PHYTOSTABILIZATION PERMANENCE WITHIN MONTANA'S CLARK FORK RIVER BASIN SUPERFUND SITES[1]

F.F. Munshower[2], D.R. Neuman, and S.R. Jennings

Abstract. Many land reclamation technologies have been used on mining-impacted lands within the Clark Fork River Basin Superfund sites over the past 20 years. Several sites are examples of *in-situ* reclamation or phytostabilization. Since phytostabilization does not remove metal contaminants, the permanence of this technology as a remedial alternative has received significant scrutiny. Many of these projects have had limited long term monitoring, and as such, the permanence of these efforts is undocumented. However, the continued existence of these sites provides a unique opportunity to evaluate the permanence of in-situ treatment strategies. The purpose of this investigation was to generate sufficient data and information from areas receiving phytostabilization treatments, varying in age from 6 to 19 years, so that the permanence and self-sufficiency of the established and reconstructed ecosystem(s) can be assessed. Six different field sites were selected that represent phytostabilization implementation in different landscape positions, using slightly different equipment, and at different times. The sites are similar in that each was degraded because of impacts from the metal mine/mill/smelter processes. Soils or tailings at the sites contain acid producing materials and are elevated in metal concentrations compared to adjacent, non-impacted landscapes. At each site, neutralizing amendments were added to raise the soil or waste pH to a target level of seven, and at some sites, other amendments were also added. Vegetation response variables observed or measured at the six sites included cover, species richness, evidence of reproduction, evidence of nutrient cycling, evidence of succession, and biomass. Soil response variables measured included pH, acid buffering capacity, and metal concentrations. This paper will present these data and discuss the efficacy of phytostabilization in terms of the sites' ability to sustain current land use and their ability to support other possible land uses. The permanence of the amendments to perform their function of attenuating acid production and immobilization of metals will also be addressed.

Additional Key Words: revegetation, metal tolerance, tailings reclamation, Superfund

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Introduction

The history of the use of basic compounds to amend acid soils is quite old. Agriculturalists have been using this practice for centuries. The history of acid minesoil rehabilitation by the addition of lime ($CaCO_3$), one of the most common acid neutralizing products available, is also quite old and contains numerous examples, unfortunately, the number of acid minesoils treated with lime that have return to acidic conditions months to years after treatment is almost as large as the number of sites amended with lime. However, the availability and economy of treating acid soils with lime has kept this insitu neutralization technique high on the list of alternatives for the treatment of acid minesoils.

Within the past two decades new methods of determining the amount of lime to be added to acid minesoils have been developed. It is now possible to determine the total acid generating capacity of a soil and add an amount of lime equal to that acid generating capacity. Soils treated by lime additions of this type should not reveal the very strong depression of pH months to years after amendment noted in older acid minesoil studies in which an inadequate amount of lime was incorporated into the acid material. Furthermore, when the pH is raised by the lime addition, the concentration of many of the phytotoxic metals solubilized by the acid environment is reduced, thereby permitting revegetation with plants native to the area of impact and the reliance on acid tolerant vegetation is lessened.

Since this technology does not remove metal contaminants often present in acid minesoils, the permanence of this technology as a remedial alternative has received significant scrutiny (CH2M Hill, 2001). In this paper, we reviewed the success of the newer lime amendment technology as applied to a series of sites dating back almost twenty growing seasons. While twenty years is a short moment in a geologic sense, it is about as old as the technology and examples of longer periods must await the passage of time.

Both abiotic and biotic monitoring can be used as tools for the determination of the permanence of in-situ reclamation. The continued success of the soil amendment on these sites is indicated by continued robust vegetative growth and low levels of soluble metals in the root zone. Plant response variables that could be evaluated to determine long-term permanence of amendment include cover, species richness, evidence of reproduction, evidence of nutrient cycling, evidence of succession, biomass, and evidence that the Phytostabilized area is capable of sustaining current land use and has the ability to support other possible land uses. Soil response variables related to the permanence of the amendments to perform their function include such parameters as pH, fertility, buffering capacity, and immobilization of metals and arsenic.

Methods and Materials

Information and existing data for six sites which had been amended with lime were pulled from the records of the Reclamation Research Unit at Montana State University. Five of the locations were within Montana's Clark Fork River Basin Superfund Sites, while the sixth location was at an abandoned hard rock mine (Figure 1). The lime addition at each site was determined by experiment or by measurement of the total acid generating capacity of the soil. The acid generating capacity of these sites ranges from kg/ha to mt/ha. The size of these sites ranges from small plots less than 1 m^2, to plots of many hectares. The amended materials have now passed through numerous growing seasons (6 to 19) without additional treatment.

Reclaimed Area Descriptions

Site 1 - Stucky Ridge (Six Growing Seasons). This site is on a ridge north of Anaconda, Montana. Soils were severely polluted with metals and arsenic by nearly 100 years of continuous airborne emissions from the Anaconda Smelters. The pH of the soils ranged from 6.0 to 6.6. Lime was incorporated at a rate of 15 t $CaCO_3$ /2000 t soil and approximately 2300 m^3 of organic matter, a commercial material (EKO Compost) or composted manure, were spread across the 28 ha of this reclamation project in the fall of 1996 (ARCO, 1996). The area was fertilized and a tillage tool with 80 cm diameter discs was used to incorporate the material to the 30 cm depth with one pass on the contour. Seeding took place in late fall 1996 or early spring 1997 (Table 1).

Site 2 - Opportunity Tailings Ponds (Eight Growing Seasons). This 0.4 ha experimental area is located in the acid producing and low pH (2.3) smelter tailings materials derived from the Anaconda Smelter. The material contained moderate concentrations (10^2 mg/kg) of metals and arsenic. Three experimental plots were implemented with different organic matter and slag incorporation depths (Reclamation Research Unit, 1997). The experimental plot was amended with 26.6 t $CaCO_3$ and 9.9 t CaO in the fall of 1994. It was topdressed with 3.6 t $CaCO_3$, 1.3 t CaO, 17 m^3 of EKO Compost, fertilized, mulched, and seeded with the species listed in Table 2 during the spring of 1995. For this paper, only Plot 1 treated with lime, EKO compost, and slag incorporated to 48 cm was evaluated.

Site 3- Drag Strip (Nine Growing Seasons). This site is located near the Lost Creek Raceway in the vicinity of Anaconda, Montana. The area was impacted by a surficial deposit of fluvially and/or aerially contaminated materials having a depressed pH (4.5) and elevated levels of arsenic, cadmium, copper, lead, and zinc. A 0.6 ha reclamation demonstration was implemented to evaluate effects of

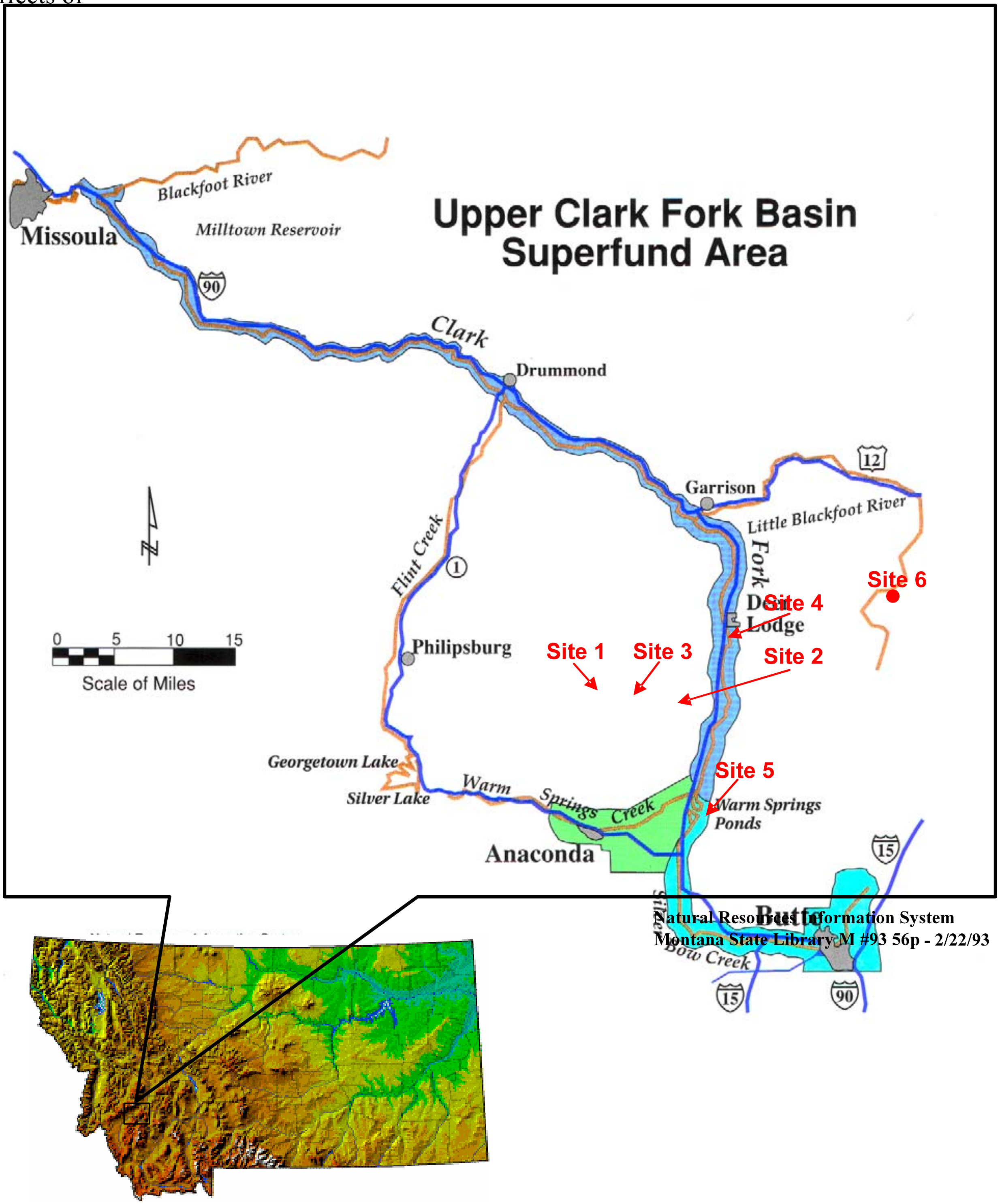
Upper Clark Fork Basin
Superfund Area
Missoula
Blackfoot River
Milltown Reservoir
90
Clark
Drummond
Garrison
12
Little Blackfoot River
Fork
Flint Creek
1
Philipsburg
0 5 10 15
Scale of Miles
Site 1
Site 2
Site 3
Site 4
Site 5
Site 6
Deer Lodge
Georgetown Lake
Silver Lake
Warm Springs Creek
Warm Springs Ponds
Anaconda
Butte
15
Silver Bow Creek
90
Natural Resources Information System
Montana State Library M #93 56p - 2/22/93

Figure 1. Study site locations.

Table 1. Vegetation seeded at Site 1[†].

Species	Common Name	Seed Rate (Kg PLS/ha)
Agropyron spicatum	Bluebunch wheatgrass	1.1
Agropyron smithii	Western wheatgrass	3.4
Agropyron dasystachyum	Thickspike wheatgrass	3.4
Agropyron trachycaulum	Slender wheatgrass	3.4
Elymus cinereus	Basin wildrye	7.8
Festuca ovina	Sheep fescue	2.2
Medicago sativa	Alfalfa	0.6

[†] Data from ARCO (1996).

different sources of organic matter, different liming material combinations, and simple deep plowing of the soils (Reclamation Research Unit, 1997). Six experimental plots were implemented. The plot evaluated for this paper was treated with 7.6 t $CaCO_3$ and 3.9 t CaO/2000 t soil incorporated to 30 cm. In addition, 100 m^3 of EKO Compost were incorporated to 15 cm.

Neutralizing amendments were incorporated in the fall of 1993. In the spring of 1994, the organic amendments and fertilizer were incorporated and the plots seeded (Table 3). In addition to the seeded vegetation, several shrub and tree species were planted as tubelings (199 tubes) in both 1994 and 1995. These included Big sagebrush, Silver buffaloberry, Rubber rabbitbrush, Green rabbitbrush, Wood's rose, Siberian peashrub, Sandcherry, Chokecherry, Lodgepole pine, Black greasewood, Ponderosa pine, Douglas fir, Russian olive, Limber pine, and Horsebrush.

<u>Site 4 - Clark Fork River Governor's Demonstration (Twelve Growing Seasons)</u>. This demonstration area is a relatively large scale test of phytostabilization technology implemented along 4 km of the upper Clark Fork River in 1990 (Schafer and Associates, 1991). Soil pH values ranged from near neutral to 2 or 3 and metal loading from normal to two or three orders of magnitude greater than background. Calcium carbonate and calcium oxide were the neutralizing amendments used at this demonstration with incorporation depths ranging from 30 to 120 cm. The amounts of lime applied were variable ranging from 8 to 170 t/ha. Application rates were determined by analyses of surficial materials in the individual field or pasture treated. The areas were seeded with mixes of grasses and the legume, alfalfa (Table 4). A limited amount of streambank stabilization and channel work was

also conducted. This large demonstration area could have been evaluated at any number of sites and in any number of ways. Simply walking through the thick vegetation attests to the persistence and

Table 2. Vegetation seeded at Site 2[†].

Scientific Name and Cultivar	Common Name	Rate (Kg PLS/ha)
Seeded Grasses and Legumes		
Agropyron dasystachyum Critana	Thickspike wheatgrass	3.3
Agropyron elongatum Alkar	Tall wheatgrass	5.6
Agropyron intermedium Tegmar	Intermediate wheatgrass	6.7
Agropyron trachycaulum Revenue	Slender wheatgrass	1.7
Agropyron trichophorum Mandan759	Pubescent wheatgrass	8.4
Elymus cinereus Magnar	Basin wildrye	3.3
Elymus giganteus Volga	Mammoth wildrye	10.0
Elymus junceus Bozoisky	Russian wildrye	3.3
Festuca ovina Covar	Hard sheep fescue	1.1
Lotus corniculatus Empire	Birdsfoot trefoil	1.1
Medicago sativa Alfagraze	Alfalfa	0.6
Native Seed Mix[‡]		0.6
Aster chilensis	Rocky Mountain aster	
Heterotheca villosa	Hairy golden aster	
Penstemon spp.	Blue Penstemon	
Gutierrezia sarothrae	Broom snakeweed	
Rumex crispus	Curly dock	
Medicago lupulina	Black medic	
Potentilla fruticosa	Shrubby cinquefoil	
Antennaria spp.	Pussytoes	

[†] Data from ARTS Phase IV Final Report (RRU 1997).

[‡] Locally collected seed.

vigor of the seeded grasses. In this study, a transect of ≈ 100 m was established perpendicular to the river flowing through the Demonstration Area. The transect was randomly placed from the edge of a treated pasture to the Clark Fork River.

Site 5 - Ramsay Flats Tailings Deposits (Fourteen Growing Seasons). This site is located on a broad expanse of flood deposited metal mining wastes along Silver Bow Creek near the town of Ramsay, Montana. Four incorporation techniques were used to mix amendments with the waste materials (Schafer and Associates and Reclamation Research Unit, 1993). These included standard

Table 3. Vegetation seeded at Site 3†.

Scientific Name & Cultivar	Common Name	Rate (Kg PLS/ha)
Seeded Grasses and Legumes		
Agropyron cristatum Ephraim	Crested wheatgrass	2.0
Agropyron intermedium Tegmar	Intermediate wheatgrass	3.5
Agropyron smithii Rosana	Western wheatgrass	3.5
Elymus cinereus Magnar	Basin wildrye	2.0
Lotus corniculatus Empire	Birdsfoot trefoil	0.5
Medicago sativa Alfagraze	Alfalfa	0.5
Other Seeded Forbs and Shrub‡		1.75 for all forbs
Aster chilensis	Rocky Mountain aster	
Senecio spp.	Yellow composite	
Penstemon spp.	Blue Penstemon	
Gutierrezia sarothrae	Broom snakeweed	
Iva axillaris	Poverty weed	
Heuchera cylindrica-	Allumroot	
Potentilla fruticosa	Shrubby cinquefoil	0.3

† Data from ARTS Phase IV Final Report (RRU 1997).

‡ Locally collected seed.

Table 4. Vegetation seeded at Site 4†.

Scientific Name & Cultivar	Common Name	Seed Rate (Kg PLS/ha)
Agropyron trichophorum Greenleaf	Pubescent wheatgrass	4.5
Agropyron riparium Sodar	Streambank wheatgrass	3.4
Elymus junceus Bozoisky Select	Russian wildrye	4.5
Elymus cinereus	Basin wildrye	4.5

Medicago sativa Spreader	Alfalfa	1.75

† Data from Schafer and Associates (1991).

agricultural tillage to a depth of 15 to 20 cm, deep tillage (120 cm) using a special plow pulled by a D8-H Caterpillar, an aqueous slurry of lime injected up to 120 cm into the tailings, and a coversoil wedge of increasing depth (0 to 50 cm). The wedge was constructed over wastes that had been amended using the agricultural tillage equipment. A fifth plot served as a control. These experimental plots were replicated four times. Only the deep plowed plots were studied for this report.

The plots were amended in the fall of 1988. They were fertilized and seeded in mid April 1989. The year 2002 was the fourteenth growing season for this phytostabilized site. The plant species seeded or sprigged at Site 5 are listed in Table 5. Two seed mixes were used at this research plot to evaluate the ability of several perennial species to germinate and persist in amended tailings.

Site 6 - Champion Mine Tailings Pond (Nineteen Growing Seasons). The earliest phytostabilization experiments on in-place mine tailings initiated by the Reclamation Research Unit were conducted at the Champion Mine in the early 1980's (Torrence, 1986). This inactive mine is located 12 km east of Galen, Montana in the Helena National Forest, west of the Continental Divide. In 1982, tailings

Table 5. Vegetation seeded or sprigged at Site 5†.

Seed Mix	**Scientific Name & Cultivar**	**Common Name**	**Rate (Kg PLS/ha)**
1	*Agropyron elongatum* Orbit	Tall wheatgrass	10.0
	Agropyron cristatum Ephraim	Crested wheatgrass	3.0
	Agropyron riparium Sodar	Streambank wheatgrass	5.0
	Distichlis spicata	Saltgrass	10 sprigs/plot
	Lotus corniculatus	Birdsfoot trefoil	1.0
	Deschampsia caespitosa	Tufted hairgrass	7 plants/plot
2	*Agropyron intermedium* Greenar	Intermediate wheatgrass	8.0
	Agropyron desertorum Nordan	Crested wheatgrass	4.0
	Agropyron trichophorum Greenleaf	Pubescent wheatgrass	8.0
	Elymus junceus Swift	Russian wildrye	5.0
	Melilotus officinalis	Yellow sweetclover	2.0

Artemisia longifolia	Long leaf sagebrush	7 plants/plot

† Data are from STARS Phase IV Final Report (Schafer & Associates and RRU, 1993).

extended over several hectares to a depth of over 100 cm. The plots on these wastes were amended with 9.14 t $Ca(CO_3)_2$ equivalent as lime kiln dust per ha/15 cm. This lime rate was experimentally derived in 1982 in related graduate student laboratory work (Russell, 1984). In addition to lime, diammonium-phosphate fertilizer (18-46-0) was applied to the site. Both amendments were incorporated to 15-20 cm with a small rototiller. Three replications of seven plant species were seeded on June 22, 1984. Species were *Agrostis alba* (Streaker), *Agrostis tenuis* (Highland), *Alopecurus arundinaceus* (Garrison), *Alopecurus pratensis*, *Lotus corniculatus*, *Poa compressa* (Reubens), and *Festuca ovina* (Covar).

Sample Collections

The number of Daubenmire frames used to assess the vegetation varied from site to site depending on site conditions and the size of the area under consideration. Some of these experimental plots were small while the phytostabilized area at the Governor's Demonstration extended along several kilometers of the Clark Fork River. On small plots, cover of the entire plant community was estimated. In larger areas, ten 20 x 50 cm Daubenmire frames were placed at 10 m intervals along a 100 m transect.

Perennial vegetation growing within each frame was clipped approximately 2 cm above the ground surface. Grasses and forbs were placed in separate paper bags for transport to the RRU laboratories. These samples were used for above ground biomass measurements. Weedy species and annual grasses were included in these collections.

Soil samples were collected adjacent to the cover frames. The depth of collection was within the rootzone to a maximum depth of 45 cm. Composite samples were mixed and placed into new polybags for transport to the RRU laboratories.

Laboratory Measurements

Vegetation. Collected vegetation was transported in paper bags that were labeled in the field, identifying site by name, frame number, notation of grass or forb, and whether a co-located soil sample was collected at that point. The vegetation samples were dried at 70 degrees C until a constant weight was achieved. The vegetation was weighed to the nearest 0.01 gram. These measurements were used to calculate the above ground biomass within each frame.

Soils. Collected soil samples were transported in polybags which were labeled in the field identifying site by name, cover frame number, and depth of sampling. These samples were air-dried and sieved to pass a 2 mm sieve. Laboratory determinations included pH and EC in saturated paste extraction solutions, and determinations of water soluble levels of As, Cd, Cu, Pb, and Zn using ICP methods (EPA, 1987). Total metal concentrations were determined by x-ray fluorescence methods (Ashe, 1995). Acid/base account was also determined (Sobek et al., 1978).

Results and Discussion

Site 1: Stucky Ridge - Six Growing Seasons

Soil pH at this site was still high, 8.1 and conductivity quite low, EC 1.3 dS/m (Table 6). Acid base potential was a positive 19 t/1000 t. Total metal concentrations in collected soils were 75 mg/kg (arsenic), 516 mg/kg (copper), 170 mg/kg (zinc), 30 mg/kg (lead), and <3.8 mg/kg (cadmium). Soluble metals in the surficial materials were low with the exception of copper at 2.4 mg/l in the soil water extract. This value was not phytotoxic to vegetation in this soil at this pH. Amended soils were friable and appeared to have high infiltration rates. The absence of erosion of the soils would lead to the assumption that precipitation was infiltrating and not running off the treated areas. Adjacent, non amended materials were crusted and impermeable and had rills and gullies as evidence of past runoff and erosion. Lead and cadmium values were not included in Table 6 because all water soluble levels of these elements were below plant toxic concentrations.

Table 6. Amended soil chemical parameters (water soluble) in 2002.

Site	pH	EC (dS/m)	Cu (mg/l)	Zn (mg/l)	As (mg/l)
1	8.1	1.3	2.4	0.04	0.4
2	7.8	2.8	0.9	0.04	0.1
3	7.5	1.3	5.5	0.32	2.2
4	7.7	6.4	3.1	0.17	0.4
5	7.8	4.3	2.3	0.33	0.5
6†	5.9‡	1.6	0.1	0.13	<0.1
	4.5*	1.4	0.1	0.34	<0.1
	3.5**	1.5	0.3	0.55	<0.1
	3.2#	1.2	0.2	0.72	<0.1

† - means of three values

‡ - 0-15 cm, limed, fertilized
* - 15-30 cm, non-limed, below amended zone
** - 0-15 cm, non-limed, fertilized
# - 15-30 cm, non-limed, below amended zone

Vegetation on this site was very robust with large plants and copious seed production (Figure 2). Basin wildrye plants were over 1 m tall and covered over 30% of the ground. Sheep fescue was also present but declining in vigor because of shading by the wildrye. Crested wheatgrass and Indian
ricegrass were found volunteering on exposed mounds of amended materials. Of the four wheatgrasses seeded on this site only Western and Bluebunch still persist in the community. Bluebunch had established in the larger bare spaces between the Basin wildrye plants. It is also contributing to the decline of the fescue. Alfalfa seeded on the site was not found in the plant community although five other desirable forbs had invaded the site from adjacent, undisturbed pastures. Weeds were present, spreading into amended and seeded areas from large stands of Canadian thistle and White top on untreated areas adjacent to the reclaimed sites. Control measures for these noxious weeds may be responsible for the absence of a legume in the plant community since broadcast spraying for weed control was practiced by the land owner.

Total ground cover measured on this study site was over 50% (Table 7) or slightly higher than anticipated on non-polluted upland range sites in this area. As native perennial forbs and shrubs invade the site this cover should increase slightly. The presence of an Aster (unknown species) and Rubber rabbitbrush indicate that this invasion has already commenced.

Figure 2.  Vegetation growing on Stucky Ridge in 2002 six

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Table 7. Plant performance at Site 1.

Life Form	Percent Cover	Production
Perennial grasses		1113 kg/ha
Basin wildrye	31	
Sheep fescue	9.3	
Intermediate wheatgrass	0.3	
Western wheatgrass	2.5	
Bluebunch wheatgrass	4.7	
Total cover perennial grass	47.8	
Forbs		0.0†
Canada thistle	1.5	
Hoary cress (Whitetop)	0.3	
Total % cover of desirable species	49.0	
Number of desirable species on site	9 perennial grasses 7 forbs 1 shrub	
Number of species with >1% cover	5	

† Biomass of noxious weeds was not determined.

A brief survey of the reclaimed site revealed nine perennial grasses (four seeded), seven forbs (none seeded), and one shrub have established. Only five of these plants were present at greater than 1% cover, however. Reproduction of grasses and forbs was observed (both seeds and young plants), but not in large numbers because of the density and size of Basin wildrye plants and a thick litter layer which averaged 67% ground cover.

Grass production was measured at 1113 kg/ha (Table 7). This compares favorably with other upland sites in this area. Biomass was increasing annually on this reclaimed site. It had not reached equilibrium with the soil and climate. Large areas (m^2 or larger) supporting only one or two grass or forb seedlings were evidence that vegetation was reproducing on the reclaimed site and that the plant community was still undergoing rapid maturation. The lack of forb production was the only weak attribute of this stand. This site needs closely managed livestock grazing to reduce the size of individual plants and to reduce litter by trampling. Weed control will continue to be a problem because of the very large stands of noxious weeds adjacent to the amended soils.

Site 2: Opportunity Tailings Pond - Eight Growing Seasons

Surficial soils at Site 2 had a pH of 7.8 and EC of 2.8 dS/m (Table 6). Acid base potential was 123 t/1000 t. Soluble heavy metal levels were all less than 1 mg/l and not phytotoxic. Total metal concentrations within the root zone were 873 mg/kg (arsenic), 1780 mg/kg (copper), 4970 mg/kg (zinc), 1070 mg/kg (lead), and 8.9 mg/kg (cadmium). Chemically and physically these amended smelter tailings appeared to be as productive as those at any of the other five sites reviewed for this paper. They were friable and little or no evidence of runoff was observed. Adjacent waste materials were crusted and impermeable as evidenced by severe rill and gully erosion and some deposition of these wastes on the plots.

The plants growing on this site were not as vigorous as the plants growing on the other sites (Figure 3). Plants were producing viable seed as evidenced by young plants on the plot but cover was low, 33% (Table 8). No desirable forbs had invaded the site or survived from the original seeding. Fortunately no noxious weeds were present in the two species plant community. Both Basin and Mammoth wildrye were growing within the amended areas but only one or two plants of each species were observed. Only four perennial grass species persisted of the 19 plant species originally seeded on this site.

Figure 3. Vegetation growing on Opportunity Tailings Po

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Table 8. Plant performance at Site 2, 2002.

Life Form	Percent Cover	Production
Perennial grasses		1201 kg/ha
Intermediate wheatgrass	21.5	
Sheep fescue	9.7	
Total cover perennial grass	31.2	
Forbs		
None		0.0
Total % cover of desirable species	33.0	
Number of desirable species on site	4 perennial grasses 0 forbs 0 shrub	
Number of species with >1% cover	2	

Total grass cover was low but not surprising given the aridity and exposure of the study plot. The thick litter layer, over 70% ground cover and over a centimeter thick in many places, protected the soil surface from erosion but it intercepted most of the moisture from light spring and summer showers and prevented soil water recharge. It also prohibited good soil/seed contact and prevented the establishment of any pioneer forbs. The accumulation of a thick litter layer indicated that nutrient cycling was not taking place. Plant community succession cannot proceed without nutrient turnover. Fertilization and livestock grazing should be implemented on these sites to break up the litter layer and encourage forb establishment.

Grass production measured 1201 kg/ha (Table 8). An amount similar to the biomass on Site 1. While four plant species were observed on the plots, only two were present at cover values >1%. Weeds were not a problem on these research plots. The plant community on these plots was the least diverse of all of the plant communities reported in this paper. This may be due to the harsh nature of the tailings materials prior to amendment, but the isolation of the research plots in the midst of a very large barren area and the absence of any management were contributing factors.

<u>Site 3: Drag Strip - Nine Growing Seasons</u>

Soils at this site were very rocky with a reduced quantity of material less than 2mm. The pH of the fine materials was 7.5 and EC was 1.3 dS/m. Both pH and salinity of the treated materials were adequate for good plant growth. The acid base potential, 28 t/1000 t, nine years after amendment indicated that the lime additions were calculated correctly and that the quantity of neutralizing amendment was sufficient for an indefinite number of years. Total soil metal levels were 608 mg/kg (arsenic), 2510 mg/kg (copper), 1230 mg/kg (zinc), 230 mg/kg (lead), and 8.4 mg/kg (cadmium). Water soluble copper was high in the amended materials from Site 3, 5.5 mg/l (Table 6), but vegetation was flourishing.

Vegetation on this large research plot continues to perform well with no treatment since final seeding and planting in 1994. Ground cover of desirable grasses was approximately 28%. Of seeded species, Basin wildrye and Intermediate wheatgrass have declined in cover and production as the site has been invaded by Redtop (probably *Agrostis alba)* but all three species were producing large amounts of seed (Figure 4). The *Agrostis* was a dominant species on surrounding lands both amended and untreated where moisture was not limiting its survival. Like White top and Canadian thistle on Site 1, it continues to pose a problem to plant community development because of very large seed producing populations adjacent to the amended soils. Unlike these noxious weeds, Redtop is a good forage grass and readily consumed by livestock. The other wheatgrasses (Western and Crested) seeded on this site have almost disappeared from the plant community.

Figure 4. Vegetation growing near Anaconda Dragstrip in 2002 - nine growing seasons.

Total cover of desirable species measured 39% in the plots evaluated (Table 9). This included two acceptable forbs, alfalfa (seeded) and Ten petal blazingstar (volunteer). Birdsfoot trefoil, another seeded legume, has persisted on the plot but did not occur within the sample frames. Both the trefoil and alfalfa appear to be slowly declining in frequency and plant size. While competition from grasses and shrubs is undoubtedly a factor in this decrease both legumes are frequently used as a food source by numerous deer and rabbits that have been using the study site as a feeding ground. Legumes were found to have been eaten back to ground level throughout the site in the spring and this annual clipping has contributed to a decline in the vigor of the plants. Five other desirable forbs have volunteered on the plot and five undesirable weedy species were present.

Big sagebrush, Chokecherry, Caragana, Russian olive, Horsebrush, Rubber rabbitbrush, and Woods rose were transplanted to the site in 1994. One or more of each of these was found to have

Table 9. Plant performance at Site 3, 2002.

Life Form	Percent Cover	Production
Perennial grasses		840 kg/ha
Intermediate wheatgrass	8.3	
Basin wildrye	3.7	
Redtop	15.7	
Total cover perennial grass	27.7	
Forbs		294 kg/ha (desirable)†
Alfalfa	5.7	
Ten petal blazingstar	5.3	
Spotted knapweed	9.7	
Kochia	4.0	
Russian thistle	0.7	
Total % cover & production of desirable species	39.0	1134 kg/ha
Number of desirable species on site	5 perennial grasses 7 forbs 7 shrubs 1 tree	
Number of species with >1% cover	5	

† Noxious weeds were not included in forb biomass.

survived the conditions of the site and wildlife use and continued to grow in amended materials. Horsebrush plants were vigorous on adjacent contaminated soils but the plants on amended materials were very small. This was probably due to shading by other plants. The rabbitbrush, sagebrush, and rose were very robust and all produced large seed crops in 2002. A few Douglas fir trees had also persisted. They were generally small and gave evidence of having been browsed by wildlife. The Rubber rabbitbrush was slowly spreading in the amended area as numerous small plants were found in this survey.

Total production of desirable species on this site was 840 kg/ha of grasses and 294 kg/ha of desirable forbs (Table 9). If the invasion of undesirable weeds had been controlled and the resources utilized by these plants converted to grass and legume production total biomass of desirable plants would have been higher. Even present production rates make these sites valuable grazing land for this region.

This area needed weed control to check the spread of noxious species. This is a continuing problem because of the large reservoir of Spotted knapweed and Canadian thistle surrounding these research plots. Livestock grazing and wildlife control would also benefit this site. These strategies would stimulate further grass and forb development, and permit greater shrub growth.

<u>Site 4: Clark Fork River Governor's Demonstration - Twelve Growing Seasons</u>

Soils at the study area yielded an averaged pH of 7.7 and EC of 6.4 dS/m. The conductivity was slightly elevated but vegetation was performing very well. Total soil levels at this site were measured at 939 mg/kg (arsenic), 1880 mg/kg (copper), 1280 mg/kg (zinc), 690 mg/kg (lead), and < 3.8 mg/kg (cadmium). Soluble copper was elevated (3.1 mg/l), but not enough to impact vegetation at the pH of these materials. The soils were friable and infiltration appeared to be very high. This is in sharp contrast to the materials prior to amendment when they were crusted, impermeable, and subject to severe erosion. The acid base account was 61 t/1000 t. This reservoir of neutralizing material in the soil after twelve growing seasons may be interpreted to mean that these soils will not reacidify in the future.

The vegetation growing on this site was very robust (Figure 5). Basin wildrye plants were commonly over 100 cm and some plants were over 125 cm tall. Grass cover was almost 60% and distributed very uniformly across the length of the treated landscape. Plant species changed from almost entirely Basin wildrye on the upland portion of the transect to almost entirely Baltic rush on the last frame measured near the Clark Fork River. Although present within the boundaries of the Demonstration, the seeded wheatgrasses were not found around our study transect. The two seeded

Figure 5. Vegetation growing within the Governor's Demonstration, Clark Fork River in 2002 - twelve growing seasons.

wildryes (Basin and Russian), an invading *Poa* (probably *secunda*), and the very common Redtop were identified within the sampling frames. Three other grass or grass-like species were observed adjacent to the transect. These included Tufted hairgrass, Nebraska sedge, Smooth brome, and Baltic rush.

Total cover of desirable species exceeded 60% (Table 10). Desirable forb cover was poor for a community in this environment. Undesirable forb species comprised another two percent cover, but by any criteria, forbs were poorly represented. Thick expanses of Willow (*Salix exigua*) and Western snowberry were scattered across this Demonstration, but the study transect was intentionally placed to avoid any of them. These clumps were expanding and this together with the vigorous grasses and a thick litter layer (>70%) contributed to the poor performance of the forbs.

Standing plant biomass on this site was very large. It exceeded 2500 kg/ha (Table 10) and was composed almost entirely of forage grasses. This Demonstration needs livestock grazing to reduce the size of the plants, crumble the litter layer, and trample the litter into the ground. Grazing would also open the canopy to the establishment of perennial forb species.

Table 10. Plant performance at Site 4, 2002.

Life Form	Percent Cover	Production
Perennial grasses		2709 kg/ha
Basin wildrye	47.3	
Bluegrass species	0.5	
Russian wildrye	1.7	
Redtop	4.5	
Baltic rush	6.3	
Total cover perennial grass	59.5	
Forbs		0.0†
Canada thistle	1.5	
Field bindweed	0.3	
Yellow sweetclover	0.3	
Chickweed	0.3	
Sow thistle	1.5	
Scouring rush	0.3	
Unidentified mustard	6.3	
Total % cover of desirable species	61.0	
Number of desirable species on site	8 perennial grasses 13 forbs 2 shrubs 2 trees	
Number of desirable species with >1% cover	5	

† Biomass of forbs (some of which were noxious weeds) was not determined.

Site 5: Ramsey Flats Tailings Deposits - Fourteen Growing Seasons

The average pH of the treated tailings on these plots was 7.8. The average EC was 4.3 dS/m. Water soluble metal levels were higher than in amended soils or wastes from the other sites reviewed in this paper, but still quite low relative to pre-amendment conditions. Only copper at 2.3 mg/l was slightly questionable, but this level is not thought to be phytotoxic. Total metal concentrations within the root zone were quite elevated: 1850 mg/kg (arsenic), 3870 mg/kg (copper), 6940 mg/kg (zinc), 3420 mg/kg (lead), and 15.4 mg/kg (cadmium). The acid base potential of the wastes (14 t/1000 t) fourteen years after amendment is evidence that these materials will remain neutral to basic for an indefinite period, probably never reacidifying. The texture of the treated materials was very good, it was friable and infiltration of water should be excellent. The adjacent non-treated materials were heavy, impermeable, crusted, and runoff appeared to be very high. Erosion on untreated materials was so severe that in some of the treated plots unamended acid wastes had been deposited on the amended materials and turned that part of the amended plot into a barren waste.

Vegetation on this site was as robust as on Site 4 (Figure 6). Two seed mixes confuse the picture but some grass species in both mixes proved very effective in amended mine wastes. In Mix 1, seeded Russian wildrye and Tufted hairgrass, probably volunteering from clumps transplanted to the site at seeding, dominated the community. In Mix 2, Tufted hairgrass and Intermediate wheatgrass dominated the community. The Tufted hairgrass definitely volunteered from the transplants placed in the area seeded by Mix 1.

Figure 6. Vegetation growing on Ramsay Flats along Silver Bow Creek in 2002 - fourteen growing seasons.

Canopy cover on Site 5, Mix 1 averaged 66% (Table 11). On Mix 2, seedings cover averaged 56%. There were no desirable forbs in the area seeded by either mix. Total cover of these communities was the cover expressed by the grasses.

Production recorded in the area seeded with Mix 1 was greater than on any other plot evaluated in this review at 3447 kg/ha (Table 11). Vegetation from Mix 2 seeded plots measured 1917 kg/ha. Both values are greater than would be anticipated from similar sites in the area. The production of forage grasses on these treatments indicate how valuable these polluted lands could be as grazing land if they were amended and seeded with the appropriate species.

There were six desirable species growing in the area seeded by Mix 1 and seven species growing in the area seeded with Mix 2 but no legumes or desirable forbs in either mix. Seedlings of almost every successful species on the plots were observed growing on the amended materials. Long term establishment of these seedlings is inhibited by the robust plants already firmly established on the materials. The more acid tolerant grasses, Tufted hairgrass and Salt grass, have proliferated along the edges of the plots and have spread over a meter into the non-treated materials between plots. Tufted hairgrass has spread by seed and Salt grass by rhizomes.

There were rodent nests on the plots and evidence that rabbits had frequented the grassy sites. While there was evidence of litter decomposition, little succession appears to have taken place in the communities on the treated materials. This may be attributed to the small size of the plots and their isolation in many hectares of barren acid wastes and the absence of any grazing animals to reduce the canopy created by standing dead litter and living clumps of grasses. These grassy plots need livestock grazing to open the canopy to volunteer forb species.

Site 6: Champion Mine tailings pond - Nineteen Growing Seasons

This study was developed for entirely different goals than the other research plots reviewed in this paper. Each small plot (50 X 50 cm) was laid out and seeded as a separate species specific evaluation. There were seven individual species plots adjacent to one another and replicated three times. After nineteen years the plant species have grown out of their plots and seeded or grown throughout the limed areas (Figures 7a and 7b). Several of the acid tolerant species have even grown beyond the limits of the limed plots. Average total metal levels in soils at this site were 81 mg/kg (arsenic), 49 mg/kg (copper), 26 mg/kg (zinc), 26 mg/kg (lead), and < 3.8 mg/kg (cadmium). Soluble metal concentrations within the root zone (Table 6) were non phytotoxic.

Table 11. Plant performance at Site 5, 2002.

Life Form	Percent (%) Cover		Production	
Perennial Grasses	**Seed Mix 1**	**Seed Mix 2**	**Mix 1**	**Mix 2**
Tufted hairgrass	13.7	19.4	3447 kg/ha	1917 kg/ha
Russian wildrye	46.9	3.1		
Redtop	1.3	7.6		
Intermediate wheatgrass	3.1	16.9		
Inland saltgrass	1.4	3.7		
Tall wheatgrass	0.1	5.0		
Squirreltail	0.0	0.1		
Total cover perennial grass	66.5	55.8		
Forbs			0.0	0.0
Groundsel	0.0	1.9		
Catchfly	0.6	0.0		
Russian thistle	0.0	1.3		
Unidentified mustard	0.1	1.3		
Mix 1				
Total % cover of desirable species	67.0			
Number of desirable species on site	6 perennial grasses			
Number of species with >1% cover	5			
Mix 2				
Total % cover of desirable species	56.0			
Number of desirable species on site	6 perennial grasses			
Number of species with >1% cover	6			

Amended materials at this tailings pond revealed an average pH of 6.0 and EC of 1.7 dS/m after nineteen growing seasons. Non-amended materials under the surficial amended zone had an average pH value of 3.5 . The acid base potential of the amended layer was less than 1 t/1000 t. The 20 cm layer under the amended zone had an acid base potential of -2 t/1000 t. The fertilized and rototilled but non-limed soils adjacent to the treated materials revealed pH values of 4.3 in surficial materials and 3.2 in buried wastes. The acid base potential of these materials were -4 t/1000 t in the surficial layer and -2 t/1000 t in the buried wastes. A wealth of fine roots were found in the deeper zone (pH of 3.5) under the amended waste. Apparently the root environment had been modified by the

Figure 7a. Vegetation growing at Champion Mine in 2001 - eighteen growing seasons.

development of roots and the addition of organic matter as these roots died. This organic addition had complexed the toxic ions in the wastes, thereby permitting additional plant growth. This plant growth was also observed in untreated wastes adjacent to the amended plots. The original tailings material was heavy, crusted, and almost impermeable. Erosion was severe. Amended materials were friable, had a very soft surface, and showed little sign of erosion. Soluble metal loadings in these waste materials were only slightly elevated before amendment, nevertheless, copper and zinc concentrations were reduced by 50% or more by the addition of lime.

Plant cover on this site exceeded 100% (Table 12). Grasses composed 58% of that cover and the numerous forbs the remainder. Seeded grasses dominated the site 19 years after seeding. The dominant forb, Birdsfoot trefoil, was also seeded. There were over eight species with greater than 1% cover, but over 13 species were found within these small study plots. Of these 13 species five

Figure 7b. Vegetation growing at Champion Mine in 2002 - nineteen growing seasons.

were seeded and eight were volunteers from the surrounding forest/grassland ecosystem. Plant production was not available on this site because cattle had completely removed all plant tissues by June 20, 2002 (Figure 7b). Cattle had apparently learned of the quality and quantity of the forage on these plots because all vegetation had been removed from these sites on several previous inspections before any of the surrounding grass stands were grazed by livestock. The plant cover data were acquired in early June 2001 (Figure 7a).

The many volunteer species on these plots were an indication of plant succession occurring on the amended tailings. In addition to the numerous forbs, three Lodgepole pine trees had established and grown within the limed plots. The ecosystem surrounding this study site was dominated by Lodgepole pine. These young trees lend evidence to the hypothesis that this waste site was undergoing very rapid succession and was returning to timber production similar to that in the surrounding forest. Amendment and transplanting would speed the return of this site to forest production, but transplanting was not necessary. Equilibrium between the waste and the surrounding forest will occur with little more than a single lime amendment, fertilization, and invasion of the site by native vegetation.

Table 12. Plant performance at Site 6, 2001.

Life Form	Percent (%) Cover
Perennial Grasses	
Creeping foxtail/Meadow foxtail†	38.3
Redtop†	18.3
Sheep fescue†	4.0
Baltic rush	0.3
Canada bluegrass†	0.3
Total cover perennial grass	61.2
Forbs	
Small-leaf pussytoes	1.3
Rose pussytoes	0.3
Common yarrow	4.0
Cudweed sagewort	0.3
Woodland strawberry	4.3
Allumroot	0.3
Birdsfoot trefoil†	35.0
Dandelion	1.0
Total % cover of desirable species	> 100%
Number of desirable species on site	5 perennial grasses 1 grass like 8 forbs 1 tree
Number of species with >1% cover	8

† Seeded species.

Summary

The review of these six sites: four research plots and two applied reclamation projects demonstrates that insitu reclamation or phytostabilization of acid waste is a valuable reclamation technique. The calcium carbonate amendment applied as ground limestone or industrial waste can be calculated to produce a non-acid root zone that will last indefinitely. There are indications that once vegetation is established on the waste the root mass growing into amended and non-amended materials complexes the toxic ions and thereby renders the materials less toxic. This permits further root proliferation into adjacent non-amended materials and the initiation of a cycle of growth/neutralization/growth that is self perpetuating. This eventually permits the establishment of less tolerant vegetation on the wastes and a plant successional cycle is underway.

The establishment of Lodgepole pine on the Champion Mine tailings was only one indication that later successional changes had occurred on insitu amended mine wastes. The proliferation of Rubber rabbitbrush on Site 3 was further evidence of this phenomenon. The spread of stands of *Juncus* and *Salix* thickets in the riparian border of the Clark Fork River at Site 4 and the development of pure stands of Basin wildrye on upland soils at this site were examples of rapid successional changes taking place on these insitu reclaimed materials. All of these species, Lodgepole pine to the Basin wildrye, were later successional stages of the ecosystem in which they were successfully developing.

The plant species noted above are long lived plant community components that will stabilize the soils of the area and will exist for very long periods of time. However, it must not be imagined that even Lodgepole pine is the final successional stage for this forest stand. These trees will be replaced by Douglas fir in the ecological zone in one to two hundred years. The fir or the pine, if it persists, will in turn be displaced within the next 500 years by fire or some climatic or geologic abnormality. The resulting barren landscape may be devoid of vegetation or covered by grasses, forbs, and/or shrubs depending on the severity of the event that removed the previous vegetation. In all examples, natural processes will begin the cycle of reclamation. After fire, or clear cutting, or volcanic eruption if we find the regrowth of trees or grasses too slow we intervene and seed or transplant vegetation to meet any desired outcome. This is reclamation and the six examples of insitu reclamation cited in this paper were simply more complex manifestation of this same process.

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