dumps, use of the < 2 mm size fraction generally should provide a worst-case scenario for metal leachability and appears to be a good choice to reduce the sampling error and reduce the sample size to one reasonable for reconnaissance field collection (K.S. Smith et al., 2000).

Metal Leachability Determination

Leaching tests are one of the main screening procedures used to evaluate and prioritize mine-waste dumps. We sought to develop a test that easily could be performed in the field, could provide on-site pH and conductivity information, and could furnish samples for metal analyses. The Field Leach Test is described in detail by Hageman and Briggs (2000). It is based on the premise that the most chemically reactive material in weathered mine waste consists of relatively soluble components in the fine fraction (< 2

mm) of the waste. The test involves combining 50 grams of < 2 mm mine-dump composite sample (see above) with 1,000 grams of deionized water in a capped one-liter polyethylene bottle. The mixture is vigorously shaken for five minutes, and then allowed to settle for 10 minutes. Specific conductance and pH can be measured in the field, and subsamples can be filtered and preserved for analyses of chemical constituents. Hageman and Briggs (2000) show that results from the Field Leach Test reveal geochemical trends that correlate favorably with results from the routinely used Synthetic Precipitation Leaching Procedure (U.S. Environmental Protection Agency, 1994).

Net Acid Production Determination

There are a variety of methods to determine the potential of a mine-waste material to produce acid. Many of these methods are designed for coal-mine waste or for fresh waste material. For historical metal-mining waste dumps that consist of weathered material, it is necessary to adopt a method that incorporates the potential acid production of secondary and tertiary minerals and the potential acid-consuming capacity of host-rock minerals (e.g., carbonates, chlorite, biotite). We have adopted a slightly modified version of the net acid production (NAP) method of Lapakko and Lawrence (1993). In this method, a sample of pulverized waste material is digested with a heated solution of 30% hydrogen peroxide. Acidic filtrates are titrated to pH 7 and NAP is calculated in terms of kilograms $CaCO_3$ per metric ton of waste. Fey et al. (2000) demonstrate that mine-waste dumps segregate into different groups when NAP is plotted against either the sum of five leachable metals (arsenic, cadmium, copper, lead, and zinc) or against leachable iron.

Microbial Activity Determination

Microbial processes can contribute to many of the geochemical parameters (e.g., acid production, metal release) determined in mine-waste dumps. The level and type of microbial activity in mine waste may be variable depending on such factors as temperature, acidity, water content, and sunlight. Many techniques, such as culture methods, direct counts, diagnostic molecular methods (e.g., chemotyping of lipids, proteins, cell wall materials), DNA/RNA sequencing techniques, and isotopic fractionation of the "bioelements" C, H, O, N, and S, can be used to determine microbial activity in mine-waste materials. Relative microbiological activities attributable to different groups of bacteria can be determined in the field (or laboratory) using BART (**B**iological **A**ctivity **R**eaction **T**ests; Hach Chemical Co., 1998).

Toxic Effects of Metals from Mine-Waste Dump Effluent (Aquatic Toxicology)

Toxicity Identification Evaluation (TIE) procedures (U.S. Environmental Protection Agency, 1991, 1993a, 1993b) offer a biological approach to identify chemical constituents that are potentially harmful to the aquatic environment. We used a modified version of these procedures to expose aquatic organisms to sample manipulations (e.g., increased/decreased pH, dilution, filtration, aeration, ligand titrations) of mine-waste dump leachates. Biological response of the test organisms revealed different types of

toxicant(s) or toxicant characteristics. Metal(s) of biological concern in mine-waste dump effluents can be determined using these TIE procedures.

NON-INVASIVE RAPID-SCREENING TOOLS

Remote Sensing

Swayze et al. (2000a, 2000b) have demonstrated that airborne or orbital imaging spectrometers can be used to map minerals resulting from weathering of acidic mine waste. This approach is based on identifying iron-bearing secondary minerals that form on the surface of mine-waste dumps under acidic conditions. The best indicator mineral for acidic conditions appears to be jarosite. These remote-sensing tools can be used to screen large areas for potentially acidic mine-waste material and to identify sites that warrant closer examination. Hand-held spectrometers also can be used for on-site work.

Geophysical Methods

Combining geological mapping with airborne geophysical surveying facilitates the task of screening large areas to locate historical mine dumps and assigning them initial priorities for further study. Airborne techniques include radiometric, magnetic, and electromagnetic mapping and can be used to map subsurface lithology, structure, and ground-water flow. B.D. Smith et al. (2000) illustrate how airborne geophysical techniques can be applied at both a regional scale (e.g., state) and a local scale (e.g., watershed, mine site). Geoelectrical methods, such as direct current resistivity, electromagnetic, and induced polarization, can be used to study conditions at depth within particular mine-waste dumps. These methods can infer information about lithology, mineralogy (especially sulfide minerals), pore-water saturation, or location of pore water or groundwater containing high total-dissolved solids. Hence, these methods can be used to trace plumes of contaminated water and discern compositional variations in mine-waste dumps. Campbell and Fitterman (2000) and Campbell et al. (1999) provide an overview of geophysical methods in mine-waste characterization.

DETERMINING THE RESIDENCE PHASE(S) OF METALS

In the study of the potential impact of mined sites on the environment, it is important to understand the source(s) of possible metal contaminants, the processes controlling their release into the environment, and their transport mechanisms. The concept of the availability of metals from natural materials, referred to as the geoavailability, is defined as that portion of a chemical element's or a compound's total content in an earth material that can be liberated to the surficial or near-surface environment (or biosphere) through mechanical, chemical, or biological processes. The geoavailability of a chemical element or a compound is related to the susceptibility and availability of its resident mineral phase(s) to alteration and weathering reactions (Smith and Huyck, 1999).

Detailed examination of the residence phase(s) of metals in mine-waste material is necessary to understand the geoavailability of metals in mine-waste dumps. A

combination of X-ray diffraction, bulk chemical analyses, chemical-extraction techniques, and X-ray microanalysis can shed light on metal geoavailability and subsequent mobility from mine-waste material (Smith et al., 1999). This type of information is key to the understanding of processes controlling metal release from mine-waste materials. Once these processes are understood, informed decisions can be made about mitigation, cleanup, disposal, and remediation of mined sites.

X-Ray Diffraction

X-ray diffraction (XRD) methods can be used to identify mineral phases in mine-waste samples. This information can be combined with bulk chemical analyses to try to account for residence phase(s) of chemical constituents. However, weathered mine-waste material commonly contains a significant portion (often as high as 40-50%) of non- or poorly crystalline material that is amorphous to XRD techniques. This amorphous material likely contributes to the geoavailability and subsequent mobility of some chemical elements. Hence, it is necessary to combine XRD methods with other methods that can address the amorphous phases in the mine-waste material.

Sequential Chemical Extractions

In sequential chemical extractions, metals are extracted from some or all of a sequence of operationally defined phases (Chao, 1984). The sequence of extractions exposes the sample to increasingly rigorous chemical treatments. This provides a means for evaluating the potential mobility of metals extracted from the various phases. The operationally defined phases adopted for our work include water soluble, ion-exchangeable, carbonate, amorphous iron oxide, crystalline iron oxide, sulfide, and silicate. Leinz et al. (1999, 2000) describe the details of the sequential chemical extractions used in our work.

X-Ray Microanalysis

Metals of interest generally reside in microscopic phases within mine-waste materials. Microanalysis techniques, including x-ray mapping, x-ray point analysis, and electron microscopy, can locate particles as small as 1 micrometer that contain trace elements. These particles can be individually analyzed to determine mineral chemistry, mineral identification, and weathering sequences.

PUTTING MINE SITES INTO CONTEXT

Use of Geologic Information

Geologic information can contribute a wealth of information about a mined site. For example, geologic setting can provide information about the pH buffering capacity of surrounding rocks, the potential ease of subsurface contaminant transport, and possible routes to receptors. The type of mineral deposit can reveal which metals are present and allow for estimation of the acid-generating and acid-consuming capacity of the waste

material (Plumlee et al., 1999). Knowledge of historical mining, milling, and metal-recovery processes can help determine the efficiency of sulfide removal and anticipate the presence of other contaminants of concern (e.g., mercury, cyanide).

Use of Spatial Modeling

Multidimensional spatial modeling techniques can be used to integrate and synthesize disparate information about a mine site. This approach can be a visually intuitive tool to examine spatial relationships and to view digital data. Yager and Stanton (2000) provide an example of spatial modeling by combining topographical, geophysical, and geochemical data for a mine-waste dump.

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REFERENCES

Campbell, D.L., Horton, R.J., Bisdorf, R.J., Fey, D.L., Powers, M.H., and Fitterman, D.V. 1999. Some geophysical methods for tailings/mine waste work, pp. 35-43 In: Tailings and Mine Waste '99 - Proceedings of the Sixth International Conference on Tailings and Mine Waste, Fort Collins, Colorado, January 24-27, 1999. A.A. Balkema, Rotterdam.

Campbell, D.L., and Fitterman, D.V. 2000 (in press). Geoelectrical methods for investigating mine dumps, In: Proceedings of the Fifth International Conference on Acid Rock Drainage, Denver, Colorado, May 21-24, 2000.

Chao, T.T. 1984. Use of partial dissolution techniques in geochemical exploration. J. Geochem. Explor. 20:101-135.

Fey, D.L., Desborough, G.A., and Church, S.E. 2000 (in press). Comparison of two leach procedures applied to metal-mining related wastes in Colorado and Montana and a relative ranking method for mine wastes, In: Proceedings of the Fifth International Conference on Acid Rock Drainage, Denver, Colorado, May 21-24, 2000.

Hach Chemical Co. 1998. BART user's manual. Loveland, Colorado.

Hageman, P.L., and Briggs, P.H. 2000 (in press). A simple field leach test for rapid screening and qualitative characterization of mine waste dump material on abandoned lands, In: Proceedings of the Fifth International Conference on Acid Rock Drainage, Denver, Colorado, May 21-24, 2000.

Lapakko, K.A., and Lawrence, R.W. 1993. Modification of the Net Acid Production (NAP) Test, pp. 145-159 In: Proceedings, British Columbia Mine Reclamation Symposium, Port Hardy, B.C., May 4-7, 1993.

Leinz, R.W., Sutley, S.J., and Briggs, P.H. 1999. The use of sequential extractions for the chemical speciation of mine wastes, pp. 555-561 In: Tailings and Mine Waste '99 - Proceedings of the Sixth International Conference on Tailings and Mine Waste, Fort Collins, Colorado, January 24-27, 1999. A.A. Balkema, Rotterdam.

Leinz, R.W., Sutley, S.J., Desborough, G.A., and Briggs, P.H. 2000 (in press). An investigation of the partitioning of metals in mine wastes using sequential extractions, In: Proceedings of the Fifth International Conference on Acid Rock Drainage, Denver, Colorado, May 21-24, 2000.

Plumlee, G.S., Smith, K.S., Montour, M.R., Ficklin, W.H., and Mosier, E.L. 1999. Geologic controls on the composition of natural waters and mine waters draining diverse mineral-deposit types, pp. 373-432 In: Filipek, L.H., and Plumlee, G.S. (eds.), The Environmental Geochemistry of Mineral Deposits, Part B. Society of Economic Geologists, Reviews in Economic Geology, v. 6B.

Smith, B.D., McCafferty, A.E., and McDougal, R.R. 2000 (in press). Utilization of airborne magnetic, electromagnetic, and radiometric data in abandoned mine land investigations, In: Proceedings of the Fifth International Conference on Acid Rock Drainage, Denver, Colorado, May 21-24, 2000.

Smith, K.S. and Huyck, H.L.O. 1999. An overview of the abundance, relative mobility, bioavailability, and human toxicity of metals, pp. 29-70 In: Plumlee, G.S., and Logsdon, M.J. (eds.), The Environmental Geochemistry of Mineral Deposits, Part A. Society of Economic Geologists, Reviews in Economic Geology, v. 6A.

Smith, K.S., Meeker, G.P., Leinz, R.W., Sutley, S.J., Huyck, H.L.O., and Desborough, G.A. 1999. Geoavailability of metals in a mine-waste material, abstract #7500 In: Ninth Annual V.M. Goldschmidt Conference, LPI Contribution No. 971. Lunar and Planetary Institute, Houston (CD-ROM).

Smith, K.S., Ramsey, C.A., and Hageman, P.L. 2000 (in press). Sampling strategy for the rapid screening of mine-waste dumps on abandoned mine lands, In: Proceedings of the Fifth International Conference on Acid Rock Drainage, Denver, Colorado, May 21-24, 2000.

Swayze, G.A., Smith, K.S., Clark, R.N., and Sutley, S.J. 2000a (in press). Imaging spectroscopy: a new screening tool for mapping acidic mine waste, In: Proceedings of the Fifth International Conference on Acid Rock Drainage, Denver, Colorado, May 21-24, 2000.

Swayze, G.A., Smith, K.S., Clark, R.N., Sutley, S.J., Pearson, R.M., Vance, J.S., Hageman, P.L., Briggs, P.H., Meier, A.L., Singleton, M.J., and Roth, S. 2000b. Using imaging spectroscopy to map acidic mine waste. Environmental Science and Technology 34:47-54.

U.S. Environmental Protection Agency. 1991. Methods for aquatic toxicity identification evaluations: Phase I Toxicity characterization procedures. EPA-600/6-91/003.

U.S. Environmental Protection Agency. 1993a. Methods for aquatic toxicity identification evaluations: Phase II Toxicity identification procedures for samples exhibiting acute and chronic toxicity. EPA-600/R-92/080.

U.S. Environmental Protection Agency. 1993b. Methods for aquatic toxicity identification evaluations: Phase III Toxicity confirmation procedures for samples exhibiting acute and chronic toxicity. EPA-600/R-92/081.

U.S. Environmental Protection Agency. 1994. Test methods for evaluating solid waste, physical/chemical methods (SW-846), 3rd edition, update 2B. Environmental Protection Agency, National Center for Environmental Publications, Cincinnati, OH 45268, telephone 800-553-6847, order number EPASW-846.3.2B. Accessed (12/1/99) at URL <http://www.epa.gov/epaoswer/hazwaste/test/sw846.htm>.

Yager, D.B., and Stanton, M.R. 2000 (in press). Multidimensional spatial modeling of the May Day Mine Waste Pile, Silverton, Colorado, In: Proceedings of the Fifth International Conference on Acid Rock Drainage, Denver, Colorado, May 21-24, 2000.

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

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The bond release process places heavy demands on applicants relative to the management and analysis of data necessary for reclamation monitoring. While a number of coordinated efforts have addressed these information management needs, a broader need still exists for the development of computer application tools capable of: 1) managing large quantities of spatial and non-spatial digital mine and reclamation data; and 2) providing an efficient means for utilizing such information in an integrated data management, analysis, and modeling environment. Our study is addressing these needs through the development of a geographic information system-based software application for the management, analysis and reporting of data associated with major components of coal mine reclamation and bond release requirements in Wyoming. Funded by the Abandoned Coal Mine Land Research Program at the University of Wyoming, the study will focus on enhancing the application of GIS technology in the hydrologic modeling arena, as well as an expansion of its use to address soils, re-vegetation, and wildlife management needs in coal mine reclamation. The overall goal of the study will be to provide resource managers with a powerful resource analysis and reclamation-tracking tool. Culmination of this effort (completion May 2001) will result in delivery of a Reclamation Management Tool (RMT) GIS software application containing components for management, analysis, and/or modeling of hydrology, soils, vegetation, and wildlife data. The RMT will be designed as an extension of a major desktop GIS software product, with support for Cad and relational database management structures compatible with generic mine data formatting requirements.

Key Words: coal mine reclamation, GIS, data management, bond release

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2000 BILLINGS LAND RECLAMATION SYMPOSIUM

USE OF GIS FOR AN INTEGRATED LAND RECLAMATION DESIGN: A PRACTICAL EXAMPLE AT A COMPLEX MONTANA SUPERFUND SITE

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ABSTRACT

Site characterization to support Remedial Design for the Uplands Portion of the Anaconda Regional Water, Waste & Soils Operable Unit of the Anaconda Smelter Superfund Site is currently underway. Design professionals are faced with the task of developing the remedial design for the site, which was impacted to various degrees by past smelter and related operations. Reclamation requirements vary from no-action to in-situ treatment of soil and revegetation with grass, trees and shrubs for various terrain and within design units, ranging in size from a few acres to over 450 acres. An integrated GIS system was used to store and evaluate very large quantities of environmental data, land ownership data, surface water and groundwater data, soils data and land use data, all of which will be utilized to present the basis for the remedial design. Additionally, the GIS database system will be used in the future to store data and evaluate and modify the post-remedy monitoring programs, land use, development, etc.

The project database consists of over 70,000 records of previously collected environmental data, over 2,000 additional environmental data records from design investigations and evaluations, as well as ortho-corrected aerial photography, topography, land use, geopolitical and other geographic data. In addition to the geographical information, environmental data has been integrated into the project database electronically from previous archives and laboratory reports and from GPS surveys. This data was categorized by various "themes," identified at the inception of design concept development, for use in design evaluations and presentations. Subsequently, the data is being queried, manipulated and evaluated in accordance with a defined set of protocols, developed to meet the requirements of the Superfund remedy and to develop and present the final designs for the numerous design units.

Additional Key Words: revegetation, remedial design, database management, treatment, heavy metals

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INTRODUCTION

Several investigation efforts conducted over many years within the Anaconda Smelter NPL Site (Smelter Site) have resulted in an extremely large amount of data over a sizable project area. It was necessary to organize, store and utilize design, construction, maintenance and monitoring information so it could be most effectively used. In order to accomplish this, a Geographic Information System (GIS) was established. This substantially aided the design and monitoring of the remedy over the large area of the Anaconda Regional Water, Waste and Soils Operable Unit (ARWWS OU).

The development of the Smelter Site GIS began in October 1997. The system became operational in January of 1998. The system is currently operational and data is continually being added and manipulated to meet the needs of it's users.

GIS technology integrates common database operations such as queries and statistical analyses with the unique visualization and geographic analysis benefits offered by the graphical interface (maps). This simple but extremely powerful and versatile concept has proven to be a valuable tool for performing analyses and producing graphics that convey the results of analyses to decision-makers.

Specifically related to the Smelter Site, GIS addresses the following needs:

- Allows designers expeditious and "hands-on" access of data and system for preparing design;
- Allows existing and future data to be used during the development of the remedial design;
- Records specified Construction Quality Assurance (CQA) data obtained during the remedial action;
- Support the O&M phase of this project; and
- Provide an accessible record of compliance data for this project.

Although this system has been specifically developed for the Smelter Site Project it is easily adaptable to other mine reclamation sites and projects.

BACKGROUND

Project Description

The Smelter Superfund Site is located in Southwest Montana and covers an area of approximately 30,000 acres. The site has been subdivided into numerous Operable Units (OU) and further divided into design units. This paper focuses on the use of GIS primarily for the Uplands Revegetation component of a single OU.

Reclamation requirements vary from no-action to in-situ treatment of soil and revegetation with grass, trees and shrubs for various terrain and within design units, ranging in size from a few acres to over 450 acres.

The project database consists of over 70,000 records of previously collected environmental data, over 2,000 additional environmental data records from design investigations and evaluations, as well as ortho-corrected aerial photography, topography, land use, geopolitical and other geographic data.

GIS SYSTEM

System Requirements

The GIS was developed to meet the following objectives:

- Support the interactive framework of the remedial design (RD), remedial action (RA) and operation, monitoring and maintenance (O&M) processes. The Smelter Site is unique in the sense that the remedial work will be conducted over a large area within several distinct land parcels or "polygons." This system allows for design and O&M plans to be optimized by graphically displaying data and analysis results.
- Keep accurate information for the RD, RA and O&M processes. Due to the large amounts of information involved at this site, it is critical to maintain control of and manage data to provide consistency and accuracy for effective remedial designs and O&M programs.
- Allow effective communication between the owner, Agencies, contractors and other users. By using the Smelter Site GIS and the data contained within, all interested parties will be using the same information. This eliminates miscommunication and different analytical findings resulting from use of different data.
- Use as much existing data from previous remedial investigation (RI), feasibility study (FS), and RD phases to minimize unnecessary additional data collection. All relevant data from previously conducted investigations was used in conjunction with new data to perform evaluations, complete the RD and analyze trends toward compliance.
- Provide a record of O&M data over time to evaluate delisting of remediated areas. This system will be used, over time, to evaluate remedy performance, thus allowing for potential delisting.

System Components

A number of specific terms are used to describe the components of the Smelter Site GIS. Some of these often-used terms are defined below.

Views – Names of data categories where information is stored (i.e. Land Use, Environmental).

Themes – A set of individual data layers. "Roads" is a theme that contains all features identified as roads (i.e. Highway 1). The "Roads" theme is located under the *Land Use* view.

Attribute – Information about a feature (point, line or shape). For example, attributes of Highway 1 would include the type of line (road) and type of road (highway) and name (Highway 1).

Layout – The graphical presentation (map) resulting from overlaying multiple themes, tables and text into one frame.

Database – The "storage unit" where themes for the Smelter Site are found.

GIS Hardware/Software

The current computer used to drive the Smelter Site GIS contains a Pentium II processor with 260 MHz processing speed and 120 megabytes of RAM. These specifications are the minimum required. Additional peripherals used for data collection include a Trimble Pathfinder GPS and a Summagraphics Summagrid IV digitizing tablet. The software used for the Smelter Site GIS is ArcView v.3.1 developed by the Environmental Systems Research Institute Inc. (ESRI).

GIS OPERATION

GIS Input Procedures

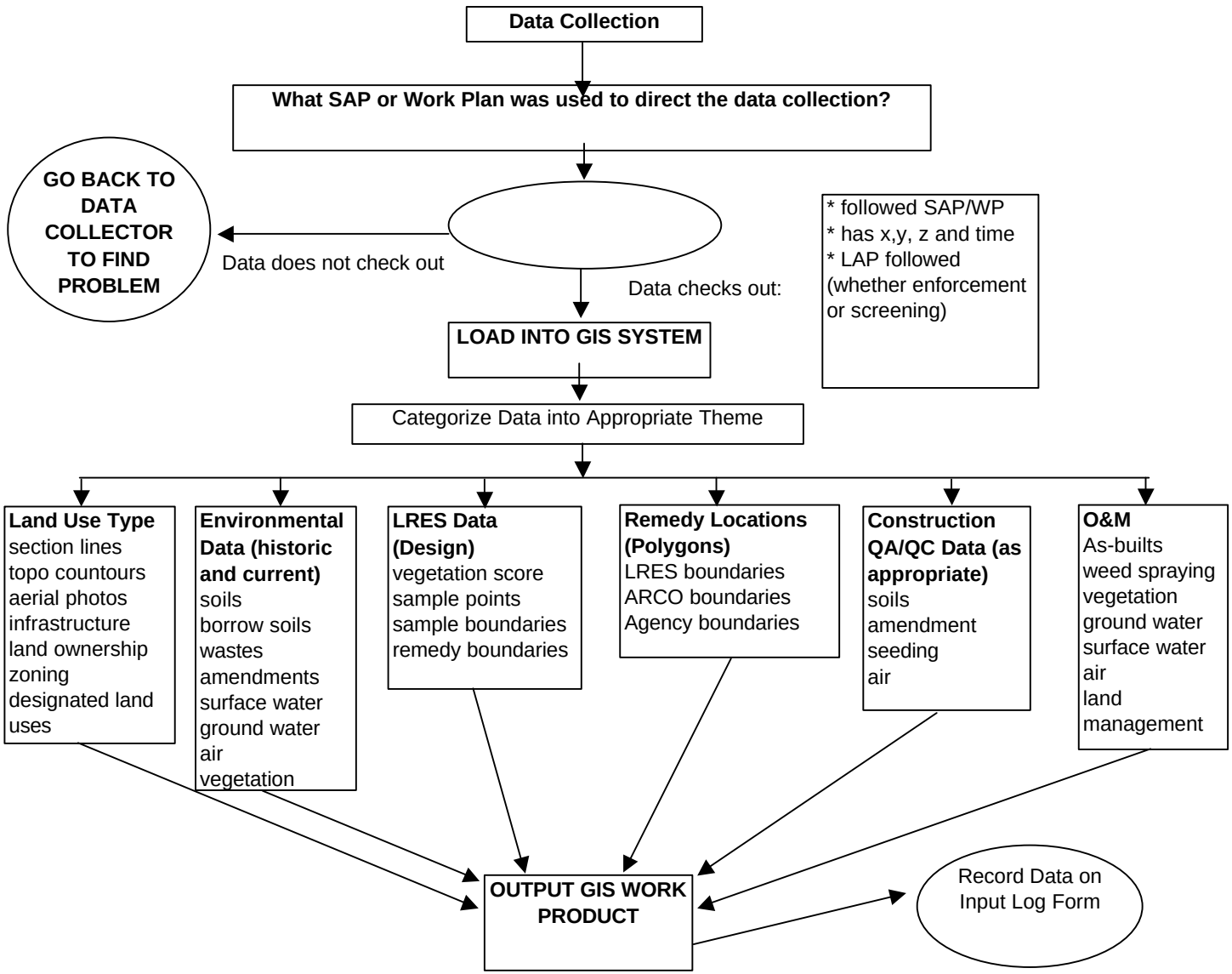
The input data is the most critical component of the Smelter Site GIS. There are many different types of data that have been included or may be input to the system, as long as the data or information can be referenced to a known location. A schematic diagram illustrating the major steps of data input into the system is shown on Figure 1.

The types of data contained in this system include aerial photos, topography, site features and other physical property data, land use/type data, environmental data (soil, waste, ground water and surface /storm water), remedy designs, construction quality assurance and O&M information. A number of sources have been used to construct the Smelter Site GIS. These sources include:

- Base topography was created from an aerial survey. Aerial photos were developed from this aerial survey and were ortho-corrected. Eventually, a digital surface model or triangulated irregular network (TIN) surface map was developed which contained topography at five and fifty foot contour intervals.
- Clark Fork Data Management System [CFDMS] data (historical environmental data) was imported to the Smelter Site GIS. This information set included tens of thousands of environmental data points within an Access database.
- Land Use/Type data included in the Smelter Site GIS was retrieved from a local county GIS Department. This information includes zoning boundaries, property ownership and other local information.
- Data from design data collection activities as well as past reclamation and maintenance activities.

Data input into the Smelter Site GIS consists of spatial, non-spatial or image data. Spatial data consists of features that can be represented by a point, line or polygon. These features

Figure 1 - GIS INPUT SCHEMATIC DIAGRAM



must be in a frame that is georeferenced (has a known coordinate system). Acceptable data file formats include shape files, ArcInfo export files and DWG or DXF files.

Non-spatial data, such as tabular data, includes analytical data, field observations or other information. This data must also include the location of the data by referencing coordinates or station locations (such as a ground water well at a specific and permanent location) with coordinates identified in other data sets. Typical data file formats include Excel, Access Dbase or ASCII.

Image data includes such items as O&M photographs or aerial photographs. Georeference information must also be included with image data, (such as photo location, direction of picture) as well as time and date that the photograph was taken and a general description of the photograph. Aerial photographs must also have a projection specified in which they were taken as well as time, date and altitude. Typical data file formats include TIFF, JPEG, IMAGINE, NITF, MrSID, CIB, CADRG and ADGR.

Data received must all be in the same projection and datum such as Montana State Plane (NAD83).

Categorizing GIS Data into Themes

Due to the large amount and varying types of information available at the Smelter Site, it is critical that the data is appropriately categorized and filed so that users of the Smelter Site GIS can effectively locate and use it. In GIS, these data categories are called "views." These GIS views are the categories under which the data is stored and can be accessed. The major views, along with GIS themes and definitions for each view, are described below. These major views include:

- Land Use/Type Data;
- Environmental Data (soils, ground water, surface water, air);
- Land Reclamation Evaluation System (LRES) Phase II Data (Design);
- Remedy Location (As-Built) Data;
- Certain Construction Quality Assurance Data; and
- O&M Data.

Land Use/Type View

The Land Use/Type view contains themes associated with land uses or types. These themes include contour lines, section lines, certain 1999 infrastructure (roads, buildings, and utility lines), 1999 land ownership, and waste management areas. The intended use of these themes is to provide reference and locational information, in the form of base maps, for other information from the RD, RA and O&M phases.

Environmental Data View

The Environmental Data view contains themes associated with environmental analytical or field data. These themes are further organized into four sub-themes based on media type. These sub-themes are soils data, ground water/surface water/air monitoring data, storm water

data and vegetation data. These themes contain all data from laboratory and field analysis relating to soil, waste, water, vegetation and air media.

Land Reclamation Evaluation System (LRES) Data View

The LRES Data view contains themes associated with the data collected during the design phase for the Smelter Site. This view contains sample points associated with the LRES field and laboratory investigation.

Remedy Location View

The "Remedy Location" view contains themes that are primarily made up of polygons depicting specific remedial designs. The polygons are specified shapes that are represented by specific remedial techniques.

Construction Quality Assurance (CQA) View

The CQA Data view includes data collected during the RA phase of the project. This may include themes relating to soil amendment and revegetation such as: lime rates, seed mix, application rate, etc. These themes are developed to categorize data that will be collected during the implementation of the remedy to ensure the remedy was constructed as the design intended.

Operations and Maintenance View

The O&M Data view contains themes that are anticipated to be used once the remedy is implemented for a specified area. In some areas of the Smelter Site, O&M activities are already being performed. For other areas, O&M activities will not be performed for a number of years, since planned remedies will not be conducted for a period of 15 to 20 years.

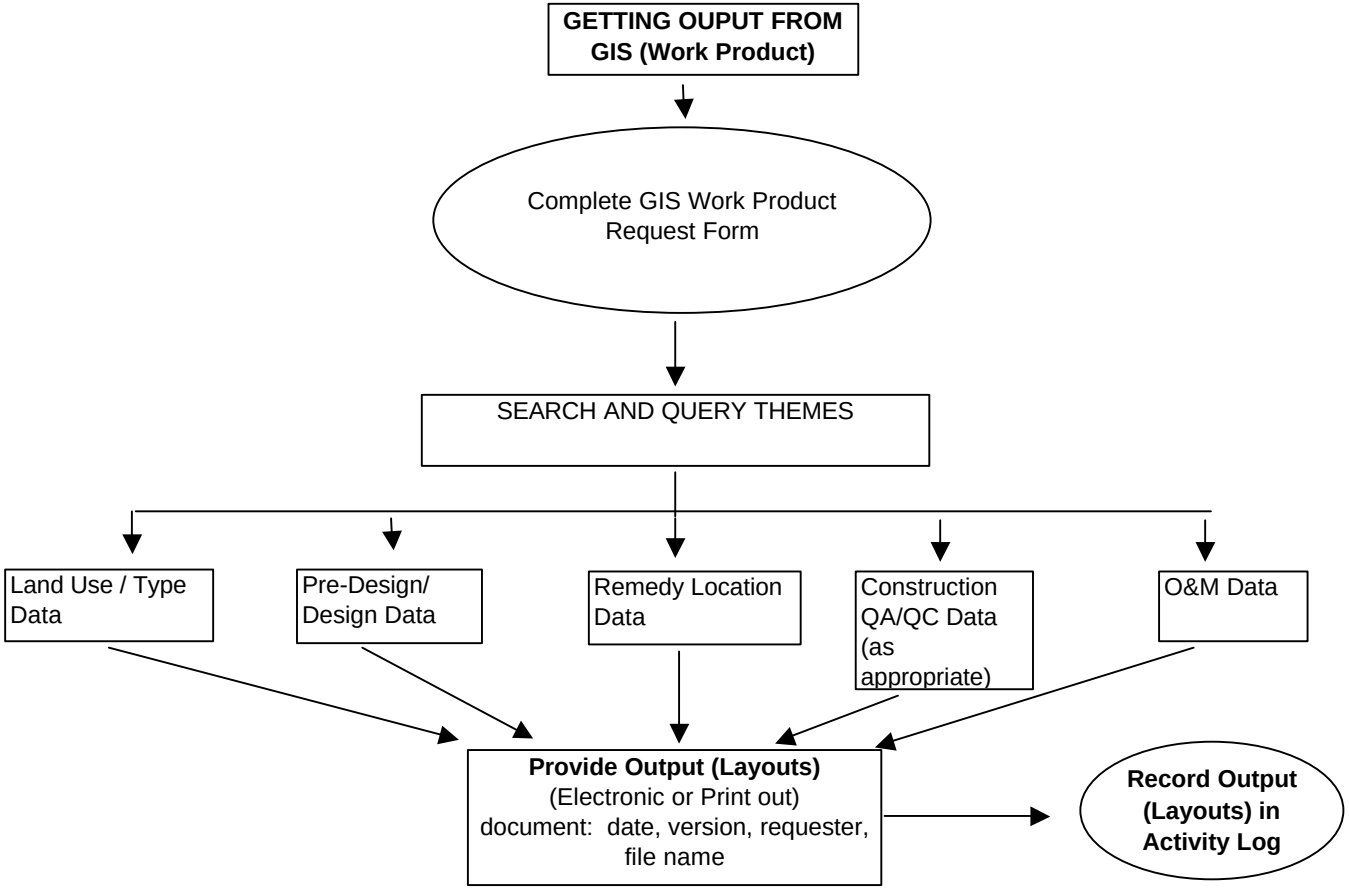
The O&M themes include: As-built drawings, Weed Spraying Control, Storm Water, Ground Water, Soils, Revegetation, Waste Management Areas/Repositories, Land Management, and the Anaconda/Deer Lodge County Development Permit System. These themes will contain spatial data (polygons) where observations have noted maintenance concerns where work was performed (i.e. revegetation or weed spraying).

The themes also contain non-spatial information relating to the analytical data at specified points of compliance. The O&M themes will also contain land management data which specifies the land ownership, zoning requirements and land use. The intent of these data themes is to provide data as it relates to ICs at the Smelter Site. These data and themes will be updated as the remedial action is completed and the O&M requirements are more fully defined.

GIS Output Procedures (Work Product)

The primary goal of the Smelter Site GIS is to provide the tools to efficiently store, manipulate, evaluate and present data such that the designers, decision makers and other appropriate personnel can design, construct and monitor the remedy for the Smelter Site. The following presents the procedures to obtain output (or work product) from the Smelter Site GIS. A schematic diagram illustrating the major steps of providing output from the Smelter Site GIS is shown on Figure 2.

Figure 2 - GIS OUTPUT SCHEMATIC DIAGRAM



Theme Query and Layout Compilation

Layouts are generated by locating the themes within the projects views. These themes are copied into a temporary view. A layout template is created to graphically represent the spatial relationships of the data. A live link exists between the temporary view and the layout template. This means that changes the operator makes to the view will be reflected in the layout. These changes may include turning themes on or off, zooming in or out, symbol changes, etc. After the desired data is represented in the layout, other map components can be added. This could be text or graphics, scale bar, north arrow, tables, legend, pictures, etc. After all desired components are represented, the live link option can be turned off and the layout can be printed to a plotter or archived as a plot file. The layout is also saved within the project folder if future revisions are needed.

Uplands Revegetation Design Example

An example of the design process is best described through graphical plots of the design drawings. However, due to the restrictions on the size of this paper it is not possible to include the example drawings. Therefore, the following presents a description of what each design drawing contains and the GIS data that were queried/compiled to create the drawing.

In order to develop drawings of a workable size, the site was divided into 47 plates to cover the Upland Revegetation area. One set of design drawings for each plate was prepared and include: the Site Location, Aerial View Base Map and Steep Slopes, Data, Land Ownership, Land Use and Institutional Controls, Storm Water controls and the Remedy per polygon. The following describes the different types of drawings that were produced. A drawing numbering system was developed as illustrated below and includes the design unit number (in this case 2), the plate number (in this case 11) and the drawing number (i.e., 1 through 7)

INDEX (Scale: 1”=2000’). An index grid (plates) over the entire OU was prepared to organize how drawings will be viewed. Characteristics of this drawing include:

- Each grid is sized to present a 1” = 500’ scale on an 11x17 page format.
- The index drawing includes: plate boundaries, plate numbers, RDU boundaries, polygon boundaries and major roads (as defined in the Theme Definition Table).

2.0 Remedial Design Unit (RDU) LOCATION (Scale: variable) – This drawing shows the entire RDU and illustrates the plates and polygons associated with a specific RDU along with topographic contours and planimetric features. It provides a reference at a smaller scale than the Index drawing. The GIS information used to create this drawing includes:

- RDU location,
- Contours (with elevation annotations),
- Plate boundaries,
- Roads,
- Section numbers,
- Streams, ponds and drainages,
- Polygon boundaries,
- Land ownership by five major categories (ARCO, ADL county, State, Federal, and private).

2.11.1 AERIAL BASE AND STEEP SLOPES (Scale: 1”=500’) – The main purposes of this drawing are to show the aerial detail of the plate, areas where slopes are greater than 3:1 and the delineation of sub-polygons. The GIS information used to create this drawing includes:

- Aerial photo (base),
- Polygons,
- Sub polygons,
- Identification of slopes steeper than 3:1,
- Section Lines,
- Roads,
- Hydrological Features (streams, ponds), and
- Match lines to other plates.

2.11.2 DATA (Scale: 1”=500’) – The purpose of this drawing is to display the location of different data types used to determine the remedial design. This drawing is accompanied by a data table, which summarizes the data results. The GIS information used to create this drawing includes:

- Soil Data locations (including LRES sample locations),
- Ground water data locations,
- Monitoring Well locations,
- Domestic Water Supply Well locations,
- Cultural and Protected Resource area locations,
- Polygon Boundaries,
- Sub-polygon boundaries,
- Surface water, and
- Topographic contours.

2.11.3 LAND OWNERSHIP (Scale: 1”=500’) – The purpose of this drawing is to identify the property boundaries of various owners in relation to the design remedy. The GIS information used to create this drawing includes:

- Existing roads,
- Topographic contours,
- Location of private landowners,
- County, State and Federal property,
- Restrictive covenant areas, and
- ARCO-owned and -leased lands.

2.11.4 LAND USE and INSTITUTIONAL CONTROLS (Scale: 1”=500’) – The purpose of this drawing is to show current and reasonably anticipated future land uses, land use restrictions, proposed access road locations and amendment stockpile locations. The GIS information used to create this drawing includes:

- Existing utilities,
- Existing wetlands,
- Soil amendment storage areas,
- Groundwater technical impracticability (TI) zones,
- Land management practices,
- Dedicated Developments,

- Waste Management Areas,
- New and existing roads,
- Repositories,
- Restrictive covenants,
- Master plan designation, and
- Polygons/sub-polygons.

2.11.5 MISCELLANEOUS INFORMATION (Scale: 1”=500’) – Certain RDUs and polygons may require site-specific details for the completion of the design drawings that are not identified on any of the other drawings in the design set.

2.11.6 STORM WATER CONTROLS (Scale: Varies) – Some plates may contain storm water features to be displayed on design drawings. The GIS information used to create this drawing includes:

- Storm water basin catchment areas,
- Channels,
- Ponds,
- Streams, and
- Wetlands.

2.11.7 REMEDY DESIGNATION (Scale:1”=500’) – The purpose of this drawing is to provide remedy details. Information provided on this drawing includes the following, as applicable:

- Remedy type by polygon,
- Cross reference to applicable specifications, and
- Reference to text detail for any modifications to documents standard (specifications, CQAP, etc.).

Conclusions

GIS is a valuable tool for the development of designs for land reclamation. It provides a system for the management of large amounts of data, creating large numbers of design drawings, easy and consistent retrieval of data and designs and for analyzing trends in the performance of reclamation efforts. The system also allows for multiple users from different companies/agencies to use the data to perform evaluations and to check designs performed by others. The system was also designed so that it can be used by those with minimal experience in GIS.

2000 Billings Land Reclamation Symposium

A GEOSTATISTICAL TOOL TO DETERMINE OPTIMUM SAMPLING FREQUENCY TO ASSESS MINE SOIL SUITABILITY

D. J. DOLLHOPF[1]

ABSTRACT

The frequency that mine soils must be sampled across a backfilled landscape to determine physicochemical suitability is a function of site characteristics and should not be based on a universal guideline specified by a State regulatory program. Using mine soil physical and chemical data from a site, a variogram model can be developed for each mine soil parameter. Each model and associated sensitivity tests are used to ascertain the optimum sampling frequency across the minesoil landscape. Different sampling frequencies are evaluated for accuracy in characterizing mine soil characteristics using kriging procedures. Case examples are presented where mine soil sampling requirements for coal mine facilities were changed as a result of using these procedures.

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INTRODUCTION

At surface coal mines, the physicochemical traits across a mined backfill area must be assessed prior to placement of coversoil. For example, in post-mine environments, portions of the graded backfill may be too acidic, sodic, saline, or clayey to ensure acceptable plant growth. Sampling strategies must be designed to delineate unsuitable soil so that remediation procedures can be implemented.

The following discussion will focus on sampling strategies for mine soils composed of graded backfill material.

State Regulatory Programs

In response to the Surface Mining Control and Reclamation Act (OSM 1977), most state coal regulatory programs require that the 0 to 4 foot depth increment of the spoil backfill contain materials suitable for plant growth. Consequently, state regulatory programs require mine operators to assess mine soil suitability for plant growth. Postmine sampling procedures are intended to identify whether suitable materials are present so that revegetation can be successfully implemented.

Each state regulatory program has different sampling guidelines since it has been uncertain what constitutes an adequate sampling intensity. For example, in Montana, regraded spoils are sampled with cores every 2.5 acres across the landscape (Montana Department of State Lands, 1983). In Wyoming, samples are collected every 250 to 1000 feet across the landscape (Wyoming Department of Environmental Quality, 1984). In North Dakota, postmine mine soils are sampled every 400 feet across the landscape (Public Service Commission, 1987). In Texas, mine soils are sampled approximately every 1.0 acre across the landscape (Railroad Commission of Texas, 1988). This diversity of sampling intensities across the USA emanates from professionals in each state instituting their best judgment based on experience.

DETERMINATION OF THE OPTIMUM SAMPLING FREQUENCY ACROSS A GRADED SPOIL BACKFILL

Initial Backfill Sampling Considerations

In order to apply geostatistical procedures an initial set of data is required for the analyte(s) of interest. The sample collection geometry across the landscape does not need to be in a regimented pattern of grids. Sample locations can be based on random, judgmental or systematic formats and, thus, be in any geometrical pattern. A minimum of approximately 30

sample sites are required, although more sites are desirable to improve representativeness, and a hundred or more sampled locations is not uncommon for this analysis. These sample sites should traverse the entire project area. Ideally, at several locations, samples should be collected more intensively. This step enables an assessment of analyte variability across short distances at different positions in the project area. This sampling protocol will help improve the accuracy of the variogram model. However, these localized areas of intense sampling are not required to develop a reliable model.

The project area boundary can be of any geometrical shape and does not have to be, for example, square or rectangular. The sampled project area does not have to be contiguous. Large gaps with no sample data may exist in the landscape that completely bisect the sampled areas. These gaps may be as large as several kilometers, or more.

A **misapplication of geostatistics** may result when, e.g. a 5000 acre project area exists but due to budget or time constituents, only a "test area" is sampled. The test area, e.g. 200 acre, is sampled intensively, and a variogram model is produced for an analyte. Extrapolating variogram results from the 200 acre area to the entire 5000 acre area runs the risk of producing a misleading result. Analyte variability is likely different across the 500 acre area and the model should be developed from samples collected from all portions of the site.

Coal surface mine project areas typically have extensive spoil backfill data across several thousand acres of the landscape as a result of years of sample collection. It has been common practice to use these data to develop variograms to guide sampling in future graded spoil backfill areas. Although these variograms were developed using data from historical backfill areas, the error in using these results to guide sampling in future spoil backfill areas may be small unless the geochemical setting changes notably.

The Variogram

Geostatistical theory, the mathematics and computer software associated with development of a variogram will not be presented in this paper. Instead, results from completed minesoil geostatistical investigations will be discussed to demonstrate to the reader the applicability of this science to mine soil landscapes. In brief, each sampled location is digitized to produce a northing (x) and easting (y) coordinate value to identify the spacial location within the graded spoil backfill. Summary statistics are produced to determine whether a data set for a physicochemical parameter approximates a normal distribution. Non-normal distributions are transformed prior to development of the variogram. Geostatistical software is used to calculate the variogram which undergoes a validation procedure.

Three key results are expressed in a variogram that are important in determining the optimum sampling procedure for a spoil backfilled landscape. A variogram is a graphical plot relating **semivariance** (y-axis) to **distance** (x-axis) between sample sites in the landscape (Figure 1). The variogram shows that as distance between sampled sites increases the

semivariance increases, but eventually semivariance reaches a plateau when distance between samples is large. This plateau is termed the **sill**, and is the distance between sampled sites, 3000 to 10000 feet (Figure 1), when there is absolutely no relationship between data collected in the landscape. Conversely, when samples were

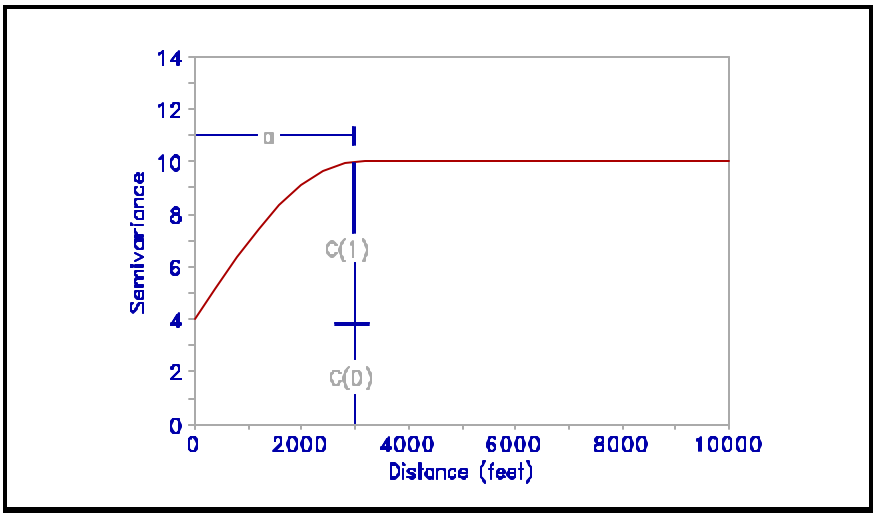

Figure 1. Idealized spherical variogram model with nugget variance, $C_{(0)}$=4; sill, $C_{(0)}+C_{(1)}$=10; and range of influence, a=3000.

collected across the landscape less than 3000 feet apart (Figure 1), then semivariance decreased indicating that the samples were starting to account for variability in the landscape, meaning we were truly beginning to characterize the landscape parameter of interest, e.g. soil pH. The **range of influence**, 0 to 3000 feet (Figure 1), is that portion of the variogram model where variance between samples is progressively decreasing as distance between samples decreases. Clearly, as distance between samples decreases, we more accurately characterize the physicochemical traits of the spoil backfill. Therefore, we need to sample the spoil backfill within the range of influence. Note that even if we had sample points inches apart across the spoil backfill, we could not perfectly characterize the physicochemical parameter of interest since a notable amount of semivariance (4.0 in Figure 1) remains unaccounted for; this is termed the **nugget variance.** The nugget value represents a random component to the semivariance. The nugget value cannot be explained by sample spatial location and is due to errors in measurement (e.g. laboratory error) and micro-variabilities of the parameter of interest.

Variograms For Graded Spoil Backfill At Surface Coal Mines

Case Example For Spoil pH

At surface coal mine sites in Texas, the state regulatory authority (Texas Railroad

Commission) requires that graded spoil backfill be sampled every 5.7 acres (composite from subsamples collected in each one acre area), meaning every 498 feet, across the landscape and samples analyzed for several parameters to demonstrate whether spoil is chemically and physically suitable for plant growth. The Alcoa Sandow Mine historically sampled their spoil backfill on a 20 acre grid basis (composite subsample collected from each one acre area), meaning every 933 feet, and were concerned about adopting the more intense sampling requirement specified by the regulatory authority.

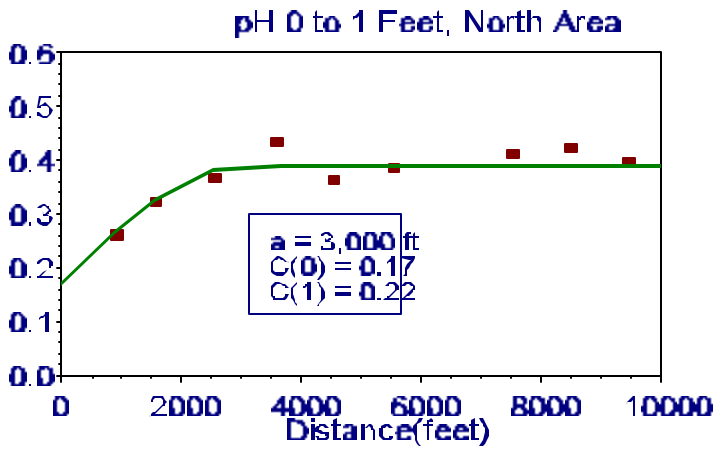

Figure 2. Variogram comparing semivariance and sample separation distance for spoil backfill pH in the 0-1 foot depth increment at the Alcoa Sandow Mine in Texas.

Variograms were developed for the spoil backfill area (3500 acres) for those parameters that frequently exceeded spoil suitability criteria, pH and acid-base account. As shown in Figure 2, the range of influence indicated samples collected more than 3000 feet apart were **independent**, meaning there was no relationship between locations and thus, an understanding

of where pH was suitable or not suitable could not be determined. However, as sample separation distance ranged below 3000 feet sampled locations were **dependent** on each other, indicating there was a relationship between sampled sites and progress was being made towards understanding where spoil pH was suitable and not suitable. Therefore, it was determined that the 20 acre grid sampling, a sample every 988 feet, that the mine had been doing for years was well within the range of influence and was effective at delineating suitable and unsuitable material.

The regulatory agencies recommendation to sample the graded spoil backfill every 5.7 acres, meaning every 498 feet, would improve the accuracy in delineating pH in the landscape, since more samples will always result in better delineation of a parameter of interest. However, it can be seen in Figure 2 that a 498 foot versus a 988 foot sampling grid would decrease semivariance (y-axis) only 0.05 units, meaning a 12.8 % decrease in the total semivariance (0.39) in the variogram. This 12.8 % decrease in semivariance comes at a cost of collecting 350 % more samples.

Variograms for acid-base account were similar to those for spoil pH. Based on these results, the regulatory agency concurred that the 20 acre grid sampling program was acceptable and did not require the Sandow Mine to convert to the more intense 5.7 acre sampling grid specified in the regulations.

The variogram in Figure 2 provides in-site into another sampling concern. Note that even if drill hole separation distance were only a few feet apart, unaccounted for semivariance is still present. That is, we cannot decrease the semivariance below the nugget value (C_o), i.e. where the variogram intercepts the y-axis. In practice, this means we can never <u>perfectly</u> delineate spoil backfill physicochemistry because unaccounted for problem variation will be present even with samples a few feet apart. The nugget value represents a random, as opposed to systematic, component to the semivariance. The nugget value cannot be explained by spoil backfill sample spatial location. The nugget value is due to *sampling error*, e.g. different personnel collecting a set of samples, *laboratory error*, i.e. precision, and *micro-variabilities* of, for example, pH. Pitard (1990) evaluated laboratory precision, using Alcoa Sandow Mine samples in Texas and determined a notable portion of the nugget semivariance was attributable to laboratory precision. Simply stated, even excellent laboratory analytical work will yield error in the reported value. This laboratory error is carried into the nugget semivariance. An example of a spoil backfill microvariability problem is the presence of either a $CaCO_3$ stone entering the sample stream or FeS_2 nugget entering the sample stream. Neither is representative of the spoil backfill chemistry, but laboratory analysis will yield a very positive or very negative acid-base account, respectively. This is a random sampling error that can be minimized with compositing but never eliminated. In summary, the nugget semivariance is due to random sampling error and analytical error. Laboratory quality control procedures to increase precision and sample compositing can help minimize but not eliminate this problem. Thus the variogram can indicate whether field compositing procedures should be enhanced in order to decrease the nugget semivariance.

USING GEOSTATISTICS TO SOLVE SAMPLING PROBLEMS AT SURFACE MINE SITES

Variograms for physicochemical characteristics in graded spoil backfill areas have been developed for six other surface coal mines located in Texas, Washington and Montana. In all cases, validated variograms provided guidance as to frequency of sampling required across the spoil landscape. Regulatory agencies in these states have accepted results presented in these variograms, resulting in lower sampling costs to the mine operator. Regulatory agencies have been willing to implement spoil backfill sampling frequencies different than that specified in the regulations when specific site investigations demonstrated the merit of less intense, or more intense, sampling is appropriate across the landscape.

REFERENCES

Montana Department of State Lands. 1983. Soil and overburden guidelines. Dept. of Environ. Qual., Reclamation Div., Coal and Uranium Bur., Helena, MT. 42 p.

Office of Surface Mining. 1977. Surface mining control and reclamation act. Public Law 95-87.91, Stat. 445 (30 USC 1201 et. seq.), Washington, DC.

Public Service Commission. 1987. Suitable plant growth material removal and redistribution. Policy Memorandum No. 17 to Mine Operators, Reclamation Div., Bismarck, ND. 37 p.

Railroad Commission of Texas. 1988. Mine soil and monitoring plan. Surface Mining and Reclamation Division, Tech. Release No. SA-4, Austin, TX. 9 p.

Wyoming Department of Environmental Quality. 1984. Guideline number 1, topsoil and overburden. Land Quality Division, Cheyenne, WY. 17 p.

2000 Billings Land Reclamation Symposium

RECENT DEVELOPMENTS IN LAND RECLAMATION / REVEGETATION EQUIPMENT

John M. Inkret[1] and Bernie Jensen[1]

ABSTRACT

Over the past decade, land reclamation implementation practices have evolved and improved through modifications of revegetation equipment, as dictated by field-testing and necessity. Standard agricultural machines and implements designed for use on quality soils and level topography can exhibit limitations and breakdowns when performing on the rockier, often compacted, soils and steeper slopes so often encountered in land reclamation. Some factory agricultural equipment, without modification, has proven very useful and effective under extreme field conditions. However most standard agricultural implements and machines must be substantially modified with respect to strength, stability, durability, dependability, and power. There are certain activities (e.g. drill seeding, lime spreading) or regulatory agency requirements (e.g. tillage depth) where no such equipment is commercially available, and this must be custom built. Extensive experience and field-testing is mandatory for the efficient and effective design and construction of custom land reclamation equipment. This paper reviews some of the more recent, specialized machinery and implements, with respective modifications and innovations, being employed by Western Reclamation Inc. on various land reclamation projects in the Clark Fork River Basin, Montana. Equipment is evaluated with respect to function, description, techniques, capabilities, limitations, and production rates.

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INTRODUCTION

Land reclamation standards have become more stringent over the past ten years. These standards apply to the physical and chemical properties of topsoil, seedbed preparation, mulching, seeding, and fertilizing. Historically, regulatory agencies have attempted to implement reclamation activities with standard agricultural farming equipment. This equipment is designed for relatively level, smooth, rock-free, non-compacted soils – it does not have the durability or capacity to operate on many of the more industrial types of reclamation projects. Frequent breakdowns are to be expected. Modern reclamation standards often include surface modifications and amendment incorporation ranging in depth for 6” to 24”. Most standard farming implements are designed to operate to a depth of 10” or less. This paper reviews some recent developments in specialized reclamation equipment designed and built by Bernie Jensen of Western Reclamation Inc. This paper and presentation are limited to the most frequently problematic operations – primarily amendment spreading, amendment incorporation, drill seeding, and straw and hay mulching.

TERRAGATOR SPREADER

The TerraGator (Figure 1) chassis is designed to haul and spread large loads of material on rough, off-road areas of limited load bearing soils. The TerraGator is based upon a high strength, ridged frame that articulates and oscillates to enable hydraulic cylinder steering. It is powered with a 185 horsepower diesel engine that drives a six-speed power shift transmission. The differentials are low speed inboard planetary reduction differentials manufactured by John Deere. The four wheels have 66 x 43.00-25 terra grip high-flotation tires. A new TerraGator chassis sells for approximately $150,000.

This unit can be fitted with dry lime spreaders, manure and compost spreaders, fertilizer spreaders, liquid spreaders, or other material hauling type boxes. It is the best machine available for implementing large-scale projects under adverse conditions. It can be operated as two or four wheel drive. It can also be used as a tractor to tow agricultural implements.

The soil amendment spreading equipment mounted on the TerraGator chassis frequently consists of commercially available, or modified versions of, highway sanding boxes. Western Reclamation designed and constructed a spreader box specifically for spreading dusty, fine-grain kiln dust, lime, and compost. The unit is capable of hauling ten ton loads of lime material with minimal fugitive dust. Specially designed heavy-duty bottom chains, material dividing channels, and very low speed spinners make this unit the best choice for spreading fine-grain lime material. Wind deflecting skirts can also be attached to the spreader unit.

Figure 1. TerraGator Spreader

COMMERCIAL MANURE SPREADERS

Commercial spreading equipment (Figure 2) has significant limitations, but can be used successfully for spreading lime, compost, and manure on smaller projects. The spreader must have a minimum of two separate heavy-duty bottom conveyor chains with closely spaced heavy-duty cross bars. Uniform calibration and spreading can be achieved only if the unit is equipped with an optional end gate located in front of the beaters (referred to as a slop gate). This type of spreader has zero tolerance for hard fragments of material such as large rocks or debris. Clean material is mandatory. In most cases, the commercial manure spreader cannot spread lime at rates less than ten tons per acre. The John Deere 680 manure spreader used by Western Reclamation has been completely rebuilt – including the running gear, spreader chains, spreader box, PTO drive line, and calibration gate.

Figure 2. Commercial Manure Spreader.

WESTERN RECLAMATION DISK PLOW

The Western Reclamation Disk Plow (Figure 3) is designed and constructed to mix soil amendments to a depth of 24 inches in adverse, non-agricultural areas. A D-6, low ground pressure (LGP) Caterpillar with a front blade is used to support and tow the plow unit. A reverse C-Frame with lift cylinders mounted on the back of the crawler serves as the plow hitch. The plow frame is constructed of heavy weight 10 and 12 inch square tubing with a special pivot point. The three heavy weight, concave, circular plow blades (32 to 38 inch diameter) are mounted on specially designed bearing assemblies and adjustable shanks welded into a twelve inch square tube main plow beam. The plow beam is designed to swing right or left 40 degrees from the line of travel.

The D-6, LGP with a heavy blade mounted on the front as a counterweight pulls the main plow beam and blades at an angle of approximately 35 degrees to the direction of travel. The crawler mounted C-Frame and hydraulic lift cylinders are used to establish the depth of plow blade penetration. The circular plow blades rotate slowly as they are pulled forward, effectively lifting bottom soils to the surface and mixing surface soils with the plowed profile. At the end of the field, the crawler tractor operator turns around and moves the main plow beam 70 degrees (35 degrees to the opposite side of the previous position) and then lowers the blades and proceeds to plow back along the furrow from the previous pass.

The capabilities of this plow are dependent on variables such as soil characteristics, steepness of sloping ground, and the size of the parcel being plowed. Small areas require extensive turning and backing up time, thus lowering efficiency. Steep slopes lower plowing efficiency and require a change in plowing techniques. Steep slope contour plowing ceases to be efficient at an approximate 3:1 slope. On steeper slopes, the plowed and turned soil tends to fall back into the furrow. Also, the crawler tractor slides and moves laterally downhill and cannot keep on line with the furrow of the previous pass. The deep plowing of steep hills can be accomplished by plowing straight down the slope. This technique was demonstrated on the Smelter Hill ARTS test plot locations. Rocky and compacted soils must be ripped on two-foot centers, prior to plowing, for the plow to achieve the required depth.

The original designers and manufacturers of disk plows specified that they were unsuitable for rocky and compacted soils. Extensive ripping to loosen soils and large rocks overcomes this negative plow characteristic. This plow will penetrate to a depth of 18 to 24 inches in rocky, heavy clay soils after ripping. Loose, sandy soils and tailings can be plowed to a depth of 24 to 36 inches without ripping if multiple passes are completed.

Figure 3. Western Reclamation Disk Plow

OFFSET DISKS

Offset disks are designed to chop and turn surface debris under and to incorporate soil amendments.They consist of two rows, or gangs, of disks offset at an angle to each other. Each gang has a separate frame and axle assembly. The angle is adjustable for varying soil conditions. The disks may have notched or straight edges. Most offset disks have wheels that are raised or lowered hydraulically for transport and to regulate operating depth. The Rome Engineering and Manufacturing Company specializes in custom building extra heavy-duty industrial strength offset disks. They can produce implements with extra large and heavy-duty blades (up to 42 inches in diameter and ½ inch thick) to withstand rocky soils. Blades can be spaced further apart to enhance penetration of compacted soils and aid in soil amendment mixing. Frames are designed extra heavy duty to withstand the rigors of being towed with crawler tractors.

Western Reclamation's Rome Disk (Figures 4 and 5) is 12 feet wide, has 42" diameter disk blades with over 1,000 pounds of down pressure on each cutting blade and requires a 200 to 300 draw bar horsepower tractor. This implement costs over $35,000 and requires several months of lead time as they are custom built on special order.

As offset disks are pulled over the area to be treated, the front gang of disks turns the soil one way and the rear gang turns it the other, giving a double disking action. Debris or brush is chopped up and incorporated into the soil. Offset disks can effectively control weedy plant growth while preparing an adequate seedbed and often break up surface soil compaction on reclamation areas or construction sites. They are well suited to dry, heavy soil and can be used on moderately rocky soil. These implements become less effective and more difficult to operate as slopes approach 3:1 grades. Soil amendments such as lime or compost require two or three passes to achieve good mixing to a depth of 12 inches. This depth is dependent upon the degree of soil compaction and the quantity of rocks limiting blade penetration. A Rome Disk (12 feet wide), towed at an average speed of two miles per hour under reasonable working conditions, should average approximately two acres per hour. Light-duty disks designed for agricultural fields cannot

penetrate rocky and/or compacted soils and cannot achieve 12 inch mixing depths. Frequent breakage occurs if this type of disk is used for industrial lands.

Figure 4. Rome Disk

Figure 5. Rome Disk

CUSTOM-BUILT, HEAVY-DUTY RECLAMATION DRILLS

Custom heavy-duty reclamation drill seeders are designed and fabricated by experienced reclamation specialists who have experimented and field tested commercial drills over thousands of hours of adverse drilling conditions. Observations of the most

frequent breakage allow for more durable and reliable designs for drilling in rough, rocky, and steep terrain.

Custom drills should have very long, heavy-duty trailing arms and extra heavy-duty disk type openers. Heavy-duty spring loaders on the trailing arms enable each arm to ride independently over rocks, irregular contours, and debris. Depth bands should be utilized to control seeding depth. Custom drills may be drawn by tractor but the most effective rough terrain reclamation drills are mounted on articulating, four wheel drive machines (Figure 6) equipped with wide flotation tires. Separating, divider plates within the seedbox are necessary to prevent the bulk of seed in the hopper from shifting to the downhill side and depriving the uphill openers of seed.

Custom drills use the same basic seed placement techniques as agricultural drills. The primary differences are as follows: a well built custom drill can accomplish precise seed placement under adverse seedbed and slope conditions and continue to operate on steeper and rougher terrain without malfunction and/or breakdowns.

These custom machines are specifically designed for seeding rough, rocky, and steep terrain. An experienced operator, with a well-designed custom drill, can drill seed areas totally inaccessible to conventional drills. However they are just as effective as conventional drills, and faster, on flat, rock-free areas. They can plant a variety of seed mixes at any rate desirable. Seeding depth is easily controlled. Minimal down time is a good indicator of a well-designed, custom-built, heavy-duty reclamation drill. They require extensive lead time to be manufactured. Tractor drawn custom drills are limited to 3:1 slopes but four wheel drive machines can negotiate 2.5:1 slopes on the contour if the soil is stable. Production rates of two and a half acres per hour can be expected if the terrain and soil conditions are reasonable. Drill seeder widths should not exceed much more than eight feet so that all the seed openers can effectively follow uneven surface contours and negotiate erosion control ditch berms.

Figure 6. Custom-Built, Heavy-Duty, Four-Wheel Drive Reclamation Drill

STRAW AND HAY MULCH SPREADERS

Straw and hay mulch spreaders are used to uniformly distribute organic stem and leaf materials over a prepared seedbed. A popular, commercially manufactured mulch spreader (Finn Corp) consists of a small (approximately 50 lb.) bale feed tray, high speed beaters, a blower powered by a large gasoline engine, and a pivoting distribution nozzle. The entire apparatus is mounted on a two-wheel trailer. After the beaters break up the bale, the blower picks up and mixes the material with a large volume of high velocity air. The material is carried up to fifty feet distant from the blower machine. This equipment is labor intensive as it requires a tow tractor operator, a spreader nozzle operator, and two to three bale handlers. It can be somewhat dangerous – the beaters and blowers can eject rocks or other projectiles. Another significant hazard is the operators standing and moving around on a trailer being towed over rough terrain.

Bernie Jensen of Western Reclamation Inc. has developed a spreader (Figure 7) that uses 1000 pound straw bales and requires only one operator located inside the enclosed cab of the towing tractor. Large bales are placed upon a controlled, chain feed apron using a second tractor (usually the crimper) equipped with a large bale handling grapple mounted on the loader bucket. The chain feed moves the bales into slow rotation rollers that meter the mulch to the flails and spreading spinners. The Western Reclamation spreader, using two operators working safely inside air-conditioned cabs, can spread and crimp mulch at a faster rate than five people operating a blower spreader. Also, slow speed rollers, as opposed to high-speed beaters, do not chop the material into short lengths. Longer stem mulch can be crimped into the soil much more effectively than short stem. The blower machine, however, can spread mulch on short distance slopes too steep for tractors.

Figure 7. Western Reclamation Straw Spreader

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RECLAIMING LANDSCAPE VISUAL QUALITY ON SURFACE MINING SITES USING COMPUTER VISUAL SIMULATIONS

John C. Ellsworth, ASLA[1]

ABSTRACT

Restoring visual quality is an important goal for reclamation of surface mines and other drastically disturbed landscapes. Visual quality management on USDA Forest Service and USDI Bureau of Land Management lands is accomplished with a variety of techniques, including the use of sophisticated computer visual simulations. The basic concepts, policies, analytical systems and procedures of these two agencies' visual resource management systems are discussed, with emphasis on computer visual simulation applied to surface mined lands.

Computer visual simulations are used to portray proposed landscape changes with photo-realistic quality. This sophisticated technology is a valuable tool for planners, landscape architects, reclamation specialists, engineers, environmental consultants, government agencies and private operators in the design and planning of surface mining operations. Several surface mining reclamation case studies, completed by the author over the course of the last ten years in the intermountain west, are presented. Detailed discussion covers the value of computer visual simulations not only in visual resource reclamation planning, but also for the design of post-mining landform, revegetation, and erosion control. Discussion of the use of this technology in facilitating stakeholder involvement is included. The issues of computer visual simulation accuracy, realism, credibility, representativeness, defensibility, and bias are discussed. Computer visual simulations are shown to be powerful and effective tools for setting reclamation goals, facilitating interdisciplinary discussion and decision making, project permitting, and evaluating reclamation success.

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Author's note: The presentation of this paper included many color slides of computer visual simulations and other images, which could not be adequately reproduced here due to space and black and white only printing restrictions.

INTRODUCTION

Surface mining sites are often located on public lands, federal or state, and are subject to reclamation laws and regulations. Restoration of visual, or scenic, quality is an important goal for reclamation of surface mines and other drastically disturbed landscapes. Computer visual simulations are an effective tool for visualizing the effects of proposed surface mining activities on visual resources as well as on various other natural and cultural resources.

Visual Resource Management and US Federal Land Management Agencies

Visual quality management on federal lands managed by the USDA Forest Service, USDI Bureau of Land Management, and other agencies is conducted with a variety of analytical techniques. Computer visual simulations are frequently used to visualize the impacts to visual and other natural resources. The basic concepts and procedures of these visual resource management systems were established over two decades ago, with ongoing updates and revisions.

USDA Forest Service VMS and SMS

In the early 1970's, the US Forest Service was the first federal agency to develop a systems approach to the inventory, analysis, and management of landscape visual resources (USDA Forest Service 1973; 1974). Their Visual Management System, or VMS, process established visual quality objectives (VQO's) through an analysis of the landscape's physical/scenic character, its visual variety, and visitors' concerns for scenic quality (called sensitivity levels). These visual quality objectives were intended to measure "degrees of acceptable alteration of the natural landscape" (USDA Forest Service 1974, p. 9). Visual simulations, some developed with the use of computers, were often used by National Forest landscape architects and others to depict the impact of proposed activities on the forest landscape's visual quality. A series of Forest Service VMS handbooks addressed visual resource management for various activities, including utilities, range management, roads, timber management, fire, ski areas, and other forms of recreation (USDA Forest Service 1975; 1977a; 1977b; 1980; 1985a; 1985b; 1987).

In 1995 the VMS was superceded by the updated and revised Scenery Management System, or SMS (USDA Forest Service 1995). The SMS retained many of the basic VMS concepts, with new emphasis placed on understanding the needs and concerns of the public and forest users ("constituents", sometimes referred to as "stakeholders"). It also encouraged the use of Geographic Information Systems (GIS) in the mapping of not only the physical attributes of the forest landscape, but also the visual and perceptual aspects such as the influence of the viewers' distance from the activity and concern for scenic values. The specific VMS activities handbooks, listed above, were

retained as part of the SMS and continue to provide some guidance for use of visual simulation in managing forest visual resources.

USDI Bureau of Land Management VRM

As with the US Forest Service, the Bureau of Land Management is responsible for the care and management of millions of acres of public lands, primarily in the western US including Alaska. In 1980, BLM initiated their Visual Resource Management (VRM) program (USDI Bureau of Land Management 1980a; 1984; 1986b). The VRM process incorporates three major steps: inventory/evaluation, visual management class designation, and contrast rating. The first two steps are similar in many ways to the Forest Service VMS. They address the landscape's visual quality (based on physical and cultural attributes), viewer sensitivity to visual change in the landscape, and viewer distance from the landscape. These two steps result in the establishment of up to four visual management classes, ranging from no allowable visual resource disturbance to extensive disturbance.

The BLM VRM system differs from the Forest Service's VMS by addressing project scale analysis as part of the basic process. Using the third step of VRM, called contrast rating (USDI Bureau of Land Management 1986a), the land manager, often a landscape architect, determines the degree to which a particular project (for example, a road, power plant, or surface mine) visually contrasts with the existing landscape. This contrast analysis is based on visual design principles and elements such as form, line, color, and texture.

VRM specifically mandates the use of visual simulations in this contrast rating analysis (USDI Bureau of Land Management 1980b). In simplest terms, the proposed project is simulated as it would appear in the landscape, then its contrast (in form, line, color, and texture) with the existing landscape is evaluated. If the contrast is too great, the project may require redesign in order to reduce its visual impact, or in extreme cases the project may not be approved at all. The development of visual simulations by manual (hand drawn) techniques is the subject of a training seminar conducted by the BLM at their National Training Center in Phoenix, Arizona (USDI Bureau of Land Management n/d). The author is currently developing an extensive training course in computer visual simulation for the BLM National Training Center (Ellsworth 2000).

Other Federal Land Management Agencies

Some other federal agencies have initiated landscape scenic management systems. Most are less extensive in scope and process due in part to the smaller and more specific landscape types managed.

The US Federal Highway Administration developed a system in the late 1970's called Visual Impact Assessment Procedures for Highway Projects (US Federal Highway Administration n/d). This system is distinguished by its detailed and flexible step-by-step

approach to assessing the visual impacts of highway projects of various scales (and of associated land disturbing activities such as borrow pits and cut and fill excavations).

The US Army Corps of Engineers (Smardon, et al 1988) developed their own system for assessing the visual impacts of water and related projects. Their Visual Resource Assessment Procedure (VRAP) shares some features with the Forest Service and BLM systems, in particular two major steps of management classification and visual impact assessment. The procedure requires ten specific steps, using detailed paperwork forms, in order to complete the visual resource assessment.

Computer Visual Simulations

Computer visual simulations are used to portray proposed landscape changes with photo-realistic quality. When done well, they illustrate the proposed conditions of a multitude of natural and cultural resource values.

Value of Computer Visual Simulations

For landscape architects and others with a primary concern for design and visual values, computer visual simulations are an indispensable design, analysis, and communication tool. Revegetation and hydrology/erosion control specialists can see how their plans will take physical form and the relationships among plants, structures, soils, and slopes. Mining engineers and planners can more effectively explore and evaluate alternative excavation, processing, facilities siting, and reclamation strategies when seen in credible, full color visual simulations. Environmental consultants and government agencies with a responsibility to their clients and the public use computer visual simulations to facilitate design reviews and public/stakeholder involvement, and to assure compliance with environmental laws and regulations.

The Technology

Today, computer visual simulations are developed using desktop computer technology. The essential elements include a camera (film or digital), computer with graphics software, high resolution monitor and color scanner, and high quality color printer (or film recorder for making slides). When this readily available hardware and software is used by skilled and trained designers and resource managers, it can result in highly useful and affordable visual simulations.

Computer Visual Simulation Issues

The development and use of computer visual simulations present a number of issues, both technical and ethical. They include accuracy, realism, credibility, representativeness, defensibility, and bias (Ellsworth 1996a; 1996b; Sheppard 1989).

Accuracy is considered one of the most important, yet least understood computer visual simulation issues (Ellsworth 1999). It is often assumed that a photographic quality

visual simulation must be perfectly accurate in order to be an effective evaluation tool. In fact, this is not necessarily true. For example, research has shown that most observers cannot detect scale inaccuracy until it approaches almost +/-15% (Watzek and Ellsworth 1994). Since this level of accuracy can be readily and affordably achieved in almost all visual simulation work, there is little value in the added time and expense required to achieve nearly perfect accuracy.

Realism, or a lifelike appearance (Sheppard 1989), is related to accuracy and credibility. With today's highly sophisticated technology, almost anything can appear real (we have probably all seen films like Jurassic Park or the Terminator). The challenge in computer visual simulation for surface mining is to depict conditions that could actually be real, not just appear real. In other words, conditions that are actually part of the mining or reclamation plan and are achievable in the real world, not just wishful thinking.

Representativeness is the extent to which a simulation shows typical views of a proposed project (Sheppard 1989). This is an important part of both the Forest Service and BLM procedures. Typical viewpoints, called key observation points (KOP's) in the VRM system, are often identified by an inter-disciplinary team in consultation with users and the public.

Bias, related to defensibility (as are all of the above issues), occurs when the viewer's reaction to a visual simulation is favorably or unfavorably affected for no valid reason (Chenoweth 1989; Sheppard 1989). Bias can take many forms such as alterations in form, line, color, texture, scale or the introduction or omission of specific elements or objects. Unintentional or careless bias can be frustrating, time consuming, and expensive when discovered. Intentional bias may result in much more serious consequences, both for the clients and users, and for the landscape if not detected before project implementation.

Computer Visual Simulation Applications for Surface Mining

Several surface mining reclamation case studies have been completed by the author over the course of the last ten years in the intermountain west. These projects were done for a variety of clients, on both private and public lands. Some were part of environmental assessment (EA) or environmental impact statement (EIS) processes. The basic desktop computer technology, as discussed above, was used on all projects. As the sophistication of the technology (especially image resolution and color depth) has improved over the years, the viewer will note a marked increase in the quality of the images.

Palomar Aggregates Mine

This project was done by the author more than ten years ago, using the technology of the time (an IBM 286 computer running at 12 megahertz with a whopping 2mb of memory and an 80mb hard drive!). The site is in southern California, near San Diego.

The client, an engineering firm, was involved in the planning for a proposed aggregates mine. Visibility was an important issue due to the proximity of the site to a major interstate highway and to a recreation area.

The most important visual disturbances were a six hundred foot highwall and the removal of the top of the peak. These would be easily seen from the highway and the recreation area. In order to assess the visual impacts, a series of computer visual simulations were developed from various viewpoints along the highway and at the recreation site. The simulations were done in the early stages of planning, and were of great benefit in refining and communicating the subsequent stages of mine plan development.

Black Pine Gold Mine

This project began in 1993 (using newer, faster, and higher image quality technology). It is a heap leach gold mining operation, located in southeastern Idaho near Burley. The client, Pegasus Gold, was in the process of planning for mine reclamation over five years. It is on US Forest Service land. Computer visual simulations were considered a valuable and necessary reclamation planning tool.

The visual simulations represented mine expansion and reclamation over a five to ten year period. The consulting landscape architects were asked to visually show new landform design as visually similar, in terms of topography and slope, to the surrounding landscape. Based on reclamation experience on-site, the mine reclamation specialists predicted 50% to 70% revegetation success.

Several mining activities were simulated, giving a clear picture of recontouring, revegetation, landform design, and erosion control. An existing mine exploration road was shown fully revegetated in three to five years, based on success at a similar altitude and aspect. A waste pile was shown regraded, and revegetated. A visual simulation of an existing mine haul road emphasized steep slope regrading, drainage channel restoration, and revegetation. The visual simulations were an essential part of the mine expansion and reclamation/closure plan submitted for agency review.

Rattlesnake Hills Quarry

The Bureau of Land Management required Umetco Minerals to produce an environmental assessment for their proposed Rattlesnake Hills Quarry in central Wyoming. The company was in the process of reclaiming and closing its nearby Gas Hills Uranium Mine and Mill to comply with regulations promulgated under the federal Uranium Mill Tailings Radiation Control Act of 1978. This would require stabilizing approximately 10 million tons of radioactive mill tailings by placement of earthen, vegetative, and rock cover durable for a minimum of 200 years (1,000 preferred). Quartzite rock on BLM land in the Rattlesnake Hills was determined suitable for these purposes, and an EA was submitted to BLM for the mineral sale. Approximately 500,000 cubic yards would be excavated from the 145 acre site over about three years.

Using the BLM VRM system, a series of key observation points (KOP's) were established by the author in consultation with state and federal agencies. Two of these KOP's were considered most useful, one from approximately .75 mile away and the other from 1.5 miles away. Computer visual simulations were developed, and used in the contrast rating process to determine the visual acceptability of the project. This process determined that the project met the visual quality requirements of the designated visual management class for the area. The contrast rating and computer visual simulations were submitted as part of the EA and at public meetings. The project was recently approved by BLM.

SUMMARY

Computer visual simulations have proven to be powerful and effective tools for achieving surface mining reclamation goals. They are useful in facilitating interdisciplinary discussion and decision making, project permitting, and reclamation success evaluation. Computer visual simulations can play a valuable and important role in surface mine planning and design when used by skilled and experienced professionals who understand the range of applications, technological capabilities, and technical and ethical issues.

REFERENCES

Chenoweth, R. 1989. Aesthetic Policy Implications of Image Processing Technology. Presentation to the American Society of Landscape Architects Annual Meeting, Orlando, Florida.

Ellsworth, J.C. 1996a. Computer Visual Simulations and Surface Mine Closure: Three Case Studies. Paper and poster session at the 20th Annual British Columbia Mine Reclamation Symposium, Kamloops, BC, Canada, June 20

Ellsworth, J.C. 1996b. Computer Visual Simulations in the Design and Planning of Surface Mine Reclamation. Presentation and paper at the 1996 Annual Conference of the International Erosion Control Association, Seattle, Washington, February 29.

Ellsworth, J.C. 1999. Ten Years of Computer Visual Simulations on Large Scale Projects in the Western United States. Paper and presentation to the American Society for Surface Mining and Reclamation Annual Conference, Scottsdale, AZ, Aug. 13-19.

Ellsworth, J.C. 2000. Computer Visual Simulation Training Course. USDI Bureau of Land Management National Training Center (in progress). Phoenix, Arizona.

Sheppard, S.R.J. 1989. Visual Simulation: A User's Guide for Architects, Engineers, and Planners. New York: Van Nostrand Reinhold.

Smardon, R. C., J. F. Palmer, A. Knopf, and K. Grinde. 1988. Visual Resources Assessment Procedure for US Army Corps of Engineers. Instruction Report EL-88-1 for US Army Corps of Engineers. Washington, D.C.: Department of the Army, US Army Corps of Engineers.

USDA Forest Service. 1973. National Forest Landscape Management: Volume 1. Agriculture Handbook No. 434. Washington, D.C.: U.S. Department of Agriculture.

USDA Forest Service. 1974. National Forest Landscape Management: Volume 2, Chapter 1: The Visual Management System. Agriculture Handbook No. 462. Washington, D.C.: U.S. Department of Agriculture.

USDA Forest Service. 1975. National Forest Landscape Management: Volume 2, Chapter 2: Utilities. Agriculture Handbook No. 478. Washington, D.C.: U.S. Department of Agriculture.

USDA Forest Service. 1977a. National Forest Landscape Management: Volume 2, Chapter 3: Range. Agriculture Handbook No. 484. Washington, D.C.: U.S. Department of Agriculture.

USDA Forest Service. 1977b. National Forest Landscape Management: Volume 2, Chapter 4: Roads. Agriculture Handbook No. 483. Washington, D.C.: U.S. Department of Agriculture.

USDA Forest Service. 1980. National Forest Landscape Management: Volume 2, Chapter 5: Timber. Agriculture Handbook No. 559. Washington, D.C.: U.S. Department of Agriculture.

USDA Forest Service. 1985a. National Forest Landscape Management: Volume 2, Chapter 6: Fire. Agriculture Handbook No. 608. Washington, D.C.: U.S. Department of Agriculture.

USDA Forest Service. 1985b. National Forest Landscape Management: Volume 2, Chapter 7: Ski Areas. Agriculture Handbook No. 617. Washington, D.C.: U.S. Department of Agriculture.

USDA Forest Service. 1987. National Forest Landscape Management: Volume 2, Chapter 8: Recreation. Agriculture Handbook No. 462. Washington, D.C.: U.S. Department of Agriculture.

USDA Forest Service. 1995. Landscape Aesthetics: A Handbook for Scenery Management. Agriculture Handbook Number 701. Washington, D.C.: Government Printing Office.

USDI Bureau of Land Management. n/d. Visual Design Techniques for Surface Disturbing Activities. Phoenix Training Center, Handbook for Course Number FP 8400-2.

USDI Bureau of Land Management. 1980a. Visual Resource Management Program. Stock No. 024-011-00116-6. Washington, D.C.: Government Printing Office.

USDI Bureau of Land Management. 1980b. Visual Simulation Techniques. Stock No. 0-302-993. Washington, D.C.: Government Printing Office.

USDI Bureau of Land Management. 1984. Visual Resource Management. BLM Manual Section 8400 revision. Washington, D.C.: Government Printing Office.

USDI Bureau of Land Management. 1986a. Visual Resource Contrast Rating. BLM Manual Handbook 8431-1. Washington, D.C.: Government Printing Office.

USDI Bureau of Land Management. 1986b. Visual Resource Inventory. BLM Manual Handbook 8410-1. Washington, D.C.: Government Printing Office.

U.S. Federal Highway Administration. n/d. Visual Impact Assessment for Highway Projects. Washington, D.C.: American Society of Landscape Architects.

Watzek, K.A., and J.C. Ellsworth. 1994. Perceived Scale Accuracy of Computer Visual Simulations. Landscape Journal, Spring, pp. 21-36.

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CONQUERING TABLE MOUNTAIN PIPELINE RESTORATION PROJECT BY HAND AND HELICOPTER

David R. Chenoweth[1]

ABSTRACT

Western States Reclamation, Inc. (WSRI) completed a difficult and diverse restoration project for Public Service Company of Colorado on the Table Mountain segment of the Natural Gas Pipeline Installation near Golden, Colorado. This portion of the pipeline project was of concern to Public Service Company because of the visual impacts it could create from the I-70 corridor, and members of the Coors family who resided at the base of Table Mountain. Also, the Table Mountain segment of the natural Gas Pipeline contains two dimensional steep slopes, which traversed both herbaceous and woody plant communities.

The objective of the land restoration efforts were initially to control erosion, while re-establishing both herbaceous and woody plant materials that would visually mask the pipeline disturbance as quickly as possible. Due to the steepness of the slopes and the inability to access this portion of the pipeline with hydroseeders or other standard seeding equipment, WSRI employed the use of all terrain vehicles to haul woody plant materials to the site for hand installation. Also, hand broadcast seeding and aerial applications of Bonded Fiber Matrix were completed.

This paper focuses on revegetation planning, adaptation of creative installation methodologies and materials, followed by an intensive monitoring and maintenance program. All of these important elements have led to today's notable high success of the self-sustaining cover for both herbaceous and woody plants.

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INTRODUCTION

Western States Reclamation, Inc. (WSRI) was contacted by Public Service Company of Colorado in March of 1998 to determine the best approach to control erosion and revegetate the Table Mountain segment of the Natural Gas Pipeline that traversed the west side of the City of Denver. The Table Mountain segment of the pipeline is located near Golden, Colorado and begins on the northern end of the Rolling Hills Golf Course and terminates on the south near the National Renewable Energy Laboratory (NREL). This project was highly sensitive because of the visual impacts it created for the I-70 corridor and homes occupied by the Coors family (related to the famous Coors Brewing Company).

The challenges in controlling erosion and revegetating the Table Mountain segment were limited access due to two dimensional slopes (both vertical and horizontal slopes) and the requirements to establish both herbaceous and woody plant cover similar to the pre-disturbance vegetative cover. As with many pipeline projects, the public's expectations were for good to exceptional vegetative cover as quick as possible to reduce the eyesore of the disturbance created by the actual pipeline installation.

REVEGETATION PLAN

Since access on over 60% of the pipeline prohibited safe use of traditional revegetation equipment, including hydroseeders/hydromulchers mounted on trucks and 4-wheel drive tractors with implements, other methods of seeding and erosion control had to be determined. WSRI worked with Public Service Company and their environmental consultant to arrive at a safe and efficient means of hauling and planting over 2,000 woody plants to the work zone, seeding, mulching, and installation of erosion control blankets.

The final plan for execution consisted of both extensive hand labor for seeding and woody plant installation. Seeding was followed by use of erosion control blankets on the more accessible portions of the slopes, and aerial applications of Bonded Fiber Matrix on the most inaccessible portions of steep slopes. Drill seeding and hydromulching with tackifier were used on all other accessible areas of the pipeline.

WSRI determined it would be best to install woody plant materials first, followed by broadcast seeding and installations of Bonded Fiber Matrix. On the other hand, the woody plants were installed after hand seeding and installation of erosion control blankets on the lower portion of the Rolling Hills Golf Course side of the pipeline.

The planting zones were divided by upper slope areas and lower slope areas. The woody plants on the upper slope areas included Wild Plum, Black Chokecherry, Skunkbush Sumac,

and Western Snowberry.

The lower slope area woody plants consisted of Mountain Mahogany, Skunkbush Sumac, Wild Plum, and Western Snowberry.

REVEGETATION EXECUTION

Work commenced on the project during the first week of April, and the majority of the woody plant and grass planting was completed by mid-May. Work was interrupted twice during April because of spring snow showers and rain. These precipitation events proved later to be very instrumental in providing much needed moisture to the woody plants and grasses.

The size of the plant materials consisted of a mixture of 5 gallon, 1 gallon, and 2 1/4" pots, and were driven by the market availability of plants and the desire to complete all woody plant installations during early Spring. The objective in installing all woody plants was to attempt the highest possible survival rates and reduce the amount of re-planting during the maintenance period.

Also, the difficulty in re-accessing the site after initial planting was a strong consideration. Therefore, as individual plantings occurred, a brush mat or filter fabric was placed around each plant with dimensions of approximately 2 ft. in diameter. Oasis Tree Shelter Cones 24" in height were then slipped over each plant for protection. The shelter cones offered protection from deer browse, temperature extremes, and ultimately from overspray of Bonded Fiber Matrix.

WSRI utilized a Kawaski Mule ATV to haul the plant materials to the work zone. Shovels, hoedads, and plant dibbles were used for the actual installation of the plant materials.

On areas that received the erosion blanket, the plants were installed after application of the actual blanket by cutting an “X” slit in the blanket to accommodate each planting.

Three different grass seed mixtures were designed to accommodate different micro-climates and vegetation zones. These grass seed mixtures consisted of an upland, warm season, and steep slope seed mixtures. The grass species in each mix were native and/or indigenous to the project site. A number of native wildflowers were also added to each native grass mixture. The environmental consultant’s concern was the varying textures and sizes of each grass and wildflower species and how WSRI would maintain an even distribution of species. Therefore, WSRI purchased and utilized a Truax hand held broadcast seeder which is unique because of its aggressive agitation system when compared to other hand broadcast spreaders. In order to achieve good seed to soil contact, hard tine rakes were utilized to cover the seed lightly with soil.

The upper inaccessible portions of the slope area were then covered with Bonded Fiber Matrix

in a unique application process. WSRI had researched and contacted other erosion control contractors in the Pacific Northwest regarding their use of aerial applications of hydromulch and Bonded Fiber Matrix. A decision was made to purchase a slurry bucket that was equipped with a gas powered hydraulic setup and electronic controls which could be affixed inside the cockpit of the helicopter. Since Public Service owns and operates its' own helicopter for use in patrolling transmission lines and natural gas pipelines, a decision was made to utilize their craft. The helicopter used was a Bell Long Ranger. While this model of helicopter is known for its comfort in transporting passengers, it has a limited lift capacity when compared to other helicopters.

WSRI realized the most critical element from a labor cost standpoint was quick cycle times between the loading/landing zone and the spray zone. A 4,000 gallon water truck was utilized to feed WSRI's 3,000 gallon Finn hydromulcher. This allowed continuous mixing and cycling of Bonded Fiber Matrix material. Three personnel were utilized for loading material into the slurry bucket, while the pilot continuously cycled between the loading zone and the spray zone. The pilot would hover as the bucket was loaded, saving time because we did not have to transition from reduced power.

To our delight the coverage from the slurry bucket was very impressive as the process advanced. The credit for the even application was Public Service Company's skilled pilot which completed the application. WSRI applied 3,000 pounds per acre of Bonded Fiber Matrix to all areas of the steep slope.

As previously mentioned, erosion control blankets were installed on the lower extremities of the steep slope areas where access was more prevalent. The erosion control blankets consisted of Bionet Straw Blankets with netting on both sides, Green Fix Model #WSO72B. This material was picked by WSRI and the environmental consultant because the netting would biodegrade the fastest.

Other portions of the pipeline project allowed access and use of a rangeland drill for drill seeding and a truck mounted hydromulcher for hydromulching.

REVEGETATION MAINTENANCE

During the planning stage of the revegetation efforts, WSRI suggested to Public Service Company and the environmental consultant that both monitoring and maintenance of the revegetation work efforts would be necessary. Initial monitoring was completed by WSRI, the environmental consultant and Public Service personnel during August of 1998. At that time an almost unheard of survival rate for woody plants was documented. Overall counts of all species indicated up to 90% survival rate for woody plants.

Native grass germination and fill-in was equally impressive. The middle to lower sections of the pipeline project was so dense it had the appearance of an irrigated pasture.

This in part was due to springs and seeps in the area and an intermittent drainage channel which gently flowed across the reclaimed site.

Upper portions of the pipeline project while good in grass cover were not quite as impressive. A notable stand of sunflowers and Canada thistle were present on this portion of the pipeline project.

WSRI feared that use of herbicide applications at this point would kill newly germinating grasses and damage ungerminated seed material in the soil surface. A decision was made to control the sunflowers and Canada thistle by use of weed eaters and cutting off the seed heads before further spread and germination of weed seeds could occur.

Another inspection of the site during this April 1999 indicated that the survival rates had not changed appreciably and maintained approximately 80%-85% survival. The weed cover persisted in being a problem on the upper slope portion. Even though it appeared the grass cover was better than witnessed in August 1998, a decision was made to apply herbicide with the use of backpack sprayers. An application of HI-DEP herbicide was utilized to help reduce weed cover and further enhance the herbaceous cover on what appears to be the only area of concern on the entire pipeline segment.

SUMMARY

In conclusion, WSRI attributes the high success of this revegetation project to the following.

1. The quality time spent in the planning stage which identified proper methods, materials and maintenance needed to encourage revegetation success.
2. Early spring plantings followed by spring snows and rainfall events.
3. The use of superior products to compliment the grass seeding and woody plant installations including the Brush Mats, Oasis Tree Shelter Cones, Bonded Fiber Matrix, and Green Fix erosion control blankets.
4. Public Service Company's commitment to allow WSRI to complete a monitoring and maintenance program and correct any problem areas/deficiencies as quickly as they were identified.

WSRI wishes to acknowledge the following vendors for their help on this project.

- Revex, Inc. for on-site assistance and timely delivery of Soil Guard, Mat Fiber Hydromulch, and Green Fix Erosion Control Blankets.

- Reforestation Technologies International in Monterey, CA for supplying Brush

Blankets and Oasis Tree Shelter Cones.

- David Buckner, PHD, ESCO Associates, Boulder, CO for excellent preparation of the revegetation plan and excellent teaming with WSRI.

2000 Billings Land Reclamation Symposium

HYDRAULIC CHARACTERISTICS OF SUBSURFACE FLOW WETLANDS

W. J. Drury[1] and K. Mainzhausen[2]

ABSTRACT

Subsurface flow (SSF) wetlands were evaluated in a field study of treatment of water containing heavy metals. SSF wetlands convert sulfate to sulfide, which is an effective precipitant for copper and zinc. To produce the anaerobic environment required for sulfide production, the water surface must be below the wetland surface. Therefore, the flow rate that can be treated effectively is limited by the wetland dimensions and substrate permeability. Rapid catastrophic hydraulic failures have occurred in such systems due to the loss of substrate permeability.

Hydraulic conductivities (*K*) of four SSF wetlands were measured over a 2.5 year period. Two horizontal flow wetlands with a gravel-only substrate had *K* of 600 ft/d (2×10^{-3} m s^{-1}) at the end of the study period. A horizontal flow wetland with 20% (volume) compost in its substrate had a *K* of 200 ft /d (7×10^{-4} m s^{-1}). A vertical flow wetland containing 50% (volume) compost in its substrate had a *K* of 0.7 ft/d (2×10^{-6} m s^{-1}) after one year of operation. Subsequently, fracturing and non-Darcian flow occurred in this wetland.

Hydraulic conductivities decreased over time by over 90%, principally in the inlet regions of the wetlands. Filter fabric clogging was a problem. Downstream of the inlet zones, little change in *K* was observed.

Effective porosities were measured in the three horizontal flow wetlands annually using tracer (bromide) tests. After two years of operation, the effective porosities in all wetlands were 0.3 and decreased by an average of 11% from year one to year two. Dispersion numbers (*D/uL*) were approximately 0.1.

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INTRODUCTION

Acid drainage that contains heavy metals is an environmental problem that can occur at abandoned and closed mines. There are a number of proven treatment technologies for removing metals and acidity from water. However, the traditional technologies require significant operational attention and have high operations costs due to requirements for continuous chemical addition. Neither the government agencies reclaiming abandoned mine sites nor the mining corporations with closing mines wish to meet these requirements. Often the abandoned mine sites are inaccessible in winter. Maintaining electrical service from public utilities is difficult and costly. There is an interest in having treatment systems with low operational costs and requiring minimal maintenance.

A passive treatment system that has been used at abandoned and closed mines is constructed wetlands. Constructed wetlands can be built as surface flow (SF) systems or subsurface flow (SSF) systems (Kadlec and Knight, 1996). SF wetlands have the water in direct contact with the atmosphere and work best when oxidizing chemical processes are desired. They work poorly for water treatment when the primary metals of concern are copper (Cu) and zinc (Zn) (Wildeman *et al.*, 1993). In SSF wetlands, water flows through a gravel bed and the free water surface stays below the top of the gravel bed. SSF wetlands foster anaerobic, reducing chemistries such as sulfate reduction if the wetlands large enough to keep the water under the wetland surface. Sulfate reduction neutralizes acid (Wildeman *et al.*, 1993) and the sulfide produced by sulfate reduction is an excellent precipitant of Cu and Zn (Patterson, 1985).

Sulfate reduction requires a low oxidation-reduction (E_h) potential. At 25°C, a pH of 7, a H_2S concentration of 1 mg S/L and a SO_4^{2-} concentration of 100 mg S/L, the E_h must be –198 mV for sulfate reduction to occur. Such a low E_h corresponds to an oxygen partial pressure of 10^{-69} atm. For comparison, 1 mg O_2/L produces an E_h of +790 mV. For metal sulfide precipitation to occur, water must be kept below the substrate surface and away from the atmosphere.

Darcy's Law is used to determine the wetland cross-sectional area (*A*) for a chosen water flow rate *Q* and an estimated hydraulic conductivity (*K*) in SSF wetland design. Darcy's Law describes laminar flow through a porous medium:

$$Q = KA\frac{dh}{dl} \tag{1}$$

where *dh* is the change in head and *dl* is the length over which *dh* occurs. *K* is time-variable; it decreases over time from substrate compaction and loss of porosity due to filtration of solids in the influent water. Decrease in *K* can be quite sudden, leading to a rapid hydraulic failure where the substrate is unable to pass the influent flow through it and still keep the water surface underground.

The Atlantic Richfield Company (ARCO) was interested in use of constructed wetlands to treat water containing Cu and Zn. From 1993 to 1998 they cooperated with the Montana Tech of the University of Montana in

researching the capabilities and limitations of such wetlands. This project culminated with pilot-scale field studies conducted in 1996-1998.

SITE DESCRIPTION

This paper utilizes data obtained from ARCO's test site in Butte, MT at the northwest corner of Kaw and George Streets. Water was pumped from the Metro Storm Drain (MSD), a channel carrying intercepted groundwater and surface runoff, into the test system. MSD water has a pH between 6.5 and 7.0, and contains significant colloidal iron (Fe) hydroxide and dissolved Zn. The treatment system consisted of a settling pond followed by four SSF wetlands in parallel, followed by two SF wetlands (Jones, 1997; Mainzhausen, 1998). SSF wetlands characteristics are listed in Table 1.

Table 1. Characteristics of the four SSF wetlands. Length and width are at the surfaces of the cells. Gravel and crushed limestone sizes were ¼- to ¾-inch.

Cell	Volume (ft^3)	Length (ft)	Width (ft)	Depth (ft)	Composition (volume %)
1	27,000	109	109	2.5	80% river gravel 20% limestone
2	16,250	53	94	4.0	20% compost 60% river gravel 20% limestone
3	6,400	44	44	6.0	50% compost 30% river gravel 20% limestone
4	12,950	76	76	2.5	80% river gravel 20% limestone

Cells 1, 2, and 4 were horizontal flow SSF wetlands. Length is the dimension parallel to the flow direction while width is perpendicular to the flow direction. Cell 3 was a vertical upflow SSF wetland. Flow rates varied from approximately zero to 14 gpm.

Hydraulic conductivity was measured on a monthly basis, except in winter when ice accumulation in vertical pipes prevented water elevation measurements (Jones, 1997). Water surfaces were measured in cleanout pipes on the influent and effluent manifold pipes as well as sampling wells in the horizontal flow SSF wetlands. In the vertical flow SSF wetland, water elevations were measured in a cleanout on the influent pipe, from horizontal sampling wells in the wetland substrate and in the hydraulic control structure on the effluent pipe. A well probe calibrated to 0.01 ft increments was used to determine water elevations relative to surveyed elevations of the tops of the various pipes, wells, and hydraulic control structure. Influent and effluent flow rates were metered continually. Hydraulic conductivity was calculated using Darcy's Law. Particle-based Reynold's

numbers were two or less, making it acceptable to model SSF wetland hydraulics with Darcy's Law. Darcy's Law can be used only with laminar flow conditions represented by Reynold's numbers less than ten (Kadlec and Knight, 1996).

Tracer tests were performed in 1997 and 1998 on the horizontal flow SSF wetlands. Bromide was the tracer chemical. Effective porosities (η) were calculated from measured bromide concentrations (equation 2):

$$h = \frac{HRT * Q}{V} \tag{2}$$

where HRT is the mean hydraulic residence time measured in the tracer tests and V is the total cell volume. HRT was calculated from the bromide concentrations. Tracer test methods and calculations can be found in Jones (1997) and Mainzhausen (1998).

RESULTS AND DISCUSSION

Hydraulic conductivities measured from inlet to outlet of all SSF wetlands decreased by over an order of magnitude over time. Across Cells 1 and 4, *K's* were 600 ft/d (2 x 10^{-3} m s^{-1}; Figures 1 and 2) at project completion. *K* was 200 ft /d (7 x 10^{-4} m s^{-1}; Figure 3) across Cell 2 at project completion. Initial measurement of *K* in Cell 3 was 12 ft/d (4 x 10^{-5} m s^{-1}). Within a year, it dropped to 0.7 ft/d (2 x 10^{-6} m s^{-1}).

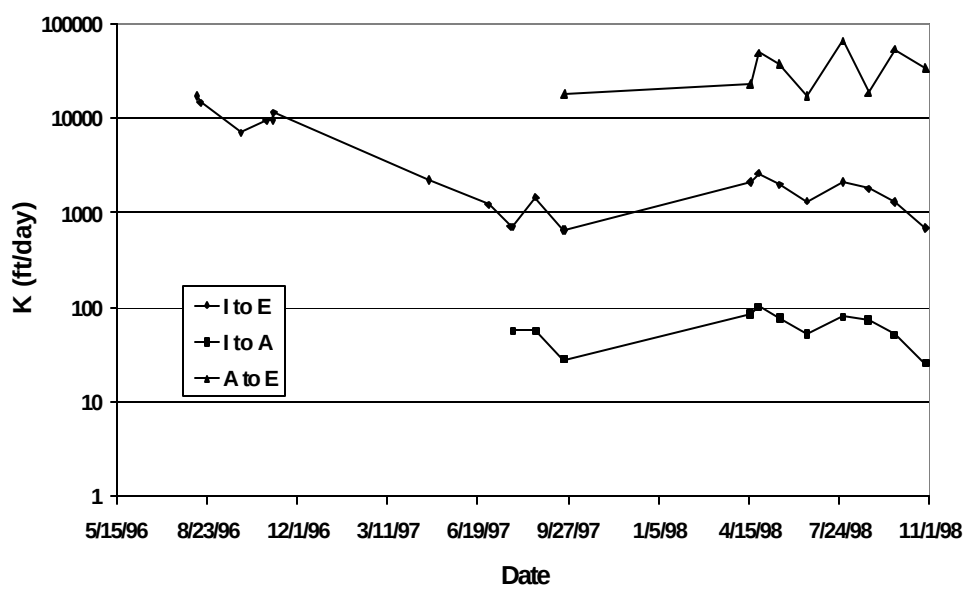

Figure 1. Hydraulic conductivity vs. date for Cell 1. "I" = influent manifold, "A" = piezometers immediately downstream from the influent manifold, and "E" = effluent manifold.

The majority of the head losses occurred at the entrances to these wetlands – from the influent manifold to the first row of sampling wells. The first row of sampling wells were located two to four feet downstream from the influent manifold in the horizontal flow SSF wetlands. Hydraulic conductivities downstream from the first row of sampling wells in these wetlands were constant over the 2.5 year project.

Inlet zones clogging of SSF wetlands may have been due to filtration of iron colloids and subsequent loss of substrate porosity. MSD water contains significant amounts of total iron – about 1 to 6 mg Fe/L. The iron colloids settled poorly in the settling pond. Thus, the influent water to the SSF wetlands contained iron colloids that filtered out on the substrates and filter fabric, clogging the pores and reducing *K*'s. It is unlikely that compaction would have caused longitudinal heterogeneity in *K*.

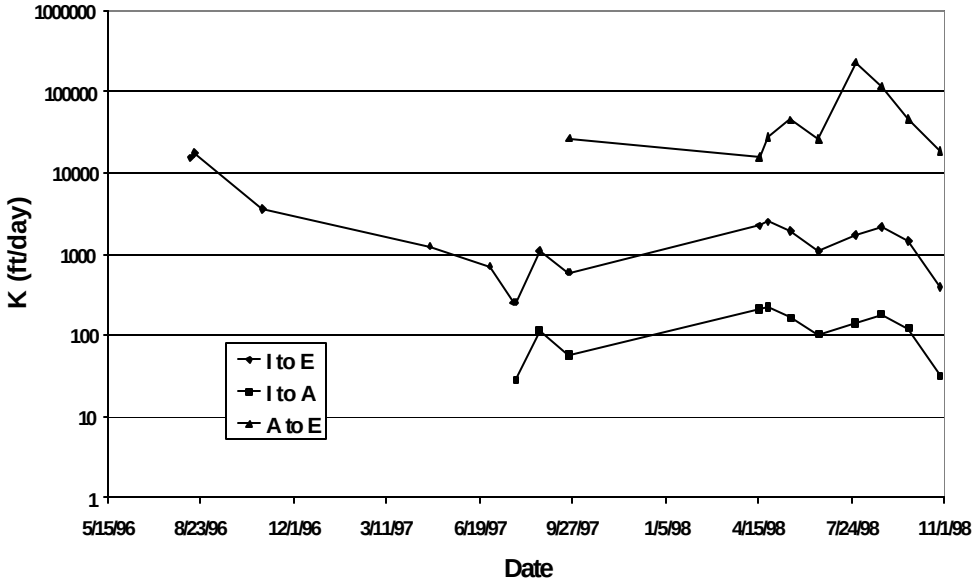

Figure 2. Hydraulic conductivity vs. date for Cell 4. "I" = influent manifold, "A" = piezometers immediately downstream from the influent manifold, and "E" = effluent manifold.

Filter fabric contributed to high head loss in the inlet regions of the SSF wetlands. In the horizontal flow SSF wetlands, water was distributed across the widths by buried perforated pipes. These pipes were surrounded by gravel packs, which in turn were surrounded by non-woven polyester filter fabric. The fabric clogged rapidly as they filtered solids out of the water. Filter fabric clogging in Cell 2 was visible within four months after start-up, and the filter fabric on the downstream side of the inlet zone was removed. Filter fabric clogging of the Cell 4 inlet was visible after 14 months of operation. While the inlet filter fabric in Cell 2 was exposed and visible to the eye, the filter fabric in the other wetlands was buried under the gravel substrates. Therefore, filter fabric clogging was difficult to observe in Cells 1 and 4. Eventually the fabric in Cell 4 ballooned to

the wetland surface because of the higher pressure within the fabric-wrapped zone, and the bulging and leakage through folds at one end of the fabric was observed. Filter fabric on the downstream side of the inlet zones and upstream sides of the outlet zones was subsequently removed from Cells 1 and 4. Fabric removed from the inlet zones had a two-mm layer of fine-grained orange solids, which appeared to be predominantly iron colloids, on their upstream sides.

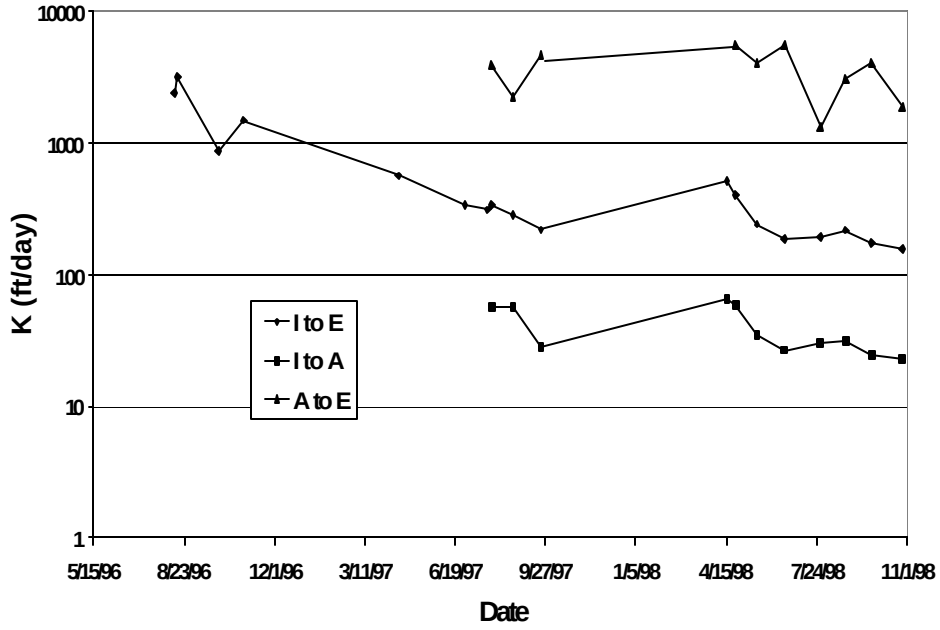

Figure 3. Hydraulic conductivity vs. date for Cell 2. "I" = influent manifold, "A" = piezometers immediately downstream from the influent manifold, and "E" = effluent manifold.

Hydraulic conductivity measurements to assess the effectiveness of filter fabric removal in Cells 1 and 4 could not be made immediately after this maintenance was done. Filter fabric removal in Cells 1 and 4 occurred in late October, 1997 after 17 months of operation. Wells from whom water elevations were measured froze within a week after this work, and *K* measurements could not be made until the spring of 1998.

Filter fabric removal caused a temporary improvement in *K* in Cell 1 and Cell 4. *K* values dropped to where they were before the filter fabrics were removed within a year (Figures 1 to 3).

Hydraulic conductivity of Cell 3 was low compared to the horizontal flow SSF wetlands. Measurements showed nearly all the head loss to occur between the inlet manifold piping and the lowest level of sampling piezometers, located one ft above the gravel pack around the inlet manifold. Between the inlet manifold and the lowest piezometers was a filter fabric separating the gravel pack around the inlet manifold and the wetland substrate. It could not be determined if the cause of the head loss was filter fabric clogging or a loss of porosity due to substrate settling

Cell 3 flow rates became too low for the flow meters to measure after about one year of operation. Periodic water pulses did move through Cell 3. The highly variable flow rate during this period may have been due to periodic substrate fracturing. Pressure would build until the substrate grains were displaced, letting water through quickly and relieving the high pressure. Darcy's Law does not describe transient flow and displacement of the granular medium, so no attempt at *K* measurements were made under such conditions.

Effective porosities were calculated from tracer data in the three horizontal flow SSF wetlands (Table 2). Effective porosity decreased, on the average, 11% over approximately one year. The pore volume decreases possibly attributable to metal sulfide accumulation between the two tracer tests, as a percentage of overall pore volume decrease, were 0.099%, 0.024%, and 0.032% for Cells 1, 2, and 4, respectively. This calculation assumes that the volumetric accumulation of all metals besides Zn was negligible, all Zn precipitated as ZnS (Gammons and Drury, 2000) and the amorphous ZnS solid had a specific gravity of 1. It can be seen that the majority of the porosity loss was due to reasons besides metal precipitates. Organic matter accumulation in SSF wetlands is an important reason for porosity loss in SSF wetlands used for BOD destruction (Tanner and Sukias, 1995), and could be a significant cause of porosity loss in SSF wetlands used for metals removal as well.

Vessel dispersion numbers (*D/uL*), a measurement of the amount of mixing in the SSF wetlands, were also calculated from the tracer test data (Table 2; Mainzhausen, 1998). The vessel dispersion numbers measured in these SSF wetlands fall between an intermediate amount of dispersion and a large amount of dispersion (Levenspiel, 1972). The results are consistent with the conclusion of Kadlec and Knight (1996) that SSF wetlands are fairly well mixed systems.

Table 2. Effective porosities and vessel dispersion numbers of three SSF wetlands.

Cell	1		2		4	
Time after start-up (mo)	12	23	10	26	11	24
Porosity (%)	34	33	37	31	32	28
D/uL	0.10	0.13	0.12	0.061	0.16	0.10

CONCLUSIONS

Hydraulic characteristics of four subsurface flow treatment wetlands were measured in a 2.5 year field-scale experiment. Wetland substrates consisted of river gravel, crushed limestone, and compost. Hydraulic conductivity was inversely proportional to the quantity of compost. Hydraulic conductivities decreased over the 2.5 year experiment by over 90%. Inlet zone clogging was observed, particularly clogging of filter fabric used to separate the wetland substrates from gravel packs around manifold pipes. Clogging was most likely

caused by filtration of colloidal iron particles. Effective porosites were about 0.3 and decreased 11% from year 1 to year 2. The SSF wetlands behaved as well mixed systems.

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REFERENCES

Gammons, C.H. and W.J. Drury. 2000. Seasonal Influences on Heavy Metal Attenuation in an Anaerobic Treatment Wetland, Butte, Montana. 3rd International Conf. On Acid Rock Drainage, Denver. CO. SME, Littleton, CO 80162-5002.

Jones, S.A. 1997. Hydraulics of Field-Scale Subsurface Flow Constructed Wetlands. M.S. Thesis, Montana Tech of the University of Montana, Butte, MT.

Kadlec, R.H. and R.L. Knight. 1996. *Treatment Wetlands.* CRC Lewis Publishers, Boca Raton. FL.

Levenspiel, O. 1972. *Chemical Reaction Engineering (2nd ed.)*. John Wiley & Sons, New York.

Mainzhausen, K. 1998. Effects of Flow Patterns on Mean Hydraulic Residence Times and on Zinc removal in Subsurface Flow Constructed Wetlands. M.S. Thesis, Montana Tech of the University of Montana, Butte, MT.

Patterson, J.W. 1985. *Industrial Wastewater Treatment Technology*. Butterworth, Boston, MA.

Tanner and Sukias (1995) Accumulation of Organic Solids in Gravel-Bed Constructed Wetlands. *Wat. Sci.Tech.* 32:229-239.

Wildeman, T., G. Brodie and J. Gusek. 1993. *Wetland Design for Mining Operations.* BiTech Publishers, Ltd., Richmond, B.C.

2000 Billings Land Reclamation Symposium

A Bioengineering Approach to Upgrading Sediment Ponds for Retention as Permanent Structures

Thomas G. Parker[1] and Darrel D. Myran[2]

ABSTRACT

Sediment storage ponds, required to capture sediment and protect watersheds during mining and reclamation, may be incorporated into post-mining land use strategies—for example, enhancing wildlife habitat or providing a watering source for livestock. Supporting post-mining land use can be an incentive to maintain ponds, while the costs associated with upgrading structures to meet regulatory requirements can be a disincentive to keeping ponds. Reclamation supervisors are particularly interested in finding ways to reduce the cost of upgrading permanent structures, because upgrading usually involves creating or enlarging open channel spillways. An alternative to enlarging the spillway is to use the entire embankment surface as the spillway. In the event of a discharge, the entire dam would be overtopped with a shallow flow, rather than the flow being concentrated into a spillway. Previous attempts to model over-topping flows have predicted dam failure as the flow velocity and depth exceeded the soil's resistance to friction. However, recent developments in synthetic geotextile technology make reinforcing soil a plausible option. By calculating stresses that would result from a 100-year flow, and comparing these to manufacturers' documented material thresholds, it is possible to demonstrate that a permanent turf reinforcement mat, combined with vegetation, will be able to withstand high flow events. In 1999, we designed and implemented this approach on a surface coal mine in eastern Montana.

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INTRODUCTION

Pursuant to regulations promulgated under Surface Mining Control and Reclamation Act of 1977 (SMCRA) and Montana Surface and Underground Mining Reclamation Act (MSUMRA), final bond release requires engineered structures to be constructed of permanent materials, or supported by maintenance in perpetuity. Any hydraulic structure must be able to withstand the stresses associated with a 100-year storm event. Sediment storage ponds, required to capture sediment and protect watersheds during mining and reclamation, may be incorporated into post-mining land use strategies—enhancing wildlife habitat or providing a watering source for livestock. Therefore, supporting post-mining land use is an incentive to keep ponds, while the costs associated with upgrading structures to meet regulatory requirements can be a disincentive for keeping ponds. Reclamation supervisors are particularly interested in finding ways to reduce the cost of upgrading permanent structures.

Sediment Pond 20, at Westmoreland Resources, Inc. Absaloka Mine, had been designed with a flow-through culvert spillway and rock armored energy dissipator designed to safely carry flows associated with a 25-year storm event. The pond is retained by an earth embankment dam with the following dimensions: 150 ft long, 20 ft high, 20 ft wide on the upper surface, and 2.5H:1V (40%) slope—resulting in approximately 10,000 ft^2 of surface area. In order to construct a spillway capable of handling the larger 100-year storm event, the natural coulee below the dam would need to be disturbed and partially filled with riprap.

As an alternative to reconstructing the spillway, we developed a design that uses the entire embankment surface as the spillway. In the event of a discharge, the entire dam would be overtopped with a shallow flow, rather than concentrating the flow into a spillway. By reinforcing the embankment surface with a permanent turf-reinforcement geotechnical fabric, we were able to ensure that any overtopping flow would be in the form of sheet flow—making the overtopping event easier to model, and providing a high safety factor for the embankment at the design flow.

While most regulations affecting small dams require an emergency, open channel spillway as part of the design, the idea of designing an embankment to withstand overtopping flows has been considered in the past. The Bureau of Reclamation used a 1:15 scale model to study the relative effectiveness of different embankment treatments for overtopping flows. As a rationale for the experiment, the BOR remarked, “some embankment dams have undergone moderate overtopping without failure…therefore it is surmised that some existing embankment dams, especially those less than 50 feet (15.24 m) high, could possibly be modified to safely permit overtopping.” (USDI Bureau of Reclamation 1988). The study was inconclusive based on the difficulty of modeling the hydraulics of failure (a transition from sheet flow to rill flow).

CONCEPTUAL DESIGN

Geotechnical Fabric Selection

Because soil by itself is subject to unpredictable erosion forces at some threshold, which is also difficult to predict, the problem can be simplified by introducing a turf-reinforcing geotextile. Manufacturers have documented material failure thresholds that have been quantified in terms of velocity and shear stress, and by duration of the stress. By calculating the velocity and shear stress given the drainage characteristics, it becomes possible to compare these values to manufacturer's specifications for turf-reinforcing geotextiles.

We selected a geotechnical fabric, of the class "Erosion Control/ Long Term Nondegradable" as defined in the Geotechnical Fabrics Report (GFR), as a turf-reinforcement mat, to provide long-term stability to the embankment upstream face, top surface, and downstream face. Permanent or long-term nondegradable geotechnical fabrics are designed to "…provide long-term reinforcement of vegetation. They are used in more challenging erosion-control applications where immediate, high-performance erosion protection is required. The materials extend the erosion resistance of soil, rock, and other materials by permanently reinforcing the vegetative root structure," (GFR Specifiers Guide 1999). We considered the following characteristics: 1) ability to withstand the forces of the design flow; 2) ability to support plant growth; and 3) longevity.

Several products have been documented to withstand the velocities and shear stresses that would result from the design flow. With respect to vegetation, non-woven, needle-punch materials were excluded because they might inhibit root growth. Similar materials are used in grow-bags, whose main purpose is to restrict root growth outside of a specified zone. Even if grass roots can grow through a needle-punch, non-woven geotextile, any root constriction caused by the geotextile would cause a shear plane at the surface of the geotextile. To meet our objective of longevity, only those products classified as permanent geotechnical fabrics were selected.

Based on careful evaluation of product data, and on discussions with technical staff employed by several manufacturers—including manufacturers who did not have any products that met our criteria—North American Green C350 was selected. In addition to having a strong, synthetic matrix, C350 has a layer of coir fibers, which retain soil moisture, aiding in seed germination and seedling establishment. Coir degrades slowly and mechanically, only minimally impacting soil nutrient availability. The coir—since it is loose, not woven— does not contribute to the product's strength, so the product would not be compromised after the coir degraded.

Flow Analysis

In order to meet the assumptions of a channel flow model, the embankment top and face must be uniform and level, so flowing water cannot concentrate on any part of the surface. An assumption of sheet flow is important. A spillway diffuses water's energy by providing a low gradient route for excess flow. However, shear stress increases with both gradient and depth (Shields 1936 as cited in Rosgen 1996). Because spillways concentrate flow into a channel, they increase the water depth, and therefore the energy affecting any given point in the spillway. Decreasing depth of flow is another way to reduce water's erosive energy.

Even though water flowing over an embankment will drop more steeply than water in a spillway, the volume is spread out over a large, uniform surface area, resulting in shear stress values within the limits of several permanent erosion fabrics that are currently available.

In order to be conservative, it was assumed that the sediment storage pond would be full at the time of the 24 hour, 100-year event, so that inflow approximately equals outflow, and the hydrograph is not altered by any storage influences in the pond. It was also assumed that the embankment top and face are uniform—any overtopping flow will be sheet flow.

To determine the duration of the peak flow, the top 10% of the hydrograph was approximated, and it was determined that the duration of this 90th percentile would be approximately 35 minutes. From HydroCad output, 75.1 cfs would be the maximum runoff over the embankment. North American Green's Erosion Control Materials Design Software 4.1 was used to calculate forces on different areas of the embankment. The face can be split into four sections—A, B, C, and D (Figure 1). Table 1 provides a summary of the forces impacting different areas of the embankment. Because the embankment toe is staggered, and the coulee bottom slopes generally toward A, all of the flow on B could potentially concentrate on the bottom of A. Flow from C and D combine into the existing spillway. The spillway is not considered part of the embankment structure.

While Gray and Sotir (1996) recommend a Manning's n value of 0.02 for a grass-covered slope steeper than 3H:1V, USDA Agricultural Handbook #667 outlines a different approach. Here, vegetation height is compared to flow depth to estimate the roughness contribution of vegetation. To summarize the reasoning—shallow flow is less likely to bend over a tall plant because of a lack of leverage on the stem. Therefore, when vegetation is considerably taller than the flow depth, even high velocities result in significant friction because the plants remain mostly erect. Significant friction causes a slower, deeper flow. Because shear stress is a function of depth and gradient, shear stress increases as friction increases. Since the additional shear stress is caused by above-ground plant biomass, the above-ground portion of plants dispel the energy. In the process of dispelling energy, grass leaves may be sheared off. However, the soil and roots, which are reinforced by the turf reinforcement mat, are protected from significant shear by the above-ground biomass. Safety factors reported in Table 1 indicate that soil and roots will not be affected by the 100-year, 24 hour event.

Table 1. Forces on different areas of Pond 20 embankment face.

Area	CFS	Velocity (ft/sec)	Depth (ft)	n	Soil Shear Stress	Safety Factor
Top	75.1	0.57	0.84	0.22	0.003	302.64
A	42.4	2.65	0.32	0.16	0.127	7.89
B	18.4	1.69	0.28	0.23	0.054	18.41
C	7.7	1.46	0.29	0.26	0.044	22.49
D	25.0	1.74	0.28	0.22	0.056	17.75

Embankment Areas Used in Calculations

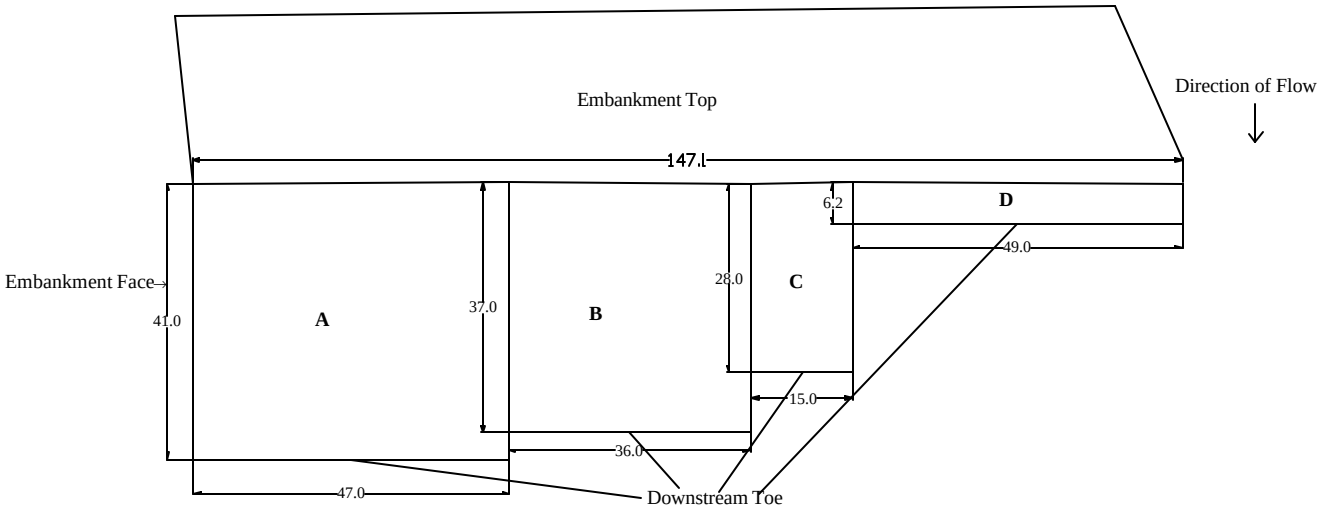

Figure 1. Areas of Pond 20 Embankment Face.

While the existing spillway remains in place after implementation, the spillway's capacity was not considered when calculating forces on the face of the embankment for the 100-year, 24 hour event. An overtopping event would partially utilize the spillway, and the spillway would be able to safely carry its portion of the total flow volume, thus increasing the safety factor for the structure.

Vegetation

Vegetation is part of the design, not only for its aesthetic and habitat values, but also for its documented engineering properties. In general, roots reinforce soil by transferring shear stress in the soil to tensile resistance in the plant roots. Specifically, in the case of shrub roots, minimum shear resistance values are approximately 10 lbs/ ft^2. Willow roots have a shear resistance between 13.8 lbs/ ft^2 and 34.7 lbs/ ft^2. (Gray and Sotir 1996). Shrubs, in addition to providing extremely high values of shear resistance, are appropriate on engineered structures like levies and embankments because they are not as likely as trees to grow large and fall over, taking part of the structure with them. Grass roots, while not as strong as shrub roots, provide up to 8 lbs/ ft^2 of shear resistance.

IMPLEMENTATION

Approximately 10,000 ft^2 of geotechnical fabric was installed on a uniform embankment surface scraped clear of vegetation, appropriately de-compacted, and seeded with native grasses. The fabric was installed from the downstream toe, over the embankment, and to the high water mark of the sediment pond. Seed was hand broadcast underneath and on top of the installed fabric. Shrubs were planted at the embankment toes and around the pond perimeter (Figure 2).

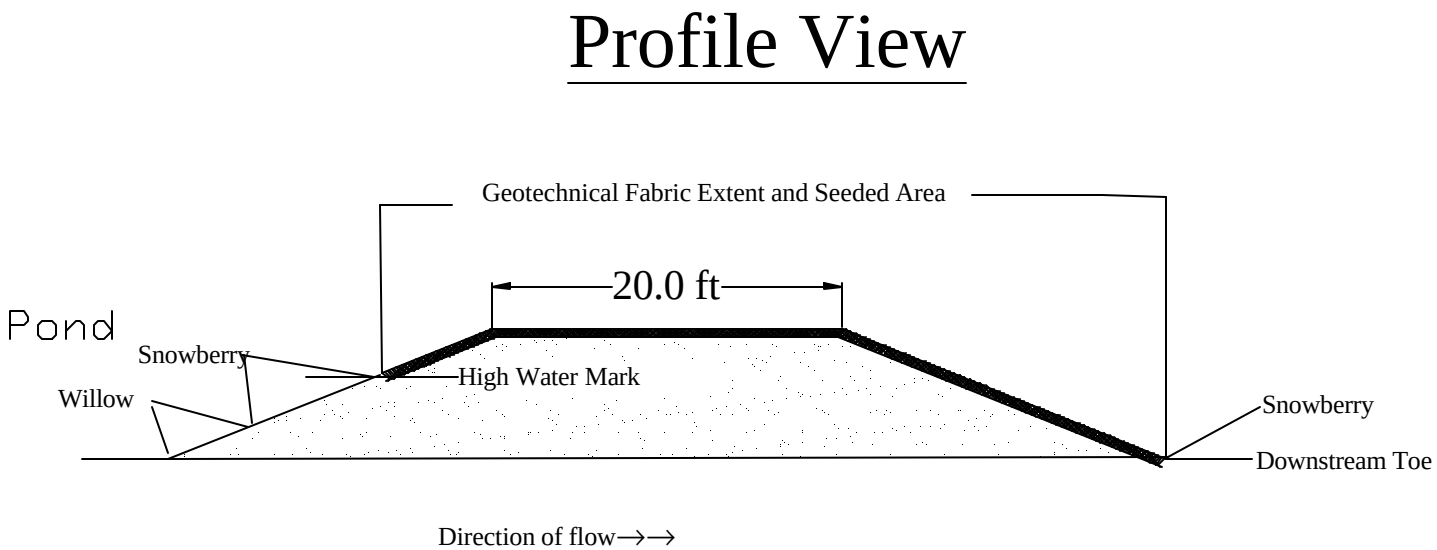

Figure 2. Profile view of Sediment Pond 20 implementation.

Prior to site preparation, the site was staked to identify excavation areas necessary to obtain a level grade. Levelness was determined using a laser level and receiver. A D-6 Caterpillar was used to level the embankment top and to scarify and flatten the embankment faces. A backhoe was used to scarify embankment areas inaccessible to the D-6. Once the embankment surface had been leveled, the surface was ripped to a depth of 12 inches to reduce compaction from prior use as a haul road. The entire embankment surface was then hand raked to ensure uniform contact between soil and the geotextile, and to prepare a seed bed for native grass seed (Table 2).

Table 2. Seeding rates by species for Pond 20.

Species	% of mix	PLS lbs/acre	Total lbs
Phlaris arundinacea (reed canarygrass)	15	2.20	0.55
Bouteloua gracilis (blue grama)	20	1.89	0.47
Agropyron smithii (western wheatgrass)	20	14.18	3.54
Elymus canadensis (Canada wildrye)	15	10.17	2.54
Agropyron dasystachyum (thickspike wheatgrass)	20	10.13	2.53
Achillea lanulosa (western white yarrow)	5	0.14	0.03
Artemisia ludoviciana (prairie sagewort)	5	0.09	0.02

After the fabric was installed, ten cubic inch containerized shrub seedlings were planted at two-foot spacing at both the upstream and downstream embankment toes with the goal of creating a continuous rhizomatous matrix of woody roots. At the upstream toe, 125 *Salix exigua* (streambank willow) were planted in two rows at the edge of a low water mark. Above this mark, 200 *Symphoricarpos occidentalis* (western snowberry) were planted at two foot spacing up to the high water mark as determined by the culvert level. At the downstream embankment toe, 150 *Symphoricarpos occidentalis* (western snowberry) were planted at two foot spacing in a six foot wide band on approximately the right half of the slope toe, and on a three foot wide band on approximately the left half of the slope, since the left half of the toe already supported a vigorous snowberry community.

As this project matures, it will be important to observe vegetation development on the embankment, because vegetation is an integral part of the design. Staff at the mine plans to monitor grass establishment and re-seed as necessary.

CONCLUSION

This method of reinforcing the entire embankment was a cost-effective alternative to increasing spillway capacity for this particular structure. Suitable rock rip-rap is rare in areas of eastern Montana and would be expensive to import. In addition, reconstructing the spillway would have required significant disturbance to the natural coulee below the sediment pond. Given the remote project location, any risk associated with attempting a new approach to upgrading a sediment pond was low.

While using a permanent turf-reinforcing geotechnical fabric was a cost-effective method for retrofitting the existing structure at Sediment Pond 20, it might prove even more cost-effective to include this type of surface-reinforcing technology in initial designs. Not only would this approach eliminate the cost of a second construction phase, but it would also eliminate the time required for obtaining new permits, as the permanent structure would be included in the initial permitting process.

REFERENCES

Gray, D.H. and R.B. Sotir. 1996. Biotechnical and soil bioengineering slope stabilization. John Wiley and Sons. New York. 378 p.

McCuen, Richard H. 1982. A guide to hydrologic analysis using SCS methods. Prentice-Hall. New Jersey. 145 p.

Rosgen, D. 1996. Applied River Morphology. Wildland Hydrology. Pagosa Springs, CO. 300 p.

Shields, A. 1936. Application of similarity principles and turbulence research to bedload movement. Mitt. Preuss. Verschsanst., Berlin. Wasserbau Schiffbau. In W.P. Ott and J.C. Uchelen (translators), California Institute of Technology, Pasadena, CA. Report No. 167. 43 p.

USDI Bureau of Reclamation. 1987. Design of Small Dams. United States Government Printing Office. Denver, CO. 860 p.

USDI Bureau of Reclamation. 1988. Overtopping flow on low embankment dams—summary report of model tests. REC-ERC-88-3. Denver Office. 29 p.

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ENGINEERING METHODS FOR ASSURING SUFFICIENT RECLAMATION BOND AMOUNTS

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ABSTRACT

Successful reclamation is the cornerstone of the Surface Mining Control and Reclamation Act of 1977 (SMCRA.) Mine permittees are required to complete reclamation in accordance with SMCRA, their approved mining permits, and the regulations. To accomplish this, reclamation plans must be well designed and detailed enough that they could be used as a "scope of work" under a contract should a regulatory authority be faced with completing the reclamation.

Coal mine permittees consider each facet of the mining and reclamation process when they estimate reclamation costs. A cost for everything from structure demolition to seeding a reclaimed area must be determined. The regulatory authority sets a bond amount based on the permittee=s cost estimate and the regulatory authority=s independent cost estimate that includes the costs of having a third party, under contract to the regulatory authority, complete the reclamation plan. The regulatory authority adds third-party costs as an allowance for contractor profit and overhead.

In 1987, OSM developed a cost-estimating handbook utilizing standard engineering principles, equipment productivity guidebooks, and construction cost references. To keep current, OSM revised the handbook in 1993 and 1999.

OSM's handbook utilizes industry-standard resources such as cost reference guides, building construction cost data, and other widely-used resources. To facilitate cost-estimating, the handbook includes detailed worksheets, examples, maps, and equipment selection guidance for earthmoving equipment.

The handbook expedites and standardizes the development of site-specific reclamation cost estimates in order to set sufficient bond amounts. OSM offers training to states and Indian Tribes on the use of the handbook. Other federal agencies, state agencies and industry representatives utilize the handbook as well. The ultimate goal is to assure that sufficient funds are available to guarantee successful reclamation in the event that the permittee defaults on reclamation obligations under the reclamation plan in the approved permit.

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2000 Billings Land Reclamation Symposium

LIVESTOCK GRAZING EFFECTS ON RECLAIMED GRASSLANDS

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ABSTRACT

Prescribed livestock grazing of reclaimed grasslands was evaluated to determine the effects on plant species diversity and seasonality. The study was conducted between 1989 and 1998 on the BNI, Freedom and Indian Head coal mines in Mercer and Oliver counties of west-central North Dakota. The grasslands were reclaimed between 1983 and 1989 and grazing began four to eight years after seeding. Grazing was conducted mid to late May through early to mid July each year to decrease the competitiveness of cool season grass species. Live basal cover and species composition were estimated using the ten-point frame method. From these data alpha, beta and mosaic diversities and cool:warm season grass ratios were determined and compared across years for each mine. On the BNI mine, grazing significantly increased alpha (small scale) diversity but beta (gradient) and mosaic (landscape) remained similar. No changes in species composition were evident. At the Freedom mine, alpha diversity was significantly higher after four years of grazing despite no changes in beta and mosaic diversities. Seasonality of species improved with warm season grasses increasing from 6% to 42% of the composition between 1995 and 1998. Diversity at any scale did not change following grazing on the Indian Head mine. However, positive species composition trends were evident following grazing including an increase in warm season grass composition from 26% to 55% and a decline in composition of introduced grass species from 47% to 6%. In summary, prescribed livestock grazing produced positive trends in plant species diversity, seasonality and composition of reclaimed mixed grasslands.

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INTRODUCTION

Re-establishment of diverse and seasonally balanced grassland plant communities following surface coal mining in the Northern Great Plains is difficult to achieve due to the competitiveness of cool season grass species. Despite seed mixes using a warm to cool season grass ratio of 3:1 or greater, diverse and seasonally balanced grasslands are not easily established and maintained. Cool season grass species establish easier and have the advantage of making most of their growth in early spring when soil moisture is advantageous for plant growth. Warm season species grow most rapidly in summer when soil moisture is often inadequate to sustain plant growth. The result is that reclaimed grasslands often become heavily dominated by cool season grass species, especially during the first few growing seasons following their establishment (Williamson 1984, Nilson et al. 1985, Krabbenhoft et al. 1993).

The objective of this study was to evaluate early season livestock grazing effects on plant species diversity and seasonality of established reclaimed grasslands (5-10 years after re-establishment) in western North Dakota. The results of this study will provide information needed to make recommendations concerning grazing management to improve diversity and seasonal balance, while maintaining productivity and ground cover of re-established native grasslands.

STUDY AREA and METHODS

The research was conducted on the BNI, Freedom, and Indian Head coal mines in Mercer and Oliver Counties of west central North Dakota. The mines are located in the Missouri Plateau Physiographic Region of North Dakota. This region lays on the western edge of an area where soils are formed from glacial deposits and residuum weathered bedrock of the sedimentary Sentinel Butte formation. The mines lie within an area used primarily for agriculture. The principal vegetative community of mixed grass prairie is dominated by grasses and grasslike plants.

In 1989, five transects were established at the BNI Mine on soils that were considered silty site types. Two transects were located on a reference area (undisturbed) and three transects were on a 65-hectare reclaimed area. Basal cover and species composition were estimated each year using the ten-pin point-frame method (Arny and Schmid 1942). Ten frame (100 points) readings were taken randomly at each sampling location (10 per transect) along transects.

The 65-hectare pasture was seeded in May, 1983, and 1984. Grazing was implemented in the fall of 1992 at 1.39 animal unit months per ha (AUM/ha). Thereafter the pasture was grazed in the springs of 1994 to 1998 at an average stocking rate of 1.46 AUM/ha.

In 1995, three transects were established on both reference and reclaimed sites at the Freedom Mine on soils that were considered silty site types. Vegetative cover was estimated each year using the ten-pin point-frame method. On the reclaimed site an average of 150 frame readings were taken between 1995 and 1998. On the two reference areas, 200 frame readings were taken each year between 1995 and 1998.

The 32.4 hectare reclaimed area was seeded and fertilized in the fall of 1989. Grazing was implemented in April, 1993. Each year (1994-1998) grazing began in mid-May and terminated the beginning of July. Stocking rate averaged 2.97 AUM/ha over the five years of grazing.

In 1989, four and two transects, each containing ten sampling points, were established in reclaimed and reference sites, respectively, on the Indian Head Mine. The sites contained clay loam soils before mining. Vegetative cover was estimated each year using the ten-pin point-frame method. Ten frame (100 points) readings were taken randomly at each sampling location (10 per transect) along transects.

The 26.7 hectare reclaimed area was seeded, mulched and crimped in 1986 and hayed in 1987. Grazing was implemented in 1994 and continued annually through 1998 with an annual stocking rate of 0.74 to 0.84 AUM/ha. Grazing began each year in mid-May and continued to late July.

Statistical Methods

Vegetation diversity can be observed and quantified at three scales, alpha, beta, and mosaic. Alpha diversity was estimated using the Shannon-Wiener index (Shannon and Weaver 1973). Beta (inter-community) diversity was estimated from presence/absence data using affinity analysis (Scheiner and Istock 1987). Using presence/absence data, mosaic diversity was estimated as the variation and degree of structuring around the mean similarity (Istock and Scheiner 1987). Mosaic diversity values were standardized and analyzed using the bootstrap technique outlined by Scheiner and Istock (1987). Beta and mosaic diversities were similar between reclaimed and reference sites each year at all three mines so will not be discussed further. The multiresponse permutation procedure (MRPP), as described by Biondini et al. (1988), was used to determine if reclaimed and reference areas of the same mine differed between years at the alpha diversity level.

RESULTS

BNI Mine

Total plant species basal cover ranged between 3.2 and 6.4% over the study period (Table 1). Basal cover of native and introduced cool season grasses remained similar, while basal cover of native warm season grasses increased during the study period. On a species level, basal cover of *Bouteloua gracilis*, *Poa* spp. and *Schizachyrium scoparium* increased, while *Stipa viridula* decreased during the same study period (data not presented).

A positive trend in plant species seasonality occurred during the study as evidenced by an increase in warm season grass relative to total basal cover (Table 1). Between 1989 and 1991, warm season grass species averaged 41% of the total basal cover. For the period 1992-1993 and 1997-1998, warm season grasses comprised 58% of the total basal cover of the study site.

Despite annual fluctuation, alpha diversity of the reclaimed grassland appeared to be increasing following grazing (Fig. 1). Alpha diversity was greater ($p<0.05$) on the

reclaimed grassland in 1997 and 1998 compared to the pre-grazing years of 1990 and 1991.

Table 1. Basal cover (%) by plant class observed on a reclaimed grassland on the BNI Mine, Center, North Dakota.

Plant Class	Idle			Grazed			
	1989	1990	1991	1992	1993	1997	1998
	……%……						
Native cool season grasses	2.3	1.7	2.9	2.1	0.6	1.7	2.6
Native warm season grasses	1.4	1.2	2.8	3.4	3.8	2.0	3.1
Native forb	0	0	0.1	0	0.3	0.4	0.3
Introduced cool season grasses	0.3	0.3	0.4	0.3	0.2	0.4	0.4
Total basal cover	4.0	3.2	6.2	5.8	4.9	4.5	6.4

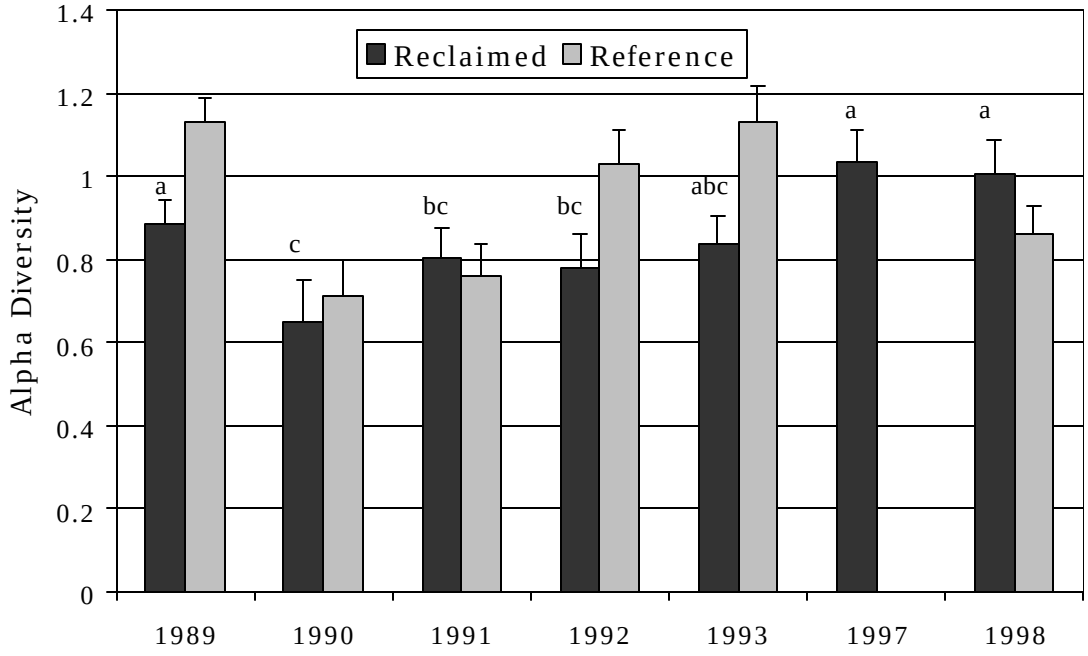

Figure 1. Alpha diversity for reclaimed and reference sites on the BNI Mine, Center, North Dakota. Annual means for reclaimed sites with the same letter were not significantly different (p>0.05).

Freedom Mine

Total plant species basal cover ranged between 2.6 and 8.2% over the study period (Table 2). Basal cover of native and introduced cool season grasses declined, while basal cover of native warm season grasses increased during the study period. On a species level, basal cover of *Bouteloua curtipendula*, *Panicum virgatum*, and *Poa* spp. increased following grazing (data not presented). Basal cover of the cool season grasses, *Agropyron smithii* and *Stipa viridula*, decreased during the same time period.

As on the BNI Mine, a positive trend in plant species seasonality occurred during the study as evidenced by an increase in warm season grasses relative to total basal cover (Table 2). In 1995 and 1996, warm season grass species accounted for 7% of the total basal cover. This increased to 25% in 1997 and by 1998 warm season grasses comprised 42% of the live total basal cover of the study site.

Table 2. Basal cover (%) by plant class observed on a reclaimed grassland on the Freedom Mine, Beulah, North Dakota.

Plant Class	**Grazed**			
	1995	1996	1997	1998
	……%……			
Native cool season grasses	6.3	2.2	3.3	2.8
Native warm season grasses	0.6	0.2	1.2	2.3
Native forb	0.7	0.2	0	0.1
Introduced cool season grasses	0.6	0	0.2	0.3
Total basal cover	8.2	2.6	4.7	5.5

Alpha diversity on the Freedom Mine study area exhibited significant changes ($p<0.05$) annually during the study period (Fig. 2). Between 1996 and 1998 alpha diversity significantly increased each year.

Indian Head Mine

Total plant species basal cover ranged between 3.1 and 6.6% over the study period (Table 3). Basal cover of native cool and warm season grasses increased, while the basal cover of introduced cool season species decreased (Table 3). On a species level, percentage basal cover of *Agropyron smithii*, *Bouteloua curtipendula*, *Bouteloua gracilis*, and *Bromus inermis* increased over the study period (data not presented). *Stipa viridula* and *Agropyron intermedium* cover decreased during the same period.

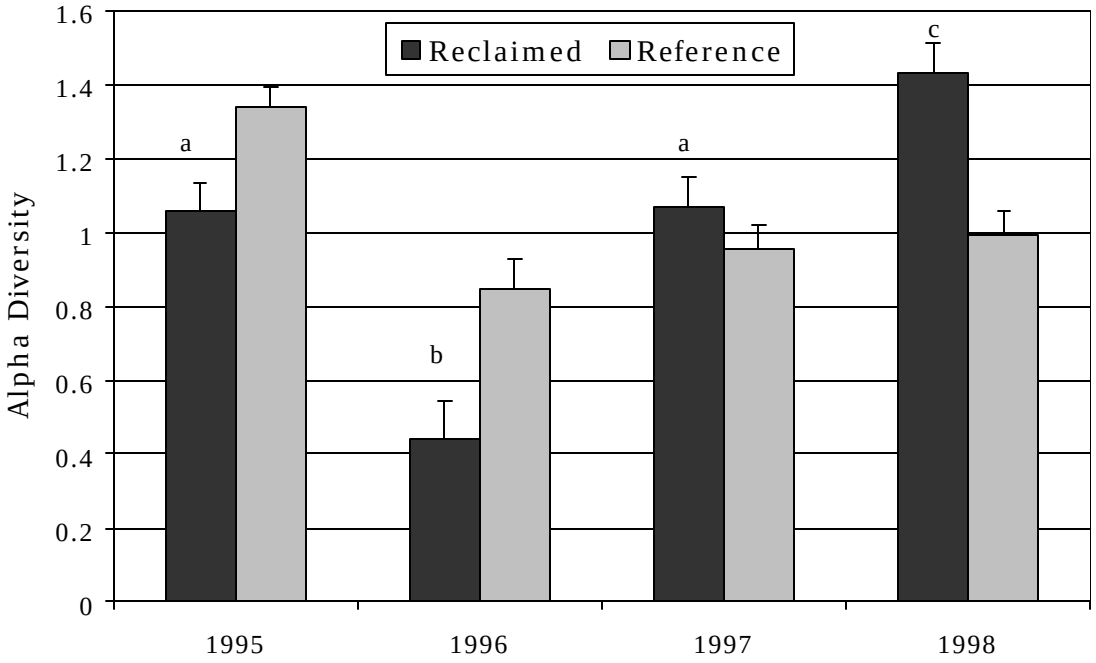

Figure 2. Alpha diversity for reclaimed and reference sites on the Freedom Mine, Beulah, North Dakota. Annual means for reclaimed sites with the same letter were not significantly different ($p>0.05$).

A positive trend in plant species seasonality occurred during the study as evidenced by an increase in warm season grass relative to total basal cover (Table 3). Between 1989 and 1990, warm season grass species averaged 29% of the total basal cover. For the period 1996 to 1998, warm season grasses averaged 54% of the total basal cover of the study site.

Alpha diversity on the reclaimed area was significantly lower ($p<0.05$) in 1989 and 1996 compared to 1990, 1997 and 1998 (Fig. 3). Alpha diversity appeared to be trending higher following the initiation of grazing on the reclaimed grassland.

CONCLUSIONS

Early season grazing increased the basal cover of warm season grasses at all three mines during the study. Basal cover of introduced cool season grasses declined at two mines while remaining similar at the third. At the species level, the warm season grasses, *Bouteloua curtipendula* and *B. gracilis* increased at three and two mines, respectively. *Stipa viridula*, a desirable cool season grass species, decreased at all three mines. This plant species may need to be monitered closely under early season grazing to be maintained at an acceptable level in grazed stands.

Table 3. Basal cover (%) by plant class observed on a reclaimed grassland on the Indian Head Mine, Zap, North Dakota.

Plant Class	**Idle**		**Grazed**		
	1989	1990	1996	1997	1998
	……%……..				
Native cool season grasses	0.9	0.8	1.8	1.9	1.8
Native warm season grasses	0.9	1.1	2.1	2.3	4.1
Native forb	0	0	0	0	0.3
Introduced cool season grasses	2.2	1.2	0.3	0.3	0.4
Total basal cover	4.0	3.1	4.2	4.5	6.6

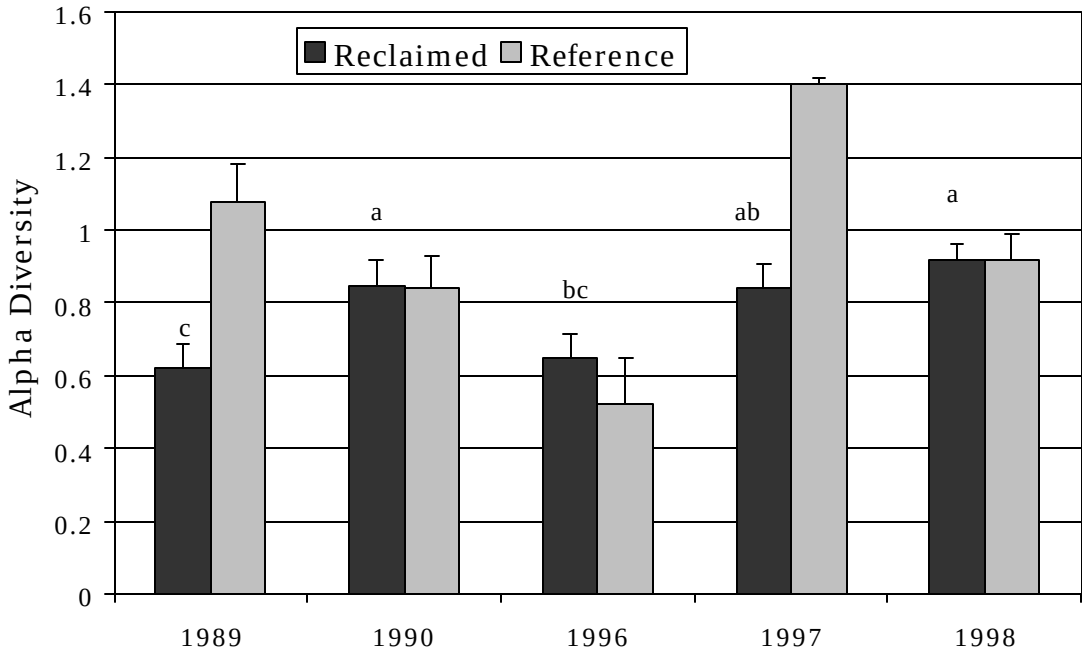

Figure 3. Alpha diversity for reclaimed and reference sites on the Indian Head Mine, Zap, North Dakota. Annual means for reclaimed sites with the same letter were not significantly different (p>0.05).

Seasonality and alpha diversity of the reclaimed grasslands improved on all three mines following initiation of grazing. Beta and mosaic diversity remained similar during the study across the three mines. Warm season grass species basal cover increased to comprise >50% of the cover on the reclaimed grasslands by the end of the study. This positive trend in warm season grass cover occurred during an usually wet climatic cycle during the growing season, which tends to favor cool season grass dominance. Introduced cool season grasses decreased with early season grazing.

Management of diverse grasslands following re-establishment should be aggressive and initiated soon after stand establishment. Grazing to improve species composition should commence 2-3 years after seeding reclaimed grasslands to prevent cool-season grass species from becoming too dominant. In addition, grazing cool-season species early in the spring of the year on reclaimed grasslands and removing animals from pastures by July 1 should also improve the competitiveness of warm season grass species.

REFERENCES

Arny, A.C. and A.R. Schmid. 1942. A study of the inclined point quadrat method of botanical analysis of pasture mixtures. J. Amer. Soc. Agron. 34:238-247.

Biondini, M.E., P.W. Mielke, and K.J. Berry. 1988. Data-dependent permutation techniques for the analysis of ecological data. Vegetatio 75:161-168.

Istock, C.A. and S.M. Scheiner. 1987. Affinities and high-order diversity within diversity within landscape mosaics. Evolutionary Ecol. 1:11-29.

Krabbenhoft K.D., D.R. Kirby, and D.J. Nilson. 1993. The effects of reclamation technique on stand maturation in western North Dakota. *In*: Planning, rehabilitation and treatment of disturbed Lands, 6th Billings Symp., Billings, Mont.

Nilson, D.J., R.L. Williamson, J.C. Thompson, and J.E. Shultz. 1985. Techniques used to establish, maintain and enhance grasslands seasonal variety on the Glenharold Mine in North Dakota. *In*: Proc. 2nd National Meeting American Society for Surface Mining and Reclamation, Denver, Colo.

Scheiner, S.M. and C.A. Istock. 1987. Affinity analysis: methodologies and statistical inference. Vegetatio 72:89-93.

Shannon, C.E. and W. Weaver. 1973. Mathematical theory of communication. Univ. of Ill. Press, Urbana.

Williamson, R.L. 1984. Re-establishing North Dakota grasslands after mining with emphasis on seasonality and the use of native species. J. Soil Water Conserv. 39:387-391.

2000 Billings Land Reclamation Symposium

IMPROVING THE HEALTH OF RECLAIMED LAND THROUGH PROPER GRAZING MANAGEMENT

Roy Liedtke[1], Miles Keogh[2] and Donnie Whitten[3]

ABSTRACT

For years reclamation of mined lands has focused on revegetation techniques such as types of seed, seeding practices, mulching, etc. Kennecott Energy's Jacobs Ranch Mine in the Powder River Basin of Wyoming has taken the next step in managing the reclaimed land to improve the health of the land and progress towards the goal of release of the reclamation bond. Jacobs Ranch Mine has approximately 1,400 hectares of permanently reclaimed land. Of that area, over 90% of it is being grazed.

A holistic approach is used to determine grazing management practices. Decisions are made depending on several factors ranging from the rate of plant growth to the long-term land use of the area. The management plan generally consists of utilizing large groups of animals for short periods of time with the goal of reducing the overgrazing of plants and improving the health of the land.

The holistic grazing approach was initiated in 1998 with 646 head of yearling steers grazing the reclaimed areas for the summer. The stocking rate was double that of adjacent undisturbed lands. Livestock weight gains were slightly over 1 kg/day. In 1999 a total of 955 yearling steers were grazed on the reclaimed areas for the summer. Signs are already visible of improved health of the reclaimed areas. New seedlings are evident, ground cover and litter has increased, plant health has improved and erosion is decreasing.

In addition to improving the health of the reclaimed land, the grazing program is established to provide a monetary return for Jacobs Ranch Mine. This is accomplished while meeting the challenges of grazing a large number of livestock in the middle of a large active surface coal mine.

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1.0. INTRODUCTION

Jacobs Ranch Mine is a surface coal mine in the Powder River Basin of northeast Wyoming. Construction began at the mine in 1975. The first coal was shipped and reclamation began in 1978. Jacobs Ranch Mine currently ships approximately 29 million tons of coal per year. As of year-end 1999 approximately 2,430 hectares have been disturbed, while 1,494 hectares have been permanently reclaimed (61% of disturbance). Jacobs Ranch Mine has received full bond release on 28 hectares and partial bond release on approximately 200 hectares of reclamation to date.

Grazing began on reclaimed areas in 1985 with a local rancher responsible for the livestock being grazed. Generally the grazing pattern was small numbers of livestock for long periods of time. Timing of grazing was somewhat dependent on the requirements of the rancher. This continued through the 1997 grazing season. In 1998 Jacobs Ranch Mine entered into an agreement with Reclamation Technologies LLP to graze 650 yearling steers on the reclaimed area.

2.0. RECLAMATION TECHNOLOGIES, LLP. AGREEMENT

The agreement between Jacobs Ranch Mine and Reclamation Technologies LLP is a reclaimed land management agreement with common goals. The agreement was written in an effort to create a win-win situation for both parties and is described below:

2.1. Goals of the Agreement

The goals of the agreement were determined jointly between the two companies. The goals include:

- Obtain reclamation bond release;
- Realize a monetary profit from the reclamation (for both Jacobs Ranch Mine and Reclamation Technologies, LLP);
- Improve the health of the land;
- Provide a high quality wildlife habitat through biological diversity.

2.2. Terms of the Agreement

The terms of the agreement were written to facilitate accomplishment of the goals.

Jacobs Ranch Mine provides:

- The reclaimed land;
- Long-term exterior fencing;
- Water at each major grazing area.

Reclamation Technologies provides:

- The livestock, owned by a third party, delivered to and from the minesite;

- Temporary electric fencing and all labor as needed to move the fence;
- All labor and equipment for watering the livestock (portable tanks and piping);
- All labor required for the management of the livestock;
- Technical knowledge and skill for managing livestock. This includes providing a season long grazing plan prior to grazing followed up with results of grazing including animal performance, levels of utilization and monitoring data as collected on plant growth and plant recovery.

Payment is determined by the yearling steer weight gains. Reclamation Technologies LLP is paid by the owners of the steers on the basis of weight gain. Jacobs Ranch Mine receives a portion of that payment. Upon bond release Reclamation Technologies LLP receives 100% of the payment from that piece of land for a predetermined number of years.

This agreement provides Reclamation Technologies LLP with a monetary incentive to obtain bond release and it allows Jacobs Ranch Mine to provide that incentive with no out-of-pocket expenditures as the land pays the incentive. Land that is healthy with vigorously growing plants produces higher livestock weight gains than land that is deteriorating; therefore, there is an additional incentive for the livestock to be managed in a manner than improves the health of the land. All of this contributes towards the common goal of bond release.

3.0. GRAZING MANAGEMENT PLAN

A planned and controlled grazing system is utilized. The steps to utilize the system are to plan, monitor, control and replan.

The grazing management plan includes a detailed day-by-day plan for the entire grazing season. The plan focuses on utilizing large numbers of animals for short periods of time. Multiple factors are considered in the development and implementation of the plan. The grazing plan is critical, as managing livestock grazing without a detailed plan is similar to driving a car by looking in the rearview mirror – all you know is where you have been!

A detailed grazing plan allows the operator to know at all times if the land is being utilized properly. The grazing plan was developed in the spring of 1998 with historical information as available. It was decided to graze the reclaimed areas with 500 head of yearling steers. Three days into the grazing program we realized we had underestimated the amount of forage. The number of steers was then increased by approximately 150 head. Without a grazing plan, we would not have realized we were understocked until much later in the grazing season. Additionally, during a drought a detailed grazing plan also allows you to realize early in the grazing season if the number of grazing animals needs to be reduced.

3.1. Definition of Overgrazing

Document research has concluded overgrazing of plants is a result of the time plants are exposed to grazing rather than the number of animals present (Voisin 1988). Overgrazing has been defined as grazing during active growth that is both severe and frequent. Generally, this results in the eventual death of the plant. In intermediate stages it results in reduced production. Overgrazing damages plants to varying degrees by utilizing energy temporarily obtained by the plant from roots sacrificed for that purpose (Savory 1988).

3.2. Development of the Grazing Plan

Development of a detailed day-by-day grazing plan requires input from several factors. The number of pastures to be grazed, the size of each pasture, the estimated amount of forage in each pasture and the quality of that forage are determined to calculate the number of animal units of grazing available. The amount of time planned to graze each pasture depends on the amount of forage available, the number of livestock to be grazed and the grazing management decision factors listed in a following section.

3.3. Implementation of the Grazing Plan

Although a detailed grazing plan is in place prior to the start of grazing, it is assumed the plan will change as environmental factors such as rainfall, temperature, insects, and etc change during the course of the grazing season. How to actually move the steers from one pasture to another with the least amount of stress on the steers and people and with the least effect on the mining operation is also taken into consideration.

3.3.1. Fencing

One goal of the grazing plan is to mimic what large herds of buffalo did for centuries in the past. Instead of using very active animals like buffalo and predators like wolves and bears, we now use yearling steers and electric fences. High tensile electric fence is used for temporary perimeter fences. Poly wire electric fence is used to sub-divide pastures into smaller units. The poly wire fences utilize lightweight plastic step-in posts that are set in the ground by simply stepping on a notch in the post. Fences are intentionally placed in different locations each time a pasture is grazed in order to avoid damage to the plants from livestock trailing along the fence lines. The temporary fences are also intentionally built crooked in order to further reduce trailing along the fence lines.

3.3.2. Water

With several small pastures and the continual changes associated with a large surface coal mining operation, it was decided to utilize a portable water system. Jacobs Ranch Mine provides water at three strategic locations on the minesite. Reclamation Technologies LLP then uses portable aboveground 5 centimeter plastic pipe to get the water to a 10,000 gallon portable storage tank. The water flows from the storage tank to

portable livestock watering troughs. This allows reclaimed areas to be grazed that had previously not been considered feasible to graze due to remote location or small size.

This water system provides a continual source of fresh water to the livestock, which is critical to good weight gains. Reclaimed ponds are fenced from livestock grazing to allow development of wildlife habitat around the pond shoreline.

3.3.3. Additional Undisturbed Pastures

Since topsoil on newly reclaimed land is unconsolidated, the impact of grazing during wet periods is greater on reclaimed areas than on native undisturbed areas. It is helpful to have an area of undisturbed pasture available for grazing during prolonged wet periods in order to avoid impacting the reclaimed areas more than desired. The need for this will vary depending on the number of animals grazed and the level of management. When grazing large numbers of animals on wet reclaimed areas, the time in a pasture may be determined by the number of hours in the pasture, not the number of days.

3.4. Grazing Management Decision Factors

The following factors are all considered when developing the grazing plan and when determining when to actually move the steers from one pasture to the next.

- Length of time in current pasture – as previously described, the length of time the plants are exposed to grazing must be considered to avoid overgrazing plants;
- Rate of plant growth – during spring when plants are growing rapidly, the length of time the plant is exposed to grazing must be less than when the plants are growing slowly in order to avoid overgrazing plants;
- Amount or quantity of grass available for consumption – if too much grass is removed, the performance of the animals will be sacrificed. Also, the more of the grass sward removed during grazing the longer the recovery time for the plant;
- Type of vegetation available –when grazing vegetation such as annual weeds or annual grain crops, the amount and time grazed will be different than when grazing perennial grasses since the purpose of grazing and the desired outcome is different;
- Soil factors – soil texture and soil moisture must be considered as the goal is to increase water infiltration by reducing soil capping and increasing litter and mulch on the soil surface (reduce bare ground);
- Wildlife factors – a diverse wildlife habitat is a primary goal of the grazing program; therefore, wildlife factors are continually taken into account during the course of the grazing program. For example, the presence of nesting birds or denning mammals can influence the timing of grazing certain pastures. Future forage requirements of wildlife such as winter forage for big game are taken into account. Livestock watering around ponds is controlled to allow riparian wildlife habitat to develop;

- Total area and pastures available – pasture moves must also consider the plant growth in future pastures, as the goal is to graze areas when the grass is in a palatable stage of growth;
- Mining operations – moving livestock from one pasture to another may interfere with the mining operation. When possible, crossing of haul roads is done between shifts, at lunch or during crew meetings in order to minimize interference.

3.5. Grazing as a Management Tool

Livestock grazing is considered one of several tools used to accomplish successful reclamation. Since the livestock generate income as opposed to being an expense, the goal is to utilize the livestock as much as possible as a management tool. In addition to grazing established reclaimed areas, the livestock are also used in the following manners:

- Weed Control – as previously mentioned, the livestock are used for weed control by grazing annual weeds for short periods of time on newly reclaimed areas. The timing of grazing is determined by the stage of growth of the annual weeds and the stage of growth of the perennial grasses, shrubs and forbs. The duration of grazing is generally very short, again depending on the stage of growth of the various plants and the utilization of each type of plant.
- Stubble Mulch Control – frequently annual grain crops are seeded to provide stubble mulch prior to interseeding the permanent reclamation seed mixtures. In order to avoid excessive volunteer growth of the grain the following year, the stubble mulch areas are grazed. This provides high quality forage for the livestock while avoiding the traditional expense of mowing.
- Wildlife Habitat Enhancement – When grazing stubble mulch areas, the late fall regrowth of the annual grains provides very desirable wildlife forage for big game animals. As discussed, grazing of established reclaimed areas is also timed around wildlife needs. Some areas are left with tall forage for wildlife use in times of heavy winter snow cover while other areas are grazed later in the season to provide fresh regrowth of plants for wildlife use.
- Erosion Control and Repair – Grazing during wet periods can result in considerable impact from the hoof action of the livestock. This can be utilized on steep hillsides to control erosion. Each hoof print becomes a miniature dam that holds water and reduces movement of water down the slope; therefore, reducing runoff and erosion. In areas where erosion has already created gullies, straw bales are placed in the gullies prior to grazing to repair the erosion. The steers very effectively incorporate the straw into the soil and break down the sides of the gully. The end result is a smoothed-over gully with considerable organic matter in the soil that provides good infiltration. The straw also provides a seed source for a quick growing stand of vegetation to help repair the gully.

4.0. GRAZING PROGRAMS

4.1. 1998 Grazing Program

During 1998 a total of 646 head of yearling steers were grazed on 1,300 hectares of reclamation from May 7 to August 29. The reclaimed area was split into 21 pastures with the average pasture size approximately 60 hectares. The largest pasture was 110 hectares while the smallest was 6 hectares.

All pastures were grazed twice during the summer. Each pasture was grazed an average of 3 days each time (the 6 hectare pasture was grazed for 18 hours). The stock density averaged approximately 1 animal per 0.1 hectare for each 3-day period. Steer weight gains averaged 1.0 kg/day.

4.2. 1999 Grazing Program

Yearling steers were again utilized for grazing in 1999. A total of 955 steers were grazed on the reclaimed area and on adjacent areas. The goal was to have more steers, but they were not available under favorable terms due to livestock market conditions. The area received very good moisture in early 1999 so there was abundant forage. Due to this several pastures were grazed only once during the summer. Steer weight gains were less than 1998 primarily due to hot dry conditions at the end of the summer. Also, the livestock market conditions resulted in multiple third party owners of the steers, ranging in locations from Montana to Oregon. This also had an adverse effect on weight gains.

The increased number of steers allowed the use of slightly larger pastures. Also, some areas grazed under wet conditions were grazed as larger pastures to avoid excessive hoof impact. A set of corrals was constructed to allow safe and efficient handling of the livestock. Improvements were also made to the watering system.

4.3. Future Grazing Programs

During the year 2000 we anticipate again increasing the number of steers to be grazed. Approximately 200 hectares of additional reclamation will be available for first-time grazing (approximately half will be established permanent reclamation and half will be newly seeded reclamation), bringing the total reclaimed area to almost 1,500 hectares.

Grazing larger numbers of animals and increasing the total amount of land to graze has several advantages:

- More impact is achieved in a shorter period of time. We are trying to impact these areas. The impact is needed to break up capping of soils and knock down standing dead material and incorporate it into the surface of the soil.
- Pasture sizes can be larger and/or grazing periods can be shorter.
- There may possibly be fewer disruptions to the mining operation due to less haul road crossings and possibly less total time spent on the reclaimed area.

- Large herds more closely replicate the herds of buffalo from centuries ago, which is how the grasslands evolved.

Since reclaimed mine land was previously disturbed by the mining process, the impact desired from the grazing animals is much less than similar undisturbed land. Soil capping is much less developed than on undisturbed land and the reclaimed area vegetation is very new compared to undisturbed land. As the planning and monitoring of the reclaimed area grazing program continues, we may decide to split the steers into multiple herds. Some reclaimed areas may be grazed primarily during drier periods of the year. Some areas may be grazed with small numbers of animals for longer periods of time (i.e. areas managed for shrubs). The continual process of planning the grazing, monitoring the effects of grazing, making changes to control future effects, and replanning will be used to make decisions on reclaimed area management practices.

5.0. SUMMARY

Overall the health of the reclaimed land is improving. We are seeing new seedlings in old stands of reclamation. There is increased litter and organic matter on the soil surface with less standing dead plant material. The health of the plants has improved and soil erosion has decreased. Numerous species of wildlife utilize the reclamation. The number of livestock grazing the reclaimed land is greater per area than the number grazing similar undisturbed land. This is critical for the economic sustainability of the reclamation.

The primary postmining land use of the area is livestock grazing. This means the primary postmining land **user** will likely be a family trying to make a living off the land; therefore, the real postmining land use is supporting families and communities. Our decisions should always keep that in mind.

REFERENCES

Savory, Allan. 1988. Holistic Resource Management, pp. 511. Island Press, Covello, CA.

Voisin, Andre. 1988. Grass Productivity. Island Press, Covello, CA.

2000 Billings Land Reclamation Symposium

CONTROL OF LEAFY SPURGE BY SHEEP GRAZING

R.E. Ries and J.F. Karn[1]

ABSTRACT

Leafy spurge is a serious invasive plant problem on native rangelands and some reclaimed mined land across the Northern Great Plains and northwestern United States. This plant has been difficult to control with herbicides because of expense and collateral damage to other plants and water supplies. Sheep will graze leafy spurge and sheep grazing has been used with varying degrees of success to control leafy spurge. We studied the use of sheep as a biological control measure for leafy spurge infested rangeland on the Heart River in central North Dakota. Prior to sheep grazing, 10 locations within 4 range sites (overflow, silty, shallow, and woody draw) were identified and caged. Leafy spurge stem density and leafy spurge and other forage dry matter production were monitored for 3 growing seasons prior to sheep grazing. After 1 year of grazing with Rambouillet sheep, leafy spurge stem density and dry matter production were measured inside and outside the cages. Data were analyzed by unequal subplot, mixed model analysis of variance. Leafy spurge density and production had a significant range site x year interaction. After 1 grazing season, leafy spurge densities were the same on ungrazed and grazed rangeland. Leafy spurge dry matter remaining after one season of sheep grazing was significantly less on grazed than ungrazed areas but the effect was not uniform for all range sites. Range sites (silty, shallow, and woody draw) that were at higher elevations, with significant air movement, were more intensively grazed by the sheep than the overflow range site along a stream bank and in protected areas. Sheep grazing can be an important leafy spurge control option on infested rangelands or reclaimed native grasslands while providing marketable products for the land owner. Understanding sheep behavior is important when managing a flock for optimum leafy spurge control.

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INTRODUCTION

Leafy spurge (*Euphorbia esula* L.) is a perennial noxious weed introduced from Europe which currently infests many hectares of range and pasture land in the Northern Great Plains of the United States and southern Canada. Sheep have been recognized for their ability to graze leafy spurge and reduce its abundance on pasture and range land (Helgeson and Thompson 1939, Johnston and Peake 1960). Sheep consume significant amounts of leafy spurge while suffering neither harmful internal effects nor a significant loss in body weight and therefore, may be an effective biological control agent for leafy spurge (Landgraf et al. 1984). Incorporating sheep grazing into ranching operations in Montana can result in positive economic returns when as little as 4% of the ranch land was infested with leafy spurge (Williams et al. 1996). Kronberg and Walker (1999) found that sheep grazed Idaho and North Dakota leafy spurge differently. Sheep preferred leafy spurge from North Dakota in a fresh or dried hay form more than Idaho spurge and also preferred fertilized leafy spurge compared to unfertilized spurge. They suggest that preference of leafy spurge by sheep may depend on the site where it was grown and that control of leafy spurge by sheep may be more successful on soils with relatively high fertility.

A recent survey of ranchers and local decision makers in 4 counties in western North Dakota and eastern Montana found leafy spurge was a major weed problem. The main reason ranchers and local decision makers did not use sheep grazing as a control mechanism was a lack of equipment and expertise to include sheep in their grazing strategies (Sell et al. 1999). However, some farmers and ranchers have successfully incorporated sheep into cow operations and have controlled leafy spurge while maintaining an economically viable ranching operation. Information from four farm and ranch operators on the Heart River Drainage in North Dakota provides some producer information on using sheep to control leafy spurge while providing a cash crop for the farm or ranch (Ries and Sedivec 1998).

In 1996, 130 ha of leafy spurge infested rangeland on the Heart River was purchased by an adjacent farmer/rancher. This rangeland had a history of cattle and horse grazing. The goal of this operator was to use this rangeland for sheep/cattle grazing. Research plots were established on this rangeland and leafy spurge was monitored before and after sheep/cattle grazing. The purpose of our study was to document the density and dry matter production of leafy spurge on the rangeland and monitor change in leafy spurge following sheep grazing.

STUDY AREA AND METHODS

In June of 1996, 10 research plots were located on 130 ha of land situated in the Heart River Breaks, 29 kilometers southwest of Mandan. The rangeland was diverse and included several range sites. Three research plots were on an overflow range site along a small intermittent stream with deep soils which received run on water from the adjacent area. Three other research plots were located on a silty range site, with good soils but little run on water. Two other research plots were on a shallow range site with limited soil resources and the final two research plots were in a woody draw range site with the potential for extra water from winter snow catch.

A cage (0.9 by 4.3-m and 1 m high) was secured at each research plot to protect the leafy spurge and other forage from being grazed by sheep or cattle. The pasture was grazed with sheep and cattle, with sheep grazing early in the season and cattle added after the sheep had reduced the leafy spurge canopy. The 130 ha of rangeland on our study area was part of a 891 ha pasture with cattle tight boundary fences. In 1996 and 1997, sheep grazing was minimal because boundary fences were not sheep tight. Before the 1998 grazing season, a boundary fence consisting of 5 barbed wires was built. During the 1998 grazing season, about 280 Rambouillet ewes with 280 lambs grazed the newly purchased 130 ha of leafy spurge infested rangeland. Sheep remained on the pasture from June until early November.

Leafy spurge stem density was counted and leafy spurge and other forage species dry matter production was clipped on 4 1/8th m^2 quadrats at each research plot. Data were collected in June 1996, 1997, and 1998 before sheep grazing and provided a 3-year record of the amount of ungrazed leafy spurge and other forage. In September 1998, 4 1/8 m^2 quadrats were clipped inside the cages and along a grazed transect outside the cages. Leafy spurge and the other forage species were separated in the laboratory before drying. Leafy spurge stems were counted and then vegetation samples were oven dried for 48 hours at 49EC and weighed.

Data were analyzed by unequal subplot, mixed model analysis of variance. Data from June 1996-98 provided an evaluation of leafy spurge density and dry matter production in relationship to each range site and growing season. Data from inside and outside the cages in September of 1998 provided information on leafy spurge removal by sheep at the different range sites.

RESULTS

There was a significant range site x year interaction for leafy spurge density (Fig. 1) because density did not respond the same among range sites in different years. A summary of weather conditions during each season and year (Table 1) provides some insight into the interactions in Fig. 1. There was a significantly higher number of leafy spurge stems on the overflow and woody draw sites in 1997 than on the silty or shallow sites. This may be explained by the amount of precipitation received as snow over the winter of 1996-97. Snow accumulated in the woody draws and on areas adjacent to the overflow range sites. Future snow melt provided more water than usual for leafy spurge seedling germination. In 1998, stem density was greatest on the silty range site. Conditions were favorable for leafy spurge germination on the silty range site because of a cool spring and less evapo-transpiration. Leafy spurge stem density varied more than leafy spurge dry matter between sites and years; however, dry matter production also responded significantly different among range sites and years (Fig. 2).

There was also a significant range site x year interaction for grass dry matter production with responses differing at the same range site in different years (Fig. 2). Forb dry matter was similar each year and was not significantly different among range sites. Forb dry matter averaged over 3 years was 168, 56, 40, and 8 kg/ha, respectively, for the overflow, silty, shallow, and woody draw range sites. Shrubs were only found in significant amounts on the

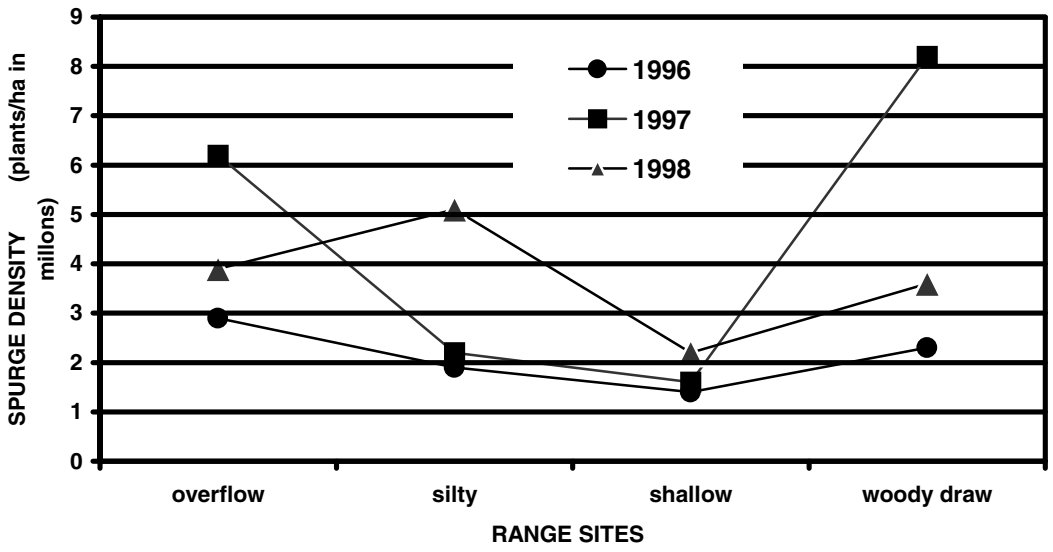

Figure 1. Significant year x range site interaction for leafy spurge density

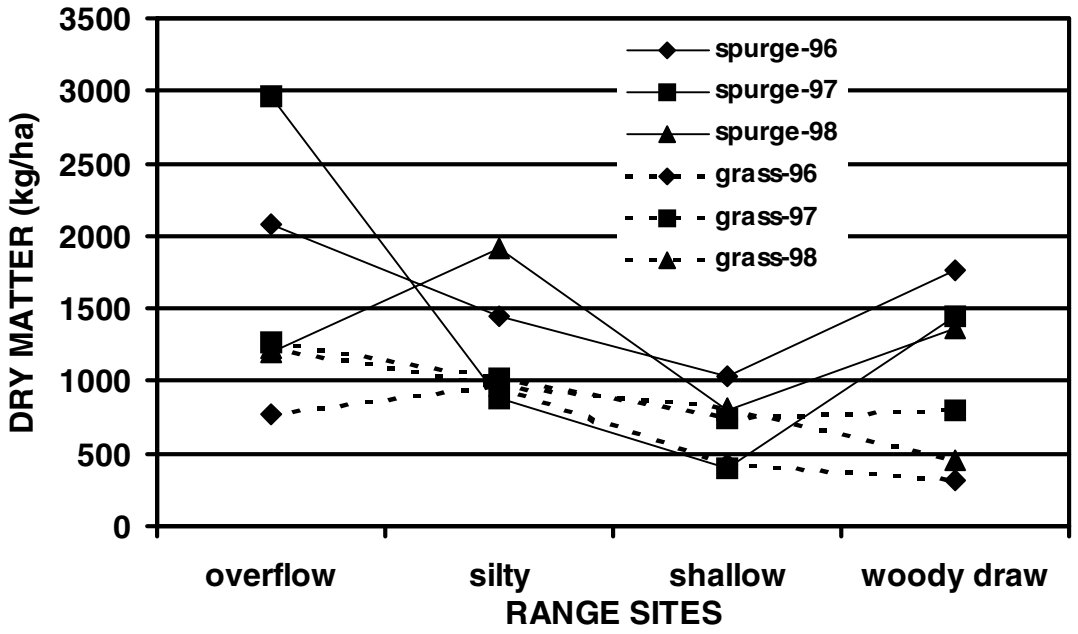

Figure 2. Significant year x range site interaction for leafy spurge and grass dry matter

woody draw range site where shrub dry matter averaged 2656 kg/ha.

Leafy spurge stem density after one season of grazing with sheep was not significantly reduced (139 stems/m^2 for ungrazed vs. 116 stems/m^2 on grazed; P>F = 0.0956). This was expected because any portion of a leafy spurge stem remaining after grazing was counted unless the stem was totally removed. There was a significant range site x grazing interaction for leafy spurge dry matter removed indicating that leafy spurge was not grazed equally on all range sites (Fig. 3). On the overflow site, leafy spurge plants were big and after grazing slightly more leafy spurge dry matter remained outside than inside the cages (+112 kg/ha). Leafy spurge dry matter was lower outside the cages at all other range sites. Sheep preferred grazing the shallow, silty, and woody draw areas because they were higher in elevation and more open. These range sites are less confining, with greater air movement resulting in cooler temperatures and fewer insects for the sheep. Preference for these 3 range sites compared to the overflow sites is also reflected in leafy spurge dry matter removal. On the silty and woody draw range sites in 1998, sheep removed 680 and 696 kg/ha of leafy spurge, respectively. At the shallow range site, sheep removed 320 kg/ha of leafy spurge in 1998. We expect leafy spurge dry matter use to also increase on the overflow range site with continued sheep grazing in future years.

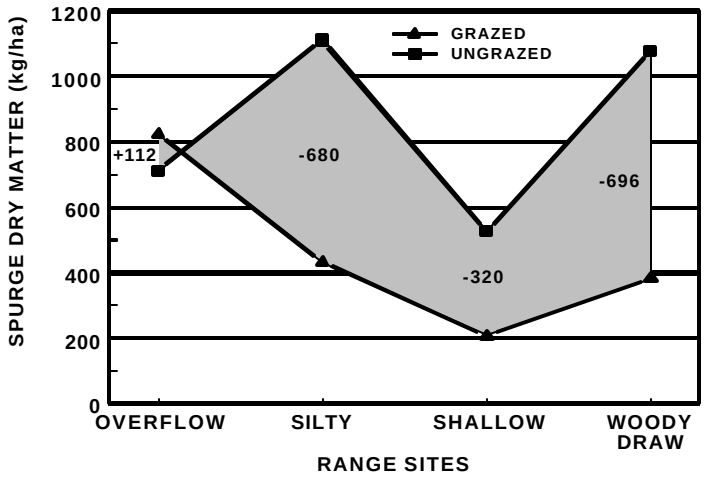

Fig. 3. Significant grazing treatment x range site interaction for leafy spurge dry matter removed during the 1998 grazing season.

Table 1. Weather data during the 3 year leafy spurge study on Heart River rangeland.

Seasons [1/]	Precipitation (mm)	Temperature (C)	Evaporation (mm)
Winter ‘95-‘96	68 [2/]	-8.3 [3/]	–
Winter ‘96-‘97	110	-1.9	–
Winter ‘97-‘98	64	-7.4	–
Spring ‘96	138	11.4	311
Spring ‘97	171	20.3	413
Spring ‘98	103	13.0	320
Summer ‘96	104	20.2	403
Summer ‘97	110	12.6	376
Summer ‘98	232	22.2	422
Fall ‘96	126	10.2	114
Fall ‘97	36	-3.0	147
Fall ‘98	150	12.6	141

[1/] Winter – Nov thru Mar; Spring – Apr thru Jun; Summer – Jul & Aug; and Fall – Sep & Oct

[2/] Snowfall (‘95-‘96 = 1466 mm; ‘96-‘97 = 2200 mm; and ‘97-‘98 = 554 mm)

[3/] Growing Season (‘96 - 5/13-9/11 - 121 days; ‘97 - 5/20-9/20 - 123 days; and ‘98 - 6/4-9/2 - 109 days)

DISCUSSION

Some research results reflect differences in degree of leafy spurge utilization by sheep because of possible differences in leafy spurge ecotypes and growing sites. Our data did not reflect this difference and further indicated that sheep can control leafy spurge by grazing and provide a cash product which is important to the economic viability of the farm/ranch operation. In our study on 130 ha of leafy spurge infested rangeland, sheep grazed significant amounts of leafy spurge from the study area even though it was part of a 891 ha pasture. The tight flock behavior and the tendencies to trail into the wind resulted in excellent utilization of the total pasture by the sheep. However, integration of sheep into a primarily cow/calf operation is not without difficulty. Fencing, timing of work, capital, and lack of experience with integration of sheep into cattle operations are often given as problems. However, there are several farm/ranch operators that have successfully integrated sheep into their operations for leafy spurge control and additional income. Including sheep in a ranching operation has often been dictated by loss of cattle forage because of leafy spurge infestation. Sheep grazing will not eradicate leafy spurge but they can control it, permitting more grass to grow for use by cattle. Sheep can play an important part in leafy spurge control on pasture and range lands of the Northern Great Plains and northwestern United States. Sheep should also be readily considered a proper biological control measure for leafy spurge infestations on reclaimed mined land.

REFERENCES

Helgeson, E.A. and E.J. Thompson. 1939. Control of leafy spurge by sheep. North Dakota Agric. Exp. Sta. Bi-monthly Bull. Vol. II:5-9.

Johnston, A. and R.W. Peake. 1960. Effect of selective grazing by sheep on the control of leafy spurge (*Euphorbia esula* L.). J. Range Manage. 13:192-195.

Kronberg, S.L. and J.W. Walker. 1999. Sheep preference for leafy spurge from Idaho and North Dakota. J. Range Manage. 52:39-44.

Landgraf, B.K., P.K. Fay, and K.M. Havstad. 1984. Utilization of leafy spurge (*Euphorbia esula*) by sheep. Weed Sci. 32:348-352.

Ries, R.E. and K. Sedivec. 1998. Ranchers combat leafy spurge infestation along Heart River using an old tool. Farm and Ranch Guide 19:44-45A.

Sell, R.S., D.A. Bangsund, and F.L. Leistritz. 1999. Perceptions of leafy spurge by ranch operators and local decision makers: An update. Agr. Econ. Stat. Ser. Rpt. No. 56. Agr. Expt. Sta. NDSU, Fargo, ND.

Williams, K.E., J.R. Lacey, and B.E. Olson. 1996. Economic feasibility of grazing sheep on leafy spurge-infested rangeland in Montana. J. Range Manage. 49:372-374.

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MANAGING A *BROMUS JAPONICUS* INFESTED RECLAIMED SITE

K. Krabbenhoft[1], D. Kirby[1] and D. Nilson[2]

ABSTRACT

A 14.7 ha area was reclaimed in 1989 on the Glenharold Mine in west central North Dakota. An extensive infestation of Japanese brome (*Bromus japonicus*) was present. Left unmanaged, the site would most likely fail to meet bond-release requirements. The site was rotary mowed in 1990, 1991, 1993 and 1995. The site was grazed by 47 cow/calf pairs from May 24th – June 22nd in 1997. During 1998, 48 cow/calf pairs grazed from May 16th – June 17th. Live basal cover was estimated using the ten-point frame method. Two thousand points in 1992, 1995 and 1998 were taken to record the abundance of Japanese brome, perennial species, annual litter and perennial litter. In 1995 and 1998, aboveground herbaceous yields were estimated by clipping 0.25m^2 quadrats. These were randomly located on transects in 1995 and 1998. Cover data in 1992 estimated that 66% was Japanese brome and annual litter. In 1995, these cover components were 50%. Japanese brome and annual litter cover was less than 1% in 1998. Yields of Japanese brome averaged 264 kg/ha (10% of the total) in 1995 and 52 kg/ha (3% of the total) in 1998. Japanese brome was present in 40% of the clipped plots in 1995 and 15% in 1998. Live basal and litter cover of Japanese brome was nearly eliminated following one year of early season intensive grazing. Yields were reduced by approximately 70% from 1995 to 1998. Japanese brome is quite palatable early in the growing season and readily grazed by cattle. By preventing seed set, the plant decreased in coverage allowing native perennials to inhabit the site. Infestations of annual grasses, such as Japanese brome, on reclaimed grasslands can be reduced through early season grazing management.

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INTRODUCTION

The Surface Mining Control and Reclamation Act of 1977 requires that a reclaimed native grassland have a diverse, effective and permanent vegetation cover of the same seasonal variety native to the region. Experience has shown that regardless of how well revegetation plans are designed and implemented, re-established native grassland stands can vary considerably. This nonpredictability is due to the inability to control certain variables in the reclamation process such as soil depth and quality, weather and weedy plant competition from species such as quackgrass (*Agropyron repens*), Kentucky bluegrass (*Poa pratensis*), smooth brome (*Bromus inermis*) and annual bromes such as Japanese brome (*Bromus japonicus*) (Nilson et al. 1985). Because of these variables, it may be necessary to employ management techniques, such as livestock grazing, to maintain or modify the seasonal balance of reclaimed native grasslands (Cline et al. 1999).

Grazing management and systems have been the most important management practices implemented for improving rangelands (Kothmann 1980). Most land disturbed by surface mining in the western United States is rangeland used by domestic livestock and wildlife (Schuman et al. 1990). If the post-mining land use is to be grazing, then a stand must sustain grazing without detrimental effects to the ecosystem. Much of the early literature dealt with grazing introduced forage species. Recent publications and abstracts often report seasonal balance shifts when dealing with grazing reclaimed land using native species. Limited information is available describing management techniques to reduce aggressive introduced annual or perennial species within a native mixture.

The objective of this study was to evaluate early season livestock grazing effects on a Japanese brome infested reclaimed grassland in western North Dakota. The results of this study should provide information necessary to make grazing recommendations for similar areas to achieve bond-release requirements.

STUDY AREA and METHODS

The research was conducted on the Glenharold coal mine in Oliver County of west central North Dakota. The mine is located in the Missouri Plateau Physiographic Region of North Dakota. This region lays on the western edge of an area where soils are formed from glacial deposits and residuum weathered bedrock of the sedimentary Sentinel Butte formation. Agriculture is the primary land use in the area adjoining the mine. Grasses and grasslike plants dominate the native vegetative communities in the surrounding mixed grass prairie.

In 1992, randomly located transects were sampled on the west pasture of Section 8 at the Glenharold Mine. Sampling continued in 1995 and 1998. The soils of the area were considered silty site types. Concurrently, data was taken from a nearby silty reference site during each of the respective years. Transects and portable grazing exclosures were randomly located across the 14.7 ha reclaimed area which was associated with an approximately equal amount (11 ha) of undisturbed rangeland and woodlands. Basal cover and species composition were estimated each year using the ten-pin point-frame method (Arny and Schmid 1942). During each sampling year, 2000 points were taken along two randomly located transects. In 1995 and 1998, aboveground herbaceous yields

were estimated by clipping 0.25 m² quadrats. Two quadrats were clipped at each of ten grazing exclosures in 1995, while three were clipped during 1998.

The reclaimed pasture was seeded in early June of 1989. The site was rotary mowed during four of its first 8 years of establishment. Grazing was implemented during year nine in the spring of 1997. The site was grazed by 47 cow/calf pairs from May 24th- June 22nd. During 1998, 48 cow/calf pairs grazed from May 16th- June 17th. The average stocking rate during these years was 1.9 animal unit months per ha (AUM/ha).

RESULTS

Live basal cover data in 1992 estimated that 66% of the total cover was Japanese brome and annual litter from previous year's growth (Fig. 1). Little change was seen in 1995 with levels of these two components still at 50%. However, following two seasons of intensive early season grazing the levels fell below 1% of the total cover in 1998 (Fig. 1).

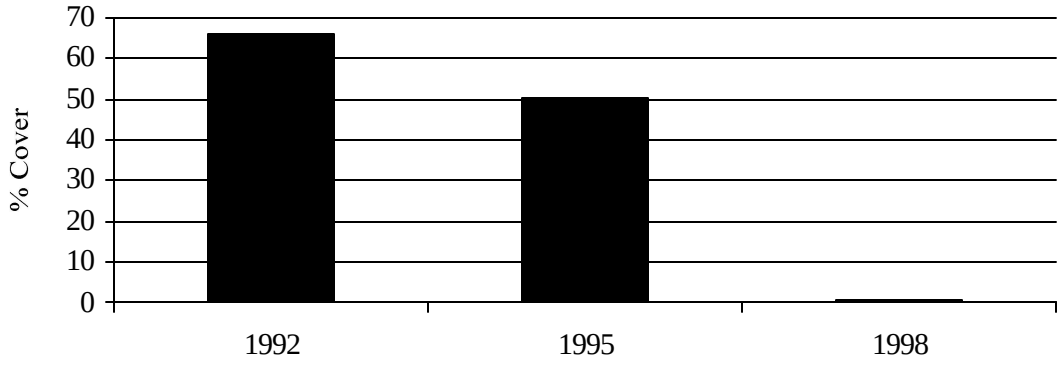

Figure 1. Basal cover (%) of Japanese brome and annual litter on the Glenharold Mine, Stanton, North Dakota.

Japanese brome yields averaged 264 kg/ha (10% of the total) in 1995 (Fig. 2). These levels dropped to 52 kg/ha (3% of the total) in 1998. Due to the use of grazing exclosures, this 70% relative decrease was seen following only one grazing season. Japanese brome was present in 40% of the clipped plots in 1995 and 15% in 1998 (data not presented).

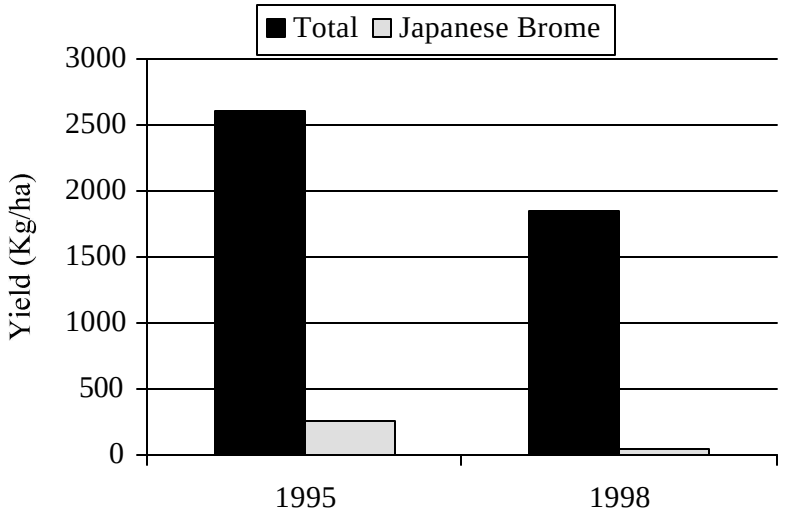

Figure 2. Total herbaceous and Japanese brome yields (kg/ha) on the Glenharold Mine, Stanton, North Dakota.

A positive trend in plant species seasonality occurred during the study. An increase in the relative amount of warm season grasses occurred for both cover and yield measurements. For live basal cover, the warm season relative percentage went from 17% in 1995 to 42% in 1998 (Fig. 3). Warm season grass yields exhibited an equally dramatic increase going from 8% to 28% during the same time frame (Fig. 4).

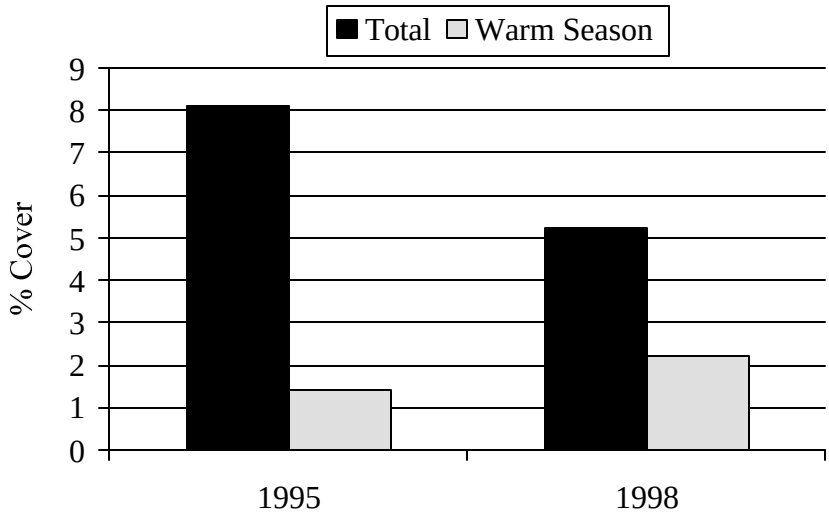

Figure 3. Total and warm season basal cover (%) on the Glenharold Mine, Stanton, North Dakota.

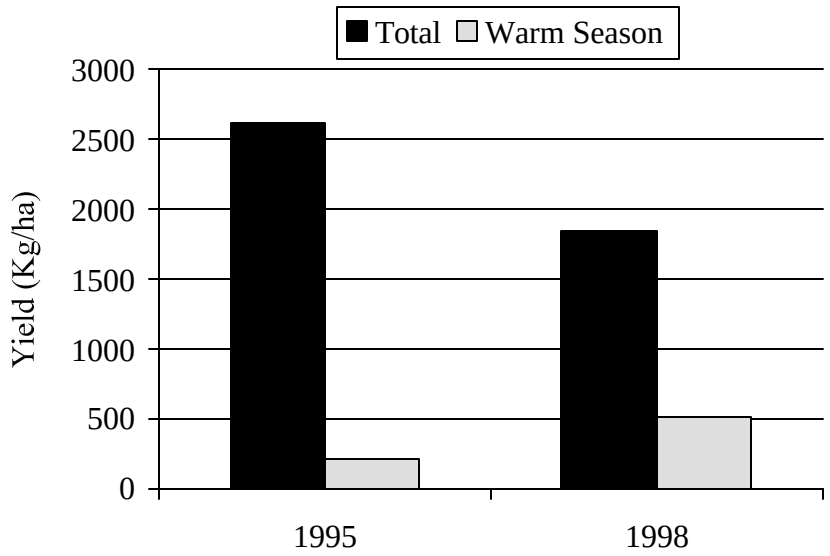

Figure 4. Total herbaceous and warm season yields (kg/ha) on the Glenharold Mine, Stanton, North Dakota.

CONCLUSIONS

Early season grazing decreased the abundance of Japanese brome based on basal cover and yield estimations to a manageable level two years following implementation. Concomitant with this observation was the positive relative composition shift in the native perennial species to that of a more seasonally balanced stand.

Japanese brome is quite palatable early in the growing season and readily grazed by cattle. By preventing seed set, the plant decreased in coverage allowing native perennials to inhabit the site. Infestations of annual grasses, such as Japanese brome, on reclaimed grasslands can be reduced through early season grazing management.

REFERENCES

Arny, A.C. and A.R. Schmid. 1942. A study of the inclined point quadrat method of botanical analysis of pasture mixtures. J. Amer. Soc. Agron. 34:238-247.

Cline, T.F., D.R. Kirby, and K.D. Krabbenhoft. 1999. Species composition trends following grazing of a reclaimed grassland. *In:* Abstracts of the 52nd Annual Meeting. Society for Range Management. Omaha, Neb.

Kothmann, M.M. 1980. Evaluation of livestock needs on designing grazing systems for rangeland. Chap. 6 Part B. *In:* Digestive Physiology and Nutrition of Ruminants, D.C. Church (ed.), Vol. 3 O & B Books, Inc. Corvallis, Ore.

Nilson, D.J., R.L. Williamson, J.C. Thompson, and J.E. Shultz. 1985. Techniques used to establish, maintain and enhance grasslands seasonal variety on the Glenharold Mine in North Dakota. *In:* Proc. 2nd National Meeting American Society for Surface Mining and Reclamation, Denver, Colo.

Schuman, G.E., D.T. Booth and J.W. Waggoner. 1990. Grazing reclaimed mined land seeded to native grasses in Wyoming. J. Soil Water Conserv. 45:653-657.

2000 Billings Land Reclamation Symposium

DETERMINING RECLAMATION SUCCESS FROM A WILDLIFE PERSPECTIVE

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ABSTRACT

Montana's coal program provides for two post-mine land uses: livestock grazing and wildlife habitat. The majority of coal mine lands reclaimed under the Montana Strip and Underground Mine Reclamation Act are classified as both livestock grazing lands and wildlife habitat. In addition to vegetation and hydrology standards, fish and wildlife habitats and related environmental values must be restored, reclaimed or protected before a mining company may receive Phase IV (final) bond release. In order to evaluate reclamation success for wildlife, pre-mine baseline studies are completed and wildlife monitoring is subsequently conducted annually at all active Montana coal mines. To the extent possible, sampling methods are consistent between mines. The data collected to date have identified the pre-mine wildlife communities and documented generalized trends in species invasion and use of reclaimed areas. Reclaimed areas vary in size from small to relatively large, are often irregular in shape, and may be scattered throughout the mine area. Consequently, when sampling wildlife populations in reclaimed areas, it is difficult at best and usually not feasible to sample intensively enough to make statistically significant determinations. However, annual wildlife monitoring using consistent sampling methods, can establish general population trends for individual mine sites. Implications regarding long-term regional trends can also be made for selected species. These trends can be used as a tool to assess the success of reclamation and whether or not reclamation qualifies for final bond release.

Additional Key Words: Bond release, reclamation, wildlife, wildlife monitoring

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INTRODUCTION

The Montana Strip and Underground Mine Reclamation Act [82-4-233(1)(a)] and the Administrative Rules of Montana [ARM 17.24.762(1)] provide for two post-mine land uses: livestock grazing and wildlife. Additionally, ARM 17.24.1116(7)(d)(ii) provides that Phase IV (final) bond release can not be completed until, "fish and wildlife habitats and related environmental values have been restored, reclaimed, or protected in accordance with the Act, the rules, and the approved permit." Montana has established a comprehensive wildlife assessment program to ensure that coal companies appropriately and adequately meet these responsibilities. Initially, coal companies are required to determine pre-mine wildlife communities. These efforts provide baseline data used both for pre-mine impact analysis, and to assess the re-establishment of a viable wildlife communities on reclaimed mine lands. Wildlife monitoring is then required [ARM 17.24.723] to determine wildlife use of mine sites during mining and reclamation, as well as wildlife use of reclaimed habitats prior to Phase IV bond release. Annual wildlife monitoring provides these data, including long-term trends needed for final bond release evaluations.

Until the early 1990's, wildlife monitoring programs at active Montana coal mines were developed without guidelines for target species or species groups, methodology or sampling intensity. In the early1990's, however, the Montana Department of State Lands, Coal and Uranium Bureau (now Department of Environmental Quality, Industrial and Energy Minerals Bureau), in cooperation with the coal companies, evaluated the past results and determined that some species and/or species groups appeared to be more reliable indicators of habitat conditions then others. Furthermore, because of the difficulty in observing animals and replicating methods, some methods (e.g., spring and summer big game aerial surveys and fawning/calving area surveys) were providing information of limited value. Therefore, wildlife-monitoring programs were modified to emphasize species groups that are effective indicators of habitat conditions while reducing the emphasis on or totally eliminating surveys for other groups. Today, annual wildlife monitoring focuses on surveys for landbirds (song birds), upland game birds (lek surveys), raptors (nest and concentration areas), small mammals (including bats), amphibians and reptiles (pond, wetland and special feature surveys), and big game winter distribution.

Surveys for upland game bird leks, raptor nests and concentration areas, and big game winter distribution are conducted on a mine-wide basis to determine annual changes in both animal numbers and distribution. Surveys for amphibians and reptiles are centered primarily on ponds and wetlands, with selected upland habitats surveyed for species such as the northern sagebrush lizard *Sceloporus gracious* and the short-horned lizard *Phrynosoma hernandesi*. While these surveys document the occurrence of amphibians and reptiles in selected habitats no population trends can be determined from these data. Thus, these surveys provide very general information indicating some forms of wildlife responses to reclamation, including seasonal habitat use and presence or absence of a variety of species.

Surveys for landbirds and small mammals are conducted in selected reclaimed habitats and representative reference areas. These surveys are more comprehensive and provide long-term population trend information, and compare use or important native and reclaimed habitats. Depending on the species, landbirds and small mammals select certain habitat conditions (vegetative species, vertical structure, ground cover, amount of litter, etc.), are good indicators of habitat quality and, therefore, have been chosen as indicators to determine reclamation success.

DISCUSSION

In this paper, we are concerned with three basic coal mining steps: (1) overburden and coal removal; (2) backfilling and regrading the disturbed area; and, (3) successfully completing reclamation and obtaining bond release. To provide guidance and help ensure survey consistency at each mine over time, as well as between the different mines, the Montana coal program has adopted Fish and Wildlife Guidelines (MDSL 1994). Since the re-establishment of a wildlife community comparable to the pre-mine situation is prerequisite for final bond release, development of a logical, econmic, consitent and defensible wildlife monitoring program is a paramount challenge for the coal mining companies. Such a program must be sound, with clear objectives, consistent and repeatable methods, and must operate within the economic and logistical constraints inherent to coal mining.

In an academic and/or research scenario, conclusions from wildlife surveys would commonly require a degree of statistical significance, such as a 90 percent confidence level. Due to the high variance often encountered when sampling wildlife populations, large sample sizes are usually required to obtain the necessary level of statistical confidence. In the "real world" scenario of coal mine wildlife monitoring, however, this intensity of sampling effort is seldom logistically or economically feasible, particularly because mining disturbs comparatively small amounts of area (e.g., less than the home ranges of individual big game animals) reducing the potential sample size, and because the life of a mine may exceed often exceed thirty years, reducing the applicability of data that represent a brief "moment in time," such as a single season of year. Indeed, depending on a number of variables that might influence the success of an intense sampling effort (e.g., weather, population size), it may be impossible to collect statistically valid samples on some mines or some reclaimed areas. Therefore, a defendable alternative monitoring strategy must be used

As discussed earlier, Montana's wildlife monitoring approach relies on implementing consistent methods that are applied every year. This approach yields two types of data: generalized trends in numbers, distribution and habitat use of certain species or species groups (including big game, upland game birds and raptors) in the mine area and a larger surrounding buffer that contains undisturbed (by mining) habitat conditions; and comparisons of species richness (for species groups such as landbirds, small mammals, reptiles and amphibians) between reclaimed habitats and appropriate unmined reference areas. The first type of data addresses the problem of small study areas for highly mobile species groups, while the second type of data addresses the issue of habitat quality restored through reclamation. Both types of data are comparatively easy to collect, meeting the objective of a study approach that is logistically feasible. Both types of data also contribute to the overall goal of determining reclamation success and suitability for Phase IV (final) bond release.

Annual monitoring over the life of the mine reduces the potential for either type of data to be dramatically influenced by variability in wildlife numbers or diversity that might be encountered in a single year, which could occur if monitoring took place on a more sporadic schedule (such as every third or fourth year). For example, in Montana there appear to be "cycles" in mule deer numbers, seasonal or annual fluctuations in small mammal numbers, and years in which amphibian reproduction may be greater (or lower). If wildlife monitoring is conducted on a sporadic schedule, there is an increased probability that such peaks or troughs in wildlife numbers or diversity could present a distorted picture of the success or failure of reclamation. In order to compensate for such variability in wildlife numbers and diversity, sampling in any given year would have to be considerably more intensive than is needed under an annual monitoring approach. As a result, the sum of annual monitoring costs would intuitively appear to be lower than the sum of greater costs incurred through

more intensive monitoring in fewer years, thus meeting the objective of providing a study approach that is economically feasible, particularly over the potentially long life of a mine.

Montana's program recognizes that, because of annual climatic variability as well as annual variability in habitat conditions such as vegetative composition, cover and structure, there may be annual variability in wildlife numbers, diversity, distribution and habitat use. Over the long term, however, a general trend will become evident and conclusions regarding the success of reclamation, in terms of Phase IV (final) bond release, can be drawn.

Montana's program also recognizes that vegetative diversity (i.e., composition, cover, structure, litter, substrate) influences the wildlife species that utilize a particular site, and that these characteristics will gradually change as reclamation matures. For example, some species such as western meadowlark (*Sturnella neglecta*) and deer mouse (*Peromyscus maniculatus*) may be considered to be habitat generalists and will often be present throughout both reclaimed habitats and undisturbed reference areas, regardless of habitat conditions. Other species prefer tall, uniform stands of grass; some, such as voles (*Microtus* spp.) favor dense accumulation of ground litter; while others like the grasshopper sparrow (*Ammodramus savannarum*) prefer short grass prairies. Over time, habitat conditions in a maturing reclaimed area will be expected to change to a greater degree than would be expected in an unmined reference area. Consequently, while wildlife species richness in a reclaimed area and its associated reference may be similar, the species composition of the wildlife communities inhabiting the two areas may be very dissimilar. Therefore, a species similarity index is a useful tool to determine the overlap of species occurring in the two habitats. As the index increases toward 1.0, the species overlap approaches 100 percent.

SUMMARY

In the 1990's, MDEQ in cooperation with the coal mining companies, has developed an effective strategy to measure the success of reclamation tin terms of Phase IV (final) bond release. The strategy is based on the comparatively intense collection of pre-mine wildlife baseline data, followed by less intense annual monitoring through the life of the mine. Annual monitoring provides a long-term trend with limited data gaps, accommodating naturally occurring fluctuations in wildlife diversity, numbers and distribution, and also allowing for change in habitat conditions in maturing reclaimed areas. Wildlife communities in reclaimed habitats can be compared with those occurring in unmined reference areas, both annually and over the long term. The development of a species richness trend, combined with a similarity index, is an effective method to determine if the wildlife communities within reclaimed habitat eventually approximate the communities found in adjacent unmined areas. While this method undoubtedly provides lower levels of statistical confidence than more intensive, large-scale sampling efforts, it does provide a very worthwhile method within the economic and logistical constraints normally imposed on coal mining companies.

REFERENCES

Montana Department of State Lands. 1994. Fish and Wildlife Guidelines for The Montana Strip and Underground Mine Reclamation Act. Coal and Uranium Bureau. Helena, MT. 48 p.

2000 Billings Land Reclamation Symposium

GEOCHEMICAL TREATMENT AND PHYTOSTABILIZATION OF ACIDIC MILL TAILINGS FROM THE PINOS ALTOS MINING DISTRICT, GRANT COUNTY, NEW MEXICO

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ABSTRACT

Acid generating mine and mill waste (tailings) resulting from hard rock mining pose significant environmental problems throughout the Western United States. One such example occurred at the abandoned Mammoth Lode mine and mill facility located within the Pinos Altos Mining District of Grant County in southern New Mexico. Acid generating mine and mill wastes at the site were located adjacent to and inside the primary drainage channel to Bear Creek. Wastes were characterized by low pH, high exchangeable acidity, high future acid generation potential, low fertility, and elevated levels of soluble heavy metals. Based on the results of a successful pilot-scale plot study, the USEPA (Region 6) selected geochemical treatment and phytostabilization as the preferred full-scale mitigation technology for the CERCLA funded Removal Action at the Mammoth Lode site. During the removal, approximately 3,000 cubic yards of the acid generating waste was excavated and treated in lifts on a treatment pad. Geochemical amendments (triple super phosphate, calcium hydroxide, and pulverized limestone) were added to each lift to neutralize the current and potential acidity of the waste and to bind soluble heavy metals. After a mellowing period for pH stabilization to between 6 and 8 units, the treated lift was consolidated into a stable on-site repository. Organic amendments (site-generated wood chips) were added to the upper six lifts, or approximately six feet, of the treated waste. Slow release fertilizer and mycorrhizal fungi inoculum were also added to the upper lift to facilitate the phytostabilization process. A seed mixture of cool and warm season native and adapted grasses was selected to form the basis of phytostabilization and a long-term sustainable ecosystem on the repository and other reclaimed areas. Monitoring of the project over three growing seasons has indicated that geochemical treatment and phytostabilization is a viable and cost effective mitigation technology for acid generating mine and mill waste sites in southern New Mexico.

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INTRODUCTION

The Mammoth Lode site is an abandoned mine and mill facility located in the Pinos Altos Mining District, Grant County, New Mexico. The Pinos Altos District lies in the Pinos Altos Mountains, a small mountain range located approximately six miles north-northeast of Silver City, Grant County, New Mexico. Gold deposits were discovered in the Pinos Altos District around 1860 and were productive until the early part of the twentieth century. Both vein and placer deposits were exploited on a limited scale by the miners of Pinos Altos. Other metal production in the district included silver, lead, and zinc. The only large scale operation in the district was the Empire Zinc Cleveland Mine, on the west side of the range.

The Mammoth Lode mining claim was located in 1887. Initial development of the prospect consisted of two shallow pits and several trenches. A stamp mill was located down slope of the mine workings. The date of construction of the stamp mill is undetermined, but a diagram of the Mammoth Stamp Mill appeared in the 1902 edition of the Sanborn Fire Insurance Map for Pinos Altos, showing the location of a stamp battery, concentrating tables and an engine house. The claim was patented by Golden Giant Mining Company in March, 1928. Construction on the Mammoth property in the twentieth century included a ball mill and floatation cells located adjacent to the original mill. It is uncertain when production activities were abandoned at the site, but it appears to have been in the 1940s.

In 1995, the Mammoth Lode site consisted primarily of limited structural remains from the mining and milling activities, waste rock piles and mill tailings. The fine-grained waste rock and mill tailings occurred adjacent to the main shaft and mill area. The bulk of the tailings were within an ephemeral stream located down slope from the floatation cells. Tailings extended within the stream channel from the Mammoth Lode onto adjacent Bureau of Land Management (BLM) property and into Bear Creek (Figure 1).

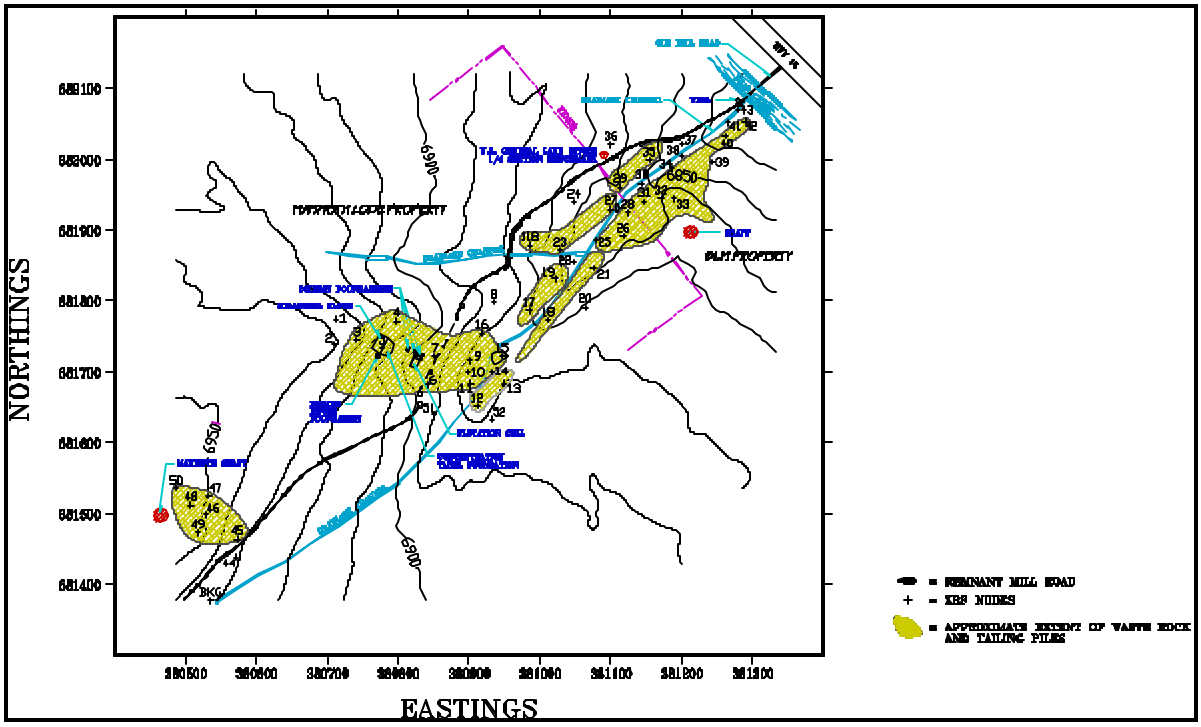

Figure 1. Mammoth Mill site feature map. Coordinates are NAD27 New Mexico West State Plane.

The U.S. Environmental Protection Agency (EPA) Region 6 Response and Prevention Branch (RPB) was notified about the Mammoth Mill site by the New Mexico Environment Department (NMED), which was concerned about acid rock drainage (ARD) and potential metals migration from the site into Bear Creek. In 1995, the EPA RPB began site characterization of the conditions present on the site. Based on the conditions identified, a pilot-scale plot study was undertaken to evaluate the potential for successful geochemical treatment and phytostabilization of the ARD material present on the site. Based on the results of the pilot-scale study, a full scale remediation of the site was undertaken. The following sections describes each of these three phases in more detail.

SITE CHARACTERIZATION

Site characterization was conducted in accordance with strategies detailed in Zehner et. al. (1997). Survey transects were established on the tailings materials at the Mammoth Lode site. *In situ* metals screening was conducted at fifty three transect nodes using a field portable X-ray fluorescence (XRF) spectrometer to estimate copper (Cu), lead (Pb) and zinc (Zn) concentrations. Three readings were taken at each node, which were averaged to derive metals concentration values. Ten percent the samples were analyzed by an independent analytical laboratory for Target Analyte List (TAL) metals (EPA SW846/6010) for confirmation of XRF results.

High accuracy Global Positioning System (GPS) surveys were performed to obtain positions of all XRF nodes. Overhead obstructions limited GPS satellite reception in some locations, so additional surveys were conducted using a total station survey unit to enhance position resolution and define cultural features. Geostatistical modeling and kriging were used to estimate grid metals concentrations from the XRF and survey data. Concentration isopleth maps were created using commercial contouring and mapping software (Figure 2).

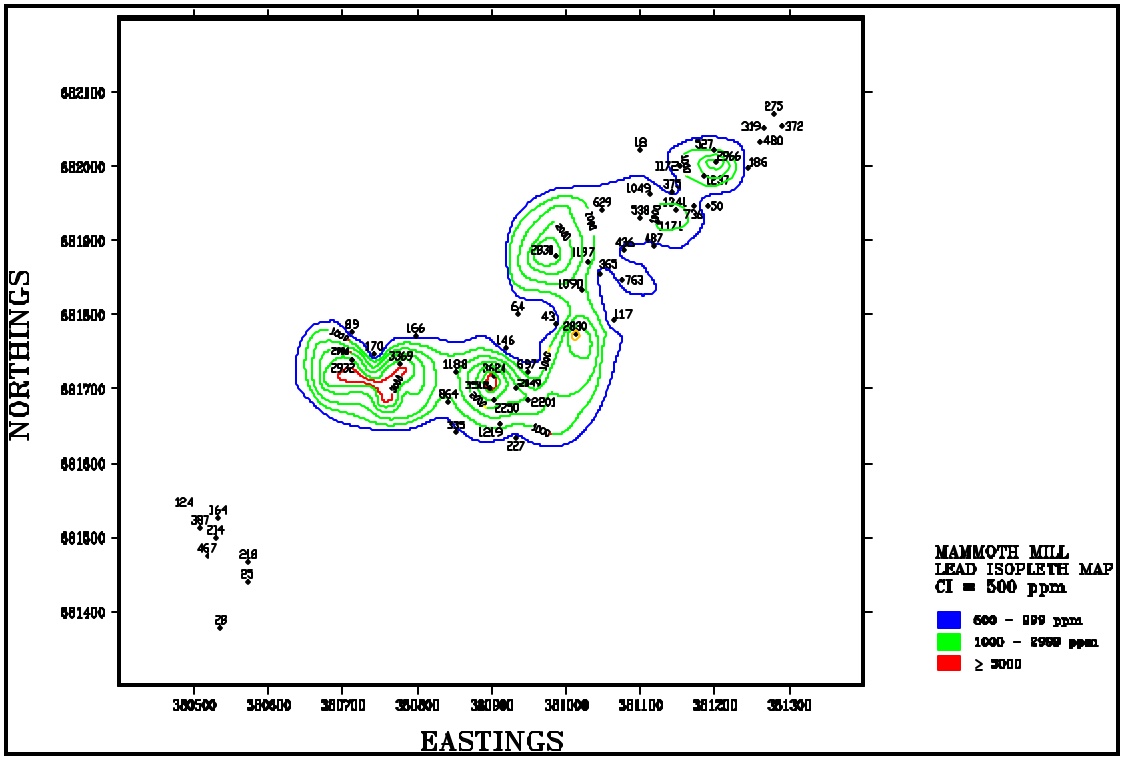

Figure 2. Lead concentration isopleth map from XRF survey of site. Circles are XRF sample points. Values are lead concentration in ppm. Map coverage is the same as Figure 1.

Composite soil samples were collected from six of the transect node locations and analyzed for standard acid/base potential tests (EPA 600/2-78-054), including neutralization potential (NP), exchangeable acidity (EXA), and sulfur forms. Acid generation potential (AP) was calculated from total sulfur. Soil samples were also analyzed for Target Analyte List (TAL) metals (EPA SW846/6010), water extractable metals (Page 1982, ASA No. 9 10-2.3.2), DPTA extractable Cd, Chromium (Cr), Cu, Iron (Fe), Manganese (Mn), Nickel (Ni), Pb and Zn (Page 1982, ASA No. 9 3-5.2.3), saturated past extraction cations (EPA 200.7), electrical conductivity (EPA 120.1), organic matter (USDA No. 60(24)), saturation percent (USDA No. 60 (2)), saturated paste soil pH (USDA No. 60(2)), texture by hydrometer (ASTM D422), water extractable nitrate (EPA 353.2) and potassium (EPA 200.7), $NaHCO_3$ extractable phosphorus (Page 1982, ASA No. 9 24-5.4.2), and water soluble boron.

Results of the site characterization revealed that mill tailings associated with the Mammoth Mill site covered approximately one acre in area and with an estimated volume of 3000 cubic yards. The tailings were void of vegetation and characterized by elevated concentrations of heavy metals (lead up to 3,600 ppm) and a low average pH (3.7 units). Further details on site characterization can be found in Cornelius et. al. (1997). According to Steffen, Robertson and Kirsten, Inc. (1992), mine rock and tailings with Net Neutralization Potential (NNP = NP - EXA - AP) values less than -20 tons of calcium carbonate ($CaCO_3$) per kiloton and NP:AP ratios less than 1:1 are considered potentially acid generating. The Mammoth Mill tailings had an average NNP of -22.27 and NP:AP ratio below 1:1, indicating a strong potential for future acid generation. Site characterization results were used to develop a pilot-scale study to evaluate the potential for geochemical treatment and revegetation of the mill tailings.

PILOT-SCALE REVEGETATION PLOT STUDY

A pilot-scale revegetation plot study was initiated in June, 1995 at the Mammoth Lode site to determine the potential for utilizing geochemical stabilization and revegetation to remediate the acidic, metals-contaminated mill tailings. The plot study addressed the following elements: 1) geochemical stabilization of the tailings; 2) addition of organic amendments and chemical fertilizers; and 3) revegetation and erosion control. In addition to the site specific data, the methodologies used in the plot study utilized information from the following sources: 1) the Streambank Tailings and Revegetation Studies-STARS (Reclamation Research Unit, et. al 1989; Schafer and Associates, et. al 1989; and Schafer and Associates and Reclamation Research Unit, 1993), a tailings revegetation study conducted on mill tailings in Silver Bow Creek, Butte, Montana by scientists from Schafer and Associates and the Reclamation Research Unit, Montana State University, Bozeman, Montana for the Montana Department of Health and Environmental Sciences, Helena, Montana in association with U.S. EPA Region 8; 2) a greenhouse revegetation potential study conducted as part of the Removal Site Assessment for the Blackhawk Mill Tailings site near Hanover, Grant County, New Mexico (Cornelius, et al, 1996); and, 3) information in Munshower (1994).

The Mammoth Lode revegetation study utilized three paired plots (six total), each with a size of approximately 10 by 10 feet. Geochemical stabilization was accomplished by the addition of calcium hydroxide, calcium carbonate and dicalcium phosphate to the tailings as described in Cornelius et al. (1997). Commercially available calcium hydroxide was added to each plot to neutralize all current acidity plus ten percent of potential acidity. One each of the three paired plots received enough additional calcium carbonate to neutralize the remainder of the potential acidity. The remaining plot of each pair received enough calcium carbonate to neutralize the tailings to a

final AP:NP ratio of 1:3. Calcium carbonate was added as crushed limestone from a local quarry source. Commercially available dicalcium phosphate was added to the tailings to enhance binding of metals and to enhance available P. After the addition of each amendment, the test plots were thoroughly tilled, watered and allowed to mellow.

Once the pH of the treated tailings fell below 8.5 units, a mixture of bark and saw mill waste was added to the plots at a rate required to bring the overall organic matter content of the upper six inches of the tailings to approximately two percent. Soil fertility analysis results indicated that N:P:K fertilizer should be amended at rates of 100:50:50 pounds per acre, which was applied to the plots as standard commercial fertilizer. Previous greenhouse studies on tailings from a nearby mine and mill site indicated that geochemical treatment may have caused a boron deficiency (Cornelius et. al. 1996), therefore, boron was applied at a rate of 1.5 lbs per acre as borax. In July 1995 each plot was seeded with a mixture of cool and warm season grass species and a nitrogen-fixing filler species (see Cornelius et. al. (1997) for details). The test plots were covered with biodegradable excelsior matting to provide surface erosion control and serve as a mulch for moisture retention.

The test plots were monitored and maintained through October 1995. Periodic maintenance included nutrient addition and irrigation of the plots. In October 1995, soil and plant tissue samples were collected for laboratory analysis. Test plots were also monitored without additional maintenance through September 1996. Vegetation cover was estimated within each plot on four sample dates during the first growing season (Cornelius et. al. 1997). Additional vegetation cover surveys were performed on two dates to document results of the second growing season.

Results of the geochemical stabilization of the mill tailings indicated that average soil pH increased from 3.7 to 6.3 units, exchangeable acidity decreased from 8.8 to 4.2 tons/kiloton, neutralization potential increased from 1.7 to 28.8 tons/kiloton, and acid/base potential increased from -14.2 to +17.0 tons/kiloton (Cornelius et. al. 1997). Native soils in the area of the Mammoth Mill site have soil pH values ranging from 5.5 to 7.5 units. No significant differences were observed in measured parameters from the test plots receiving the greater amount of calcium carbonate. The addition of logging waste increased the average soil organic matter from 0.5 to 1.73 percent. Soil fertilizer amendments increased plant nutrients from very low levels to levels conducive to plant growth, including boron, nitrogen, phosphorus and potassium.

Results from the short duration of this plot study indicate that revegetation was successful. Seed germination was observed within one week of sowing. Cover was relatively high on all sample dates (range 27-80%), even though all plots showed signs of intense grazing damage from local populations of deer, elk, and javelina. Observed seed production was low on all plots during the 1995 growing season. Several of the treatment plots had small areas within them characterized by very low plant cover. Both seed production and grass cover increased during the second (1996) growing season.

Plant tissue analysis of clover and blue grama from the test plots showed elevated heavy metal concentrations relative to plants from comparative background areas (data not shown). However, average concentrations of all metals were below Maximum Tolerable Levels of Dietary Minerals (MTLDM) standards for cattle (Subcommittee on Mineral Toxicity in Animals, 1980), except for Cd and Mg. Cadmium standards were based on human food residue considerations, and likely are biased high.

Results from the plot study at the Mammoth Lode indicated that geochemical treatment and phytostabilization is a successful and viable application for remediation of the pyritic mine waste at the site. The treated plots maintained a near neutral pH and an acceptable growing medium for the vegetative cover. The probabilities of long term stability of the treatment method also appear

favorable. The percent cover and density of the vegetation increased from the first growing season to the second growing season, surviving both extensive grazing pressure and extended drought conditions without supplemental irrigation or maintenance past the first growing season. Based on the success of the pilot-scale study a full-scale remediation plan was developed and implemented for the site.

FULL SCALE PROJECT

In October 1996, the Region 6 USEPA RPB initiated a Superfund removal action using geochemical treatment and phytostabilization as the remediation alternative at the Mammoth Lode site. The removal action was separated into the following work phases: 1) initial site preparation; 2) excavation, geochemical treatment, and consolidation of waste material; 3) site reclamation; and 4) maintenance and monitoring.

Phase 1 - Initial Site Preparation

Initial site preparation included restoration and construction of site roads, preparation of the on-site geochemical treatment pads and repository, and procurement of equipment and supplies.

Phase 2 - Excavation, Geochemical Treatment and Consolidation of Mine Waste

The removal construction contractor excavated approximately 3000 cubic yards of mine and mill waste for the Mammoth Mill Project. Excavation areas were defined and evaluated using XRF and soil pH data. Material was relocated to an on-site treatment pad for geochemical stabilization.

Geochemical treatment was based on the plot study results and proposed the use of dicalcium phosphate applied at a rate of five tons/kiloton of waste, calcium hydroxide applied at a rate of nine tons per kiloton of waste, and pulverized limestone applied at a rate of 17.5 tons/kiloton of waste. For the Mammoth removal, triple super phosphate (0-38-0) was substituted in place of dicalcium phosphate, as it was not readily available in the required quantities at the time of the removal. Triple super phosphate was readily available, had a lower cost per ton, and required less volume than dicalcium phosphate to treat the mill tailings. The triple super phosphate was applied at a rate of 2.5 tons/kiloton (acre-half foot) of treatment material. The sequence and timing for application of geochemical amendments and mellowing periods is important for obtaining the desired results. Cornelius et. al. (1997) gives a detailed discussion of the treatment methodology that was followed for this site.

The Mammoth Mill waste material was treated in thirteen, one foot thick treatment lifts. Amendment quantities were varied depending upon the specific characteristics of each treatment lift. A combination of heavy equipment ripping teeth and an agricultural disc plow were used to mix the tailings and geochemical amendments. After amendment addition and mixing, a mellowing period allowed for completion of metals binding and stabilization of soil pH to seven to eight units. As part of the mellowing process, water was applied periodically at amounts equivalent to 0.5 to 1.0 inches of precipitation to maintain soil moisture levels at approximately sixty to eighty percent saturation capacity.

Phase 3 - Site Restoration

Restoration activities at the Mammoth Mill site involved the physical stabilization and phytostabilization (revegetation) of the drainage/excavation area and the on-site repository. The treated tailings excavated from the Mammoth lode were consolidated to a single repository located east of the Mammoth shaft. The single repository had sufficient capacity for the treated tailings, was in an area previously disturbed by mining operations and did not require extensive engineering controls.

The upper three feet of the repository was amended with 20 tons of site-generated wood chips per kiloton of treated material to increase organic content. Nitrogen (N), phosphorous (P), and potassium (K) fertilizer was added to the upper surface at a rate of 200:100:100 pounds per acre. Boron as borax was added at a rate of 1.5 pounds per acre. A commercially available microrhyzal inoculum was also added to the top lift at manufacturer recommended application rates.

Restoration of the drainage/excavation area involved the use of limestone riprap and erosion control matting. On December 22, 1997 personnel demobilized from the Mammoth Mill site to allow for mellowing of the treatment material and to postpone revegetation activities to coincide with commencement of the summer rainy season.

On June 23, 1997 personnel and equipment were re-mobilized to the Mammoth Mill site to complete restoration activities. The drainage/excavation area and repository were revegetated with a seed mix consisting of native and adapted species of shrubs, sub-shrubs, cool season grasses and warm season grasses (Table 1). Seeding rates were based on critical area recommendations for southern New Mexico rangeland (Allison, 1992). An automated, temporary irrigation system was installed to maintain optimum moisture levels during the first growing season. Restoration activities were completed and personnel and equipment demobilized from the Mammoth Mill site on July 23, 1997.

Table 1. Plant species included in the seed mix for revegetation of the Mammoth Mill site.

Cool Season Grasses	Warm Season Grasses	Shrubs/Sub-Shrubs
Agropyron elongatum Tall Wheatgrass	*Bouteloua gracilis* Blue Grama	*Artemesia ludoviciana* Prairie Sage
Agropyron intermedium Intermediate Wheatgrass	*Bouteloua curtipendula* Side Oats Grama	*Atriplex canescens* Four-wing Saltbush
Agropyron dasystachium Thickspike Wheatgrass	*Hilaria Jamesii* Galleta	*Cercocarpus Montanus* Mountain Mahogany
Agropyron riparium Streambank Wheatgrass	*Muhlenbergia Wrightii* Spike Muhly	*Cowania mexicana* Mexican Cliffrose
Bromus marginatus Mountain Brome	*Panicum virgatum* Switchgrass	*Eurotia lanata* Winter Fat
Festuca arizonica Arizona Fescue	*Sporobolus airoides* Alkali Sacaton	*Rhus trilobata* Skunk Bush
Festuca ovina var. duriuscula Hard Fescue		

Phase 4 - Maintenance and Monitoring

Maintenance and monitoring at the Mammoth Mill site involved periodic site visits to evaluate/document the establishment of vegetation, monitor soil nutrient and ph levels, and perform any required maintenance on the irrigation system. The temporary irrigation system was dismantled in October 1997, after the first growing season. Total grass cover estimates for fall monitoring visits during 1997-1999 are presented in Table 2. Total grass cover has been stable on the site during the three growing seasons since the removal was completed. Grass cover of treated areas were comparable to a revegetated, disturbed control area.

Table 2. Fall 1997, 1998 and 1999 total percent grass cover estimates taken from revegetated areas at the Mammoth Mill Site.

Location	Total Grass Cover		
	Fall 1997	Fall 1998	Fall 1999
Disturbed Control	27	22	18
Repository	22	15	21
BLM Property	25	22	15

SUMMARY AND CONCLUSIONS

The USEPA Region 6 conducted a site characterization of the Mammoth Mill site in the Pinos Altos Mining District, Grant County, New Mexico. Results indicated that acid generating mine and mill wastes were located adjacent to and inside the primary drainage channel to Bear Creek. Wastes were characterized by low pH, high exchangeable acidity, high future acid generation potential, low fertility, and elevated levels of soluble heavy metals. A pilot-scale plot study was conducted, which indicated that geochemical treatment and phytostabilization was an appropriate full-scale mitigation technology for the CERCLA funded Removal Action at the site. During the removal, 3,000 cubic yards of acid generating waste was excavated, treated and transferred to an on-site repository. All impacted areas were treated with organic amendments and revegetated. Site remediation has been successful for three growing seasons, with treated waste and vegetation cover stable. The geochemical treatment and phytostabilization processes used for remediation of the Mammoth Mill site had a lower cost relative to conventional excavation and disposal remediation methods.

NOTICE

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REFERENCES

Allison, C. 1992. Seeding New Mexico Rangeland. Circular 525, New Mexico State University, Cooperative Extension Service.

Cornelius, J.M. D.L. Beeson, W.G. Whitford and W.B. Zehner. 1997. Geochemical treatment and phytostabilization of acidic mill tailings in the southern Rocky Mountains. pp 571-578, in Brandt, J.E. (ed.) Proceedings, 1997 Annual National Meeting of the American Society for Surface Mining and Reclamation, Austin, Texas.

Cornelius, J. M., M. Gomez, D. L. Beeson, W. C. Lindemann, W. G. Whitford, and W. B. Zehner. 1996. Revegetation potential of acidic mill tailings in southwestern New Mexico. pp 174-182, in F.F. Munshower and S.E. Fisher, Jr. (eds), 1996, Planning, Rehabilitation and Treatment of Disturbed Lands, Seventh Billings Symposium. Reclamation Research Unit Publication No. 9603. Montana State University, Billings, Montana.

Munshower, F. F. 1994. Practical Handbook of Disturbed Land Revegetation. CRC Press, Boca Raton, Florida. 265 p.

Page, A.L., ed. 1982. Methods of soil analysis, Part 2, chemical and microbiological properties. 2nd Edition, American Society of Agronomy, Soil Science Society of America, Madison, Wisconsin.

Reclamation Research Unit, Schafer and Associates and CH2M Hill, Inc. 1989. Final Summary Report. Phase I: Bench-Scale Column and Greenhouse Treatability Studies and Tailings Ranking System. Silver Bow Creek RI/FS. Streambank Tailings and Revegetation Studies. Montana State University, Bozeman, MT.

Subcommittee on Mineral Toxicity in Animals. 1980. Mineral Tolerance of Domestic Animals. National Academy of Sciences. Washington D.C. pp. 3-6.

Schafer and Associates, Reclamation Research Unit, and CH2M Hill, Inc. 1989. Final Summary Report - STARS Phase II: Field Scale Treatability Study Plot Construction. Silver Bow Creek RI/FS. SBC-STARS-Phase II-F-R1-051789. May 17, 1989.

Schafer and Associates, and Reclamation Research Unit. 1993. STARS Phase III: Final Report. Silver Bow Creek RI/FS. Doc. No. SBC-STARS-III--D-RO-013193.

Steffen, Robertson, and Kirsten, Inc. 1992. Report No. 93301 Mine Rock Guidelines Design and Control of Drainage Water Quality. Saskatchewan Environment and Public Safety Mine Pollution Control Branch. pp 5:18 - 5:22.

Zehner, W.B., J.M. Cornelius and D.L. Beeson. 1997. Methodologies for the characterization of hard-rock mine sites. pp 404-409, in Brandt, J.E. (Ed.) Proceedings, 1997 Annual National Meeting of the American Society for Surface Mining and Reclamation, Austin, Texas, May 10-15, 1997.

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METAL MINE TAILING REPROCESSING FOR ENHANCED VEGETATION ESTABLISHMENT: CLEAN TAILING TECHNOLOGY

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ABSTRACT

Mine tailing reprocessing was evaluated as an innovative reclamation technology for sulfide mine tailings. Mill tailings resulting from metal mining commonly cause resource degradation through oxidation of acid-forming minerals resulting in the release of metals and acidity to the environment. Reclamation technologies employed at the present time for sulfide tailing materials typically employ isolation or chemical treatment approaches for control of acid generation. Pyrite and other sulfides are not removed during treatment. The long-term permanence of these isolation and treatment technologies is therefore unknown, since sulfides may be exposed through deterioration of engineered caps or when amendments added during in-situ treatment are consumed or eroded. In laboratory and greenhouse evaluation of Clean Tailing Technology, sulfides were removed from tailings by reprocessing to create a more hospitable plant rooting media. Tailing reprocessing resulted in decreased total and water soluble metal levels in the cleaned tailing material. Vegetation establishment in the cleaned tailing media relative to growth in topsoil and lime amended tailings was measured and favorably demonstrates the potential for plant establishment and cost savings using Clean Tailing Technology. A field demonstration of the technology was implemented in 1999.

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INTRODUCTION

A history of environmentally insensitive tailing disposal practices has resulted in large scale ecological harm caused by acid mine drainage (AMD). In addition to water quality impairment, loss of vegetation, and prevalent erosion have resulted. In the state of Montana over 20,000 inactive or abandoned mine sites have been identified as contributing to degradation of over 1,000 miles of stream (Friel et al., 1991).

Current tailing reclamation practices in the United States are of two main types: capping, and in-place stabilization. Capping approaches are intended to provide waste isolation from air and water, though the degree to which this has been accomplished reflects the design of the cap, for which no standard design exists. Chemical barriers have been used in revegetation programs in Butte, Montana. Lime barriers of 4 to 6 cm were placed below coversoils of 50 cm thickness. This technique has been successful but a limited number of plant species has developed (Keammerer, 1992). Water-balance caps using thick soil and subsoil layers placed over waste are sometimes constructed in areas of limited precipitation where infiltration of water into waste can be prevented by storage and evapotranspiration (Strong, 1994). Engineered caps where soil is placed over impermeable geomembranes have also been constructed.

In-place stabilization of tailing material through the use of plants (phytostabilization) is an alternative tailing reclamation technology. This reclamation approach often requires addition of chemical amendments for control of conditions inhospitable to plant growth, most notably acidity. Lime addition is consequently the backbone of remedial efforts for in-situ revegetation of acid producing tailings. In the Clark Fork River Basin (Montana) where large expanses of acid-producing tailings are exposed, the STARS (Schafer and Associates and Reclamation Research Unit (RRU), 1993) and ARTS (RRU 1997) technologies are commonly considered for stabilization of acid producing tailings when sufficient soil resource is not available for capping or when damages caused by tailing excavation compel consideration of alternative reclamation approaches. These phytostabilization methods have demonstrated successful establishment of native plant species in lime amended tailings, yet concern exists over the permanence of these techniques.

Current reclamation techniques are subject to some limitations. Capping and tailing amendment can be very expensive. Phytostabilization techniques utilizing lime addition pose the additional threat of reacidification once the neutralizing capacity of the amendment has been consumed. In addition to the threat of reacidification, total metal concentrations are unchanged by in-place tailing reclamation. Water soluble metal concentrations in the rootzone are reduced by lime addition allowing for plant establishment, yet pH control is permanently required. High cost of implementation, coupled with risk of reacidification, causes concern for the permanence and feasibility of in-place tailing reclamation techniques.

Capping technologies utilizing soil or non-toxic geologic media are a common reclamation approach, although adequate amounts of cover material are frequently difficult to locate. If coversoil requires transportation to the site from another source, the costs may outweigh the benefits (Williamson et al., 1982). A major concern of all capping technique is that tailings are still present on the site with the same, or somewhat reduced, potential to generate acidity and release heavy metals. Degradation of cap integrity by erosion can re-expose tailings to weathering processes. Clay barriers can crack and plastic liners can be damaged or deteriorate, both of which undermine the application of capping techniques (Pulford, 1991).

Reprocessing of tailing materials has not been previously evaluated as a reclamation technology, but has been considered as an approach for recovery of metals. At INCO Ltd. Clarabelle Mill in Canada, sulfide minerals were removed from tailing material using froth flotation. The following conclusions were reached: 1) up to 94% of INCO's main tailings can be converted to low sulphur tailings, 2) low sulphur tailings showed a net neutralizing potential while non-reprocessed tailings remained potentially acid generating, 3) low sulfur tailings produced neutral seepage with low nickel, iron, and sulfate concentrations even after 1400 mm of cumulative rainfall and three peak oxidation periods, and 4) low sulfur tailings demonstrated low oxygen consumption, (Stuparyk et al., 1995).

In another study, four samples of tailings from three operating mines were characterized for acid generating potential and reprocessed to remove sulfide minerals. The sample contained 2.34% S, 4.15% S, 3.5% S, and greater than 20% S. All four samples showed an acid producing potential exceeded the neutralization potential. Using flotation, researchers were able to reduce the sulphur content to a range of 0.15-0.35% S, corresponding to recovery rates of 93%-98% (Humber, 1995).

In some instances, reprocessing may yield sufficient grades of economically valuable metals to consider recovery rather than disposal. Bench tests performed on copper-bearing open-pit strip waste showed considerable recovery of copper following crushing, sizing, flotation, and leaching techniques. Eight to fifteen percent recovery of other precious metals (gold and silver) was demonstrated (McKinney et al., 1973). According to research performed by Cristovici (1986), historic gold recovery by amalgamation and gravity concentration plants was low. Such tailings may still hold significant amounts of recoverable gold. Research determined the optimum grinding size for gold flotation at this site was 60% to 70% less than 74Fm, resulting in gold recovery of about 92%. This concentrate contained greater than 20 g Au/t. A forty-eight hour cyanidation treatment gave best results, regardless of grain size. Cristovici and others (1986) concluded recovery of gold from the tailings pond was economically feasible with the possibility to turn a profit by a relatively simple process.

Reprocessing of tailings has been selected as the remedial technology for cleanup at the Cleveland Mill Superfund site in New Mexico. Froth flotation has been evaluated as the best way to reduce metals concentrations in tailings materials at an abandoned lead and zinc mine

(Ecology and Environment, Inc., 1993). Eighteen acres along Little Walnut Creek and one of its tributaries were contaminated by tailings, ore, and dust with elevated metal levels. Excavation and transportation of material to a processing plant has been deemed the most economically, and environmentally sound alternative for treatment of the tailing material (U.S. Environmental Protection Agency, 1993).

EXPERIMENTAL METHODS

Tailing materials were field collected from three locations characterizing the dissimilar age, texture and administrative control of tailing materials in southwest Montana. The sites chosen for this study were: 1) an operational Copper Mine (CM), 2) a Superfund Site (SS) and 3) an abandoned tailings (AT) impoundment. These materials were field collected by hand excavation from the 0-60 cm depth at each site.

The effectiveness of different tailing reprocessing techniques was evaluated for each tailing material by a contracted laboratory specializing in mineral separation. The most effective method of sulfide separation was determined for each sample and applied to the 60kg bulk samples provided. Representative cleaned and sulfide concentrate fractions from each tailing sample were returned and utilized in laboratory and greenhouse testing at Montana State University. Subsamples were collected from each sample and submitted to an analytical laboratory for total metal and acid-base account analyses.

Water soluble chemistry evaluation of tailing treatments was performed through laboratory leaching utilizing Tempe pressure cells and deionized water. The treatments evaluated were cleaned tailings, cleaned tailings plus lime, lime amended tailings (STARS/ARTS technology), unamended tailings and a topsoil control (50% soil, 50% sand). Three pore volumes of deionized water were passed under pressure (0.5 bar) through each treatment and the resulting leachate collected. Analysis of the leachate for total metal levels, pH and electrical conductivity was performed. Five replications of each treatment were evaluated. Leachate levels of boron, calcium, copper, iron, potassium, magnesium, manganese, sodium, phosphorus, sulfur, zinc, chromium, cadmium, arsenic, and aluminum were determined.

Following completion of the laboratory leaching study, experimental tailing treatments were prepared for greenhouse evaluation of clean tailing reclamation (CTR) technology. The experimental design of the greenhouse study consisted of four treatments (unamended tailings, topsoil cap, lime amended tailings, cleaned tailings) from each of the three sites (CM, SS, AT). Two plant species were evaluated for growth response, *Elymus cinereus* (Basin wildrye) and *Poa pratensis* (Kentucky bluegrass). Five replications were performed of each treatment, resulting in 120 growth tubes. Seeds of these two plant species were placed in the growth tubes and were allowed to grow for 120 days in a climate controlled plant growth facility at Montana State University. After 120 days, above ground biomass was collected. Upon

harvesting, Munsell plant color, number of plants, height of each, and vigor were recorded.

Implementation of a field pilot test of CTR technology was conducted during 1999 at an operational mine generating acid producing tailing material. A specialty contractor provided spiral separation equipment which was used to reprocess approximately 200 dry tons cleaned tailing material. Test plots were allowed to dry over the summer (approximately 4 months) and subsequently regraded, amended with compost, fertilized and seeded. Mycorrhizae inoculated plants were also planted in replication at the test plots. Future monitoring will evaluate the effectiveness of these test plots.

RESULTS

All three tailing materials were successfully reprocessed resulting in a cleaned tailing material and high-grade sulfide concentrate. The high-grade concentrate represented approximately 10% of the original mass, while the cleaned tailings comprised approximately 90% of the original mass. Cleaning was performed by both gravimetric and floatation separation methods at the bench scale for each material. Floatation separation was effective on all tailing materials, though gravimetric separation performed well only on the CM and SS samples.

Reprocessing of tailing materials resulted in enrichment of sulfides in the high-grade concentrate and removal from the tailing material (Table 1). This process resulted

Table 1. Summary of mineral separation effectiveness for removal of sulfides from tailing materials.

Site	Bulk Tailings			Cleaned Tailings			Lime Cost Reduction
	Sulfide S	Lime Requirement (t/4000t)	Lime Cost ($/acre-2ft)	Sulfide S	Lime Requirement (t/4000t)	Lime Cost ($/acre-2ft)	
SS	3.9	487	19,500	0.17	21	850	96%
CM	0.58	72	2,900	0.28	35	400	51%
AT	0.08	10	400	0.05	6	250	37%

in prominent decreases in lime requirement, most notably from the SS sample where the tailing sulfide sulfur was reduced from 3.9% to 0.17%. Furthermore, scanning electron microscope study of the cleaned tailing material failed to identify any acid-forming sulfide minerals. Barite ($BaSO_4$), a non-acid-forming sulfate mineral was identified and likely contributed the trace sulfide sulfur content of the cleaned tailing material.

Coincident with recovery of sulfide minerals during reprocessing, Pb, As, Cu, Zn and other trace elements were recovered and express an elevated signature in the high-grade concentrate relative to the bulk tailings while the cleaned tailings demonstrated depressed levels of the same elements (Table 2). For example, the SS bulk tailings contained 167 mg Cu/kg while the cleaned tailings contained 96 mg Cu/kg. By contrast, the high-grade concentrate contained 708 mg Cu/kg. This represents a 4.23 fold magnification of copper from the bulk tailings to the high-grade while the cleaned tailings exhibited copper levels 42% lower than the bulk tailings. The degree to which any element is co-recovered with sulfide minerals is dependent on the complex mineralogical associations and weathering reactions occurring in each tailing media therefore confounding any broad prediction regarding the ability of CTR technology to reduce specific metal levels in tailings. Overall, total metals exhibit elevated levels in the high-grade concentrate compared to bulk tailing levels, while clean tailing exhibit reduced levels.

Each of the experimental treatments yielded water soluble constituents that were distinctly associated with the site and experimental treatment (Table 3). Statistically significant differences were evident for many comparisons between treatments observed within each site. Both the topsoil and unamended tailings were controls relative to the experimental treatments, yet both controls provide a different benchmark. The topsoil control was a very fertile, agriculturally productive soil while the unamended tailings control was a plant inhibitory or phytotoxic soil matrix. The degree to which deleterious plant available metal levels were observed was strongly related to pH. The pH of the SS unamended tailings was near 2.0 and corresponded to very high soluble metal concentrations. The AT soil material exhibited a pH near 3.0, and similarly expressed elevated soluble metal levels and no field plant growth. In contrast, the CM tailings were neutral (pH =7.0). This tailing material was fresh and unweathered, consequently pyrite oxidation had not expressed a negative influence on the soil solution pH.

As a general interpretation, the data suggest that the topsoil treatment has the highest levels of plant nutrients and low water soluble levels of plant inhibitory elements. The unamended tailings expressed high levels of plant inhibitory elements, and moderate to high levels of plant nutrients, while the experimental treatments expressed low levels of both nutrients and plant inhibitory elements. Exceptions to this general trend are observed. It is also emphasized that some unexpected trends were observed. For example, water soluble arsenic levels in the topsoil treatment were in excess of the tailing treatments. Water soluble As in the SS control was highest and significantly greater than the topsoil which was also significantly greater than the clean, lime and clean+lime experimental treatments.

Greenhouse plant performance of clean tailing technology was evaluated (Krueger, 1997), but is not included in this paper. Establishment of vegetation at the field demonstration site will be recorded during summer 2000.

Table 2. Total metal levels in field tailing samples, cleaned tailings and high-grade concentrates following mineralogical separation by reprocessing.

Site	Treatment	Mo (mg/kg)	Cu (mg/kg)	Pb (mg/kg)	Zn (mg/kg)	Mn (mg/kg)	Fe (%)	As (mg/kg)	Al (%)	Ag (mg/kg)	Au (µg/kg)
CM	none (field sample)	161 (2)	1290 (3)	24 (2)	285 (3)	343 (3)	2.5 (3)	68 (2)	7.2 (2)	0.49 (1)	3 (1)
CM	reprocessed (clean tailings)	130 (2)	1060 (3)	22 (2)	265 (3)	336 (3)	2.1 (3)	3.5 (1)	6.5 (1)	0.50(1)	21 (1)
CM	reprocessed (high-grade concentrate)	1270 (2)	14300 (3)	345 (3)	1440 (3)	701 (3)	32 (3)	8480 (2)	2.1 (2)	6.1 (2)	374 (1)
SS	none (field sample)	22 (2)	167 (3)	196 (2)	330 (3)	134 (3)	5.1 (3)	30 (3)	6.4 (2)	3.3 (2)	38 (1)
SS	reprocessed (clean tailings)	13 (1)	96 (3)	202 (3)	334 (3)	132 (3)	2.6 (3)	21 (2)	7.3 (2)	2.0 (1)	176 (1)
SS	reprocessed (high-grade concentrate)	66 (2)	708 (3)	186 (3)	165 (3)	98 (3)	30 (3)	76 (1)	2.4 (2)	5.9 (2)	343 (1)
AT	none (field sample)	61 (2)	196 (3)	1300 (3)	157 (3)	112 (3)	1.5 (3)	87 (2)	3.9 (2)	22 (2)	501 (1)
AT	reprocessed (clean tailings)	39 (2)	127 (3)	837 (3)	91 (3)	108 (3)	1.2 (3)	69 (2)	3.1 (2)	16 (2)	570 (1)
AT	reprocessed (high-grade concentrate)	180 (2)	780 (3)	5170 (3)	692 (3)	112 (3)	3.9 (3)	315 (2)	6.2 (2)	100 (2)	3200 (1)
Topsoil	none (50% soil/50% sand)	4.2 (1)	18 (2)	15 (2)	40 (2)	264 (2)	2.1 (2)	6.7 (2)	2.3 (2)	na	na

(2) number in parentheses represent number of measurements, mean values are presented
na- not analyzed

Table 3. Median water soluble chemistry observed during Tempe cell leaching of experimental treatments (n=5).

Site	Treatment	Element												
		B (µg/L)	Ca (mg/L)	Cu (µg/L)	Fe (µg/L)	K (µg/L)	Mg (µg/L)	Mn (µg/L)	Na (µg/L)	P (µg/L)	S (mg/L)	Zn (µg/L)	As (µg/L)	Al (µg/L)
CM	control	151 d**	19 c	2 c	4 c	1300 c	3000 c	82 d	1800c	6 c	20 c	3 c	4 c	70 a
CM	lime	13 b	30 c	1 b	2 a	1300 c	11 a	0 a	1200 b	0 a	2.1 a	0 a	2 b	38 a
CM	clean	77 c	2.1 a	0 a	2 a	650 a	240 b	1 b	620 a	20 c	2.0 a	2 c	0 a	22 a
CM	clean + lime	11 a	18 b	1 b	2 b	870 b	17 a	0 a	1000 b	3 b	9.0 b	1 b	2 b	28 a
	topsoil	404 e	100 d	5 d	34 d	4000 d	22000 d	20 c	5400d	42 d	93 d	8 d	11 d	156 c
SS	control	127 d	26 b	757 d	136700 e	86 b	11000 c	828 d	250 c	742 d	180 e	770 e	141 e	13000 d
SS	lime	73 c	66 c	6 b	4 a	18000 d	35 a	1 a	490 d	0 a	31 b	0 a	6 c	56 b
SS	clean	12 b	7.9 a	59 c	1030 d	27 a	440 b	32 b	130 b	2 b	9.0 a	60 d	3 a	260 c
SS	clean + lime	7 a	42 d	1 a	7 b	20 a	9700 c	445 c	47 a	2 b	40 c	20 c	5 b	13 a
	topsoil	404 e	100 e	5 b	34 c	4000 c	22000 d	20 b	5400 e	42 c	93 d	8 b	11 d	156 c
AT	control	185 c	1.6 a	1066 d	975 d	330 b	690 c	320 e	0.41 c	8000 b	14 b	899 d	5 b	4580 a
AT	lime	13 b	30 c	2 b	3 a	210 b	400 b	1 a	0.10 b	0 a	21 c	1 a	4 b	20 b
AT	clean	12 b	1.7 a	15 c	45 c	310 b	150 a	36 c	0.55 d	0 a	2.4 a	75 c	1 a	30 b
AT	clean + lime	7 a	28 b	0 a	2 a	33 a	610 c	112 d	0.076 a	0 a	23 c	14 b	1 a	0 a
	topsoil	404 d	100 d	5 c	34 b	4000 c	22000 d	20 b	5.4 e	42000 c	93 d	8 b	11 c	156 c

*Kruskal-Wallis non-parametric ANOVA ($P<0.05$)
**values followed by different letters are significantly different

CONCLUSIONS

Tailings resulting from metal mining at three different sites were successfully reprocessed for separation of pyrite and other sulfides from silicate minerals. This process resulted in a high-grade sulfide concentrate representing 10% of the original material volume and dominated by the mineral pyrite. Coincident with the recovery of pyrite, heavy metals and arsenic were co-recovered and were found at elevated levels in the sulfide concentrate compared to the bulk tailing material. Conversely, the cleaned silicate tailing material consisted of 90% of the original material mass and exhibited decreased metal concentrations. Greenhouse plant growth and water soluble leaching characteristics of cleaned tailing material was subsequently evaluated and compared to untreated tailings, lime amended tailings and a topsoil control. The highest levels of water soluble plant nutrients and best plant growth was observed in the topsoil treatment, while the cleaned and lime amended treatments demonstrated comparatively lower plant growth and lower levels of plant macronutrients. The unamended control treatments demonstrated the highest observed water soluble metal concentrations and lowest level of plant performance, particularly on tailing sites with low pH.

ACKNOWLEDGMENTS

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REFERENCES

Cristovici, M.A. 1986. Recovery of gold from old tailing ponds. CIM Bulletin, 79:27-33.

Ecology and Environment, Inc. 1993. Froth Flotation Treatability Study Report. Prepared for New Mexico Environment Department, Ground Water Protection and Remediation Bureau. Sante Fe, NM. 13 pages.

Friel, L., Larson, D., Wilson, A. and R. Juntunen. 1991. Inactive and abandoned noncoal mines, a scoping study. Prepared for the Western Governors' Association Mine Waste Task Force by the Western Interstate Energy Board.

Humber, A.J. 1995. Separation of sulfide minerals from mill tailings. Sudbury '95 Mining and

the Environment; Conference Proceedings, 149-158.

Keammerer, W.R., Arther, D. and A. Kuenstling. 1992. Anaconda Longterm Vegetation Monitoring Project, 1988-1990, Smelter Hill and Butte Sites. Report to ARCO, Anaconda, MT.

Krueger, J.M. 1997. Clean Tailing Reclamation: Revegetation of Mill Tailings Following Removal of Pyrite and Heavy Metals. M.S. Thesis, Montana State University, Bozeman, MT., 82 pp.

McKinney, W.A., Evans, L.G. and W.W. Simpson. 1973. Recovery of copper from crushed and sized porphyry mine waste. Transactions, 254:295-296.

Pulford, I.D. 1991. A review of methods to control acid generation in pyritic coal mine waste, pp. 269-279 In Proc. of The International Conference on Land Reclamation: An End to Dereliction? University of Wales College of Cardiff.

Reclamation Research Unit. 1997. ARTS Phase 4 Final Report: Anaconda revegetation treatability studies phase 4: Monitoring and evaluation. Volume 1. Document No.: ASSS-ARTS-IV-FR-073197. Montana State University, Bozeman, MT.

Schafer and Associates and Reclamation Research. 1993. Streambank Tailing and Revegetation Study, STARS Phase 3 Final Report, Volume 1. Document No.: SBC-STARS-III-F-111093. Montana Dept. of Env. Qual., Helena, Montana.

Strong, M.R. 1994. Hydrologic Evaluation of Tailing Covers at the Golden Sunlight Mine. M.S. Thesis, Montana State University, Bozeman, MT., 179 pp.

Stuparyk, R.A., Kipkie, W.B., Kerr, A.N. and D.W. Blowes. 1995. Production and evaluation of low sulphur tailings at INCO's Clarabelle Mill, pp. 159-169 In. Proceedings of the Sudbury '95 Mining and the Environment Conference.

U.S. Environmental Protection Agency. 1993. Record of Decision; Cleveland Mill Superfund Site, Silver City, New Mexico; Final Source Action. Dallas, TX.

Williamson, Johnson and Bradshaw. 1982. Mine Wastes Reclamation; The Establishment of Vegetation on Metal Mine Wastes. Surface improvement in mine waste reclamation. Chapter 10, pp. 68-78.

2000 Billings Land Reclamation Symposium

RECLAMATION OF THE PIEGAN-GLOSTER MILLSITE

C.R. Serviss[1], K.S. Rauch[2] and J.E. Chavez[3]

ABSTRACT

The Piegan-Gloster Millsite, an abandoned hardrock mine/mill site ranked No. 8 on the Montana Mine Waste Cleanup Bureau Priority List, is located in the Marysville Mining District, Lewis and Clark County, Montana. Hardrock and placer mining for gold and silver dates back to the 1870's. The site is located within the Piegan Creek drainage basin, a 5-square mile area of steep, forested terrain with some open grassland contained within private and Bureau of Land Management property. Piegan Creek discharges to Little Prickly Pear Creek, a Class III fishery, approximately two miles below the millsite. Elevation ranges from 4,520 to 6,000 feet above mean sea level and annual precipitation is 17 inches per year. Land use is primarily recreational and cattle grazing.

The Piegan-Gloster Millsite contains four tailings impoundments, two waste rock piles and a dilapidated mill. Site characterization and risk assessment studies indicated that three tailings piles, which contain an estimated 219,350 cubic yards and occupy 11.2 acres, presented the highest risk to human health and the environment. The tailings contain moderately elevated concentrations of lead, zinc, manganese, mercury and cyanide. Tailings were being eroded and released to Piegan Creek during stormwater/snowmelt runoff events resulting in surface water quality degradation and impacts to stream sediments.

An EE/CA indicated that an in-place containment reclamation strategy offered a cost-effective method for controlling direct contact and impacts to surface water quality. Tailings were excavated from the estimated 100-year floodplain, consolidated and graded to minimize erosion; the stream channel was reestablished and stabilized using natural backfill and riprap; water runon controls were established; the tailings areas were capped with 1.5 feet of soil, fertilized, seeded and mulched; and reclaimed areas were fenced to control cattle grazing. From the initial work plan development to the reclamation construction, the Piegan-Gloster Millsite project took 24 months to complete at an expenditure of $838,990.

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INTRODUCTION

The Piegan-Gloster Millsite is an abandoned hardrock mine/mill site ranked No. 8 on the Montana Department of Environmental Quality, Mine Waste Cleanup Bureau (MDEQ/MWCB) Priority Sites List. The mine/mill workings and tailings impoundments are located in the Marysville Mining District, Lewis and Clark County, Montana. The district produced gold and silver in the late 1800's to early 1900's from placers and epithermal quartz and carbonate veins hosted in igneous and/or metamorphic rocks (Walker, 1992). The site is located within the Piegan Creek drainage basin and occupies portions of Sections 15, 16, 21, 22, 27 and 28 of Township 12 North, Range 6 West, Montana Principal Meridian (Figure 1). The elevation of the site ranges from 4,520 feet above mean sea level, where Piegan Creek discharges to Little Prickly Pear Creek, to 6,000 feet above mean sea level at mine workings near the Gloster Townsite. The terrain surrounding the site is generally rugged, consisting of relatively steep (20 to 30 degrees) mostly timbered slopes with some open grassland. The site is located predominantly on private property that is surrounded by Bureau of Land Management (BLM) property. Annual precipitation is estimated at 16 to 17 inches per year. The area surrounding the site is important habitat for a variety of animals and birds and is considered critical winter range for elk and mule deer. Piegan Creek discharges to Little Prickly Pear Creek which is rated as a Class III fishery and is considered important spawning habitat for Rainbow and Brown Trout from the Missouri River. The current land use around the site area is primarily recreation and cattle grazing. The nearest residence is located approximately 1.5 miles from tailings impoundment TP-3 and the Great Divide ski resort is located approximately 1.5 miles south of the Piegan-Gloster millsite.

SITE CHARACTERIZATION

Site characterization work focused on the following evaluations: background soil chemistry, mine/mill waste chemistry and volumes, surface water and ground water chemistry, stream sediment chemistry, assessment of airborne particulate emissions, assessment of physical hazards and an evaluation of revegetation parameters. Table 1 summarizes mean chemistry results for tailings, waste rock, placer tailings and native soils. The tailings are moderately elevated in Pb, Zn, Mn, Hg and cyanide and slightly elevated in As and Cu relative to background soils. Waste rock and placers are only slightly elevated in these elements with the exception of Hg. Field observations, alkaline pH, low total sulfur concentrations (<0.2 percent) and positive acid/base accounting results indicate that the wastes from the Piegan-Gloster Millsite are not acid generating.

Surface water chemistry results indicate that Pb, As, Zn, Cu and Hg are elevated above background and, in many cases, exceed human health and/or aquatic life standards in Piegan Creek downstream of the tailing piles TP-2, TP-3 and TP-4. Stream sediment chemistry results showed that the same element suite, along with Mn and total cyanide, are also elevated above background concentrations in Piegan Creek below these tailings.

Tailing pile TP-1 and the majority of the placer tailings are well vegetated and are generally isolated from the Piegan Creek active stream channel. The waste rock piles are generally coarse-gained rock and are located well upstream of the headwaters of Piegan Creek. The near surface tailings in TP-2, TP-3 and TP-4 have particle size distributions that range from 74% to 90% silt and clay. These fines are elevated in Pb, Zn and Mn and present an

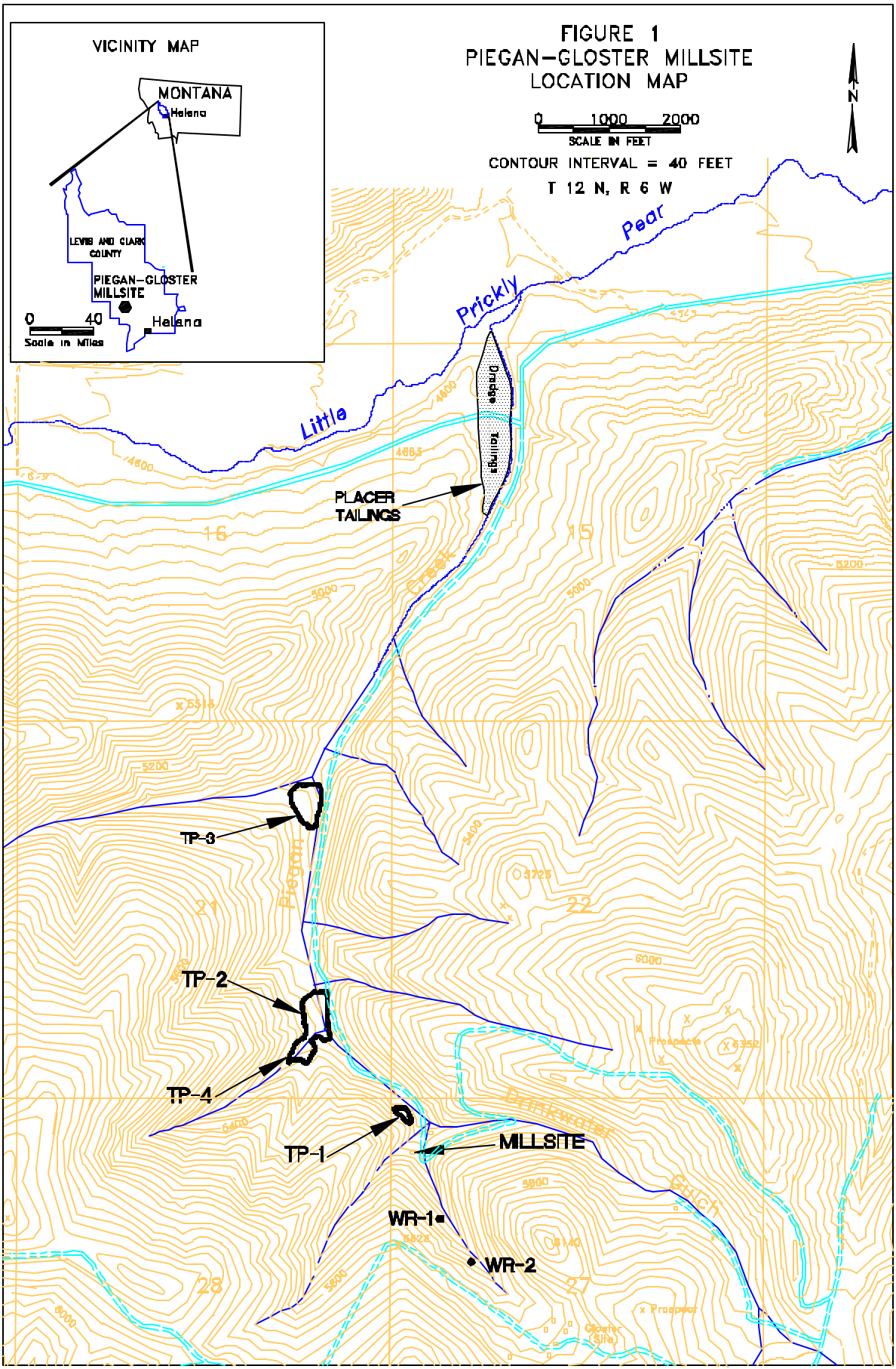


FIGURE 1
PIEGAN-GLOSTER MILLSITE
LOCATION MAP
0 1000 2000
SCALE IN FEET
CONTOUR INTERVAL = 40 FEET
T 12 N, R 6 W
N
VICINITY MAP
MONTANA
Helena
LEWIS AND CLARK COUNTY
PIEGAN-GLOSTER MILLSITE
Helena
0 40
Scale in Miles
Little Prickly Pear
Tailings
PLACER TAILINGS
Creek
Piegan
TP-3
TP-2
TP-4
TP-1
MILLSITE
WR-1
WR-2
Drinkwater Gulch
Prospects
Prosper
Gloster (Site)
16
15
24
22
28
27

Table 1. Mine/Mill Waste Mean Chemistry, Area and Volume Summary

Media	Area (Acres)	Volume (CY)	pH (SU)	ABP t/1000t $CaCO_3$	Total Cyanide (mg/kg)
TP-1	0.595	1,887	7.80	21.38	3.5
TP-2	4.85	99,983	8.56	95.73	7.1
TP-3	4.43	70,483	7.88	88.04	8.7
TP-4	1.88	48,884	9.70	85.91	1.2
Waste Rock	0.95	14,778	7.95	36.38	ND
Placer			8.37	51.31	ND
Native Soil					ND

Media	As (mg/kg)	Cu (mg/kg)	Hg (mg/kg)	Mn (mg/kg)	Pb (mg/kg)	Zn (mg/kg)
TP-1	51.2	61.3	0.86	1123	267.1	579
TP-2	61.5	170	0.10	4438	1340	1740
TP-3	70.8	377	0.24	3783	2738	3248
TP-4	68.9	168	0.45	6590	898	1317
Waste Rock	24.1	93.3	0.63	811	84.4	122.7
Placer	51.8	21.6	0.54	640	30.0	70.3
Native Soil	14.5	17.3	ND	532	14.6	64.8

ND = not detected

exposure risk via direct contact and airborne emissions. The only physical hazard identified was the dilapidated Piegan-Gloster mill. The results of the site characterization indicated that tailings piles TP-2, TP-3 and TP-4 posed the greatest risk to human health and the environment. Metal and cyanide-bearing tailings from these facilities were being eroded and released to Piegan Creek during storm water and snowmelt runoff events resulting in surface water quality degradation and impacts to stream sediments.

ENGINEERING EVALUATION/COST ANALYSIS

An Engineering Evaluation/Cost Analysis (EE/CA) included: residential/recreational risk assessments, development and screening of reclamation alternatives, evaluation of eight reclamation alternatives and a proposal for a preferred alternative.

The mill tailings in TP-2, TP-3 and TP-4 are the principal waste source contributing to environmental impacts at the Piegan-Gloster Millsite. Waste rock sources do not appear to be a problem at the site. The mill tailings base metal chemistry is, for the most part, significantly lower than most mill tailings and these tailings, after nearly 100 years of exposure, show no evidence of acid rock drainage (ARD) characteristics. The tailings are alkaline and this has limited the solubility of most metal constituents in the tailings piles, with the exception of arsenic. Although arsenic is generally more soluble under neutral to alkaline conditions, its impact to the environment is limited because the maximum concentration of arsenic in the tailings is less than 100 mg/kg. The principal source of ground water in the Piegan-Gloster site area is bedrock where ground water movement is most likely fault and fracture controlled. The bedrock in the tailings areas is predominantly

shales and limestones that may or may not be metamorphosed depending on their proximity to the quartz diorite stock near the headwaters area of Piegan Creek. The subsurface geology in the area of the tailings piles is a positive factor for limiting the downward migration of contaminants into a bedrock aquifer because of the low permeability of the shale and the neutralization potential of the limestone.

The greatest risk to human health and the environment in the Piegan-Gloster Millsite area is the release of tailings sediment into Piegan Creek and in its unnamed tributary containing tailings pile TP-4. Erosion cuts up to 24 feet deep were observed in some of the tailings piles. Metal contaminants of concern are predominantly transported as suspended sediment by surface water mainly during storm water and snow melt runoff events. Direct contact with the tailings also presents a significant risk to human health and the environment. Metals contained in the exposed tailings are subject to ingestion and dust inhalation.

Table 2 summarizes the five reclamation alternatives that were evaluated in detail for the Piegan-Gloster Millsite. Based on the conclusions of the detailed analysis and comparative analysis of alternatives, Alternative 3 - In-Place Containment was selected as the preferred alternative for the Piegan-Gloster Millsite. This alternative is considered the most appropriate and cost-effective means to reduce risk to human health and the environment to an acceptable level.

Table 2. Summary of Reclamation Alternatives and Cost Estimate

Alternative	Description	Cost Estimate ($)
1	No Action	0
2	Institutional Controls	150,671
3	In-Place Containment	1,298,486
4	On-site Disposal in Constructed Repository	3,585,105
5	Partial 0n-site Disposal/In-Place Containment	2,359,683

DESIGN AND IMPLEMENTATION OF THE RECLAMATION ALTERNATIVE

The primary design objectives were to provide long-term stabilization of the tailings by controlling surface water and reducing erosion and sedimentation, to reduce exposure via a soil cap and to reconstruct Piegan Creek and its unnamed tributary in the vicinity of the reclaimed tailings piles.

The Piegan Creek drainage basin occupies an area of 5.02 square miles of generally steep, forested terrain with some open parks. Piegan Creek and its tributaries occur in narrow canyons with valley floors usually less than 200 feet in width. Elevation differences from the valley floors to adjacent ridges is on the order of 800 feet. The Piegan Creek stream channel is generally less than 10 feet wide. Piegan Creek has a moderately steep gradient for most of its length with an average gradient of approximately 6% in the area of the tailings impoundments. The stream has a low sinuosity, low width/depth ratio, and the channel materials are predominantly cobbles with a mixture of sand, gravel and some boulders. Based on these parameters, Piegan Creek, in the vicinity of the tailings, is an A3 stream according to the Rosgen classification system (Rosgen, 1996). The unnamed tributary to

Piegan Creek that flows through tailings pile TP-4 has a gradient exceeding 10% and is a Rosgen class A3a+ stream.

A hydrologic study of the Piegan Creek Basin was completed and the data used in the stream channel design and to estimate the volume of tailings that would require removal from the channel/floodplain area in the vicinity of each tailings impoundment. USDA Soil Conservation Service TR-55 methods were used to estimate peak flows (Table 3) at tailings impoundments TP-2, TP-3, and TP-4. The rainfall events used in the TR-55 calculations were taken from the NOAA (1973), and are as follows: 2-year, 24-hour (1.2 inches), 5-year, 24-hour (1.6 inches), 10-year, 24-hour (1.9 inches), 25-year, 24-hour (2.2 inches), 50-year, 24-hour (2.6 inches) and the 100-year, 24-hour (2.8 inches).

Table 3. Peak Discharge Estimates for Tailings Impoundments TP-2, TP-3, and TP-4

Location	Peak Discharge, cfs					
	2-year	5-year	10-year	25-year	50-year	100-year
TP-2	<1	6	22	47	96	143
TP-3	<1	10	32	64	137	198
TP-4	<1	5	10	20	45	59
Mouth of Piegan Creek	<1	19	54	103	225	316

A riprap channel lining was selected to provide long-term stabilization of the tailings because of the steep channel gradients and because the natural stream above and below the tailings is largely cobble-size material, which is similar to riprap. Figure 2 shows tailings piles TP-2 and TP-4 before and after reclamation, and a typical channel cross section. The TP-2 stream channel was lined with 12-inch minus riprap and a geotextile filter fabric. The riprap was blended with soil to provide a growth medium for vegetation and the channel banks were seeded with grasses. The stream channel through tailings pile TP-4 was reconstructed with several riprap-lined drop structures with riprap up to 28-inch diameter. The drop structures were designed as cascading chutes. Tailings pile TP-3 (Figure 3) was also designed with small drop structures.

Open-channel flow assessments indicated that the following channels should contain the discharge from the 100-year, 24-hour rainfall:

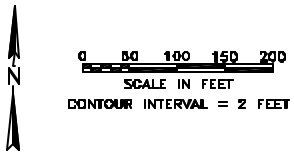
Location	Depth (including freeboard)	Base Width	Side Slopes
TP-2	4 ft	6 ft	2H:1V
TP-3	4 ft	10 ft	2H:1V
TP-4	2 ft	6 ft	2H:1V

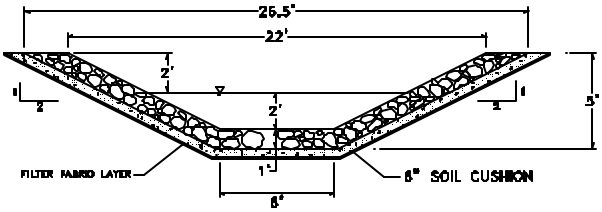
Tailings contained in the active stream drainage were excavated and relocated on areas of the tailings piles away from the creek. Piegan Creek is a mountain stream with youthful stream valley characteristics in that it is developing its channel in the vertical and shows very little meandering. Examination of the tailings bank erosion cuts verify vertical channel development.

FIGURE 2
TAILINGS PILES TP-2 AND TP-4

PRE-RECLAMATION

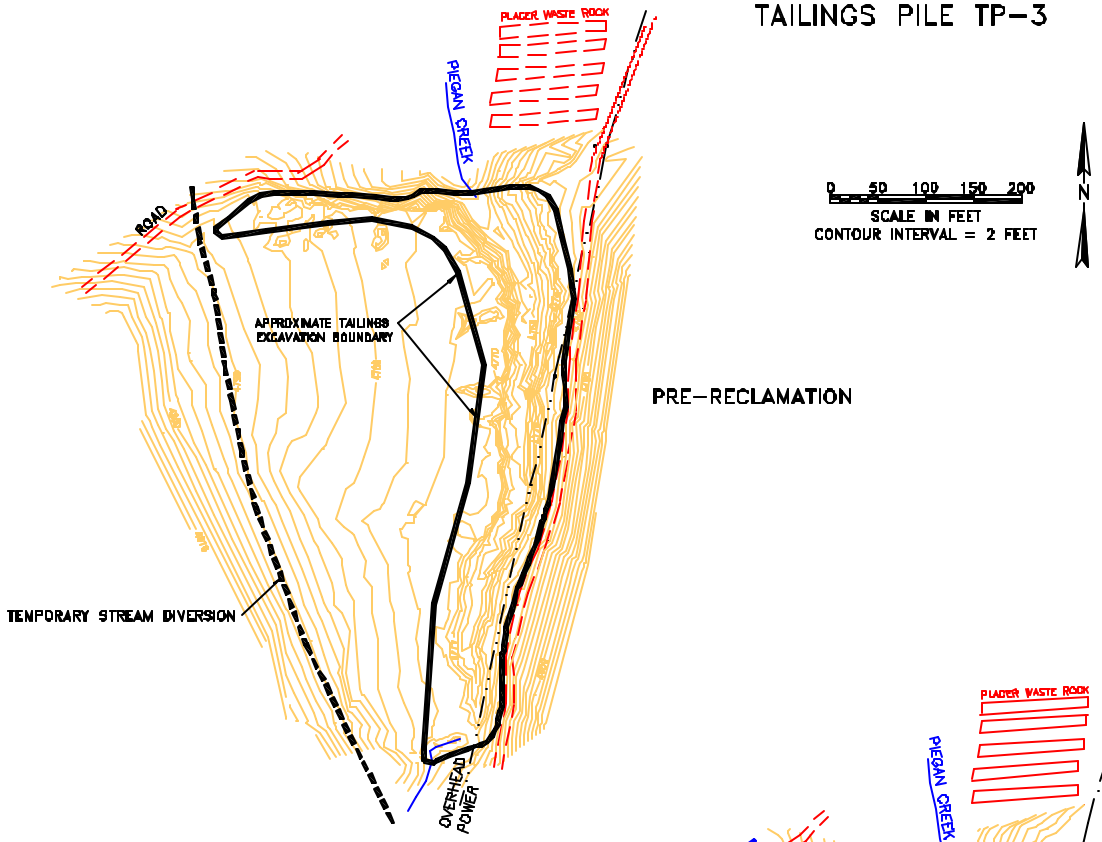
POST-RECLAMATION



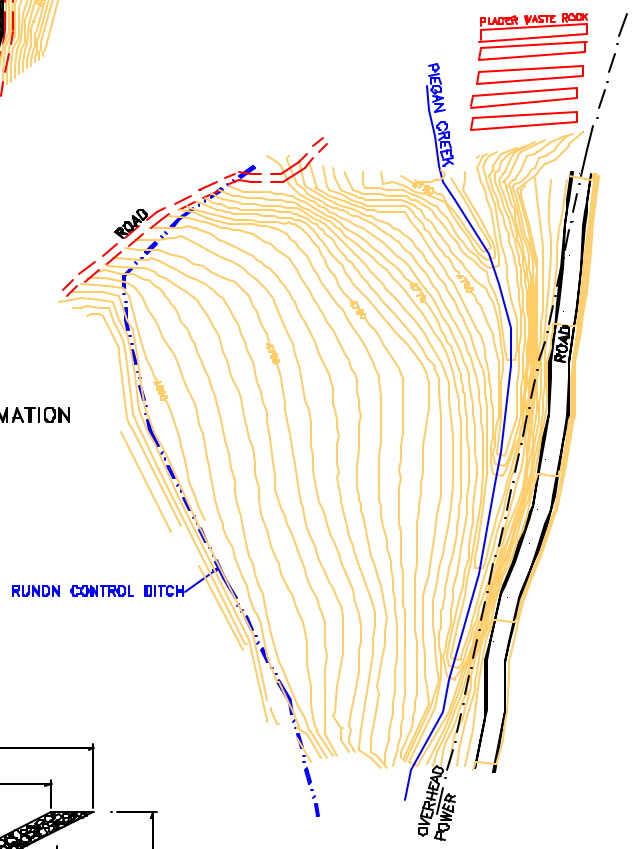


TP-2 TYPICAL CHANNEL CROSS SECTION

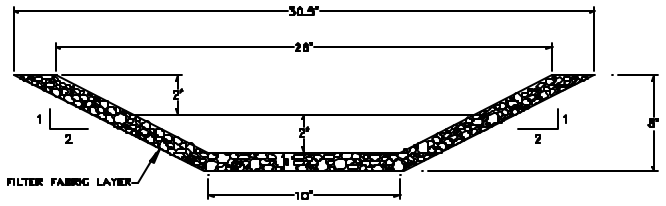
FIGURE 3
TAILINGS PILE TP-3



PRE-RECLAMATION



POST-RECLAMATION



TP-3 TYPICAL CHANNEL CROSS SECTION

Tailings pile TP-1 has naturally revegetated with grasses and shows almost no erosion effects. Erosion has been minimized by the fact that Piegan Creek does not flow through the pile, grades are gentle and abundant grass cover is present. Because acid rock drainage is not a problem, lime amendment was not required. On the other tailings piles, erosion was controlled by reconstructing stream channels, a grading plan and stormwater diversion controls. To accelerate the growth of a self-sustaining plant community, a 1.5-foot thick soil cap was applied to provide a suitable medium for establishing vegetation. Cover soil, channel backfill and riprap borrow sources were acquired on site by using native soil, selected placer tailings and quartz diorite talus.

The general construction steps used for implementing the In-Place Containment reclamation alternative were as follows:

- construction of temporary surface water diversion structures to divert flow during construction activities;
- excavation and relocation of tailings from the stream channel and floodplain in the area of tailings piles TP-2, TP-3 and TP-4;
- excavation and redistribution of material from the tailings dam faces to reduce the slopes to 3H:1V or less;
- backfilling of appropriate fill material and riprap to stabilize the channel in the vicinity of the tailings piles;
- grading of the tailings piles (typically 4H:1V or less) to reduce erosion from surface water run-off;
- constructing surface water diversion ditches strategically located to control water run-on during revegetation;
- covering the tailings with a 1.5-foot thick soil layer derived from placer tailings and other sources;
- establishing vegetation on the covered tailings piles by seeding (five grasses and three forbs) and fertilizing;
- mulching of the seeded areas; and
- constructing a four-strand barb wire fence around the reclaimed tailings and stream channel areas.

In addition, the wood and steel debris from the Piegan-Gloster mill was removed and buried on site to mitigate the physical hazard posed by the dilapidated structure.

FINAL RECLAMATION COST SUMMARY

Table 4 presents a summary of the actual costs incurred for the various phases of the Piegan-Gloster Millsite reclamation project. The project took 24 months to complete the tasks from the initial reclamation work plan through final construction.

Table 4. Summary of Reclamation Costs

Task	Cost ($)
Reclamation Work Plan, Field Sampling Plan & Supporting Documentation	25,432.37
Site Characterization	81,963.41
Engineering Evaluation/Cost Analysis	21,391.00
Engineering Design and Bid Specification Preparation	26,630.14
Construction Engineering	46,540.08
Subtotal	201,957.00
Reclamation Construction	637,033.00
Total	838,990.00

REFERENCES

MDEQ/AMRB, 1995, Reclamation Work Plan for the Piegan-Gloster Millsite Remedial Investigation Prepared by Olympus Environmental Science and Engineering, Inc., August 1995 112p.

MDEQ/AMRB. 1995. Site Characterization Report for the Piegan-Gloster Millsite. Prepared by Olympus Environmental Science and Engineering, Inc. December 1995, v1 and v2. 70p.

MDEQ/AMRB. 1996. Expanded Engineering Evaluation/Cost Analysis for the Piegan-Gloster Millsite. Prepared by Olympus Environmental Science and Engineering, Inc. April 1996. 181p.

MDEQ/AMRB. 1996. Final Design/Bid Specification Package for the Piegan-Gloster Millsite Reclamation Project, Lewis and Clark County, Montana. Prepared by Olympus Environmental Science and Engineering, Inc. June 1996.

Rosgen, D.A. 1996. Applied River Morphology. Published by Wildland Hydrology.

Walker, G.E. 1992. Geology and History of the Marysville Mining District and the Drumlummon Mine, Lewis and Clark County, Montana. Montana Bureau of Mines and Geology Open File Report 254. 27p.

2000 Billings Land Reclamation Symposium

CLOSURE OF THE ABANDONED SKOOKUM SLOPE MINE

Ginger Kaldenbach and Michael Bailey, P.E.

ABSTRACT

This presentation describes closure and reclamation of the Skookum Slope Mine, a complex of underground coal mines which operated for more than 70 years prior to abandonment around 1950.

Reclamation included closure of open shafts and tunnels, preservation of historic structures, and wetlands and stream protection. Permitting and construction was complicated since most of the mine workings are flooded and discharge through open shafts into a wetland, beaver ponds and an adjacent stream which has a protected fisheries status. Eleven permits required for the reclamation were obtained from local, state and Federal agencies. Reclamation is complete including monitoring of wetland revegetation.

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2000 Billings Land Reclamation Symposium

HIGH ORE CREEK STREAM SIDE TAILINGS RECLAMATION

M. F. Browne[1] and J.D. Belanger-Woods[2]

ABSTRACT

Metal-mining wastes and mill tailings from the Comet Mine have eroded into High Ore Creek for over 80 years. Thirty-two thousand cubic yards of stream side tailings and 5,800 cubic yards of waste rock were distributed throughout the 3.7 mile High Ore Creek flood plain below the Comet Mine. The stream side tailings is the largest mine waste source of concern because of high contributions of metals and sediment to the surface water. Concentrations of antimony, arsenic, cadmium, copper, iron, lead, manganese, silver, and zinc were significantly elevated above background concentrations (>3X) in the flood plain and surrounding area (BLM, 1999). An Expanded Engineering Evaluation/Cost Analysis was used to present the detailed analysis of reclamation alternatives in accordance with the National Contingency Plan. This analysis was then used to select the preferred alternative for the reclamation of High Ore Creek based on the amount of risk reduction with each alternative. The reclamation alternatives for High Ore Creek varied from complete tailings removal and flood plain reconstruction to partial or no tailings removal and some stream bank reconstruction where no tailings were present. Stream side tailings were classified, for the purpose of site assessment and reclamation, into three types of tailings impacted areas. Areas with no vegetation growing on the tailings were classified as High Impact Areas. Areas where tailings were visible with some vegetation were classified as a Medium Impact Areas. Low Impact Areas represent all remaining areas of the flood plain where vegetation was prominent with little to no effect from the tailings. The reclamation of metal-mining wastes in the High Ore Creek drainage basin in Jefferson County, Montana is expected to reduce the detrimental impacts to water quality and riparian vegetation as well as reduce the adverse impacts to human health and the environment. Not all tailings have been removed from High Ore Creek. The necessity to remove all tailings rather than partial removal of tailings cannot be adequately assessed until post reclamation monitoring has been completed following reclamation.

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INTRODUCTION

High Ore Creek is located NW of Boulder, Montana in Jefferson County. High Ore Creek flows through the Comet Mine site and into the Boulder River approximately two miles northeast of the town of Basin.

The Comet Mine and Millsite is one of the oldest abandoned hardrock mine sites in the Basin/Cataract Mining District. The site was first mined in about 1880 by the Alta-Montana Mining Company. The majority of the production from the Comet occurred from 1883 to 1893 while owned by the Helena Mine and Reduction Company. The Basin Montana Tunnel Company acquired the Comet in 1926 and constructed a 200-ton flotation mill to process Comet ore as well as custom mill ores from other mines in the district. The mill was closed and dismantled in 1941. The Basin/Cataract Mining District produced large quantities of gold, silver, lead, and other metals with an estimated total value of $11,000,000. Production consisted of 129,000 ounces of gold; 5,600,000 ounces of silver; 35,000,000 pounds of lead, and 27,000,000 pounds of zinc (MBMG, 1960).

The High Ore Creek Stream Side Tailings Reclamation project begins below the Comet Mine site and continues to the creek's confluence with the Boulder River. The stream side tailings reclamation includes approximately 32,000 cubic yards of stream side tailings and 5,800 cubic yards of waste rock that is distributed throughout the 3.7 mile High Ore Creek flood plain below the Comet Mine. Forty-three percent of the lands on High Ore Creek are Public Lands administered by U.S. Department of Interior, Bureau of Land Management (BLM) and 57% of the land is private property belonging to 20 landowners with 34 patented mining claims. Nine County, State, and Federal Agencies along with numerous consultants, contractors and interested parties worked together to investigate, characterize, design, and mitigate environmental impacts on High Ore Creek.

ABANDONED MINE LAND RECLAMATION, BLM, WESTERN MONTANA

The National Oil and Hazardous Substances Pollution Contingency Plan (NCP) requires the BLM to complete removal site evaluations for releases or threatened releases identified for possible Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) responses on Public Lands (40 CFR, §300.410 (b)). The BLM is also responsible, under the guidance of the National Environmental Policy Act (NEPA), for making decisions that are based on an understanding of environmental consequences, and taking actions that protect, restore, and enhance the environment. The Butte Field Office's Resource Management Plan/Environmental Impact Statement (RMP/EIS) requires soils to be managed to maintain productivity and minimize erosion. The BLM (1983) is required to maintain or improve water quality in accordance with State and Federal standards.

The High Ore Creek Stream Side Tailings Reclamation project was considered a non-time critical removal action under the NCP. In accordance with the NCP, a Expanded Engineering Evaluation/Cost Analysis (EEE/CA) for the High Ore Creek Stream Side Tailings Reclamation Project was completed and used to present the detailed analysis of reclamation

alternatives. The site background, waste characteristics, applicable or relevant and appropriate requirements (ARARs), risk assessment, and preliminary development and screening of reclamation alternatives was included in the EEE/CA. The detailed analysis of alternatives and additional background information provided in the EEE/CA was used to determine the preferred alternative for the reclamation of High Ore Creek.

HIGH ORE CREEK RECLAMATION

Stream side tailings deposits from the Comet Mine and mill site (Figure 1) eroded into High Ore Creek for many years. These tailings, deposited throughout the High Ore Creek flood plain are the largest mine waste source of concern because they are one of the highest contributors of metals and sediment to the surface water. These tailings severely affect the vegetation in the flood plain of High Ore Creek.

Figure 1 - Comet Mine and Tailings

In 1990 the Montana Department of Fish, Wildlife, and Parks (FW&P) sponsored reconstruction of a pre-existing creek diversion (Fig. 2) around the waste rock piles and mill tailings at the Comet Mine. The FW&P also reconstructed the existing sedimentation ponds to control the release of mine waste sediments from the tailings impoundments into High Ore Creek.

Figure 2 - High Ore Creek Diversion

The Montana Department of Environmental Quality, Mine Waste Cleanup Bureau (MWCB) inventoried the Comet Mine in 1993 for inclusion on the Abandoned Hardrock Mine Priority List (DEQ/MWCB-Pioneer, 1995). The Comet scored 10 th out of 276 sites using the Abandoned and Inactive Mines Scoring System (AIMSS). The MWCB conducted interim reclamation activities at the mill site in 1995 and 1996 to improve erosion and sediment control from the tailings in preparation for full-scale reclamation of the site (DEQ/MWCB-Pioneer, 1996). The MWCB initiated the first phase of the Comet Mine and Mill Site reclamation in 1997. The first phase of the Comet Mine and Mill Site reclamation required the construction of a mine waste repository at the location of the original glory hole. Approximately 500,000 cubic yards of waste rock and tailings were removed from the flood plain and placed in a constructed repository at the Comet mine site (Figure 3). The second phase of the Comet Mine reclamation will take place in the year 2000. This reclamation will involve removal of approximately 15,000 cubic yards of tailings and waste rock material beneath the High Ore Creek diversion channel and placement of these materials into the BLM repository located 1 mile SE of the Comet

Figure 3 - Comet Mine Repository

Mine. Reclamation will also involve reconstruction of the High Ore Creek stream channel in the bottom of the drainage, placement of cover soil and topsoil over the Comet Repository, and revegetation of any reclaimed or disturbed lands associated with the reclamation of the Comet Mine.

The Montana Bureau of Mines and Geology (MBMG, 1997) and the BLM (BLM, 1999) found concentrations of antimony, arsenic, cadmium, copper, iron, lead, manganese, silver, and zinc were significantly elevated above background concentrations (>3X) in soil and water samples in the flood plain and surrounding area. Preliminary findings by the U.S. Geological Survey also indicate that sediments, fluvial tailings and water from High Ore Creek are significant contributors to water quality degradation of the Boulder River below Basin, Montana (USGS, 1999). In 1998 the BLM initiated the reclamation of High Ore Creek with the development of the Expanded Engineering Evaluation/Cost Analysis (EEE/CA) to evaluate reclamation alternatives.

Objective

The objective of reclamation in the High Ore Creek drainage basin is to reduce the detrimental impacts to water quality and riparian vegetation as well as the impacts to human health and the environment. Reclamation is expected to restore riparian vegetation; allow High Ore Creek to function properly; improve water quality; and potentially establish a healthy, diverse biotic community and fisheries. The necessity to completely remove all of the tailings rather than partial removal of tailings will be evaluated and assessed after post reclamation monitoring has been completed on High Ore Creek. The High Ore Creek reclamation is expected to bring the BLM into compliance with the requirements of the NCP, the Butte Field Office's RMP/EIS , and the Clean Water Act.

Site Assessment

Site assessment began with the initiation of the EEE/CA in February 1998. Site assessment, in addition to the EEE/CA, included: 1) Owner/Operator History Report, 2) Community Relations Plan, 3) Quality Assurance Project Plan, 4) Laboratory Analytical Protocol, 5) Health and Safety Plan, 6) Cultural Inventory Report, and 7) Engineering Design/Construction Bid Specification Package.

The stream side tailings was the largest mine waste source of concern because of high contributions of metals and sediment to the surface water. Reclamation first required the

identification of mine waste types, location, volumes, and impacts to human health and the environment. The BLM conducted a stream inventory on High Ore Creek in 1998 to identify stream reach segments that required reclamation. Twenty-one reaches with 45 sub-reaches were identified that required reclamation as a result of mining impacts or poorly functioning riparian areas. The stream side tailings were separated into three types of tailings impacted areas. Areas with no vegetation growing on the tailings (approximately 21 acres) were classified as High Impact Areas (Figure 4). Areas where tailings were visible with some vegetation were classified as Medium Impact Areas (Figure 5). All remaining areas of the High Ore Creek flood plain were considered Low Impact Areas (Figure 6). Vegetation was prominent in these areas with little or no effect from the tailings. Some Low Impact Areas required stream bank reconstruction to return riparian areas to a functioning condition. Discrete and composite samples, from separate sampling events, in the High Ore Creek flood plain were collected by Pioneer Technical Services Inc. (Pioneer), the MBMG, and the BLM. Thirty-seven discrete samples and one composite sample were collected for X-ray Fluorescence Spectrometer (XRF) analysis, while three composite samples were collected for analysis of total metals, Acid Base Accounting (ABA), agronomic and Toxicity Characteristic Leaching Procedure.

Figure 4 - High Impact Areas

Figure 5 - Medium Impact Areas

Figure 6 - Low Impact Area

Risk Assessment

Stream side tailings were separated into three types of tailings impacted areas to assist with the analysis of alternatives based on the following criteria: 1) the relative protectiveness of human health and the environment provided by the alternatives; 2) the long-term effectiveness provided by the alternatives; and 3) the estimated attainment of ARARs for each alternative. An alternative screening summary, Table 1, was used to determine alternatives retained for detailed

analysis. Table 2 is a summary of overall cost comparisons between the Alternatives based on the amount of Human Health (HH) and Ecological Risk Reduction (E).

Table 1
Alternatives Screening Summary (BLM, 1999)

ALTERNATIVE DESCRIPTION	EFFECTIVE-NESS	IMPLEMENT-ABLE	EST. COST	RETAINED FOR DETAILED ANALYSIS
Alt. 1: No Action	NA	NA	$0	Yes
Alt. 2: Institutional Controls	Low	Yes	$390,000	No
Alt. 3: In-Place Containment of Wastes With Cover soil	Low-Medium	Yes	$674,298	No
Alt. 4a: Partial Removal/Disposal in Constructed Repository and Partial In-Place Containment (bottom liner and drainage layer)	High	Yes	$1,139,602	Yes
Alt. 4b: Partial Removal/Disposal in Constructed Repository and Partial In-Place Containment (no bottom liner)	High	Yes	$1,020,211	Yes
Alt. 5a: Removal/Disposal of all Solid Waste Material in a Constructed Repository (bottom liner and drainage layer)	High	Yes	$1,529,393	Yes
Alt. 5b: Removal/Disposal of all Solid Waste Material in a Constructed Repository (no bottom liner)	High	Yes	$1,343,786	Yes

Table 2
Alternative Cost-Effectiveness Comparison Summary (BLM, 1999)

ALTERNATIVE	Ecologic Risk Reduction (E)	Human Health Risk Reduction (HH)	Total Present Worth Value	Cost per 1% Reduction in Risk ($)
Alternative 1	0%	0%	$1.14 Million	NA
Alternative 4a	72%	94%	$1.02 Million	$15,833 (E) $12,128 (EH)
Alternative 4b	72%	94%	$1.02 Million	$14,167 (E) $10,851 (HH)
Alternative 5a	76%	100%	$1. 53 Million	$20,132 (E) $15,300 (HH)
Alternative 5b	76%	100%	$1.53 Million	$17,632 (E) $13,400 (HH)

Alternative 4b was selected as the preferred alternative for the reclamation of High Ore Creek. This alternative should protect human health and the environment by removing the highest risk mine wastes in the High Ore Creek watershed. This alternative consists of excavating selected solid waste material from the High Ore Creek flood plain and disposing of it in a modified RCRA repository constructed about 1 mile southeast of the Comet Mine site. The repository design includes a multi-layered cap with no bottom liner. This alternative is expected to reduce risks to human health by 94% and ecological risks by 72%. The long-term effectiveness of this alternative is expected to improve the water quality protect human health and the environment.

Figure 7 - Tailings Removal, Channel, & Flood Plain Reconstruction

Reclamation

The construction bid package for reclamation was administered for the BLM by the U.S. Army Corp of Engineers (USACE) and contained the reclamation engineering design, project plans and specifications prepared by Pioneer. Schumaker Trucking and Excavating (Schumaker), from Great Falls, MT, was awarded the construction contract and issued a Notice to Proceed by the USACE in September 1999. Schumaker began construction in September, 1999 and was shut-down by weather on December 15, 1999.

The reclamation of High Ore Creek in 1999 included: areas with complete tailings removal, channel, and flood plain reconstruction (Figure 7); areas with partial tailings removal and flood plain reconstruction (Figure 8), areas with only stream bank reconstruction ; and areas with no tailings removal or stream bank reconstruction. The construction contract involved removing waste adjacent to High Ore Creek and disposing of these materials in a constructed repository located approximately 1 mile southeast of the Comet Mine and Mill site.

Figure 8 - Tailings Removal and Flood Plain Reconstruction

Reclamation completed in 1999 included:

- Clearing, grubbing, and constructing a six acre borrow area/repository and improving the existing access road to the repository,
- Stockpiling 34,000 cubic yards of cover soil to be used by the MWCB for Phase 2 of the Comet Mine reclamation,

- Excavating and hauling 31,155 cubic yards of stream side tailings and mine wastes to the BLM repository,
- Installing 4,127 lineal feet of stream protection structures,
- Installing 12,246 lineal feet of silt fence,
- Reconstructing 3,459 lineal feet of High Ore Creek stream channel,
- Reconstructing flood plain with 14,276 cubic yards of clean cover soil,
- Backfilling flood plain with 18,103 cubic yards of clean, organically amended cover soil (topsoil) following waste removal,
- Constructing streambed including steps, pools, and grade control structures,
- Installing 4,612 square yards of Type A bank stabilization fabric,
- Installing 8,442 square yards of Type B erosion control mat,
- Installing willow cuttings and 833 lineal feet of willow fascines on stream banks, and
- Seeding and mulching reconstructed and stabilized streambanks.

Project Start-Up is expected to begin on May 1, 2000 to complete the remaining portions of the reclamation contract. Construction to be completed in the spring of 2000 includes:

- Construction of the repository cap:
  1. Installation of 19,000 square yards of a geotextile cushion over the uppermost lift of compacted mine wastes,
  2. Installation of 19,000 square yards of Geosynthetic Clay Liner,
  3. Installation of 19,000 square yards of a Geonoet and filter fabric geocomposite,
  4. Apply and grade 12,225 cubic yards of organically amended cover soil,
  5. Apply and grade salvaged topsoil, and
  6. Seed and mulch.
- Construction of repository run-on/runoff control ditches,
- Replace and install four properly sized culverts on High Ore Creek,
- Complete installation of Type A fabric along stream bank stabilization reaches. This includes seeding, mulching, installing willow fascines, etc. and
- Obliterating and reseeding temporary haul roads and the existing access road between the Comet repository and the new BLM repository.

To-date the construction cost for this project is $939,885.00. The total construction contract for this reclamation project is $1,520,837.

CONCLUSION

The necessity to completely remove all tailings rather than partial removal of tailings can not be adequately assessed until post reclamation monitoring has been completed following the completion of this reclamation project. The High Ore Creek Stream Side Tailings Reclamation project will not be completed until the summer of 2000. Water quality and re-establishment of vegetation will be closely monitored for the next 3-5 years to determine the success of this reclamation project.

Preliminary and unpublished results for this project seem to indicate that visual observation and subsequent removal of stream side tailings may be adequate for determination of metal contaminated tailings. X-ray Fluorescence Spectrometer and/or lab analysis of tailings to be removed should continue to be used to validate visual observations.

REFERENCES

BLM, 1999. Final Draft Expanded Engineering Evaluation/Cost Analysis for the High Ore Creek Stream Side Tailings Reclamation Project. Prepared by Pioneer Technical Services, Inc., Butte, Mt., 59702.

BLM, 1983. U.S. Department of Interior/Bureau of Land Management. Headwaters Resource Area Resource Management Plan/Environmental Impact Statement, p. 12.

DEQ/MWCB-Pioneer, 1996. Montana Department of Environmental Quality, Mine Waste Cleanup Bureau. Final Reclamation Work Plan for the Comet Mine, Prepared by Pioneer Technical Services, Inc. May 1996.

DEQ/MWCB-Pioneer, 1995. Montana Department of Environmental Quality, Mine Waste Cleanup Bureau. Abandoned Hardrock Mine Priority Sites. 1995 Summary Report. Prepared by Pioneer Technical Services, Inc. April 1995.

MBMG, July, 1997. Montana Bureau of Mines and Geology. Open-file Report. Abandoned/Inactive Mines of Montana, U.S. Bureau of Land Management. MBMG No. 348. July 1997.

MBMG, 1960. Montana Bureau of Mines and Geology. Mines and Mineral Deposits (Except Fuels), Jefferson County, Montana, Bulletin 16. Written by R.N. Roby, W.C. Ackerman, F.B. Fulkerson, and F.A. Crowley, June 1960.

USGS, 1999. Analytical results for 42 fluvial tailings cores and 7 stream sediment samples from High Ore Creek, northern Jefferson County, Montana. Open File Report 98-215. 49 pp.

2000 Billings Land Reclamation Symposium

Tailing Pond Flow Modeling Used To Predict Long-Term Tailing Seepage

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ABSTRACT

Characterization of the hydrogeology and geochemistry of tailing ponds is necessary to design effective closure plans for these facilities. A seepage investigation was recently conducted for a tailing pond in the Southwest United States to determine the current quantity and quality of seepage, evaluate the controlling factors affecting seepage, and predict long-term seepage flow from the facility. The results of the flow modeling are being incorporated into a hydrogeochemical model to predict the future quality of seepage from the tailing pond. Ultimately, the seepage flow and transport models will be used in conjunction with cover design studies to evaluate various closure alternatives for the tailing pond.

Based on a pond construction model developed from historical records and field characterization results, a conceptual model of flow in the tailing pond was developed for a period of active tailing deposition and a period after tailing deposition ceased. A two-dimensional, variably saturated, finite-difference code (VS2D) was used to simulate seepage flow within and beneath one tailing pond (Lappala et al., 1987; Healy, 1990). For the modeling, the tailing pond was divided into three areas based on the tailing surface topography and material characteristics. For each of the three areas, multiple representative two-dimensional cross-sectional models were developed to account for localized differences in underlying drainage patterns and geology. The model was calibrated using in-situ water levels, matric potentials, and antecedent water contents obtained from nested wells installed in the tailing pond.

The simulation results indicate that approximately 15 percent (2.4 inches) of average annual precipitation (16 inches) at the site infiltrates into the tailing pond in an uncovered scenario. Steady-state flow conditions are predicted to occur following a 50 to 70 year period of transient drainage. Once steady-state flow conditions are established, the estimated residence time for a particle of water entering the pond surface ranges between 45 and 317 years. In addition, the vast majority of the seepage (between 97 and 100 percent) migrates preferentially into alluvium lying within pre-existing surface water drainages.

Conservative estimates of water seepage from the alluvial drainage(s) into an underlying bedrock unit were obtained using the Green-Ampt infiltration model (Stephens, 1996). With a bedrock saturated hydraulic conductivity (K_s) of 1.61×10^{-7} cm/s, the seepage flow was estimated to be approximately two percent of the average annual precipitation at the site.

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2000 Billings Land Reclamation Symposium

EFFECTIVE MAINTENANCE TECHNIQUES TO DETERMINE LONG-TERM SUSTAINABILITY OF MINING RECLAMATION AT UPTOWN BUTTE, MT[1]

C.M. Mayn

ABSTRACT

Mining began at Butte, Montana, in 1864 and still continues today. Consequently, millions of cubic yards of low pH, high sulfide, and metal contaminated mine wastes were stockpiled at various locations across uptown Butte. The large-scale mining of the Butte area has created the largest EPA superfund site in the northwest. Mine wastes with high metal concentrations located in residential areas pose serious threats to human health and the environment. Storm water runoff events continually load Silver Bow Creek with sediments containing high metal concentrations. As a result, mine waste piles must undergo reclamation by complete removal and/or recontouring and capping with coversoil. The coversoil must be properly revegetated to stabilize reclamation and reduce erosion. Reclamation of mine waste began in the early 1980's. Since initial reclamation attempts, vegetation is currently failing live plant cover standards on many reclaimed areas. Incorporation of effective maintenance techniques must be performed to ensure the long-term sustainability of vegetation on these reclaimed areas.

A total of nine treatment combinations implementing both organic and inorganic nitrogen additions will be researched for two growing seasons to determine effects on existing vegetation and inter-seeded species. An introduced species seed mixture and a native species seed mixture have been inter-seeded among existing vegetation to determine if successional components drive long-term success of reclaimed soil cap stability. Daubenmire frame measurements of vegetative canopy cover and density by plant species will be collected during peak stand of two growing seasons. Vegetative biomass data will be gathered at the end of the second growing season. Soil analyses were performed prior the to treatment plot construction and will be performed after the second growing season to determine chemical and physical changes in soil structure. Currently, coversoil data for fourteen reclaimed areas and treatment plot vegetative data for the first growing season have been collected.

[1] Funding for this research was provided by the Atlantic Richfield Company, Anaconda, MT

BACKGROUND

The intensive, 130 years of copper mining in Butte, Montana, has produced serious impacts to the environmental integrity of the area. Associated with copper extraction were enormous volumes of waste rock, tailings, and smelter emissions. Immense volumes of mine waste containing low pH overburden with high sulfide and iron pyrite concentrations were stockpiled at various locations across uptown Butte. In addition to low pH and sulfides, the mine waste contains high concentrations toxic metals (As, Pb, Zn, Cd, Mg, Fe, and Cu) hazardous to human health and the environment.

A number of Comprehensive Environmental Response Compensation and Liability Act (CERCLA) superfund sites were identified in the Butte/Anaconda area by the Environmental Protection Agency (EPA). In Butte alone, several Time Critical Removal Actions (TCRAs) have been instituted to ensure the reclamation of various mine waste dumps. The EPA TCRA guidelines for Butte reclamation included that all mine waste be removed and/or recontoured to slopes of 3:1 or less. The contoured areas must then be capped with a 2 inch lime rock layer (approximately 350 tons/acre) and a minimum of 18 inches of coversoil to protect human health and the environment. The site is then seeded with a suitable seed mixture and straw mulched at 2 tons/acre.

ARCO began the reclamation of mine waste dumps at uptown Butte in 1985 and have been on going and improving since. However, vegetation productivity on many reclaimed areas is not meeting 35% live plant cover standards adopted by the local Butte Silver Bow county government. Coarse textured sandy loams weathered from decomposed granite have been used for reclamation at uptown Butte. The sandy loams possess poor water holding capacity and are often deficient in nutrients, organic matter, and microorganisms essential for healthy and productive vegetation.

Many reclaimed areas at uptown Butte have slopes of 3:1 with south facing aspects. The Butte area receives only 12 – 14 inches of precipitation annually. The combination of slope, hot and dry aspect, coversoil with limited nutrients and plant available water, and limited annual moisture hinders the establishment of vegetation capable of providing 35% live plant canopy cover. Sites with unproductive vegetation often succumb to excessive erosion, ultimately requiring complete reconstruction of the reclaimed cap.

RESEARCH PROCEDURES

The research project has been performed in a two-phase process. Phase I involves the evaluation of uptown Butte reclamation characteristics of initial site construction, vegetative performance, and coversoil properties. Phase II involves the implementation of field test plots to research the effects of nitrogen fertilization, organic matter incorporation, inter-seeding, and various combinations to determine effective vegetation establishment methods. Vegetative measurements for the first growing season were collected in July 1999. Second year measurements will be performed in late July 2000.

Phase I

Fourteen reclaimed areas at uptown Butte, Montana, were selected for coversoil evaluation using data collected from Environmental Protection Agency (EPA) reclamation assessments performed in 1992 and 1996. The EPA assessments noted vegetation characteristics, erosion, signs of disturbance, and mass instability on various reclaimed areas. In addition, results from Butte Hill Revegetation Monitoring 1994 – 1997, vegetation monitoring reports performed by Rich Prodgers of Bighorn Environmental, were also referenced. Site variables such as slope, aspect, source and depth of borrow material, institutional controls, and original seed mixtures were also considered when selecting the fourteen reclaimed sites for coversoil evaluation. Initial reclamation of the fourteen areas was performed from 1989 to 1991.

The coversoil evaluation involved the collection of three replicate soil samples from the 0 – 10 cm depth increment and the 10 – 40 cm depth increment from fourteen reclaimed areas. The three replicate samples at each depth were consolidated to form two separate composite samples in order to identify differences within the reclaimed cap possibly created by the lime rock barrier and/or the underlying toxic mine waste. Soil sample analyses were performed at the Montana State University Soils Laboratory. Analyses of soil chemical properties included total metals (Cu, Fe, Zn, Pb, Cd, Mn, and As), DTPA extractable metals (Cu, Fe, Zn, Pb, Cd, Mn, As, Cr, and Al), exchangeable acidity, Total Kjedahl Nitrogen (TKN), pH, EC, KCl extractable nitrate and ammonium, Olsen's phosphorus, and extractable potassium. In addition, soil physical features including saturation percentage, course fragment percentage, water holding capacity, texture, and organic matter percentage were determined.

Phase II

The field research involved the implementation of nine different treatments replicated three times on two selected reclaimed areas at uptown Butte, Montana. The two reclaimed areas selected for treatment plot construction were the Poulin Waste Dump #53 and the Washoe Sampling Works #135. An area that contained homogeneous plant cover and soil properties within each reclaimed area was selected for treatment plot construction. The nine treatment combinations consist of inter-seeding, organic nitrogen treatment, and inorganic nitrogen treatment, and varied combinations (Table I).

Table I. Treatment Combinations

Inter-seeding Seedmix		Control (No Nitrogen Treatments)	Inter-seeding Seedmix		Inorganic Nitrogen Treatment (50 lbs N/acre)	Inter-seeding Seedmix		Organic Nitrogen Treatment (Compost)
1. None	+	None	**4.** None	+	2 Applications	**7.** None	+	Compost
2. ARCO 97	+	None	**5.** ARCO 97	+	2 Applications	**8.** ARCO 97	+	Compost
3. Native	+	None	**6.** Native	+	2 Applications	**9.** Native	+	Compost

The treatment applications consisting of inter-seeding, inorganic nitrogen fertilization, and organic nitrogen addition (compost) focus on remedying the low nitrogen and low organic matter contents found at many uptown Butte reclaimed areas. The treatments selected will test three different views for creating healthy and diverse plant communities:

- the nitrogen treatments will improve soil nutrient conditions for existing plant communities;
- the inter-seeding treatments will create plant communities that are adapted to the infertile conditions at the sites; and/or
- a combination of improving soil nutrient conditions and matching plant communities adapted to the improved conditions will improve vegetation performance.

The experimental design is a completely randomized configuration with each square treatment plot covering 4 m^2. Twenty-seven treatment plots are randomly organized on each reclaimed area as shown in Figure 1.

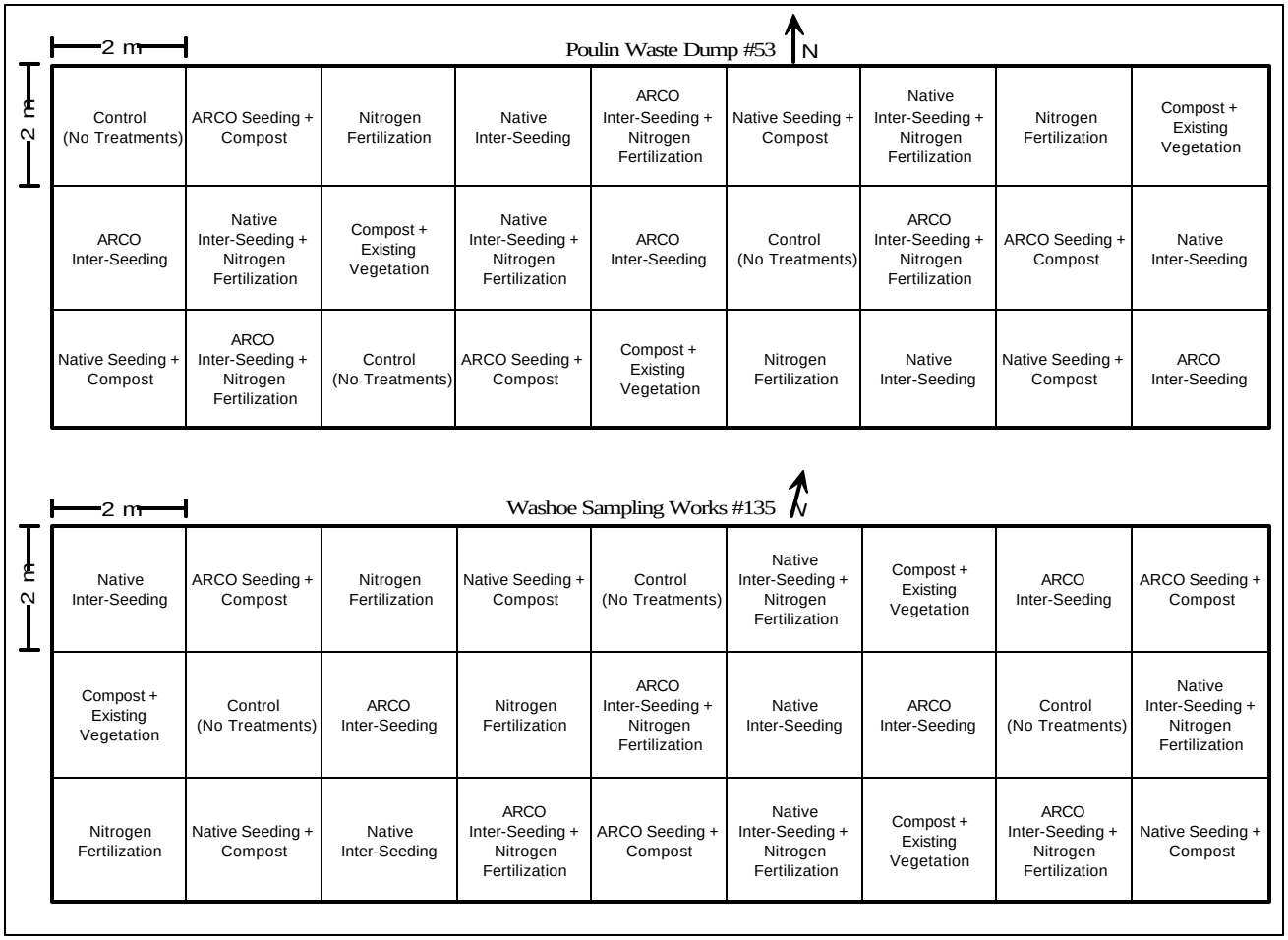

Figure 1. Randomized Treatment Design on each Reclaimed Area

Inter-seeding

Bare soil, which is highly susceptible to erosion and invasion by exotic species, is frequently encountered on many reclaimed areas at uptown Butte. Several different seed mixtures were assessed for inter-seeding methods on the treatment plots. The seed mixtures chosen for research consist of the ARCO 97 Primary seed mixture (currently used for all reclamation at uptown Butte) and a mixture of native perennial grasses and forbs. The broadcast seeding method was utilized; therefore, the recommended drill-seeding rate for each plant species was doubled to ensure initial

establishment (*Sheley, Jacobs, & Velagala, 1999*). Seeding rates are displayed in pounds of pure live seed per acre (PLS#/acre) in Table II.

Table II. Inter-seeding Seed Mixtures

Control	ARCO 97 Primary Seed Mixture	Seeding Rate (PLS/ac)	Native Seed Mixture	Seeding Rate (PLS#/acre)
No inter-seeding was performed on these selected treatment plots.	Slender wheatgrass	3.0 x 2	Yarrow	0.2 x 2
	Thickspike wheatgrass	2.0 x 2	Sandbergs bluegrass	0.2 x 2
	Sheep fescue	2.0 x 2	Bluebunch wheatgrass	1.4 x 2
	Crested wheatgrass	1.0 x 2	Indian ricegrass	0.6 x 2
	Ladak alfalfa	1.0 x 2	Prarie sandreed	0.8 x 2
	Red clover	2.0 x 2	Lewis flax	0.3 x 2
	Canada bluegrass	1.0 x 2	Mountain brome	1.7 x 2
	Bird's Foot trefoil	1.0 x 2		
	Total	**13.0 x 2 = 26.0**	**Total**	**5.2 x 2 = 10.4**

Reclaimed areas with low nitrogen and organic matter contents have great difficulty supporting highly productive introduced species without the addition of nutrients and intensive management. Undisturbed, native sites with impoverished soils found throughout many landscapes often have high plant species diversity and productivity without the need for added management practices and chemical inputs (*Huston 1993*). Therefore, the seed mixture consisting of native species is being explored to determine vegetative success in these low nutrient environments.

Inorganic Nitrogen (Urea Fertilization)

Two incremental urea (46-0-0) applications were performed on selected treatment plots. One application was performed early June and the second application in early July. The fertilizer was applied at 50 lbs nitrogen/acre during each application. Granular urea fertilizer was completely dissolved in water and applied with a hand held sprayer to ensure that all nitrogen was absorbed into the soil immediately. The fertilizer applications will be continued during the second research year.

Organic Nitrogen Addition (Compost Incorporation)

Compost was incorporated on designated treatment plots at an application rate of 1.68 % organic amendment. The application rate was calculated on a dry weight basis for incorporation into the upper six inches of cover soil. The compost was mixed to the six-inch depth with a small tractor and roto-tiller. Compost incorporation destroyed all existing vegetation on treatment plots where seeding treatments were also applied. Conversely, to assess the effects of compost on the existing species, a garden claw tool was used to mix the compost into the soil. The garden tool effectively mixed the compost with the soil without posing adverse effects to the existing species. Compost application was performed during initial treatment plot construction and will not be applied again throughout the research.

Measurement of Response Variables

First year measurements of each treatment plot included the quantification of individual and total plant species densities, individual species and total live plant canopy cover, litter, bare ground, and moss and lichen coverage. Quantification of the response variables was performed with the use of a 2 x 5 dm Daubenmire frame (*Daubenmire 1959*). The Daubenmire frame was randomly placed within each treatment plot at fifteen different locations. An analysis of variance (ANOVA) was used to statistically evaluate the data collected from the treatment plots. During the second year of research, plant densities, canopy cover, seed relation, and mortality of inter-seeded species will be measured by individual plant species. Treatment plot soil properties will be measured after the second field season to determine alterations produced by treatment conditions.

PHASE I RESULTS

The analyses of soil samples collected from the fourteen uptown Butte reclaimed areas indicate that soil chemical properties are most likely not phytotoxic to vegetative growth. However, average total metal concentrations for copper, lead, and zinc are considerably higher than suitable coversoil criteria adopted for the Butte area (*Alice Dump Response Action Design Report, February 14, 1999*) displayed in Table III.

Table III. Comparison of Criteria & Measured Total Metal Concentrations in Butte Coversoils

Metal	*Acceptable Total Metal Conc.* (mg/kg)	*Maximum Measured Conc. (mg/kg)*	*Average Measured Conc. (mg/kg)*
Arsenic	<97	50.00	23.64
Cadmium	<4	5.60	1.97
Copper	<250	631.00	191.36
Lead	<100	692.00	103.96
Zinc	<250	1588.00	313.82
Manganese	400 – 1000*	2536.00	1484.64
Iron	Criteria not established	5.48	4.00

*Phytotoxic data from Kabata-Pendias and Pendias, 1992

Excess copper concentrations can cause observable tissue damage and depressed plant growth, seedling development, and root development (*Tiller and Merry, 1981*). Copper concentrations in soil that lead to phytotoxic plant conditions are highly variable and complex. Elements within the soil form complex interactions with copper that can be both favorable and toxic to vegetative processes. The toxicity of the complexes depends upon the elements involved and their associated concentrations (*Kabata-Pendias and Pendias, 1992)*. Observable copper toxicity of plants was not observed during sampling. Unproductive plant growth is more likely associated with coarse textured soils and limited available water.

Elevated zinc concentrations can cause depressed plant growth and chlorosis of new growth; however, zinc is not considered to be highly phytotoxic and only select sensitive plant species (cereals and spinach) at various growth stages show effects of poisoning (*Davis 1979*). Upper toxic

levels of zinc have been measured at 500 ppm in plant tissues, a small fraction of the total zinc concentrated in the soil.

Lead contamination of soil negatively affects microbial activities important for nutrient cycling and organic matter decomposition (*Tyler 1976)*. On the other hand, elevated soil lead concentrations tend have limited effect on plants. Soil lead is often unavailable to plant roots and studies have shown that much less than 1% of the total lead in soil is taken up by plants (*Wilson and Cline, 1966*).

Total manganese criteria concentrations have not been established for Butte coversoil; however, analyses of reclaimed area soil samples detected considerable manganese concentrations. The tolerance of plants to manganese is dependent upon the proper manganese to iron ration within plant tissues. However, the ratios and effects differ greatly among species and their growth stages (*Kabata-Pendias and Pendias, 1992).*

Soil physical properties of reclaimed area coversoils are a major limitation to plant growth. The sandy loam soils contain an average clay concentration of 11.8%, corresponding to low average values of complete saturation (18.58%), field capacity (11.74%), and wilting point (6.05%). Coarse fragments comprise an average of 32.55% of the soil volume. Average plant available nitrogen concentrations are also notably low. Surprisingly, the average soil organic matter (OM) percentage is 0.36%. The organic matter percentage is very low, yet higher than anticipated for the coarse textured cover soils. Suitable coversoil criteria (*Surface Mining and Coal Reclamation Act, 1977*) and measured average, maximum, and minimum levels are displayed in Table IV.

Table IV. Acceptable Coversoil Criteria & Measured Levels

Parameter	*Suitable Levels*	*Average Measured Levels*	*Maximum Measured Levels*	*Minimum Measured Levels*
pH	5.5 – 8.5	7.65	8.40	6.40
Conductivity (mmhos/cm)	< 4.0	0.20	0.32	0.08
Soil Nitrogen (mg/kg)	> 17 mg/kg	3.33	9.50	0.80
Soil Olsen's Phosphorus (mg/kg)	> 4 mg/kg	11.10	25.90	1.90
Soil Potassium (mg/kg)	> 75 mg/kg	159.00	442.00	62.00
Saturation percentage	25 – 90 %	18.58	24.54	9.72
Coarse Fragments	< 20%	32.55	58.50	19.90
% Water at 1/3 Bar	Unverified	11.74	17.00	7.70
% Water at 15 Bar	Unverified	6.05	8.80	3.60
Organic Matter %	Unverified	0.36	1.06	0.08
Carbon to Nitrogen Ratio	< 18	5.53	10.00	1.92

Based upon the criteria presented in Table IV, reclaimed area coversoils sampled only meet acceptable limits for pH, conductivity, Olsen's phosphorus, and potassium. Coarse fragments for many of the reclaimed areas are well above 20%, correlating to very low saturation percentage values (< 25%). Water holding capacity is extremely poor and is most likely the largest limiting factor to productive plant growth. A moist climate could compensate for poor water holding capacity; however, uptown Butte received only 4.86 inches of precipitation from May 1, 1998 to August 15, 1998.

PHASE II RESULTS

In general, treatment values for total plant cover, litter accumulation, and bare ground are very similar on both sites. Major vegetation differences noted between the sites appear to be highly dependent upon the plant communities present before treatment plot construction. The Poulin Waste Dump vegetation consisted of a diverse community of species, largely weedy. Noxious weeds such as *Centaurea maculosa* (Spotted knapweed), *Verbascum thapsus* (Common mullein), and *Trapogon dubius* (Yellow salsify) were a major component of the plant community. Vegetative species dominant prior to the treatment plot construction on the Poulin Waste Dump have continued to play a major role, greatly affecting the first year of treatment results. Vegetation on the Washoe Sampling Works consisted of primarily *Festuca ovina* (Sheep fescue), and *Melilotus alba* (White sweet clover). Some weedy species such as *Verbascum thapsus* (Common mullein) were present, but did not play a dominant role. Inter-seeding treatments appear to have more success among this existing plant community. Germination rates of inter-seeded species were relatively abundant on both sites, yet actual species establishment rates are difficult to accurately assess prior to the second growing season.

The vegetation that existed on the Poulin Waste Dump prior to experiment implementation has essentially controlled the treatment plot plant communities. Weedy species dominated the site prior to the treatments and have continued dominance through the first growing season. The invasive species are a major concern for establishing vegetation; therefore, a weed management strategy must be developed for the research plots that will not alter the current treatments. Spot spraying weeds with herbicide and mowing the plots are two alternatives considered. Spraying poses large risks to broadleaf inter-seeded species and could drastically alter the current treatment effects. Mowing is a cost-effective alternative that will not significantly pose harm to the inter-seeded species, yet it is not always effective and must be continued throughout strategic points in the growing season and for consecutive years. If chosen, the mowing treatment will be performed early in the second growing season to reduce early weed competition and possibly during mid-growing season if weedy species still dominate the plant community.

CONCLUSIONS

The coversoil used for reclamation at uptown Butte, Montana, does contain some elevated heavy metal concentrations; though, concentrations present are not phytotoxic to the perennial grasses and forbs. Average plant available nitrogen and organic matter percentages are greatly limited on many reclaimed areas at less than 3.33 mg/kg and 0.36% respectively. The calculated average carbon to nitrogen ratio is 5.53 indicating mineralization is providing some plant available nitrogen (*Sylvia, D., et al 1998*). Poor coversoil physical properties are the utmost limiting factor to plant growth. The sandy loam coversoils contain an average of 32.55% coarse fragments that can hold only 18.58% percent water at complete saturation. Limited annual precipitation combined with south facing hot and dry aspects pose great challenges to healthy plant community establishment.

The treatment plot vegetation data collected for the first growing season demonstrate that plant species existing prior to the treatment plot construction continue to remain dominant over inter-seeded species. Invasive weedy species are highly competitive and are most likely benefiting the greatest from the added nitrogen treatments. A mowing strategy will likely be developed for the

second year of research to reduce weed competition and increase perennial grass and forb performance. The inter-seeding treatments had greater effect upon the Washoe Sampling Works site where few invasive species were present and a large percentage of bare ground provided adequate safe sites for vegetation establishment. Inter-seeding treatment effectiveness would be much greater if invasive species were reduced or eliminated prior to seeding. Forthcoming data from the second growing should provide greater insight on treatment plot effects of nitrogen addition (compost and fertilizer) and species establishment from the ARCO 97 and native inter-seeding mixtures.

REFERENCES

Davis R., Uptake of Copper, Nickel, Zinc by Crops Growing in Contaminated Soils. Journal of Science. Food and Agriculture, 30, 937. 1979.

Dinauer, R. C. Chemical and Microbiological Properties Second Edition. Methods of Soil Analysis. Madison: American Society of Agronomy, Inc., Soil Science Society of America, Inc. 1982.

Franson, M. A. Standard Methods for the Examination of Water and Wastewater. Boston: American Public Health Association, Water Pollution Control Federation, 1989.

Huston, M. Biological Diversity, Soils, and Economics. Science 262 : 1676-80.

Kabata-Pendias A., and Pendias H. Trace Elements in Soils and Plants 2nd Editon. Ann Arbor: CRC Press. 1992.

Sheley, R., Jacobs, J., and Velagala, R. Enhancing Intermediate Wheatgrass Establishment in Spotted Knapweed Infested Rangeland. Journal of Range Management 52(1), January 1999.

Shimel, D. Carbon and Nitrogen Turnover in Adjacent Grassland and Cropland Ecosystems. Biogeochemistry 2: 345-357. 1986.

Sylvia, D., Furhrmann, J., Hartel, P., Zuberer, D., Principles and Applications of Soil Applications of Soil Microbiology. Prentice Hall: New Jersey. 1998.

Tiller, K., and Merry, R., Copper Pollution of Agricultural Soils, in Copper In Soils and Plants, Longeragon, J., Robson, A., and Graham, R., Eds., Academic Press, New York. 1981.

Tyler, G., Heavy Metal Pollution, Phosphatase Activitiy and Mineralization of Organic Phosphorus in Forest Soil. Soil Biology. Biochemistry. 1967.

Wilson D., and Cline J. Removal of Plutonium-239, Tungsten-185, and Lead-210 from Soils. Nature, London, 209, 941. 1966.

2000 Billings Land Reclamation Symposium

SOURCE CONTROL - SURFACE WASTE PILE DEMONSTRATION PROJECT

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ABSTRACT

The Source Control - Surface Waste Pile Demonstration Project will demonstrate the feasibility of using an innovative source control technology for in situ stabilization of a surface waste pile at an abandoned mine. The work is being conducted under the Mine Waste Technology Program (MWTP), which is funded by the U.S. Environmental Protection Agency (EPA) and jointly administered by the EPA and the U.S. Department of Energy through an interagency agreement (IAG). The project addresses EPA=s technical issue of *Mobile Toxic Constituents B Water* by performing a field demonstration at a remote, inactive mine.

The source control technology(s) being demonstrated is designed to prevent the influx of water, whether precipitation or groundwater, through a surface waste pile, thus decreasing acid mine drainage (AMD) formation. Site characterization, materials testing/evaluation, and field emplacement were performed to define the optimal material and material application method for the demonstration. The alternate method used to seal the surface of the waste pile and inhibit infiltration of precipitation involved the spray application of a modified version of General Polymers 4994 KOBAthane grout directly onto the surface waste pile. A French drain that functions as a hydraulic barrier was constructed to divert the groundwater away from the surface waste pile.

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INTRODUCTION

Acid mine drainage typically results from sulfide-rich ore bodies and metal-sulfide mineral [particularly pyrite (iron disulfide)] coming into contact with oxygen and water. This reaction occurs in many surface waste piles resulting in increased acidity (lowered pH) of the water and increased metal mobility. Conventionally the surface waste pile at the mine is physically removed and deposited in a designated repository to prevent acid formation, heavy metal leachate, and suspended solids from entering the aquifer or adjacent surface water system. This solution can in some instances be very expensive, envasive to the environment, or not feasible due to the lack of a suitable repository location. The MWTP Source Control - Surface Waste Pile Demonstration Project was performed to find an alternate method(s) other than physical removal of the surface waste pile as a reclamation solution. Application of the MWTP source control technology was designed to provide a solution that could be applied in situ, be less envasive to the environment, be more cost effective than the removal option, and could be easily applied. This project was divided into three phases:

Phase I, Mine Site Selection/Site Characterization
Phase II, Materials Testing
Phase III, Field Emplacement

Phase I resulted in the selection of the Peerless Mine as the demonstration site. Prominent features resulting from historic mining activities include surface waste piles that were characterized as eroding, contaminated sediments, and two discharging adits. The water from the mine site flows into the East Fork of Banner Creek, which is part of the City of Helena, Montana=s water supply system. Additionally, AMD formed within the surface waste pile was affecting the surface water quality at the headwaters of Banner Creek. During Phase II, materials testing was performed at the MSE Technology Applications, Inc. (MSE) Testing Facility and IT Geotechnical Laboratories, Inc. (IT). During Phase III, the field emplacement consisted of the construction of a French drain system to hydraulically control the groundwater system and the application of the cap system using General Polymers 4994 KOBAthane grout reinforced with a woven jute material.

PHASE I, MINE SITE SELECTION/SITE CHARACTERIZATION

In 1998, the MWTP selected the Peerless Mine as a demonstration site for the field implementation and evaluation of the Source Control - Surface Waste Pile Technology Demonstration. Water discharging from the surface waste piles at the Peerless Mine was considered to be a main source of pollution to Banner Creek. The surface pile discharges range from 2.6 to 22.6 gallons per minute (gpm) and contained zinc, manganese, and cadmium at levels exceeding the National Drinking Water Maximum Contaminant Standards.

From these results, it was determined that the adit discharge from the Peerless Mine infiltrates into the downgradient surface piles and is the main source of groundwater flow, see Figure 1. However, other contributions to groundwater flow within the pile include the losing streams that flow on either side of the surface waste piles and infiltration by precipitation. Because surface water and groundwater both contribute to the AMD problems at the Peerless Mine, a multi-phase solution was considered for the field demonstration.

Rain water and water discharging from mine systems have a pH close to neutral and do not carry large percentages of heavy metals or suspended solids. When this water travels across the surface waste piles and becomes exposed to oxygen and sulfide ores, AMD is formed. To reduce and/or eliminate water from infiltrating the hydraulic connections/ voids in the surface waste piles, this demonstration proposed to place stabilization material(s) into the voids in the waste pile and hydraulic interconnections as an in situ stabilization technology forming an impervious barrier. This barrier will reduce or eliminate the amount of water infiltrating into the mine surface waste pile and decrease the generation of acidic and metal-laden waters.

PHASE II, MATERIALS TESTING

Phase II evaluated and compared the effectiveness of approximately 50 different stabilization materials under simulated field conditions. The objective of the materials testing was to provide a rational set of measurements and results by which decisions could be made regarding stabilization materials. Although many of these tests were site specific to the Peerless Mine, they could be generalized and modified for other applications. However, specific treatment requirements depend on the performance goals defined for a specific site. The initial feasibility of the potential stabilization materials was determined in the laboratory using the selected tests described in the *Site Characterization and Materials Testing Report*: *Surface Waste Piles Source Control Demonstration Project*.

The primary success criteria for the potential stabilization materials required that it 1) be environmentally benign; 2) achieve a hydraulic conductivity when mixed with the mine waste materials of 10-6 centimeters per second; 3) be able to withstand acidic mine water having a pH of 3 for an extended period of time; 4) be able to be applied for a field demonstration; and 5) be cost effective. The secondary success criteria for the potential stabilization materials were that the materials could withstand both wet-dry cycling and freeze-thaw cycling tests for 12 cycles maintaining less than 50% material loss over the duration of the testing. The stabilization materials were evaluated for performance, durability, applicability, and economics for the field demonstration. These tests were performed by MSE and at IT Laboratories. Each material was ranked as either passing or failing each test with three materials passing all tests. The three stabilization materials that passed all tests then underwent preliminary field testing to establish final application and cost parameters. After performing application testing and a cost analysis of the selected materials, the 4994 KOBAthane grout was selected as the final stabilization material.

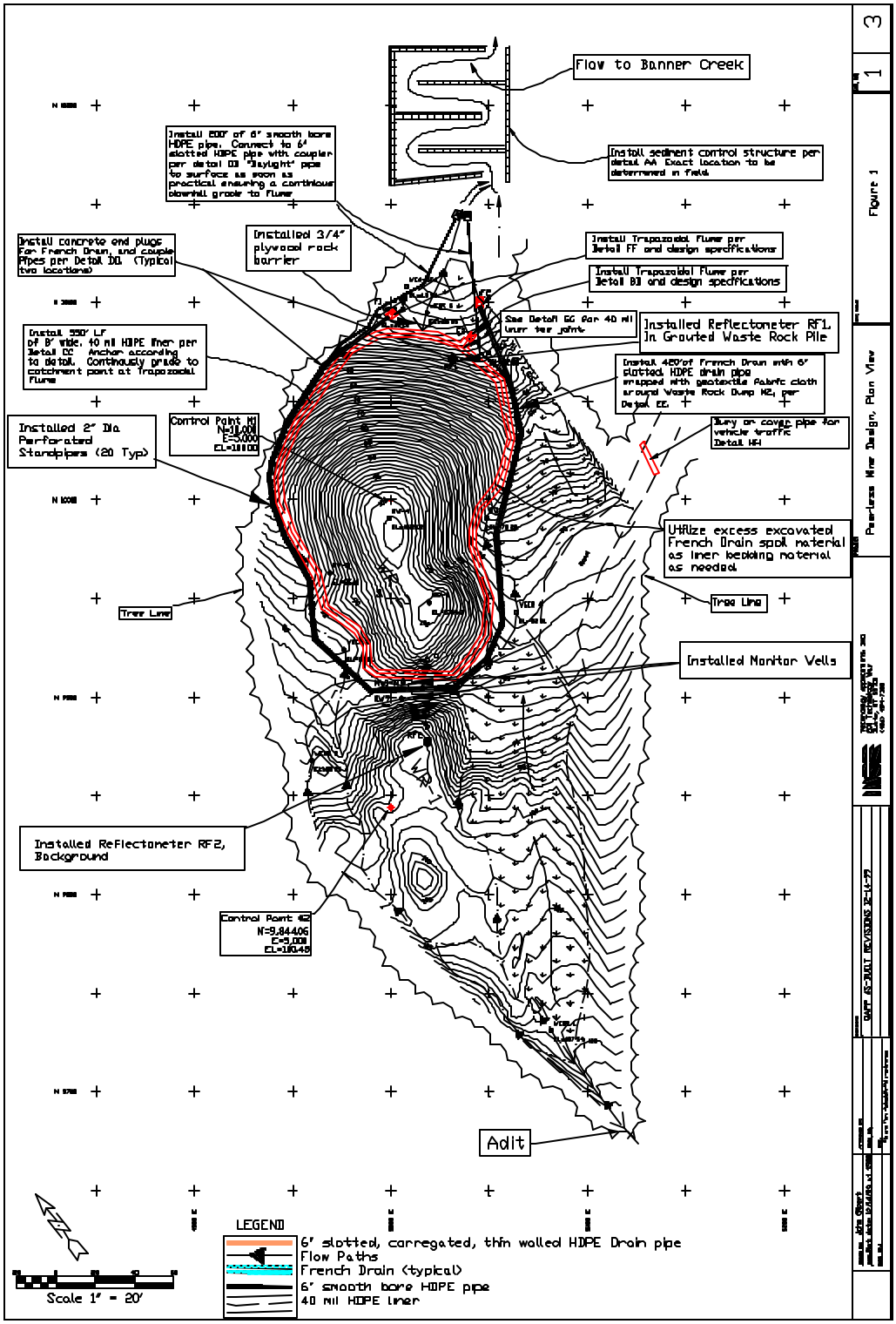

Figure 1. Peerless mine design.

PHASE III, FIELD EMPLACEMENT

Field emplacement was performed during October and November 1999. As part of the field emplacement, a French drain system was constructed to act as a hydraulic barrier to help eliminate the flow of groundwater through and beneath the surface waste pile, see Figure 2. In general, the French drain construction included: 1) excavating a 420-foot by 4-foot by 10-foot (on average) trench around the up-gradient perimeter of the surface waste pile; 2) installing 420 feet of 6-inch, slotted, high-density polyethylene (HDPE) pipe wrapped with geotextile filter cloth surrounded by 1½-inch minus washed gravel; 3) installing to surface grade, 6-inch minus, screened river-run, rip-rap over the previous smaller gravel; and 4) installing two concrete end plugs to anchor the wrapped pipe and to connect the slotted pipe to 200 additional feet of smooth bore HDPE drain pipe.

Once the French drain had been installed, a surface water collection channel was constructed on the inside perimeter of the drain. The collection channel, approximately 640 feet by 6 feet by 2 feet deep was lined with 40-mil HDPE liner and keyed into the surface waste pile. The collection channel was constructed to collect runoff from the surface waste pile.

To prevent infiltration of precipitation into the surface waste pile, General Polymers 4994 KOBAthane grout was spray applied. Approximately 930 gallons of 4994 KOBAthane grout (a two-component aromatic membrane urethane grout) was used to cover the 16,828 square feet of surface area. After applying the grout, the pile was covered with a heavy woven jute and burlap material. The surface waste pile is scheduled to be covered with soil and seeded in the summer of 2000.

Additional monitoring equipment (three large 60E trapezoidal flumes) was installed to monitor the flows from the French drain and collection channel and the flow from the toe of the surface waste pile. Reflectometers were installed to monitor the moisture content of the surface waste pile under the stabilized cap.

EMPLACEMENT OBSERVATIONS AND RESULTS

During the construction of the French drain system and the emplacement of the 4994 KOBAthane grout, visual observations and flow measurements were logged. The observations below were made.

1) The surface waste pile is very heterogeneous; the waste material contains a mixture of very fine silt to large 6- to 12-inch rocks. The pile was disturbed during the emplacement of the collection channel and during preparation of the surface waste pile for acceptance of the 4994 KOBAthane grout. The disturbed areas of the pile were difficult to spray because the fine, disturbed soil would dislodge or roll down the slope and follow preferential pathways down steeply sloped areas.

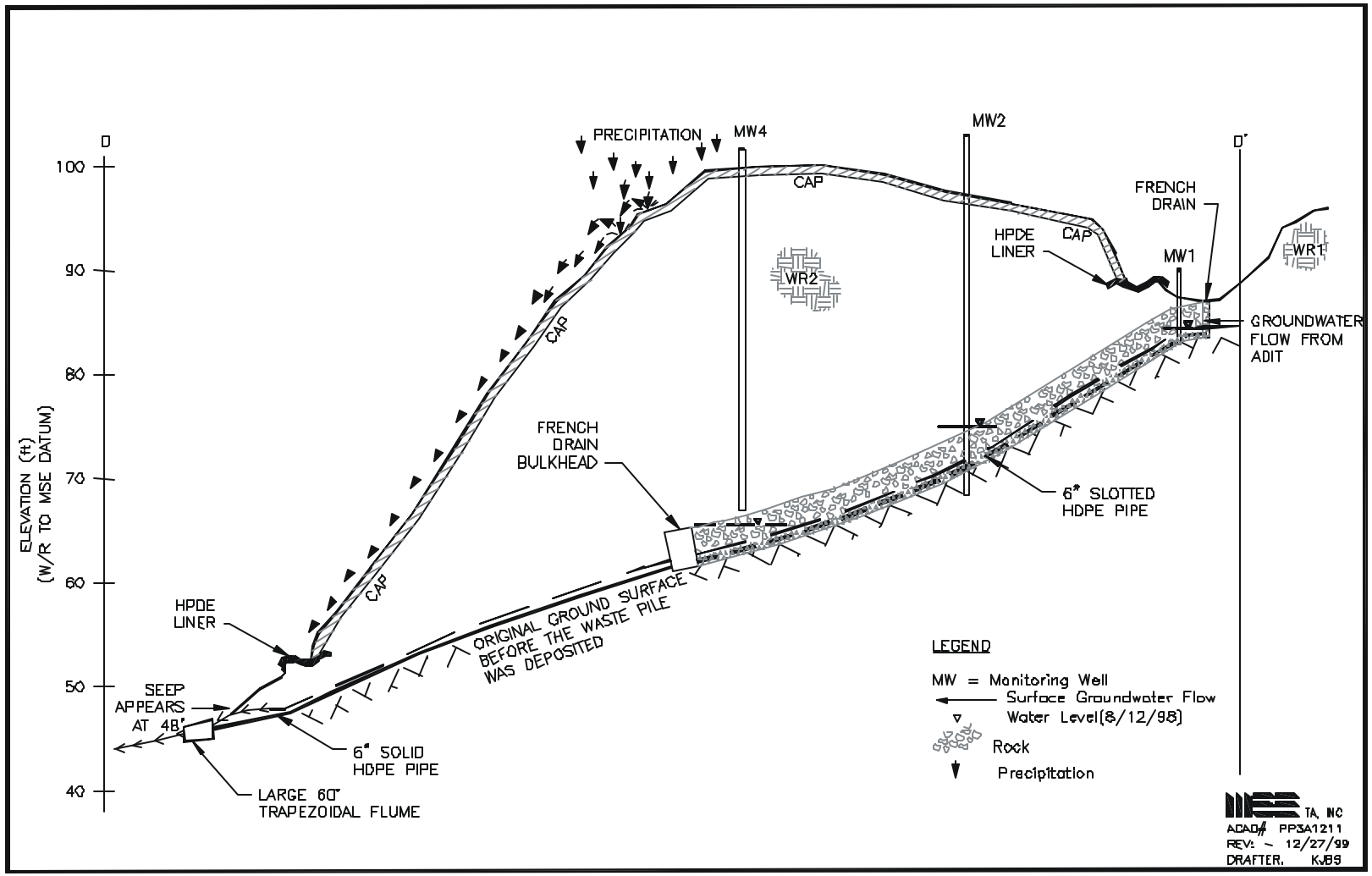

Figure 2. Peerless Mine cross section D-D' (not to scale).

2) In the steeply sloped portions of the pile, the 4994 KOBAthane grout followed the preferential pathways and sagged a great deal. This was partially due to the spray tip being too large and partially due to the lack of thixothropy in the grout product.

3) It was observed that 4994 KOBAthane grout applied directly to the surface waste pile was fairly successful. Many areas achieved a seal and served to stabilize the pile; however, voids could be observed around larger rocks.

4) In areas where the grout material was applied over areas of snow and ice, curdling occurred. In some areas the curdling effect caused the coating to be breached.

5) It was observed that after the 4994 KOBAthane grout had cured for at least 24 hours, people were able to walk on the stabilized surface. The binding of the 4994 KOBAthane grout to the surface waste pile material allows for precipitation to occur without erosional effects. The cap formed by the spray-applied 4994 KOBAthane grout over the surface waste pile provides erosion control in areas that are not accessible by motorized vehicle.

6) In some areas of the surface waste pile, the 4994 KOBAthane grout was sprayed onto the woven burlap and jute material instead of being sprayed onto just the surface waste pile. In those areas, less grout was required to cover the surface of the jute and burlap, and the final stabilized area produced an impermeable, continuous capped layer that bonded to the surface waste pile. The holes in the stabilized material applied directly to the surface waste pile were not present in areas with the jute and burlap.

7) Once the French drain was installed, the majority of the water flowing from the toe of the surface waste pile was reduced to only 2 gpm. However, once the water from the adit was placed back into its original flow regime, the flow at the toe of the surface waste pile increase to approximately 3 gpm, and flow was measured at .5 gpm at the large 60° trapezoidal flumes connected to the French drain system.

8) The pH before the demonstration was approximately 3.8; however, a month after the demonstration project was completed, the pH reading was 5.78. Two months after the demonstration project, the pH reading was 7.28. Long-term monitoring will determine whether the pH will remain at 7.28.

CONCLUSIONS AND RECOMMENDATIONS

The objective of the technology demonstration is to show the effectiveness and feasibility of using a source control technology to provide in situ stabilization/encapsulation to reduce and/or eliminate infiltration of surface and shallow groundwater into the surface waste pile. From the data taken to date, it appears that the placement of the French drain system and the 4994 KOBAthane grout cap have improved the quality of the water flowing from the toe of the

surface waste pile. This is apparent from the rise in pH levels from 3.8 to 7.28, the decrease in water temperature of approximately 2 degrees, and the change in the water quality at the toe of the surface waste pile.

It was also determined that if the jute and burlap material were applied to the surface waste pile before the 4994 KOBAthane grout was sprayed over the pile, most of the soil instability problem and the rock bridging would be solved. Also, less 4994 KOBAthane grout would be used to acquire the desired coverage of the surface waste pile because the grout binds in the woven fibers of the jute and burlap material, does not flow down the slope, and forms a smooth and consistent surface.

In areas where the slope was very steep, the grout should be made more thixotropic, allowing the grout to adhere to the soil on the area in which it was sprayed rather than flow down the slope in a preferential pathway.

For future applications, the spray equipment and tips should be optimized to determine which applicators would provide the best cover and still provide ease of application. By optimizing the equipment, this grout material could be applied at locations that are inaccessible by large earth-moving equipment.

From the work performed, it is apparent that the 4994 KOBAthane grout not only works as a capping material to reduce infiltration through the surface waste pile, but the grout was very effective at reducing and eliminating erosion of waste material into adjacent receiving surface waters.

ACKNOWLEDGMENTS

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REFERENCES

MSE Technology Applications, Inc., *Site Characterization and Materials Testing Report: Surface Waste Piles Source Control Demonstration Project,* Mine Waste Technology Program, Activity III, Project 10, MWTP-144, pg. 3-5.

MSE Technology Applications, Inc., *Test Plan-Surface Waste Piles Source Demonstration Project,* Mine Waste Technology Program, Activity III, Project 10, Phase 2, MWTP-108, pg. 11.

2000 Billings Land Reclamation Symposium

CYANIDE HEAP BIOLOGICAL DETOXIFICATION

Diane M. Jordan[1] and Tom M. Malloy[1]

ABSTRACT

A large-scale column test utilizing bacteria and a sulfide ore was conducted at McClelland Laboratories, Inc., in Sparks, Nevada, as part of the Mine Waste Technology Program (MWTP).

Through a Request for Proposal, four technology providers were subcontracted to provide their respective technology for participation in this demonstration. The sulfide ore, process effluent, and make-up water were provided by a Nevada mining company. A process effluent column and a hydrogen peroxide column, along with columns for each of the four biological technologies tested, were set side-by-side on a pad adjacent to the McClelland Laboratory building. The process effluent and hydrogen peroxide columns were used as experimental controls. The six, 4-foot outside diameter columns measuring 22 feet in height were constructed of high-density polyethylene pipe.

The project=s goal was to evaluate the viability and feasibility of the aforementioned biodegradation technologies to reduce weak acid dissociable cyanide concentration to the regulatory level of 0.2 parts per million (ppm) within an acceptable time and with low operational costs.

The MWTP is funded by the U.S. Environmental Protection Agency (EPA) and is jointly administered through an interagency agreement with the U.S. Department of Energy (DOE). This work was conducted through the DOE National Energy Technology Laboratory at the Western Environmental Technology Office under DOE contract Number DE-ACC22-96EW96405.

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INTRODUCTION

Cyanide is widely used in the mining industry to dissolve precious metals. Since certain cyanide species are hazardous to the environment, numerous cyanide detoxification processes have been developed. Most of these processes involve chemical oxidization and are expensive to construct and operate. Therefore, biological detoxification has been instituted as a replacement for chemical degradation.

The purpose of this demonstration was to obtain performance data and evaluate efficiencies of four biological technologies relative to a chemical rinse stage. Although biological detoxification technologies are commercially available, questions remain regarding efficiency, capital and operating costs, applicability to multiple ore types, and effects of biological treatment on related discharge parameters.

Principal cyanide heap neutralization rinsing data include: the extent and rate of weak acid dissociable (WAD) cyanide neutralization; decrease and rate of decrease in rinse effluent pH; and final rinse regulated contaminant concentrations.

TECHNOLOGY PROVIDERS

Four technology providers were selected to participate in this demonstration: 1) Applied Microbiology & Biotechnology Inc.; 2) Compliance Technology; 3) Little Bear Laboratories; and 4) Whitlock & Associates.

They were responsible for providing a bioreactor system, biological/bacteriological cultures, nutrients, and inoculation media.

TECHNOLOGY

Process water rinse is the simplest method of all the technologies as the process water is simply recirculated continually through the heap.

Hydrogen peroxide, frequently combined with a catalyst, is commonly used in the mining industry to detoxify heap leach solutions.

Biological cyanide detoxification is accomplished by introducing cyanide-metabolizing bacteria to a contaminated source or by stimulating indigenous bacteria through nutrient addition.

PROJECT OBJECTIVES

The primary objective of the project was to demonstrate if biological technologies are capable of reducing WAD cyanide concentration in the treated effluent to <0.2 milligrams per liter (mg/L) WAD cyanide.

Secondary objectives included:

- determining the effectiveness of the biological detoxification technologies in reducing heavy metals in the process solution;
- monitoring the variation in total metals in the treatment effluent over the test cycle; and
- determining cost in comparison to conventional technologies.

DEMONSTRATION

The demonstration took place at the McClelland Laboratories Inc. facility (MLI) in Sparks, Nevada. The demonstration consisted of six large-scale high-density polyethylene (HDPE) columns each measuring 22 feet in height with a 4-foot outside diameter. The columns were each loaded with approximately 9.1 tons of ore in November 1998. Cyanide-bearing process solution flowed to the columns at a rate of 0.004 gpm/ft^2 of column cross-sectional area and was recirculated for 2 weeks allowing finer particles to settle, thus, simulating actual heap conditions. On December 4, 1998, the four biological columns were inoculated, hydrogen peroxide solution was applied to the fifth column at a 5:1 stoichiometric ratio. The sixth column was the process water rinse.

RESULTS AND DISCUSSION

Operation of the columns began on December 4, 1998 and continued until May 17, 1999. The total solution applied to each column charge was equivalent to 4.3 tons solution per ton of solids (between 38 and 41 tons of solution per column). Parameters monitored during the test period included: WAD and total cyanide, heavy metal, and nitrate concentrations, pH and temperature.

WAD Cyanide

All six columns were effective in decreasing WAD cyanide concentration in the final rinse effluents to less than 1.3 mg/L. Over 99.9% of the WAD cyanide contained in the process water was neutralized by the rinsing processes. WAD cyanide concentration in the final rinse effluent from the chemical rinse and Whitlock & Associates were below the current drinking water maximum contaminant level (MCL) of 0.2 mg/L.

Effluent pH

Effluent pH decreased with all rinsing processes with the final effluent pH of the chemical rinse and Whitlock & Associates columns being within the MCL range. The process water rinse column required a longer rinse to meet the pH MCL.

CONSTITUENTS

Constituent analyses during the field demonstration included: arsenic; cadmium; cobalt; copper; iron; manganese; magnesium; mercury; nickel; selenium; silver; and zinc. With the exception of selenium, the six rinsing processes demonstrated were effective in decreasing process water constituent concentrations. Fluoride and magnesium concentrations, however, were below the secondary MCL. Manganese was mobilized in the hydrogen peroxide, Applied Microbiology and Whitlock & Associates columns. A decrease in manganese was noted in the process water, Compliance Technology and Little Bear Laboratories columns.

Copper

Copper values steadily dropped within the effluent for all six columns. The process water added to the columns contained soluble copper cyanide. In the hydrogen peroxide column, copper precipitated as a copper hydroxide or as cuproferro cyanide complex. This reduction of copper in the hydrogen peroxide rinse was dependent upon pH and available copper.

Biological technologies attack soluble copper cyanide causing the bond between copper and cyanide to break; copper is adsorbed or absorbed into the biomass where bacteria collect copper at the cell membrane. In the biological aerobic systems, copper deposited as a hydroxide is minimal.

Gold

Gold concentration in all six columns decreased as available cyanide concentration was reduced. Gold recovery decreased from 350 Fg/L to between 35 to 50 Fg/L within the first two to three weeks of the demonstration in all six columns. There was no significant difference in gold recovery between the simple water rinse, hydrogen peroxide rinse, and biological rinse columns.

Magnesium

The magnesium value from the six columns was low at startup and slowly decreased for approximately 107 days showing no significant variation among the six columns. On March 29, a significant increase in magnesium was noted in the hydrogen peroxide rinse column. The remaining five columns showed a slight and steady increase after 107 days of testing. This data trend corresponds with the trends in column discharge pH. As pH decreases, magnesium hydroxide dissolves from the ore causing an increase in effluent magnesium.

Nickel

The nickel value in the six column discharges decreased as the concentration of available cyanide was reduced. Nickel readily complexes with cyanide; in the absence of available cyanide, soluble nickel values decrease.

In the first two weeks of the demonstration, nickel values decreased from 2,500 Fg/L to approximately 1,000 Fg/L in all six columns. The soluble nickel stabilized for approximately six weeks, and then three of the six columns began to show a significant variation in nickel discharge.

During the first week of February, nickel values in the hydrogen peroxide rinse column decreased coinciding with the decrease in cyanide. The process water rinse column and the four biological columns remained slightly higher until cyanide concentrations approached low levels.

Nitrate/Nitrite-N

Nitrate discharge levels in the process water rinse, hydrogen peroxide rinse, Compliance Technology, Applied Microbiology and Little Bear Laboratories columns did not vary significantly. However, the Whitlock & Associates column showed a significant decrease in the nitrate discharge level. Permit nitrate discharge limits were low and it was necessary for the level to be reduced.

Selenium

Variations in selenium discharge levels for all six columns increased or decreased at the same rate.

Silver

Silver values in the six columns discharges decreased as the concentrations of available cyanide decreased. Silver readily complexes with cyanide; thus, in the absence of available cyanide, silver levels decrease rapidly.

Sulfate

During the first six weeks of the demonstration, all six columns produced similar sulfate levels. After 6 weeks, sulfate values began to increase slowly in the hydrogen peroxide rinse column. This trend continued until the demonstration ended. The biological columns showed a slow increase in sulfate discharge values with a slightly higher increase than the process water rinse column. The increased sulfate concentration is believed to be caused by the oxidizing nature of

hydrogen peroxide which converts sulfides to dissolvable sulfates. The increase in sulfates corresponded closely with the increase in hydrogen peroxide concentration.

Zinc

The zinc levels in the six columns discharges readily decreased as the concentration of the available cyanide decreased. Zinc readily complexes with cyanide. Therefore, in the absence of available cyanide, zinc levels rapidly decrease.

Zinc levels decreased from 60,000 Fg/L to approximately 6,000 Fg/L within the first month of the demonstration.

COST

A cost comparison of the demonstrated cyanide destruction technologies was based upon a previous study by MSE in November 1998. Detoxification of an abandoned heap would produce similar comparisons between technologies.

Process Water Rinse

The process water rinse requires the following capital costs: pumping systems; cyanide analyzer; piping and distribution systems; instrumentation; analytical equipment; sampling equipment; holding ponds; and a fixed or temporary facility. In addition operating funds include: personnel; analytical support; make-up water; and power.

Hydrogen Peroxide Rinse

The capital and operating costs of using hydrogen peroxide would require, in addition to the costs described for a process water rinse: holding tanks; mixing tanks; mixing equipment; process level control; storage area; procurement of the hydrogen peroxide; procurement of catalysts (if needed); additional equipment power; and additional labor.

Biological Rinse

Capital and operating cost requirements for a biological heap rinse operation, in addition to the costs of a process water rinse are: bioreactor tank(s); heaters (if necessary); clean water storage tank; live-culture holding tank; culture circulation pumps; process level control; air compressor; mixing and/or aeration equipment; additional piping; microbe isolation and/or procurement; nutrients; additional labor; and additional power.

Common Heap Rinse Costs

Depending on the technology used, costs for a common heap rinse vary. Labor rates associated with treatment system operation vary depending on the complexity of the treatment

system. Process water rinse labor costs are low due to simplicity. However, process water rinse requires longer retention time to reduce cyanide compared to hydrogen peroxide rinse and biological degradation. It is assumed that hydrogen peroxide rinse and biological degradation would require approximately the same amount of time. However, hydrogen peroxide costs are significantly higher than material costs associated with biological degradation. Hydrogen peroxide is copper catalyzed; therefore, more time and energy is expended with process control. Sludge produced by chemical systems can be an order of magnitude greater than biological systems.

Biological systems can utilize existing lined ponds or tanks. Microbe generation may be important for initial startup; however, biological growth is a self-sustaining process. Biological systems can be simplified to a greater degree than chemical systems and normally produce an effluent compatible with the environment. Biological systems will change with conditions; chemical rinse systems will not which can cause expensive upset conditions.

CONCLUSIONS

The hydrogen peroxide rinse column had the highest WAD cyanide degradation rate as the regulatory limit of <0.2 mg/L was reached in 36 days. This performance was expected as hydrogen peroxide is a strong oxidizer and readily degrades available cyanide. The process water rinse column showed a cyanide degradation curve of approximately one-third the rate of the hydrogen peroxide rinse column. All of the biological columns demonstrated had degradation rates higher than the process water rinse. Three of the biological columns were approaching the regulatory limit at the termination of the demonstration; however, one technology provider reached the regulatory limit in 151 days.

It is important to note that this was a demonstration of a difficult scenario for the biological technologies. Under optimal conditions, it is believed that the biological processes would have exhibited significantly higher rates of cyanide reduction. Several factors which added to the bio-difficulty of this demonstration were:

- The ore and process water used for this demonstration contained elevated cyanide concentrations far above the level normally associated with bio-destruction. Some strains of bacteria can tolerate cyanide levels above 250 mg/L; however, many strains of bacteria are severely inhibited at high concentrations.

- The extreme cold weather conditions greatly reduced the degradation rate of the biological columns. Low temperatures inhibit the growth rate of cyanide degrading bacteria.

- The ore type selected for this demonstration was a highly sulfidic, polymetallic ore.

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MICROBIAL CAPPING BARRIER FOR THE CONTROL OF ACID MINE DRAINAGE

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ABSTRACT

Acid mine drainage from mining wastes has been responsible for the degradation of surface and groundwater quality at many locations in Montana and throughout the world. Oxidation of sulfide minerals in mine tailings and waste-rock occurs when oxygenated water infiltrates tailings, resulting in acid generation and the solubilization of metals. Microbial capping technology involves the stimulation of beneficial bacteria at the surface of the tailings or waste-rock pile to remove oxygen from water infiltrating the waste, thereby, reducing acidic drainage and stabilizing dissolved metal ions. Laboratory-scale experiments were conducted using tailings collected from an abandoned hard rock mine and placed in six 0.3 m diameter columns that were 1.2 m long. Clean water was added to the top of the columns using a timer-controlled peristaltic pump. Effluent water from the columns was monitored for pH, oxidation-reduction potential, dissolved metals, and bacterial populations. Although field samples indicated acidic conditions, none of the six columns developed acidic effluents. Test columns received nutrient treatment applications to stimulate beneficial bacteria, while identical control columns were not treated. Nutrient treatments applied to the test columns were effective for stimulating the removal of oxygen from infiltrating water. The oxidation-reduction potential of treated columns was maintained below -250 mV, while the control columns remained in an oxidized-state. Populations of total bacteria and sulfate reducing bacteria showed a significant increase following the nutrient treatment. However, a measurable increase in the populations of heterotrophic bacteria in the treated columns was not observed. Overall, these results indicate that the nutrient treatments were effective for generating anaerobic conditions within the test columns. Column tests are currently being performed using tailings from an alternative site. This work is being conducted as part of the Mine Waste Technology Program under Interagency Agreement Number DW89938513-01-0 between the U.S. Environmental Protection Agency and the U.S. Department of Energy, Contract Number DE-AC22-96EW96405.

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INTRODUCTION

The oxidation of sulfide-containing minerals in mine tailings has resulted in acid production and the liberation of dissolved heavy metals to form acid mine drainage. Acidic drainage from mine tailings has been detrimental to surface and groundwater quality in current and former mining areas. Cost-effective treatments are required to stabilize mine tailings and prevent the formation of acidic drainage. Microbial capping barrier technology involves using nutrient treatments to stimulate beneficial bacteria within the tailings, creating a biologically active zone within the tailings that consumes oxygen and prevents the oxidation of sulfide mineral deposits.

Abiotic oxidation of sulfide-containing mine tailings occurs when oxygen-rich rainwater or surface water infiltrates tailings impoundments. Pyrite (FeS_2), a common constituent of mine tailings, undergoes the following reaction under these conditions:

$$4FeS_2 + 15O_2 + 2H_2O \rightarrow 4Fe^{3+} + 8SO_4^{2-} + 4H^+ \qquad (1)$$

Ferric iron produced in this reaction is a strong oxidant, which further abiotically oxidizes pyrite (or other mineral sulfides) as follows:

$$FeS_2 + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+ \qquad (2)$$

These reactions generate ferrous iron and large quantities of acid, which favor the growth of acidophillic, chemolithotrophic bacteria. The role of iron and sulfur-oxidizing bacteria (such as *Thiobacillus ferrooxidans*) in accelerating the production of acidic drainage from sulfide-containing mine tailings has been known for decades (Silverman and Lundgren, 1959). Populations of this or other naturally occurring and environmentally ubiquitous chemolithotrophs colonize open tailings after placement and accelerate acid production through the cycling of ferrous to ferric iron (Brierley and Brierley, 1996):

$$4Fe^{2+} + O_2 + 4H^+ \rightarrow 4Fe^{3+} + 2H_2O \qquad (3)$$

Though this reaction consumes some acidity, the overall effect is the regeneration of ferric iron, which can then oxidize more pyrite and generate much more acidity (via reaction 2). It has been estimated that an active population of *T. ferrooxidans* increases the rate of pyrite oxidation up to 6 orders of magnitude over simple abiotic oxidation (Brierley, 1978). The acidity generated in these reactions further assists the growth and downward migration of *Thiobacilli* through the tailings column by providing the low pH conditions necessary for their growth.

The key to controlling the generation of acid mine drainage is preventing the initial oxidation of pyrite. Bound with iron, the sulfur in pyrite is unable to participate in the microbially catalyzed reactions that cause acid generation. Prevention of oxygen infiltration into tailings then is necessary to prevent oxidation of pyrite and subsequent acid generation. An innovative method to prevent oxygen transport into tailings is the

construction and maintenance of a biologically active barrier on the surface of the tailings.

The basis of biological capping barrier technology is the formation of a biologically active zone occupying the free pore space in the uppermost layer of the tailings. This zone consists of bacteria and other microorganisms enmeshed in a matrix of extracellular polymeric substances (EPS). The metabolism of aerobic and facultative microorganisms in the capping layer removes oxygen from infiltrating water resulting in a decrease in pyrite oxidation and subsequent acid generation and metal solubilization. Furthermore, the presence of the microorganisms and EPS may reduce the hydraulic conductivity of the tailings, thereby, decreasing the flux of water through the tailings. Stabilization of the tailings is also enhanced by the removal of oxygen and production of fermentation products by the capping layer, which promotes the growth of sulfate reducing bacteria (SRB) deeper within the tailings. The growth of SRB results in a pH increase due to carbonate production and precipitation of heavy metals as metal sulfides.

A previous laboratory study used small-scale tests with tailings columns and demonstrated that nutrient treatments to stimulate bacterial growth resulted in an increase in pH, reduction of permeability, and the generation of anaerobic conditions within the columns (Blenkinsopp *et al.*, 1992). This study reports the preliminary results of relatively large-scale column tests with tailings collected from a proposed demonstration site for the field-scale implementation of biological capping barrier technology. The goal of these experiments was to determine if nutrient additions could stimulate indigenous, aerobic bacteria in the soil columns, resulting in increased effluent pH and decreased metals mobility. Specific objectives were to: (1) determine the effects of nutrient addition on the oxidation-reduction potential (ORP), pH, and metals content of column effluent; (2) determine the longevity of these effects from a single nutrient addition; and (3) determine the effects of nutrient addition on the microbial consortia active in the columns.

A series of six columns were packed with tailings from an abandoned mine site and irrigated daily with clean water. After stabilization, four of the columns received nutrient treatments, while two served as untreated controls. The nutrient treatments resulted in a significant decrease in ORP and an increase in the populations of total bacteria and sulfate-reducing bacteria. However, neither the test nor control columns generated acidic effluent or significant concentrations of dissolved metals. Nonetheless, the results demonstrate the effectiveness of nutrient treatments for generating anaerobic conditions within the test columns.

MATERIALS AND METHODS

Tailings from an abandoned hardrock mine near Rimini, Montana, were studied for acid production potential and the applicability of a microbial capping barrier for mitigation of acid mine drainage. Field measurements of tailings surface water runoff indicated acidic conditions (pH under 4.0) and high concentrations of aluminum, iron, lead, and zinc. In October, 1998, approximately 1 cubic yard of tailings material was transported from the

mine site to laboratories at the Center for Biofilm Engineering at Montana State University in Bozeman, Montana. The tailings were packed into PVC columns (12 inches in diameter and 48 inches long). Six tailings columns were constructed and began operating in February 1999. In May 1999, after background conditions had been fully established for the columns, nutrient treatments were applied to four of the columns. Two control columns did not receive nutrient additions.

Each of the six PVC columns (C1–C6) was filled to a depth of 40 inches with tailings from the mine site. After placement in the columns, the tailings were flooded and drained twice to facilitate packing and allow close approximation of actual site permeability. After each flooding, columns were allowed to drain under gravity.

All six columns were operated in an unsaturated condition with dechlorinated tap water applied to the top of the column that was open to the atmosphere. Column influent was adjusted to a flowrate of 10 milliliters/minute for 60 minutes each day. Columns were allowed to drain freely under gravity. Drainage from the bottom of the columns was collected on a periodic basis for pH, ORP, heterotrophic plate counts (HPC), direct counts (DC) and SRB analyses.

The ORP and pH were measured with electrodes. The SRB were enumerated using Postgate B media and most-probable number (MPN) techniques. Direct counts were taken via microscopy, and HPC were enumerated on Difco R2A agar using serial dilution technique.

On May 10, after two months of operation, 10 liters of nutrient solution was added to columns 2, 3, 4, and 6. Columns 1 and 5 received an equal amount of unamended tap water. A second treatment of nutrient solution (5 liters) was added to the treated columns two weeks after the initial treatment.

RESULTS AND DISCUSSION

Although field samples indicated acidic conditions were present in ponded water atop the tailings pile, acidic effluent did not develop in any of the six tailings columns. Column effluent pH varied from 6.5 to 7.2 prior to the nutrient treatments. This range narrowed slightly, from 6.8 to 7.2 following treatment, but did not show significant change. Despite this lack of a critical measure of the treatment effectiveness, the test was continued to determine the effect of nutrient dosing on ORP and tailings microbiology.

As expected, the ORP dropped significantly in columns that received the nutrient treatment. Prior to adding nutrient solution, ORP in the columns varied from approximately –100 to +250 millivolts. Despite this high variability, ORP in all treated columns dropped significantly following treatment. Treated column ORP was generally in the range of –300 to –400 millivolts three weeks after the treatment occurred. The high variability in individual column response to the nutrient addition is attributed to natural variation in an unsaturated flow situation. The ORP in treated columns generally remained below –250 millivolts for at least 60 days following treatment.

Sulfate reducing bacterial (SRB) cell numbers were observed to increase over time in the effluent from columns receiving nutrient additions. Prior to nutrient addition, SRB were observed in column effluents at concentrations ranging from 1 to 10 cells/milliliter. Approximately two weeks following nutrient addition, test column effluents had SRB concentrations ranging from 10^2 to 10^4 cells/milliliter. Interestingly, one of the control columns remained at very low effluent SRB concentrations (column C5 at 10 cells/ milliliter) and one exhibited elevated levels (column C1 at 10^3 cells/milliliter). SRB growth would be expected to follow the onset of anaerobic conditions. Column C1 was observed to have a ORP indicative of slightly anaerobic conditions early in the experiments, while the ORP in column C5 was consistently in the aerobic range. The increase in SRB in the test columns is thought to result from the depletion of oxygen from infiltrating water by aerobic bacteria. This is a highly desirable result because SRB produce hydrogen sulfide (H_2S) as a product of metabolism. H_2S readily reacts with metals present in solution to form insoluble and immobile metal sulfide phases.

Heterotrophic plate counts from column effluents were not observed to have a significant response to adding nutrients to the tailings columns. The HPC is a measure of all the bacteria that are capable of growing on the nutrient agar under aerobic conditions. It was expected that adding nutrients would increase the total bacterial cell numbers growing in the column, hence, in the column effluent as well. The lack of measurable increase in HPC cell numbers in the effluents may have been due to the generation of anaerobic conditions throughout most of the test column length, which did not favor the proliferation of bacteria capable of aerobic growth. The population of aerobic heterotrophic bacteria was likely localized near the upper (inlet) sections of the columns.

Bacterial direct counts performed on column effluent indicated a slight increase in cells from test columns while showing mixed results from control columns. Direct counts are intended as a measure of all cells in a sample, living and dead. As such, it would be expected that DC results would be higher than HPC. This was found to be the case with DC levels in the range of 10^6 to 10^8 cells/milliliter for all samples. In comparing HPC and DC results, HPC levels were observed to drop in mid July (approximately 60 days following nutrient addition), while no such drop was observed in DC results. This could be due to the proliferation of anaerobic bacteria within the columns that were unable to grow under the aerobic conditions of the HPC assay.

Effluent from all columns was tested for dissolved metals (Al, As, Cd, Cu, Fe, Pb, Mn, Zn) on May 10, 1999. At that time, the columns had operated with declorinated tap water influent for approximately 10 weeks, yet no nutrient additions had yet been made. Results from this sampling indicate the absence of elevated concentrations of any of the eight analytes. In many cases, concentrations of target metal analytes were below detection limits.

CONCLUSIONS

Because column pH remained in the neutral range and metals were not mobilized from the columns, the abandoned mine from which the tailings were collected was deemed an

inappropriate site for demonstration of this technology. The data collected does demonstrate several useful facts, however:

1. Dosing 15 liters of nutrient solution effectively reduced the ORP in mine tailings columns for a period of at least 60 days.

2. The effects of nutrient addition on HPC were not observable in column effluents, but nutrient addition significantly increased SRB in column effluents, suggesting the potential to precipitate dissolved metals as metal-sulfide complexes.

3. Adequate populations of SRB and HPC bacteria exist in these mine tailings such that bacterial additions to the columns were unnecessary. Simply adding a nutrient solution was adequate to provide for sustained, measurable populations of these organisms.

An alternative site for demonstration of this technology has been selected and column studies using tailings from this site is currently being performed.

ACKNOWLEDGEMENTS

This work is being conducted as part of the Mine Waste Technology Program under an interagency agreement, IAG ID No. DW89938513-01-0, between the U.S. Environmental Protection Agency and the U.S. Department of Energy, Contract Number DE-AC22-96EW96405.

REFERENCES

Blenkinsopp, S.A., Herman, D.C., McCready, R.G.L., and J.W. Costerton. 1992. Acidogenic Mine Tailings: The Use of Biofilm Bacteria to Exclude Oxygen. *Applied Biochemistry and Biotechnology*. 34/35: 801-809.

Brierley, C.L. 1978. Bacterial leaching. *Critical Reviews in Microbiology*. 6: 207–262.

Brierley, C.L., and J.A. Brierley. 1996. Microbiology for the Metal Mining Industry, pp. 830–841. *Manual of Environmental Microbiology*. C.J. Hurst (ed.). ASM Press, Washington, D.C.

Silverman, M. P., and D. G. Lundgren. 1959. Studies on the chemolithotrophic iron bacterium *Ferrobacillus ferrooxidans*: An improved medium and a harvesting procedure for securing high cell yields. *Journal of Bacteriology*. 77: 642–647.

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ARSENIC REMOVAL AND LONG-TERM STABILIZATION FOR SOLIDS

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Dr. Larry Twidwell, [2] and Glenn Vicevic[3]

ABSTRACT

Three technologies were demonstrated and evaluated for arsenic removal and stabilization of arsenic by-products. Each technology was evaluated treating two separate industrial waste water streams. The baseline technology was ferrihydrite precipitation with concurrent adsorption of arsenic onto the ferrihydrite surface. The two innovative technologies demonstrated were: 1) an integrated adsorption membrane filtration process that used activated alumina and micro filtration; and 2) a process called mineral-like precipitation. Each of the technologies were evaluated for arsenic removal capabilities, long-term stabilities of by-products produced, and process costs. The overall results will be presented and discussed. MSE Technology Applications, Inc., managed the project and demonstrated these technologies through the U.S. Department of Energy (DOE) and U.S. Environmental Protection Agency's Mine Waste Technology Program under Interagency Agreement Number DW89938513-01-0. Work was conducted through the DOE National Energy Technology Laboratory at the Western Environmental Technology Office under DOE Contract Number DE-AC22-96EW96405.

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INTRODUCTION

Project Management

This paper describes the research that was conducted and summarizes the technical results that were obtained by the Arsenic Removal Demonstration Project The Arsenic Removal Demonstration Project was performed for the U.S. Environmental Protection Agency's (EPA) Mine Waste Technology Program (MWTP). MSE Technology Applications, Inc. (MSE) implements the MWTP and owns/operates the MSE Testing Facility in Butte, Montana. The Arsenic Removal Demonstration Project was funded by the U.S. EPA MWTP.

Project Purpose

The purpose of the Arsenic Removal Demonstration Project was to demonstrate alternative water treatment technologies capable of effectively removing arsenic. Two innovative technologies, mineral-like precipitation and alumina adsorption with microfiltration, and one conventional technology, ferrihydrite adsorption, were chosen to be evaluated under the Arsenic Removal Demonstration Project.

Scope of Problem

Acidic, metal-bearing water draining from remote, abandoned mines has been identified by the EPA as a significant environmental/ health hazard in the Western United States (U.S. EPA).

Arsenic compounds and solutions are frequently an unwanted byproduct of the mining and metallurgical extraction of metals such as copper, gold, lead, and nickel. Arsenic waste problems will continue to grow as high-grade ores with low-arsenic content are depleted, and the processing of sulfide ores with high arsenic content becomes increasingly common. An example of arsenic-bearing solid wastes from the processing of gold and base metal ores is the flue dust produced from roasting and smelting unit operations. The flue dust is often concentrated in arsenic, and the arsenic is usually present as arsenic trioxide. Large quantities of flue dust from past and current mineral-processing operations are being kept in temporary storage pending the development of safe disposal methods.

Dissolved arsenic has two common valence states (III and V). Generally, arsenic in the arsenite state (III) is more soluble than arsenic in the arsenate state (V). Due to this chemical trait, arsenic is generally removed more effectively from solutions in the oxidized or arsenate state (Robins, 1983).

The U.S. National Drinking Water Standard for arsenic is 50 parts per billion (ppb). Due to concerns for cancer risk associated with arsenic, the World Health Organization recently revised the guideline for arsenic in drinking water from 50 to 10 ppb in 1993 (Rosengrant and Fargo, 1990).

Statement of Project Objectives

The primary objective of the field demonstration project was to assess the effectiveness of the chosen processes for removing arsenic from solution. Another objective of the project was to evaluate the products formed from each process to determine if they are environmentally stable. More specifically, the project objectives are:

- Reduction of the concentration of dissolved arsenic in the effluent waters to a level less than the National Primary Drinking Water Regulation Limit for arsenic established by the EPA of 50 ppb, or reduce the concentration of dissolved arsenic by 50% if the influent concentration was less than 50 ppb.

- Production of the concentrated arsenic-bearing solids from the processes that are environmentally stable by demonstrating that arsenic results using toxicity characteristic leachate procedure (TCLP) will be below the maximum concentration for toxicity of 5.0 milligrams per liter.

TECHNOLOGY DESCRIPTIONS

The three arsenic removal technologies demonstrated during the Arsenic Removal Demonstration Project were 1) mineral-like precipitation; 2) alumina adsorption with microfiltration; and 3) ferrihydrite adsorption.

Mineral-Like Precipitation

Mineral-like precipitation has been extensively investigated on bench-scale by Dr. Larry Twidwell, a Montana Tech of the University of Montana (Montana Tech) professor. The research has been performed over 10 years on several different arsenic-bearing waters.

The objective of the mineral-like precipitation technology is to strip arsenic from solutions in a way so as to produce mineral-like precipitated products that are stable for long-term storage in outdoor pond environments. Arsenic is incorporated into a mineral matrix that is stable against atmospheric reagents such as carbon dioxide. The precipitation of the mineral-like products can remove arsenic from solution to well below the U.S. Environmental Protection Agency (EPA) regulatory discharge standard as well as remove other heavy metals.

Alumina Adsorption with Microfiltration

Alumina adsorption is a widely recognized technology for removing arsenic from water. An innovative approach using alumina adsorption combined with microfiltration has been developed by ZENON Environmental Inc. (ZENON) of Canada.

Ferrihydrite Adsorption

The ferrihydrite adsorption process is EPA's Best Demonstrated Available Technology to remove arsenic from industrial waters. This technology was used as the baseline technology for comparative purposes to the innovative technologies of alumina adsorption with microfiltration and mineral-like precipitation.

DESCRIPTIONS OF TREATED WATERS

The pilot-scale demonstrations were performed on three waters: 1) scrubber blowdown water, and/or 2) thickener overflow water from the gas cleaning system prior to entering an acid plant of a lead smelter, and 3) an abandoned mine water. Chemical profiles of these waters is presented in Table 1.

Table 1. Constituents of treated waters.

Constituent	Dissolved Species micrograms/liter (F/L)[1]
Scrubber Blowdown Water	
As(III)	3,913,000
As(V)	702,000
Thickener Overflow Water	
As(III)	4,060
As(Total)	5,810
Abandoned Mine Water	
As(V)	366
As(Total)	362 (range was 366–670)
[1]Dissolved concentrations (i.e., sample filter through a 0.2 micron high-density polyethylene filter disk).	

Field testing of these processes was conducted by MSE, Montana Tech, and ZENON personnel. Monitoring of pH, E_H, and flow rates were performed at both sites.

Inorganic chemical analyses for samples collected at both sites were conducted at the MSE-HKM Analytical Laboratory, which is located in Butte, Montana. Long-term stability tests are being conducted on the solids produced from the ferrihydrite process and the mineral-like precipitation process at Montana Tech.

DEMONSTRATION RESULTS

Mineral-Like Precipitation

Scrubber Blowdown Water Analytical Results

Removing arsenic from the scrubber blowdown water by the mineral-like precipitation technology was very effective. The effluent water from the settler (after 24-hours continuous operation) contained <10 ppb arsenic [the goal was to remove the arsenic to below 50 parts per billion (ppb)]. The influent and effluent experimental results are summarized in Table 2.

Table 2. Mineral-like precipitation analytical results.

	Influent Arsenic (ppb)	**Effluent Arsenic (ppb)**
Scrubber Blowdown Water	3,300,000	<10
Thickener Overflow Water	5,800	<15
Abandoned Mine Water	420	<10

Thickener Overflow Water Analytical Results

Removing arsenic from the thickener overflow water by the mineral-like precipitation technology was very effective [e.g., the effluent water from the settler (after 8-hours continuous operation) was <15 ppb arsenic (the goal was to remove the arsenic to below 50 ppb)]. The influent and effluent experimental results are summarized in Table 2.

Abandoned Mine Water Analytical Results

Removing arsenic from the abandoned mine water by the mineral-like precipitation technology was very effective [e.g., the effluent water from the settler (after only 1 hour of continuous operation) was <10 ppb (one sample was 25 Fmg/L, the goal was to remove the arsenic to below 50 ppb)]. The influent and effluent experimental results are summarized in Table 2.

Toxicity Characteristic Leachate Procedure (TCLP)

The TCLP was performed on the composite solids produced at the end of each demonstration. The product solids produced from the demonstration on each passed the TCLP test; therefore, these solids are considered to be nonhazardous with respect to handling and land disposal.

Long-Term Stability

The solids that are produced by other technologies (lime precipitation and ferrihydrite adsorption) may not be stable for long-term outdoor storage. The mineral-like precipitation technology solves the storage problem because the product is thermodynamically stable against conversion to calcium carbonate by carbon dioxide in atmospheric air.

To validate that the mineral-like product is indeed stable, long-term stability testing was initiated and will be continued for 2 years. Test slurries of the solids produced from the Arsenic Removal Demonstration Project were prepared and set up so air could be sparged into the slurries. Solution pH, Eh, and temperature are monitored monthly. The solubility of the solids will be determined after 1 and 2 years of exposure.

Alumina Adsorption with Microfiltration Results

Four tests were conducted treating thickener overflow water and one test treating abandoned mine water. A summary of the analytical results is presented in Table 3. High concentrations of sulfate [up to 2,500 parts per million (ppm)] in the thickener overflow were competing with arsenic for adsorption sites on activated alumina.

Table 3. Alumina adsorption with microfiltration analytical results.

	Initial Arsenic (ppb)	**Final Arsenic (ppb)**
Thickener Overflow Water	5,800	180–1,420
Abandoned Mine Water	420	< 20

Ferrihydrite Adsorption

Thickener Overflow Water Analytical Results

For removing arsenic in thickener overflow water, two separate parameters were used. An iron to arsenic mole ratio of both 8 and 10 was used for ferrihydrite adsorption. The removal of arsenic from thickener overflow water is dependent on the amount of iron inputted into the system. Ferrihydrite adsorption technology was performed at the lead smelter site using their existing facility.

<u>Low Iron Demonstration</u>

Using an iron to arsenic mole ratio of 8, arsenic concentrations were lowered from 5.8 ppm to 100 ppb at a pH of 7. Ferrihydrite absorption was effective for arsenic removal; however, the established drinking water standard of 50 ppb was never achieved at this iron to arsenic mole ratio. The analytical results can be observed in Table 4.

Table 4. Ferrihydrite adsorption analytical results.

	Influent Arsenic (ppb)	Effluent Arsenic (ppb)
Thickener Overflow Water (Fe/As ratio = 8)	5,800	100
Thickener Overflow Water (Fe/As ratio = 10)	5,800	<20
Abandoned Mine Water (Fe/As ratio = 10)	420	<20

High Iron Demonstration

Increasing the iron content was very effective for removing arsenic from the thickener overflow water. Concentrations were lowered from 5.8 ppm to less than 20 ppb. The influent and the effluent water analytical results are summarized in Table 4.

Abandoned Mine Water Analytical Results

Removing arsenic using abandoned mine water by ferrihydrite adsorption was very effective. Results indicate arsenic concentrations were lowered from 420 ppb to less than the drinking water standard of 50 ppb. The arsenic to iron mole ratio used for this demonstration was 10, which proved to be sufficient. Analytical results are summarized in Table 4.

ECONOMIC ANALYSIS

One objective of this study was to perform a first order cost estimate for each of the treatment flow sheets. The cost estimate presented here is not a detailed engineering cost analysis; it is a first order cost estimate that should be within ±30%.

The three different technologies, mineral-like precipitation, alumina adsorption with microfiltration, and ferrihydrite adsorption, were economically evaluated for a system that contained 0.5 ppb arsenic at a flowrate of 300 gallons per minute. The comparative results can be seen in Table 5.

Table 5. Economic evaluation for selected technologies.

	Mineral-Like Precipitation	**Alumina Adsorption**	**Ferrihydrite Adsorption**
Capital	$250,000 ±$75,000	$396,000 ±$118, 800	$250,000 ±75, 000
Operations and Maintenance per Year	$41,080	$130,700	$78,904
Operations and Maintenance per 1,000 gallons treated	$0.30 ± 0.09	$0.70 ± 0.30	$0.55 ± 0.16

REFERENCES

Robins, R.G., 1983, "The Stabilities of Arsenic (V) and Arsenic (III) Compounds in Aqueous Metal Extraction Systems," pp. 291–310. *Hydrometallurgy Research, Development and Plant Practice*, Ed:, K. Osseo-Asare, J.D. Miller, TMS-AIME, Warrendale, PA.

Rosengrant, L.L, Fargo, L., *1990, Final Best Demonstrated Available Technology (BDAT) Background Document for K031, K084, K101, K102, Characteristic Arsenic Wastes (D004), Characteristic Selenium Wastes (D010), and P and U Wastes Containing Arsenic and Selenium Listing Constituents,* Vol. 1, 124 p., Versar Inc., Springfield, VA, USA, EPA/530/SW-90/059A, NTIS PB90-234014.

U.S. Environmental Protection Agency, Management of Mining Wastes, RCRA Subtitle D, Regulatory Program Development, Detailed Management Plan.

2000 Billings Land Reclamation Symposium

ACID REMEDIATION AT HOMESTAKE'S SANTA FE MINE USING A CHEMICAL CAP

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ABSTRACT

The Santa Fe Mine, located in west central Nevada, began leaching ore in 1988 and completed ore processing in 1995. Homestake Mining Company has completed final reclamation of the site, including remediation of waste dump acid conditions resulting from the oxidation of near-surface sulfide minerals. The production of acidity and the migration of acidity into coversoil became a significant detriment to previous revegetation success at the site. Acid geochemical conditions at the site indicated that the actual production and concentrations of acidity were relatively low, the result of low moisture regime, low biological activity, and limited oxidation of ferric ions. The oxidation of sulfides was a near-surface condition and the spread of acidity into coversoil materials was largely the result of chemical diffusion processes. After examining several remediation options, Homestake elected to construct a chemical cap on the waste dumps to prevent the diffusion of acidity into new coversoil materials. Monitoring data from the site has indicated that the chemical cap has been successful in preventing the diffusion of acidity into coversoil materials and the long-term goal of revegetation success is likely.

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INTRODUCTION

Hardrock mine plans in the early 1980's did not generally include provisions for managing waste rock containing pyrite or other sulfidic minerals. By the late 1980's, mine operators and regulators began to understand the potential problems associated with mining sulfidic rocks. As has been well documented, the oxidation of sulfides will result in the generation of significant acidity and the potential for the release of acid mine drainage. The sulfide oxidation process, and resultant acid production, has plagued many hardrock mines in recent years. The lack of planning for management of sulfidic rock during mine-planning and permitting phases resulted from the fact that most cyanide leach facilities developed in the early 1980's mined primarily oxide deposits. That is, the minerals in the deposits, including pyrite, were highly oxidized resulting in a deposit that is amenable to cyanide leaching. In addition, the majority of rock characterization was aimed at defining the ore reserve and less attention was paid to waste rock characterization. Waste rock was placed randomly in waste dumps and it was generally thought that the rainfall amounts in arid and semi-arid climates were not sufficient to cause environmental or reclamation concerns.

The Santa Fe Mine was developed in the late 1980's with ore processing completed in late 1995. Homestake Mining Company acquired the Santa Fe Mine in 1992 as part of a merger with another mining company. The operator began to reclaim the waste dumps in 1991 and 1992. The waste dumps were characterized by long angle-of-repose side-slopes and relatively flat tops, configurations common at the time for dumps constructed by end-dumping trucks. The original reclamation plans included the placement of 4 to 6 inches of coversoil on the tops and sides of the dumps, straw mulching, and seeding with a native seed mix. Initial revegetation growth was excellent with the establishment of a native grass, shrub, or forb community.

In 1997, revegetation monitoring and site observations indicated that the re-seeded vegetation was dying, leaving bare areas on the tops and side-slopes of the dumps. Examination of these areas confirmed that the oxidation of sulfides and the subsequent migration of acidity were responsible for the decline of vegetation. Homestake contracted with RIMCON to develop an acid rock remediation plan for the site and to assist Homestake in implementing that plan. Details of the remediation and results of first year monitoring are presented in this paper.

GEOLOGIC AND MINING BACKGROUND

The geologic setting and the mining practices at the Santa Fe Mine were typical of the mining operations and operational practices of the 1980's. The Santa Fe gold-silver deposit is located in the foothills of the eastern margin of Todd Mountain, within the south-central portion of the northwest trending Gabbs Valley Range in Nevada. The surface elevation of the mine site ranges from 5975 feet to 6160 feet above sea level. Three major rock units are present at the site. The oldest unit is the Triassic Luning Formation, which is intruded by a Mesozoic pluton. These rocks are overlain by, or in fault contact with, Tertiary volcanics and Quaternary to Recent alluvium (Fiannaca, 1987).

The Luning Formation comprises blue-grey, medium-bedded to massive brecciated limestone, micrite, and rare amounts of siltstone. These rocks are usually carbonaceous and

occasionally pyritic. Near intrusive margins, dull-green hornfels, whitish brown marble pods and calc-silicate skarns occur with pyrite as a common accessory mineral. The Tertiary volcanic rock unconformably overlies, or is in fault contact with the Luning Formation. This ash flow has a densely welded basal rhyodacite which grades upward into a partially welded rhyolite and both are generally non-pyritic (Fiannaca, 1987).

The gold and silver mined at the Santa Fe Mine came largely from the highly oxidized zones within the pit. As such, the rock placed on the heap leach pads did not contain appreciable concentrations of pyrite or sulfides and did not produce acidity upon leaching. Drill cuttings from the in-pit blast-hole drilling were analyzed for ore grade and oxidation state in relation to sulfides. Ore rock containing appreciable concentrations of pyrite (sulfide ore) was selectively handled and placed in a stockpile. This ore was generally not considered readily amenable to cyanide leaching and was stockpiled as a contingency for possible future processing.

Waste rock consisted of a combination of oxidized, mixed and sulfidic rock that was not mineralized. Waste rock dumps at the Santa Fe Mine were typical end-dump repositories. That is, the rock was dumped by trucks in piles and the piles were dozed flat to form a layer in the dump. This process resulted in long, angle-of-repose sideslopes and relatively flat tops. The mining process moved in and out of rock that contained pyrite and this process resulted in the sulfidic rock being placed randomly in the dumps. As stated previously, during this mining period, there was little concern by mining companies or regulators that the sulfides could create environmental or reclamation problems in the future. The Santa Fe Mine provides a case study of the types of remedial problems that can occur in an arid climate when pre-planning for management of sulfides has not occurred.

SITE GEOCHEMICAL CHARACTERIZATION

In 1997, Homestake personnel observed that vegetative cover was declining, significant bare areas were developing, and the bare areas appeared to be growing in number and size. Revegetation specialists examined the site and evaluated numerous agronomic characteristics to determine the cause of the dying vegetation. Based on their review and the subsequent field examination by RIMCON, it was determined that the majority of bare areas were the direct result of the oxidation of sulfides in the waste rock.

Since the waste rock was placed randomly in the dumps, the occurrence of the acid areas was also random and the location of other potential acid generating areas was difficult to predict. Numerous areas of the waste dumps exhibited classic symptoms of the sulfide oxidation process. That is, oxidation by-products, such as iron and manganese hydroxides and gypsum were present. Surfaces were crusted and exhibited telltale red, yellow-orange, and black colors. Where some of the acidity had been neutralized by adjacent limestone, clayey residues resulted, further enabling surface crusting as the materials dried. In some areas, the oxidation and weathering processes allowed for significant expansion or swelling of the waste materials creating a hummocky landscape.

The development of a remediation plan for the site depended on numerous factors including the sulfide oxidation mechanisms. The sulfide oxidation process is generally

complicated and involves both chemical and biological oxidation components. The rate of chemical oxidation is influenced by factors including pH, oxygen concentrations, temperature, moisture content and the ferrous/ferric iron equilibria. The chemical oxidation of pyrite is quite sensitive to the pH of the reaction media, particularly on the influence of pH on the ferrous/ferric iron equilibria. That is, at very low pH, ferric iron serves as an oxidant of ferrous iron resulting in a significant increase in both the rate and quantity of acid generation. If the oxidation process is limited and pH levels remain generally above 4.5, the oxidation of ferric iron will be limited (Sobek, etal., 1997).

Microorganisms also serve as catalysts to the oxidation process and are most active in the pH range of 2.0 to 4.5. The organisms have optimum temperature requirements and must have moisture to be active. Generally the organisms obtain their energy from oxidation of elemental sulfur and can actually regenerate ferric iron in the process. When bacteria are active, the generation of acidity may be increased 50-fold by increasing the rate of ferrous iron oxidation (Sobek, etal., 1987).

Table 1 summarizes some of the site geochemical characteristics from selected areas. The table has been divided into two sections, one summarizing data from areas that did not contain oxidizing sulfides and the other from areas that had oxidizing sulfides. As is typical of most acid generating materials, the sulfidic areas exhibited elevated iron, manganese, and sulfate levels. The sulfate concentrations for the sulfidic areas ranged from 100 to 880 ppm while the sulfate concentrations for the non-sulfide areas ranged from 6.6 to 64 ppm. Manganese concentrations for the sulfide areas ranged from 98 to 820 ppm as compared to the concentration range for non-sulfide areas of 3.3 to 46 ppm. The iron concentrations, often the most identifiable element associated with acid generation, ranged from 190 to 4600 ppm for the sulfide samples and ranged from 6.7 to 95 ppm for the non-sulfide samples. With the exception of one sample (5C), pH values for the sulfidic areas were greater than 4.5 and ranged up to 5.9. The sampled identified as 5C exhibited a very low pH value of 2.6.

Table 1. Waste dump geochemical characteristics.

Sample Site	pH	Iron mg/l	Manganese mg/l	Sulfate mg/l
Non-sulfides				
4A	7.6	13	7.4	64
15	7.0	79	46	39
16	6.9	95	24	41
17	7.9	8.2	3.8	6.6
21A	7.9	6.7	3.3	12
Sulfides				
13B	5.5	1000	320	180
4D	5.9	190	98	140
5C	2.6	4600	820	880
23C-1	4.5	2800	410	320
23C-2	5.6	1900	110	100

While the generated acidity was sufficient to degrade coversoil, the actual concentration of acidity was somewhat limited. Laboratory weathering tests of samples 5C and 23C-1 show that total titrateable acidity generated in the samples was only 380 and 420 mg/l,

respectively. These results can be compared to numerous other mine sites where total generated acidity often exceeds several thousand mg/l. This data, along with the observations described above and field observations, indicated that the relatively low acid generation was the result of several rate limiting factors, including low moisture regime, limited biological activity, and limited oxidation of ferric ions. This conclusion was very important for the selection of a cost-effective remediation plan.

REMEDIATION PLAN

Several factors resulted in the degradation of coversoil and vegetation at the Santa Fe Mine. Because precipitation is limited at the site (7 inch average), the generation of acidity was strictly a near-surface condition. Limited grading of the dump and dump settlement resulted in brief ponding and collection of rainfall runoff in low areas. This moisture was sufficient to allow for oxidation of near-surface sulfides and the production of low-level acidity. While the sulfide rock was often deposited in the vicinity of other waste rock derived from the Luning limestone, geochemical kinetics were limited and little neutralization of the acidity occurred. Generally, the acid generation process was very rapid and the limestone surface area was too large to allow for significant neutralization of the acidity. Additional field observations of acid areas showed typical iron hydroxide coating of the limestone, further restricting the ability of the limestone to neutralize the acidity. In areas where rainfall did not collect for extended periods of time, the sulfide waste rock had not yet began to oxidize and generate acid.

The migration and spread of acidity into the coversoil was the result of chemical diffusion rather than movement by convective flow. That is, the acid solute moved from areas of high concentrations to areas of lower concentrations without significant water movement. Because of this process, the final remediation design had to consider ways to prevent the diffusion of the acidity into new coversoil. Since many areas of the dump had sulfide waste that had not yet significantly oxidized, the plan had to be inclusive of these areas also. Covering the dumps with non-sulfide waste rock was not an option since mining had ceased, all waste rock was randomly mixed with sulfidic rock, and coversoil availability was also limited.

Since the oxidation was accelerated in low areas on the dumps, the final remediation plan involved grading the surface of the dumps to prevent ponding of the limited precipitation. The crests of the dumps were graded to prevent rainfall from flowing directly over the steep sideslopes creating rilling and erosion. In addition, drainage channels were designed into the plan to route precipitation from potential high rainfall events away from the dumps. While the grading plan may create a less diverse vegetative stand over time, the prevention of ponding was considered very important to preventing isolated high oxidation areas.

The final, and most important aspect of the remediation plan, was the construction of a chemical cap that was placed on the dump tops and sideslopes before coversoil application. Chermak and Runnells (1997) discussed the use of a chemical cap at an unamed Nevada mine site. They attempted to create a permanent chemical cap, or hardpan, by neutralizing surface acidity with lime. The chemical reactions produced gypsum and amorphous iron oxyhydroxides, which were produced in an attempt to limit water infiltration into the dump. Conversely, the Santa Fe Mine chemical cap function was to neutralize existing near surface

acidity and to serve as a barrier for diffusion of acid solutes. The chemical cap was placed over the entire surface of the dumps and selected areas of the sideslopes since the location of potentially new acid generating areas was difficult to locate even with intensive sampling.

The chemical cap consisted of the placement of 20 tons per acre of magnesite (magnesium carbonate) and brucite (magnesium hydroxide) mined in nearby Gabbs, Nevada. The application rate was significantly higher than was necessary to neutralize any potential acidity. The application rate was finally estimated by the ability of available equipment to apply the chemical uniformly over the dump surfaces. The chemical was not disked into the surface as is common but was left as a concentrated amendment, maximizing chemical gradient differences. A total of 1850 tons of magnesite and brucite were applied to the dumps. Following placement of the cap, 8 to 12 inches of coversoil, borrowed from a nearby native draw, was placed carefully over the cap and seeded with a native seed mix.

While used at times for water treatment, the use of magnesite and brucite as a chemical amendment for remediation of acid rock conditions is somewhat rarer. Theses chemicals had a total alkalinity of 1920 mg/kg and a neutralizing potential (NP) of 600 tons per 1000 tons CaCO3 equivalent. Laboratory observations indicated that the rate of chemical neutralization was slightly slower than for calcium carbonate due to a slower dissolution rate. However, the magnesite and brucite had significant buffering capacities and the fact that the materials were mined very close to the site made them an extremely cost-effective and technically sound amendment.

REMEDIATION RESULTS

Construction of the chemical cap and coversoil placement was finished in late 1997 and revegetation efforts on the remediated dumps were completed by spring 1998. The site was visited in late April 1999 to monitor the effects of the chemical cap and to make general observations of the site conditions. Vegetation monitoring has been conducted separately from this study.

Monitoring procedures consisted of hand-dug holes to a depth below the chemical cap. Monitoring sites were selected randomly throughout the tops and sideslopes of the waste dumps. A total of 21 monitoring holes were dug and observations of coversoil depth, coversoil pH, waste pH, chemical cap conditions, and other general observations were recorded. Photographic documentation of the monitoring holes was also performed.

Table 2 and Table 3 summarize the results of those field observations for the east and west waste dumps. In all cases, where sulfidic waste was noted below the cap, no diffusion of acid solutes has occurred. One site, identified as site W-9 showed evidence that the coversoil, chemical cap, and sulfidic waste had been disked and thoroughly mixed. While oxidation by-products were clearly visible in the materials, field pH measurements indicated that neutralization of the acidity had occurred as evidenced by a 6.9 pH value. The mean pH of all coversoil immediately above the chemical cap was 7.2 with a range of 6.9 to 7.6. The mean pH of the sulfidic waste present immediately below the chemical cap was 5.5 with a range of 4.7 to 5.9.

At this point in time, rainfall quantities have not been sufficient to reach the chemical cap. The 8 to 12 inches of coversoil is sufficient to store all of the moisture received during a normal rainfall year. In the absence of sufficient moisture to allow for convective movement of acid solutes, conditions are ideal for chemical diffusion to occur. The presence of the chemical cap has prevented the diffusion of acidity into the coversoil and it is likely that the chemical gradient created by the cap will result in long-term mitigation of any potential diffusion.

Table 2. West waste dump chemical cap monitoring observations.

Location	Coversoil Depth - in.	Coversoil pH	Waste pH	Visual Observations
W-1	11	7.6	5.9	No visible acid by-products in coversoil; amendments visible
W-2	13	7.5	4.9	No visible acid by-products in coversoil; amendments visible
W-3	8			Non-sulfidic waste; amendments visible
W-4	9			Non-sulfidic waste; amendments visible
W-5	10			Non-sulfidic waste; amendments visible
W-6	8	7.2	5.9	No visible acid by-products in coversoil; amendments visible
W-7	12			No visible acid by-products in coversoil; amendments visible
W-8	8			No visible acid by-products in coversoil; amendments visible
W-9*	0	6.9	6.9	Coversoil/waste mixed; small area; acidity neutralized
W-10	8			No visible acid by-products in coversoil; amendments visible
W-11	10			No visible acid by-products in coversoil; amendments visible
W-12	10			Non-sulfidic waste; amendments visible
W-13	8	7.1	5.9	No visible acid by-products in coversoil; amendments visible
W-14	8			No visible acid by-products in coversoil; amendments visible
W-15	8			Non-sulfidic waste; amendments visible
W-16**	12	7.4	4.7	No visible acid by-products in coversoil; amendments visible
W-17	8	7.1	5.8	Side slope site; no visible acid by-products in coversoil
W-18	8			Side slope site; no visible acid by-products in coversoil

* Coversoil, waste, and amendments have been disked together at this location. Acidity has been neutralized.
** Location in area of intense weathering and oxidation before remediation. Area was very wet and generating steam on cold days. Amendments were applied at a rate of 40 tons/acre.

Table 3. East waste dump chemical cap monitoring observations.

Location	Coversoil Depth - in.	Coversoil pH	Waste pH	Visual Observations
E-1*	24			No visible acid by-products; amendments not reached
E-2	9	7.3	5.9	No visible acid by-products in coversoil; amendments visible
E-3	11			No visible acid by-products in coversoil; amendments visible
E-4**	12	7.1	2.7	No visible acid by-products in coversoil; amendments visible
E-5	8			Non-sulfidic waste; amendments visible
E-6	9			Non-sulfidic waste; amendments visible
E-7	8			No visible acid by-products in coversoil; amendments visible
E-8	8	7.0	5.9	No visible acid by-products in coversoil; amendments visible
E-9	8			No visible acid by-products in coversoil; amendments visible
E-10	10	7.2	5.8	No visible acid by-products in coversoil; amendments visible
E-11	10			No visible acid by-products in coversoil; amendments visible
E-12	8	7.0	5.2	No visible acid by-products in coversoil; amendments visible
E-13	8			

* For unexplained reasons, this sampling site is very deep and amendments were not reached.
** This location is the site of significant acid generation compared to other areas. The chemical cap is functioning at this severe site.

ECONOMIC CONSIDERATIONS

Table 4 summarizes the costs associated with the acid remediation plan and does not include the internal management expenses encountered by Homestake. In addition to the

expenses noted in Table 4, Homestake also had internal site review costs, remediation plan development and review costs, on-site construction management costs, and site maintenance costs.

As can be seen from Table 4, Homestake's voluntary waste dump remediation efforts cost the company in excess of $775,000 not including their internal costs. These costs are a case study of a relatively uncomplicated remediation plan, the result of low precipitation levels. Many sites that have developed acid problems, including acid mine drainage, are faced with remediation costs that often exceed several million dollars. In fact, acid remediation construction costs at two mines in South Dakota that are of similar size to the Santa Fe Mine are estimated in excess of $12,000,000 each, not including post-remediation water treatment and management costs (SDDENR, 1999).

Table 4. Santa Fe Mine remediation and reclamation costs.

Expense category	Cost
Mobilization, demobilization, site grading, and drainage construction	$146,000
Chemical amendment purchase, haulage, and application	$139,000
Coversoil haulage, application, and revegetation	$442,000
Engineering and construction management	$ 50,000
Total	$776,000

CONCLUSION

The selection of the chemical cap technology for remediation of acid conditions at the Santa Fe Mine was cost-effective. Other alternative options, such as a combined physical and chemical cap, would have cost significantly more than the chemical cap. The voluntary effort by Homestake to improve the revegetation success of the site appears to have been very successful. This project is indicative of Homestake's desire to be proactive in the reclamation and management of all of their mine sites.

REFERENCES

Fiannaca, M. 1987. Geology of the Santa Fe gold-silver deposit, Mineral County, Nevada, In Johnson, J.L. ed., bulk Metal Deposits of the Western United States, Geological Society of Nevada. 1987 Symposium, p. 233-239.

Chermak, J.A. and D.D. Runnells. 1997. Development of chemical caps in acid rock Drainage environments. Mining Engineering. P. 93-97.

Sobek, A. A., Hossner, L.R., Sorenson, D.L., Sullivan, P.J. and Fransway, D.F. 1987. Acid-base potential and sulfur forms. In Reclaiming mine soils and overburden in The western United States, R. Dean Williams and Gerald E. Schuman, editors, Soil Conservation Society of America, Ankeny, IA, p.223-258.

South Dakota Department of Environment and Natural Resources, Minerals and Mining Division. 1999. Personal communication, Pierre, SD.

2000 BILLINGS LAND RECLAMATION SYMPOSIUM

ALTERNATIVE MINE WASTE REPOSITORY DESIGN TO ALLOW FOR REDEVELOPMENT AND REUSE OF LAND IN BUTTE, MONTANA

Chuck Stilwell, P.E. and Brad Archibald, P.E.[1]

ABSTRACT

Reclamation of mine waste areas and design of mine waste repositories and covers must take into consideration regulatory, technical, and end-use issues. Presented here is a case study of a site in Butte, Montana, where a unique approach was taken to design and construct a mine waste repository and municipal landfill that met all regulatory requirements while allowing the redevelopment of the site into a multi-functional recreational complex for the community.

The Clark Tailings were a historic tailings impoundment approximately one mile southwest of Butte, Montana. The 60-acre (24-hectare) site contained approximately 1,000,000 cubic yards [yd^3] (765,000 m^3) of mine waste and is adjacent to the old Butte municipal landfill. A combined remedy for the mine waste and landfill was performed under RCRA jurisdiction. Also, 850,000 yd^3 (650,000 m^3) of mine waste from another site in Butte were consolidated at the site. The waste placement and repository cover designs considered plans for future redevelopment into a recreational complex, which included large irrigated areas for turf-grass ballfields, play areas, Park buildings, and parking areas. Though the cap was designed to meet the prescriptive regulatory requirements, many alternative features were incorporated, including using locally available soil to meet strict infiltration barrier requirements. Waste placement and the final cover were designed in 1997 and constructed in 1997 and 1998. Park improvements are scheduled for construction in 1999 and 2000.

Introduction

A combination of conditions and concerns related to several/mine waste reclamation projects and a recently closed, previously used municipal solid waste landfill near Butte provides an opportunity for a creative solution to all. This paper describes how the challenge of cleaning up two sites, a mine waste site and a landfill in an urban setting, while creating a recreational amenity for the community in the process was met.

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Background

The Clark Tailings, located in southwest Butte, are wastes generated by the William Clark's Timber Butte zinc mill, operated between 1914 and the 1930s. The historic tailings impoundment containing approximately 1,000,000 yd^3 (765,000 m^3) of tailings on a 60 acres (25 hectares) site was partially reclaimed in the mid-1980s, but concerns remained regarding their possibility to impact the surrounding area. The once remote site, now has residential and light industrial development adjacent to it, and was to be studied to determine the need for further, more permanent reclamation.

Adjacent to the west of Clark Tailings was the old Butte municipal landfill, operated between the 1960s and 1995. Groundwater contamination detected in 1994 precipitated a Corrective Measures Assessment for the landfill. The landfill was closed in the mid-1990s in accordance with applicable Subtitle D regulations. The closure included a soil cover and grading to achieve positive drainage from the waste areas, the surface revegetated with native grasses, and a landfill gas venting system installed to mitigate groundwater contamination present beneath and downgradient of the landfill. Though the closure was complete, no foreseeable active land use was likely - as with many closed municipal landfills - due to the uncompacted fill, methane generation and site maintenance issues.

A second area impacted by mine waste called the Lower Area One (LAO) site was located one mile north of the Clark Tailings and Butte landfill sites. Approximately 1.2 million yd^3 (917,000 m^3) of tailings were to be removed from a historic floodplain and wetland setting, which was causing significant metals impacts to the Silver Bow Creek surface and groundwater. LAO was in the process of being remediated, which involved an action of removing much of the accessible tailings from the Silver Bow Creek floodplain for a span of about a mile of the stream and disposed of them via rail 25 miles away in the Opportunity tailings ponds, near Anaconda, MT. The LAO tailings removal was already underway, with approximately 400,000 yd^3 of dry, unsaturated tailings already moved to the Opportunity Ponds. What tailings remained was to take up to six years to remove and haul, given the originally selected mode of transportation - rail. This lengthy construction schedule was due specifically to lack of rail car availability and capacity and the distance and time to haul 25 miles away. Under isolated conditions, a six-year project length could have been accommodated. Yet in the case of LAO, this project's schedule was interrelated with other planned remediation in the Butte area. If the LAO project took another four to six years to complete, the Butte area clean-up effort would likely have been delayed the same length of time.

Finally, an unrelated need existed in Butte - Butte had a lack of modern community recreational facilities. The prospect of a publicly funded facility was unlikely due to an uncertain economic tax base similar to many Montana communities. By working together, ARCO, which was performing much of the reclamation in Butte Butte's local government, State, and Federal Agencies overseeing mine waste and landfill reclamation, conceptualized a creative solution to these issues.

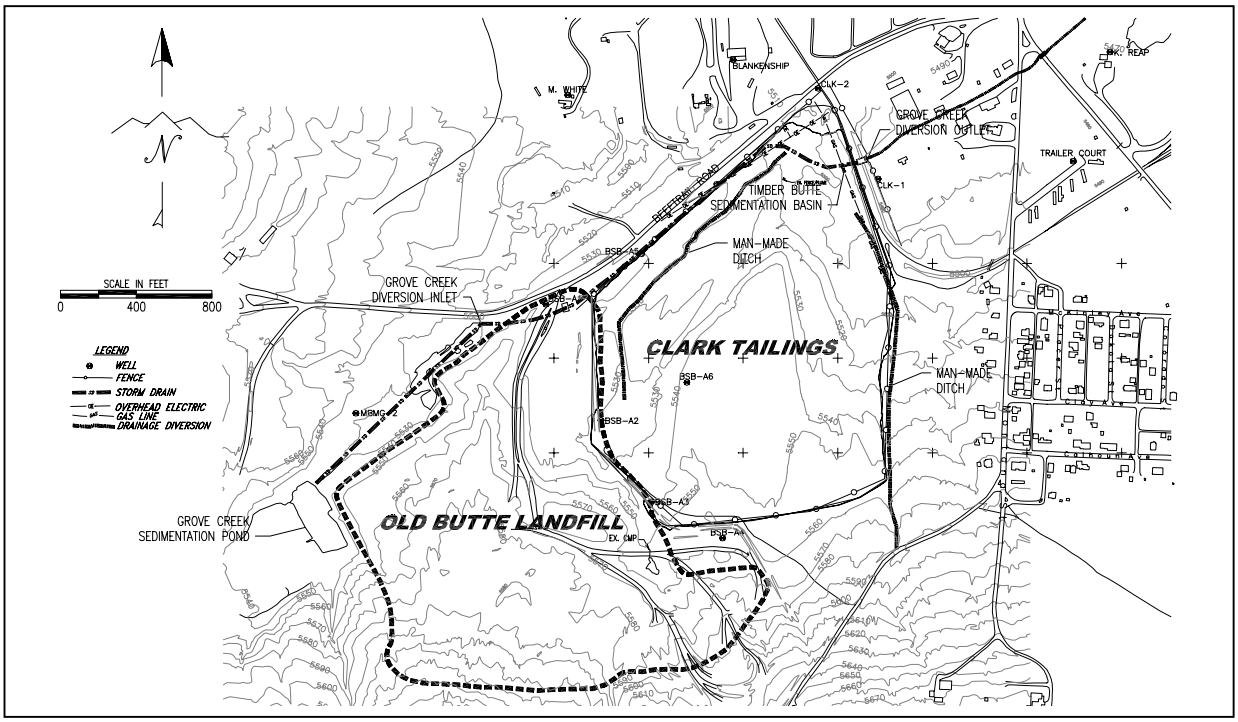

Figure 1. Pre-Remediation Site Map.

Conceptual Plan

The prospect of a protracted remediation schedule at LAO if the Opportunity Ponds disposal site continued to be used initiated a study to find a closer alternative repository site which would be environmentally acceptable for the long-term and would allow a safe haul operation during construction. Though several sites were potentially available near Butte, Clark Tailings provided several advantages, including:

- proximity (approximately one mile away from LAO);
- a likely off-road large truck haul route (for safe haul off public roads using high capacity 35-50 ton trucks);
- shorter schedule (hauling in 35-ton trucks to Clark Tailings would allow the LAO tailings removal and disposal to be completed in two years); and
- the possibility of combining the closure of the partially reclaimed Clark Tailings at the same time as the LAO remediation.

Several advantages also existed in reclaiming the Clark Tailings and Butte's old landfill as a consolidated waste management unit. The landfill had impacted groundwater downgradient of the site, and there were elevated metals in the groundwater downgradient of the Clark Tailings. Closing, monitoring, and managing the groundwater impacts as part of a consolidated waste management unit offered a efficient and effective solution to both of the groundwater issues.

One small disadvantage of hauling to Clark Tailings was having the off-road haul trucks cross public streets frequently (every 2 to 10 minutes during work hours) at two locations over several months. Another concern was the public perception of "new" waste being brought into a part of town which had an adjacent residential neighborhood, commonly called the "Not in My Backyard" issue. To accommodate these concerns, it was agreed that a "brownfield"-type remediation was appropriate. Specifically, the site could be reclaimed and re-developed for functional use as a multi-purpose recreational facility to benefit the community at large. A recreational facility had several advantages – both technical and social. First, waste fills - such as newly placed mine tailings - are typically relatively unconsolidated and material settling over time is inevitable. Allowing commercial or residential buildings would require costly building foundations. Secondly, no future land use which would be incompatible with a closed mine waste repository should be allowed. This would not allow any activity which disturbed the repository cap or vegetation and exposed the tailings underneath.

A dedicated recreational facility with limited building structures, ball fields which would tolerate minor consolidation expected of the newly fill placed tailings (and the newly stressed historical tailings) and ample open space was very compatible with maintaining the repository. Also, a public dedicated development would more likely be better-maintained and be subjected to less unauthorized uses (dirt bikes, etc.), than an inactive and fenced repository. Finally, the recreational facility, or Park, in itself offered the community a new, modern public amenity. The combined repository/closed landfill/park idea was formalized in a Conceptual Plan, which was conditionally approved by the representative Agencies as long as the regulatory requirements for both landfill and mine waste repository closures were met.

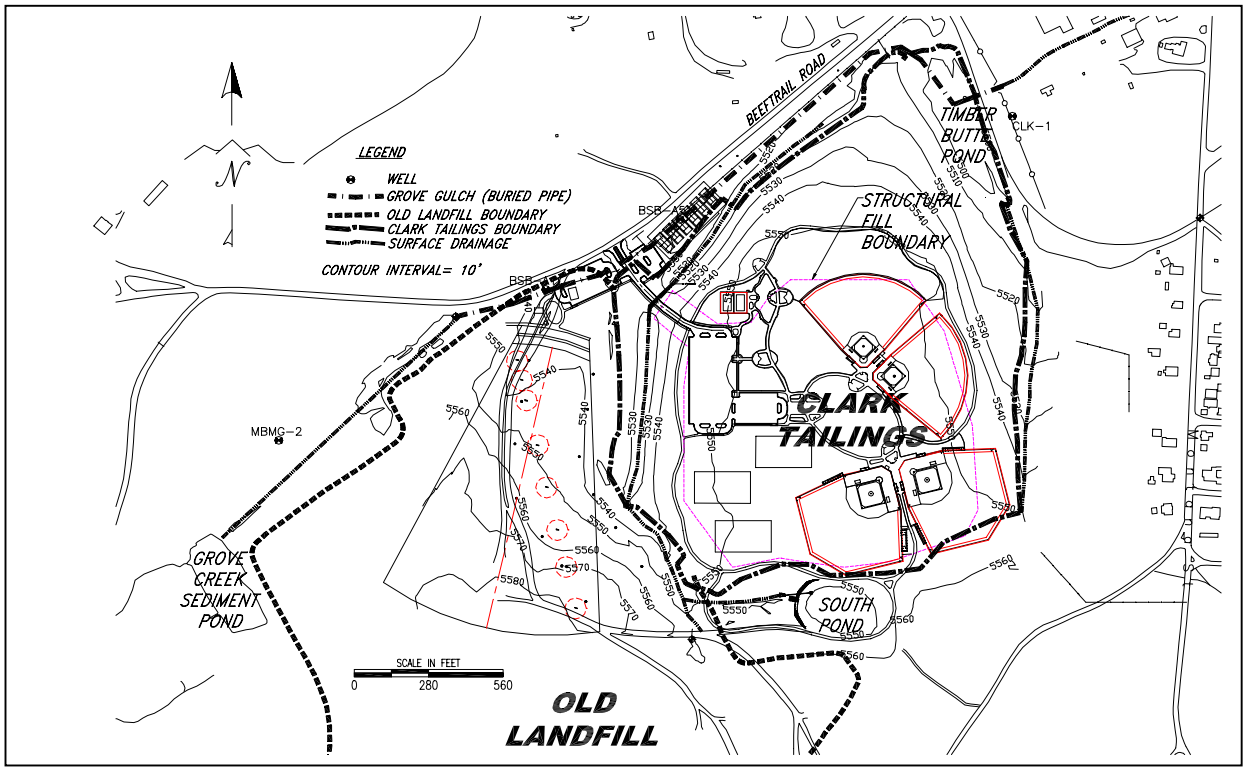

Figure 2. Site map for Post-Remediation with Park Features shown.

Repository and Park Design

With the Conceptual Plan set to build a recreational facility at the Clark Tailings once the Colorado Tailings from LAO were placed there, detailed design of the repository could begin. Designing a tailings repository cap before all the tailings materials are placed and knowing its end land use offered many advantages to having to close an existing tailings pond which was created during a mine processing facility's operation. To integrate the recreation facility's (Park's) design and repository design, both the primary repository design requirements (and objectives) and Park design features had to be understood.

Repository Design Requirements - Primary requirements for the repository were established by the Montana Department of Environmental Quality's Solid Waste Program (MDEQ/SW) who regulates municipal and hazardous waste repositories in Montana. The MDEQ/SW was also the authority overseeing the old Butte landfill's closure, adjacent to the Clark Tailings. Two memoranda of agreement between federal Environmental Protection Agency (EPA) and MDEQ/SW (EPA, 1995 and MDHES, 1995) transferred the Superfund (CERCLA)[2] authority to the MDEQ/SW related to placing LAO's tailings at Clark Tailings and closing the old Clark Tailings as a consolidated waste facility closure with the old Butte Landfill. All solid and hazardous waste regulatory requirements had to be met in this consolidated closure. The presence of groundwater contamination dictated the need for a Corrective Measures Assessment (Pioneer, 1997) for the combined site. The assessment included developing a closure plan to show which requirements must be met and how they were to be achieved.

The primary requirements to ensure the Clark Tailings repository would be constructed and maintained to be permanently protective were established using a risk-based approach. This risk-based approach recognized certain realities of such a mine-waste closure, but with the ultimate goal of reducing significant risk to the human population living in the repository area, as well as the local environment. The realities at Clark Tailings were tailings in an uncontrolled condition with the potential to pose continued risk via direct contract and as a source of surface and ground water running through the site. In fact, the groundwater beneath and immediately downgradient of the site contained highly elevated levels of zinc, on the order of 100 ppm (Pioneer, 1997). Though groundwater was contaminated immediately adjacent to the site, groundwater further downgradient (within ¼ mile) was not. Groundwater beyond the site's perimeter, which was used by the local community, contained zinc levels well below regulatory standards.

The basic plan to eliminate significant risk of further exposure to from metals at the Clark Tailings was to: 1. Consolidate the waste; 2. Isolate the waste; and 3. Monitor the groundwater to show that groundwater downgradient of the site does not get worse and shows steady improvement over time. The specific design features needed to achieve this plan are summarized below:

[2] Comprehensive Environmental Response Compensation Liability Act, 1980

1. Consolidate the Waste – Tailings from LAO and historic Clark Tailings, which had been spread out at the site by wind and water, were to be consolidated in a main repository within the existing "foot-print" of the Clark Tailings Site. This foot-print was approximately 60-acres (24 hectares), and contained an estimated 1,000,000 yd^3 (765,000 m^3) of consolidated tailings. The new repository at Clark Tailings has a 53-acre foot-print.

2. Isolate the Waste – Isolating the waste from exposure pathways was the primary challenge that was to be met. The waste had to be isolated to prevent further exposure to surface water or groundwater flowing near and through the site. This was done through meeting several design objectives:

a. Cap the Waste with Engineered "Prescriptive" Cover – Once consolidated, the approximately 1,850,000 yd^3 (1,414,000 m^3) of waste must be capped with cover intended to isolate the waste from surface exposures via direct contact of the waste, and more importantly, mitigate the potential for further infiltration of water to and through the waste. This was to be achieved with an engineered cover intended to meet the technical requirements determined in the Corrective Measures Assessment and the prescriptive requirements of RCRA and related MDEQ/SW regulations. The cap consists of a multi-layered soil and geosynthetic cover, that limited infiltration, as shown on Figure 3. The layers included from the top down: a. 18 inches of topsoil (fine-textured, locally available soil) to allow vegetated growth; b. geotextile, which is a non-woven, needle-punched fabric intended to keep fine-grained materials from penetrating from the cover soil into the gravel layer; c. 4.5 inch gravel layer to allow any water infiltrating through the topsoil to freely drain laterally off the site, rather than continue infiltrating vertically and to provide a capillary break, increasing the water-holding capacity of the overlying topsoil and preventing the upward migration of acid from the underlying tailings; d. infiltration barrier consisting of 18 inches of native clay/silt materials with a maximum hydraulic conductivity of 1×10^{-7} cm/sec to reduce further infiltration; and e. compacted, low permeability tailings material of depths varying from 2 to 20 feet, which in itself deters significant water infiltration.

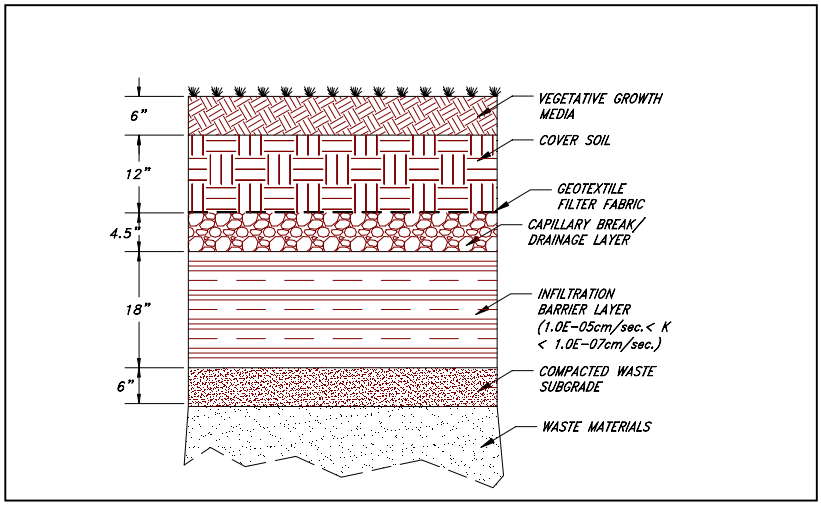

Figure 3. Typical Cap Cross-Section.

b. **Control Surface Water Run-on and Run-off** – By managing the surface water flowing onto the site so that it does not contact the waste or is allowed to collect and infiltrate into the waste, surface and groundwater exposures are largely cut off at the site. Historically, surface water flowing off of Timber Butte above the site was allowed to flow onto the Clark Tailings, washing the tailings via surface erosion and infiltrating to exacerbate poor groundwater quality conditions. Under the closure plan, all surface water running on the site would be routed around the perimeter of the repository via lined open channels. All surface water generated from precipitation falling on the site would be routed to these same channels.

c. **Clean and Line Timber Butte Sediment Pond** – A primary suspected pathway of historic groundwater contamination was an unlined sediment pond which collected all run-off from the Clark Tailings before it entered the surface drainage, Grove Gulch, running adjacent to the site. The unlined pond collected surface water and sediment with elevated metals from the site and likely allowed active infiltration to the downgradient groundwater. The only downgradient well in which groundwater quality standards were exceeded was directly downgradient of this pond. By controlling run-on and run-off of surface water and capping tailings to eliminate water from direct tailings exposure, the water reaching the Timber Butte sediment pond would be of much-improved quality. By cleaning out existing sediment and consolidating it into the new repository, then lining the pond, a significant source of infiltration of poor quality water would be likely eliminated.

d. **Site Grading –** Positive drainage was required for the entire final surface of the repository to promote run-off of precipitation on the site. Also, a maximum of 4:1 (horizontal to vertical) surface grade was allowed to ensure the revegetated surface would not be subjected to significant erosion and final slopes were stable under static and dynamic conditions. As further discussed below under Park Design, the design team was able to work within those grading constraints to develop a functional and aesthetically pleasing Park design.

3. Monitor the Groundwater – The two major engineering actions of consolidating and isolating the wastes are intended to eliminate future pathways of surface and groundwater contamination. To confirm that these actions actually achieved their objectives, a simple yet effective groundwater monitoring program was established for the site. After all surrounding and onsite groundwater was characterized, it was determined that two wells immediately downgradient of the site (CLK-1 and CLK-2) would be monitored. CLK-1 well was the closest well (115 feet east (downgradient) of Timber Butte Pond/Clark Tailings boundary) and showed highly elevated zinc levels (120 mg/L, mean value) (Pioneer, 1999). The CLK-2 well was also very close to the perimeter of the Clark Tailings, but was not immediately downgradient of the Timber Butte Pond. It showed much less zinc impacts (.050 mg/L, mean value) (Pioneer, 1999). By monitoring these two wells on a semi-annual basis, it is expected that a trend of improvement will be established, given the engineered improvements to reduce metals flux to the groundwater. This trend is expected to be realized over a time period of 15 to 50 years, given the hydrogeologic setting that dictates groundwater velocities and flow. These time frames

to allow improvement are acceptable, since the groundwater under or immediately adjacent to the site would not be available for use and all groundwater data further downgradient showed no exceedences of groundwater quality standards, as mentioned above.

These primary design features were laid out in a detailed repository design and constructed as the haul and disposal of LAO tailings at the Clark Tailings was completed between 1997 and 1998.

Other Repository Design Elements

In the completion of the repository at Clark Tailings several unique or site-specific variations on the primary design were used which both met the design's requirements and offset some of the additional costs of constructing the repository to allow a Park to be built on it.

Infiltration Barrier Material - The specification for the infiltration barrier was meeting or exceeding a $1x10^{-7}$ cm/sec permeability requirement. Normally, this specification is met using a natural true clay material or a geomanufactured geosynthetic product. With Clark Tailing's new repository size (49 acres) and barrier layer depth (18 inches), a volume of approximately 120,000 yd^3 (74 ac-ft) of natural clay or geosynthetic clay (GCL) liner material would have been required. Given the geology around Butte, little or no large sources of true clay exist, but there was a silt-clay material that had the potential as a low-permeability material. A procedure to test the locally-available silt-clay was approved by MDEQ/SW, so that the infiltration barrier specification could be met using the available silt-clay material. The ability to use the locally-available material, rather than importing natural clay or purchasing a geosynthetic liner product, saved the project approximately $500,000.

Parking Lot as Barrier – Knowing the Park layout as the repository was being designed offered several advantages. An important example of this was allowing a variation to the infiltration barrier layer of the cap in the 2.3 acre area where the Park's main parking lot was to be located. The parking area, with its asphalt cover, would be impervious to infiltration; therefore, the normal infiltration layer was not required under the parking lot area.

Park Design

Once it was decided a park would be the permanent future use of the new Clark Tailings repository, a detailed design for the Park which was fully integrated with the repository design was required. Being able to design the Park prior to the completion of the repository allowed for more effective integration of repository's and Park's designs. Though there are numerous examples of this, several of the more important integration elements are discussed here.

Park Grading, Landform – One of the most important issues in integrating the Park's design with the repository was the placement, shaping and grading of the tailings within the repository to accommodate the needs of the Park. The primary landform need of the

Park was a large, relatively flat surface where the ballfields, parking lot, and support facilities would be located. In its existing condition, the Clark Tailings had only a few contiguous flat acres, and being on the side of the Timber Butte hill this offered an interesting challenge. To achieve a relatively flat area for the primary Park area of approximately 25 acres, the repository's design had to include a fairly precise fill and grading plan for the tailings imported from LAO. The repository "fill plan" generally provided that a 25 acre bench would be created with fill depths (all requiring 90% compaction to minimize differential setting) of up to 20 feet at the northern edge of the site. In addition, the tailings had to be placed in some locations to be a suitable foundation for buildings and other structures. These structural fill areas were identified in advance and only tailings with the material strength to hold structures were placed there.

A second design objective related to the grading of the repository was creating a landform which was more natural-looking than the conventional engineered repository. Often repositories, as with many engineered earthworks, have square or rigid planforms, 3:1 side slopes and a flat top. Though the Clark Tailings repository needed to be relatively flat for the Park's design, the side slopes which generally faced northeast toward the town were designed to be more natural-looking and blend into the surrounding landscape. A basic maximum slope of 4:1, instead of 3:1, was chosen. Then actual slopes on the northeast side (the most visible side) were varied from 4:1 to 10:1, interjecting some subtle ridges and depressions extending from top to bottom of the slopes. The subtle ridges and depressions offer a more natural foothill-looking landform as well as ultimately allowing vegetation to mature with more diversity given a slight variation of water availability from the ridges to the depressions.

Park Structures and Cap Penetrations – The Park's design called for several buildings, shelters, five ballfields with associated fences and backstops, and other minor structures which all required foundations. These foundations, as well as the necessary underground utilities, required construction at depths below the ground level within the repository's cap. For all Park construction requiring cap penetration, a design was required which provided a retrofit around the penetration with an equivalently protective cap. Figure 4 shows one such design for a fence post.

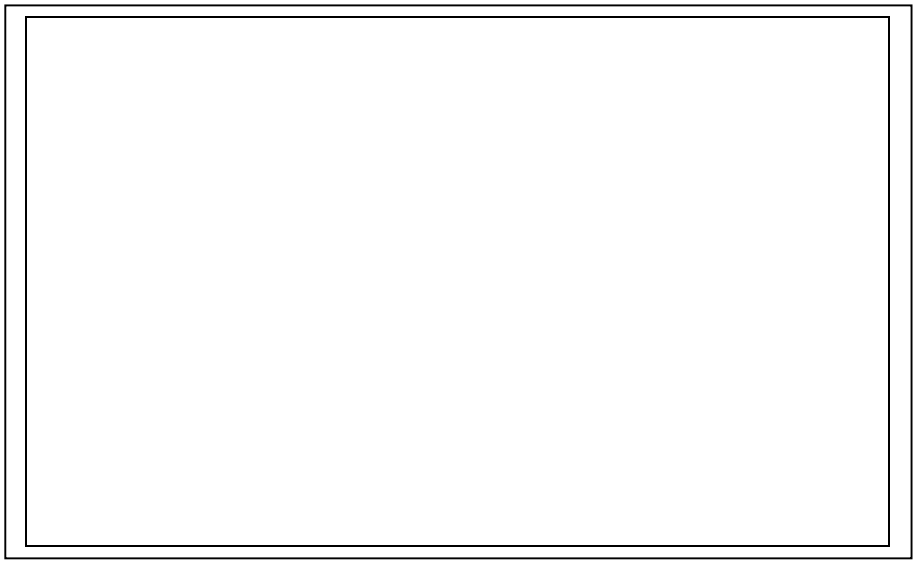

Figure 4. Typical Cap Penetration (example shown for a fence post).

Use of Adjacent Landfill in Park Design – Though the primary Park elements were designed to be on the new Clark Tailings repository, Butte's closed municipal landfill adjacent to the site was integrated into the Park's design. Given its unconsolidated and unlevel fill, its suitability was limited. Yet, it was generally acceptable as a landing area for a golf driving range. With appropriate grading and infrastructure design of tee areas where the public would access, a golf driving range was designed as a compatible future option to the Park.

Summary

By planning and designing the Park in tandem with the repository, they could be integrated and coordinated much more effectively and efficiently. The repository was constructed as designed between 1997 and 1998. The Park will be constructed between 1999 and 2000. The Park will be available for community use by spring of 2001. Groundwater monitoring to track the groundwater's quality at the downgradient edge of the site will continue to ensure the repository remains protective of the aquifer downgradient of the site.

This project provides an example of how industry, a community, and regulatory agencies can coordinate well to successfully meet an environmental challenge. Though the circumstances described herein precipitating the creation of a municipal Park from an old mine tailings area was somewhat unique, many of the technical designs and regulatory decisions leading to the successful redevelopment of Clark Tailings mining site are applicable elsewhere.

REFERENCES

EPA, 1995. Letter from John Wardell, EPA to Jack Lynch, Butte-Silver Bow County (3/1/95).

MDHES, 1995. Letter from Bob Robinson, MDHES, to Jack Lynch, Butte-Silver Bow County (3/23/95).

Pioneer, 1997. Butte-Silver Bow Landfill/Clark Tailings Corrective Measures Assessment (January, 1997, final addendum, February, 1997). Prepared by Pioneer Technical Services, Butte, MT.

Pioneer, 1999. August 23, 1999 letter from Shawn Bisch to Pat Crowley regarding semi-annual groundwater monitoring results. Data on file at Montana Department of Environmental Quality.

On-Site Repository Construction and Rehabilitation of the Silver Crescent Abandoned Mine Site, Shoshone County, Idaho

J. K. Johnson

The Silver Crescent abandoned mine and mill site is located in Idaho's Silver Valley near Kellogg. The mine produced lead, zinc, and silver ore which was initially processed by gravity separation in a jig mill, while a subsequent ball mill at the site also served as a custom processor for ore from other sources. Approximately 92,000 cubic meters of tailings and waste rock were deposited in the floodplain of the east fork of Moon Creek which is a tributary to the south fork of the Coeur d'Alene River. The actively eroding tailings impoundments and waste rock dumps have been a source of heavy metal contamination in the surface and ground water at the site. The U.S. Forest Service began a non-time crtical removal action under CERCLA authority at the site in 1998. Goals of the removal action include reduction of dissolved and particulate metal loading into the east fork of Moon Creek by incorporating the tailings and waste rock dumps into an on-site capped repository. Soft foundation engineering of the repository includes the use of a geoweb mattress to provide stability and compensate for settling of the tailings. The Silver Crescent project is currently active and should be completed in early 2000. Methods and results will be discussed as part of the symposium presentation.

Key Words: cadmium, aluminum, revegetation, reclamation, adit closure, portal closure, shaft closure

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2000 Billings Land Reclamation Symposium

ALTERNATIVES ANALYSIS FOR MINE WASTE RELOCATION REPOSITORIES

B. Grant, M. Cormier, W.H. Bucher[1]

ABSTRACT

The Streamside Tailings Operable Unit, Silver Bow Creek/Butte Area, Montana NPL site requires disposal of mine and milling waste materials in mine waste relocation repositories. The Record of Decision (ROD) for the site requires that the mine wastes be amended with lime and revegetated, and that the repositories be sited in a protective location, potentially near Silver Bow Creek. If the near-stream setting for repositories are not sufficiently protective of human health and the environment, then the ROD provides for locating the repositories off-site where conditions would be more protective. An analysis was completed for the purpose of comparing the near-stream and off-stream settings, as well as to assess what types of design elements could be incorporated into the repository to raise the level of protectiveness to the environment. The completed analysis explored liner system alternatives, leachate generation rates, synthetic leachate characteristics, soil attenuation characteristics, estimated contaminant concentrations (particularly arsenic) in groundwater, and the cost associated with each of the alternatives.

[1] Maxim Technologies, Inc., Helena, Montana

INTRODUCTION

The Streamside Tailings Operable Unit (SSTOU) is one of several Operable Units that make up the Silver Bow Creek/Butte Area NPL Site. This NPL Site encompasses the historic mining and milling operations within the vicinity of the town of Butte, Montana as well as the mining and milling wastes present in Silver Bow Creek from its headwaters to the terminus of the site where Silver Bow Creek leaves the Warm Springs Ponds system. The SSTOU is defined as Silver Bow Creek, its present stream channel, current and historic floodplain, and railroad beds and embankments adjacent to the floodplain, and extends from the edge of Butte to the Warm Springs Ponds, a distance of about 40 km. Numerous studies have been completed to date as part of remedial investigation activities. Among others, soil sampling has documented the extent and magnitude of waste materials and levels of metals and arsenic in the waste and revegetation studies have been conducted to evaluate lime amendment methods and plant establishment techniques.

The remedial action for the SSTOU consists of removing mine and milling waste from the floodplain and areas adjacent to the stream. Mine waste relocation repositories (MWRRs) are a central component of the remedial action. The Record of Decision (MDEQ, 1995) for the site requires that the mine wastes be amended with lime and revegetated and that the MWRRs be sited in a protective location, potentially near Silver Bow Creek.

The evaluation which this paper presents was completed to study whether placing the MWRRs near Silver Bow Creek was a viable remedial action, or if locating the MWRRs further away from the stream in a more upland setting would provide a higher level of protectiveness that the near- stream setting could not afford. Determining the exact sites and design requirements for MWRRs was not a specific goal for the study. The evaluation was completed for Subarea 1 of the SSTOU which includes the upper reaches of the stream (Figure 1) in which six proposed, near-stream MWRRs were located. Total waste to be removed within the subarea is estimated at 380,000 m^3.

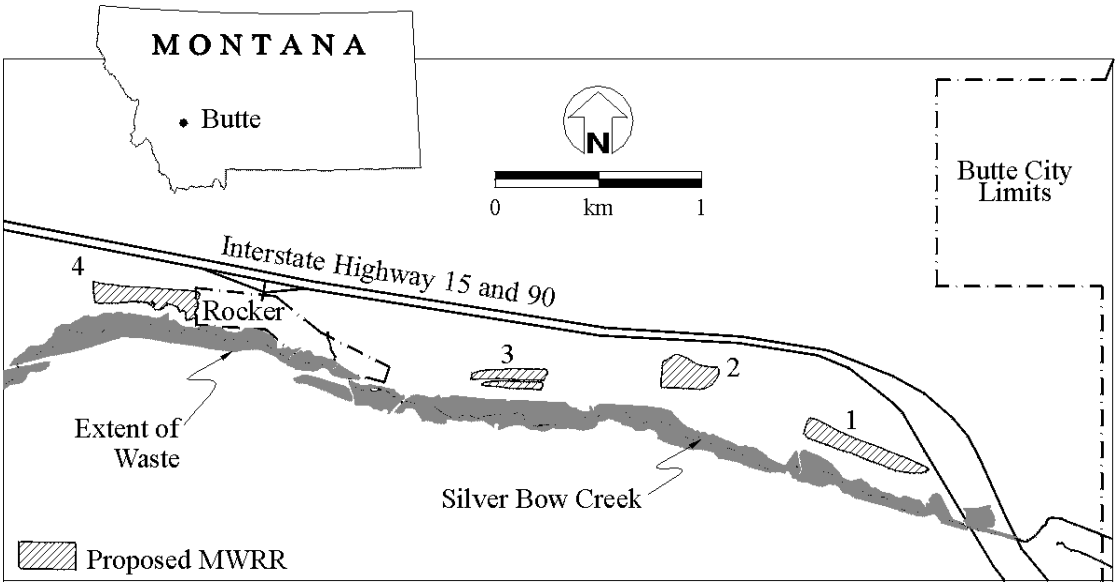

Figure 1. SSTOU, Subarea 1, Upper Reach

The waste is characterized as a silty sand, with elevated levels of copper, lead, zinc, cadmium and arsenic, which has been fluvially deposited within the approximate 100-year floodplain of the creek.

Design criteria used to evaluate near-stream and off-site settings included geology, surface water hydrology, groundwater hydrology, community impacts and land use. The principal criterion was groundwater quality. Discharges to groundwater may not exceed Montana DEQ Circular WQB-7 standards for groundwater (Table 1). The arsenic concentration goal is quite low in comparison to the U.S. EPA maximum contaminant level for drinking water supplies of 50 µg/l.

Table 1. Groundwater Standards

Constituent	Concentration (µg/l)
Copper	1000
Lead	15
Zinc	5000
Cadmium	5
Arsenic	18
Mercury	0.14

METHODS

Essential components of the evaluation were determining leachate quality from the tailings waste and adsorption characteristics for soil which will underlie the repositories. Methods used for assisting in determining these characteristics are described in this section.

To approximate leachate quality, a synthetic leachate was derived. Waste material used to derive the leachate was acquired by obtaining a composite sample prepared from selected soil depth intervals from 9 test pits. Test pit locations and sample depths were determined using an existing database for 435 test pits. Preparation of the composite was patterned toward the average soil grain size (silty sand) and metal and arsenic concentrations that would approximate the third quartile levels of all samples collected from the 435 test pits. The composite sample was analyzed for saturated paste pH, arsenic, metals and several other analyses for determining the lime amendment rate.

Synthetic leachate solutions were prepared for amended waste and for unamended waste. Preparation of the synthetic leachate for unamended tailings was performed following EPA Method 1312 using a 60/40 mixture of nitric and sulfuric acid at an unbuffered pH level of 4.2. Preparation of the synthetic leachate for the lime amended waste was performed using reagent grade deionized water since the lime amended tailings are expected to produce a buffered leachate. Each synthetic leachate was prepared in triplicate batches with the extract fluid from each filtered and analyzed for pH, arsenic and metals.

Sorption testing was completed on subsurface soil materials from Settings 1 and 2 (discussed below). The Setting 1 sample was a composite sample collected from a boring located at proposed MWRR-2. The Setting 2 sample was collected from beneath the surface of an excavation cut immediately north of Rocker. Developed soil horizons were excluded from each soil sample. The sorption testing consisted of introducing 800 milliliters of synthetic amended tailings leachate at dilutions of 0, 50, 75 and 90 percent to 40 grams of soil. The tests were conducted in a manner similar to the leaching test by placing the solution and soil in a rotating drum for 18 hours. The extract fluid from each test was filtered (0.45

micron filter media) and the filtrate analyzed for total arsenic and copper.

DEVELOPMENT OF ALTERNATIVES

The process used to develop alternative repository designs is similar to the feasibility study process outlined in EPA guidance documents for evaluating National Priority List sites (USEPA, 1988). The first step of the process was to complete an initial screening of potential design components. These design components provided the building blocks for several different design options which were then applied to a selected set of environmental conditions. The initial screening of design components brought forward only the most likely components that could potentially meet or exceed repository design and siting criteria, either separately or in combination with other components.

Repository Design Components

The general elements of a waste repository include a cover system, the waste materials, and a leachate collection system. Design components were developed for each of these three elements during the initial screening process, with several components being selected for use above and below the mine wastes. The design components selected for incorporation into design options are described below.

Cover System

The function of a cover system is to protect the waste material enclosed within the repository from climatic effects of wind and precipitation. The major concerns associated with these effects are infiltration and erosion. The design components for a cover system that passed the initial screening are the following: 1) directly amending waste materials with lime and revegetating; 2) placing a cover soil over the waste to promote evapotranspiration; and, 3) constructing a low permeable cover using geosynthetic materials. In regards to the first component, revegetation studies have shown that the amended tailings material can be revegetated (RRU and Schaefer & Assoc., 1993). For the third component, a cover design using a geosynthetic clay liner (GCL) with an overlying drainage layer was selected.

Waste Material

For design components, only treatment or non-treatment of waste materials were considered for inclusion in the design options. Treatment would consist of incorporating a lime amendment with waste materials to reduce the mobility of metals

Leachate Collection System

Low permeability liner systems at the base of a repository are often used to intercept and collect leachate percolating down through the waste material. The leachate collection system design component would consist of a drainage layer overlying a low permeable base liner constructed with HDPE. The leachate collected would be disposed of by evaporation, incineration, or transported to an approved waste management facility.

Repository Design Options

Several designs options were constructed using the design components described above (Figure 2). The design options include the repository design as described in the ROD and presented in an Intermediate Design Report (ARCO, 1997) along with four alternate designs. The following discussion explains the components of each design option.

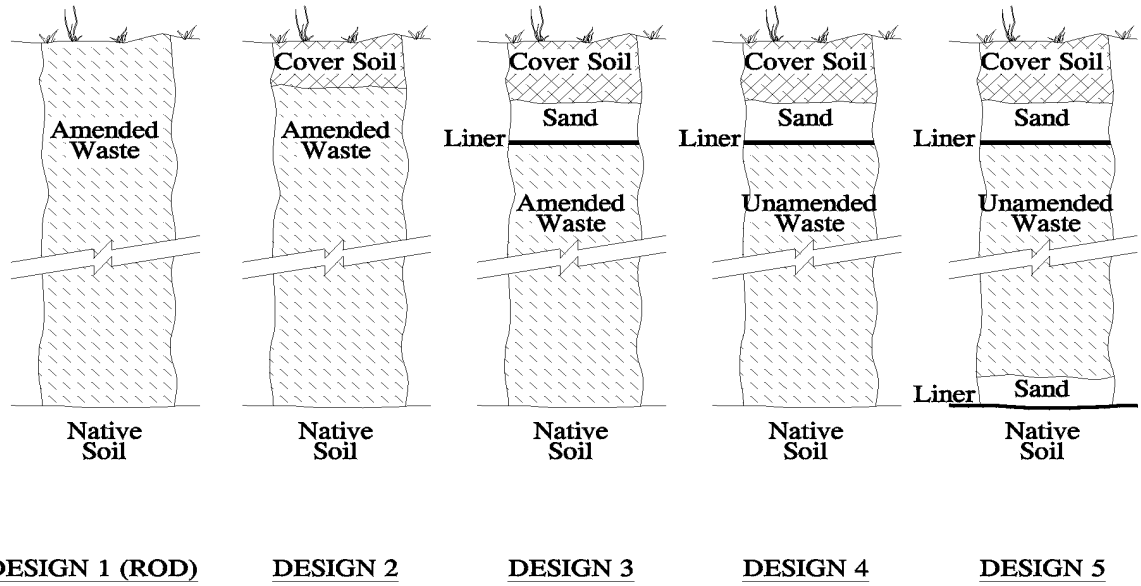

Figure 2. Repository Design Options

- Design 1 - Revegetated Amended Waste Material (ROD Design) - Waste material would be amended with lime and placed in the repository. Amended waste material at the surface of the repository would be revegetated to reduce infiltration and erosion.

- Design 2 - Improved Cover, Amended Waste Material - A soil cap consisting of at least 18 inches of borrow soil would be placed over the amended tailings. The use of 18 inches of soil cover was selected for this design to provide adequate rooting depth and to improve soil moisture storage capacity in the cap.

- Design 3 - Improved Cover with Low Permeable Liner, Amended Waste Material - This design is similar to Design 2 but incorporates a low permeable liner in the cover system to reduce infiltration into the repository.

- Design 4 - Improved Cover with Low Permeable Liner, Unamended Waste Material - This design is similar to Design 3 but evaluates placing unamended tailings in the repository. In this design, higher metal concentrations may be produced in leachate since the waste is unamended.

- Design 5 - Improved Cover with Low Permeable Liner, Unamended Waste Material, Leachate Collection System - This design is similar to Design 4 but includes a leachate collection system.

Site Environmental Settings

In order to evaluate the alternative MWRR designs, two potential site settings were assumed to be the most likely for siting the repositories. The differences between the two site settings is primarily subsurface soil texture, depth to ground water, and distance from the 100-year floodplain. The following describes the general environmental conditions expected to be encountered at the two sites.

- Setting 1 - Near-Stream Repository Site. Near-stream repository sites would be located immediately adjacent to the 100-year floodplain as propsoed in the ROD. A typical setting for these sites is on moderate slopes adjacent to Silver Bow Creek. Hydrogeologic characteristics are:

  - Soil Type — medium sand
  - Saturated Permeability — 10^{-2} cm/sec
  - Groundwater Gradient — 0.01 m/m
  - Depth to Groundwater — 3 m

- Setting 2 - Off-stream Repository Site. These sites are located in an upland setting underlain by Tertiary sediments and located well away from the 100-year floodplain. Tertiary sediments north of Silver Bow Creek typically exhibit a higher content of silt and clay than near-stream sites. Hydrogeologic characteristics for this setting are:

  - Soil Type — sandy silt
  - Saturated Permeability — 10^{-4} cm/sec
  - Groundwater Gradient — 0.01 m/m
  - Depth to Groundwater — 12 m

Number of Repository Sites

The ROD identified six near-stream locations for MWRRs within Subarea 1. Figure 1 shows the location of four of the MWRRs. Designing numerous repositories in a near-stream location minimizes haul distances and reduces cost but has disadvantages as well, such as greater area to volume ratios, requiring more land to be overlaid with tailings and greater disturbance area for construction. The numerous repositories will require an increase in the amount of vegetation needed for erosion protection and, if the design includes a low permeable cover, greater construction material quantities and associated costs. In addition, higher monitoring and maintenance costs may result from numerous repositories with lesser volumes of tailings per repository.

In the near-stream setting (Setting 1), construction of three repositories for designs other than Design 1 was selected to provide a balance between cost of construction, hauling tailings a greater distance, and maintenance of the repositories. In the off-stream setting (Setting 2), two repositories were selected by extension of the reasons given for Setting 1.

Repository Design Alternatives

Repository design alternatives were developed by combining the various design options with the two environmental settings (Table 2). Design 4 was not considered to comply with the ROD if placed in Setting 1 without a base liner. Design 5 was not

considered for Setting 2 because Setting 2 is considered to provide an added depth to groundwater and offered native materials that could provide attenuation of metals and arsenic in leachate.

Table 2. Repository Design Alternatives

Alternative No.	Design/Setting	No. of Sites	Alternative No.	Design/Setting	No. of Sites
1	Design 1/Setting 1	6	5	Design 2/Setting 2	2
2	Design 2/Setting 1	3	6	Design 3/Setting 2	2
3	Design 3/ Setting 1	3	7	Design 4/Setting 2	2
4	Design 1/Setting 2	2	8	Design 5/Setting 1	2

GROUNDWATER PROTECTION ANALYSIS

Physical and chemical characteristics associated with each of the alternatives affect metal and arsenic concentrations in groundwater downgradient of the MWRR. The repository designs are analyzed with respect to their effectiveness in protecting groundwater quality. To perform the analysis, information on leachate characteristics was obtained. The various repository designs are then evaluated with respect to contaminant loading to the subsurface and attenuation of metal and arsenic concentrations by soil sorption and dilution/dispersion in groundwater.

Leachate Characteristics

Amending tailings material placed in the MWRR would result in minimizing the potential for acid conditions to develop. Most mobile metal cations in the tailings (Cu, Pb, Zn, Cd) would form relatively stable precipitates as a result of the lime addition. At high pH levels, similar to which may be found in the amended tailings, arsenic may exhibit an increase in solubility (Dragun, 1988).

Table 3 presents metal and arsenic concentrations in the composite waste sample, which was used for preparing the synthetic leachates, along with statistical data for these elements collected across the site (ARCO, 1995a). The pH of a saturated paste made from the waste was 4.5. Table 4 compares metal concentrations for fluids from amended waste obtained from recent SSTOU studies and from the synthetic leachate study. Arsenic concentrations in leachate are approximately one order of magnitude greater than the WQB-7 standard; cadmium is only slightly elevated above the standard.

Table 3. Metal Concentrations in Composite Waste Sample (mg/kg)

Description	Copper	Lead	Zinc	Cadmium	Arsenic
Composite tailing sample	1717	2243	3337	22	1059
Subarea 1, mean values	739	540	2400	8	278
Subarea 1, third quartile	2458	1048	3560	17	491

Table 4. Metal Concentrations in Leachate from Amended Tailings Material (µg/l)

Sample Location	Copper	Lead	Zinc	Cadmium	Arsenic
Lysimeter 07D14; 40 and 90 cm depth, collected 1991 and 1992; mean concentrations[1]	121	2.5	1530	9.6	208
Lysimeter SPW3-S, depth 45 cm, mean concentrations [2]	182	7	717	9	175
Synthetic Leachate, Amended Tailings	130	<150	<30	<15	210

WQB-7 Standards	1000	15	5000	5	18

Data Source: [1] RRU and Schaefer, 1993; [2] Schaefer, 1997

Table 5 presents pore water metal concentrations from lysimeters in unamended tailings and from synthetic leachate. The unamended tailings exhibit higher concentrations of several elements with exceedances of WQB-7 standards possible for copper, lead, zinc, cadmium and arsenic. With the exception of arsenic, amendment of the tailings with lime results in a noticeable improvement in leachate quality.

Table 5. Metal Concentrations for Leachate Solution from Unamended Tailings (µg/l)

Sample Location	Copper	Lead	Zinc	Cadmium	Arsenic
Highest measured concentrations in lysimeters installed within Clark Fork River untreated test areas, collected 1992 [1]	1050	nm	222	nm	23
Lysimeter SPW3-D, depth 45 cm, mean concentrations [1]	3076	7	15,225	60	135
Synthetic Leachate, Unamended Tailings	35,500	3820	28,300	39	350
WQB-7 Standard	1000	15	5000	5	18

nm = not measured
data source: [1] Schaefer, 1997

Performance Evaluation of Alternative Designs

An evaluation of the alternative designs was completed using the generalized hydrogeologic characteristics for the two types of settings to gain an understanding of what effects leachate metal and arsenic concentrations may have on groundwater quality. This evaluation was performed for the two types of hydrogeologic settings defined.

Leachate Production Estimates

Each of the MWRR designs was evaluated using the Hydrologic Evaluation of Landfill Performance (HELP) model, version 3.05 (Schroeder, et. al., 1994) to predict the amount of leachate which would percolate through the base of each design. The results are summarized in Table 6. The model was run using 100 years of local precipitation data.

Table 6. Leachate Production Estimates

Design No.	Leachate (cm/yr))
1	5.5
2	1.6
3	0.08
4	0.08
5	0.02

Attenuation of Metals by Sorption

Metal cations and arsenic anions in leachate flowing through the subsurface will be attenuated by sorption which includes the processes of adsorption, fixation and precipitation. Sorption testing was performed using the amended tailings synthetic leachate for soil samples collected from Settings 1 and 2. Fluid from the testing was analyzed for copper and arsenic because only these two elements were present at significant concentrations in the synthetic leachate. Sorption testing was not completed using unamended tailings synthetic leachate.

Figure 3 presents the isotherms generated from the sorption testing using Cs (sorbed mass) versus Ce (equilibrium concentration) graphs. The arsenic isotherms indicates that the soil sorption affinity decreases at lower equilibrium concentrations and that the Setting 1 soil more readily adsorbs arsenic than Setting 2 soil. Arsenic sorption did not appear to occur at concentrations below about 0.024 mg/l for the Setting 1 sample and 0.018 mg/l for the Setting 2 sample. The lower limit of arsenic sorption in the test are similar to arsenic concentrations observed in a nearby background well (well C-15) which exhibits an arsenic concentration near 11 µg/l (ARCO, 1995b). The copper isotherms indicate that the metal is adsorbed to the soil. Several of the copper equilibrium concentrations were below laboratory detection.

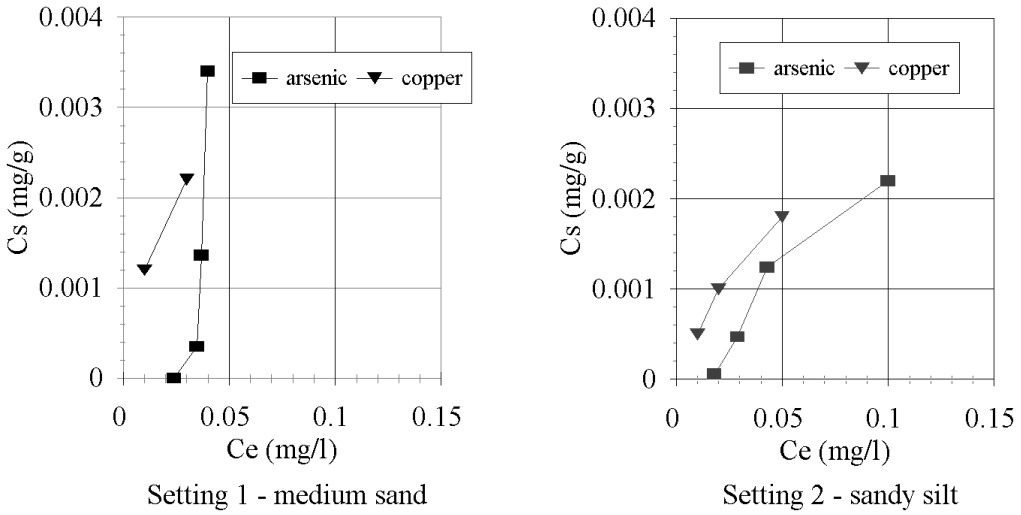

Figure 3. Sorption Isotherms

Dispersion/Dilution

Leachate which enters the groundwater system beneath the repository will be dispersed and diluted. Leachate and attenuation test data indicate that repositories constructed with amended tailings will show relatively low concentrations of arsenic in the leachate which reaches groundwater. Copper, lead, zinc, and cadmium will not likely be present due to amendment of tailings with lime and/or sorption of the metals with soil. Table 7 presents estimates for arsenic concentrations in groundwater for Alternatives 1 through 6 (amended waste). To prepare these estimates we assumed that the repository is 4 ha in area with a length to width aspect of 1:1 and that leachate is mixed within the uppermost 3 m of the aquifer. Estimates of arsenic in leachate reaching the groundwater were obtained from the attenuation testing of synthetic leachate (24 and 18 µg/L), and to demonstrate the sensitivity of the mixing calculation, estimates were also prepared under the assumption that attenuation of arsenic is relatively ineffective in the subsurface and the leachate contains 100 µg/L or 200 µg/L of arsenic. This could be the case if very little attenuating material is located under the repository or if the arsenic attenuation capacity of the subsoil is exhausted over time. A background arsenic concentration in groundwater was selected using data for an

upgradient well.

Table 7. Estimated Arsenic Concentration in Groundwater After Dilution/Dispersion of Leachate (µg/l)

Alternative No.	Setting 1 As=24 µg/l	Setting 2 As=18 µg/l	Setting 1 As=100 µg/l	Setting 2 As=100 µg/l	Setting 1 As=200 µg/l	Setting 2 As=200 µg/l
1	13	--	21	--	31	--
2	12	--	14	--	17	--
3	11	--	12	--	12	--
4	--	17	--	93	--	185
5	--	16	--	79	--	156
6	--	12	--	25	--	40
7	na					
8	na					

WQB-7 Standard = 18µg/l
Background Groundwater = 11.4 µg/l

-- not applicable, the alternative does not apply to this setting
na = not analyzed (unamended tailings)

Results shown in Table 7 indicate that arsenic may not exceed WQB-7 groundwater standard provided certain design components are added to the repository. For Setting 1 and using the attenuation test results, incorporation of a low permeable liner into the repository cover system does not appreciably affect arsenic concentrations as indicated by the 2 µg/l difference between Alternative No. 1 and Alternative No. 3. As compared to Setting 1, the Setting 2 alternatives result in higher arsenic concentrations in large part because of slower groundwater velocities and therefore less dilution of the leachate. For Setting 2 (Alternatives 4, 5, 6) inclusion of a liner in the cover shows a more distinct advantage in lowering arsenic concentrations in groundwater.

It is interesting to note the sensitivity of this calculation to the leachate quality. If we assume that leachate has 100 µg/L or 200 µg/l of arsenic, only Alternatives 2 and 3 provide sufficient protection to meet the Circular WQB-7 standard after mixing. This analysis demonstrates the value of the improved cover designs within Setting 1 if attenuation capacity can not be relied upon to reduce arsenic concentrations.

SUMMARY

The most significant points resulting from the evaluation include the following.

- Arsenic appears to be the only constituent in the amended tailings case which has the potential to exceed regulatory levels in groundwater downgradient of the repositories.

- Alternatives 1, 2 and 3 (Setting 1) appear to provide adequate protection to groundwater resources as compared to Alternatives 4, 5, 6 and 7 which are located off-site (Setting 2).

- Alternatives 2 and 3, which provide an improved repository cover over Alternative 1, do not substantially reduce the arsenic concentration in groundwater because of elevated background arsenic concentration in groundwater. However, cover improvements contained in Alternatives 2 and 3 do reduce the contaminant load reaching the groundwater system and provide greater assurance that groundwater quality standards will not be exceeded.

- Alternative 1 includes several repositories some of which are smaller in size than the size evaluated by this study (4 ha). The smaller repositories are less prone to result in arsenic exceedances in groundwater due to a smaller area over which leachate is entering groundwater. One of the main disadvantages of this alternative is the smaller repositories are less efficient in storing tailings so that more land area is disturbed. The overall area for Alternative 1 repositories is approximately 24 to 28 ha and the overall area for Alternatives 2 through 8 repositories is approximately 6 to 8 ha.

The calculations of leachate production, leachate loading, attenuation, and groundwater mixing completed in the study are subject to a number of limitations due to limited data on which the analysis is based and the inherent uncertainty in geochemical and hydrogeological parameters used in the calculations. Because of limitations in data and uncertainties in calculations, the quantitative results of the evaluation were used more to gauge the relative protectiveness of the alternatives rather than their absolute capabilities.

REFERENCES

Atlantic Richfield Company (ARCO) 1997. Silver Bow Creek/Butte Area NPL Site (NPL). Streamside Tailing Operable Unit. Intermediate Design Report. July 1997.

_____1995a. Silver Bow Creek/Butte Area National Priorities List Site (NPL). Streamside Tailing Operable Unit. Draft Remedial Investigation Report. January 1995.

_____1995b. Silver Bow Creek/Butte Area NPL Site. Streamside Tailings Operable Unit. Draft Feasibility Study Report, Revision 2.

Dragun, J., 1988. *The Soil Chemistry of Hazardous Materials*. Silver Spring, Maryland: Hazardous Materials Control Resources Institute

Montana Department of Environmental Quality (MDEQ), 1995. Record of Decision, Streamside Tailings Operable Unit of the Silver Bow Creek/Butte Area National Priorities List Site.

Reclamation Research Unit of Montana State University (RRU) and Schaefer & Associates, 1993. Streambank Tailings and Revegetation Studies, STARS Phase III Final Report. Montana Department of Health and Environmental Sciences. Helena Montana.

Schaefer & Associates, 1997. Clark Fork River Governor's Demonstration Monitoring (1993 1996). Final Report.

Schroeder, P.R., Dozier, T.S., Zappi, P.A., McEnroe, B.M., Sjostrom, J.W., & Peyton, R.L.,

1994 *The Hydrologic Evaluation of Landfill Performance (HELP) Model: Engineering Documentation for Version 3*, EPA/600/9-94, U.S. Environmental Protection Agency Risk Reduction Engineering Laboratory, Cincinnati, OH.

USEPA 1988. *Draft Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA*. Office of Emergency and Remedial Response and Office of Solid Waste and Emergency Response.

2000 Billings Land Reclamation Symposium

MICROBIAL INOCULATION POTENTIAL OF ORGANIC MATTER AMENDMENTS FOR MINE TAILINGS RECLAMATION

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ABSTRACT

Microorganisms are important for successful reclamation because of their role in nutrient cycling, plant establishment, geochemical transformations, and soil formation. Microbial communities associated with mine disturbance often show decreased density and diversity, relative to undisturbed sites. While the chemical and structural contributions of organic matter amendments to mine tailing reclamation efforts are often considered, little is known about the microbial communities associated with organic amendments. This research examines microbial communities associated with common organic matter amendments, as compared to baseline mine tailings substrates. The microbial communities were characterized with heterotrophic bacteria plate counts, actinomycete plate counts, fungal plate counts, and carbon substrate utilization profiles. Samples included 4 reference mine waste substrates and 4 organic matter types including sawdust, manure, soil, and landfill compost (4 replicates of each). The compost consistently showed the highest plate count numbers and carbon substrate metabolic diversity, followed by the soil sample. The manure had relatively high heterotrophic bacteria counts, but low metabolic diversity. The sawdust had lower plate count numbers than the other organic matter samples, but comparable metabolic diversity. Future research will examine changes in organic matter microbial communities after incubation with mine tailings. Understanding the microbial inoculation potential of organic matter amendments will lead to better reclamation strategies and more complete remediation of mine waste disturbed systems.

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INTRODUCTION

Soil microorganisms are crucial for proper soil functioning and development of plant communities (Bolton et al. 1993). A diverse microbial community can affect plant growth through improved nutrient uptake, transformation of soil properties, nitrogen fixation, pathogen protection, and production of phytohormones (Bolton et al. 1993, Azcon-Aguilar and Barea 1996, Arshad 1993). Plant community composition can be directly affected by the composition of soil microbial communities (van der Heijden et al. 1998, Bever 1988). And soil processes, such as soil aggregate formation, mobilization and immobilization of nutrients, and transformation of soil organic matter are controlled by soil microbes (Bolton et al. 1993, Edgerton et al. 1995, Francis and Dodge 1988, Lovely 1991, Levi-Minzi et al. 1990). For these reasons, plant ecologists and restoration ecologists have paid increasing attention to soil microbial communities.

Successful revegetation of harsh mine waste soils (often dry, acidic, and metal-contaminated) depends on amelioration of the soil environment (Noyd 1995). Common mine waste amelioration strategies include neutralization and the addition of organic matter. Organic matter sources used for reclamation include a wide range of materials such as topsoil, straw, various composts, sawdust, fungal mycelia byproduct, and manure, each of which offers a different suite of benefits to the disturbed soil. For example, Noyd et al. (1995, 1996, 1997) found that composted yard waste added to taconite iron ore tailings increased plant cover, mycorrhizal properties, and accrual of organic matter in soil. Organic additions have also been shown to increase plant cover (DeLuca and Lynch 1997, Meikle et al. 1999, Noyd et al. 1996), reduce soil bulk density (Schoenholtz et al. 1992, Tester 1990), lower penetration resistance (Tester 1990), increase water content (Schoenholtz et al. 1992, Tester 1990), increase total and mineralizable N (Schoenholtz et al. 1992), decrease exchangeable metal levels (DeLuca and Lynch 1997) and alter pH (DeLuca and Lynch 1997, Tester 1990) in a variety of soil types. Such soil alterations can lead to improved conditions for soil biota and plant root growth. Together, these studies show that benefits of organic matter addition depend on the combination of organic matter type and disturbed soil properties (DeLuca and Lynch 1997, Tester 1990).

While previous research has examined the physical and chemical benefits of various organic matter additions, little is known about the relative benefits of these amendments as microbial inoculum sources. Noyd et al. (1995) measured increased microbial biomass and increased numbers of several important soil microbial populations in taconite iron ore tailings in field plots amended with composted yard waste. Other studies have shown that organic matter additions can increase microbial biomass (DeLuca and Lynch 1997, Noyd et al. 1995) and enhance decomposition rates of organic matter (Levi-Minzi et al. 1990).

The objective of this research was to directly compare microbial communities associated with four common organic matter amendments and with several different mine tailings substrates. A diversity of microorganisms is required for soil functioning and improved plant growth. For example, actinomycetes are common soil bacteria that are important for decomposition of complex carbonaceous substrates such as chitin, celluloses and hemicelluloses (Killham 1994). A variety of heterotrophic bacteria are responsible for many other soil functions, such as non-symbiotic nitrogen fixation, plant mutualisms, and decomposition. Soil fungi have a number of important roles in the soil (such as plant symbionts and pathogens), the most important of which is the decomposition of organic

matter. They metabolize both simple and complex carbohydrates, and fungal biomass in the soil is important for soil structure and stability (Killham 1994). A primary function of many soil microorganisms during soil restoration is to promote organic matter turnover and nutrient cycling through diverse metabolic functioning. Carbon-utilization profiles, generated with Biolog microtiter plates, can be used to estimate potential metabolic diversity on a wide array of carbon sources (Garland and Mills 1991, Lehman et al. 1995, Zak et al. 1994). These microplates consist of 96 wells, 95 that contain unique sole carbon sources and one control well with no carbon. Minimal salts for growth and tetrazolium redox indicator dye also are included in each well. The carbon-utilization patterns that develop provide a metabolic profile for the sample community, and serve as an indicator of the carbon-based metabolic diversity of the microbial community. Data from these different microbial assessments can be used to compare the microbial communities associated with organic matter sources and tailings types.

METHODS

Sample Collection

The experiment compared five organic matter treatments and five mine tailings substrates. The organic matter treatments were 1) fresh sawdust from a lumber mill; 2) cattle manure; 3) soil from an undisturbed range site near Missoula, MT; and 4) landfill compost. The substrates included 1) silica sand (control); 2) acidic mine tailings; 3) new tailings, freshly processed and de-watered at an active mine near Butte, MT; 4) "clean" tailings, in which pyrite was removed through an extra separation step; and 5) an old tailings substrate, taken from a 10 year old marginally vegetated test plot at the same active mine. Plant material was detected in the old tailings, but none of the other substrates. Substrates and organic matter additions were collected, sieved (2mm mesh), and homogenized for sampling. Four subsamples were taken from each organic matter and substrate type and placed in sterile sample bags for immediate processing. Sample soil not used for immediate processing was dried and stored for future analyses.

Soil Parameters

Soil moisture content was determined gravimetrically in both organic amendments and soil substrates. Twenty-five grams of each sample was weighed, dried at 60° C for three days, and re-weighed. Measurement of soil pH was performed by addition of 20 ml deionized water to 10 grams dry soil followed by a 5 minute equilibriation period prior to measurement with a pH probe.

Culturable Bacteria and Fungi

Soil samples were homogenized, diluted 1:10 in 0.1% sodium pyrophosphate (Sigma Chemicals Co.), sonicated for ten minutes (Bransonic Ultrasonic Cleaner 3210, Danbury, CT), and used for the various microbiological assays. Heterotrophic bacteria and actinomycetes (as detected by colony and microscopic morphology) were determined on R2A agar (Difco Laboratories). Total fungal counts were determined on Rose Bengal agar (Difco Laboratories) supplemented with 0.1g/L chloramphenicol (Sigma Chemicals Company, St. Louis, MO).

Carbon-utilization Pattern Analysis

Heterotrophic plate count data were used to adjust the samples to a standard cell density for Biolog plate inoculation. A second soil slurry was prepared as described above. This slurry was further diluted in phosphate-buffered saline to a standard density of $1x10^4$ CFU/ml. 150µl of each sample was inoculated into Biolog GN microplates and incubated at 23°C for 300 hours. The optical density of the wells was measured approximately every 24 hours with an ELISA microplate reader at 570nm (Molecular Devices, Menlo Park, CA).

Biolog data was analyzed by calculating average well color development (AWCD) across time, averaging the absorbance readings for each well in a single plate after subtracting the time zero reading (Garland and Mills 1991). The number of active wells on a given plate was determined by quantification of the number of positive wells (>0.100 absorbance units above the time zero reading) in each sample. Plates were analyzed at 144 h because this was the time at which patterns were established and stabilized, but visible fungal biomass had not appeared any of in the plates (Zak et al. 1994).

Statistical Analyses

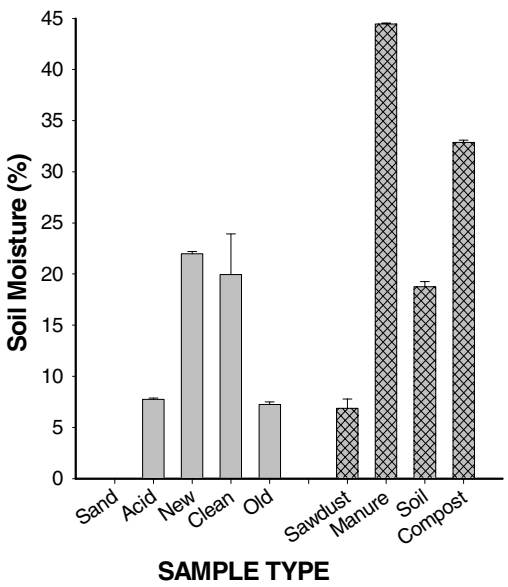
Treatment differences were detected with Kruskal-Wallis analysis of variance (anova) on ranks, followed by a Student-Newman-Keuls post-hoc test for multiple comparisons. Analysis of variance was used to measure differences between substrates separately from differences between organic matter sources. An adjusted alpha level of 0.025 was used to judge significance of the multiple tests.

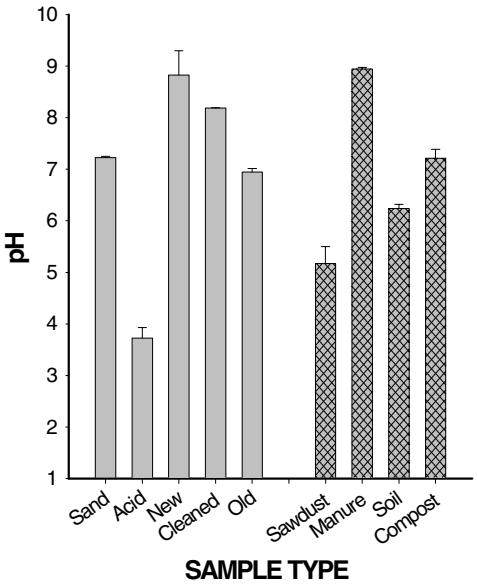
RESULTS

Soil measurements

Soil moisture contents were significantly different between substrates and organic matter types (Figure 1). Sand moisture was undetectable, acid and old tailings had low moisture (approx. 5%), and the new and clean tailings had the highest moisture content (approx. 20%). Moisture was significantly lowest in the sawdust (approx. 4%), higher in soil, higher still in compost, and highest in manure samples.

The pH of the acid tailings was significantly lower than all of the other substrates, while the old tailings was more acidic than the sand, clean tailings and new tailings (Figure 2) The pH was significantly higher in the manure than the sawdust, but the soil and compost were not different from any of the other treatments.





Heterotrophic Plate Counts

Heterotrophic plate counts are a measure of culturable bacteria, or the total number of colony forming units that are able to grow on agar medium in the laboratory. Since the growing requirements of many bacteria may include conditions unique to a soil environment that are not well simulated within the lab, heterotrophic plate counts are thought to represent only a small portion (less than ten percent) of the total bacteria in the sample. Nevertheless, plate counts provide a relative measure of culturable bacterial numbers between samples.

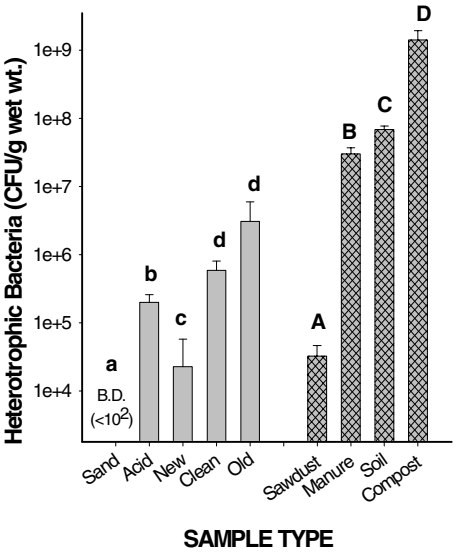


Figure 3. Heterotrophic bacteria plate counts for all samples. Lowercase letters designate statistically significant substrate treatment differences ($p<0.001$), and uppercase letters designate organic matter treatment differences ($p=0.003$). n=4. Error bars represent ± SE.

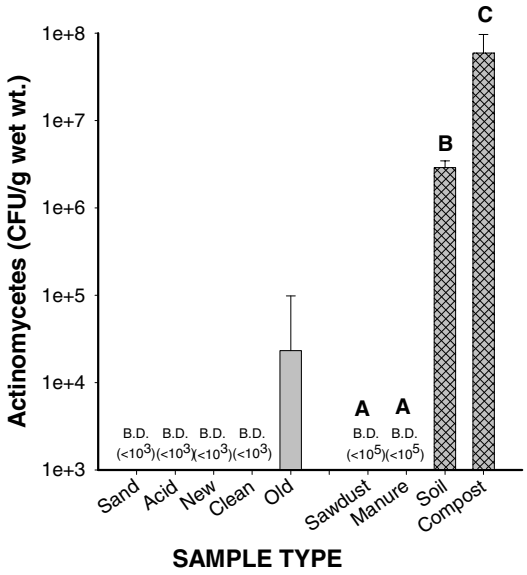
Culturable heterotrophic bacterial counts differed across substrates with the lowest numbers (below detection level of 10^2 CFU/g wet weight of substrate) in samples of sand (Figure 3). Both clean tailings and old tailings showed the highest number of CFU's, and were not significantly different from one another. New tailings and acid tailings were intermediate, with higher levels in the acid tailings than the new tailings. Plate counts of organic amendments were lowest in the sawdust (7.75×10^4 CFU/g substrate), followed by manure, soil, and compost, which were between 10^4 and 10^5 times higher than sawdust (Figure 3).

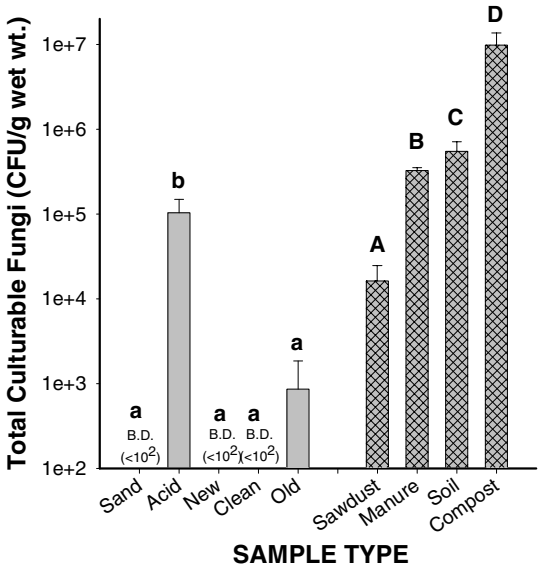
Actinomycete Plate Counts

Actinomycetes are a category of important soil bacteria that are thought to be especially important for the decomposition of complex substrates. Only one of the substrates, old tailings, showed any detectable (>10^3 CFU/g) actinomycete activity (Figure 4). The 'old tailing' and 'soil' samples supported plant growth at the time of sample collection unlike any of the other treatments. Because actinomycete numbers in the organic matter were expected to be higher than in substrates, the level of detection for the organic amendments was set at 10^5 CFU/g. Only the soil and compost had actinomycete activity, which was significantly higher in the compost than in the soil (Figure 4). It should be noted that the 'soil' treatment is not strictly an organic amendment since it is dominantly inorganic material, yet was included among the set of organic amendments since it contained abundant organic matter.

Culturable Fungi Plate Counts

Soil fungi are especially important for the breakdown of complex organic matter and maintaining soil structure. Culturable fungi were significantly higher in acid tailings than any of the other substrates (Figure 5). The mean number of culturable fungi was 9.7 x 10^4 CFU/g in the acid tailings and either below detection (<10^2 CFU/g) or 1.5 x 10^3 CFU/g in the old tailings. All of the organic amendments contained culturable fungi, with the lowest level in the sawdust, followed by manure, and soil, and the highest level in the compost (Figure 5).





Number of Carbons Used

The number of carbons used by each sample indicates how many unique carbon sources were metabolized, giving an absorbance reading greater than 0.100. This reflects diversity of carbon-based metabolism of the microbial community in each sample. It is important to note that this is a functional measure, not a measure of genetic or taxonomic diversity.

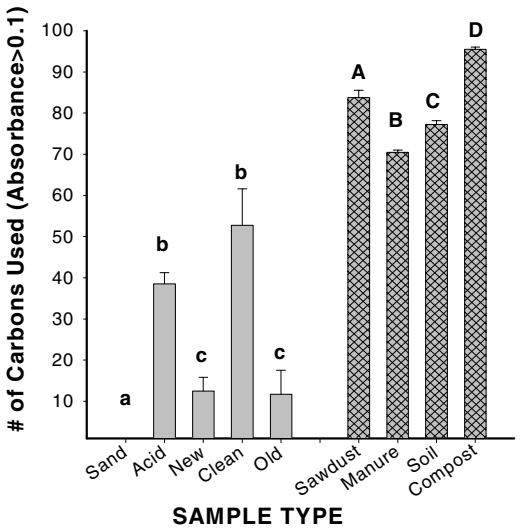


Figure 6. Number of carbons used for all samples. Lowercase letters designate substrate treatment differences (p=0.003), and uppercase letters designate organic matter treatment differences (p=0.003). n=4. Error bars represent ± SE.

The number of carbons used was lower in the substrates than in the organic matter types (Figure 6). The new and old tailings showed lower carbon-utilization diversity than the acid tailings and cleaned tailings. All substrate measurements had large variances associated with the data. The compost had the highest number of carbons used, with almost all 95 substrates showing significant activity (Figure 6). The other organic matter sources also showed high carbon-utilization diversity with manure being the lowest, followed by soil, and then sawdust. It is interesting to note the relatively high metabolic diversity of the sawdust, in spite of relatively low plate counts.

AWCD Across Time.

Organic amendments, in general, had higher levels of microbial activity, as measured by AWCD of Biolog plates (Figure 7). Compost showed the highest level of activity, a pattern that was established within 48 hours, and consistent across time. Soil and sawdust also showed higher levels of activity than the substrates. The response curve for manure was unique, in that microbial activity was initially very low, but after 300 hours, which is longer than we usually monitor Biolog plates, activity on manure substrates was equivalent to that of soil and sawdust. Substrates were consistently low in microbial activity, but the clean tailings treatment showed higher activity than the other substrates.

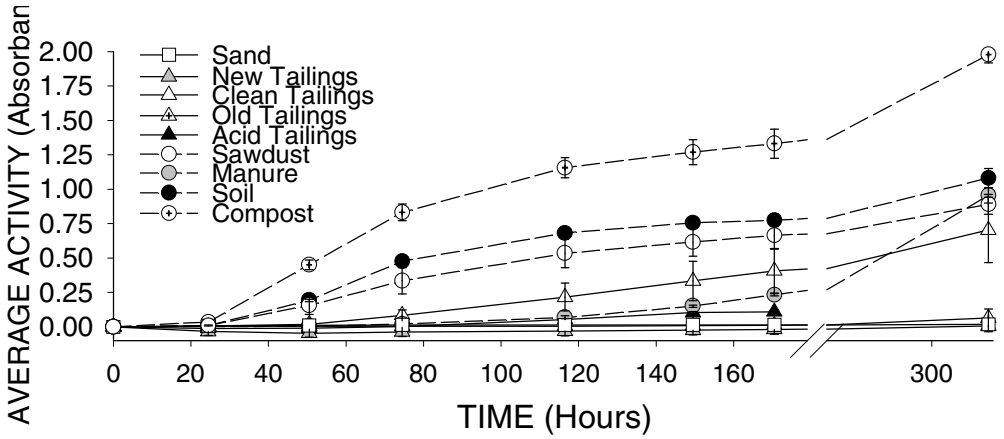


Figure 7. Analysis of average carbon-utilization activity across time for pre-incubation samples. Data points represent the mean +/- SE. n=4.

DISCUSSION AND CONCLUSIONS

Substrate Differences

When considering the inoculation potential of organic matter sources for mine reclamation, it is important to understand how various types of mine tailings can differ geochemically and biologically. The tailings substrates measured in this study varied in pH, moisture content, and microbial characteristics, all of which could affect the survival and composition of the organic matter introduced microbial communities.

The silica sand measurements were below detection limits for microbial measurements and soil moisture. The acid tailings samples were interesting because soil moisture, and especially pH, were low. The significantly higher fungal numbers in the acid tailings are typical of dry, acidic, metal-rich soils. The new and clean tailings generally had intermediate values for the parameters measured. The clean tailings had slightly higher carbon-utilization activity and diversity, but those measurements showed a large variance. Both had higher moisture content and pH than the other substrates. The old tailings had higher plate counts than other substrates, and was the only substrate containing detectable actinomycete bacteria. Those actinomycetes could have been associated with the plant matter observed during soil processing.

It is likely that various organic matter microbial communities would respond differently to these different soil environments. The next phase of this research will consider how the microbial communities associated with each of the organic matter sources changes after incubation with each of the substrate types.

Organic Matter Differences

The organic matter sources varied significantly in their microbial communities and soil measurements. The sawdust had the lowest moisture content, and lower pH than the manure. The sawdust also had the lowest heterotrophic bacteria, actinomycete, and fungal plate counts. In spite of these low counts the sawdust microbial community showed higher carbon utilization diversity than the manure and soil and comparable carbon-utilization activity.

Topsoil samples had moderate moisture and pH measurements. The soil had high heterotrophic bacteria, actinomycete, and fungal plate counts and carbon-utilization activity measurements, second only to compost. The soil was one of only two organic matter types that contained detectable actinomycete colonies.

The manure, which had the highest moisture content and pH, showed moderate microbial community measurements. Heterotrophic bacteria and fungi were lower than compost and soil, and there were no detectable actinomycetes. Manure showed the lowest carbon-utilization diversity and activity, until the final reading after almost two weeks of incubation.

The compost samples had the most abundant and diverse microbial community. While soil moisture and pH were moderate, the compost had the highest heterotrophic, actinomycete, and fungal plate counts. Both carbon-utilization diversity and activity were significantly higher than the other organic matter sources.

Conclusions

This study suggests that different organic matter amendments can potentially alter soil microbial communities when used as tailings amendments. It should be emphasized that microbial inoculation potential is only one of many important factors that should be considered when selecting an organic matter amendment. Other contributions of organic matter addition include effects on soil structure and bulk density, long- and short-term nutrient quality, and effects on desired plant species.

This research provides important insights to microbial changes with organic matter additions, but its applicability is limited by the fact that these are baseline measurements. The next phase of this research project will examine how microbial communities of organic matter additions change after incubation with the various mine tailings substrates. This work also should be repeated in a more realistic field setting to include influences such as influx of microbes through abiotic and biotic vectors, temperature fluctuations, and natural wetting and drying cycles.

These results underscore the importance of further studies examining effects of different organic matter types on reclaimed microbial communities. Further studies should go beyond microbial community characterization to examine soil ecosystem functions, such as organic matter degradation, nitrogen fixation, and soil formation. Such studies can result in a better understanding of ecological soil restoration, which will lead to more successful mine revegetation and restoration.

REFERENCES

Arshad, M., Frankenberger, W.T. and Blaine, F. Microbial Production of Plant Growth Regulators. 1993. pp.646 In Metting and Blaine, F. (Eds.), Soil Microbial Ecology. Marcel Dekker, Inc., New York.

Azcon-Aguilar, C. and Barea, J.M. 1996. Arbuscular mycorrhizas and biological control of soil-borne plant pathogens - an overview of the mechanisms involved. Mycorrhiza 6: 457-464.

Bolton, H.J., Frederickson, J.K., Elliot, L.F. and Blaine, F. Microbial ecology of the rhizosphere. 1993. In Metting and Blaine (Eds.), Soil Microbial Ecology. Marcel Dekker, Inc., New York.

Brookes, P.C. and McGrath, S.P. 1984. Effects of metal toxicity on the size of the soil microbial biomass. J. Soil Sci. 35: 341-346.

Deluca, T.H. and Lynch, E.L. 1997. Assessment of amendments in the reclamation of an abandoned mine in Montana. Intermountain J. Sci. 3: 38-46.

Edgerton, D.L., Harris, J.A., Birch, P. and Bullock, P. 1995. Linear relationship between aggregate stability and microbial biomass in three restored soils. Soil Biol. Biochem. 27: 1499-1501.

Francis, A.J. and Dodge, C.J. 1988. Anaerobic microbial dissolution of transition and heavy metal oxides. Appl. Environ. Microbiol. 54: 1009-1014.

Garland, J.L. and Mills, A. 1991. Classification and characterization of heterotrophic microbial communities on the basis of patterns of community-level sole-carbon-source utilization. Appl.Environ.Microbiol. 57: 2351-2359.

Killham, K. 1994. Soil Ecology. Cambridge University Press.

Lehman, R.M., Colwell, F.S., Ringelberg, D.B. and White, D.C. 1995. Combined microbial community-level analyses for quality assurance of terrestrial subsurface cores. J. Microbiol. Methods 22: 263-281.

Levi-Minzi, R., Riffaldi, R. and Saviozzi, A. 1990. Carbon mineralization in soil amended with different organic materials. Agriculture, Ecosystems, and Environ. 31: 325-335.

Lovley, D.R. 1991. Dissimilatory Fe(III) and Mn(IV) reduction. Microbiol. Rev. 55: 259-287.

Meikle, T.W., Lu, S. and Barta, J.P. 1999. Evaluation of nutrient and biological amendments on waste rock. SME Annual Meeting, Denver, Colorado.

Noyd, R.K., Pfleger, F.L., Norland, M.R. and Sadowsky, M.J. 1995. Native prairie grasses and microbial community responses to reclamation of taconite iron ore tailing. Can. J. Bot. 73: 1645-1654.

Noyd, R.K., Pfleger, F.L. and Norland, M.R. 1996. Field responses to added organic matter, arbuscular mycorrhizal fungi, and fertilizer in reclamation of taconite iron ore tailing. Plant and Soil 179: 89-97.

Noyd, R.K., Pfleger, F.L., Norland, M.R. and Hall, D.L. 1997. Native plant productivity and litter decomposition in reclamation of taconite iron ore tailing. J. Environ. Qual. 26: 682-687.

Schoenholtz, S.H., Burger, J.A. and Kreh, R.E. 1992. Fertilizer and organic amendment effects on mine soil properties and revegetation success. Soil Sci. Soc. Am. J. 56: 1177-1184.

Tester, C.F. 1990. Organic amendment effects on physical and chemical properties of a sandy soil. Soil Sci. Soc. Am. J. 54: 827-831.

Van der Heijden, M.G.A., Klironomos, J.N., Ursic, M., Moutoglis, P., Streitwolf-Engel, R., Boller, T., Wiemken, A. and Sanders, I.R. 1998. Mycorrhizal fungal diversity determines plant biodiversity, ecosystem variability, and productivity. Nature 396: 69-72.

Zak, J.C., Willig, M.R., Moorhead, D.L. and Wildman, H.G. 1994. Functional diversity of microbial communities: a quantitative approach. Soil Biol. Biochem. 26: 1101-1108.

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ABSTRACT

EVALUATING ORGANIC AMENDMENTS FOR REVEGETATION

PART 1: ORGANIC CONTENT AND COST

R. A. Prodgers[1]

Organic soil amendments may benefit reclamation in many ways, especially where biologically inert coversoils must be revegetated. A good compost usually is the best organic amendment. This information is needed to calculate the amount of amendment needed:

Target organic concentration of soil, minus existing concentration.
Dry bulk density of amendment.
Organic matter as a percent of amendment (dry weight basis).

With this information and measured or assumed bulk density of the target soil, amendment quantities can be calculated. The cost for three commercial composts required to bring the organic content of a given volume of soil (e.g., 6-inch-acre slice of coversoil) to the target organic content is compared without the cost of distributing and incorporating amendments. Calculations are explained. Heterogeneity of organic amendments and inaccurate laboratory analysis are the major limitations to reliable amendment characterization.

Key Words: organic matter content, compost, bulk density, percent dry matter.

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INTRODUCTION

Organic amendments may be prescribed in revegetation to improve the physical condition of the soil, to provide nutrient and carbon pools that otherwise would take decades to accumulate, to attenuate metals, to fertilize the soil, and to provide useful soil microorganisms populations. A good organic amendment can significantly advance the development of biologically inert coversoils and prevent plant diseases, which bears directly on vegetational development.

The first part of this paper provides criteria and evaluates three compost products in terms of cost per unit of organic matter (OM). In the second part, evaluation continues considering fertility and the abundance and diversity of soil microorganisms. Certain commercial compost properties have been changed to prevent identification by means of advertised characteristics.

COMMON ORGANIC AMENDMENTS

In the western United States, the most commonly used organic amendments are compost, bovine manure, and wood waste. Of these, a good compost is the best organic amendment for revegetation. Composting is a process that uses microbial activity to degrade raw organic materials, yielding a lesser quantity of relatively stable amendment. Composting stimulates the decomposition of OM by providing the proper ratio of high-N material, green leafy material, and wide C:N material, often combined with microbiological inocula. Under near-optimal conditions of moisture, temperature, and aeration, decomposition is accelerated. A 3-day sustained temperature of 57° to 68° C (135° to 155° F) kills weed seed and undesirable pathogens. In a mature compost, the food for bacteria, actinomycetes, and fungi is nearly exhausted. As temperature drops, the microbial grazers/predators necessary for nutrient cycling reestablish. Compost is relatively rich in humic materials that have long residence times in soils.

The problem with the wide C:N (>100) amendments such as sawdust is that they consist largely of decomposition-resistant substrates to which few microorganisms are adapted. When carbon does become available to soil microorganisms, it cannot be assimilated except in ratio to N and other nutrients. For these and environmental reasons, decomposition is slow and little N is available to vascular plants. Nitrate levels in soils thus amended and planted are usually near zero during the growing season. Thus, amending soils with decomposition-resistant, wide C:N products is a long-term nutrient impoverishment strategy best applied to soils considered excessively fertile.

Uncomposted manure immediately boosts fertility, but the effects don't persist. Manure is an active, nitrogen-rich amendment that decomposes rather quickly, mineralizing N. Raw wastes lose their OM and degrade in a few years (Cole 1998). Since manure decomposition is bacteria-dominated, it will "burn up" quickly; aerobic bacteria may fix only 5-10% of the carbon from a substrate. Manure that hasn't been composted is a potential weed source, always an important consideration, but the focus here is fertility and microbiological aspects. Fresh manure may be almost 8% N, but 1.5-3.5% N is a reasonable estimate for generic manure (Eck and Stewart 1995, Table 1, p. 172). However, the same authors cautioned that bovine manures that have been aged by cycles of wetting and drying and leached by rainwater may lose much of their value as fertilizer. Phosphorus and potassium do not volatilize and are less subject to leaching than nitrogen.

SAMPLING AND ANALYZING AMENDMENTS

It's a challenge to accurately characterize the "as sold" condition of organic amendments due to inherent heterogeneity. Composite sampling is necessary. In composite sampling, numerous subsamples are combined and thoroughly mixed before analysis to attempt to get representative values while minimizing laboratory costs. Any static pile, whether it be compost or manure or even wood waste, will vary. Depth or nearness to the surface determines oxygen availability and temperature. Unless aerated, deeper portions may become anaerobic while exterior portions may not fully compost. The degree of initial mixing also plays a role. Amendments that are regularly turned for aeration are more homogeneous.

Samples should be taken from screened amendment or following the final mixing step before load out. Take a composite sample consisting of 10 subsamples from different portions of the pile at different depths. The temperature inside the pile should not differ greatly from near the surface. Thoroughly mix the subsamples for analysis. Better yet, take several composite samples and calculate the variance as well as the mean for important parameters. Due to cost, this is rarely done, but it allows putting a confidence interval on important amendment characteristics.

Composite samples from a low-nutrient, low-salinity compost of the type discussed here were submitted to six laboratories for analysis of 10 parameters (Granatstein, 1997). Of the parameters mentioned in this paper, pH, OM, and C:N ratio values were consistent across laboratories. Less reliable were measurements of total K, available P, nitrate, and EC. An example would be a nitrate mean of 486 ppm with a coefficient of variation (CV) of 35% but individual values ranging from 324 to 800 ppm. The least reliable parameter was ammonium, with values ranging from 17 to 3100 ppm and a CV of 150% – virtually useless data.

ORGANIC MATTER CONTENT

Organic matter refers to compounds formed by living organisms and the organisms themselves, most of which contain carbon in cell walls and other compounds. Plant tissues are approximately 40-50% carbon on a dry weight basis. In soils, OM originates as plant materials on and within the soil, animal tissues and excretory products, and soil organisms. Water-soluble compounds are the most easily used (labile) forms of OM for soil microflora and lignin and some aromatic compounds are among the most resistant to decomposition (recalcitrant). Cellulose, the most common polysaccharide in the nature, is intermediary: about six months to decompose under good conditions. Hemicellulose is somewhat more readily decomposed.

The organic content of compost depends on the feedstock, the amount of mineral material present in or added to the compost (e.g., dirt introduced in moving or mixing compost), and the compost age. The less the mineral content, the higher the organic content. The older the compost, the lower but more stable the organic fraction, because microbial decomposition produces CO_2, depleting the organic C pool. The same reactions lower the C:N ratio.

The three evaluated compost products combine wood products with sewage sludge, garden wastes, and some incidental dirt. One product is a volumetric blend of approximately 63% wood

waste, 25% dewatered sewage sludge, 8% yard waste, and 4% barnyard manure. If you wash any of these compost products with a medium-pressure stream of water, you will find lots of distinguishable wood pieces. The wood constituent provides intermediate and recalcitrant forms of carbon, whereas the sewage sludge provides nutrients and more labile forms of carbon and nitrogen (and sometimes biological contaminants). If properly composted, vascular plant propagules and human pathogens will be killed in thermophilic decomposition, but a healthy microflora will endure or reestablish.

There are several ways to quantify the OM content of composts. Those skeptical of advertising claims should get their own data. The best technique is to oxidize the OM in a LECO furnace (Nelson and Sommers 1996, pp. 975-976), analyzing for CO_2. For composts lacking carbonates, the procedure is straightforward. For the best comparisons, have a single laboratory determine the OM content of all amendments being evaluated.

A more commonly available procedure is to ignite the sample at high temperature in a muffle furnace (loss on ignition test or LOI). Temperature is a major variable. Heating to less than about 375° C, especially when coupled with short times, results in incomplete removal of OM. Temperatures above about 500° C may remove some constituent other than OM. In discussing loss on ignition procedures, Nelson and Sommers (1996) concluded that "...ignition of soils at 400 to 450° C will remove all organic matter and cause minimal dehydroxylation of clay minerals." **They cite and recommend heating to 400° C for 16 hours.** High temperatures such as 750° C will result in overestimates.

The Walkley-Black technique determines organic carbon, but it is not well-suited to the high organic content of organic amendments. In any method, the empirical constants used to extrapolate from organic carbon to OM should be appropriate for the organic amendment.

The OM content for dry samples of the three compost products ranged from 55% for Compost A to 70% for Compost C, with Compost B in the middle at about 60% (Table 1).

EVALUATING COST

Evaluating cost is easy once you have the information in the proper units, which is the cost of delivered amendment it will take to bring a given volume of soil to the target OM content. In this comparison, the target will be 1% organic content in a six-inch-acre slice of coversoil. Although not reported here, the cost of distributing and incorporating amendments must be included.

Target OM concentrations are likely to range from 0.5 to 3%, with cost playing a major role. Turning deep borrow material into an approximation of a mature soil with organic amendment is impractical. It takes many pounds of OM to eventually get one pound of humus in the soil. In coarse soils, the high rate of gas exchange will result in quicker oxidation of OM than would occur in fine-textured soils. In contrast, clays will retain carbon and suppress decomposition. A bacteria-dominated decomposer population will fix less carbon (put out more CO_2) than a fungi-dominated one.

Table 1. Compost Properties.

	Wet Bulk Density (lbs./cy)	Dry Matter (%)	Dry Bulk Denstiy (lbs./cy)	Organic Matter (%)	Organic Matter (lbs./cy)	NO_3 (ppm)	P (Olsen,ppm)
Compost A	830	55	456	55	251	170	240
Compost B	1030	45	463	60	278	900	450
Compost C	800	40	320	70	224	2000	1200

Information needed for a cost evaluation:

Delivered cost per cubic yard of amendment,
Weight of dry matter in one cubic yard, as delivered, and
Organic content on a dry weight basis.

To determine bulk density for a sample, calculate the percentage of dry matter [dry weight divided by wet weight] X 100, or the dry bulk density, which is the ratio of the mass of dried organic amendment to its volume. To determine this, you need a metal container such as a three-pound coffee can. Weigh the empty can and figure out the volume in English units such as pounds/cu. ft. Fill it with amendment and thump it down on the floor until it settles, then top it off and thump it a little more. Stop when you have a reasonably constant volume for the full container. Weigh it.

Heat it at 105° C, preferably with circulating air to carry off the moisture. This will take less time if you spread it on a cake pan, but it still could take 24 hours. Don't take a high T shortcut and risk charring the amendment. When the weight doesn't change with continued drying, it's oven-dry. Record the dry weight.

Wet bulk density is the weight of the can full of amendment, minus the can weight, divided by the volume of the can. For composts produced outdoors, wet bulk density is influenced by weather.

Dry bulk density is the weight of the amendment after drying, divided by the volume of the can. Particle size plays an important role in determining bulk density for a specified feedstock.

Percent dry matter on a weight basis is [weight of the dry amendment divided by the weight of the wet amendment] X 100. You can multiply the % dry matter by the wet bulk density to get the dry bulk density.

Among composts evaluated, Compost A was more than half dry matter, whereas Composts B and C contained more moisture (Table 1). Composts A and C had similar bulk densities of about 800 pounds/cubic yard, but the bulk density of Compost B was about 1,000 pounds/cubic yard.

Multiplying percent dry weight X percent OM X wet bulk density in pounds/cubic yard gives the pounds of OM on a dry weight basis per cubic yard of compost. Divide this number into 20,400

pounds (1% the mass of a six-inch-acre slice of soil assuming a bulk density of 1.5 g/cc) to determine the number of cubic yards of compost that must be added to a six-inch-acre slice of soil to bring the OM content to one 1% (first column, Table 2). Use a different bulk density for the coversoil if appropriate. The relationship is linear, so for 2% OM in the upper six inches or 1% OM in a one-foot-acre slice, double the amount of compost added.

The relative costs of the three compost products excluding shipping are summarized in Table 2. While not included, the cost of spreading and incorporating compost is pretty much a linear function of volume, so it would be highest for Compost C and least for Compost B. Composts A & B are the best values considering only the cost/unit OM.

CONCLUSIONS

Calculating the needed quantity of organic amendment begins with a target OM concentration for the soil or coversoil. To calculate the amount of organic amendment needed to bring the soil to the target concentration, determine the dry bulk density and organic matter content of the product. Calculate the weight (mass) of organic matter per dry cubic yard and divide into the desired percentage of a mass of soil. At 1.5 g/cc, a six-inch-acre slice of soil weighs about two million pounds. One percent of that is 20,000 pounds, which is the amount of organic matter needed to bring one six-inch-acre slice of soil to 1%.

In the comparison of three commercial composts reported here, between 73 and 91 cubic yards of amendment would be required to bring the coversoil concentration to 1%/six-inch-acre slice. Cost without application ranged from $970 to $1,820.

Compost properties can change, e.g., as a result of differences in raw materials and composting procedures. Test fresh samples immediately before ordering, using composite sampling and, if possible, replicates. By sharing your test results with manufacturers, you will provide them with useful information and emphasize to them the importance of providing a high-quality product.

Other considerations for evaluating amendments are discussed in Part 2.

Table 2. Compost Cost, Application Rates, and Resulting Fertility.

	CuYd of Compost / 6"- Acre Slice*[1] For 1% OM	Compost Cost / CuYd (FOB)	Compost Cost / 6"- Acre Slice *[2]	Resulting N conc. (ppm) *[3]	Effective N conc. with mulch (ppm)*[4]	Resulting P conc. (ppm)*[3]
Compost A	81	$12 - $14	$972 - $1,134	3	0	4
Compost B (3/8" minus)	73	$13.70 - $15.20	$1,000 - $1,110	15	0	7
Compost C	91	$20	$1,820	28	14	17

*[1] Volume of compost needed to bring the organic matter content of the coversoil (1.5g/cc) to 1%.

*[2] Compost cost per 6"-acre slice, not counting application and incorporation.

*[3] The concentraions of nitrogen and phosphorus in a 6"-acre slice after amendment, assuming no nitrogen or phosphorous prior to amendment.

*[4] Based on applying 1.5T/acre mulch, assuming soil microbes immobilize 10 lbs./acre nitrogen per 1000 lbs. of mulch.

REFERENCES

Cole, M. 1998. An analysis of composting as an environmental remediation technology. EPA530-R-98-008.

Eck, H., and B. Stewart. 1995. Manure. pp. 169-198 *In*: Jack Rechcigl ed. Soil Amendments and Environmental Quality. Lewis Publishers, Boca Raton Fl. 504 pp.

Granatstein, D. 1997. Lab comparison study completed. pp. 1-5 *In*: The Compost Connection Newsletter, No. 4. Http://csanr.wsu.edu/compost/newsletter/compcon4.html

Nelson, D., and L. Sommers. 1996. Total carbon, organic carbon, and organic matter. Chapter 34. pp. 961-1010 *In:* J. Bartels and J. Bigham eds. Methods of Soil Analysis, Part 3, Chemical Methods. Soil Sci. Soc. Of Amer. Inc. Madison, Wisc. 1390 pp.

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ABSTRACT

EVALUATING ORGANIC AMENDMENTS FOR REVEGETATION

PART 2: FERTILITY AND MICROBIOLOGY

R. A. Prodgers[1]

The type and application rate of amendment must complement other aspects of the revegetation plan. Fertility concerns include plant nutrition, nitrogen fixation, and mycorrhizae establishment. Short-term fertility concerns include nutritional requirements of vascular plants and the desirability of establishing plants in a fertility regime similar to long-term conditions, ruderal-controlling strategies, nitrate levels that complement nitrogen fixation, and phosphorus concentrations that don't inhibit mycorrhizae establishment. The unamended fertility of the soil must also be considered. Focusing solely on the C:N:P ratio ignores the fact that recalcitrant carbon-rich residues will persist for years. The major midterm nutritional concern is the nutrient-immobilizing tendency of amendments once labile constituents have decomposed. For successful revegetation, decomposition must complement primary productivity. A good compost should provide adequate densities of bacteria, fungi, protozoa, and beneficial nematodes to establish a functioning soil food web and assure nutrient cycling. Microbiological targets include more than 100 ug/g total bacteria and fungi (each) and at least 30,000 protozoa/gdy will. Bacterial dominance would be normal for a grassland soil. No root-feeding nematodes should be tolerated in amendments.

Key Words: organic matter, soil fertility targets, nitrogen fixation, mycorrhizae establishment, C:N:P ratios, soil microbiology.

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INTRODUCTION

Organic amendments are often evaluated solely based on cost and organic content or C:N ratio. From an ecological perspective, other attributes are equally important. The suitability of a given product depends on other details of the revegetation plan. An organic amendment may complement one revegetation strategy but conflict with another.

This paper provides criteria and evaluates three compost products in terms of fertility and the abundance and diversity of soil microorganisms. Certain commercial compost properties have been changed to prevent identification by means of advertised characteristics.

COMPOST AND PLANT NUTRITION

Abundant essential nutrients make plants grow big and fast. Nonecologists typically are impressed when target areas turn green fast, but in a seminatural system high fertility isn't necessarily better – especially if temporary. The response of native prairie plants to fertilization is variable, with some species benefitting from all reasonable fertilization rates and others responding positively to light fertilization but negatively to higher levels of fertilization (Anonymous 1975). Others hardly respond at all. In mixed plant communities, fertility is a powerful selective force. High initial fertility selects for heavy nutrient users, but these same species might be poorly adapted to conditions after fertilization ceases or the mineralized nutrients in compost become depleted. At the same time, temporarily fertile soils select against species well-adapted to a low fertility regime. This sets the stage for declining plant performance and sometimes weed proliferation or invasion.

High levels of mineralized N also can inhibit *Rhizobium* establishment for nitrogen fixation and depress populations of chemoautotrophic bacteria responsible for nitrification, but the latter process will reestablish as nitrate levels decline. A coversoil concentration of 12 to 15 ppm nitrate would be the upper desirable concentration, but nodule formation will be greater at nitrate levels <5 ppm. Vascular plants are likely to quickly immobilize up to 15 ppm nitrate supplied by the compost.

Short-Term Nutrition Concerns (Mineralized Nutrients)

High but declining mineralized nitrogen concentrations are undesirable for three reasons. First, the critical plant establishment dynamic should occur in a fertility regime similar to the long-term condition, not in an environment that favors copious nutrient users. Second, nodule formation for nitrogen fixation is greatly diminished by high nitrate levels, and the challenge of revegetating biologically inert coversoils often is best addressed with a combination of organic amendment and nitrogen fixation. Third, high nitrogen fertility promotes some types of weeds.

The mineralized N (ammonium, nitrate, and nitrite) and P (Olsen) concentrations in the amendment are determined with fair precision using standard agronomic tests. Determine nitrate (plus ammonium and

nitrite, but these should be scarce at neutral to alkaline pH if nitrification is ongoing) and Olsen P in ppm (or mg/kg, etc.). **This will be on a dry weight basis for the amendment, not just the organic matter.** It's easy to consider only the organic content, since this is what we used to evaluate cost, and underestimate the effect of amendment on initial fertility.

Remember: a six-inch-acre slice weighs around two million pounds. (At 1.5 g/cc, it would weigh 2.04 X 10^6 pounds, or you can adjust for known soil bulk density.) At 50% organic content, it takes 40,000 pounds of dry matter in the amendment to bring the organic content of a six-inch-acre slice to 1% OM.

One easy way to calculate the effect of N or P additions, whether from compost or mineral, is based on the fact that 10 ppm (nitrate, P, whatever) in a six-inch-acre slice weighs about 20 pounds and all relationships are linear. For example, adding 12 pounds of nitrate would raise the concentration by 6 ppm.

Although a nitrate target of around 5 ppm might seem desirable, field trials often show soil that should have about 5 ppm nitrate actually drop to <1 ppm in a few weeks as plants establish. In other words, vascular plants quickly immobilize the nitrate. Thus, a target of 12-15 ppm nitrate may be appropriate even for nitrogen fixation. Without nitrogen fixation, incremental nitrogen fertilization may be desirable during the first few growing seasons.

There is one more consideration regarding nitrate. If the revegetation plan calls for organic mulching with a wide C:N product such as straw, its decomposition will immobilize more N. Decomposition of a substrate such as straw will be sped by having more N in the soil, but as mentioned earlier, the initial hydrolysis of lignin and other recalcitrant compounds limits the rate of decomposition. It's complicated and not completely predictable (straw in air vs. straw in soil, etc.), but a "rule of thumb" is to allow 10 pounds of nitrogen for each 1,000 pounds of mulch. If the mulch was half carbon and had a C:N ratio of 100:1, adding 10 pounds of N would change the ratio to 33:1. Thus the mulch acts less as a nitrogen sink. A typical heavy application of mulch might be 1.5 tons/acre, requiring 30 pounds of N/acre.

As Table 2 (Part 1) indicates, the relatively infertile Compost A could be applied in conjunction with nitrogen fertilizer even without mulch, and B would need some nitrogen fertilizer if used with 1.5 tons straw/acre. Alternatively, one could say that enough of Compost A could be added to bring the upper six inches to 3% OM without making the coversoil too fertile for nitrogen fixation. If nitrogen fixation is desired and nitrate-loving weeds are not, Compost C provides excessive fertility even at a 1% OM application rate. These calculations were for biologically inert coversoils initially containing no nitrate.

Elevated levels of P inhibit establishment of the fungal component of vesicular-arbuscular mycorrhizae (VAM), thus conflicting with plant nutrition strategies that rely on their establishment. VAM are especially adept at securing P from phosphorus-poor soils (St. John 1996). For VAM to establish, P must be sparingly available, on the order of 10 ppm (St. John pers. comm., 1998), although the inhibitory concentration depends on circumstances.

Olsen P in the composts ranged from 240 ppm for Compost A up to 1,200 ppm for Compost C

(Table 1, Part 1). The last column in Table 2 (Part 1) indicates that one could add enough Compost A to bring the OM content of a six-inch-acre slice to almost 2% while P remained low enough for VAM to establish. For Compost B, only enough compost could be added to bring the OM content of a six-inch-acre slice to 1% if VAM establishment is desired. However quickly it would grow plants, the wonderfully rich Compost C is at the upper threshold for VAM to establish even with no available P present in the unamended coversoil.

The above assessment assumes that P is absent from the soil or coversoil before amendment. If P already is present at >15 ppm before amendment, VAM in conjunction with compost may not be an option. In that case, there is no downside to abundant mineral P. A straw mulch (C:P ratio >300) favors immobilization. Mulch will immobilize P in ratio to N. The nitrogen mineralized is eight to 15 times the amount of phosphate made available, often generalized as 10:1. Therefore, if 1.5 tons/acre of straw mulch will immobilize 30 pounds of N, it will also immobilize roughly three pounds P (1.5 ppm in a 6-inch-acre slice). Of course, the establishment of revegetation will immobilize some of the free P, and it readily forms insoluble compounds in low pH soils. The net effect is best assessed by determining the P concentration in similar soils with two-year-old revegetation.

Summing up so far, rather infertile compost may be desirable where nitrogen fixation and VAM are part of revegetation prescriptions. High nitrogen levels can promote weeds, inhibit nitrogen fixation, and select for vascular plant species ill-suited to a lower long-term fertility regime. High plant-available phosphorus concentrations may conflict with optimal VAM establishment. The reason is that P may already be near or above optimal levels in soils/coversoil prior to amendment.

Midterm Nutritional Concerns

Much more difficult to evaluate is how fertility will change after the coversoil is amended and vegetated, when vascular plants are immobilizing nutrients and the labile constituents of plant and microbial litter are simultaneously being decomposed, etc. In the OM and microflora, nitrogen mineralization and immobilization can be thought of as opposing processes occurring simultaneously at rates determined by the substrate types involved and the abundance and diversity of soil microorganisms. This is related to the C:N:P ratio of the amendment and also by how easily degraded the compost constituents are. Only the net effect is measured.

Midterm fertility can be evaluated empirically. For a labile, nutrient-rich amendment such as bovine manure, evaluate the C:N:P ratio and estimate the decomposition rate. Unless it has long been weathered, manure is likely to bring N and P concentrations above target levels and elevate K even more, but too much K probably won't become a problem when a single application of manure is applied unless the unamended coversoil is already saline.

Wood-based compost tends toward nutrient impoverishment once the labile constituents have been immobilized in the soil-plant system. About 42 pounds/acre of mineral N was immobilized just a few months after application in first-year, compost-amended and mulched Butte Hill revegetation. A soil-plant system that immobilizes added nutrients is desirable, within limits. Absent nitrogen fixation,

incremental annual fertilization may be desirable for a few years until mineralization and immobilization equilibrate.

Wood waste is a strong nutrient impoverishment amendment that may bring N and P below 1 ppm and, in conjunction with growing plants, keep it there. This type of amendment is appropriate only when nutrient impoverishment is desired.

Summing up, low to moderate amounts of bovine manure have a low residence time; consequently midterm fertility is much diminished from the initial condition. If considering compost composed of wood waste, sewage sludge, and garden waste, the midterm nutritional consequences tend toward nutritional impoverishment because the recalcitrant substrates endure while the labile ones disappear quickly. At the same time, the C:N ratio declines naturally through time. A slight nutritional deficit is compatible with nitrogen fixation or incremental mineral fertilization, which may be necessary during the establishment phase. Wood wastes tend to bring about nutrient impoverishment in the short- and midterm. Fertility should approximate long-term conditions.

The C:N Ratio

The ratio of carbon to nitrogen is often given too much weight in evaluating organic amendments. Since humus typically has a C:N ratio between 5:1 and 15:1, a similar ratio sometimes is specified for compost. The guiding principle is that nitrogen will be conserved while carbon is lost as CO_2, so the ratio narrows through time until an equilibrium is reached. This is despite the fact that some N may be lost through leaching of nitrate/ ammonium, through denitrification (N_2), and through volatilization (NH_3).

Of course, as the C:N ratio narrows, C will be found in increasingly recalcitrant forms. Decomposition of these gigantic polysaccharides is limited by lack of enzymes capable of their initial hydrolysis. (Otherwise, adding mineral N to mature compost, straw, or wood waste would result in the dramatic decomposition of carbon substrates.) These exoenzymes, often originating with fungi, usually are rare in grassland soils and are absent from biologically inert coversoils. When carbon becomes available to soil microorganisms, it cannot be assimilated except in ratio to N and other nutrients. For these and environmental reasons, decomposition is slow. When mineralized, most nutrients rarely persist in inorganic form long enough for plants to access them because the microflora assimilates essentially all the nitrogen contained in protein-poor residues. The apparent retarding influence of carbohydrates on the production of ammonium from proteins and amino acids may be attributed to an assimilation of ammonium by the additional organisms appearing in the decomposition of the carbohydrate (Alexander 1991, Chapter 15).

Thus the C:N ratio reveals only part of the picture of N availability. In practice, as C becomes recalcitrant, substrates such as wood chips act more as bulking agents than as N sinks. Further decomposition is limited by critical enzymes, not just the quantity of available N. If mineral N is applied to amended coversoil, vascular plants will get most of the nitrogen, not the microflora.

For a producer, the C:N ratio can be altered only by changing the original feedstock (more N) or by letting the compost sit longer while the ratio narrows. But as carbon is respired, the physical quantity of compost decreases. The producer is much more likely to apply relatively inexpensive mineral fertilizer. Now we have a C:N ratio near "equilibrium," but it consists of mineral N and a pool of recalcitrant C. The initial justification for a narrow ratio has been stood on its head. Nitrate levels of amended soils become elevated in the plant establishment phase and infertile later, a subject already discussed.

MICROBIOLOGICAL CONSIDERATIONS

In amending coversoils originating as deep (>1 m) borrow material, the microflora in compost is among its most important potential long-term contributions. Microbial enzymes are key agents of the decomposition and transformation of organic substrates. Without them, there will be no nutrient cycling. The heterogeneity of organic constituents and important environmental conditions such as temperature, reactivity, fertility, and moisture largely determine which class and even which species of soil organisms are most active for a given substrate and environment. Each species has a complex of enzymes that is effective on a fixed array of chemical compounds, but not others.

A good organic amendment for biologically inert coversoils should provide an incipient "soil food web." The idea is to provide a diverse set of beneficial microorganisms, the best-adapted of which will establish in the coversoil, feeding off the organic amendment first and plant residues as they become available. Having the proper microorganisms in the soil is important to prevent disease in vascular plants as well as for nutrient cycling. Soil organisms hold nutrients in the soil. Without bacteria and fungi in the soil, most applied fertilizer will wash through the soil, which explains why Reeder (1990) found that fertilized spoil was ineffective in providing N to vascular plants.

Nutrient cycling cannot occur without several groups of soil microorganisms. Soils contain five major groups: bacteria, actinomycetes, fungi, algae, and protozoa. In adequately aerated soils, bacteria and fungi dominate, whereas bacteria alone account for most biologic activity where oxygen is strongly deficient (e.g., wetlands). Actinomycetes are important in the composting process, especially at elevated temperature. Compost is not expected to contain a significant number of mycorrhizal fungi.

In evaluating compost, focus on total (as opposed to active) bacteria and fungi, protozoa and nematode density, and the ratio of bacteria to fungi. In grasslands, a bacterial dominance is normal, but the fungal component remains important. The optimal ratio of fungi to bacteria changes with soil type, but, in general, grassland soils have bacterial dominance, whereas soils of woody plants have fungal dominance. Units for bacteria and fungi are ug/g dry compost.

Bacteria are the major decomposers of alkaline soils and quickest to respond to changes in environmental conditions and substrate. They are most effective on labile compounds, and their populations can build very quickly when food is available. Bacteria produce "slime layers" around their bodies, which they use to glue themselves to surfaces. This prevents them from being washed out of the soil and is a major agent of microaggregation of soil particles. This slime layer is most often made of alkaline materials, which may cause soil to become more alkaline. In alkaline

environments, maintained by the slime layers and secondary metabolites that bacteria produce, nitrifying bacteria thrive and convert ammonium to nitrate quite rapidly. Nitrate is the preferred form of N for most grasses. Thus, these plants grow best in bacterial-dominated soils.

Composts A and C had the same amounts of active and total bacteria, with Compost B lagging.

Fungi: Fungi are important decomposers of intermediate and recalcitrant forms of carbon (including otherwise toxic compounds), especially in acid soils. Fungi make organic acids as their waste products, lowering the pH of initially neutral substrates. Because fungi maintain soil pH on the acidic side, and indeed, beneficial fungi appear to buffer soil pH between a pH of 5.5 and 6.5, nitrifying bacteria are excluded from the food web in strongly fungal-dominated soils. Fungi retain N in the soil, compete with some pathogens, and promote soil aggregation. Fungi grow as long threads which bind the microaggregates together into macroaggregates. Aerobic bacteria may fix only 5-10% of the carbon from a substrate compared to 30-40% by fungi, so OM accumulates more rapidly in fungal-dominated soils.

Total and active fungi were highest in Compost A. Total fungi biomass in Composts B and C was very low, suggesting they may have become anaerobic during the composting process.

Protozoa are primitive, single-celled animals. Bacteria are eaten by protozoa and bacterial-feeding nematodes, releasing ammonium into the soil. Protozoa are essential for nutrient cycling. Without protozoa, nutrients become immobilized in bacteria for too long and vascular plants suffer. Straw and hay (as in mulch) can provide a good inoculant. Among composts, products A and C were excellent sources, whereas Compost B lacked protozoa.

Nematodes are unsegmented worms; all terrestrial species are microscopic. Fungi are eaten by fungal-feeding nematodes, a few species of large amoebae, and fungal-feeding microarthropods. Nematodes can be common in compost but may not be critical in local grassland soils. Check a healthy local soil to see how important nematodes are locally.

Composts A and C contained some bacteria-feeding nematodes, and Compost A also contained a fungi-feeding species of nematode. (Compost C had virtually no fungi, hence no fungi-feeding nematodes.) Compost B not only had few desirable nematodes, but it also contained a root-feeding nematode -- good compost shouldn't contain any root-feeding nematodes. Zero.

Summarizing microbiological factors, Compost A was superior, Compost C was good in some respects but lacked fungi, and Compost B was inferior in all respects.

The following densities are characteristic of good compost:

1. Total Bacteria: >100 ug/g (ug/gram dry weight [gdy] of compost).

2. Total Fungi: >100 ug/g (for compost with a strong wood component).

3. Protozoa: >30,000 individuals per gdy.

4. Nematodes: Zero root-feeding nematodes. A specified minimum density of beneficial nematodes may be appropriate for some coversoils, depending upon the indigenous density in native soils.

In writing technical standards for compost, fungi density might be lowered to 50 ug/g for grassland soils. A minimum protozoa density might be 10,000 per gdy.

CONCLUSIONS

It is important to tie compost requirements to other aspects of the revegetation plan, including anticipated temporal developments. Compost can be a big budget item, and should provide commensurate benefits to both plants and soils.

Nutritional effects of amendments must not exceed mineralized nutrient targets in coversoils, but nitrate levels can be above targets because establishing vascular plants will immobilize it quickly. Below-target macronutrient concentrations are less of a problem than excesses.

Unless decomposition complements primary productivity, revegetation will eventually stagnate no matter how good it looks initially. A good amendment should initiate a healthy soil food web in biologically inert coversoil. Where a functioning soil food web exists, OM acts more like food for existing microorganisms. Soil microbes are agents of soil aggregation in addition to their direct effects on plant performance.

It is important to recognize that no reasonable amount of compost will make marginal soil materials into good ones. Although a good organic amendment will advance the development of biologically inert coversoils, organic amendments are not humus. However, a proper compost with incipient soil food web can greatly advance soil development and enhance the performance of coversoil as a plant growth medium

REFERENCES

Alexander, M. 1991. Introduction to Soil Microbiology. Second ed. Krieger Pub. Co., Malabar, FL. 467 pp.

Anonymous. 1975. Range fertilization experiments, Central Montana Agricultural Research Center, Moccasin, MT. pp. 20-51 *In:* Proceedings Range Fertilization Symposium, Havre, MT, July, 1974. Mt. Ag. Expt. Sta. - MSU Res. Rept. 70.

Reeder, J. 1990. Nitrogen cycling in disturbed lands. pp. 122-137 *In*: Proceedings High Altitude Revegetation Workshop No. 9. July. Co. St. Univ. – Co. Water Resource Research Inst. Information Series No. 63. 257 pp.

St. John, T. 1998. Personal communication. Mr. St. John holds in doctorate in mycology and is an expert in mycorrhizae.

St. John, T. 1996. Mycorrhizal inoculation: advice for growers & restorationists. Hortus West 7(2). Pages not listed in reprint.

2000 Billings Land Reclamation Symposium

SOIL AND WATER QUALITY ASSOCIATED WITH LAND APPLICATION OF BIOSOLIDS FOR SURFACE MINE RECLAMATION: FOUR CASE STUDIES

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ABSTRACT

Land application of biosolids (municipal and industrial wastewater treatment plant solids) was employed as a beneficial-use soil amendment for reclamation of four surface coal mines in Pennsylvania. Soil and water quality data collected for regulatory reporting before, during, and after biosolids application were analyzed to assess the effects of application on site soils and surrounding receiving water points. The number of background water samples included in the regulatory sampling program was found to be insufficient to make comparisons between pre- and post-application water quality conditions. Soil sampling data from the biosolids application areas indicate that phosphate levels are relatively constant for the first four years following application, while potash and magnesium levels decrease by approximately 15 percent per year, and cation exchange capacity decreases by approximately 9 percent per year. Although declining trends were observed for the latter parameters, post-application levels of all four parameters were significantly higher than pre-application levels, and the addition of biosolids to severely disturbed soils benefits soil quality in the short term and promotes long-term improvements in soil fertility. Additional data not included in the regulatory monitoring program for these sites would be required to fully evaluate the success of biosolids application with regards to water and soil quality.

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INTRODUCTION

Restoration of acceptable vegetative cover on reclaimed mine lands can be difficult because post-mining soils often have a less developed soil structure and reduced organic matter and plant-available nutrient contents than the original in-situ soils. Bulk stripping of soil tends to mix organic topsoil and mineral subsoil horizons, resulting in a new media on which it can be difficult to establish and maintain vegetative cover. Segregation of soil horizons during site clearing and replacement of horizons in their original order is impractical, and it is still inevitable that productive soil structure and properties will be lost. Additionally, on many mine sites, thin soils or poor initial soil quality precludes stripping and replacement, necessitating the use of a manufactured soil substitute created from crushed spoil and various amendments. A common solution in Pennsylvania has been the addition of organic material and mineral fertilizer to either the stockpiled soils or crushed spoil to create a material capable of supporting seed germination and establishing initial plant cover.

One class of organic amendments being increasingly used for mine reclamation is biosolids, which are municipal and industrial wastewater treatment plant byproducts that possess a high organic-carbon content, contain valuable plant-available nutrients, and have a high water holding capacity. Municipal sewage sludge is probably the most common biosolid used for mine reclamation, but many industrial and food processing operations can yield similar materials. These materials are often disposed of as a solid waste, but biosolids are now widely recognized by regulators as a beneficial soil amendment and are increasingly being used in agricultural and mine reclamation activities. Biosolids offer the double advantages of superior vegetative establishment on disturbed soils for the mine operator, and reduction of landfill disposal costs for the biosolids generator.

The Soil Foodweb

In healthy soil, there are typically millions of microscopic organisms that live in the soil and around the roots of plants. The environment that these organisms inhabit and the ways in which they interact with each other and with plants is called the soil *foodweb*. There is an optimum balance of soil air, water, nutrients, and different microorganisms that allows plants to establish and thrive. Healthy soil should have a developed structure with voids for soil air and water, a balanced supply of plant-available macro- and micro-nutrients, as well as contain beneficial species of bacteria, fungi, nematodes, and protozoa, which are often missing in severely disturbed mine soils.

Developing the proper physical, chemical, and biological environments in the root zone can yield substantial benefits to mine soil reclamation projects. A balanced soil foodweb will: (1) suppress disease-causing and pest organisms; (2) retain nitrogen and other nutrients, such as calcium, iron, potassium, and phosphorus; (3) make nutrients available for plant growth at the times and rates that plants require; (4) decompose plant residues rapidly; and (5) produce good soil structure, improving water infiltration, oxygen diffusion, and water-holding capacity.

Disease suppression requires specific species of soil bacteria and fungi that compete with, inhibit, and parasitize disease-causing organisms. A plant uses a minimum of 25% of its fixed energy each year to feed beneficial organisms in the volume of soil around its roots. Pesticides and intensive earthmoving activities (bare soil for long periods) significantly reduce the diversity and amount of these beneficial organisms. In order to reestablish a viable soil foodweb, these organisms must be reintroduced through inoculation or through feeding with the right kinds of materials. A healthy soil contains a broad diversity of microbial types and most often contains species that consume, inhibit, or suppress the kinds of fungi that cause root rots and the kinds of nematodes that attack roots.

Nitrogen and other nutrients can leach out and be lost unless they are contained in less mobile forms in the soil until required for plant growth. Nutrient retention can occur when bacteria and fungi multiply in an organic-enriched environment and increase their populations in the soil. When bacteria and fungi multiply, they gather nitrates, ammonium, and other forms of nitrogen from the soil and convert it into protein in their bodies. Nitrogen in this form does not leach easily and is not lost as a gas. Products and cultural practices, such as biosolids applications that stimulate a "bloom" of bacteria or fungi reproductive growth, can be used as tools to achieve nutrient retention. When this function is working in the soil, lower rates of nitrogen and phosphorus can be applied with no reduction in crop yield. Organic amendments such as biosolids help retain the soils' N, P, S, Ca, K, Fe, etc, for plant use, and make these parameters less likely to leach into surface or groundwater resources.

Plant residues will only decompose if certain species of fungi and bacteria, the "decomposers," digest them and allow the nutrient recycling processes to occur. The ideal decomposition process forms large amounts of humus. The decay function breaks down plant residues and converts the food energy in fresh organic matter into biological forms that feed other soil organisms that perform different indispensable functions.

In order to maintain a well-aggregated soil structure (i.e., to improve or maintain good tilth), the organisms that glue, bind, and engineer soil structure and soil pores must be present. Good tilth or good soil structure allows optimum infiltration of air, water, and roots. Aggregates will not form unless sand, silt, and clay particles are "glued" together by the gums and gels that many species of soil bacteria produce. These aggregates are further strengthened against collapse by species of beneficial fungi that grow throughout the aggregate and physically bind it. The large pore spaces holding "reservoirs" of water must be built by larger organisms: microarthropods, earthworms, beetle larvae, enchytraeids, etc. The better the set of soil organisms producing resilient structure, the more "strength" a soil will have to resist damage, such as by vehicle passage.

Site Backgrounds

The four biosolids application sites, referenced herein as the PS, MS, SM, and PAC sites, were surface bituminous coal mines located in central Pennsylvania. The mines were situated on ridge crests above incised stream valleys, and discharged through erosion and sedimentation controls during the application periods. Reclamation typically progressed in

phases, with biosolids application occurring following regrading of mine spoils and, when employed, replacement of stockpiled soils. Biosolids and fertilizer were applied one time on each regraded area, incorporated, and then seeded.

The applied biosolids were a "mine mix" consisting by dry weight of approximately 57% wood chips and 43% municipal sludge cake obtained from the Philadelphia Water Department (wastewater treatment solids). The mine mix was applied to achieve 60 dry tons of sludge per acre, equivalent to 332 wet tons as received when accounting for the moisture content of the mix material. Spreading occurred between April 15 and September 15 using conventional tractor-towed agricultural manure spreaders. After initial spreading, the mine mix was incorporated into the upper 6 to 12 inches of the regraded spoil surface using a chisel plow. Lime additions and any needed N-P-K fertilizers were applied on a site-specific basis as determined by nutrient analysis of the stockpiled soil or spoil.

Between 1993 and 1998, Gannett Fleming monitored soil and water quality on the four sites to satisfy land application permit reporting requirements administered by the Pennsylvania Department of Environmental Protection (PADEP). Following completion of the monitoring programs, Gannett Fleming examined these data sets to quantitatively evaluate the impact of the four application projects on water quality and the regulatory-selected soil quality parameters of nutrient levels and cation exchange capacity (CEC).

METHODS

Water quality monitoring points surrounding the application sites were selected in accordance with PADEP requirements to represent upstream and downstream conditions in receiving streams, downgradient groundwater discharges, and private water supplies. Sample parameters included a wide range of physical and chemical parameters, including nutrients and EPA priority pollutant heavy metals. The PADEP monitoring schedule for the application sites included collection of two background samples prior to biosolids application, and quarterly sample collection concurrent with and following biosolids application until the PADEP released the sites from further sampling. The water sampling duration ranged from 1 to 2 years following application.

Soil samples for PADEP reporting were collected from representative plots within the application areas of each mine site, with the number of samples varying depending on the size of the site. Samples were collected from the upper 6 to 8 inches of the soil surface by grab methods. Laboratory analyses of soil macro- and micro-nutrient levels and exchangeable cations were performed by the Agricultural Analytical Services Laboratory (AASL) of the Pennsylvania State University. The AASL provided results in the form of recommendations for liming and nutrient amendments for each sample based on the determined background soil levels, type of desired cover crop, and regional climatic conditions. In this study, initial pre-biosolids application samples were collected on three of the four sites, with no background sample required for the SM site. Additional samples were then collected on all four sites annually following biosolids application until the PADEP released the sites from further sampling. The duration of soil sampling ranged from 3 to 4 years following application.

RESULTS

The following presents the findings of the water and soil quality analyses for the four sites in composite, with discussion of the specific factors that may influence the results observed for each of the parameters considered.

Water Quality

After an analytical review of the water quality sampling programs for the four application sites, it was determined that the data sets were insufficient in size to reliably determine differences in water quality conditions due to biosolids application. All data in this study were collected solely for regulatory compliance purposes, which did not lend itself to a proper statistical design and analysis (treatment vs. effect). The PADEP required only two initial background samples and this proved inadequate to quantify baseline water quality conditions that existed prior to biosolids application. Valid analysis would require a minimum of one year of pre-application water quality baseline data, coupled with control samples from an area with no biosolids amendment or solely conventional mineral fertilizer amendment. No significant isolation of treatment vs. effect can be drawn, so the water quality analysis is not presented in this paper.

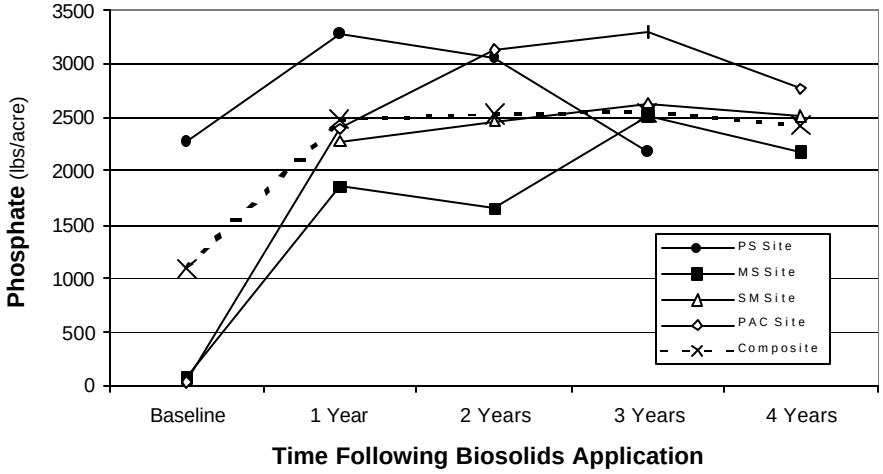
Soil Quality

The soils data sets were similarly shaped by the regulatory requirement of one round of background samples. However, these have been found more relevant because the post-application information covers a longer period than the water quality sampling, and the reported soil parameters are not expected to be as heavily influenced by seasonal fluctuations. Overall trends in soil parameters were found to be reasonably consistent over time and between separate sites. The results discussed here are for the soil macro- and micro-nutrient levels of phosphate, potash, and magnesium nutrient levels and overall soil CEC. These parameter trends are presented in Figures 1 – 4, respectively, as the composite trends for all the samples of each individual site and as a composite of the sampling data for all four sites.

Phosphate

Phosphate is not a highly mobile parameter (as compared to nitrate) and is normally only lost through erosion and plant uptake. In Figure 1, phosphate levels on the individual biosolids application sites varied between 1,650 and 3,280 pounds per acre (lbs/acre) in the years following application. The composite trend for all site data indicates little variation with time from an average of about 2,500 lbs/acre. None of the composite averages for years following application are significantly different from preceding post-application years. These data indicate that a good cover crop has been established and that erosion has not removed this plant-essential macro-nutrient provided by the biosolids application. Due to the large initial phosphate application rate, it is likely that any reduction in soil levels due to plant uptake has been overshadowed during these first four years.

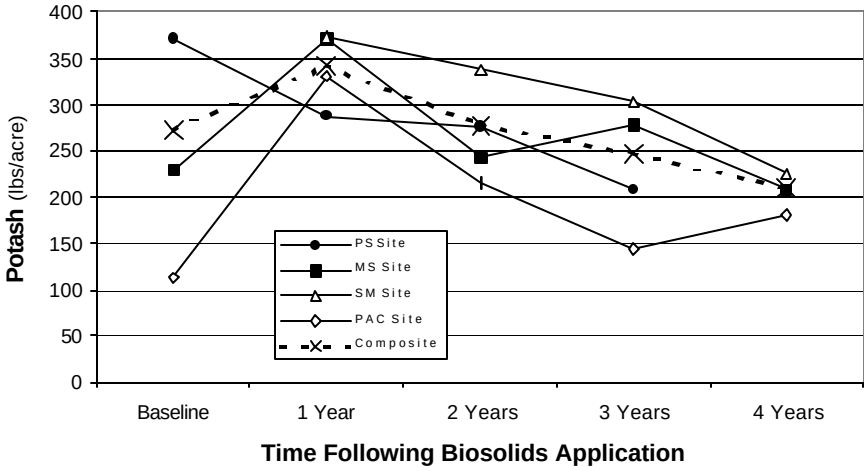
Figure 1. Phosphate Nutrient Levels with Time



Potash

Potash levels shown by Figure 2 range from a high of 373 lbs/acre to a low of 144 lbs/acre in a relatively consistent diminishing trend for the individual sites. This is apparent in the composite trend as well, with potash levels decreasing by approximately 15 percent each year following biosolids application. These decreases are highly significant between Year 1 and Year 2, and significant between Year 2 and Year 3, but not significant between Year 3 and Year 4. These decreases in potash levels are in agreement with the typical plant uptake rate of 200 lbs/acre for the cover crop of cool season grasses. The leveling off of potash removal between Years 3 and 4 may indicate the beginning of nutrient cycling in the newly established biosolids-amended mine soil.

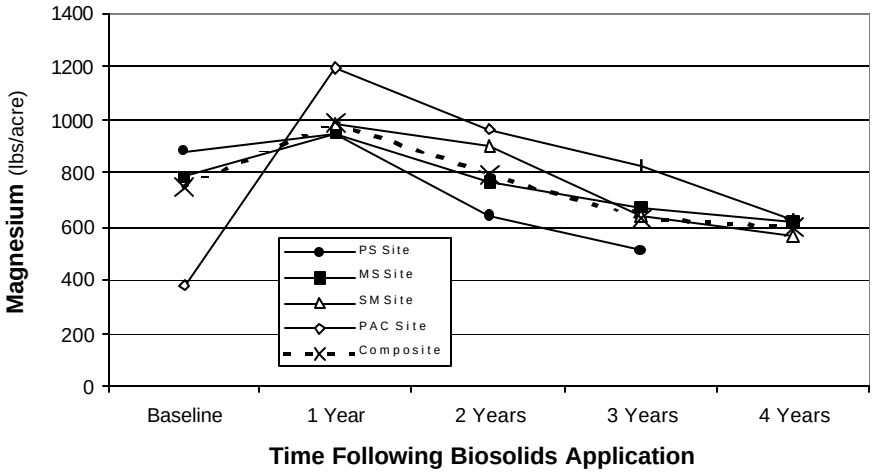
Figure 2. Potash Nutrient Levels with Time



Magnesium

Trends for magnesium levels, shown by Figure 3, are similar to those for potash and range from a high of 1,195 lbs/acre to a low of 507 lbs/acre. The average decrease of the composite trend is also about 15 percent per year following biosolids application and appears to begin an asymptotic reduction in change in Year 4. Decreases in magnesium levels are highly significant between Year 1 and Year 2, and between Year 2 and Year 3, but are not significant between Year 3 and Year 4. Soil magnesium is a moderately leachable nutrient and greater amounts are often found in the subsoil than in upper parts of the profile. The initial decreases in soil magnesium are likely due to plant removal and may indicate that the more mobile forms of magnesium (primary, acid soluble, and exchangeable) have moved below sampling depth, leaving mainly the organically-complexed material in the top horizon.

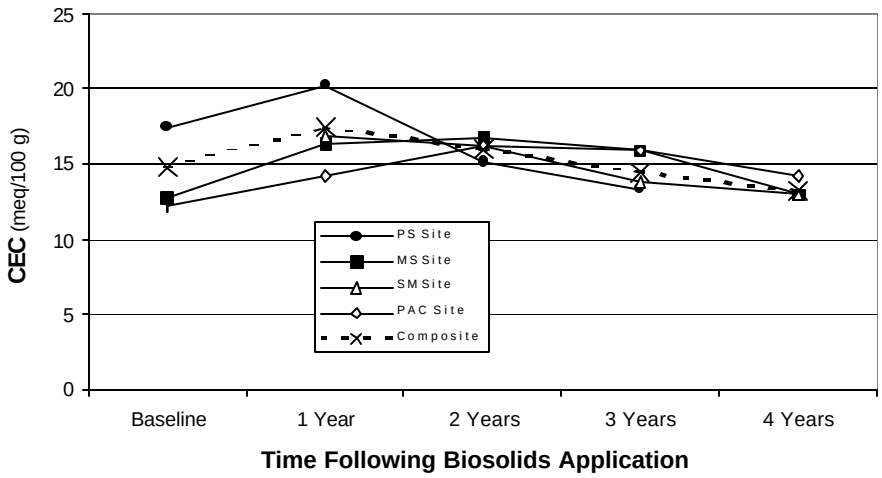
Figure 3. Magnesium Nutrient Levels with Time



Cation Exchange Capacity

CEC trends between the four sites are relatively well grouped on Figure 4, ranging from a high of 20.2 meq/100g to a low of 12.9 meq/100g for the individual sites. The composite trend is consistent over time and averages a decrease of approximately 9 percent per year following biosolids application. The decrease between Year 2 and Year 3 is highly significant, while the decreases between Year 1 and Year 2, and between Year 3 and Year 4, are just under the threshold of significance. CEC can vary depending on soil pH, and broad trends in the soil data suggest that in the initially acidic soil samples, pH rose as expected after the lime and biosolids application. The soil pH and CEC decreased over time in these same samples, and this is attributed to acid deposition (rain) and the formation of organic acids. In the initially acidic and low CEC level pre-application soils, biosolids and lime raised the CEC significantly.

Figure 4. Cation Exchange Capacity with Time



DISCUSSION

Regulations governing the land application of biosolids stress that these materials should pose no greater risk to the environment and the public health than conventional reclamation materials (mineral fertilizers and lime). With this as the guiding principal, the required regulatory sampling is heavily slanted towards the more easily understood and commonly measured soil chemistry parameters. This study found that this type of testing stresses only the "chemical" fertilizer benefits of biosolids, and provides a poor evaluation for this proven reclamation method. Of the three primary soil quality factors - physical, chemical, and biological - the least measurable benefits from biosolids applications are related to soil chemistry. The greatest benefit of biosolids is in helping rebuild soil structure and restock the soil foodweb for beneficial biological organisms.

Biosolids-amended soils by definition have a higher organic matter content and, therefore, increased water holding capacity, tilth (porosity), nutrient holding capacity, buffering capacity, availability of soil minerals, activity of soil microorganisms, and both short- and long-term improvement in soil fertility. The authors have worked with biosolids in numerous reclamation and agricultural settings and found their use to be highly beneficial in establishing and maintaining plant growth in harsh conditions. In our studies provided to regulators, yields of plant biomass and health evaluations of plants cultivated in biosolids-amended soil were always significantly higher than the control samples (untreated soil). Laboratory surface and groundwater water quality assessments showed that biosolids were a clean, low-impacting source of plant nutrients, and have lower non-point source pollution potential than commercial fertilizers. Nitrogen and phosphorous content of the surface runoff and groundwater recharge from biosolids-amended soils were less than that of fertilizer-amended soils, even in the extreme case where the total nitrogen application rate was 10 times greater for the biosolids than for the mineral fertilizer.

CONCLUSIONS

The trends in soil nutrient content and CEC observed on the four biosolids application sites are consistent with establishment of viable soil foodwebs within the reclamation soils. Biosolids are an effective means of improving soil structure and nutrient content on mine reclamation sites. However, current regulatory monitoring programs may not provide sufficient background information to reliably assess the benefits and impacts of biosolids applications, particularly with regard to water quality and the physical and biological properties of reclamation soils.

REFERENCES

Fixen, P. E. and J. H. Grove. 1990. Testing Soils for Phosphorous. In: R. L. Westerman (ed) Soil Testing and Plant Analysis, Book 3. Soil Science Society of America , Madison, WS.

Harby V. A., Russelle, M. P., and E. O. Skogley. 1990. Testing Soils for Potassium, Calcium, and Magnesium. In: R.L. Westerman (ed) Soil Testing and Plant Analysis, Book 3. Soil Science Society of America , Madison, WS.

Herlihy, T. E., and W. H. Billings. 1996. An Environmental Assessment and Feasibility Study of Using Vegetable Tannery Biosolids as a Soil Conditioner/Plant Growth Supplement. Journal of the American Leather Chemists Association. 1996 (91), No. 3, pg.64-79.

Herlihy, T. E. (1999). An environmental assessment of vegetable tannery biosolids as an organic fertilizer and soil conditioner. In: G. G. Gross, R. W. Hemingway, T. Yoshida, Plant Polyphenols 2: Chemistry, Biology, Pharmacology, Ecology. Kluwer Academic/Plenum Publishers, New York, N.Y. (in press).

Kuhlman, L. R. 1992. Value of composting cattle feedlot manure. Australian Lot Feeders Association Conference (BEEFEX 92) Coffs Harbour, New South Wales, Australia.

Pennsylvania State University Agronomy Guide, 1997-1998. 1994. University Park, PA.

Stevenson, F.J. 1991. Organic Matter-Micronutrient Reactions in Soil. In: J. J. Mortvedt et al (ed), Micronutrients in Agriculture, Book 4. Soil Science Society of America, Madison, WS.

Stomberg, A. L., Hemphill, J. R., and V. V. Volk. 1894. Yield and Elemental Concentration of Sweet Corn Grown on Tannery Waste Amended Soil. Journal of Environmental Quality (13), No.1, pg. 162-166.

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ALKALINE INDUSTRIAL BY-PRODUCTS AS MINE WASTE AMENDMENTS*

S.R. Winking[1] and D.J. Dollhopf[2]

ABSTRACT

A great amount of neutralizing chemicals are necessary to remediate acidic mine wastes in the Butte and upper Clark Fork River Basin, Montana. A potentially important alternative to commercial-grade lime used to treat acidic/metalliferous mine tailings exists in recycling industrial by-products such as kiln dust from the production of cement and lime. A greenhouse experiment was conducted to test the efficacy of industrial by-product lime materials vs. commercial liming products as alkaline amendments for acidic/metalliferous tailings from the Butte-Anaconda site. Industrial by-products tested were lime kiln dust from the Continental Lime facility near Townsend, MT and Di-Cal, a product resulting from the production of magnesium from dolomite, from Northwest Alloys in Addy, Washington. A completely random experimental design was instituted with four replications of each treatment. The substrate used was tailings from the Opportunity impoundment in Anaconda, Montana. Treatments tested were: greenhouse potting soil control, unamended tailings; tailings amended with commercial grade calcium carbonate and calcium oxide; tailings amended with Townsend lime kiln dust; and, tailings amended with Di-Cal. Two plant species were planted, *Thinopyrum intermedium* (Intermediate wheatgrass) and *Elymus trachycaulus* (Slender wheatgrass). All treatments received an equal fertilizer and water application.

Results indicate that Di-Cal, although an excellent neutralizing amendment, has unknown chemical constituents that significantly reduce plant growth. Based on these data, tailings treated with the industrial by-product Townsend lime kiln dust produced plant growth comparable to that attained with commercial lime.

However, in the Montana Limestone commercial lime amended tailings, some of the CaO had not been sufficiently carbonated to $CaCO_3$ indicated by a root zone pH of 9 during the plant growth period. Therefore, the lower nutrient availability and potential caustic effects on plant roots may have emanated in a lowering of the plant growth characteristics of the commercial lime treated tailings. So if the pH had been <8.5 in the Montana Limestone commercial lime, the plant productivity may have been greater.

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INTRODUCTION

Throughout the United States, certain agricultural or mining practices have left large areas of land too acidic to support normal plant growth. The standard method for treating these acid soils relies on commercial-grade lime, which is very expensive, often prohibitively so in the Northern Plains and other areas of the United States. This experiment evaluated an alternative approach one that is both lower cost and environmentally attractive. The new method recycles alkaline industrial by-products that are presently disposed of in landfills, using these inexpensive by-products to chemically treat soil acidity.

Because there is little or no market for these alkaline by-products, which are now simply placed in landfills, they can be acquired at little or no cost. An added benefit is that utilization of these by-products results in removal of a potential industrial waste stream. This potentially valuable resource is being lost to landfills. The experiment outlined here investigated the use of alkaline industrial by-products to treat soil acidity in waste materials resulting from mining and evaluated this methods efficacy for facilitating good plant growth.

The Butte-Anaconda area of Montana has vast tailings deposits in the landscape that have elevated metal concentrations (Cu, Zn, Pb, Cd) and are highly acidic, with pH values typically ranging from 2.4 to 4.5. In the soil solution, these metals are soluble at pH levels lower than 5.5, a result that is phytotoxic to plant growth, and the tailing impoundments are devoid of vegetation. In Anaconda, Montana, alone, two tailing impoundments cover 3,800 acres of land.

The technology at present is to treat the acidity and heavy metal contamination with commercial-grade lime, such as calcium carbonate ($CaCO_3$), calcium oxide (CaO), or calcium hydroxide (CaOH). Greenhouse experiments and field tests have demonstrated that using these amendments will raise the soil pH level to a suitable range (6.5-8.5), which has enabled good plant growth. Raising the soils pH level precipitated the heavy metals and removed these contaminants from the soil solution, thereby removing the phytotoxic or inhibitory effects on plant growth.

The problem with this method is that treating such vast areas of land requires large amounts of expensive commercial-grade lime. Added to this tremendous cost are the costs of amendment incorporation, labor, seed, fertilizer, mulch application, etc. needed for successful re-vegetation. Utilization of alkaline industrial by-products to treat acid materials has potential to notably decrease land reclamation costs. However, these by-products may contain additional contaminants arising from 1) the ore body used, 2) from the industrial process of re-circulating the product through a kiln (which concentrates undesirable compounds), or 3) from the type of fuel used to fire the kiln. Preliminary research shows that some by-products can be enriched in heavy metals and in certain cases are at higher concentration levels than those at the sites to be treated (Dollhopf 1996ab). Therefore, plant growth must be tested.

MATERIALS AND METHODS

A bulk composite waste sample (661 liters) was collected from the Opportunity tailings impoundment (Pond D) located adjacent to Anaconda, MT. A specific pit location within Pond D has been used in past greenhouse investigations and the physicochemical characteristics of this material were known. These tailings are acidic (pH 2.2) and had an electrical conductivity of 16.9 dS/m. The total concentration of zinc was 470 ppm and copper was 410 pmm. The tailings had enriched levels of other metals and arsenic as well.

Approximately 23 kg of calcium carbonate (≤ 60 mesh) and calcium oxide (≤60 mesh) were acquired from Montana Limestone. A 44-liter bulk sample of lime kiln dust (LKD) was acquired from Continental Limestone, Townsend, MT. A 44-liter bulk sample of Di-Cal (a by-product resulting from the production of magnesium from dolomite) was acquired from Northwest Alloys in Addy, Washington.

The total lime requirement of the Opportunity tailings was calculated to be 17.4 g $CaCO_3$/200 g waste using an assessment of the potential acidity with acid-base accounting, and active acidity using the SMP test (Sobek et al. 1978 and McLean 1982). The lime requirement for the commercial limestone treatment was met using a 60% $CaCO_3$/40% CaO mixture. The physiochemical characteristics of the lime materials used are listed in Table 1:

Table 1. Physiochemical characteristics of the substrate treatments.

	Calcium		Gravimetric
Montana Limestone $CaCO_3$	94%	100	0
Montana Limestone CaO	105%	100	0
Townsend lime kiln dust	89.5%	100	0
Di-Cal	85.5%	100	0

Mixed substrates of tailings and lime materials that exhibited a saturated paste extract of >8.5 s.u. were purged with CO_2 gas and dry ice to transform oxides and hydroxides of calcium into carbonates, which resulted in a soil pH of < 8.5. This was verified with a saturated paste extract pH measurement prior to seeding. The substrate pH values before seeding and at the time the plants were harvested are listed in Table 2.

Table 2. Substrate treatment pH values before seeding and at the time the plants were harvested.

Substrate Treatments	pH (s.u.) prior to	pH (s.u.) post-
Unamended Opportunity tailings	2.19	3.57
Montana Limestone $CaCO_3$ and CaO	7.58	**9.0**
Townsend lime kiln dust	7.49	8.03
Di-Cal	7.65	7.64

These greenhouse growth trials were conducted in the Montana State University Plant

Growth Center. A completely random experimental design was instituted with four replications of each treatment. The study used two plant growth substrates, the greenhouse potting soil (optimal control) and Opportunity tailings. Each of the replications for all the controls and treatments received a fertilizer application of 377.0 kg/ha-Nitrogen, 280.3 kg/ha-phosphorous, and 103.7kg-ha potassium.

Two plant species were used as indicators of the effectiveness of the treatments in amending acidic-metalliferous waste: *Thinopyrum intermedium* (Intermediate wheatgrass, var. Tegmar) and *Elymus trachycaulus* (Slender wheatgrass, var. Pryor).

Each plant growth container consisted of a PVC pipe, 10.16 cm in diameter and 61 cm long. Substrates identified in Table 3 were prepared, and then used to fill each cylinder. Ten seeds per cylinder were planted 1.27 cm deep. Each cylinder was watered daily. After germination and emergence, plants were culled to five per cylinder. The growth period was 90 days. Greenhouse conditions were 14 hours of light per day with a daytime temperature of 21° C and a night-time temperature of 18 ^{o} C.

Table 3. Plant growth study treatments. Two plant species (Intermediate wheatgrass and Slender wheatgrass) were evaluated in 5 different substrate treatments and the experiment was replicated four times. This effort resulted in 40 growth cylinders.

Substrate	Treatment
Greenhouse potting soil	Control with NPK fertilizer
Opportunity tailings	NPK fertilizer
Opportunity tailings	Montana Limestone $CaCO_3$ and CaO with NPK fertilizer
Opportunity tailings	Townsend lime kiln dust with NPK fertilizer
Opportunity tailings	Di-Cal and NPK fertilizer

The following plant growth response variables were measured in each cylinder:

1. Above ground production - The above ground biomass of all plants after drying at 50 ^{o} C for 24 hours.
2. Height - Distance from the ground to the end of the longest leaf for each plant measured.
3. Maximum root length - The maximum root length in each growth cylinder measured in centimeters (cm).
4. Root distribution - The number of roots at 5 cm, 10cm, 20cm, and 30cm.
5. Vigor - Plant vigor characterized by a numerical value of 4 = robust; 3 = good; 2 = acceptable; 1 = poor; and 0 = dead. The greenhouse control provided a gauge for robust growth.

Data from plant growth response variables were applied to analysis of variance techniques and mean separation tests to ascertain whether significant differences are present at the 95% level of confidence ($p = 0.05$). Significant differences at were separated using the Student-Newman-Keuls method of pair-wise multiple comparison for equal size data sets. These analyses were made using SigmaStat (Jandel 1995).

GROWTH OF INTERMEDIATE WHEATGASS IN AMENDED TAILINGS

In the greenhouse potting soil, 82.5% of the Intermediate wheatgrass seeds germinated (Table 4). Conversely, no seeds germinated in the unamended tailings. In the Montana Limestone commercial lime, 70% of the seeds germinated and 57.5% and 60% of the seeds germinated in the Townsend lime kiln dust and Di-Cal respectively. There were no statistical differences between the lime treatments.

Above ground production of the Intermediate wheatgrass in the greenhouse potting soil averaged 9.3 grams and zero in the unamended tailing. Production in the tailings amended with Montana Limestone commercial lime was 1.9 grams (Table 4). The treatment amended with Townsend lime kiln dust produced 1.2 grams of above-ground biomass and the Di-Cal amended treatment produced 0.12 grams of plant material. In the amended tailings, the production was significantly less than the greenhouse potting soil. There was no significant difference between the tailings amended with commercial lime from Montana Limestone and the industrial by-product Townsend lime kiln dust. The Di-Cal amended tailings had significantly less production than the other lime materials.

Plant height in the Intermediate wheatgrass averaged 40.8 cm in the greenhouse potting soil, 38.3 cm in the tailings amended with Montana Limestone commercial lime, 38.3 cm in the Townsend lime kiln dust amended tailings, and 18.2 cm in the tailings amended with Di-Cal (Table 4). The unamended tailings had no plant growth. There were no statistical differences between the greenhouse potting soil, Montana limestone commercial lime, and the Townsend lime kiln dust industrial by-product. The Di-Cal amended tailings had significantly less plant height.

At the 5 cm and 10 cm soil depth, the Intermediate wheatgrass grown in greenhouse potting soil had significantly more fine roots (< 1mm diameter) than those grown in the Montana Limestone commercial lime (Table 4). The plants grown in the Townsend lime kiln dust amended tailings had significantly more fine roots than the plants grown in tailings treated with Di-Cal. There were no statistical differences in the number of coarse roots (1-2 mm and >2mm diameters) between any of the treatments. At the 20 cm soil depth, there were no statistical differences between the number of fine roots in the greenhouse potting soil plants and the plants grown in tailings amended with Montana limestone commercial lime and Townsend lime kiln dust. The plants grown in Di-Cal amended tailings had significantly less fine roots. At the 30 cm soil depth, there were no statistical differences between the number of fine roots in the plants grown in Montana Limestone commercial lime and those grown in Townsend lime kiln dust amended tailings, and significantly less fine roots in the greenhouse potting soil, Di-Cal, and unamended tailings plants. For the number of coarse roots at the 30 cm depth, there were no statistical differences between any of the treatments.

The greenhouse potting enabled significantly better plant vigor in the Intermediate

wheatgrass compared to other treatments. The Montana Limestone commercial lime and the Townsend lime kiln dust amended tailings were significantly better than the tailings amended with Di-Cal (Table 4).

GROWTH OF SLENDER WHEATGRASS IN AMENDED TAILINGS

In the greenhouse potting soil, 65% of the Slender wheat grass seeds germinated (Table 5). Conversely, no seeds germinated in the unamended tailings. In the Montana Limestone commercial lime treatment, 65% of the seeds germinated. The Townsend lime kiln dust treatment had 75% seed germination. In the Di-Cal treatment, 67.5% of the seeds germinated. There were no statistical difference between germination in the greenhouse potting soil and all lime treatments.

Above-ground production of the Slender wheat grass in the greenhouse potting soil averaged 7.9 grams and zero in the unamended tailings. Production in the tailings amended with Montana Limestone was 0.41 grams (Table 5). The Townsend lime kiln dust amended tailings produced 1.45 grams of above-ground biomass and the Di-Cal treatment produced 0.06 grams of plant material. In the amended tailings, the production was significantly less than the greenhouse potting soil. There was no significant difference between the tailings amended with commercial lime from Montana Limestone and the industrial by-product Townsend lime kiln dust. The Di-Cal amended tailings had significantly less production than the other lime materials.

Plant height in the Slender wheat grass averaged 46.5 cm in the greenhouse potting soil, 26.3 cm in the tailings amended with Montana Limestone commercial lime, 46.4 cm in the Townsend lime kiln dust amended tailings, and 11.1 cm in the tailings amended with Di-Cal (Table 5). The unamended tailings had no plant growth. There were no statistical differences between the height of plants grown in greenhouse potting soil and Townsend lime kiln dust amended tailings. The Montana Limestone commercial lime had significantly less plant height than the Townsend lime kiln dust and greenhouse potting soil treatments, and the Di-Cal had significantly less than the commercial lime.

At the 5 cm and 10 cm soil depth, the Slender wheat grass grown in greenhouse potting soil had significantly more fine roots (< 1mm diameter) than those grown in all other treatments (Table 5). The plants grown in Montana Limestone commercial lime and Townsend lime kiln dust amended tailings had significantly more fine roots than the plants grown in tailings treated with Di-Cal. The unamended tailings had no plant growth and there was no significant difference between the number of plant roots in the unamended tailings and those amended with Di-Cal. There were no statistical differences in the number of coarse roots (1-2 mm and >2mm diameters) at the 5 cm and 10 cm soil depth in any of the treatments. At the 20 cm and 30 cm soil depth, the Slender wheat grass plants grown in greenhouse potting soil had significantly more fine roots. The plants grown in tailings amended with Townsend lime kiln dust had significantly more fine roots than those grown in the Montana Limestone commercial lime and Di-Cal amended tailing did. There were no statistical differences between the number of fine roots in the plants grown in the Montana Limestone commercial lime, Di-Cal and the unamended tailings. The number of coarse roots (both 1-2 mm and >2mm diameters) at the 20 cm soil depth showed no significant differences in any of the treatments.

The greenhouse potting enabled significantly better plant vigor compared to other treatments. The Montana Limestone commercial lime and the Townsend lime kiln dust amended tailings produced plant vigor that was significantly better than the vigor of the Slender wheatgrass grown in tailing amended with Di-Cal (Table 5).

CONCLUSION

In the Montana Limestone commercial lime amended tailings, some of the CaO had not been sufficiently carbonated to $CaCO_3$ as indicated by a root zone pH of 9 during the plant growth period. Therefore, the lower nutrient availability and potential caustic effects on plant roots may have emanated in a lowering of the plant growth characteristics of the commercial lime. So if the pH had been <8.5 in the Montana Limestone commercial lime, the plant productivity may have been greater.

The results of this study indicate that Di-Cal, although an excellent neutralizing amendment, has unknown chemical constituents that significantly reduced plant growth. Based on these data, it appears that the industrial by-product Townsend lime kiln dust produced plant growth comparable to that obtained with commercial lime.

These results were obtained with optimal plant growth conditions such as daily watering, fertilizer, and optimal lighting regime to facilitate maximum plant growth.

Table 4. Mean plant growth response variables for **Intermediate wheat grass** grown in greenhouse potting soil, unamended Opportunity tailings, and amended Opportunity tailings, Anaconda Montana (n=4). All treatments had nitrogen, phosphorus and potassium fertilizer added.

	TREATMENT AMENDMENTS				
Response Variable	**Greenhouse Potting Soil**	**Unamended Opportunity tailings**	**Opportunity tailings amended with Montana Limestone $CaCO_3$ and CaO**	**Opportunity tailings amended with Townsend Lime Kiln Dust**	**Opportunity tailings amended with Di-Cal**
Germination (percent out of 10 seeds planted)	82.5a[1]	0c	70b	57.5b	60b
Above ground production (g)	9.303a	0c	1.907b	1.185b	0.123c
Plant Height (cm)	40.775a	0c	38.305a	38.324a	18.162b
Maximum root depth (cm) up to 32.5 cm	30.75a[2]	0b	32.5a	32.5a	28c
Root distribution at 5 cm depth (<1mm diameter)	193.75a	0c	112.5b	85.0b	18.75c
Root distribution at 5 cm depth (1-2 mm diameter)	16a	0a	4.75a	8a	0.75a
Root distribution at 5 cm depth (>2 mm diameter)	0a	0a	0.25a	0a	0.5a
Root distribution at 10 cm depth (<1mm diameter)	150a	0c	82.5b	71.75b	8.75c
Root distribution at 10 cm depth (1-2 mm diameter)	3a	0a	1.5a	5.25a	0.25a
Root distribution at 10 cm depth (>2 mm diameter)	0a	0a	0.25a	0a	0.5a
Root distribution at 20 cm depth (<1 mm diameter)	57.5a	0b	58a	80a	4b
Root distribution at 20 cm depth (1-2 mm diameter)	0.25a	0a	0.5a	2.25a	0.25a
Root distribution at 20 cm depth (>2 mm diameter)	0a	0a	0.25a	0a	0.5a
Root distribution at 30 cm depth (<1mm diameter)	6.25b	0b	44.5a	68.7a	1.25b
Root distribution at 30 cm depth (1-2 mm diameter)	0a	0a	0a	1a	0a
Root distribution at 30 cm depth (>2 mm diameter)	0a	0a	0.25a	0a	0a
Plant Vigor 0 = dead 1 = poor 2 = acceptable 3 = good 4 = robust	4a	0d	2.75b	2.75b	1.25c

[1] Means followed by the same letter in the same row are not significantly different.
[2] Numbers reported in this row are medians and not means.

Table 5. Mean plant growth response variables for **Slender wheatgrass** grown in greenhouse potting soil, unamended Opportunity tailings, and amended Opportunity tailings, Anaconda Montana (n=4). All treatments had nitrogen, phosphorus and potassium fertilizer added.

Response Variable	TREATMENT AMENDMENTS (1) Greenhouse Potting Soil	(2) Unamended Opportunity tailings	(3) Opportunity tailings amended with commercial $CaCO_3$ and CaO	(4) Opportunity tailings amended with Townsend Lime Kiln Dust	(5) Opportunity tailings amended with Di-Cal
Germination (percent out of 10 seeds planted)	65a	0.25b	65a	75a	67.5a
Above ground production (g)	7.9a[1]	0c	0.407d	1.447d	0.06c
Plant Height (cm)	46.485a	0d	26.265b	46.360a	11.060c
Maximum root depth (cm) up to 32.5 cm	33.75a	0b	32.5a	33.125a	22.625c
Root distribution at 5 cm depth (<1mm diameter)	212.5a	0c	71.25b	54.5b	19.5c
Root distribution at 5 cm depth (1-2 mm diameter)	5.5a	0a	3a	13.25a	0a
Root distribution at 5 cm depth (>2 mm diameter)	1.0a	0a	0a	0a	5.75a
Root distribution at 10 cm depth (<1mm diameter)	212.5a	0c	28.75b	52.75b	8.5c
Root distribution at 10 cm depth (1-2 mm diameter)	3.75a	0a	0.5a	5.0a	0a
Root distribution at 10 cm depth (>2 mm diameter)	1a	0a	0a	0a	2a
Root distribution at 20 cm depth (<1 mm diameter)	200a	0c	7.25c	46b	0.5c
Root distribution at 20 cm depth (1-2 mm diameter)	3.5a	0a	0.25a	0a	0a
Root distribution at 20 cm depth (>2 mm diameter)	1.0a	0a	0a	0a	0a
Root distribution at 30 cm depth (<1mm diameter)	200a	0c	4c	36.25b	0.5c
Root distribution at 30 cm depth (1-2 mm diameter)	3.25a	0a	0.25a	0a	0a
Root distribution at 30 cm depth (>2 mm diameter)	1a	0a	0a	0a	0a
Plant Vigor 0 = dead 1 = poor 2 = acceptable 3 = good 4 = robust	4a[2]	0d	2b	3b	1c

[1] Means followed by the same letter in the same row are not significantly different 0.
[2] Numbers reported in this row are medians and not means.

REFERENCES

Ashe Analytics. 1995. Clark Fork River Superfund Investigations Laboratory Analytical Protocol for XRF Analysis.

Brady, Nyle C. and Ray R. Weil. 1996. The Nature and Properties of Soils. Prentice-Hall, Inc. Upper Saddle River, New Jersey 07458.

Dollhopf, D.J. 1996 a. Suitability of lime kiln dust for neutralization of acid producing mine wastes: Report prepared for the Montana Department of Environmental Quality by Reclamation Research Unit, Montana State University, Bozeman, MT, Publ. No. 9602, 15 p.

Dollhopf, D.J. 1996 b. Suitability of cement kiln dust and coke ash for neutralization of acid producing mine wastes: Report prepared for Montana Department of Environmental Quality, by Reclamation Research Unit, Montana State University, Bozeman, Publ. No. 9601, 30p.

Dollhopf, D. J. and L. S. McDaniel. 1997. Effect of dolomitic industrial by-product on pH control and leachate chemistry of acidic-metalliferous mine wastes. Reclamation Research Unit Publ. No 9701. Montana State University, Bozeman, MT. 104 p.

Jandel Corporation. 1995. SigmaStat for Windows. Version 2.0

Kelly, L.S. 1997. Effect of two dolomitic industrial by-products on pH control, leachate chemistry and plant response on acidic-metalliferous mine waste. M.S. Thesis. Montana State University, Bozeman. 191 pages.

Lichthardt, J.J. and J.S. Jacobsen. 1992. Fertilizer guidelines for Montana: Montana State University Extension Service, Bozeman, MT, EB 104.

McLean, E.O. 1982. Soil pH and lime requirement. In: A.L. Page et al., eds. Methods of soil analysis, Part 2, Agron. Mono. 9. ASA and SSSA, Madison, WI. p. 199-225.

Sobek, AA., W.A. Schuller, J.R. Freeman, and R.S. Smith. 1978. Field and laboratory methods applicable to mine soils. U.S. Env. Prot. Agency. Cincinnati, OH. EPA-600/2-78-054. 204 p.

Soil Survey Staff. 1993. Natural Resource Conservation Service, Soil Survey Manual: Dept. of Agric. Hndbk No. 18, U.S. Government Printing Office, Washington, D.C.

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EVALUATING THE EFFECTIVENESS OF STREAMBANK STABILIZATION TECHNIQUES FOR REDUCING BANK EROSION ON THE UPPER CLARK FORK RIVER, WESTERN MONTANA

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ABSTRACT

Lateral channel movement on the upper Clark Fork River in western Montana has resulted in loss of valuable agricultural land and delivery of sediment and mine tailings into the river. In spring 1996, we initiated a study to evaluate the effectiveness of streambank stabilization techniques to reduce bank erosion. This study examines the effectiveness of 21 different bioengineering stabilization techniques used for reducing bank erosion on a large river system. The treatments incorporated a variety of materials; including container vegetation, willow (*Salix* spp.) pole cuttings, mature shrub transplants, log barbs, root wads, Douglas fir (*Pseudotsuga menziesii*) and Rocky Mountain juniper (*Juniperus scopulorum*) revetments, fascines, layered and non-layered coir (coconut husk) fabric, coir fascines, rock barbs, sod mats, gradient control, and riprap. Treatments were installed in fall 1996, spring and summer 1997, and fall 1998 on 23 areas totaling 1,735 m in length. Seven control reaches including 2,874 m of bank are also being monitored. 140 permanently monumented cross sections were surveyed before and after treatment implementation, after ice events in 1997 and 1998 for treatments established at that time, and after peak flow events in 1997 and 1998. Survival rates of various vegetative treatments were also monitored, and costs of construction for each individual treatment were calculated from detailed monitoring of construction activities. The 1996-97 and 1997-1998 ice events caused little erosion. However, the 1997 peak flow event caused substantial erosion of treatment and control banks. 1997 and 1998 peak flow erosion rates varied between treatments. Lateral migration rates for banks with treatments ranged widely from an erosion rate of 5.88 ft/year to a deposition of 0.5 ft/year. Three treatments (coir fabric and willow poles, Rocky Mountain juniper revetments and willow stakes, and container plantings alone) experienced very high rates of erosion (2.13, 3.65, and 5.88 ft/year). Six other treatments also experienced moderate levels of bank erosion in the years following treatment implementation. However, three treatments (sloped bank with coir fabric, container plantings and rock, coir fascine or willow/red-osier dogwood fascines), while untreated during the 1997 peak flow event, experienced very little erosion at all after the 1998 peak flow event compared to their pre-treatment erosion rates. The average erosion rates of the control sites from 1996-1998 varied from 4.6 ft/year to a deposition of 0.83 ft/year. A site established as a reference area for Clark Fork River erosion rates eroded at a rate of 0.02 ft/year. Cost of various treatment implementations ranged widely from a low of $5.58/ft to a high of $82.29/ft.

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INTRODUCTION

Like most rivers, the upper Clark Fork River naturally migrates across its floodplain. However, this rate of lateral channel movement appears to be accelerated above its natural rate. Factors contributing to an accelerated rate of lateral channel movement in the upper Clark Fork River watershed are difficult to identify. However, they can include changes in the uplands such as road building, timber harvesting, mining, and changes in the floodplain such as clearing for agriculture and development, grazing, and channelization by railroads and roads. Together these factors alter the timing, duration, and frequency of runoff and can prevent a river from naturally accessing its floodplain (Dunne and Leopold 1978). Accelerated lateral channel movement on the upper Clark Fork River has resulted in loss of valuable agricultural land and introduction of sediment and mine tailings into the river system.

In 1996, the Riparian and Wetland Research Program (RWRP) and ARCO Environmental Remediation, L.L.C. (AERL), initiated a streambank stabilization pilot study on the upper Clark Fork River. The objective of the study is to evaluate the effectiveness of various streambank stabilization techniques to reduce bank erosion. The treatments implemented in this study focus on bioengineering and the use of native riparian vegetation to stabilize banks instead of traditional "hard" treatments such as riprap.

STUDY AREA

Location

The study area is located in the upper Clark Fork River watershed in western Montana. Through most of the study area, bankfull widths range from 20–40 m, and the river can be described as a C4 channel (Rosgen, 1996). Typical treatment reaches consist of eroding, near-vertical banks ranging in height from three to seven feet above baseflow water levels. All treatment reaches are located on the concave (eroding) bank of channel meanders. The treatment reaches were not randomly selected as landowners requested assistance in stabilizing their banks. Since the treatment reaches were not randomly selected, the treatment reaches may not be representative of all the upper Clark Fork River banks.

Treatments

A total of 1,735 m of bank distributed across 23 areas on the upper Clark Fork River was treated between fall 1996 and December 1998. The treatments incorporated a variety of materials, including planted vegetation, log barbs, root wads, Douglas fir (*Pseudotsuga menziesii*) and Rocky Mountain juniper (*Juniperus scopulorum*) revetments, fascines,

layered and non-layered coir (coconut husk) fabric, coir fascines, rock barbs, sod mats, gradient control, and riprap. Planted riparian vegetation included willow (*Salix* spp.) pole cuttings, mature shrub transplants, and container vegetation. The materials were arranged into 21 distinct combinations and include the following:

- coir fabric and willow poles
- coir fabric, willow poles, and log barbs
- coir fabric, rock barbs, rock toe, and container plantings
- coir fabric, willow and red-osier dogwood fascine toe, and container plantings
- coir fabric, coir fascine toe, and container plantings
- coir fascine toe and container plantings
- container plantings
- Douglas fir revetments and willow stakes
- Rocky Mountain juniper revetments and willow stakes
- mature shrub transplants and willow stakes
- root wads, mature shrub transplants, and container plantings; and
- rock barbs and mature shrub transplants
- layered coir fabric, container plantings, and coir fascine toe
- layered coir fabric, container plantings, vertical willow stakes and rock toe
- layered coir fabric, container plantings, and rock toe
- layered coir fabric, container plantings , root wads, and coir fascine toe
- layered coir fabric, container plantings, mature transplants, root wads, and rock toe
- layered coir fabric, container plantings, vertical willow stakes, and coir fascine toe
- gradient control installation
- riprap
- sod mats

An additional 2,874 m of bank in seven areas was also monitored as controls. Control areas were selected that were similar in location, adjacent land use, and bank height and structure to treatment area sites. One of these areas, a particularly well-vegetated area, functions as a reference condition for upper Clark Fork River erosion rates.

METHODS

Treatment Implementation

Construction was completed on five treatment areas (FW01-FW04, and DT01) in October 1996, on eight areas in March 1997 (FW01, FW04, PRA1, PRA2, and PRB1-PRB4), on three areas in July 1997 (WLA0, WLA1, and WLA2) and on nine areas in October 1998 (DL02-DL10).

All treatments were designed and implemented with the long-term objective of establishing vegetation, both woody and herbaceous, on the streambanks. The vegetation

will help to stabilize the banks with its binding root mass and structural protection against the erosive forces of ice and water. Materials such as coir erosion control fabric, log barbs, cut conifer revetments, coir fascines, and rock were used to provide temporary protection until vegetation can establish. Following construction, the sites were fenced to allow the vegetation time to establish. Grazing is not precluded and may be used as a management tool to control weeds.

In order to determine the cost-effectiveness of each treatment in reducing bank erosion, the cost of equipment, materials, and labor expenses of the construction process during treatment implementation was closely tracked. Costs were tracked through daily logging of construction activities and through billing information provided by contractors. Costs associated with mobilization of equipment will vary depending on individual contractors and on distance traveled, and thus are not included. Project oversight costs by RWRP are also not included.

Monitoring

A total of 140 cross sections was established throughout the 23 treatment areas and monitored repeatedly over time. Permanently monumented cross sections were established at each site by placing 1.7 m long rebar into the floodplain on both sides of the river perpendicular to the flow every 17–70 m depending upon the channel width. For most study reaches, cross sections were spaced at a distance equal to the bankfull width of the respective study reach.

Cross sections were measured using protocols similar to those recommended by Harrelson and others (1994), Kondolf and Micheli (1995), and Rosgen (1996). Cross sections were measured at regular intervals with two-member teams using a laser level and graduated rod with laser detector. In all cases, at least 20 measurements were made between the bankfull indicators. The following features were also recorded at the appropriate stations for each cross section: left pin, left terrace, left bankfull, left edge of water, right edge of water, right bankfull, right terrace, and right pin.

All cross sections were measured at least once, but most were measured four times: after the 1996-97 ice event, after the spring 1997 peak flow event, after the 1997-1998 ice event, and after the 1998 peak flow event. Each cross section was also measured at least once before treatment implementation and at least once after treatment implementation.

Data Analysis

All cross sectional data was entered into a spreadsheet and then imported into a FileMaker's FileMaker Pro 4.0 relational database. Data for each cross section were standardized with the permanent left pin elevation, and the following computations were made: width, mean depth, cross section area, width/depth ratio, entrenchment ratio, estimated velocity, stress in the near bank region, and Manning's roughness coefficient.

RESULTS

Although relatively common in terms of its peak flow (6.67 year recurrence interval at the Deer Lodge gage [1,980 cfs] and 10 year recurrence interval at the Galen gage [1,210 cfs]), the spring 1997 flood was an unusual event because of its volume and duration. In stark contrast to the high intensity, high duration ice and peak flow events of 1997, the 1998 peak flows were less intense and peaked later. The 1998 peak flow also was shorter in duration than 1997, lasting approximately four weeks. The base flows however, occurred at a greater intensity than 1997. All treatment and control reaches experienced a significantly higher rate of erosion as a result of the 1997 peak flow event compared to the 1998 peak flow event.

Treatment Areas

Lateral migration rates for banks with treatments ranged widely from an erosion rate of 5.88 ft/year to a deposition of 0.5 ft/year (Table 1). However, despite the implementation of bank stabilization treatments, most treatments experienced erosion after the 1997 and 1998 peak flow events. The average rate of erosion for all treatments was 1.5 ft/year for the period from 1996-1998. All treatments experienced a significantly higher rate of erosion as a result of the 1997 peak flow event than due to the 1998 peak flow event or the 1997 or 1998 ice events.

Three treatments (coir fabric and willow poles, Rocky Mountain juniper revetments and willow stakes, and container plantings alone) experienced very high rates of erosion (2.13, 3.65, and 5.88 ft/year). Six other treatments also experienced moderate levels of bank erosion in the years following treatment implementation.

However, the WLA0, WLA1, and WLA2 treatments (sloped bank with coir fabric, container plantings and rock, coir fascine or willow/red-osier dogwood fascines), while untreated during the 1997 peak flow event, experienced very little erosion at all after the 1998 peak flow event compared to their pre-treatment erosion rates. Additionally, the coir fabric and sloped willow poles treatment appears to have experienced a minor amount of deposition since implementation.

Table 1. Lateral Erosion/Deposition Rates by Treatment

Reach	Description	Erosion/deposition (ft/year)
DT01	Rock barbs and mature transplants	-0.6
PRA1	Coir fabric and willow poles	-2.1
PRA2	Rocky Mountain juniper revetments and willow stakes	-3.7
PRB1	Container plantings	-5.9
PRB2	Mature shrub transplants and willow stakes	-1.3
PRB3	Coir fascine and container plantings	-1.8
PRB4	Coir fabric and willow poles	+0.5
FW01	Container plantings	-1.8
FW02	Coir fabric, willow poles, and log barbs	-1.6
FW03	Root wads, mature shrub transplants, and container plantings	-1.2
FW04	Douglas fir revetments and willow stakes	-1.5
WLA0	Coir fabric, rock barbs, rock toe and container plantings	+0.1
WLA1	Coir fabric, coir fascine toe and container plantings	0
WLA2	Coir fabric, willow and red-osier dogwood fascine toe, and container plantings	0
Treatment Average		**-1.5**
DT	Control	-0.5
BK	Control	+0.8
PRA	Control	-2.3
PRB	Control	-0.4
PRC	Control	-1.2
FW	Control	-0.3
WLA	Control	-0.4
WLB	Control	-0.4
WLC	Control	-4.6
Control Average		**1.1**
GP	Reference	-0.2

Control Areas

Erosion rates for areas established as control sites in Reach A and Reach B of the upper Clark Fork River were highly variable and ranged from a high of 4.6 ft/year to a deposition of 0.83 ft/year (Table 1). Control sites averaged an erosion rate of 1.08 ft/year.

Reference Area

A heavily vegetated river reach located in the Governor's Project demonstration could function as a reference condition for upper Clark For river erosion rates. The average erosion rate for this area from 1997-1998 was 0.02 ft/year.

Treatment Implementation Costs

Treatment costs ranged widely from a low of $5.58/ft for mature shrub transplants to a high of $100.03/ft for installation of a gradient control. The average treatment cost was $41.30/ft.

DISCUSSION

As expected, all treatments where vegetation was planted on the terrace away from the immediate bank (as in container plantings alone and mature transplants with willow stakes) and the bank was not adjusted (e.g. sloped), the bank continued to erode. Theoretically, this erosion would cease once the bank erodes to the point where the roots of the vegetation stabilize it.

Calculations for the WLA treatments (sloped bank with coir fabric, container plantings and rock, coir fascine or willow/red-osier dogwood fascines) indicate that in 1998, these treatments experienced substantially less bank erosion than they had in 1997 prior to treatment implementation. Additionally, the treatment of rock barbs and mature transplants (DT01) received only very minimal bank erosion as well.

It appears that each cross section of bank is affected by varying factors that contribute to its rate of erosion. Therefore, it may not be appropriate to directly compare control areas to treatment areas. However, it may be more appropriate to compare treatment banks to the same bank at pretreatment levels of erosion. In order to accomplish this, it would be necessary to monitor the banks for a full peak flow season before conducting treatments. It is also necessary to continue monitoring for several years in order to assess the effect of treatment on the rate of erosion under a variety of flow conditions. With this information, one would be in a better position to assess how individual treatments influence erosion rates by comparing the treatments to themselves and each other over time.

In general, treatments that required heavy equipment are less expensive than those that are labor-intensive. Treatments installed in March (spring) were more expensive than those installed in October or July (fall or summer), probably due to the high water and colder working conditions. Treatments which required substantial resloping of high banks (e.g., WLA1) are also considerably more expensive. Various treatments to stabilize the toe of the bank also affect the cost of the treatments. The costs of the seven layered coir fabric treatments ranged from $33.35/ft to $52.49/ft, with an average cost of $41.31/ft. These treatments all were structurally similar in that they contained a bank excavated to a 4:1 slope with coir fabric secured at the toe and then laid on a rock platform. Sod was placed on top of the fabric, and the fabric was then rolled back over the sod and stapled down. Main differences occur with the manner in which the toe was secured (rock toe or coir fascines) and in the vegetation used for stabilization (container plantings, vertical stakes, and mature transplants). Those treatments that used a coir fascine toe (DL02, DL05, and DL09) instead of rock toe (DL03, DL04, DL07, and DL08) had higher material costs. These treatments also used slightly more labor than treatments with a rock toe. Average cost of treatments using a coir fascine toe was $49.77/ft compared to the average cost of a rock toe ($34.99/ft).

The average cost of the treatments was $41.30/ft. However, when treatments are implemented on a large scale, costs should decrease. Factors such as substantial lead time to grow plant material or to work during the lowest water conditions, opportunities to order material in bulk, and lower mobilization expenses with longer treatment reaches should reduce costs. Familiarity with installation procedures can also contribute to reduced costs.

In general, those treatments that were implemented on shorter bank lengths seem to be more costly than similar treatments implement on longer banks. When implemented on the large scale, longer treatment reaches should reduce the cost per foot of each treatment.

REFERENCES

Dunne, T. and L. B. Leopold, 1978. Water in Environmental Planning. W. H. Freeman and Company, New York, NY.

Harrelson, Cheryl C., C. L. Rawlins, John P. Potyondy. 1994. Stream channel reference sites: An illustrated guide to field technique. GTR RM-245. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. Fort Collins, CO. 61 pp.

Kondolf, G. Mathias and Elisabeth R. Micheli. 1995. Evaluating stream restoration projects. Environmental Management 19(1)1-15.

Rosgen, David L. 1996. Applied river morphology. Wildland Hydrology Consultants, Pagosa Springs, CO. 380 pp.

2000 Billings Land Reclamation Symposium

GEOMORPHIC DEVELOPMENT OF A RECONSTRUCTED SUBALPINE STREAM CHANNEL

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ABSTRACT

In the Fall of 1998 a stream channel was constructed at a coal mine reclamation site in west-central Colorado based solely on a geomorphic design. The project site was located at 8000 feet AMSL in a subalpine watershed that yields perennial streamflow primarily from snowmelt runoff. The native channel had a very coarse-grained substrate derived from infrequent debris flows. The reconstructed channel was built with native debris flow material having the same particle size distribution as the substrate of the native channel. The reconstructed channel was built to a nearly uniform 6.8 percent gradient and was approximately 1250 feet long, 40 feet wide, about 10 to 30 feet deep with a "pilot" channel that was about 14 feet wide and two feet deep. The reconstructed channel was built with virtually the same width, depth, gradient, and low sinuosity as the native channel upstream of the project site. Two channel surveys, one conducted immediately after construction and one after the 1999 runoff season, indicated that the channel bed experienced only minor vertical adjustments and no significant change to its substrate size distribution. However, step pools developed due to the redistribution of cobbles and boulders within the channel during high flow. The step pools in the constructed channel function and appear indistinguishably from the step pools in the native channel. The development of step pools resulted in a new thalweg gradient profile that varied from -10 percent to +50 percent. The highly variable thalweg gradient profile did not indicate a stability problem, because the native channel had a similarly variable thalweg gradient profile and there was no indication of channel incision. Also, the reconstructed channel did not appreciably widen or migrate laterally during the 1999 runoff season. The channel's configuration and coarse native substrate were critical to maintaining the channel's thalweg gradient and natural appearance. This project supports the simple notion that a reconstructed stream channel can function and appear like a native stream channel if only its basic morphometric elements (channel width, depth, gradient, and alignment) and substrate are restored.

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INTRODUCTION

In late Fall of 1998, members of the State of Colorado, Division of Minerals and Geology (DMG) and the U.S. Office of Surface Mining Reclamation and Enforcement (OSM) supervised the construction of an unusual perennial stream channel at the former "Coal Basin mine." The stream - Dutch Creek - is unusual, because it is located in a scenic subalpine watershed (see Figure 1) and the primary channel-forming agents are infrequent cobble- and boulder-laden debris flows (see Figure 2).

PROJECT AREA LOCATION AND SITE DESCRIPTION

The project area is located in a scenic west-central Colorado watershed, four miles west of Redstone, CO. Redstone is located approximately 21 miles west of Aspen, CO and 26 miles south of Glenwood Springs, CO. The project area lies between 7995 and 8085 feet AMSL (see Figure 1). Dutch Creek is a tributary of Coal Creek, which flows into the Crystal River at Redstone, CO. The project area once was a coal mine facility site constructed by leveling a debris fan near the mouth of Dutch Creek.

Geomorphic Setting

The Dutch Creek watershed lies between about 8,000 feet and 11,000 feet AMSL and has a total drainage area of approximately 4.1 square miles. The Mancos Shale that underlies this watershed has been thermally metamorphosed, giving it greater resistance to erosion than the relatively soft unmetamorphosed Mancos Shale. Accordingly, the Dutch Creek watershed is relatively steep. Cliff-forming sandstone units within the Mancos Shale are found near the watershed divides and provide material for infrequently occurring debris flows (see Figure 1).

Debris flow is the major channel-forming process for Dutch Creek and the entire Coal Creek watershed (Costa and Jarrett, 1981). Dutch Creek flows in a relatively small “pilot” channel ontained within the bottom of the much larger debris-flow channel (see Figure 2). Except for floods and rare debris flows, Dutch Creek flows within the “pilot” channel.

Flow Characteristics

Dutch Creek is a perennial stream that flows primarily in response to snowmelt runoff and secondarily to rainfall events and groundwater inflow (see Figure 3). Annual snowfall typically exceeds 200 inches at the project area. Rainfall in a high-elevation watershed such as this is typically far less intense than at lower elevations (Jarrett, 1990). Based on an extensive evaluation of USGS flow records, Jarrett (1987) found that Colorado streams above 2300 meters AMSL (7546 feet) produce a maximum unit discharge of 1.1 cubic meters per second per square kilometer. This maximum flow is 413 cfs at the mouth of Dutch Creek.

Figure 1 - The Dutch Creek Watershed and a portion of the project area.

Figure 2 - View of native Dutch Creek showing channel in coarse debris flow material. The design for the 1250-foot reach of Dutch Creek through the project area was based only on Geomorphic design parameters (see Pranger et. al., 1996).

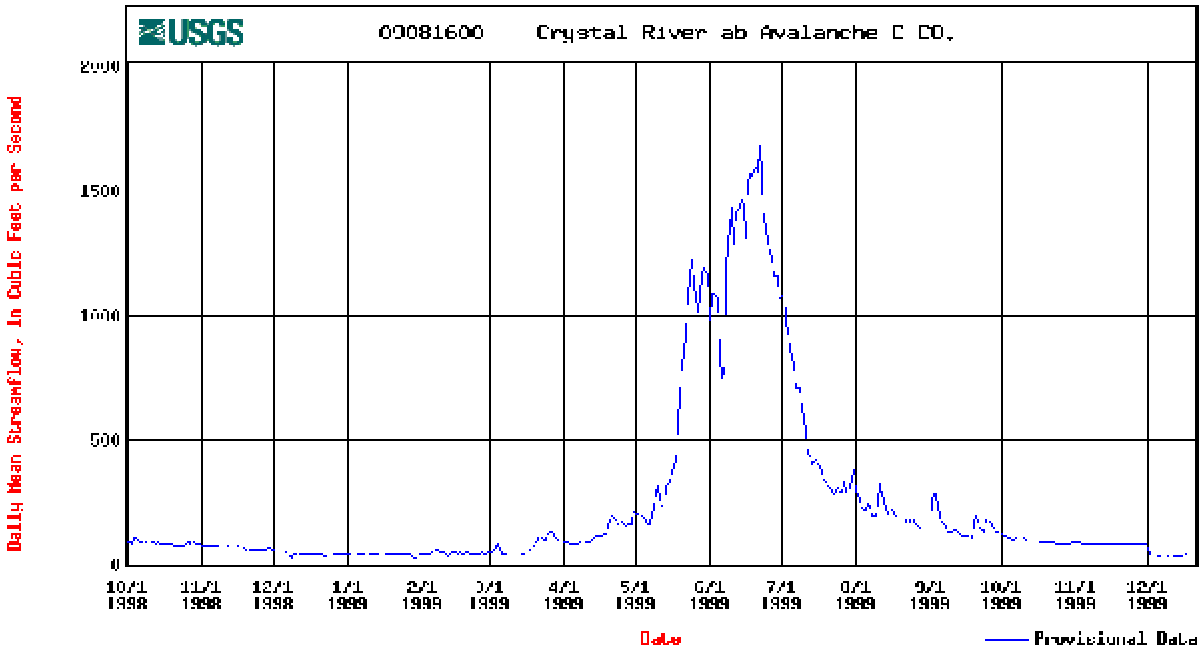

Figure 3 - USGS 1999 annual hydrograph for Crystal river seven miles downstream of the project area. Dutch Creek's hydrograph has a similar shape and is indicative of snowmelt runoff.

RECONSTRUCTED CHANNEL SUBSTRATE CHARACTERISTICS

Channel design characteristics were obtained from a 1750 foot long reference reach (see Harrelson et al, 1994 and Rosgen, 1994) of the native Dutch Creek channel located immediately upstream of the project area. The reconstructed channel was built with the same native substrate material and virtually the same width, depth, gradient, and low sinuosity as the native channel upstream of the project site (see Pranger et. al., 1996). The channel was surveyed immediately after construction and in late August 1999 to track the project's success (Kondolf, 1995; Kondolf and Micheli, 1995)

Wolman pebble counts were used to determine the substrate grain size distributions of the reference reach and the constructed channel (see Wolman, 1954 and Figure 4). The distributions are all relatively similar. The distributions all range from boulders to clay particles. The D_{50} for the native and reclaimed channels, respectively, was four and six inches. After the 1999 runoff season the distribution of material greater than about two inches in diameter in the constructed channel remained constant. However, the amount of material smaller than two inches was reduced. The channel transported the excess fine fraction out of the system. The coarser fraction remained virtually unchanged. The distribution in the constructed channel after the 1999 runoff season is a composite of the native and as-built distributions.

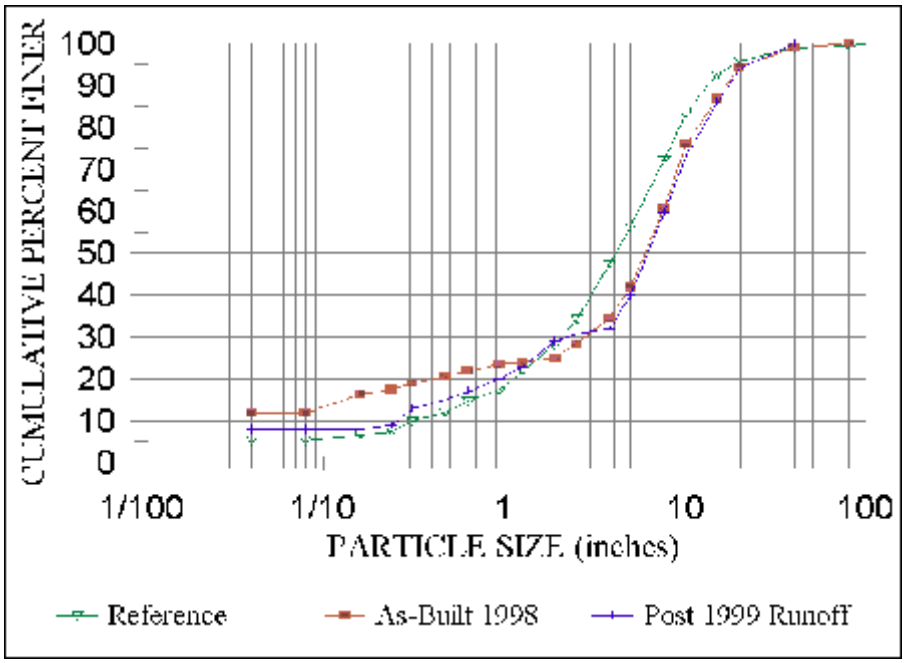

Figure 4 - Dutch Creek grain size distributions for the reference reach (Reference), the constructed reach immediately after construction (As-Built 1998), and the constructed reach after the 1999 runoff season (Post 1999 Runoff), based on Wolman pebble counts.

RECONSTRUCTED CHANNEL MORPHOMETRIC CHARACTERISTICS

The constructed channel had a fairly uniform 6.8 percent gradient, compared to 6.3 percent in the reference reach (See Table 1). The average gradient of the constructed channel was slightly higher than the reference reach due to spatial constraints in the project area. However, the channel stability was not decreased, because of the slightly coarser substrate material in the constructed channel (Figure 4). Also, the native channel width, depth, and sinuosity were closely approximated in the constructed channel. Images of the entire project area (Figure 5), the constructed channel (Figure 6) and the native channel (Figure 2) demonstrate that the channel had a natural appearance.

Parameter	Reference Reach Mean	Constructed Reach Mean
'Pilot' Channel Gradient (Percent)	6.3	6.8
'Pilot' Channel Width (Feet)	17.7	~14
'Pilot' Channel Depth (Feet)	1.6	~2
Channel Sinuosity	1.05	1.13

Table 1 - Morphometric comparison of the reference and constructed reaches of Dutch Creek.

Figure 5 - Overall view of the reconstructed Dutch Creek channel.

Figure 6 - Example reach of reconstructed Dutch Creek channel. Notice step pools.

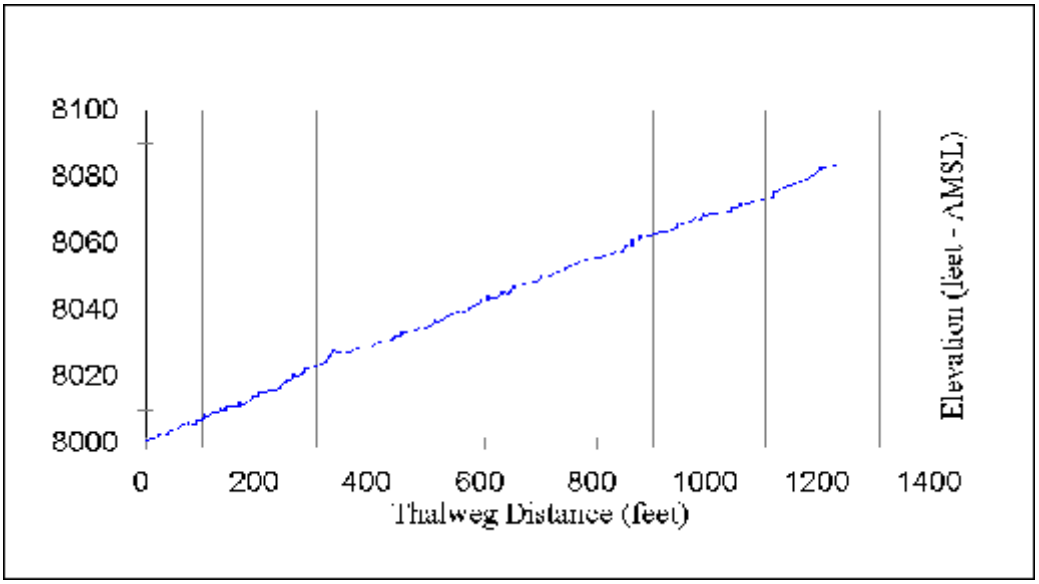

Figure 7 - Reconstructed Dutch Creek thalweg profile. Small undulations are step pools, except for the one at a distance of about 340 feet, which is a temporary road crossing.

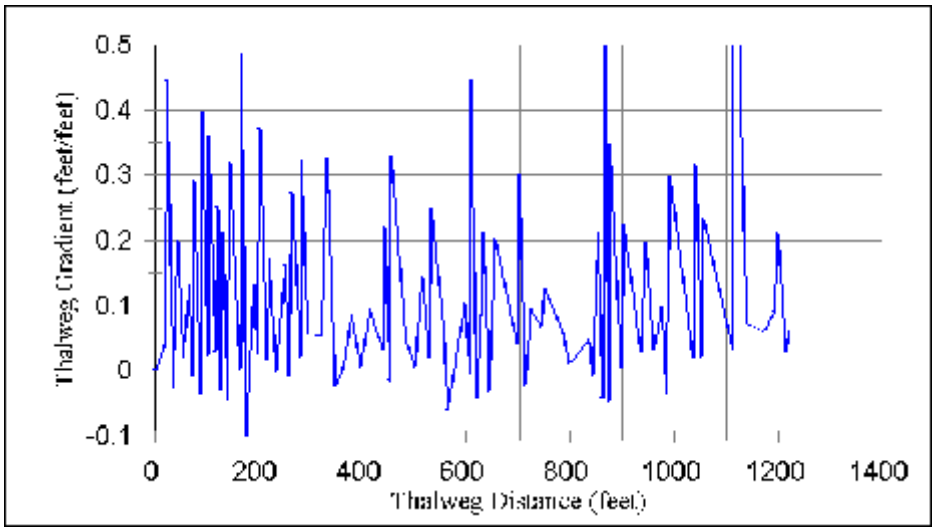

Figure 8 - Reconstructed Dutch Creek thalweg gradient profile after 1999 runoff season.

The profile of the reconstructed channel thalweg after the 1999 runoff season indicated that the channel bed experienced only minor vertical adjustments (Figure 7). The minor vertical adjustments are step pools that developed from the redistribution of cobbles and boulders within the channel during high flow (Figures 6 and 7). The step pools in the constructed channel function and appear indistinguishably from the step pools in the native channel. The development of step pools resulted in a new thalweg gradient profile that varied from about -10 percent to +50 percent (Figure 8).

The highly variable thalweg gradient profile did not indicate a stability problem, because the native channel had a similarly variable thalweg gradient profile (see Pranger et. al, 1996) and there was no indication of channel incision (Figure 7). Also, the reconstructed channel did not measurably widen or migrate laterally during the 1999 runoff season. Stream channel instability is indicated when a stream is: 1) aggrading; 2) degrading; 3) changing bed material particle sizes; 4) changing the rate of lateral migration through accelerated bank erosion; and/or 5) changing morphological type through evolutionary sequences (Rosgen, 1995). This channel has not changed its stream type (a Rosgen type A3 channel), and has no visible signs of instability.

IMPLICATIONS OF THE PROJECT

The channel's configuration and coarse native substrate were critical to maintaining the channel's thalweg gradient and natural appearance. This project supports the simple notion that a reconstructed stream channel can function and appear like a native stream channel if only its basic morphometric elements (channel width, depth, gradient, and alignment) and substrate are restored.

This project was successful, because the channel's shape and substrate materials were essentially restored to "native" geomorphic conditions. By restoring the shape of the channel, the hydraulic and gravitational forces causing erosion were maintained. By restoring the substrate materials of the stream, the forces resisting erosion were reestablished (see Schumm and Harvey, 1993). This approach met a key goal of shortening the time required for the channel to reach its "equilibrium morphology" (Jackson and Van Haveren, 1984). The equilibrium morphology of this channel included step pools that were best created by natural streamflow. This channel was built with simple morphometric and sedimentologic approximations that were sufficient to ensure a natural appearance and stability equal to the native channel. The initial field evaluation of Dutch Creek's response after construction validated the geomorphic channel design approach.

REFERENCES

Costa, J.E., and R.D. Jarrett. 1981. Debris Flows in Small Mountain Stream Channels of Colorado and Their Hydrologic Implications. Bulletin of the Association of Engineering Geologists. 18;3:309-322.

Harrelson, C.C., Rawlins, C.L., and J.P. Potyondy. 1994. Stream Channel Reference Sites: An Illustrated Guide to Field Technique. USDA Forest Service, General Technical Report RM-245:61p.

Jackson, W.L. and B.P. Van Haveren. 1984. Design for a Stable Channel in Coarse Alluvium for Riparian Zone Restoration. Water Resources Bulletin. 20;5:695-703.

Jarrett, R.D. 1987. Flood Hydrology of Foothill and Mountain Streams in Colorado. Ph.D Dissertation, Colorado State University, Fort Collins. 239p.

Jarrett, R.D. 1990. Hydrologic and Hydraulic Research in Mountain Rivers. Water Resources Bulletin. 26;3:419-429.

Kondolf, G.M. 1995. Learning From Stream Restoration Projects. Watersheds 94' - Proceedings of the Fifth Biennial Watershed Management Conference. University of California Water Resources Center Report 86:107-110.

Kondolf, G.M. E.R. Micheli. 1995. Evaluating Stream Restoration Projects. Environmental Management. 19;1:1-15.

Pranger, H.S. II, A.B. Wilhelm, J.O. Wilcox, and R.A. Welsh, Jr. 1996. Geomorphic Engineering Design of a Perennial-Stream Channel at a Subalpine Colorado Coal Mine. Proceedings, 1996 Billings Reclamation Symposium - Planning, Rehabilitation and Treatment of Disturbed Lands, March 17-23, 1996. Montana State University Reclamation Research Unit Publication No. 9603:320-329.

Rosgen, D.L. 1994. A classification of natural rivers. Catena. 22:169-199.

Schumm, S.A. and M.D. Harvey. 1993. Engineering Geomorphology. Proceedings of the 1993 conference on Hydraulic Engineering, sponsored by the Hydraulics Division, Am. Soc. Civil Engineers. 2:394-399.

Wolman, M.G. 1954. A method of sampling coarse river-bed material. Trans. Am. Geophys. Union. 35:951-956.

INTRODUCTION

The question - to reclaim or not - is no longer relevant. Every reputable mining company, the EPA, state highway departments, and other industries or government agencies attempt to rehabilitate to some extent the lands they disturb or the lands within their jurisdiction. The question today is what is adequate reclamation.

A definition of reclamation is appropriate at this point. Reclamation is the goal of returning the soil and the plant community it supports to conditions in which the stability and productivity of the site are comparable to that of the site prior to disturbance. Reclamation includes components of hydrology, soils and vegetation. Arguments that disturbed sites should be returned to pre disturbance conditions aren't relevant because it is not possible to do so.

We cannot restore a site even after an action as simple as plowing because of all of the changes produced in the soil physical, chemical, and biological properties by the action of turning over or mixing the top six inches of the profile. However, we can revegetate the site to some or most of the plant species found on the site prior to disturbance by very careful and selective reclamation. Whether this is called restoration or reclamation is not relevant, it is simply academic and I prefer to use the term reclamation. Many researchers call this type of reclamation restoration but as Allen (1995) pointed out, "...even the best examples of restoration have been able to reintroduce only a fraction of the plant species richness and natural recolonization is slow at best."

In the late 1960's and early 1970's western coal mining was bursting out of the constraints imposed by transportation costs and cheap eastern coal because of the growing demand for energy and air pollution awareness. The Arab oil embargo simply exacerbated the demand for western coal. At that time the potential for returning livestock to range sites after they had been surface mined was not considered good. Curry (1975) for example was quite skeptical that Great Plains minesoils would ever be productive after stripmining. Today we know that livestock gain weight and reproduce as well on reclaimed mined lands as they do on native range. We know that the land can be as stable as it was before disturbance and that wildlife invade the land even before mining is finished. These generalizations pertain to reclaimed mountain soils as well as reclaimed soils on the plains.

We now have thousands of acres of western land that was disturbed by surface mining in various stages of reclamation. Some of this land has been supporting crops or livestock since before the Surface Mining Control and Reclamation Act was enacted in 1977 but little of this land has received approval as successfully reclaimed. If the soils and vegetation were considered successful, then one would assume that final and complete bond release would be authorized. This has rarely been the case on coal mines in our region and I do not know of any superfund sites that have met with widespread approval after rehabilitation. Therefore I must assume that the reclamation of these sites is lacking in some quality.

THE QUESTION

The big question today at mines, superfund sites, linear rights-of-way, and other disturbances is, are the results of reclamation good enough for final approval be it as full bond release on coal mine sites or some other criteria that signifies adequacy at a superfund site or along a highway right-of-way. For various reasons many agencies (e.g. EPA), advocacy groups, and others are attempting to apply the final bond release criteria of SMCRA to disturbances of interest to the group, therefore, I shall use the success criteria of this law as the basis for my discussion. But, please be aware that what I am about to say pertains to the determination of reclamation success on all forms of surface disturbances in the semiarid west.

In an attempt to answer this question of successful or unsuccessful reclamation a group of terms were introduced into the Surface Mining Control and Reclamation Act of 1977 (Public Law 95-87). These include diversity, production, self perpetuating, native, and succession among others. All of these terms pertain to the plant community growing on the disturbed site and all have shortcomings that lessen their ability to quantify successful reclamation. This I believe is the cause of our inability to document successful reclamation. Our definition of successful reclamation is based on ambiguous terms or on ideas and concepts that we have not fully considered. I will attempt to illustrate this.

Diversity

The first of these terms was 'diversity'. As several authors have pointed out this term has almost as many definitions as individuals attempting to define it (Chambers 1983, Whittaker 1975, McIntosh 1967). It definitely is not species richness, or simply the number of species within a predetermined area because diversity includes some intangible reference to the distribution and number of each species. This is what makes it so hard to quantify, these intangibles. In addition to this weakness if we carefully inspect undisturbed environments we find that in areas of uniform soil, slope, aspect, and exposure the number of species is surprisingly small. The reports of large numbers of species are always from more mesic areas to the east or if from our region then they are from disturbed sites, grazed sites, or landscapes of diverse soils, slopes, aspect, exposure, etc. But, both federal and state law or regulation require that those disturbing a site reconstruct a uniform soil of relatively constant slope on the site after the disturbance. How can the individual responsible for reclamation produce a diverse plant community on a disturbed site, even if we could define it, when they are restricted to a uniform environment? As Prodgers and Keck (1996) so apply pointed out habitat is one of the critical keys to vegetational diversity.

Production

Production was the second term I mentioned. In every instance in which a report describes the production measured on a disturbance the parameter measured was actually standing crop not production. Production is the amount of tissue produced by the plant not the amount of above ground biomass that was measured after a number of herbivores have chewed on the vegetation. Production should include the underground component of the plant. This is rarely measured. But in terms of site

stability it is probably more important that above ground biomass. Several years ago Rich Prodgers carried out a vegetation study in the area of a proposed coal mine near Circle, Montana. In one year of sampling he recorded between 10 and 20 lb/a of standing crop. On the same transects he recorded almost 2,000 lb/a the next year. A plant parameter that varies over two orders of magnitude from one year to the next is not a reliable interpreter of revegetation success.

Self Perpetuating

Many groups and individuals ask if the vegetation growing on a disturbance is self perpetuating. Federal and state laws or regulations state that vegetation on coal minesoils must be 'self perpetuating' or 'self regenerating'. I presume this means the plants must be reproducing themselves. This can not be addressed other then stating that the plants are forming seedheads because there are no safe sites for new plants to develop on young minesoils for many years after the original seeding. The following example illustrates this principle.

Area to be reclaimed: One acre

Seed Mix:

	Rate (PLS)	
Grasses	Seeds/ft^2	lb/a
Western wheatgrass	4	1.5
Blue bunch wheatgrass	4	1.5
Needle-and-thread	4	1.5
Forbs		
Purple prairie clover	2	0.3
Prairie coneflower	2	0.1
Black sampson	2	0.6

If we assume that half of the seed germinates and establishes there remain nine plants on each square foot of soil. There are neither adequate nutrients nor sufficient water to support that number of rapidly growing plants. By the time of review for determination of adequacy of reclamation there are probably only one or two plants surviving on this foot of minesoil. Which plant will it be. Probably the one with the genetic constituents that enable it to utilize the resources of the site rapidly before another plant can absorb them and the plant lucky enough to find these nutrients and moisture. That is, the most competitive and tolerant of the seeded species. We are selecting cultivars for exactly those reasons. We want the new plants to be rapid growing and tolerant of the cold and drought of our prairies and mountains. They do this so well they absorb most of the nutrients and moisture in the soil and leave little for most other plants of the system.

What is the life expectancy of these plant on the Great Plains? We do not know exactly but we know that it is 10 years for some of these species and probably much longer than that, possibly several

decades, for many of the perennial grasses. Since our seeded area has produced the maximum number of plants permitted by the soil and climate of the area there are no safe sites for seeds to germinate and establish. How then can the investigator state that new plants are establishing on the site. The new plants cannot enter the ecosystem until one of the older plants dies and this will not occur for many years. The investigator can state that the plants growing on the disturbed site are setting seed and there may be a young plant or two but it is rare that it can be definitely stated that new plants have established from seed produced by the plants growing on the reclaimed site.

Native

Vegetation seeded on disturbed sites is to be composed predominately of native species. The reason given for this regulation is that natives are better adapted to the rigors of our soils and climate than introduced species. That isn't necessarily true and is becoming less so each day as more and more exotic plants invade our native grasslands. If it were true we would not have so many noxious weeds and few plants are as well adapted to the west as Crested wheatgrass (Walker et al. 1995). Introduced species may be undesirable but lack of adaptation to the site, low forage production, or lack of palatability can not be used as rejection criteria.

Succession

Finally, new plant communities growing on disturbed sites are supposed to be undergoing succession. Succession is defined as the progressive changes in vegetation and animal life that culminate in the climax plant community. Succession is readily observable during the first few years of plant growth on disturbed sites. Let us say three to five growing seasons as the annual weedy species that rapidly invaded the new plant community during its first growing season are replaced by the very aggressive, perennial, stress tolerant cultivars in the seed mix. During the next undetermined number of years very few changes occur in the plant community. Possibly a few tough weeds invade it, possibly two or more seeded species disappear from the community but the anticipated invasion of the site by propagules from adjacent rangeland does not occur in any great amount during anything close to the bonding period. Observations have not shown a return to anything like original vegetation on semiarid grasslands even when grazing is excluded (Laycock 1991, Allen 1988).

Successional concepts as developed in the more mesic coniferous forest of the west or in the more mesic east occur at such a slow rate on the plains that the changes cannot be measured in a few decades. We have no idea what final climax vegetation would look like on the Northern Great Plains and the foothills of the Rockies. What European man found when he arrived in the west was an ecosystem maintained by burning and grazing. This system was never allowed to develop to a climatic climax but was maintained in a fire climax. Lewis and Clark (Ambrose 1996) noted the large fires used by the native Americans to mark the flotillas progress westward and fire was also used by the American Indians to remove vegetation surrounding winter villages. As early as 1793 fires on the Northern Great Plains were noted. Fidler (1793) said, "These large plains either in one place or another is constantly on fire..." He further noted that, "The lightning in the spring and fall frequently lights the grass, and in winter it is done by the Indians." These were not small fires. Haley (1929) gave an account of a fire in

1885 that started in the Arkansas River country of western Kansas and burned 175 miles to the Canadian River Breaks of Texas. He also gave accounts of several large fires of 20 by 60 miles.

Clearly fire and climate are the major factors controlling vegetation on the Great Plains (Wright and Bailey 1980) and many authors maintain that fire is the reason why the Great Plains are treeless (Stewart 1953). Which stage of succession are the reclamation programs of the Great Plains to strive to create - the unknown climax, a forested stage, some seral grassland stage, or none at all. Many say establish what was there prior to disturbance. With the exception of plowed crop land most of the acreage disturbed by mining and linear rights-of-way on the Great Plains is native rangeland. But, this vegetation is a midseral stage of succession, a disclimax maintained by burning and grazing. If this is what we want than we in fact do not want succession to take place.

Clearly we need better criteria for reclamation success or final bond will never be released on many acres of western surface mined land. Reference areas or technical standards have value and should be incorporated into these new criteria but the terms mentioned above have serious shortcomings.

A POSSIBLE SOLUTION

If the soils, land forms, and hydrologic balance of the disturbed site have been rehabilitated and an approved seeding and planting has taken place what final criteria should be evaluated to determine reclamation success. Obviously, a thousand years of stable soil and vegetation production would be a good answer but not a realistic one. Some set of parameters must be defined to answer this question and they must be applicable within a reasonable amount of time. In our region the ten year bonding period of SMCRA is a reasonable starting point for a reclamation time frame.

For all disturbances from highway meridians and shoulders, through all types of mining, to hazardous and non hazardous waste disposal sites vegetation cover has been the parameter evaluated for determination of final reclamation success. At best this analysis has been a contentious determiner of reclamation success and in the worse case vegetation is simply not acceptable as the determiner. The best case occurs on surface coal minesoils with all of the problems noted above obstructing a clear definition of reclamation success. The worse case occurs on hazardous waste sites on which vegetation can be readily grown but is of questionable longevity. Rather than placing total confidence in plant performance I would like to propose that we give a better look at the soil profile than is presently advocated. The rootzone is less influenced by perturbations in the weather and several characteristics of this soil layer may be more clearly defined and evaluated than vegetative parameters. If the surface soil horizons express certain characteristics vegetation will develop on and in it whether intentionally seeded or not. Vegetation is in reality a visible reflection of the attributes of the rootzone. I shall discuss several attributes of soil on a disturbed site which might be evaluated to determine reclamation success.

Topsoil

Coal mine regulations necessitate that topsoil be salvaged and saved for application to recontoured minesoils, but, both the quality and quantity of this material are important to a functioning soil system. Stored topsoil may be degraded and require some type of rejuvenation after application to the disturbed landscape to quickly regain its predisturbance plant supporting capacity. The coal industry has rapidly learned how to maximize recovery and minimize destruction of this valuable resource. Highway departments have been slow to maximize recovery of better surface soils and still often spread poor quality material for topsoil along meridians or shoulders. The EPA, Forest Service, Bureau of Land Management, and state Abandoned Mines Programs often find themselves without any topsoil at disturbed sites under their jurisdiction. At these sites the construction of good quality topsoil may be accomplished but it is expensive and time consuming. Nevertheless, the importance of this soil layer to the performance of vegetation cannot be overstated. The quality and quantity of topsoil directly influence the germination, growth, production and reproduction of plants (Barth and Martin 1982, Doll et al. 1984). The quality of topsoil can be defined by determination of the chemical, physical, and biological characteristics of the material.

Biological System in the Soil

Organisms within and on the soil represent an integral component of a functioning soil system. While concentrated in the topsoil cover they also extend in limited quantity into lower horizons. They range from the small bacteria to animals as large as earthworms and small rodents. The major types and ranges of their numbers are available. The larger animals initiate the decomposition of plant and animal tissues by pulverizing, granulating and incorporating these materials within the soil. The smaller invertebrates and worms continue the process by degrading large organic materials to smaller pieces. Finally bacteria, fungi, and actinomycetes complete the conversion of large organic molecules to carbon dioxide, water and nutrients. All of these organisms are, therefore, indispensable in a healthy soil. Trends in the populations and species of these organisms can or already have been established. Decreases in the number of species precede degradation of plant communities. On coal mine sites when direct haul topsoil in applied to recontoured minesoils populations of these organisms are maintained or recover rapidly. When stored topsoil is spread on a site these numbers have been reduced. On polluted soils of many superfund sites the number of species are markedly reduced (Hartmen 1973) but construction of a new topsoil may raise their numbers.

Chemical System in the Soil

The enumeration of all of the chemical reactions in the soil is impossible but several major components of these reactions may be measured and serve to indicate that the disturbed soil has or is in the process of recovering from disturbance. Like the biological components of the soil system these reactions are concentrated in topsoil but they also occur to greater or lesser degrees in lower horizons. Parameters such as the infiltration rate and water holding capacity, cation exchange capacity, organic matter content, and concentrations of the major and minor nutrients are of major importance to a healthy soil system.

On coal minesoils the characteristics of materials in the top four feet of the profile are carefully regulated but such is not the case on superfund sites or hardrock mine wastes. At these latter sites the presence of materials with low water holding capacity or elevated levels of alkaline, saline, or acid generating materials within the top four feet of the soil profile are common. It may be as subtle as sandy materials with inadequate number of exchange sites to prevent leaching of nutrients or selenium leaching into ground water from surface layers; it may be an obvious problem such as acid generation in the cap on a tailings pond. These soil deficiencies may not even pose a problem within a reasonable amount of time (10 years). They may not be detectable without special studies but preliminary determinations can indicate their possibility and prevent construction of soils possessing these attributes. The presence of low cation exchange capacity and coarse textured materials or detrimental soluble trace element concentrations should be enough to prevent declaration of reclamation success even though plant growth on the soil surface may meet all success criteria as defined by pre-reclamation agreements.

Depth of the Rootzone

The Office of Surface Mining has already addressed this problem. Federal and most state regulations clearly state that a non-toxic layer of soil at least four feet thick must be laid over recontoured coal mine disturbances. Montana requires eight feet of this non-toxic material. Numerous range plants and many woody species commonly develop roots deeper than four feet. A toxic layer at four feet hinders the establishment or presents an obstruction to the long term persistence of these species on prairie or mountain soils.

The depth of non-toxic material is especially important at numerous superfund and abandoned mine sites across the west. The use of an 18 inch coversoil over toxic material has been demonstrated at Butte and a few other locations with phytotoxic surface materials. The limitations of this type of reclamation are obvious: few species composing the plant community and a continuing maintenance problem. The more subtle problems with this reclamation are not so obvious. Is the development of new soil on these sites compensating for soil loss? Is this what we want to call successful reclamation?

SUMMARY

This discussion was not intended to be a condemnation of any existing system of reclamation success determination but simply a suggestion that looking at other facets of the reclaimed landscape might provide a faster and better determinant of final reclamation success. Obviously, something is wrong. At one of the few coal sites approved for final bond release in Colorado a massive land slide wiped out many years of excellent plant growth. On the other hand many acres of livestock supporting minesoils in Montana have been awaiting final bond release for over a decade because they do not meet some minor determinate of reclamation success. At superfund sites the growth of three or four acid and metal tolerant species on 18 inches of coversoil over toxic wastes is considered successful reclamation despite the lack of topsoil and an adequate root zone. We should reevaluate present success criteria and develop a realistic set of parameters to be measured for final determination of reclamation success.

The vegetation growing on our prairie and mountain soils are the result of centuries of slow weathering, plant growth, grazing, regrowth, fire, and again regrowth. Every time they are disturbed they change. If you drive a vehicle across the prairie during the wet season the tracks of the vehicle are visible for many years. Plowed fields returned to grazing in the 1930's still do to support vegetation comparable to that found on adjoining non disturbed areas. Yet, we expect a minesoil to support vegetation comparable to that on the site prior to disturbance. At the same time in our haste to cover the scars of past mineral exploitation in our mountains we pull a few inches of non-toxic material over the disturbance and call it reclaimed. Somehow these two extremes do not mesh. There should be some middle ground, some criteria that indicate that in the long run things will continue to improve even though the site will never get back to what it was before disturbance. Yellowstone National Park will never be the same as it was before 1988 but it is improving daily. The vegetation and soils along many of our highways, on numerous minesoils, and around some superfund sites are also improving daily. We should be able to distinguish those that are improving, those that are successfully reclaimed, or those changing in a manner that suggests that they are successfully reclaimed and separate them from those sites that are destined to fail. I believe that looking into the soil profile is a step in the right direction.

REFERENCES

Allen, E.B. 1988. Some trajectories of succession in Wyoming sagebrush grassland, pp 89-112 In: Allen, E.B. (ed.) The Reconstruction of Disturbed Arid Ecosystems. Westview Press, Boulder, CO.

Allen, E.B. 1995. Restoration Ecology: Limits and possibilities in arid and semiarid lands, pp 5-13 in: Proc. Wildland Shrub and Arid Land Restoration Symposium. USDA For. Serv. Gen. Tech. Rpt. INT-GTR-315. Intermt. Resch. Sta., Ogden, UT.

Ambrose, S.E. 1996. Undaunted Courage. Simon and Schuster Inc., New York. 474 p.

Barth, R.C. and B.K. Martin. 1982. Soil-Depth Requirements to Reclaim Surface-mined Areas in the Northern Great Plains. A mining research contract report. CO School of Mines, Environ. Tech. Div., Golden, CO. 182 p.

Chambers, J. 1983. Measuring Species Diversity on Revegetated Surface Mines: An Evaluation of Techniques. USDA For. Serv. Resch. Pap. INT-322.

Curry, R.R. 1975. Biogeochemical Limitations on Western Reclamation. Paper presented at the Symposium Sponsored by U.S. Dept Interior, Bureau of Mines and Univ of ND. Grand Forks, ND.

Doll, E.C., S.D. Merrill, and G.A. Halvorson. 1984. Soil Replacement for Reclamation of Stripmined Lands in North Dakota. Bull. 514, Agric. Exp. Sta. ND State Univ., Fargo, ND 24 p.

Fidler, P. 1793. Diary of Peter Fidler for the period 1792-93. Glenbow-Alberta Inst. Calgary.

Haley, J.E. 1929. Grass fires of southern Great Plains. West Texas Hist. Year Book 5:23-42.

Hartman, L.M. 1976. Fungal Flora of the Soil as Conditioned by Varying Concentrations of Heavy Metals. Ph.D. Dissertation. Univ. Montana, Missoula, MT.

Laycock, W.A. 1991. Stable states and thresholds of range condition on North American rangelands: a viewpoint. J. Range Mngt. 44:427-433.

McIntosh, R.P. 1967. An index of diversity and the relation of certain concepts to diversity. Ecol. 48:392-404.

Prodgers, R.A. and T.J. Keck. 1996. Vegetational diversity concepts and strategies for reclamation, pp.141-157 in: Proc. of the Billings Symposium. Reclamation Research Unit, Montana State Univ. Publ. No. 9603. Bozeman, MT.

Stewart, O.C. 1953. Why the Great Plains are treeless. Univ. CO. CO Quart. 1:40-50.

Whittaker, R.H. 1975. Communities and Ecosystems. Macmillan Publishing Co., Inc. New York. 387 p.

Wright, H.A. and A.W. Bailey. 1980. USDA For. Serv. Gen. Tech. Rpt. INT-77. Intermt. For. and Range Exp. Sta., Ogden, UT. 60 p.

2000 Billings Land Reclamation Symposium

RECONSTRUCTION OF A SUBALPINE STREAM CHANNEL WITH THE AID OF OSM'S TIPS TECHNOLOGY

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ABSTRACT

In the Fall of 1998 a 1250 foot long reach of a stream channel was constructed at 8000 feet AMSL in a subalpine Colorado watershed. The channel consisted of a "pilot" channel flowing within a larger debris flow channel. The tasks of creating a construction map and guiding the heavy equipment operators relied largely on the U.S. Office of Surface Mining's (OSM's) Technical Information Processing Systems (TIPS) technology. The construction map was a one foot contour interval cut and fill map overlain with a 10-foot grid. The cut and fill map was created with TIPS surface modeling software by subtracting the design map from the previously existing ground surface map. A TIPS Global Positioning System (GPS) data recorder was used to locate and stake the zero cut and fill contour lines onto the surface of the project area. The stakes were marked with the required slope gradients and cut and fill depths for the heavy equipment operators. After the grade of the larger channel was established, the outline of the "pilot" channel was staked, again using the GPS recorders as a guide. The "pilot" channel was excavated two feet into the larger channel. During construction, unanticipated spatial constraints required a rapid adjustment to construction maps for the upper 400 feet of the project area. Additional surface data points were gathered with the GPS data recorder in order to modify the existing surface, design and cut and fill maps. Revised maps were created in two days. The upper project area was subsequently staked according to the revised cut and fill map without any interruption to the heavy equipment operators. The entire project was completed in six weeks just before heavy snow fell. The rapid field adjustments were made easy with the TIPS technology. The successful construction of this sensitive excavation project demonstrated a viable alternative to standard surveying methods.

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THE NEED FOR PROPERLY RECLAIMING EPHEMERAL CHANNELS AND ASSOCIATED SIDESLOPES IN LANDS DISTURBED BY STRIP MINING

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ABSTRACT

Ephemeral channels are often the most commonly encountered and hydrologically important features to replace in reclaimed, arid landscapes. They are the foundation for the postmine topography, the design of which requires input from multiple and overlapping natural resource disciplines. Despite this, reconstructed channels and sideslopes all too often do not closely resemble premine dimensions. Channel construction designs generally do not incorporate the overall hydrologic significance of these features, nor take into consideration criteria necessary to reestablish vegetative diversity and production, and wildlife habitat. Channels are often located along former haulroads, with insufficient thought given towards proper size and shape, blending the channel into sideslopes, or creating a meandering pattern. Channels are frequently reclaimed as broad swales, even though they may be replacement features for coulees or small, incised channels. Although broad swales may be relatively stable once vegetation becomes established, the initial lack of vegetative cover, and absence of meanders, often results in severe erosion and undesirable hydrologic effects, such as the formation of braided channels. Concurrent concerns are limitations on restoring appropriate and diverse vegetation and wildlife habitat when features such as coulees and small, incised channels are replaced with broad swales. The value of replacement features such as snow catchments that will hold and retain moisture, as well as areas wherein wildlife can take shelter from sun, wind and observation are often lost when appropriate channel and sideslope features are not considered during reclamation.

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INTRODUCTION

Ephemeral channels are often the most commonly encountered and hydraulically important features to replace in reclaimed, arid landscapes. As noted by Tarquin and Baeder "The design and reconstruction of lower (first and second) order stream channels presents a unique problem since these channels comprise the majority of the total stream length on premining surfaces and usually occur on the steepest slopes (1983)." The importance of ephemeral channels is based not only upon the sheer number of ephemeral channels, and their contribution to overall drainage density, but also in the role channel and sideslope features play in creating microsites for vegetation and wildlife.

Drainage channels are a very dynamic part of any landscape, and have significant influences on ecosystems and hydrologic systems. These facts are an important consideration in reclamation of drainages in drastically disturbed lands. Drainages must be reconstructed to pass water into, through, and off the disturbed area. Reconstruction of drainages must be compatible with protection of the hydrologic balance, the reestablishment of essential ecological functions, and the proposed post-mine land-use goals.

Concave longitudinal stream profiles are necessary to establish dynamic equilibrium, thereby reducing erosion, and are directly applicable to the design of a stable postmining topography (Bishop, 1980). Watershed divides may need to be adjusted, but the approved post mine topography should closely represent what existed in the premine state. Usually, this is accomplished through a comparison of premine and proposed postmine contour maps, noting the location, lengths and orientation of each channel and respective watershed areas. It is widely accepted, and important to the postmine hydrologic and ecologic function, that the postmining drainage density be at least equal to what existed premining [Bauer (1980), Stiller et. al., (1980), Bishop (1980), Gregory et. al. (1987)] and that channel sinuosity comparable to premine be restored [Shields et. al., (1995a), Welford (1993) and Bishop, (1980)].

Since all of these factors must be considered in the evaluation of ephemeral channel designs, input from multiple and overlapping natural resource disciplines is required. This can make the design of drainage channels in land disturbed by strip mining challenging, and complex.

REQUIREMENTS

Montana rules and regulations require that the; Design of reclaimed drainages must emphasize channel and floodplain dimensions that approximate the premining configuration and that will blend with the undisturbed drainage system above and below the area to be reclaimed. The rules further go on to state that; ...the channel and floodplain must be designed and constructed to … establish or restore the drainage channel to its natural habitat or characteristic pattern with a geomorphically acceptable gradient as determined by the Department," to; "… allow the drainage channel to remain in dynamic equilibrium with the drainage basin system without the use of artificial structural controls unless approved by the Department, to; "…improve upon unstable conditions which existed in the drainage system prior to mining where practicable in consultation with and upon approval by the Department," and to; "… restore, enhance where practicable, or maintain natural

riparian vegetation in order to comply with …" revegetation and postmine landuse requirements and standards.

EVALUATION AND GOALS

The operator will need to evaluate channel and sideslope features that exist premine. This evaluation should take into consideration that, as noted by Pinet (1997), channels are not "things in space" but rather "processes through time." Once the channel is evaluated, and criteria such as area of the postmine drainage basin and revegetation and habitat restoration plans are known, the appropriate channel size and shape can be formulated, as can complementing sideslope features. A detailed examination of characteristics of each premining drainage channel to be disturbed may not be necessary with the approval of generic designs. As noted by Goodwin (1999), the classification of channels based on relative and absolute size factors may prove especially beneficial for reclamation purposes.

Derivation and application of some generic channel design criteria may be acceptable due to the nature of strip mining. Preceding actual mining, vegetation and soil, as well as overburden, is removed from most, if not all, of the drainage basin. Only after the coal is removed will the area be backfilled, regraded, topsoiled and seeded. Due to the drastic impact that strip mining has on ephemeral drainage basins, and the realization that the reclaimed surface configuration will only be an approximation of what once existed, a detailed premining channel study and analysis is of limited value. Of critical importance in the postmine landscape is the replacement of channel and sideslope features that compliment the undisturbed upgradient and downgradient channel and sidelsopes, and approved postmine land uses.

A primary goal of reclaiming drainage channels is to provide suitable habitats for aquatic and riparian vegetation, which are often found as linear features along drainage channels. Such habitat features are often associated with irregular drainage sideslope topography, and irregularities in the channels themselves. The creation of drainage area microsites promotes vegetation and habitat diversity, the importance of which is often overlooked during channel design processes, and during the physical work of reclamation. Although premine diversity is often noted in baseline data, described in permit application narratives, and labeled on maps as Drainage Bottom Types, Riparian Types, and 'Herbaceous Bottom, with additional subtypes labeled as overflow, subirrigated, marsh, wetland, and subirrigated,' appropriate consideration of the need to recreate such niches is often overlooked. It is important that ephemeral drainage channel designs provide for microhabitat features for vegetation, and that these features be replaced in the postmining landscape.

In consort with other Montana coal mine reclamation requirements, revegetation plans are directed towards reestablishing diverse, effective and permanent vegetation of the same seasonal variety and utility as vegetation native to the land to be disturbed. Properly constructed channels and sideslopes help fulfill this goal by creating a landscape that promotes vegetation community types such as grassland, conifer woodland, wooded drainage, and riparian/aquatic. The problem with rigorously engineered channels is that while they may be functional in terms of transporting water, they do not contain the ecological properties of native channels (Anderson, 1994). Designs

are complicated by the reality of inherent channel instability, large fluctuations in discharge and a complex ecology (Shields et al., 1995a). Yet, if channels are appropriately designed and revegetated with riparian species, artificial erosion and sediment control measures should not be necessary (Stiller et. al., 1980). Therefore, efforts made towards natural channel restoration can produce immediate benefits for mine operators.

COMMON PROBLEMS

Reconstructed channels and sideslopes may not always closely resemble premine dimensions, and designs generally cannot take into account all hydraulic influences on these reclaimed features. What was once an undisturbed watershed has been backfilled with unconsolidated material, usually to a depth of one hundred feet or more, spoil graded, topsoil laid down, the area seeded, and perhaps shrubs and trees planted. After the upstream drainage channel is reconstructed, or perhaps reconnected with undisturbed portions of the basin, runoff is once again allowed to flow across the landscape. Runoff at this time, and until a stabilizing vegetative cover has been established, initiates the fluvial processes of erosion and deposition. It often takes three or more years for vegetative cover to become established on reclaimed sites, and, according to Martin (Martin et. al., 1988) it may take six years for infiltration and runoff to return to normal.

Constructed drainage channels are usually overly wide and simplified in comparison to what once existed, since channels are often located along former haulroads, often due, at least in part, to perceived or real equipment constraints. All too frequently, channels are reclaimed as straight, broad swales, even though they may be replacement features for coulees or small, incised channels that frequently exhibit considerable sinuosity. This is contrary to the fact that when most naturally occurring streams are viewed in cross-section they are not parabolic or semicircular in shape. Most natural stream channels are generally trapezoidal in straight reaches and asymmetric at curves and bends (Leopold, 1994). The construction of broad swales results in the creation of ecologically limited sites when compared to the diversity found in sinuous, irregular shaped channels (Shields et. al., 1995b). Although broad swales may achieve a suitable level of stability once vegetation becomes established, the initial lack of vegetative cover, and absence of meanders, often results in severe erosion, the formation of braided channels, and significant maintenance efforts during the first few years. Along with the problem of erosion, is the limited ability to achieve appropriate and diverse revegetation and wildlife habitat, when features such as coulees and small, incised channels are replaced with broad swales. The loss of microhabitat results in the loss of plant and animal diversity and in limited ecologic function.

SUGGESTED PRACTICES

Material can be placed in the overly wide channels to reduce channel width, thereby obtaining the appropriate width to depth ratio in reclaimed channels. Such features, as point bars or meander points, act as energy dissipaters and help to establish a meandering channel pattern. Narrowing drainage channel width does not necessarily infringe upon the required discharge capacity of the channel; rather it creates the proper channel width for a limited flow length. As noted by McIntosh (1989); Minor flows which contacted a bar eventually made an adjustment from relatively straight to sinuous as low flow water was guided around the tip of each bar. Major

floods coursed over the bars. Thus the bars, rather than bed slope inconsistencies, dictated low-flow channel shape, and a return to premine sinuosity resulted. Delimited channel downcutting results from deflecting flows along the stream course, thereby allowing lateral erosional processes to enhance sinuosity. The end point of the lateral process is a meandering channel pattern (Hupp and Simon, 1991). When drainage channels and floodplains are reclaimed to an appropriate width and configuration during rough regrading, additional soil or overburden material, or engineered structures, may not need to be placed in the channel to form meander points. As indicated by Leopold and Wolman (1960), "The most characteristic features of all stream channels, regardless of size, are the absence of long straight reaches and the presence of frequent sinuous reversals of curvature."

Without meander points, or some other appropriate means of delimiting and deflecting stream energy, reconstructed channels tend to downcut, or to braid extensively, potentially leading to excessive instability, erosion and gullying. While other acceptable methods of delimiting and deflecting stream energy and creating suitable reclaimed channel sinuosity are available, establishing meander points in reclaimed drainage channels has proven to be beneficial at some Montana coal mines. With appropriate meander points in place, events greater than bankfull discharge are forced to flow over these low features, dissipating energy. These structures should be angled so that the downstream face is perpendicular to the desired direction of flow. This will direct the flow of water towards the center of the channel, away from the embankment, thereby further reducing the potential for erosion (Reichmuth, 1991). The spacing between meander points can be based on the relationship between meander length and bankfull channel width (Leopold and Wolman, 1960), the relationship between meander length and bankfull discharge (ASCE, 1997), or through the use of pertinent aerial photographs. Bankfull discharge is often approximated by the two-year annual peak flow event (Lowham and Smith, 1993).

The spacing of meander points in reclaimed drainages is intended to provide a semblance of a naturally occurring meander pattern. It is not expected that this reconstructed pattern will be a "perfect fit" within the hydraulically influenced landscape, or that localized erosion and aggradation will not continue to occur, especially during the first few years after reclamation. However, when properly placed, meander points can direct channel formation to an appropriate and acceptable level of relative stability and functionality in a reasonable timeframe. Without meander points, reclaimed channels often degrade into discontinuous and parallel gullies, with associated and unacceptable levels of erosion, possibly requiring years of maintenance work along with the accompanying delay in achieving postmining land use goals and bond release.

The use of meander points is a somewhat limited approach to proper drainage channel reclamation and does not compensate for improperly constructed flood-prone areas or sideslope features. If reconstructed channels, flood-prone areas, sideslopes and side tributaries were to more closely resemble what existed premining, the ability to achieve many reclamation goals and requirements would be further enhanced.

Meander points can provide a niche for planting trees and shrubs, e.g., stilling pools form at the junction of the placed material and embankment resulting in the deposition of sediment; some enhanced or variable moisture gradients can result at such sites, and; in general, microsites are created that allow for the establishment and survival of diverse vegetation. When trees, shrubs,

forbs and grasses that my require such niches become established, they contribute towards a sustainable level of channel stability, and can enhance the ability of reclaimed landscapes to achieve overall revegetation and reclamation goals and standards.

The creation of features such as snow catchments, which collect and retain moisture, as well as areas wherein wildlife can take shelter from sun, wind and observation, also needs to be considered during channel reconstruction. As noted by Brookes (1995), "…improvement in ecological integrity will follow re-creation of physical characteristics."

There are a number of ways to estimate what the reclaimed channel width and depth and meander patterns should be; including taking actual predisturbance measurements in channels prior to disturbance, and the use of regional regression equations to provide an estimate of channel dimensions. However, since reclamation is to take place after strip mining, the proposed postmine topography needs to be considered in channel design. There may be significant differences between the premine and postmine landscape for a particular watershed, especially for the smaller basins. For such watersheds there may be relatively large gains or losses in drainage area, an overall change in the drainage channel slope, as well as in the length of flow from the drainage divide to the watershed outlet. Therefore, methods for designing channels may need to incorporate computer modeling to predict what the bankfull flow will be in the altered watershed, based on the reclaimed postmining topography.

The use of bankfull flow data for designing channel dimensions and form is preferable to most other methods, as this value is the end product of a multiple of factors (drainage area, slope, flow length, soil type, vegetation, etc.,). Generic designs could be created and categorized by various ranges of bankfull flow. Using predicted bankfull flow to design channels has to date resulted in reconstructed drainage channels that quickly achieved overall stability and functional use, while allowing on-going channel shaping geomorphic processes to proceed. Final channel shape will be influenced by initiation of erosional processes preceding the development of a stable and permanent vegetative cover.

CONCLUSION

If sufficient evaluation of relevant hydrological and ecological data and appropriate science and engineering is applied to channel design, the likelihood of returning reclaimed drainages to an acceptable and appropriate level of stability and functionality is enhanced. It is very important that reclaimed channels, and surrounding landscapes, are properly regraded, and in particular that drainages have a concave longitudinal profile with appropriately restored channel sinuosity. If regrading has left knickpoints, if an appropriate meandering pattern has not been incorporated into the channel design, if the vegetation does not `take, or a large storm event occurs during the early stages of revegetation, fluvial processes will likely cause severe erosion, requiring significant and repeated maintenance work. As noted by Stiller et al. (1980), successful reclamation depends on planning, and integration of the reclaimed surface and drainage network into the surrounding landscape.

Derivation and application of some generic or categorical channel design criteria may be

relevant and useful in reclamation. Such designs could be derived that would adequately represent the majority of drainage channels that are to be reclaimed. However, there will always be instances when such generic designs are not adequate for achieving prescribed goals and functions. For example, case and site specific design criteria will likely be necessitated when drainages are to be reconstructed in steep landscapes, or when special ecological requirements must be met. In other cases, designs may not be needed at all, such as for small watersheds, or for the upper reaches of a watershed. In such instances, it may be appropriate to construct swales, or allow for short reaches of steep-sided and comparatively erosive channels.

REFERENCES

American Society of Civil Engineers (ASCE). 1997. Channel Stability Assessment for Flood Control Projects. Technical Engineering and Design Guides as Adapted from the US Army Corps of Engineers, No. 20. ASCE Press, New York

Anderson, A.A., 1994. A Classification of Drainage Basins in the Eastern Powder River Basin Coal Field of Wyoming. Master of Science Thesis, University of Wyoming. Laramie, Wyoming.

Bauer, W.B. 1980. Drainage Density – An Integrative Measure of the Dynamics and the Quality of Watersheds. Annals of Geomorphology. Vol. 24, #3.

Bishop, M.B. 1980. Geomorphic Concepts and their Application to Ephemeral Stream Channel Reclamation. Proceedings of the Second Wyoming Mining Hydrology Symposium, University of Wyoming.

Brookes, A. 1995. River Channel Restoration: Theory and Practice. Chichester, New York. John Wiley and Sons, ltd.

Ellison, M.S. 1996. Applying Geomorphic Principals to Restore Streams Impacted by Surface Mining. Proceedings: American Society of Surface Mining and Reclamation. Success and Failures: Applying Research Results to Insure Reclamation Success. Knoxville, Tennessee.

Goodwin, C.N. 1999. Fluvial Classification: Neanderthal Necessity or Needless Normalcy. American Water Resources Association. Wildland Hydrology Symposium. Bozeman, Montana.

Gregory, D. Mills, R. and C.C. Watson. 1987. Determination of Approximate Original Contour. Billings Symposium on Surface Mining and Reclamation in the Great Plains and Fourth Annual Meeting of the American Society for Surface Mining and Reclamation, March 16-20, 1987, Billings, Montana.

Hupp, C.R. and A. Simon. 1991. Bank Accretion and the Development of the Vegetated Depositional Surfaces along Modified Alluvial Channels. Geomorphology, Vol. 4.

Leopold, L.B. 1994. A View of the River. Harvard University Press, Cambridge, Massachusetts.

Leopold, L.B. and M.G. Wolman. 1960. River Meanders. Bulletin of the Geological Society of America. Vol. 71.

Lowham, H.W. and M.E. Smith. 1993. Characteristics of Fluvial Systems in the Plains and Deserts of Wyoming. U.S.G.S. Water-Resources Investigations Report 91-4153.

Martin, L.J., Naftz, D.L., Lowham, H. W., and Rankl, J. G., 1988. Cumulative Potential Hydrologic Impacts of Surface Coal Mining in the Eastern Powder River Structural Basin, Northeastern Wyoming: U.S. Geological Survey Water-Resources Investigations Report 88-4046.

McIntosh, S. 1989. A Combination of Techniques for Reconstruction of Ephemeral, Stream Channels in Wyoming. Proceedings: Canadian Land Reclamation Association and the American Society for Surface Mining and Reclamation. Calgary, Canada.

Pinet, P.R. 1997. The State of the Natural World and the Responsibility of Geoscientist: A Deep Ecological Perspective. Geological Society of America Annual Meeting Abstracts and Proceedings.

Reichmuth, D. 1991. Living with Fluvial and Lacustrine Systems. A Short Course on River and Lake Mechanics. Montana Department of Highways, Helena, Montana.

Rosgen, D. 1996. Applied River Morphology. Printed Media Companies, Minneapolis, Minnesota.

Shields Jr., F.D., Cooper, C.M., and S.S. Knight. 1995a. Experiments in Stream Restoration. Journal of Hydraulic Engineers. Vol. 121, No. 6.

Shields Jr., F.D., Knight, S.S., and C.M. Cooper. 1995b. Rehabilitation of Watersheds with Incising Channels. Water Resources Bulletin. American Water Resources Association. Vol. 31, No. 6.

Stiller, D.M., Zimpfer, G.L., and M. Bishop. 1980. Application of Geomorphic Principles to Surface Mine Reclamation in the Semiarid West. Journal of Soil and Water Conservation. Vol. 35, No. 16.

Tarquin, P.A. and L.D. Baeder 1983. Stream Channel Reconstruction: The Problem of Designing Lower Order Streams. Symposium on Surface Mining, Hydrology, Sedimentology and Reclamation. Univ. of Kentucky.

Welford, M.R. 1993. A Field Evaluation of the Formative Conditions, Wavelengths and Heights of Alternate Bars in Alluvial Channels. Doctorate theses. University of Illinois at Urbana-Champaign.

2000 Billings Land Reclamation Symposium

ROOTING HABITS OF LODGEPOLE PINE (*PINUS CONTORTA*) IN RELATION TO SOIL CHARACTERISTICS ON COPPER-COBALT MINE SPOILS

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ABSTRACT

Many studies have shown that applying a layer of topsoil over acid mine spoils increases the survivability of vegetation; however, the penetration of roots through the topsoil and into the spoil material is not well documented. This study reports current findings on rooting depth of lodgepole pine (*Pinus contorta* Dougl. ex Loudon) in relation to spoil characteristics from a 24-year old reclamation project on copper-cobalt mine spoils of the Blackbird Cobalt mine near Salmon, Idaho. Site preparation in the early 1970's included topsoiling over acid spoils along with incorporating fertilizer, mulch, and lime. A mixture of native and introduced seeds was broadcast onto the site, and lodgepole pine saplings were then planted. In 1999, pits were dug next to lodgepole pine trees to collect soil profile samples and to assess rooting depth. The spoil material was slightly acidic, had low organic matter content, and contained high concentrations of Al, Ca, Co, Pb, and other minerals. The depth of topsoil at these pits averaged around 20 cm and generally had lower concentrations of heavy metals. Large lateral roots of the lodgepole pines were shallow and, for the most part, remained in the topsoil horizon. Medium and fine-sized roots penetrated the spoil material up to 120 cm. Because the roots penetrated spoil materials, lodgepole pines may be considered as a feasible candidate for reclamation processes.

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INTRODUCTION

Rooting habits of lodgepole pine (*Pinus contorta*) have been extensively studied in various soil types and under diverse conditions (Gail and Long 1935, Horton 1958, Bishop 1962, Bowen et al 1975, Coutts 1982, Nadeau and Pluth 1997). A few studies have shown that under 'normal' conditions the lateral roots of lodgepole pines tend to originate within the top few centimeters of the soil surface and remain within 60 cm (2 feet) of the surface as they grow outward (Gail and Long 1935, Horton 1958, Bishop 1962). In extreme cases, lateral roots can reach a radius of 8 m and vertical roots a depth of over 3 m (Stone and Kalisz 1991). Horton (1958) found that roots for this species reach a maximum area of coverage by about 30 years.

Physical and chemical factors of the soil combine to influence rooting habits of vegetation (Klepper 1987, Sabey et al 1987). Physical factors include soil structure, texture, temperature, and water content (Klepper 1987). Soil compaction, which can be caused by the use of heavy equipment, can alter these factors and may create zones impenetrable to roots, decrease water infiltration, and restrict air supply to plant roots (Sabey et al 1987). Soil chemical factors, such as toxicity, mineral deficiencies, pH levels, amounts of organic matter, and cation exchange capacity, also play an important role in influencing root distribution (Klepper 1987). Determining how roots react in the presence of various physical and chemical conditions is a complicated process as these conditions are very much interrelated and species specific. For example, aluminum toxicity reduces root penetration, but only at low pH levels (Barber 1995).

Lodgepole pine is a pioneer species, which makes it important in reclamation practices (Peattie 1980); however, little is known about the penetration of lodgepole pine roots into acid mine spoils. This paper helps elucidate this issue by studying the rooting habits of lodgepole pine planted in 1976 on copper-cobalt mine spoils near Salmon, Idaho, in relation to physical and chemical soil characteristics found on the site.

STUDY SITE

Blackbird mine is located southwest of Salmon, Idaho, within the Salmon-Challis National Forest. Mining for gold and copper on Blackbird mine began around 1893 and continued until World War II when the government found that the area had potential to yield cobalt. After that, various private firms took over and, in 1949, the mine was converted to an underground copper-cobalt mine. Mining continued until 1960 when the mine was shut down. Three years later, it reopened as a surface pit and underground mine, and continued operating until 1967. It has been largely inactive since that time (Farmer et al 1976).

The study site is located on an overburden spoil waste pile of the Blackbird mine at 2,365 m (7,760 feet) in elevation. Annual precipitation ranges between 60 and 100 cm, most of which falls in winter as snow. This waste pile has been estimated to contain 1 million cubic meters of overburden waste material, with a maximum fill depth of 23 meters (Farmer et al 1976).

METHODS

In the spring of 1974, the overburden waste pile was topsoiled with 20 to 25 cm of soil which was excavated from the surrounding forest and mixed with burnt lime at a rate of 2,030 kg/ha (1,800 lb/acre). The area sat fallow for the summer, and in October, an additional 4,470 kg/ha (4,000 lb/acre) of burnt lime was incorporated into the topsoil. The site was then seeded with a mixture of native and introduced grasses. Following the seeding, the area was fertilized at a rate of 1,420 kg/ha (1,300 lb/acre) of liquid 10-34-0 fertilizer and mulched with 3,050 kg/ha (2,700 lb/acre) of wood fiber. During the summer of 1975, an additional 254 kg/ha (225 lb/acre) of a slow-release 26-3-5 fertilizer was applied, and in September, 5,080 kg/ha (4,500 lb/acre) of agricultural crushed limestone was used to relime the site (Farmer and Richardson 1981). In 1976, lodgepole pine saplings were planted at 10-foot intervals across the site.

In August 1999, 5 pits were dug with a backhoe in order to collect soil samples and determine rooting habits of the lodgepole pines growing on the site. The pits were dug approximately 5 cm away from the base of the tree, and the depth of each pit extended just beyond the deepest roots. The depth of large roots, (> ½" in diameter), medium roots (½" > ¼"), and fine roots (< ¼"), was also recorded. The height and crown diameter of each tree was measured, and the percent of the tree that was discolored was recorded. The age of the tree was roughly estimated by counting the number of whorls (1 whorl/year). The trees were aged to help determine if they were the ones planted in 1976, or if their presence represented natural regeneration, as some natural regeneration was evident on the site. While digging by one of the trees, a main lateral root was hit, and the tree fell over. This pit was abandoned and the results presented here are based on the 4 remaining pits.

Soil samples were collected from various levels in the soil horizon. Since there were few visible horizons, samples were taken from the topsoiled layer and from layers corresponding to the depths at which the aforementioned roots stopped growing. Analyses of the soil included: abundance of minerals, pH, CEC, electrical conductivity, and organic matter content[1].

RESULTS

Four mature trees were chosen that represented the health and size of most of the planted trees on the reclaimed area. Table 1 shows the age estimates as well as the height, crown diameter, and % discoloration of each tree. Trees 1a, 3-1, and 3-3 appear to be those planted in 1976. Tree 3-2 was about 5 to 6 years younger, was much larger than the others, and appears to be a product of natural recruitment.

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[1] Soil analyses were performed at the Soils and Plant Analysis Lab at Brigham Young University in Provo, Utah.

Table 1. Size, age, and % discoloration of each tree. Each site refers to an individual lodgepole pine.

Tree Characteristics	Sites			
	1a	3-1	3-2	3-3
Height (cm)	370	470	515	440
Crown diameter	180	225	320	250
# of whorls (age)	25	27	19	28
% Discoloration	60	40	85	80

The depth of the large lateral roots correlated closely with the depth of the topsoil, while medium and fine roots penetrated deeper into the spoil material (Table 2). The soil surface had a plate-like structure in all 4 pits. Pit 1a had a 5-cm thick compacted and cemented layer in the 15 to 20 cm horizon. Although there were no cemented layers that might inhibit root elongation in the other pits, the spoils in all 4 pits were composed of 60% to 80% rock fragments ranging in size from small pebbles to rocks measuring10 cm in length.

Table 2. Depth of topsoil and large (> ½" in diameter), medium (½" > ¼"), and fine roots (< ¼").

Topsoil and Root Sizes	Sites			
	1a	3-1	3-2	3-3
Topsoil Depth	15 cm	23 cm	30 cm	20 cm
Large Roots	15 cm	20 cm	35 cm	26 cm
Medium Roots	110 cm	120 cm	70 cm	26 cm
Fine Roots	120 cm	120 cm	110 cm	90 cm

Soil nutrient values greatly impact root distribution. Nutrient concentrations that promote normal plant growth are listed in Table 3, and the values of the nutrients found at the study site are presented in Table 4.

Table 3. Commonly held nutrient values for normal plant growth (taken from Lowe 1998).

Properties	Low	Adequate	High
% OM	< 2%	2 – 3%	>3%
pH	<7	7	>7
El. conductivity		0 – 4	>4
Cu (ppm)		0 – 0.2	>0.2
Fe (ppm)	<5	5	>5
K-available (ppm)	<60	60 – 80	>80
Mn (ppm)	<0.5	0.5	>0.5
NO_3-N	<10	10 – 40	>40
P (ppm)	<11	11	>11
Zn (ppm)	<1.5	1.5	>1.5

The percentage of organic matter at each pit was highest in the topsoil and drastically decreased with increasing depth. No pit had adequate OM. Pit 3-3 had almost half as much as pit 1a, and all pits were virtually void of OM at the deepest levels. pH levels varied in each pit but tended to decrease (become more acidic) in all pits from the topsoil horizon to the deeper spoil layers. The trend in electrical conductivity (EC) went from high to low with increasing depth, but none were as drastic as in pit 1a. There was a wide range of variation in cation exchange capacity (CEC) between pits and at different depths within pits, but values were usually higher in the topsoil than at deeper depths.

Table 4. Soil properties at various depths for all 4 pits.

Site, Horizon Depth	% OM	pH	EC (mmhos/cm)	CEC
1a, 0 – 15cm†	**1.77**	**7.46**	**6.0**	**8.04**
1a, 15 – 20cm	0.05	7.94	4.0	7.57
1a, 20 – 34 cm	0.29	7.0	1.44	6.09
1a, 34 – 120cm	0.14	6.76	2.25	3.43
3-1, 0 – 23cm	**1.53**	**6.73**	**0.48**	**1.61**
3-1, 23 – 30cm	0.33	6.93	2.75	2.74
3-1, 30 –35 cm	0.77	7.08	0.35	1.87
3-1, 35 -100cm	0.28	6.07	0.55	1.26
3-2, 0 – 16cm	**0.81**	**6.60**	**0.29**	**1.65**
3-2, 16-30cm‡	**0.32**	**6.90**	**0.44**	**4.13**
3-2, 30 -100cm	0.15	6.20	0.20	4.83
3-3, 0 – 20cm	**0.93**	**6.18**	**2.0**	**4.57**
3-3, 20 -120cm	0.06	6.05	1.42	3.57

† Values in bold print represent topsoil layers.
‡ Most grass roots stopped 16cm, but the topsoil layer continued to 30cm.

Results from analyses on the abundance of various elements found in each pit are listed in table 5. Note the high amounts of As, Ca, Co, Cu, Fe, K, P, and Pb in the cemented 15-20 cm layer in pit 1a. This layer also had the highest pH of all layers in all pits. The large roots of this lodgepole didn't penetrate this layer, and this tree was the smallest of the 4.

The horizons in pit 3-1 show a distinct pattern. The abundance of all minerals but NO_3-N decreased drastically from the surface horizon to the second horizon. It then increased from the second to the third layer. All but 2 minerals were more abundant in the third layer than in the surface horizon. Abundance then dropped in the fourth layer.

Looking across all layers, pit 3-2 exhibited lower amounts of Al, As, Co, Cu, and P than other pits. This was the largest tree but also had the highest percent discoloration.

As depth increased, concentrations of several of the minerals also increased (eg. Cu and Pb). Conversely, some of the elements decreased with increasing soil depth (eg. Zn and NO3-N), while many showed both patterns.

Table 5. Abundance of minerals in 4 soil pits. Units are parts per million unless stated otherwise.

Site, Horizon Depth	Al	As	Ca (EX)†	Co	Cu	Fe	K-AV	Mg (EX)	Mn	NO_3-N	P	Pb	Zn
1a, 0 – 15cm‡	**2753**	**5.1**	**2216**	**13.2**	**9.2**	**31.8**	**288**	**37.3**	**8.8**	**3.36**	**24.0**	**14.7**	**0.33**
1a, 15 – 20cm	3210	48.9	2692	54.3	44.6	67.9	576	80.3	3.9	2.37	97.1	33.5	0.17
1a, 20 – 34 cm	3209	15.0	504	18.0	9.3	37.2	323	117.5	1.4	2.25	20.0	31.8	0.21
1a, 34 – 120cm	2660	3.3	442	13.7	9.8	31.6	291	128.3	2.4	2.52	11.2	24.9	0.23
3-1, 0 – 23cm	**3162**	**8.0**	**849**	**13.2**	**35.2**	**49.0**	**237**	**21.9**	**4.7**	**2.31**	**16.4**	**27.8**	**0.69**
3-1, 23 – 30cm	1170	2.9	342	5.6	4.0	18.5	138	18.2	0.9	2.58	3.3	8.9	0.2
3-1, 30 – 35cm	4306	28.6	1933	146.7	76.6	37.0	339	33.4	1.2	6.78	53.8	44.2	1.05
3-1, 35 -100cm	2843	12.0	334	23.4	40.5	43.4	269	15.2	1.3	4.36	27.0	31.9	0.38
3-2, 0 – 16cm	**1280**	**0.93**	**557**	**7.2**	**8.1**	**45.5**	**166**	**40.2**	**5.0**	**2.43**	**11.6**	**20.0**	**0.31**
3-2, 16 – 30cm	**1622**	**1.67**	**1260**	**7.8**	**3.8**	**33.8**	**144**	**77.3**	**2.3**	**1.80**	**5.9**	**13.3**	**0.24**
3-2, 30 -100cm	1530	5.96	499	35.5	34.1	25.5	282	35.0	12.0	1.71	13.3	25.0	0.32
3-3, 0 – 20cm	**2036**	**2.5**	**558**	**9.6**	**18.5**	**61**	**182**	**29.5**	**8.5**	**5.63**	**15.0**	**17.3**	**0.31**
3-3, 20 -120cm	2551	10.6	467	13.1	43.2	66.7	323	12.9	0.57	4.19	42.0	31.0	0.16

† EX stands for the amount of the element in the soil that is exchangeable.
‡ Bold horizon depths represent topsoil layers.

DISCUSSION

The results presented here are based on 4 lodgepole pines. Although there is little statistical strength in such a small sample, these results are important because they show trends in root distribution on copper-cobalt mine spoils.

It is difficult to determine why the roots of these lodgepole pines behave the way they do by just looking at these results. It is important to keep in mind that each soil factor influences other factors. For instance, Cu is more soluble in acid soils than in alkaline soils, and the uptake of Cu is inhibited by high organic matter (Neuman et al 1987). These spoils are slightly acidic, which make Cu more soluble, and they are also very low in organic matter, which should increase the uptake of Cu.

pH influences the availability of other nutrients as well (Tucker et al 1987). The pH of the spoils at this site fall within a range that would enhance the availability of Fe, Mg, Mn, N, P, and Zn.

The large lateral roots of these trees generally stayed within the topsoil horizon. Besides pit 1a, none of the sites had a compacted layer that would have acted as a physical barrier to root penetration. pH levels were usually highest in the topsoil which could decrease the availability of the previously mentioned elements. However, it is not known whether these roots remain in this horizon because of better soil conditions or if they simply follow the same distribution of lateral roots of other lodgepole pines as described by Gail and Long (1935), Horton (1958), and Bishop (1962). Future research on this site should include a study of the rooting habits of lodgepole pine from the surrounding undisturbed forest.

Although the large lateral roots remained near the soil surface, medium roots grew to a wide variety of depths, and the fine roots of the 4 trees grew to depths between 90 and 120 cm. All pits had high amounts of Al, Cu, Fe, K, Mn, and P and exhibited deficiencies in Zn and No_3-N throughout the layers. The fine roots may have stopped between 90 and 120 cm because of unfavorable conditions such as low OM and NO_3-N and increases in toxicity of elements such as Al, Co, Cu, and Pb. Some lower horizons appear to have concentrations of these ions high enough to correspond to the hotspots discussed by Farmer et al (1976). Soil samples below 120 cm would have aided in determining if the trend in increasing toxicity continued and limited fine roots to this depth.

This study has examined the rooting behavior of lodgepole pines on copper-cobalt mine spoils 24 years after reclamation practices began. Rooting behavior on this spoil is similar to that found on undisturbed sites. The fact that medium and fine roots penetrate the spoil material, and thus help stabilize the soil, shows that this species may be a good candidate for reclamation activities.

REFERENCES

Barber, S. A. 1995. Soil Nutrient Bioavailablity. pp. 150-153. John Wiley & Sons, Inc. New York, NY.

Bishop, D. M. 1962. Lodgepole pine rooting habits in the blue mountains of northeastern Oregon. Ecology 43 (1):140-142.

Bowen, M. R., J. Howarth, and K. A. Longman. 1975. Effects of auxins and other factors on the rooting of Pinus contorta Dougl. cuttings. Ann. Bot. 39:647-656.

Coutts, M. P. 1982. The tolerance of tree roots to waterlogging: V. Growth of woody roots of sitka spruce and lodgepole pine in waterlogged soil. New Phytol. 90:467-476.

Gail, F. W. and E. M. Long. 1935. A study of site, root development, and transpiration in relation to the distribution of *Pinus contorta*. Ecology 16 (1):88-100.

Farmer, E. E. and B. Z. Richardson. 1981. Acid mine waste revegetation: Influence on soil-water quality. USDA Forest Service Research Paper INT-266.

Farmer, E. E., B. Z. Richardson and R. W. Brown. 1976. Revegetation of acid mining wastes in central Idaho. USDA Forest Service Research Paper INT-178.

Horton, K. W. 1958. Rooting habits of lodgepole pine. Can. Dep. North. Aff. Natl. Resour. For. Res. Div. Tech. Note No. 67.

Klepper, B. 1987. Origin, branching and distribution of root systems, pp. 103-124 In: Root Development and Function. P. J. Gregory, J. V. Lake and D. A. Rose (eds.). Soc. for Exper. Biol. Seminar Series 30. Cambridge University Press, Cambridge, England.

Lowe, G. E. 1998. Revegetation following topsoil applications of the Ballard Phosphate mine, Soda Springs, Idaho. Dept. of Botany and Range Science, Master's Thesis, Brigham Young University.

Nadeau, L. B. and D. J. Pluth. 1997. Spatial distribution of lodgepole pine and white spruce seedling roots 10 years after deep tillage of a Gray Luvisol. Can. J. For. Res. 27: 1606-1613.

Neuman, D. R., J. L. Schrack, and L. P. Gough. 1987. Copper and molybdenum, pp. 215-232. In: Reclaiming Mine Soils and Overburden in the Western United States: Analytic Parameters and Procedures. R. D. Williams and G. E. Schuman (eds.). Soil Conservation Society of America, Ankeny, Iowa.

Peattie, D. C. 1980. A Natural History of Western Trees. pg. 105. University of Nebraska Press, Lincoln, NE.

Sabey, B., J. Herron, D. G. Scholl, and J. Bokich. 1987. Particle size distribution, pp. 59-73. In: Reclaiming Mine Soils and Overburden in the Western United States: Analytic Parameters and Procedures. R. D. Williams and G. E. Schuman (eds.). Soil Conservation Society of America, Ankeny, Iowa.

Stone, E. L. and P. J. Kalisz. 1991. On the maximum extent of tree roots. For. Ecol. Manage. 46:59-102.

Tucker, G. B., W. A. Berg, and D. H. Gentz. 1987. pH, pp. 3-26. In: Reclaiming Mine Soils and Overburden in the Western United States: Analytic Parameters and Procedures. R. D. Williams and G. E. Schuman (eds.). Soil Conservation Society of America, Ankeny, Iowa.

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An International Perspective on the Environmental Management of Sulfidic Mine Wastes

by
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Abstract: The environmental management of sulfidic mine wastes is one of the most important issues facing the minerals industry not only in Australia but around the globe. In the past, inappropriate management techniques have led to a legacy of significant environmental impacts including acid drainage (AD) which results from the oxidation of sulfidic minerals exposed to atmospheric conditions and subsequent release of acidic solutions containing high concentrations of metal pollutants. These are transported to ground and surface water and can severely impact the immediate and surrounding environment. It is therefore vital now and in the future that sulfidic mine wastes are well managed to prevent a repeat of historical environmental problems.

In Australia, it has been estimated that the minerals industry faces liabilities of about A$0.9 billion for managing potentially acid forming sulfidic mine wastes at current mine sites. Liabilities associated with abandoned and historic sites have not yet been quantified. From an international perspective, these costs pale into insignificance as it has been estimated that the cost of reclamation of abandoned mine sites in the USA alone is between A$150 billion and A$750 billion.

In recent times, our understanding of the challenges associated with AD has increased and strategies have been developed to improve the environmental management of sulfidic mine wastes. In 1998, the Australian Minerals and Energy Environment Foundation (AMEEF) supported an International Travelling Scholarship to gather information from a number of overseas countries facing similar environmental problems to Australia. This paper provides a summary of the main findings of the AMEEF Travelling Scholarship and presents some of the techniques used to manage sulfidic mine wastes and control/remediate AD. A number of case studies are presented to highlight the application of promising management strategies in the field.

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1.0 INTRODUCTION

The environmental management of sulfidic mine wastes is one of the most significant and complex environmental issues facing the mining industry not only in Australia but around the world. In the past, inappropriate or non-existent environmental management techniques have led to a legacy of ongoing environmental problems including acid drainage.

Acid drainage (AD) occurs when sulfidic minerals (*eg.* pyrite, FeS_2) react with oxygen and water on exposure to atmospheric conditions, especially in the presence of bacteria such as *Thiobacillus ferrooxidans*. The resultant acidic solutions may mobilise metals such as Al, Cu, Fe, Mn and Zn from the surrounding matrix, transport these to ground and surface water, and affect the immediate and surrounding environment (CMA, 1992). In nature, the geological processes leading to the development of acidity generally occur over a very long period of time and contaminants can be assimilated by the receiving environment. In contrast, anthropogenic activities such as mining, can disturb and expose large volumes of sulfidic waste minerals in a relatively short time. The acid generation rate may be far in excess of that which the receiving environment can handle and the effects on the downstream ecosystem can be devastating. Environmental impacts can continue long after mining operations are complete as shown in the Rio-Tinto region of Spain where historical mines have been a source of ongoing pollution for more than two millennia (Taylor, 1997).

When the topic of AD is raised in Australia, a number of famous historical mine sites spring to mind (*eg.* Captains Flat, Rum Jungle and Mount Lyell) as particularly acute examples of the significant ongoing environmental problems that can occur if the potential for acidity and contaminated leachate is not considered and managed accordingly. Even when the AD potential is considered in the initial Environmental Assessment phase of a mining project, constant vigilance and monitoring is required as unexpected challenges can arise during the production phase and at cessation of mining (Tarlinton, 1995).

Liability associated with managing sulfidic mine wastes at current Australian mine sites has been estimated at A$900M (Harries, 1997) and has not yet been quantified for abandoned and historic sites. The Australian minerals industry has dramatically improved its environmental performance over the past few decades and recognises that it should contribute to the remediation and rehabilitation efforts at historical mine sites. Recent initiatives such as the Australian Mineral Industry's *Code for Environmental Management* will help to minimise the risk of AD in future and improve the industry's public image. Continuous improvement in environmental management and performance forms an integral part of the *Code* and it is important that the most appropriate techniques to manage sulfidic mine wastes and to control and remediate AD are implemented to prevent a repeat of historical environmental problems.

In recent times, our understanding of the challenges associated with AD has increased and strategies have been developed to improve the environmental management of sulfidic mine wastes. In 1998, the Australian Minerals and Energy Environment Foundation (AMEEF) supported an International Travelling Scholarship to gather information from a number of overseas countries facing similar environmental problems to Australia. This paper provides a summary of the main findings of the AMEEF Travelling Scholarship and presents some of the techniques used to manage sulfidic mine wastes and control/remediate AD. A number

of case studies are presented to highlight the application of promising management strategies in the field.

2.0 BACKGROUND

The main sources of AD at mine sites are waste rock dumps, stockpiles, tailings impoundments and abandoned mine areas. The environmental impacts of AD include the release and transport of highly acidic contaminated leachates into the downstream environment. Even where neutralisation of the generated acidity occurs through interaction with carbonate minerals, contaminants can remain mobile at neutral pH.

The successful management of sulfidic mine wastes and control or remediation of AD requires an understanding of the geochemistry of the problem and factors influencing the rate of acid generation. A number of factors can influence the process including oxygen and water availability, microbial activity, pH, temperature, ferrous/ferric iron equilibrium, physical nature of the waste material and the presence of any neutralising minerals. These factors will vary from site to site and management practices for dealing with the problem may also have to be varied to suit particular site conditions.

The management process should involve initial characterisation of the various rock types likely to be generated during mining activities. An evaluation of similar mining operations in the region may also provide some indication of the acid forming nature of the regional ore bodies and host rocks. Examination of drill core can provide useful information on sulfide mineralogy and presence of any potentially neutralising materials. Sampling techniques should reflect the geological variability and complexity in rock types and the level of confidence required in predictive ability.

As well as a geological assessment, characterisation of mine rock types can be achieved using a number of static and kinetic geochemical tests. The variety of these tests available are well documented and have been the subject of much research (AMIRA, 1996; Miller *et al.,* 1997). Geological modelling of the acquired information can form the basis of initial mine planning strategies (Scott *et al*., 1996).

The oxidation of pyrite is a complex multi-staged process (MCA, 1992) but is often summarised as:

$$\textbf{1.} \quad FeS_2 + 15/4\ O_2 + 7/2\ H_20 = Fe(OH)_3 + 2\ H_2SO_4$$

From reaction 1, it is clear that the formation of AD requires at least three components: oxygen, water and reactive sulfidic rock. Management techniques used to deal with sulfidic mine wastes containing reactive pyrite are numerous, but typically aim to reduce the rate of oxidation and limit the transport of oxidation products to the receiving environment. These objectives can be achieved by limiting the supply of oxygen to the reactive sulfides and minimising the amount of water available to transport contaminants to surface and ground waters. The net amount of acid formed by a particular waste can be reduced by adding neutralising agents such as lime or utilising bactericides which limit the bacteria that catalyse the oxidation. Bacterial catalysis only becomes important below pH 3.5, however, bactericides can work effectively if combined with neutralising material and natural organic

fertilisers which stimulate the growth of vegetation and benign microbes. Covers, caps and seals can be used to isolate or encapsulate sulfidic waste materials and minimise oxygen and/or water access. Oxygen exclusion can effectively prevent sulfide oxidation but may be difficult to achieve. Capping materials which have been successfully used to minimise oxygen diffusion include water, compacted soils and geofabric materials. The most appropriate strategy for managing sulfidic mine wastes may utilise a combination of some or all of the above methods.

The plethora of strategies used in Australia for managing potentially acid forming sulfidic mine wastes have been reviewed (Miller, 1995; Harries 1997) and practical engineering options for minimising AD or controlling its effects have been described (Watson, 1995; Marszalek, 1996). Where management strategies have been absent or ineffective and AD is apparent, a number of active and passive treatment and control techniques are available. The subject of AD treatment has recently been critically reviewed in some detail (Parker & Robertson, 1999).

Active treatment (*eg.* neutralisation with alkaline reagents) tends to be expensive and produces a metal rich precipitated sludge requiring separate disposal. Treatment may have to be continued for many years after mine decommissioning. However, if the contaminated leachate contains dissolved metals in sufficient concentrations, funds generated from metal recovery may offset operating costs. Passive treatment techniques (*eg.* constructed wetlands) have been the subject of some research (Tyrrell, 1995) and are becoming more prevalent but there is a paucity of information regarding their long term effectiveness and ongoing maintenance costs. Passive treatment techniques are probably most beneficial when used to treat relatively low acidity and low flow AD streams.

Traditional active and passive treatment techniques do not significantly reduce the total sulfate load released that, at sufficiently high concentration, may be toxic to downstream freshwater biota. The use of sulfate reducing bacteria in conjunction with both active and passive treatment techniques has shown some promise in improving the quality of mine waste waters impacted by AD in particular reducing sulfate concentrations (Robertson, 1998; Tyrrell *et al*., 1998).

The effectiveness of the selected management strategy should be monitored to ensure that predictions are accurate and no long term financial or social liability exists. Monitoring should be considered an essential part of sulfidic mine waste management as regulating authorities need to be convinced of the integrity of the overall strategy and are unlikely to accept transfer of responsibility without confirmation of predictions by comprehensive scientific studies with good field data.

On-site monitoring should include geotechnical, hydrological, physical and chemical studies. Off-site monitoring should include chemical and biological studies to provide further information on the effectiveness of the selected control/remediation strategy and give some indication of short and long term ecosystem rehabilitation success.

3.0 CASE STUDIES - AMEEF TRAVELLING SCHOLARSHIP

This paper highlights one Australian case study and three selected overseas case studies investigated as part of the AMEEF Travelling Scholarship undertaken from May to June 1998. The Scholarship involved travel to New Zealand, The USA, Canada and The Netherlands and included visits to an international conference on mine rehabilitation, sixteen mine sites and six research centres. The majority of the Scholarship was spent in North America and included visits to a number of active mine sites currently managing sulfidic mine wastes and several historical mine sites having a legacy of ongoing environmental degradation due to inappropriate management of sulfidic mine wastes.

3.1 Australia - Mt. Lyell

The Mt. Lyell Mine is located in a high rainfall environment (2.5 - 3 m/yr) on the west coast of Tasmania and has a history of mining activities over more than a century which have resulted in substantial modifications to environmental conditions. Disposal of sulfidic waste rock across the lease has left a legacy of ongoing environmental impacts. AD emitted from underground workings and waste rock dumps at the mine site has severely impacted on water quality downstream in the Queen and King Rivers and Macquarie Harbour.

Some 55 Mt of sulfidic waste rock, at an average of 10% pyrite, has been historically disposed of in more than 10 waste rock dumps across the surface of the Mt Lyell lease with scant regard for possible environmental impacts (EGi, 1993). Modelling of the pyritic oxidation rates in the abandoned West Lyell open cut waste rock dumps by the Australian Nuclear Science and Technology Organisation (ANSTO) has revealed that leachate from these dumps will continue to be a source of AD for an estimated 600 years (ANSTO 1994 a, 1994b).

The Mt Lyell mine ceased operation in December 1994 and the Tasmanian State Government granted Copper Mines of Tasmania Pty. Ltd. (CMT) a mining lease the following year for redevelopment of Mt. Lyell and indemnity from actions concerning pollution from previous occupation and use of leased land. The Environmental Management Plan (EMP) for the Mt. Lyell redevelopment has committed CMT to be responsible for waste rock dumps generated from current and future activities and to ensure that environmental management is in line with the principles of best practice (Robertson *et al*., 1997).

The Author has first hand experience of the environmental standards at the CMT operation having carried out the duties of Environmental Superintendent at the mine in 1996 and 1997. The Company treats a portion of the AD generated with alkaline tailings prior to sub-aqueous disposal of neutral tailings/AD mixture in a new A$12M tailings dam built in 1995, thus ending the historical practice of tailings disposal in the Queen River. Nevertheless, the ongoing legacy of AD from historical waste rock dumps and underground workings continues and contributes over two tonnes of dissolved copper per day, as well as other metal pollutants, to the downstream Queen and King Rivers and Macquarie Harbour (Clarke, 1997). The nature and possible remediation of this AD have been the subject of much research including the Mount Lyell Research, Remediation and Demonstration Program (MLRRDP) (Koehnken, 1997).

In recent years funds have been made available from the Australian Federal Government to establish a Solvent Extraction Electrowinning (SXEW) treatment plant alongside the mining operation to remove the majority of the dissolved copper from the most pollute streams. The SXEW plant is due to be commissioned this year whilst the feasibility of using an active Solvent Reducing Bacteria (SRB) plant as a final polishing step in the water treatment regime is being investigated (NTBC, 1997).

3.2 New Zealand - Golden Cross Mine

The Golden Cross mine lies at the head of the Waitekauri Valley, 10 km northwest of Waihi in an area that was farmed prior to mining. This hard rock gold mine is located in the Coromandel region on the East Coast of New Zealand's North Island, carries a large bond to ensure environmental protection and final rehabilitation. Coeur Gold NZ Ltd announced the mine's closure in December 1997 and has completed an extensive decommissioning program with site activities including remediation of tailings, open cut and underground areas. Potentially acid forming waste rock from around the site has been encapsulated by inert waste rock within the open pit area which is being progressively refilled and rehabilitated .

Extensive drainage and earthmoving work has now stabilised the tailings dam area which is partially capped with inert waste rock. One of the main management objectives for the tailings dam closure is to reduce the volume of water in the dam as ongoing treatment of this water will be required into the future. A series of constructed wetland facilities have been constructed to treat water from the tailings surface and under drains as well as discharge from underground workings. Water quality and aquatic life downstream from the mine are regularly monitored by the company as well as independent agencies and controls on the treated water discharge into the Waitekauri River are based on extensive studies of water quality and freshwater life. Studies carried out by the Company show young trout to be the most sensitive to minor changes in water quality, and the water is treated to a standard to protect them and their habitat. It is interesting that water quality criteria for gold mining operations are more stringent than for other industries in New Zealand.

Final rehabilitation of the mine site is now all but complete with underground workings having progressively being allowed to flood. The Company plan to develop a commercial forestry program on site and use projected future income from timber sales to offset a significant proportion of current decommissioning costs. Post mining land use is a topic which is likely to receive increased attention in the future (Kuhn, 1998).

Many lessons can be learned from the Golden Cross mine in terms of experience in managing sulfidic mine wastes. Clearly, identification of the potential for AD should be undertaken at the environmental assessment stage and the selected management strategy should be integrated into forward planning (and budgeting). The overall cost of environmental management can be drastically reduced if carried out progressively during the project life rather than retrospectively, especially if disturbed land can be rehabilitated and returned to productive use following decommissioning.

3.3 USA - Bingham Canyon

The cost of reclamation of abandoned mine sites in the USA is estimated to be between AS150 billion and A$750 billion (MSU,1998). Approximately 15,000 km of rivers and streams are impacted by AD from coal and metalliferous mining and on United States Forest Service lands alone there are between 20,000 and 50,000 mines generating AD (USDA,1993).

The Travelling Scholarship involved spending seventeen days in the USA allowing attendance at one international conference (ASSMR, and inspection of a total of nine historical and/or active metalliferous mine sites in five states including Alaska, Colorado, Missouri, Montana and Utah.

The Bingham Canyon Copper Mine operated by Kennecott Utah Copper located near Salt Lake City in Utah is almost 4 km wide by 1 km deep and is the largest man-made excavation on earth. It is one of only two man made structures visible from space, the other being the Great Wall of China. The Company employs large-scale open pit mining methods to excavate sulfidic materials (160,000 tons of copper ore and 290,000 tonnes of waste rock per day). Following mineral processing, the concentrated ore reports to flash smelting and refining facilities which recover 99.9 % of sulfur dioxide emissions and are claimed to be the cleanest in the world. The sulfur is converted to sulfuric acid and about 1,000,000 tons of acid is produced annually for the domestic market.

An extensive water management system segregates waters of different quality to put each water type to its most beneficial use. Stormwater and snowmelt from above the mine site is routed around any area of disturbance in order to protect its purity and is partially used as process water. Contaminated water from within the mine and other operating areas is captured and diverted into the process system. The company recycle approximately 60 % of total water demand which is vital given the arid environment in which the mine is situated,

There are several waste rock disposal areas around the site and an A$80M investment in an extensive leach and stormwater capture system has turned a dissolved copper liability into a resource of 20 tons of solid copper daily. A series of French drains and cut-off walls capture 98% of the total flow and work is in progress to capture the rest. A major demonstration reclamation project covers over 80 hectares of waste rock on the site as the operators study the feasibility of various reclamation techniques for final decommissioning. The use of sulphate reducing bacteria (SRB) for the active treatment of contaminated ground water seepage from mining areas has been piloted at the mine in collaboration with Paques Bio Systems BV of the Netherlands. The system utilises CO_2 gas as a carbon source instead of *eg*. biosolids as this provides a more easily controlled and uniform supply for pilot studies.

Tailings from the Kennecott operation are stored in a 2300 hectare impoundment using a peripheral discharge system to maintain surface moisture and minimise dust. Excess water is recycled back to the production circuit and the perimeter embankments of the impoundment are revegetated as the dykes are raised. Kennecott has spent over A$300M on site rehabilitation initiatives in recent years and an agreement has been reached with the US EPA to keep the Company's Utah properties off the NPL of Superfund sites. Major activities include the re-establishment of native vegetation to ensure sustainable habitats for wildlife. Over 100,000 trees have been planted in recent years and these efforts have helped to control significant historical problems associated with flooding and soil erosion.

3.4 Canada - Equity Silver Mine

A total of fifteen days were spent in Canada which allowed inspection of five historical and/or active metalliferous mine sites and five research centres in three Provinces. The collective liability from sulfidic mine wastes in Canada has been estimated to be between A$2 and 5 billion (Feasby and Jones, 1994) with potentially acid generating metalliferous sites covering over 15,000 hectares (Feasby et al, 1991).

The Equity Silver mine owned by Placer Dome Inc. is located near Smithers in the semi-humid alpine environment of central British Columbia. The mean annual precipitation is around 700 mm which exceeds the total annual potential evaporation which is between 300 and 500 mm. The mine was closed in 1994 with the requirement for a bond in excess of $A60M to ensure complete financing for site reclamation. Since closure, approximately 77 Mt of sulfidic waste rock has been reshaped (20° slopes), compacted and covered (A$38,000/hectare) to minimise sulfide oxidation and AD. The dumps were originally constructed by end dumping and later in 10 m lifts with waste rock typically containing 2-3% pyritic sulfide. An uncompacted and revegetated 0.3m thick till cover overlies a 0.5m thick clay layer compacted to a minimum of 95 % of the saturated proctor density of $1.9tm^{-3}$ at an optimum gravimeter water content of approximately 14 %. Monitoring equipment has been installed below the cover of the waste rock facility to measure temperature, oxygen concentration, thermal conductivity, water content, matrix suction and water infiltration (Wilson, 1995). The monitoring has been carried out as part of a five year study project carried out by the University of Saskatchewan which has revealed that water infiltration has been reduced from about 70 to 2 percent. One indication of reduced sulfide oxidation due to reduced oxygen diffusion into waste rock since cover implementation is the fact that waste rock dumps no longer vent to atmosphere during winter months (Wilson, 1998).

Extensive drainage structures have been installed to capture AD from dumps prior to treatment at a lime plant to pH 8.5 at an annual cost of over A$1.2 M. The plant effluent is discharged to settling ponds where metal complexes settle out as calcium sulfate/metal hydroxide sludge. Clear supernatant decanted from sludge settling ponds into a diversion pond and is discharged to the environment during spring. Treatment capacity varies between 60 to 150 L/s depending on acidity levels and average lime use is around 5000 tonnes. The treatment system typically reduces the concentration of dissolved metal contaminants such as Cu, Fe and Zn from 116, 1340 and 154 mg/L to 0.01, 0.05 and 0.04 mg/L, respectively. It is expected that the annual treatment costs will diminish as the cover takes effect but it is likely that ongoing treatment will be required for at least the next 100 years.

Other remediation activities conducted on-site include flooding of the 120 hectare tailings impoundment to a depth ranging from 2 to 7 metres and progressive flooding of final void areas resulting from open pit mining activities to a depth of 350 m. The flooding of the tailings area has been particularly successful in improving water quality in this area although elevated ammonia concentrations are still apparent in the supernatant water probably due to the breakdown of cyanide used in the gold extraction process. Additional water treatment techniques are being considered but it is likely that ammonia will naturally degrade and concentrations reduce to acceptable levels with time.

In Canada, regulators are actively discussing the merits of introducing construction standards and decommissioning criteria to enable tailings impoundments to withstand maximum possible flood (MPF) and maximum creditable earthquake (MCE) events. These discussions

are perhaps not surprising given the highly publicised failures of sulfidic tailings impoundments and significant pollution events in some parts of the world in recent years (Sassoon, 1998).

3.5 Canada - MEND program

No discussion on AD in Canada would be complete without at least a brief mention of the Canadian Minesite Environment Neutral Drainage (MEND) program which began in 1989. It was established as a co-operative research organisation to facilitate co-operation between the Canadian mining industry and government organisations to develop technology to prevent and control AD. The MEND program has been successful in reducing the liability from sulfidic mine wastes by at least C$400 million, from an investment of C$18 million over eight years. The main findings of the MEND program were discussed in detail at the 4th International Conference on Acid Rock Drainage (ICARD) held in Vancouver in June 1997 (Feasby *et al*., 1997).

The MEND program has confirmed that, given appropriate climatic conditions, the use of water covers and underwater disposal is the best prevention technology for managing sulfidic mine wastes. However, if oxidation is already in progress, ongoing maintenance of containing embankments may be required. Natural or engineered underwater systems with an organic surface or sedimentation layer minimise the risk of oxygen dissolved in water from oxidising sulfides. The use of multi-zone earth covers has also been shown to be an effective, if expensive, management tool for handling sulfidic mine wastes.

Much research has been applied to the use of "dry" covers and has concluded that a variety of materials, including waste materials from other industries (*eg.* urban biosolids and forestry waste) provide excellent potential at lower cost for generating moisture retaining, oxygen consuming surface barriers.

A number of disposal technologies to reduce acid generation have been investigated. These include: the use of depyritised tailings as cover materials; blending of different waste rock types; and mixing with alkaline materials prior to covering or backfilling into mined out areas. The MEND experience is that results from passive treatment systems such as engineered wetlands and anoxic limestone drains have been disappointing whereas trials using sulfate reducing barriers and engineered biosulfide processes are much more promising.

The MEND program partners have agreed that additional co-operative work is required to further reduce the liability and to confirm results of large-scale field tests of MEND developed technologies. A three year initiative called MEND 2000 is now in progress which will allow project management and monitoring to continue alongside various technology transfer initiatives including an internet site (http://www.nrcan.gc.ca/mets/mend). Information exchange with similar research projects such as the Mitigation of Environment Impact from Mining Waste (MiMi -Sweden) and the Acid Drainage Technology Initiative (ADTI – USA) has been identified as a priority.

MEND is represented on the International Network on Acid Prevention (INAP) which was formed in 1998 and brings together the best expertise in the world to identify the research needs and opportunities with respect to sulfidic mine waste management and control and remediation of AD. At least 18 multi-national mining companies, a number of expert

consultants and representatives from Government organisations have shown a keen interest in this forum to discuss the issues of waste characterisation and material management. One of the key findings is the need to establish an international communications network with links to relevant government or private institutes in various countries where available information on international research projects can be collected and the results reviewed and disseminated to program participants.

INAP was officially launched last year in Australia at the 23rd MCA Annual Environmental Workshop in Melbourne (Brehaut,1998). This is an excellent initiative and it is possible in the future that the information benefits of INAP will be made more widely available, through internet access for example, to assist less well financially endowed organisations. One of the themes of the MCA Workshop was the need to assist smaller mining operators to tackle a variety of environmental challenges including the appropriate management of sulfidic mine wastes to minimise the risk of AD. Community perceptions of the mining industry can easily be tarnished by the environmental performance of the smaller operator, often most at risk from developing significant environmental problems. If the mining industry is to further improve its reputation in terms of environmental performance then any steps that can be taken to lend the smaller operators a guiding hand should be implemented wherever possible.

4.0 DISCUSSION AND CONCLUSIONS

The objective of this paper is to provide readers with an international perspective on the environmental management of sulfidic mine wastes by describing the findings of several case studies in Australia, New Zealand and North America. Some of the findings and conclusions discussed below were gathered from additional case studies undertaken as part of the 1998 AMEEF Travelling Scholarship and these case studies are not described in this paper. A copy of the full report on the AMEEF Travelling Scholarship will be made available when this paper is presented at the 2000 Billings Land Reclamation Symposium.

There is no single magic solution to managing sulfidic mine wastes and minimising the risk of AD. Successful management and disposal requires a good understanding of the geochemical processes involved and the utilisation of a range of management techniques appropriate to the particular site characteristics. In New Zealand, recent experiences demonstrate that significant financial benefits can be gained by incorporating the management and disposal of sulfidic mine wastes into mine planning, development and operation, especially if disturbed land can be rehabilitated and returned to productive use following decommissioning.

For new and active mines, more emphasis should be placed on preventing or controlling the acid forming processes rather than dealing with environmental problems. Mining companies have many more control options if measures are progressively put in place at the construction and mining stages rather than at the decommissioning stage. If sulfidic mine wastes are exposed and react to produce acidity, the process is extremely difficult to stop. Collection and treatment of AD is an expensive, ongoing last resort which should only be used if appropriate control measures cannot be implemented or have failed. It is also apparent that acidity can be produced from sulfidic mine wastes many years after the disposal area has been established. Ongoing treatment can be required for decades and treatment and remediation costs must be considered in site rehabilitation provisions.

In North America, a number of mining companies carry substantial site reclamation bonds particularly those handling potentially acid forming sulfidic mine wastes. Regulating authorities are becoming more reluctant to accept transfer of responsibility and are developing decommissioning criteria for sulfidic waste facilities that are extremely difficult to satisfy such that future operators may be faced with “perpetual leases”. It is vital that the Australian Minerals Industry adopt a pro-active and self-regulatory approach to the management of sulfidic mine wastes to avoid similar developments being adopted in Australia. If adopted, these developments could have serious economic consequences for the Australian Minerals Industry.

If Australian regulating authorities can be convinced of the integrity of the selected management strategy or control/treatment technique they are more likely to accept transfer of responsibility and be assured that no long term financial, environmental or social liabilities exist. In this respect, it is important to provide confirmation of environmental predictions using comprehensive scientific studies with good field data. Extensive on-site monitoring should be complemented by off-site monitoring studies to give some indication of ecosystem rehabilitation success. This strategy will allow access to mineral resources in the future and ensure the long-term sustainability of both the minerals industry and the environment.

In the Australian context, it is important that the most appropriate techniques used to manage sulfidic mine wastes and to control and treat AD are identified and implemented to prevent a repeat of historical environmental problems. Implementation of initiatives described in the Australian Mineral Industry Code for Environmental Management, will help to reduce the risk of AD in the future.

In North America, dry covers and liners of soil (or geofabric) in conjunction with a vegetative cover have been used with some success to minimise the entry of water or oxygen into sulfidic waste materials, and control sulfide oxidation. However, dry covers can be expensive and as with may other management techniques, have to incorporate plans to control surface and ground water movement. The long term stability and effectiveness of dry covers also remain the subject of some debate. Similar questions remain unresolved regarding passive AD treatment systems (*eg.* constructed wetlands) which are becoming more widely used in The USA. Passive systems tend to be more successful if built to sufficient scale to deal with the magnitude of the pollution problem or used as a final polishing step in conjunction with other treatments such as passive biotreatment or active lime neutralisation.

Active treatment of AD can be a highly successful, if expensive, method of protecting the environment. However, very strict regulatory criteria including high construction standards imposed by some authorities may necessitate significant capital expenditure as well as ongoing operating costs. For some mining operations, the overall cost of the active AD treatment system can be offset by the recovery of clean water, marketable metals and other mineral resources from heavily contaminated AD. New active treatment technologies are now emerging (*eg.* sulfate reducing bacteria (SRB)) which may provide a more efficient, lower cost option for the treatment of AD (Vegt de, 1997; Scheeren, *et al.*, 1993).

Other technologies being tested in North America to handle sulfidic tailings materials include: direct revegetation of tailings using lime and fertiliser amendments; use of tailings as backfill for mined out areas; covers of partially decomposed domestic waste or digested sewage sludge combined with alkaline material; and the use of depyritised tailings covers achieved either by amending the final metallurgical process or by reprocessing of historically deposited tailings.

The results of the Canadian MEND program indicate that, given appropriate climatic conditions, sub-aqueous or wet covers are the best preventative technology to manage sulfidic mine wastes. Additional organic surface or sedimentation layers minimise the risk of oxygen dissolved in water from oxidising reactive sulfides. Multi-zone earth covers are also an effective, if expensive, management tool for handling sulfidic mine wastes. MEND studies also suggest that "dry" covers incorporating waste materials from other industries hold promise for generating moisture retaining, oxygen consuming surface barriers. Management techniques involving: depyritised tailings covers; blending of different waste rock types; and mixing with alkaline materials prior to covering or placing back into mined out areas have also shown promise. Results from passive treatment systems such as engineered wetlands and anoxic limestone drains have been disappointing whereas trials using sulfate reducing barriers and engineered biosulfide processes are much more promising. The MEND 2000 program will allow project management and monitoring of projects to continue alongside various technology transfer initiatives. These national research projects will be complimented in the future by international co-operation through INAP, for example. The formation of this organisation will help to identify international research

needs and opportunities, facilitate global networking and will hopefully allow relevant information to be accessed by all interested parties in the future.

It could be argued that the climatic conditions in Australia are considerably different from those found overseas. However, the challenges are in many ways similar, in particular the need for inexpensive and robust technologies to manage sulfidic mine wastes and to control and treat AD. The best results are likely to be achieved by using a range of environmental management techniques that are in harmony with natural processes rather than attempting to engineer solutions that may not be sustainable in the longer term.

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6.0 REFERENCES

AMIRA (Australian Mineral Industries Research Association Ltd.) 1996. *Project P387, Mine waste management - Prediction and identification of acid forming mine waste,* (EGi Pty. Ltd., Balmain, NSW).

ANSTO (Australian Nuclear Science and Technology Organisation) 1994a. *A model for predicting pollutant generation in the Mount Lyell waste rock heap*. (ANSTO, Lucas Heights, NSW).

ANSTO (Australian Nuclear Science and Technology Organisation) 1994b. *Monitoring hole installation and quantification of oxidation in a mine waste dump at the Mount Lyell mine*. (ANSTO, Lucas Heights, NSW).

Brehaut, H., 1998. *The International Network on Acid Prevention (INAP).* Presentation by the Senior Vice President of Placer Dome Inc. at the 23rd Annual Mineral Council of Australia, Environmental Workshop, Melbourne, Vic, 25-30 October, 1998, (Unpublished).

Californian Mining Association (CMA), 1992. *Prediction of Acid Generating Potential. In Mine Waste Management* (Eds. Hutchison, I.P.G. and Ellison, R.D.); pp. 123-199. (Lewis Publishers Inc., Chelsea, Michigan, USA).

Clarke, N.C., 1997. *AD control strategies for Mt Lyell: On-site issues.* Paper presented at the ACMRR/OSS Third Australian Workshop on Acid Mine Drainage, Darwin, NT, July 1997, (ACMRR, Kenmore, Qld).

Environment Australia, 1997. *Managing Sulphidic Mine Wastes and Acid Drainage*. Booklet in a series on Best Practice Environmental Management in Mining, p11-12. Federal Department of the Environment, Sport and Territories (Canberra, ACT).

Environmental Geochemistry International (EGi) Pty. Ltd. 1993. *Modelling of water quality in the Queen and King Rivers below the Mount Lyell mine*. (EGi, Balmain, NSW).

Environmental Geochemistry International (EGi), 1993. *Acid forming characteristics of tailings and implications for closure.* Final Report to Woodlawn Mines. (EGi Balmain, NSW).

Feasby, D.G., Blanchette, M. and Tremblay, G.A., 1991. *The mine environment neutral program.* In Proceedings of the 2nd International Conference on the Abatement of Acid Drainage, V1, pp1-26. Ottawa. (MEND: CANMET, Ottawa, Ontario, Canada).

Feasby, D.G. and Jones, R.K., 1994. *Report of results of a workshop on mine reclamation hosted by the Intergovernmental Working Group – Industry Task Force on Mine Reclamation*, Toronto, Ontario, March 10-11, 1994, pp1-18. (CANMET, Ottawa, Ontario, Canada).

Feasby, D.G., Tremblay, G.A. and Weatherell, C.J., 1997. *A decade of technology improvement to the challenge of acid drainage – A Canadian perspective*. Paper presented at the 4th International Conference on Acid Rock Drainage, Vancouver, BC, Canada, May 31 – June 6, 1997. (MEND:CANMET, Ottawa, Ontario, Canada).

Harries, J. 1997. *Acid Mine Drainage in Australia: Its Extent and Potential Future Liability*. Supervising Scientists Report 125, (Supervising Scientist, Canberra, ACT).

Kuhn, A.K., 1998. *Rational selection of post mining land use.* In Proceedings of the 15th National Meeting of the American Society for Surface Mining and Reclamation, St Louis, Missouri, May 17-21, 1998 pp522-529.

Koehnken, L. 1997. *Mount Lyell Remediation Research and Demonstration Program - Final Report.* Supervising Scientist Report 126 (Supervising Scientist, Canberra, ACT).

Marszalek, A.S., 1996. *Preventative and remedial environmental engineering measures to control acid mine drainage in Australia.* Paper presented at the Institute of Engineers Australia National Engineering Conference, Darwin, NT, 21-24 April 1996. (Institute of Engineers Australia, Barton, ACT).

Miller, S.D. and Jeffery, J.J. 1995. *Advances in the prediction of acid generating mine waste materials.* In Proceedings of the Second Australian Acid Mine Drainage Workshop. (Eds. Grundon, N.J. and Bell, L.C.). Charters Towers, Qld, March 1995, pp 33-42. (ACMRR, Kenmore, Qld.).

Miller, S.D., Robertson, A.M. and Donohue, T.A. 1997. *Advances in acid drainage prediction using the net acid generation test.* Paper presented at the 4th International Conference on Acid Rock Drainage, Vancouver, B.C., Canada, June 1997. (Venue West Conference Services, Vancouver, B.C., Canada).

Montana State University (MSU), 1998. *National program for high-elevation mine land restoration.* Information brochure on a program proposal published by the MSU-Bozeman Office of the Vice President for Research, Creativity, and Technology Transfer, Montana State University, Bozeman, Montana, USA.

NTBC, 1997. *Proposal for use of the biosulfide process at the Mt Lyell mine.* Proposal submitted to Imtech Proprietary Ltd and Copper Mines of Tasmania by the NTBC Research Corporation & Biomet Corporation, September 15, 1997.

Parker, G. and Robertson, A.M. (1999) *Acid Drainage: A critical review of acid generation resulting from sulfide oxidation – Processes, treatment and control. An investigation of strategies used overseas for the environmental management of sulfidic mine wastes.* Australian Minerals & Energy Environment Foundation, Occasional Paper No. 11. AMEEF, Melbourne, Victoria.)

Reid, A., 1998. *Environmental Data management using GIS: a tool for data management, assessment and communication at Woodlawn Mines best environmental practice in mining*. In proceedings of the 23rd Annual Mineral Council of Australia, Environmental Workshop, Melbourne, Victoria, 25-30 October, 1998, pp461-469 (Minerals Council of Australia, Dickson, ACT).

Robertson, A.M., Stanley, I.M., Brett, D. and Dickson, R.,1997. *Environmental management of sulfidic waste rock at Mt Lyell, Tasmania.* In Proceedings of the 3rd International Mining Geology Conference, Launceston, Tasmania, November 10-14, 1997, pp 189-192 (The Australasian Institute of Mining and Metallurgy, Carlton, Victoria).

Robertson, A. M. 1998. *An investigation of international strategies used for the environmental management of sulfidic mine wastes.* In proceedings of the 23rd Annual Mineral Council of Australia, Environmental Workshop, Melbourne, Victoria, 25-30 October, 1998, pp 411-423 (Minerals Council of Australia, Dickson, ACT).

Sassoon, M., 1998. *Los Frailes aftermath.* Mining Environmental Management, V6, No.4, p8-12, July 1998. (The Mining Journal Limited, London, UK).

Scheeren, P.J.H., Koch, R.O. and Buisman, C.J.N. Geohydrological containment system and microbial water treatment plant for metal-contaminated groundwater at Budelco. In Proceedings of the International Symposium – World Zinc 93, 10-13 October 1993, Hobart Tasmania, pp373-383.

Scott, P. Ryan, P. and Joyce C., 1996. *The importance of geological controls in predicting acid mine drainage.* In Proceedings of the 3rd International and the 21st Annual Minerals Council of Australia Environmental Workshop, Newcastle, NSW, v2, p 442, 14-18 October, 1996.

Tarlinton, S.E., 1995. *Management of AMD at Woodlawn Mines*. In Proceedings of the Second Australian Acid Mine Drainage Workshop. (Eds. Grundon, N.J. and Bell, L.C.). Charters Towers, Qld, March 1995, pp 75-82. (ACMRR, Kenmore, Qld.).

Taylor, G., 1997. *Acid Mine Drainage – a worldwide perspective.* Paper presented at the 22nd Annual Mineral Council of Australia, Environmental Workshop, Adelaide, SA, 12-17 October, 1997.

Tyrrell, W.R., 1995. A review of wetlands for treating coal mine waste water, particularly in low rainfall environments in Australia. Australian Minerals and Energy Environment Foundation (AMEEF), Occasional Paper No. 3. (AMEEF, Melbourne, Vic).

Tyrrell, W.R., Mulligan, D.R. and Sly, L.I., 1998. *Using wetlands to improve the quality of mining waste waters – emphasising sulfate removal.* Poster presented at the 23rd Annual Mineral Council of Australia, Environmental Workshop, Melbourne, Vic, 25-30 October, 1998.

USDA, 1993. *Acid drainage from mines on the National Forest: A management challenge*. US Forest Service Publication, 1505, pp1-12.

Vegt de, A.L., Bayer,H.G. and Buisman, C.J., 1997. *Biological sulfate removal and metal recovery from mine waters.* In proceedings of the SME Annual Meeting, Denver, Colorado, pp93-97.

Watson, A., 1995. *Practical engineering options to minimise AMD potential.* In Proceedings of the Second Australian Acid Mine Drainage Workshop. (Eds. Grundon, N.J. and Bell, L.C.). Charters Towers, Qld, March 1995, pp 53-65. (ACMRR, Kenmore, Qld.).

Wilson, G.W., 1995. *Assessment of protective covers and dump behaviour.* In Proceedings of the Second Australian Acid Mine Drainage Workshop. (Eds. Grundon, N.J. and Bell, L.C.). Charters Towers, Qld, March 1995, pp 147-164. (ACMRR, Kenmore, Qld.).

Wilson, G.W., 1998. On-site seminar and field trip presenting the major environmental issues at the Equity Silver mine, 3 June, 1998. (Unpublished).