# RECLAMATION OF ABANDONED BENTONITE MINES IN WYOMING WITH WOODWASTE AND CALCIUM AMENDMENTS TO MITIGATE SODIC SOILS[1]

by

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**Abstract:** The Wyoming Abandoned Mine Land Program has reclaimed 8635 acres of abandoned bentonite surface mines since 1985. Available minesoils were high sodium, heavy clay residual overburden materials with Exchangeable Sodium Percentages as high as 81. An amendment program to mitigate the clay and sodic problems was developed that included sawmill residues such as chips, bark and sawdust in combination with calcium compounds such as calcium chloride, gypsum and phosphogypsum or calcium compounds alone. The cost of the amendments varied depending upon sodium levels and the amendment or combinations used. Mean cost per acre for reclamation was $4879.42 and the combined amendments were 21.3% of the total reclamation cost. Reclamation completing its fifth growing season and subjected to livestock grazing during this period shows good visual performance.

Additional Key words: Bentonite, sodic soils, Revegetation

## Introduction

Surface mining for bentonite clay started in Wyoming in 1888 near the present day community of Rock River, northwest of Laramie in the southeastern portion of the State (IMEC 1985). This early activity was done with hand tools on shallow outcrops and the product was shipped to the east where it was used as a dressing for inflamed horses hooves. By 1900, extensive reserves had been discovered between Newcastle and Moorcroft in the northeastern portion of the state. These deposits began to be intensively developed in the 1920s and processing mills were erected later in that decade.

Bentonite clay, as an important mineral, had been used in cosmetics and in paper manufacture prior to the 1920s. It came into its own, however, in the late 1920s with its application in iron and steel foundry casting molds and as a

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[1] Presented at the 1991 National American Society for Surface Mining and Reclamation meeting in Durango, CO, May 14-17, 1991.

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Proceedings America Society of Mining and Reclamation, 1991 pp 455-478
DOI: 10.21000/JASMR91020455
https://doi.org/10.21000/JASMR91010455

lubricant and cuttings transport fluid for oil well drilling. Following World War II and the corresponding dramatic expansion in petroleum resource development, demand for bentonite clay increased again. Developments in the iron and steel industry in the 1950s further stimulated bentonite production for use in pelletizing iron ore concentrates as lower grade taconite ores replaced exhausted higher grade ores.

By the mid 1950s, bentonite mining was a major industrial and economic activity in Wyoming, with production activities centered along the western edge of the Black Hills uplift in the northeastern corner of the State, in the western Powder River Basin along the eastern front of the Big Horn Mountains in north-central Wyoming and in the Big Horn Basin along the western toe of the Big Horn Mountains. Wyoming became the world's leader of swelling sodium bentonite, a title it continues to hold today (IMEC 1985, Tyler 1990).

Bentonite is a clay derived from volcanic ash that was deposited in shallow seas during the Cretaceous geologic period, some 70 to 75 million years ago. It is a very fine-grained montmorillonite clay of the smectite group, generally light gray, yellowish, greenish or occasionally bluish in the unweathered state, but almost always weathers to a grayish white (IMEC 1985, Dollhopf et al 1988). Unique properties of Wyoming (and adjacent Montana and South Dakota) bentonite include its high sodium content, approximately 3%, that gives the material exceptional swelling and gelling properties. It expands up to fifteen times its dry bulk volume when wetted (Black Hills Bentonite Co.). These swelling and water absorption properties make this material highly desirable for oil well drilling

Bentonite, like so many of the lesser known industrial minerals, finds its way into much of our everyday lives in addition to the uses already mentioned. Early uses that have been noted included soaps and cosmetics by the Native American peoples, soaps by the Hudson's Bay Company for washing their famous blankets and as emergency lubricants for wagon wheels (IMEC 1985). More contemporary uses include as a sealant in irrigation ditches, water impoundments and small dams; in detergents and polishing compounds, in an assortment of agricultural applications, water purifiers and treatment systems, pharmaceuticals and cosmetics and in a variety of insulations, construction and building applications (Black Hills Bentonite Co.). Wyoming's bentonite production records reflect the increasing demand for the clay to provide for these uses:

| YEAR | (SHORT TONS) |
|---|---|
| 1890 | 60(est) |
| 1920 | 433 |
| 1930 | 25,006 |
| 1950 | 299,210 |
| 1970 | 2,373,253 |
| 1989 | 2,220,000 |

## Bentonite Setting And Mining

Bentonite deposition varies from mining district to mining district within the State. In the Black Hills district in the northeast, the recoverable bentonite beds are shallow and relatively flat lying, with a slight dip of a few degrees toward the north, northwest or west, away from the Black Hills uplift. The topography is flat to gently rolling except along the breaks of the Belle Fourche River where it is deeply and steeply incised by erosion. Area surface mining is the predominant mining method, reflecting the limited outcrop exposures.

In the Powder River Basin, the beds dip more steeply, about 10 degrees toward the east, away from the Big Horn Mountains. The topography is rough, deeply cut by geologic erosion. Outcrop or contour mining and ridge top or "mountain top removal" surface mining methods are the most prevalent.

The Big Horn Basin district is notably different from the other two districts in that the beds here are steeply dipping to nearly vertical, some lineal in shape and others sharply contorted as the bentonite outcrops follow a small, but distinct, localized anticlinal structure. Mining in this district most often follows the outcrop in long, often three to five miles in length, but relatively narrow pits, up to 200 yards wide, depending upon how deep the mining went.

Common throughout the three major bentonite producing districts in Wyoming is the highly sodic and saline conditions that are associated with the clay and the overburden materials generated by the surface mining activities. Sodium causes soil particles to disperse upon wetting, resulting in a sealing of the soil surface. This sealing prevents the infiltration of water into the soil profile and root zone, ultimately creating a drouth condition that inhibits seed germination or kills establishing (or established) plants. Upon drying, the dispersed soil particles form a hard crust, often impenetrable to seedling emergence or root penetration (Dollhopf et al 1988, Meining 1991). Soils are considered sodic when Sodium Adsorption Ratios (SAR) are in excess of 12 (WDEQ 1984) or when Exchangeable Sodium Percentage (ESP) exceeds 15 (USDA 1954). Overburdens associated with bentonite mining in all of the districts in Wyoming may be characterized as sodic.

High sodium concentrations in agricultural soils have been recognized as problematic for a long time and there has been significant research into sodic soil mine reclamation over the past two decades, mostly in coal related situations (Dollhopf and Bauman 1981, Schuman et al 1984). Dollhopf et al (1988) reported that little research into the reclamation of sodic-saline bentonite mining disturbances occurred until the mid 1970s. As in most initial reclamation efforts, activities were limited to grading and shaping of overburden piles and backfilling of some mine pits.

Revegetation consisted of seeding or planting directly into the graded overburden. In some instances, thin veneers of topsoil had been placed on the surface of the graded and shaped overburden before revegetation efforts were made. These early reclamation efforts, though well intended and based upon apparent successes elsewhere, were generally unsuccessful and reflected the lack of knowledge of soil chemistry and physical properties so necessary for successful reclamation of severely altered conditions associated with surface mining.

Initial research into bentonite reclamation followed traditional patterns: investigations of natural revegetation of mine disturbances, seeding and planting trials to determine the species and techniques most successful to bentonite mine conditions and ultimately, investigations into the modification of the physical and chemical properties of the minesoils to be reclaimed.

The first research oriented toward minesoil modification was performed in 1979 by Schuman and Sedbrook. This study evaluated the incorporation of different amounts of sawmill residues into highly sodic, heavy clay bentonitic overburden mined in the mid 1950s near Upton in the northeastern portion of Wyoming (Schuman and Sedbrook 1984). This study demonstrated the effectiveness of wood wastes such as chips, sawdust and bark in the establishment and productivity of planted grasses. Schuman and his colleagues continued investigations in this area investigating the addition of fertilizers and edaphic changes over time and soil chemistry changes (Meining 1991). Meanwhile, Dollhopf and Bauman (1981) investigated organic and chemical soil amendments in western South Dakota near Belle Fourche, only a few miles from the Wyoming state line. In this study, several chemical compounds were evaluated including sulfuric acid, calcium chloride, gypsum and combinations thereof. Vegetative response after the first year was reported as poor. Unfortunately, the study was prematurely terminated for lack of funding. Four years later, members of the research team revisited the Belle Fourche site and "...what was observed was exciting, if somewhat unexpected....some of the chemical treatments exhibited remarkable vegetation growth." (Dollhopf et al 1988).

## The Wyoming AML Bentonite Reclamation Program

Many thousands of acres have been disturbed by the surface mining for bentonite in Wyoming, only one underground mining operation having been reported, and that having occurred around the turn of the century (Dollhopf and Bauman 1981, IMEC 1985). A large proportion of this disturbed area was mined during the 1950s and 1960s, prior to the enactment of any reclamation laws. Much of the early volunteer or required reclamation was unsuccessful or only partially so because the full extent of the sodium problem was not recognized.

The Abandoned Mine Land Program was authorized by Title IV of the federal Surface Mining Control and Reclamation Act of 1977 (PL 95-87, 30 USC 1231-1243). Wyoming's plan for the reclamation of lands disturbed by mining and for which there is no obligation by the mining companies to reclaim was approved by the federal Office of Surface Mining Reclamation and Enforcement (OSM) in 1981. Wyoming was able to certify that its abandoned coal mining problems had been or were in the process of being addressed in 1983, thus the State could begin to address abandoned mine reclamation problems caused by mining for non-coal minerals including gold, copper, uranium and bentonite.

The Wyoming AML Program initiated the reclamation of abandoned bentonite disturbances in 1984 near Upton, Weston County in northeastern Wyoming with Project 12A-1. This project was a cooperative effort between the AML Program of the Wyoming Department of Environmental Quality, Land Quality Division; the Wyoming State Forestry Division and the High Plains Grassland Research Station USDA-ARS. The project area was located a short distance from the research study plots installed by Schuman and Sedbrook in 1979 and was designed to utilize their findings.

The project location is characterized as semi-arid, receiving approximately 14 to 16 inches of precipitation per year. Most of this precipitation falls during the growing season between April 1 and August 31. Temperatures range from a mean low of -10.8C in January to a mean high of 21.6C in July (Meining 1991). The undisturbed areas in the vicinity of the project site are gently rolling hills vegetated with ponderosa pine (*Pinus ponderosa*) and shrub-grassland communities. Vegetation on the project site and other adjacent bentonite mine disturbances was sparse, consisting of an occasional greasewood bush (*Sarcobatus vermiculatus*) and assorted annual forbs. No soil analyses were made, but it is evident as inferred from other studies in the nearby area, that highly sodic and heavy clay soil conditions were predominant (HKM 1986).

Designed around the original Schuman and Sedbrook findings as reported in 1984, thirty tons dry-weight of wood waste, 300 pounds of elemental nitrogen and 40 pounds of elemental phosphorous per acre were spread over 42 acres of graded overburden. These amendments were thoroughly incorporated into the surface 12 inches by discing (HKM 1985). The amended site was revegetated as shown on Table 1.

Table 1
Project 12 Seed Mixture

| SPECIES | RATE (PLS / Acre) |
|---|---|
| Western wheatgrass, Rosana(*Agropyron smithii*) | 6 lbs |
| Thickspike wheatgrass, Critana(*A. dasystachyum*) | 3 lbs |
| Streambank wheatgrass, Sodar(*A. repens*) | 3 lbs |
| Slender wheatgrass, Revenue(*A. trachycaulum*) | 4 lbs |
| Smooth bromegrass, Lincoln (*Bromus inermis*) | 2 lbs |
| Yellow sweetclover, Madrid(*Melilotus officinales*) | 1 lb |
| Gardner saltbush, (*Atriplex gardneri*) | 5 lbs |
| TOTAL | 24 lbs |

Although the work was planned to be completed in the late fall of 1984, freezing temperatures prevented completion until mid April of the following year.

Efforts were made to segregate unsuitable material such as bentonite cleanings (contaminated or subgrade bentonite clay) and high salt and/or sodic materials during the course of earthmoving. Such determinations were made by visual identification and the unsuitable material was buried at a depth of two feet below the final graded surface. Germination and emergence of the planted grasses was delayed until the spring of 1986.

All reclamation work for this project was done by contract awarded through competitive bid. The Wyoming State Forestry Division procured the woodwaste at a unit price of $12.50 per ton delivered to the site. A separate contract was awarded by the AML Program for all other phases of the work. A summary of the final project costs as shown in Table 2 (HKM 1985).

Table 2
Project 12 Reclamation Costs

| ACTIVITY | UNIT COST | COST/ACRE | % OF TOTAL |
|---|---|---|---|
| Woodwaste Procurement | $12.50/T | $531.25 | 12.6 |
| Chisel Plowing | $75.00/A | $ 75.00 | 1.8 |
| Fertilizer | $150.00/A | $150.00 | 3.5 |
| Woodwaste Application | $200.00/A | $200.00 | 4.7 |
| Woodwaste, Fertilizer Incorporation | $100.00/A | $100.00 | 2.4 |
| Seeding | $200.00/A | $200.00 | 4.7 |
| Earthmoving | $0.58/Cy | $2565.00 | 60.7 |
| Other* | NA | $404.24 | 9.6 |
| TOTAL COST | NA | $4226.25 | 100.0 |

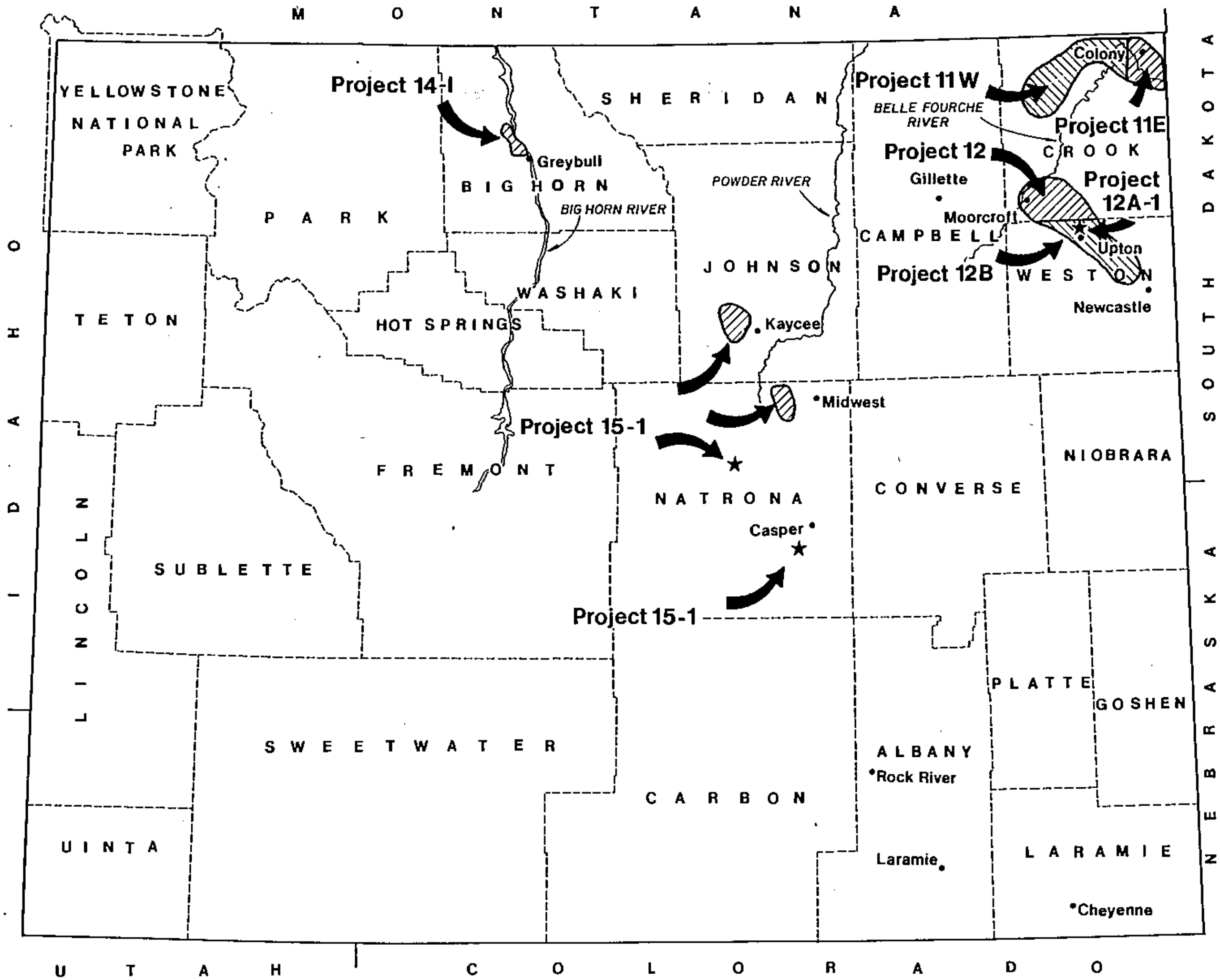
* Other includes mobilization, fencing and rock removal

The second bentonite mine reclamation project undertaken by the Wyoming AML Program, Project 11, was initiated in the early spring, 1985 and was located in the extreme northeastern corner of the State. Two consulting firms were hired to conduct investigations of site characteristics, develop reclamation approaches, prepare plans and specifications and, ultimately, to supervise the day to day reclamation construction activities. Investigations proceeded through the spring and summer of 1985 and the first reclamation contracts were let in October of that year.

Project 11 was the first large scale bentonite mine reclamation project undertaken by the AML Program. When completed three and one half years later, 3967 acres had been reclaimed.

The project area forms an arc following the bentonite outcrops around the northern and northwestern flank of the Bearlodge Mountains, an extension of the Black Hills. Elevations range from 3200 feet above mean sea level, the lowest point in Wyoming where the Belle Fourche River crosses the state line into South Dakota, to 4100 feet MSL near New Haven, Wyoming near the southwestern-most limb of the arc (Figure 1). The Project 11 area climate is similar to that of the Project 12A-1 area, as is the topography and vegetative characteristics.

Project 11 was divided into two sub-projects for ease and time considerations. Project 11E, the eastern portion, contained 71 individual reclaimed sites that were concentrated in a 60 square




# Figure 1

## Bentonite Reclamation Projects
## Wyoming Abandoned Mine Land Program

mile area. Project 11W, the western portion, consisted of 62 reclaimed sites spread over more than 130 square miles. Because of this wide area of coverage, distinct differences were encountered, particularly in the geology and soil chemistry of the sites.

The geology of the eastern portion of the project area consists of Mowry Shale, a dark gray, siliceous shale that underlies the "C" or "Clay Spur" bentonite bed, the principal recoverable seam. The Clay Spur bentonite is overlain by the Belle Fourche Shale, a dark gray to black, soft claystone with numerous siderite inclusions in the lower portions of the formation. The Belle Fourche Shale is highly sodic but exhibits a moderate Ph in the Project 11E area (HARZA 1985, IMEC 1985).

The geology of the Project 11W area is similar to the eastern portion except that the lower portions of the Belle Fourche Shale exhibited an acidic Ph in the western portion. Occasional sites along the western edge of the 11W area included the Newcastle Sandstone formation, a lighter colored, fine grained sandstone unit that stratigraphically underlies the Mowry Shale. The Newcastle, as a rule is better suited for revegetative purposes than the Belle Fourche Shale from a textural point of view, but often exhibited an acidic reaction (HARZA 1985). Selected mine soil analyses from the Project 11W area are shown on Table 3 (HARZA 1985):

Table 3
Selected Soil Analysis, Project 11W

| MATERIAL | pH MEAN | pH LO | pH HI | EC mmho/cm MEAN | EC mmho/cm LO | EC mmho/cm HI |
|---|---|---|---|---|---|---|
| Mowry Shale | 4.7 | 4.2 | 7.0 | 6.8 | 1.1 | 11.3 |
| Belle Fourche Shale | 5.6 | 3.7 | 8.3 | – | – | – |

| SAR MEAN | SAR LO | SAR HI | ESP MEAN | ESP LO | ESP HI | SAT% MEAN | SAT% LO | SAT% HI |
|---|---|---|---|---|---|---|---|---|
| 26.6 | 1.4 | 47.8 | 21.1 | 5.4 | 37.6 | 67.7 | 45.8 | 133.0 |
| 17.5 | 6.6 | 28.9 | 16.2 | 6.8 | 47.2 | 165.4 | 53.8 | 370.0 |

Dollhopf and Bauman (1981) reported the following for the test plots in South Dakota located a few miles from the eastern boundary of Project 11E.

Table 4
Selected Soil Analysis, Project 11E

| MATERIAL | pH MEAN | pH LO | pH HI | EC mmho/cm MEAN | EC mmho/cm LO | EC mmho/cm HI |
|---|---|---|---|---|---|---|
| Belle Fourche Overburden | 7.9 | 7.6 | 8.4 | 6.2 | 3.2 | 7.7 |

| SAR MEAN | SAR LO | SAR HI | ESP MEAN | ESP LO | ESP HI | SAT% MEAN | SAT% LO | SAT% HI |
|---|---|---|---|---|---|---|---|---|
| 24.8 | 3.7 | 37.3 | 19.4 | 4.9 | 46.5 | 85.3 | 69.0 | 101.0 |

Vegetation naturally occurring over the Project 11 area consists of grassland-shrub communities dominated by western wheatgrass, blue grama (*Bouteloua gracillis*), bluegrasses, (*Poa spp.*), wildryes (*Elymus spp.*) and cheatgrass or downy chess (*Bromus tectorum*). Sagebrush (*Artemesia tridentata*), rubber rabbitbrush (*Chrysothamnous nauseosus*), Douglas rabbitbrush (*C. viscidiflorus*) and black greasewood (*Sarcobatus vermiculatus*) are common shrubs. Bur oak (*Quercus macrocarpa*) and ponderosa pine often occur on low hills and ridges, indicating the presence of Mowry Shale at or near the surface (HARZA 1985, IMEC 1985).

At the start of Project 11, an approach to deal with the high sodium, and to a lesser degree saline, minesoils associated with bentonite mining had not been determined or selected by the Wyoming AML Program. The research demonstrations of Schuman and his colleagues were persuasive, but the consultant teams' soil and vegetation specialists and the AML personnel strongly leaned toward the use of available topsoil, from on site as well as from extensively borrowed sources, as a medium for vegetative reclamation. However, investigations by one of the consultants demonstrated that earlier reclamation attempts that used a thin veneer (6 inches or less) of topsoil had failed because of upward migration of sodium from the graded overburden, causing sealing of the soil surface and loss of permeability, death of the established plants and subsequent severe surface erosion. Only remnants of the topsoil and vegetation remained of these early reclamation efforts and they were in very poor condition. It was determined that a minimum of 18 inches of topsoil or other suitable soil cover material would be required to mitigate the upward sodium movement problem (IMEC 1985). The same consultant "rediscovered" the Dollhopf chemical amendment plots that had been reported in 1981 as failures and found unexpectedly good vegetative performance some four growing seasons after the initial work. Further investigations indicated that the plots that had been treated with calcium amendments had significantly lower soil Exchangeable Sodium Percentages than those plots without amendment.

After considerable deliberation, the AML Program elected to proceed with a soil amendment program based on a combination of woodwaste and chemical amendments in lieu of large scale topsoil borrow. Topsoil obtained from highwall reduction or found in recoverable quantities in overburden piles or otherwise readily available from on-site sources would be used to the maximum extent possible.

The Project 11 amendments were applied as follows (HARZA 1987, IMEC 1987):

Woodwaste, mainly chips, but which also included sawdust, bark and occasional larger chunks of wood, was applied at approximately 20 tons or 134 cubic yards per acre. This is equivalent to a layer of woodwaste approximately 1 to 1-1/2 inches deep.

Calcium amendments were applied as a mixture of calcium chloride ($CaCl_2$) and gypsum ($CaSO_4 \cdot 2H_2O$) in amounts necessary to reduce the final graded surface ESP to 10. Proportions of calcium chloride and gypsum varied between the two sub-projects in order to evaluate costs and ultimate success. A proportion of 65% calcium chloride, an expensive but highly water soluble compound, and 35% gypsum, an inexpensive but also a less soluble compound, was used for Project 11E. Project 11W used a mixture of 75% gypsum and 25% calcium chloride. Lime ($CaCO_3$) was also used in 11W on materials that exhibited low pH values.

Nitrogen fertilizer was applied to compensate for the demands of the woodwaste decay organisms at a rate of 220 pounds per acre, or 1.64 pounds per cubic yard of woodwaste on Project 11E and elemental nitrogen at the rate of 185 pounds per acre, or 1.38 pounds per cubic yard, on 11W. Phosphorous fertilizer at the rate of 90 pounds of $P_2O_4$ was also applied to Project 11W sites.

Soil sampling of the final graded surface was crucial in determining the amount of calcium amendment needed. Throughout the reclamation process, the contractor, with advice and direction by the construction inspector, strived to selectively handle the overburden and soil materials. Bentonite cleanings, a readily distinguishable material by color and texture, was buried at a minimum of two feet below the final plan elevations. Topsoil, when encountered, was stockpiled for later application or, if grading had progressed far enough, was direct-hauled and placed on the final graded surface. Otherwise, the color and texture of the majority of earthen materials was not sufficiently different to be able to identify suitable (low sodium) from unsuitable materials.

Sampling was based on a grid representing approximately two acres and generally consisted of five samples collected and composited to provide a representation. All samples were taken of the surface 12 inches. Depending upon the sub-project, samples were analyzed for pH, saturation percentage, electrical conductivity and Exchangeable Sodium Percentage. ESP was selected as a better measure for determining calcium requirements than SAR because ESP is an expression of soil sodium content whereas SAR is more of an expression of water soluble sodium in relation to calcium and magnesium. Amendment rates based upon ESP will generally result in less calcium needs than rates based upon SAR.

Woodwaste, calcium amendments and fertilizers were spread on the final graded surface and promptly incorporated into the regraded overburden by deep ripping to 18 inches followed by discing for thorough incorporation to 12 inches. Initially, amendments were applied and incorporated as final elevations were reached and calcium determinations were made following sampling and analysis. Revegetation into the amended surface would wait until the optimal time for the semi-arid conditions in the west, after mid-September until ground freeze-up in the fall, and in the spring after the frost leaves the ground until the first of May. However, it was quickly learned that woodwaste incorporated into the soil acted like a sponge and the ground became too wet and soft to support revegetation equipment, even with the slightest amount of rain. Subsequently, amendment incorporation was deferred until the start of the revegetation season, and no amendment incorporation was allowed more than 48 hours before revegetation would commence. If rain or snow was forecasted, amendment incorporation would be delayed until dry conditions returned (HARZA 1985, IMEC 1985).

Revegetation was accomplished by pitting and broadcast seeding except for a few early sites that were drill seeded and hay mulched. Pitting was accomplished by home-made as well as modified factory-built devices that excavate shallow pits, 6 to 8 inches deep, 10 to 12 inches in diameter and roughly two feet apart in length and breadth, giving the ground surface a dimpled appearance. The purpose of the pitting was to retain as much moisture on the surface for both vegetative utilization as well as to maximize the amount of moisture to mobilize the calcium compounds in order to mitigate the sodium problems.

Species seeded included grasses and shrubs native or adapted to the site conditions of the Project 11 area, Included were western, streambank and slender wheatgrasses, Russian wildrye (*Elymus junceus v. Vinall*), Gardner saltbush, rubber rabbitbrush and yellow sweetclover. Additional species were added or subtracted by the respective consulting firms to reflect minor variations in site conditions such as drainage channel bottoms or rocky conditions.

Nearly all of the reclaimed sites were fenced to protect the newly established revegetation from livestock grazing.

The second major bentonite reclamation project undertaken by the Wyoming AML Program was Project 12, located in southern Crook and Weston counties in northeastern Wyoming (Figure 1). This project was initiated in the fall of 1985 with initial reclamation construction starting the following spring. The project was completed in the fall of 1989.

The project area forms a small arc along a portion of the southwestern and southern edge of the main Black Hills uplift in northeastern Wyoming. It is characterized by gently rolling topography, grass and shrub covered openings and fringes bordered by ponderosa pine and Rocky Mountain juniper (*Juniperus scopulorum*) vegetative cover.

AML Project 12A-1 previously described, and the Schuman and Sedbrook study plots, are located almost in the center of this northwest-southeast trending project area. The climate and vegetative characteristics described for these and for Project 11 also apply to the overall Project 12 area. Elevations range from 4100 feet MSL in the north to a high of 4500 feet in the east-central portion of the project area and back down to 4200 feet in the southeastern portion.

The geology of the project area consists of Belle Fourche Shale overlying the Clay Spur bentonite that overlies the

Mowry Shale in the north. The Belle Fourche Shale exhibited an acidic reaction in the northern portion of the project area, and in places, was divided by the "E" bentonite bed, which had been mined. The upper Belle Fourche Shale, above the "E" bed, was notably more suitable for revegetation than the lower Belle Fourche material. In the southern portion of the project area, Newcastle Sandstone was frequently encountered below the Mowry Shale. Minesoil characteristics in Project 12 are similar to those of Project 11 as shown on Table 5 (CHEN 1986 HKM 1986).

Table 5
Selected Soil Analysis, Projects 12 and 12 B

| MATERIAL | pH MEAN | pH LO | pH HI | EC mmho/cm MEAN | EC mmho/cm LO | EC mmho/cm HI |
|---|---|---|---|---|---|---|
| Topsoil, Proj. 12 | 7.5 | 6.4 | 8.0 | 2.3 | 0.2 | 6.9 |
| Topsoil, Proj. 12B | 7.4 | 4.9 | 8.1 | 4.4 | 0.5 | 12.3 |
| Mowry Overburden | 7.1 | 4.4 | 8.1 | 6.7 | 2.9 | 13.9 |
| Belle Fourche O'bdn | 6.5 | 4.2 | 8.1 | 8.6 | 3.7 | 17.7 |

| SAR MEAN | SAR LO | SAR HI | ESP MEAN | ESP LO | ESP HI | SAT% MEAN | SAT% LO | SAT% HI |
|---|---|---|---|---|---|---|---|---|
| 6.7 | 0.4 | 19.0 | – | – | – | 42.6 | 26.7 | 65.5 |
| 7.6 | 0.8 | 25.0 | – | – | – | – | – | – |
| 31.6 | 21.1 | 38.4 | 39.7 | 27.1 | 56.4 | 206.8 | 87.2 | 392.0 |
| 28.4 | 7.0 | 41.9 | 29.4 | 18.0 | 47.8 | 103.4 | 56.5 | 226.0 |

Project 12, like Project 11, was divided into two sub-projects, each with a separate consulting firm performing the same functions as previously described. Project 12 consisted of 34 bentonite mine sites spread over approximately 90 square miles in southern Crook County. Project 12B consisted of 45 sites in the western portion of Weston County, extending from Osage and Upton, Wyoming north to the Crook County line, an area approximately 110 square miles in size. The combined reclamation totalled 3412 acres, not including the demolition and reclamation of the Clay Spur Mill, one of the first processing plants to be erected in the area during the late 1920s.

The amendment prescription developed for Project 11 was adopted in principle for Project 12. Initially, extensive topsoil borrow had been proposed but mining companies, fearing that topsoil resources overlying unmined bentonite would not be available for their future use, expressed reservations, hence the woodwaste and calcium amendment concept was adopted.

Initially, 20 tons per acre of woodwaste, in the form of bark from sawmill debarking operations, had been specified for Project 12. However, as the reclamation work progressed, bark woodwaste supplies became limited and the specifications were broadened to include woodchips and sawdust. The quantity of the mixed woodwaste was increased to 24 tons or 160 cubic yards per acre (CHEN 1988).

There were significant changes in the calcium portion of the amendment prescriptions for Project 12. Phosphogypsum, a fine particle sized waste product of phosphate mining and processing, was used as the calcium amendment on minesoils with a pH greater than 6.0. Lime (calcium carbonate) was used as a calcium amendment on minesoils with a pH of less than 6.0. Calcium amendments were applied as needed to reduce ESPs to 12.

Phosphogypsum often contains amounts of radioactivity in excess of allowable regulatory standards and its suitability for use in applications such as mine reclamation has been questioned. However, the fine particle size of the gypsum component make phosphogypsum potentially more effective as a calcium amendment than regular gypsum because of its size related increased solubility. Other desirable characteristics of this material are its low cost as an otherwise undesirable waste product and its potential fertilizer properties resulting from the residual phosphate remaining after the processing activity.

The AML Program recognized the concerns about radioactivity and commissioned its consultant to undertake field trials of phosphogypsum to evaluate residual radioactivity. Two lots of phosphogypsum were tested, one analyzed at 21 picocuries per gram (pCi/g) and the other at 31 pCi/g. The two lots of phosphogypsum were applied and incorporated into Belle Fourche and Mowry Shale derived minesoil test plots and mixed by discing to a depth of 8 to 10 inches. Radioactivity levels of the amended plots after incorporation ranged from 1.7 pCi/G to 2.9 pCi/g, depending upon the source of the material and the minesoil treated. An acceptable radioactivity standard for intensive human activity and occupation is 5 pCi/g and 20 pCi/g for low intensity human activities associated with rural areas. The results of this test indicated that phosphogypsum would be a safe source of calcium amendment for bentonite mine reclamation in the Project 12 application (Range Inventory and Analysis 1986).

Nitrogen fertilizer was applied at the rate of 240 pounds of elemental N per acre. Phosphorous was added through the residual values contained in the phosphogypsum. Occasionally, a 2:1:1 fertilizer formulation was applied.

The amendments were incorporated using two steps. First, the calcium and fertilizer were incorporated by discing into the top 12 inches of minesoil. The application and incorporation of the woodwaste followed the chemical amendment incorporation. It was felt that a more effective incorporation of the chemicals was achieved in this manner because of the difficulty with incorporating woodwaste to the depths specified. In many cases, and as a final recommendation by the Project 12 consultant, two-thirds of the calcium was applied and incorporated to the specified depth. This was followed by the application of the remaining one-third and its incorporation into the top 3 inches of the minesoil (CHEN 1988).

The sites in Project 12 were revegetated by drill seeding and then mulched with a native grass hay. Initial mulching rates were two tons per acre, but the rate was reduced to one and one-half tons per acre later in the construction phase as a cost savings measure.

Project 12B utilized the same basic soil amendment prescription of woodwaste and calcium as the previous projects, but with additional variations. The woodwaste material was specified to include chips and sawdust, but a limitation not to exceed 20% by volume of bark was included, a different approach than Project 12. Three application rates of woodwaste were specified based upon the clay content and the geologic origin of the minesoil. The application rates were 10 tons (67 cy), 20 tons (132cy) and 30 tons (200cy) per acre (HKM 1988).

Calcium amendments for Project 12B were lime for minesoils exhibiting a pH of less than 6.0 and gypsum for those with a pH greater than 6.0.

Nitrogen fertilizer was applied in accordance with the amount of woodwaste at the following rates per acre: 100 pounds elemental N for 10 tons of woodwaste, 200 lb of N for 20 tons of woodwaste and 300 pounds of N for 30 tons of woodwaste, or 10 lb of N per ton of woodwaste. Phosphorous was applied at the rate of 80 lb. of elemental P per acre.

Incorporation of the amendments was further modified on Project 12B. All woodwaste, fertilizer and two-thirds of the gypsum or lime were first applied to the final graded surface. The sites were then chiseled or ripped to a depth of 18 inches to achieve a deep incorporation of the amendments. Discing to 12 inches followed the chiseling operation to thoroughly mix the amendments with the minesoil. Once the incorporation steps were completed, the final one third of the calcium amendment (lime or gypsum) was uniformly spread over the amended surface without further incorporation (HKM 1988).

Drill seeding or pitting and broadcast seeding were both employed for the revegetation of the Project 12B sites. The consultant's initial recommendation was to employ pitting and broadcast seeding in areas of heavy clay soils with low permeabilities and moisture holding capabilities and on steep slopes. Drill seeding was recommended for soils with higher permeabilities such as Newcastle Sandstone materials.

The same species were included in the seed mixtures as have been used before with the addition of four-wing saltbush (*Atriplex canescens*). However, the application rates of the individual species were varied. The total seed mixture rate applied by broadcasting over the pitted areas was 28 pounds PLS per acre. The total rate for drill seeding was 16.5 pounds per acre. Drill seeded areas were not mulched with hay as in Project 12 because it was felt that the woodwaste would provide the necessary mulching function (HKM 1986).

Project 15-1 was the third abandoned bentonite mine reclamation project undertaken by the Wyoming AML Program. Investigations and reclamation designs were initiated in September, 1986. Reclamation began in December, 1987 and was completed in the spring of 1989. A total of 19 sites amounting to 667 acres were reclaimed.

The Project 15-1 area lies along the eastern foothills of the Big Horn Mountains on the western edge of the Powder River Basin in northcentral Wyoming. The sites reclaimed stretch from Kaycee, in Johnson county, south to just west of Casper, in Natrona County. Sites are scattered throughout this broad area, but the greatest concentration of sites is in a 30 square mile area near Kaycee (Figure 1). Elevations range from 4800 feet MSL in the north to 5700 feet at the site west of Casper.

The climate of the Project 15-1 area is a little more severe than that of the Black Hills district, with an annual average precipitation of 11 inches in the southern portion of the project area and 12.1 inches in the north near Kaycee. Approximately 75% of the precipitation falls during the months April through September. Temperatures are extreme; the lowest recorded near Kaycee in 1905 at -51F and a high of 104F reported in July, 1954 at Casper. The average January temperature is 7F and July is 88F for the Kaycee area (Western Water 1986).

The topography is dominated by the stratigraphy of this foothill region which dips to the east rather steeply at 10 degrees. Accordingly, the area can be characterized as rough, broken land with a high density of steep, incised drainages.

The bentonite bearing stratigraphy includes the Frontier Formation overlying the Mowry Shale which is underlain by the Thermopolis Shale. Recoverable bentonite occurs in the upper portion of the Mowry Shale as a locally known "First Lower Layer" bed which is 40 to 60 feet above the Clay Spur bed. The Thermopolis Shale contains two bentonite beds. The shales have been described as fissile or clay type, usually strongly saline and can be highly sodic, calcareous or acid. Sandstones, when encountered, are hard (Kaycee Bentonite Partnership 1985). Selected minesoil analyses from the Project 15-1 area are as shown on Table 6 (Western Water 1986).

Table 6
Selected Soil Analysis, Project 15-I

| pH | | | EC mmho/cm | | | ESP | | |
|---|---|---|---|---|---|---|---|---|
| MEAN | LO | HI | MEAN | LO | HI | MEAN | LO | HI |
| 6.4 | 4.0 | 8.2 | 5.5 | 0.3 | 40.0 | 22.2 | 0.1 | 81.3 |

Vegetation of the project area reflects its soils and climate, and can be characterized as a shrub-grassland type. Ponderosa pine and Rocky Mountain juniper are found on uplands and steep hillsides. Other species commonly present in the adjacent undisturbed areas are the same as those described for Projects 11 and 12 with the addition of Indian ricegrass (*Oryzopsis hymenoides*) and bluebunch wheatgrass (*Agropyron spicatum*) (Western Water 1986).

The reclamation approach for Project 15-1 included a major change from the two projects in the Black Hills district. Woodwaste, a major component of the soil amendment prescription, was dropped. Minesoils derived from the overburdens associated with the

Project 15-1 sites are mostly sandy clay loams, clay loams or sandy loams and generally contained less than 28% clays. Accordingly, the need for an organic amendment such as woodwaste to physically open the soil surface was determined not to be necessary. Additionally, there were no sources of woodwaste close enough to the project area to provide a cost effective supply. The calcium amendment consisted of a 65% calcium chloride and 35% gypsum combination as needed to reduce ESPs to 10 as used in Project 11E. The amendments were also incorporated as described for Project 11E, except that the specified incorporation depth was reduced to eight inches. Fifty pounds of elemental nitrogen were applied per acre.

The seed mixture used for Project 15-1 was changed to reflect the soil and climatic conditions of the project area:

Table 7
Project 15I Seed Mixture

| SPECIES | RATE/ACRE (PLS) |
|---|---|
| Western wheatgrass, Rosana | 5.0 |
| Thickspike wheatgrass, Critana | 5.0 |
| Streambank wheatgrass, Sodar | 5.0 |
| Bluebunch wheatgrass, Secor | 4.0 |
| Russian wildrye, Vinal | 4.0 |
| Rubber rabbitbrush | 0.25 |
| Four-wing saltbush | 1.0 |
| Creeping meadow foxtail, Garrison (*Alopecurus pratensis*) | 1.0 |
| Basin wildrye, Magnar (*Elymus cinereus*) | 2.0 |
| TOTAL | 27.25 |

The methods used for revegetation on Project 15-1, pitting and broadcast seeding, were the same as used on Project 11E (Western Water 1986).

Project 14-I is the last abandoned bentonite mine project to be completed by the Wyoming AML Program to date. It was initiated in August, 1987 and was completed in the fall of 1989. The project included 9 sites and a total of 600 acres was reclaimed.

The Project 14-I area is located a few miles north of Greybull, Wyoming in the Big Horn Basin, at the foot of the western front of the Big Horn Mountains (Figure 1). Elevations of the sites, all but one concentrated within a 6 square mile area, range from 4000 to 4400 feet above sea level. The climate in the Big Horn Basin, including the project area, is perhaps some of the harshest in Wyoming. Precipitation, intercepted by high mountain ranges on all sides of the basin, averages only six inches per year. Typically, precipitation is very sporadic and undependable, some areas receiving little or none from one year to the next. Occasionally, a single brief but intense shower may provide an inch or more in less than an hour's time. Temperatures are likewise extreme, ranging from -50F in the winter to as much as 106F summer (Centennial Engineering 1987).

The geology of the Project 14-I area is complex. The project lies on the Alkali Anticline, a localized, tightly folded structure. The bentonite beds dip in all directions, very steeply to near vertical, as they follow the sharp, "V" shaped anticline. The stratigraphy is the same as that found in Project 15-I on the east side of the Big Horn Mountains;

Frontier Formation shales overlying Mowry Shale which overlies the Thermopolis Shale. One notable difference is the presence of the Peay Sandstone, which is between the Frontier and the Mowry. The Peay Sandstone is a white-gray, medium grained arkosic sandstone with inclusions of fine grained sandstones and siltstones. The Frontier Formation contains two minable bentonite beds, the Mowry Shale two, and the Thermopolis Shale three minable beds in the project area. All minesoils derived from these strata are highly sodic and saline, but like the Project 15-I area, are relatively low in clay content. An analysis of the soil materials for Project 14-I is shown on Table 8 (Centennial Engineering 1987).

Table 8
Selected Soil Analysis, Project 14-F

| MATERIAL | pH MEAN | pH LO | pH HI | EC mmho/cm MEAN | EC mmho/cm LO | EC mmho/cm HI |
|---|---|---|---|---|---|---|
| Native / Topsoil | 8.1 | 7.8 | 8.3 | 1.0 | 0.4 | 1.9 |
| Overburden | 6.9 | 5.3 | 8.5 | 5.0 | 1.4 | 24.8 |

| MATERIAL | ESP MEAN | ESP LO | ESP HI | SAR MEAN | SAR LO | SAR HI |
|---|---|---|---|---|---|---|
| Native / Topsoil | 4.2 | 1.6 | 10.1 | – | – | – |
| Overburden | 19.2 | 2.2 | 48.3 | 26.1 | 10.8 | 32.7 |

The vegetation on the surrounding undisturbed sites reflects the climate and the variable soil qualities resulting from the exposed outcrops. The vegetation is best described as salt shrub communities, with big sagebrush, Gardner saltbush, bud sage (*Artemesia spinescens*), spiny hopsage (*Grayia spinosa*) and black greasewood the most common. Grasses and forbs present include bluebunch wheatgrass, needle and thread (*Stipa comata*), western wheatgrass, thickspike wheatgrass, squirreltail, Douglas rabbittbrush, cactus (*Opuntia spp.*) and halogeton.

The amendment prescription for Project 14-I was similar to that of Project 15-1. No woodwaste was used because of favorable soil textures and a combination of 25% calcium chloride and 75% gypsum was used where needed to reduce ESPs to 10. No fertilizer was applied to Project 14-I.

Incorporation of the amendments followed the established pattern of ripping followed by discing. However, depths of each activity were modified, ripping to a depth of 8 to 14 inches, depending upon the depth of cover material, and discing for thorough mixing to a depth of 6 to 8 inches.

Revegetation was done by pitting and broadcast seeding. The following seed mixture shown in Table 9 was used (Centennial Engineering 1988):

Table 9
Project 14-I Seed Mixture

| SPECIES | RATE/ACRE (PLS) |
|---|---|
| Gardner Saltbush | 6.0 |
| Greasewood | 1.0 |
| Thickspike wheatgrass, Critana | 3.0 |
| Streambank wheatgrass, Sodar | 3.0 |
| Russian wildrye, Vinal | 2.0 |
| Crested wheatgrass, Hycrest (*Agropyron desertorum*) | 2.0 |
| Indian ricegrass, Paloma | 2.0 |
| White sweetclover (*Melilotus alba*) | 1.0 |
| TOTAL | 20.0 |

The Wyoming AML Program currently has another bentonite reclamation project under way, Project 14B. This project is also located in the Big Horn Basin, and when completed in the fall of 1992, will have reclaimed approximately 1500 acres. Project 15D, near Kaycee, Wyoming in the Powder River Basin, is expected to commence during the summer of 1991, and will reclaim approximately 75 acres.

## Reclamation Costs

The cost of reclaiming 8635 acres of abandoned bentonite surface mines by the Wyoming Abandoned Mine Land Program during the latter half of the 1980s was $42,133,874.00, or $4879.42 per acre. At the outset of the bentonite reclamation program, the anticipated costs associated with the unproven amendment technologies were frightening. The large scale application of amendments over the five years of the program has done much to dispel those fears. The construction work performed for the Wyoming AML bentonite reclamation projects was all done by competitively bid contracts. The designs and specifications were prepared by the consulting firms hired by the AML Program for each of the six projects. Because of the inherent differences between projects, the developing technologies in sodium mitigating amendments and the individual philosophies of the consulting firms, the detail written into the specifications varied from project to project, and often from construction contract to contract. For instance, the work category "unclassified excavation" or "earthmoving" in the Project 11 contracts was limited to the cutting and filling aspects of grading. For other projects, this category also included the draining of ponds and the special handling of soft, unstable bentonitic muck that was often associated with accumulations of water. In another example, each individual step in the procurement, application and incorporation of the amendments was separated as an individual pay item. In others, all steps of the amendment process were combined and were paid under one pay item. Therefore, many of the individual unit costs reported and discussed herein are composites. However, the information is a realistic evaluation of the components of the soil amendment prescriptions used in the Wyoming AML bentonite mine reclamation activities. All costs reported here are mean values developed from construction project records.

The greatest single cost item in abandoned bentonite surface mine reclamation is earthwork. There were 37,144,248 cubic yards of overburden materials moved to achieve the desired grading and surface elevations. The work included the identification and special handling of readily identifiable unsuitable materials including bentonitic muck, cleanings and any other obviously recognizable sodic, saline or high clay content soils as well as topsoils. The total cost for this activity was $20,793,959.73, or $0.56 per cubic yard. Earthwork, as a whole, amounted to 49.35% of the total reclamation cost.

A special item for topsoil or suitable cover soil handling was specified in all of the contracted reclamation work. This item generally provided additional payment for the removal of topsoil from stockpiles generated during the course of the reclamation work and its placement on the final graded surfaces. The initial salvage of topsoils and its placement into stockpiles or as a direct pick-up and placement on final graded surfaces was generally paid as earthwork. This item also included some relatively small topsoil borrow activities. Topsoil costs were $491,536.06 for handling 784,535 cubic yards. The cost for topsoil handling was $0.63 per cubic yard and this item was 1.17% of the total work.

The total cost of the amendment program, including woodwaste, calcium amendments, fertilizers and their incorporation amounted to $8,966,207.00. This is equivalent to $1038.36 per acre and comprised 21.28% of the total reclamation cost. The cost per acre is based on all amendment costs divided by the total acres of the bentonite reclamation. A more specific analysis of amendment costs follows.

Woodwaste was used in the two Black Hills district projects, 11 and 12, where heavy clay soils were the rule. Specifications included the procurement and spreading of the woodwaste as one pay item. The total amount of woodwaste used was 164,134 tons, or 1,099,699 cubic yards for a total cost of $4,003,351.00. Approximately 22 tons or 149 cubic yards of material were used per acre for a cost of $543.42 per acre. The woodwaste amendment amounted to 10.79% of the total construction cost of the projects where it was used.

Calcium chloride, a costly amendment, was the subject of much uncertainty during the bentonite mine reclamation activities. Its relative high solubility makes the material very attractive where available moisture is limited. However, its high cost is a deterrent. When used, application proportions with gypsum varied from 75% of the prescription to 25%. Overall, 3,463.75 tons of calcium chloride was used, at a cost of $162.99 per acre for the projects on which it was used. Calcium chloride made up 3.40% of the applicable total construction costs. The overall cost per ton was $247.26.

Gypsum was the most extensively used of any of the calcium amendments in the AML bentonite reclamation work. All projects except Project 12 used this material. A total of 24,673.08 tons were used, or 3.44 tons per acre. Costs for gypsum were $61.78 per ton and $212.34 per acre. Gypsum was 4.39% of the total reclamation cost.

Phosphogypsum was used only on Project 12. The cost of this material was $70.54 per ton, and 8.0 tons per acre were used. Therefore, the cost of phosphogypsum per acre was $564.50, and it was 11.02% of the total Project 12 reclamation costs.

Lime was used to mitigate excessive sodium in minesoils exhibiting pHs of less than 6.0 on Projects 11W, 12 and 12B. 10,482.08 tons were used at a price of $43.44 per ton and at application of 2.04 tons per acre. The cost per acre was $88.46, and lime was 1.69% of the total construction costs.

Fertilizers were used on some of the bentonite mine reclamation projects, but not on others. The need for nitrogen fertilizers to assist in the decay of the woodwaste was recognized early in the development of the project philosophy. However, the use of nutrient supplements as a general rule in semi-arid climates where moisture is a critical limiting factor has been a subject of debate. Nitrogen, where used, averaged 290 pounds or 0.145 tons per acre. The cost per acre was $61.64, and nitrogen fertilizer made up 1.23% of the total cost.

Phosphorous was used to a lesser extent than nitrogen for the reasons stated above. Where used, 81.79 pounds or 0.04 tons per acre was applied. The application of phosphorous cost $30.77 per acre, 0.58% of the total reclamation costs.

The specifications for incorporation and payment of the calcium and fertilizer amendments was highly variable between the six bentonite reclamation projects. Rather than to present an analysis of each of the several methods of amendment incorporation and payment, all were combined. In one case, the application and incorporation of nitrogen fertilizer is included. The methods of incorporation include ripping, discing, chisel plowing and assorted combinations of one or more of these activities. Incorporation costs amounted to $105.32 per acre, or 2.11% of the total reclamation cost.

The total cost of revegetation was $3,247,346.00, or $376.07 per acre. This represents all revegetation activities such as the cost of seed and mulch, where used, and the drilling or pitting operations. One project included the costs of amendment incorporation in the seeding pay item as a cost of seedbed preparation. The revegetation activity made up 7.71% of the total reclamation cost.

## Summary And Conclusions

The Wyoming Abandoned Mine Land Program reclaimed 8635 acres of abandoned bentonite surface mines over a five year period beginning in 1985. High levels of sodium in the overburdens and resultant minesoils associated with these bentonite mines presented heretofore unsolvable hurdles in achieving successful vegetative cover without adequate depths of a suitable soil covering. Many of the disturbances had lain barren for twenty or more years.

The amendment prescriptions developed and refined by the several consulting firms participating in the AML bentonite projects were based upon then-recent research in Wyoming and South Dakota. These research projects demonstrated the effectiveness of an organic amendment, woodwaste, and calcium amendments, mainly calcium chloride and gypsum, in mitigating the adverse effects of sodium in the abandoned bentonite overburdens and minesoils.

There was concern with the high cost of amendments. However, there was little choice but to use them, the other alternative being to borrow extensive quantities of topsoil or other suitable cover soil materials from off-site sources. Aside from the fact that the borrowing of off-site material was not a viable option because of land surface and mineral owner concerns, the cost of borrowed topsoil was also perceived not be an economic alternative. A cost analysis of topsoil borrowing on AML Project 11 demonstrated that a borrowed soil cover of 18 inches, the amount needed in the Black Hills to prevent upward migration of sodium into the root zone, would cost approximately $2517.00 per acre, based upon experienced borrowing costs of $0.948 per cubic yard (Richmond, 1989). A covering of borrowed soil 9.25 inches deep, the depth recommended for the lower rainfall, lower clay content soils of AML Projects 15-1 and 14-I, would cost $1395.00 per acre. In contrast, the amendment prescription used for Project 11 that included woodwaste, calcium chloride, gypsum and lime would cost approximately $1084.00 per acre at the costs shown in this analysis. Without the woodwaste, the amendment prescription cost would be $541 per acre. Clearly, the use of soil amendments to mitigate the adverse effects of sodic soils, is a viable economic alternative where adequate sources of suitable cover soils are not available on the site to be reclaimed.

A major factor in keeping the cost of the amendment prescriptions as low as they were was the judicious and diligent management of the earthwork phase of the bentonite reclamation projects. Exceptionally good cooperation between the contractors performing the work and the construction supervisory personnel resulted in maximum amounts of suitable soil materials being placed on the final graded surface and the unsuitable materials being buried. This effort alone resulted in minimum amounts of finished surface having sodium concentrations that required amendment mitigation.

Vegetative response on the AML reclaimed bentonite mine sites has been encouraging. As many as four complete growing seasons have elapsed since the first seeding on amended minesoils. For the most part, response has been very satisfactory, and stand densities and cover have been increasing, in spite of premature and often heavy grazing by livestock. Unfortunately, comprehensive post reclamation vegetative response data is not available, and only visual assessments have been made. No post reclamation soils analyses have been made to assess the effects of the calcium amendments on sodium levels. However, preliminary data from current research by the University of Wyoming indicates that calcium amendments do have a positive effect on sodium mitigation (Schuman 1990, Meining 1991).

The long term effectiveness of the woodwaste and calcium amendments is yet to be seen. It may take up to 20 years or more to fully assess their effects. In spite of the satisfactory cost and vegetative performances that are apparent at the present time, the use of amendment prescriptions as a substitute for available suitable soils is not recommended.

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