New World Mining Response and Restoration Project
Long Term Revegetation Plan
draft 2002
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Gallatin National Forest

Introduction

Background

Mitigation of historic mining wastes has been an on-going interest of numerous parties since the 1970s. One of the first to investigate revegetation in the District was the USDA-FS Intermountain Research Station (Brown, 1996). This research has focused on reclamation of high elevation mine disturbances including species selection, fertilization, planting season, organic amendments, acid soil amendments, and surface soil treatments. Larger scale reclamation efforts have also been conducted by numerous parties involved in reclamation of the McLaren Tailings near Cooke City. In 1969, the Bear Creek Mining Company covered the McLaren Tailings with soil and rerouted Soda Butte Creek. In 1989, the EPA constructed a dam at the lower end of the tailings to stabilize the banks of Soda Butte Creek Other areas of the tailings have been recontoured and revegetated since that time.

Some reclamation work was completed by CBMI on District Properties as part of their exploration and proposed mine development work. In 1993, CBMI began surface restoration work to reclaim the historic MacLaren open pit mine disturbance and areas disturbed by exploration activity in the Como Basin. Reclamation activities at the MacLaren pit included recontouring, construction of runon control ditches, treating acid soils with a lime amendment, and fertilizing and seeding with native grasses. Similar reclamation work was completed in the Como Basin area although additional work was done in this area to construct runon controls to prevent water from entering a raise connected to the Glengarry adit. From 1993 to 1996, CBMI also reclaimed a number of exploration roads and drill pads

In August 1998, Crown Butte Mines, Inc.(CBMI) entered into a consent decree with the United States Government, the State of Montana and several non-profit organizations which provided funding for, and guidance on, response and restoration actions to be implemented on historic mine related disturbances in the District. At that time, the USDA-FS became the lead agency in the clean up effort. The work, among other aspects, includes evaluating revegetation efforts that have been completed in the past as well as those revegetation projects that will be completed over the expected 8-year life of the project.

Site Location and Description

The District is located in Park County in south-central Montana. It is bounded on the south by the Montana-Wyoming state line, on the west by Yellowstone National Park and on the north and east by the Absaroka-Beartooth Wilderness area boundary (Figure 1). The District is characteristic of high alpine regions of the northern Rocky Mountains with elevations that range from approximately 7,000 feet to over 10,000 feet. Accumulated snow pack in the higher elevations range from 10 feet to over 20 feet deep where drifting occurs. The ground is generally snow covered from late October through mid May at the lower elevations and from early October through late July at the higher elevations. Perennial and semi- perennial snow fields occupy the north facing slopes of the highest mountain peaks.

Three drainage basins have been identified as potentially being impacted by the proposed response and restoration actions: 1) Fisher Creek and the Clarks Fork of the Yellowstone River; 2) Daisy Creek and the Stillwater River drainage basin; and, 3) Miller Creek and Soda Butte Creek drainage basin.

Predominant native vegetation communities in the project area include upland forest types, upland herbaceous and shrub types, bottomland types, and avalanche complex types. Upland forests generally predominate below 9600=; however, several types composed of whitebark pine (Pinus albicaulis) and subalpine fir (Abies lasiocarpa) extend into mid and upper slopes above this elevation primarily on southerly slopes. Several upland herbaceous and shrub types exist, their distribution determined by factors such as elevation, slope, aspect, topographic position, and soil characteristics. Bottomland forests extend along riparian areas throughout the project area, increasing in tree cover with decreasing elevation. Avalanche areas are present in upper Fisher Creek and at the head of other drainages. Composition of vegetation communities varies with intensity and frequency of snow movement, topographic features, and soil characteristics (Scow et al., 1992).

Natural soils in the area are relatively weakly developed, when compared to soils at lower elevations. Summers are short and cool, and winters are long and cold. Soil forming processes are primarily physical weathering from frost, slow movement of material downhill under the force of gravity, and small additions of organic materials from vegetation. The nature of soil features reflects these processes, with weakly expressed horizons and little clay accumulation. The parent material (that material from which the soil has formed) contributes most of the soils= characteristics.

The upper third of the area has soils that are generally shallow, with many rock fragments. Soil fertility and water holding capacity is relatively low. These soils have formed in glacial till and colluvium derived from a variety of intrusive, metamorphic, and igneous rocks. These soils have from 30 percent rock fragments on gentle slopes to over 70% rock fragments on slopes over 20%. Most of these rocks contain significant quantities of sulphide minerals, which have influenced soil and vegetative development. Soils under or near grasslands at lower elevations have deep, dark surface layers, accumulation of clay, and few rock fragments. They have relatively high fertility and water holding capacity. These soils have formed in glacial till derived from Paleozoic limestone and shale, with some intrusive rocks. In the southwestern part of the area, similar soils have formed in glacial till derived from Tertiary volcanic rocks. Granitic or other hard-crystalline rocks occur in all areas, a result of glacial movement from the Beartooth Plateau.

Fine to medium textured alluvium occurs in drainage bottoms and in depressions. These soils are seasonally wet, and are fine textured.

Several hundred acres have been severely disturbed by past mining activities. Soils in these areas may be only 50 years old, with very little development and no or very limited vegetation. Some areas have high concentrations of sulphides and other growth-limiting materials, and almost no fine materials. Other areas have little sulphidic material, but have a high proportion of rock fragments, limiting vegetation establishment. These disturbances probably have re-created conditions similar to those existing just after de-glaciation about 8,000 years ago.

Purpose and Objectives

The purpose of re-vegetating disturbed areas in response and restoration is to provide an effective erosion control measure; to produce a self-sustaining vegetation community that reflects the natural conditions of the undisturbed, native communities in the District (as far as possible given disturbance levels); and to reduce the quantity of water infiltrating past the soil solum, an aid in improving water quality. An allied objective is to minimize long term maintenance of these communities. Several cost reduction measures are recommended, including using high-quality compost from Yellowstone National Park, advanced hydromulch techniques, and minimization of topsoil re-distribution. Towards these ends, we are emphasizing an ecological approach to revegetation, modified by cost considerations and environmental constraints. In many areas, we will accept a higher short term cost to assure revegetation measures will continue to be effective under the harsh climatic environment and with very little long term maintenance.

Towards these ends, we have determined that Anormal@ revegetation practices, those that work well at lower elevations and in favorable materials, will probably not be adequate here. Little research has been done at these high elevations, harsh climates, and in such poor growth media. We are fortunate, however, to have a long term revegetation research project under just those conditions, in fact at the sites we are addressing, and with objectives compatible with our restoration and response project. The work has progressed to the point where recommendations for successful revegetation have been tested and documented. It has been primarily carried out by Dr. Ray W. Brown, Project Leader of the Restoration Ecology of Disturbed Lands Research Work Unit, USDA Forest Service, Rocky Mountain Research Station, Forestry Sciences Laboratory, Logan, UT. This research forms the basis for our revegetation prescriptions.

The Role of Research in Ecosystem Restoration

Restoring ecosystem health to disturbed wildlands is one of the most critical challenges for land managers. The urgency to implement restoration of disturbed ecosystems stems from various concerns. We are moving in the direction of ecological management of these areas, and away from merely maximizing vegetation growth. However, in some environments the scientific knowledge of how ecosystems respond to disturbances, how natural ecosystem processes such as succession can be reinitiated on severe disturbances, and how these are impacted by current land management policies, is lacking.

Over the short span of the last 200 years, human society has progressively imposed increasingly more diverse and complex disturbances and stresses on North American ecosystems than those under which ecosystems naturally evolved. With the advent of European-style society in western North America, and especially with the large and rapid increases in population and cultural growth in recent decades, the ranges and extent of human caused disturbances on ecosystems have grown as a result of two primary kinds of activities: construction-development-extraction enterprises; and inappropriate wildland management policies. Techniques for amelioration of these disturbances are well developed in many environments, as long as their intensity is not too great. However, the restoration of ecosystems that have faced high intensity disturbances has not been adequately address as of yet.

Disturbances can be referred to as "severe" if they result in the complete loss of native soil and vegetation, and if they disrupt or destroy natural surface and subsurface hydrologic pathways. Severe disturbances are normally most significant on the local or watershed scale, but may have far greater impacts on water quality and quantity, wildlife habitat, and other attributes than some much larger scale disturbances. The occurrence of locally severe disturbances is accelerating on public lands throughout the Nation, but especially so in the West as population and associated development expands.

Intact functioning ecosystems conserve matter and energy, hence the net loss of energy or other components needed to sustain them is low. Because natural intact ecosystems are self-regulating, they are internally and naturally buffered against all but the most severe outside forces. However, in harsh western or semiarid regions and in extreme environments at high elevations, natural recovery from disturbance occurs slowly over long periods. Here human activities have formidable impacts when they occur in headwaters of drainages, near streams or rivers, or on steep unstable slopes where the potential for erosion, sediment movement, and subsequent degradation of water quality is maximized. Thus, some very real dangers stem from altering the natural form of western ecosystems,

In recent decades we have learned that many traditional land management practices, including remedial reclamation and revegetation, are not compatible with natural ecosystem form and function. The intentional exclusion or modification of natural fire cycles and other natural disturbances by land managers has dramatically altered the form and function of virtually all ecosystems in the West. For example, research has documented that the intentional exclusion of fire combined with heavy livestock use has resulted in the loss of half of the aspen (Populus tremuloides) forest type in the Intermountain West. In addition, spurious vegetation-reclamation activities, such as the introduction of highly competitive exotic species, have resulted in seemingly permanent losses in biodiversity, arrested sustainability and successional development, and degraded resiliency to climate change and to the impacts of cyclic re-disturbances caused by either natural or human agents. Often the use of exotic plant species and various cultural treatments in disturbed ecosystems, although providing short-term surface stability and protection from the immediate problems of surface erosion, ultimately lead to highly oversimplified and quite artificial ecosystems. Vast areas of these unnatural systems have been created throughout the West as a result of unfortunate land management decisions and poor information, and not only have these areas not returned to a natural ecosystem state, but may in-fact be retarding or delaying ecosystem reestablishment following disturbance.

The adoption of ecosystem management guidelines for managing public lands suggests recognition of long-term significance of natural intact ecosystem form and function for achieving diversity, sustainability, and resiliency. With ecosystem management as the goal, we need to comprehend how ecosystems function, but to achieve that we also need to understand how ecosystems develop from genesis to maturity. Research dedicated to developing new knowledge about restoring fundamental ecosystem processes on disturbed lands provides a unique opportunity to achieve that understanding. Aldo Leopold noted that "If we are serious about restoring or maintaining ecosystem health and ecological integrity, then we must first know what the land was like to begin with" (quote in Covington and Moore, 1994, J. Forestry 92:39-47).

Mission of the ARestoration Ecology of Disturbed Lands Research Work Unit@

The research unit is represented Dr. Ray W. Brown and Dr. Michael C. Amacher. Dr Brown is the Project Leader of the Restoration Ecology of Disturbed Lands Research Work Unit, USDA Forest Service, Rocky Mountain Research Station, Forestry Sciences Laboratory, Logan, UT. He received a B.S. degree in forestry in 1963 and an M.S. degree in range ecology in 1965, both from the University of Montana, Missoula. In 1974 he received a Ph.D. degree in plant physiology from Utah State University. In 1995 he received the National Minerals Management Award from the Forest Service. He has authored more than 100 research publications. His co-worker, Dr. Michael C. Amacher is a soil chemist with the Restoration Ecology Work Unit at the Forestry Sciences Laboratory in Logan, UT. He holds B.S. and M.S. degrees in Chemistry and a Ph.D. degree in soil chemistry, all from The Pennsylvania State University. He joined the Intermountain Research Station in 1989. He studies geochemical weathering in disturbed environments and develops methods for mitigating damage to watersheds from mining and other land use activities.

The research unit focuses on developing new knowledge about how to reinitiate natural ecosystem-forming processes such as succession on lands that have been severely disturbed. They are primarily concerned about severe disturbances because they tend to stall or suspend the natural processes of succession once the land has been altered beyond the range of recoverability under which they evolved by natural processes alone. Succession is a natural process guided by climate, geology, and biological forces, but can be retarded or repressed when environmental factors exceed certain un-ameliorated limits. As envisioned here, the process of restoration does not necessarily "just happen" naturally following severe disturbance. They have targeted succession for intensive research in order to determine the limits under which it progresses, and to determine how land managers may practice "intentional intervention" in ecosystem management to better understand how succession may be reinitiated on severely disturbed lands that lead to natural ecosystem development.

The mission of this research unit is to increase the scientific basis for understanding how the biological, chemical, and physical processes responsible for ecosystem development can be reestablished on severely disturbed lands. This program attempts to balance both basic and applied research in the fields of plant physiology, ecology, soil chemistry and physics, hydrology, and water quality while also working in close cooperation with land managers and land users to enhance our knowledge of how the fundamental processes of ecosystem formation can be implemented. More knowledge is needed about the effects of toxic mine wastes, acid drainage, unstable steep slopes, erosion, and geochemical weathering on succession and water quality in both high elevation and arid land watersheds. As such, their core program focuses on a two-part scientific research effort that includes the following

1) On severely disturbed lands, research and development leading to an improved understanding of restoration and reclamation techniques required to:

   1. Initiate natural succession that leads to the reestablishment of self-sustaining natural communities, habitats, and ecosystems.
   2. Initiate soil genesis and nutrient cycling.
   3. Restore natural surface and subsurface hydrologic pathways.
   4. Improve water quality in headwater streams, rivers, and other waters, and

2) on degraded or poorly managed wildlands, research to enhance the scientific basis for understanding how management options can be used compatibly with natural ecosystem processes to successfully reestablish degraded or lost communities, leading to improved watershed integrity, enhanced water quality and quantity, and sustainable biodiversity and habitat conditions on local and landscape scales.

Restoration Research in the New World District

This project has been in operation for the last twenty eight years. Dr Brown and Dr. R. Johnston began conducting research at New World in 1972. Objectives then were to determine: 1) if plants could be established on mine spoils-any plants and 2) water quality impacts of those spoils. A series of small plots were installed at various times over the years to test specific hypotheses. A Demonstration Area was installed in 1976 in three parts:

A. A seeded portion
B. A transplant portion
C. A native seed rain portion.

Numerous smaller plot complexes were installed after that on the MacLaren and Como Pit, and on various road cuts in the area (e.g., 1974, 1976, 1978, 1980, 1981; most of those were destroyed by recent reshaping and contouring by Crown Butte in the early 1990's.

The significant results of this early research included the following:

A. Only about 8-10 species of the total 120+ vascular plants occurring in the area are suitable for revegetation.
B. No introduced species appear to be adapted, and all disappeared within 3-5 years in every research study conducted between 1974 and 1984.
C. Liming is essential at pH below about 5.
D. Incorporation of organic matter appears to be beneficial.
E. Surface mulching appeared to be essential.
F. Refertilization appeared to be highly beneficial.
G. Including sedges in the seed mixture is not recommended (photoblastism).
H. Including forbs in the seed mixture is not required; they invade and colonize quickly after refertilization is discontinued.
I. Refertilization appears to encourage the formation of a solid grass sward; however, this condition deteriorates rapidly in years following the discontinuation of refertilization.
J. Species and lifeform richness and composition changes occur slowly, and only after refertilization is discontinued.
K. Natural seed rain appeared to be significant, and became the primary source of increased species richness in treated spoils.

More significant is a set of research plots established in 1993, to address the following:

A. The importance of source of mine spoil material within the New World area (different types of mine spoil, MacLaren vs Glengarry wastes).
B. The effects of season of seeding (spring vs fall)
C. The effects of seeding vs not seeding (to assess the relative importance of natural seed rain).
D. The effects of incorporating organic matter vs no OM
E. The effects of surface mulching vs no mulch
F. The effects of repeated refertilization inputs on plant community development.

Additionally, the following points were investigated:

A. The role of enhanced P applications

B. The relative performance of the primary seral grasses in both intra-and inter-competition.

C. Encouraging Capa establishment and growth, and determine relative rate of basal growth related to soil treatments.

D. Applicability of mine spoil restoration techniques for restoring native communities on obliterated, reshaped, and contoured roads.

E. The significance of deep liming to encourage rooting and plant development in acidic spoils.

F. The efficiency of these techniques in encouraging soil genesis and nutrient cycling.

Significant results of these experiments include:

- There are no statistically significant differences in treatments on erosion, deposition, or surface roughness.

- There is no significant difference in biomass production due to liming depth.

- Not liming results in no plant establishment.

- There is a significant difference in live plant cover due to liming depth.

- Although significant differences in biomass and live cover due to Phosphorus enhanced fertilizer occur mostly between the lowest (50 lbs/ac) and highest (400 lbs/ac) rates, there is a definite increase in biomass and cover with increasing rate of application.

- Deca, Phal, and Poal show the most sustained biomass and cover contribution over time. Trsp, Agtr, and Peru Ck. Deca contribute more variable biomass and cover, apparently highly dependent on current climate.

- Biomass and live cover in the MacLaren Demonstration area show no significant differences from those in adjacent native reference areas since the mid-1980's. Prior to 1985, differences were significant, probably due to repeated refertilization that occurred between 1977-1983.

- A plot of the 95% confidence interval between biomass and live cover for the MacLaren Demonstration Area and native reference areas sustains the conclusion above.

- The total number of vascular plant species found within the MacLaren

Demonstration Area has been similar to that observed in native reference areas (about 50+) since 1995. The number of species found as active successional components on acidic mine spoils is about 25, whereas in reference areas the total is about 50-55.

- There are significant differences in biomass and live cover in the MacLaren Demonstration Area seeded area and transplant area, and in the native seed rain area. However, as of 1996, the differences are no longer significant in the seeded and native seed rain areas.

- The first forb invaders in the Demonstration Area were observed in 1986; since then, forbs, sedges, and woody plants have been colonizing within the seeded portion.

-At present, the composition of lifeforms within the Demonstration Area is beginning to more closely resemble that observed in native reference areas than observed at any time in the past.

- There are significant differences in Capa diameter growth due to lime and fertilizer in highly acidic spoils, but not in less acidic spoils.

- Introduced species are not adapted to New World conditions, and should not be included in any seed mixtures.

- The is no evidence that acidic mine spoils tend to re-acidify with time after being treated with hydrated lime.

- Retreating old revegetation communities with lime is not necessary; re-liming does not significantly improve biomass or cover.

- Retreating old revegetation communities with fertilizer significantly enhances biomass and cover for 1 to several years.

- There were significant differences in biomass and live cover observed between 1994-1998 in seeded vs unseeded plots (seeded vs natural seed rain). Also, differences were significant between the MacLaren and Glengarry sites (MacLaren was significantly higher). There are no differences in live cover on the Glengarry Adit site.

- Differences in biomass and live cover were significant in seeded vs unseeded plots in all years between 1994-1998.

- Spring seeded plots resulted in significantly higher biomass and live cover than fall seeded plots, in all years 1994-1998.

- There were no significant differences in organic matter vs no organic matter plots when averaged for all years, but differences were highly significant during the first year or two after seeding (organic matter treated plots had higher biomass and live cover).

- Organic matter incorporation resulted in significant differences in biomass and cover in more acidic spoils, but no differences were observed in less-acidic spoils (e.g., Glengarry vs MacLaren Mine).

- Organic matter incorporation was highly significant for biomass and cover on the ``deep-limed" plots on the MacLaren Mine.

- Surface mulching resulted in significantly higher biomass and live cover that in un-mulched plots in all years and locations.

- Mulching resulted in significantly higher biomass and live cover in native seed rain (unseeded) plots.

Principles for Ecosystem Restoration for the New World District

The following are conclusions for re-establishing natural plant communities in the higher elevations of the New World Project area. They are based on the research results obtained above.

Retain natural soil for application where available. The term Anatural soil@ refers to that material in the surface 12 inches that was present before disturbance. It does not mean material taken from different soil types.

Shape and contour disturbed sites to similar natural topographic condition. This enhances proper drainage, collection of natural rain and snowmelt, and reduces erosion potential.

Analyze physical and chemical properties of disturbed soils or spoils, and contrast with natural soils to determine extreme or limiting conditions. These conditions will dictate liming quantity and need for other soil amendments to provide an appropriate growth medium.

Apply amendments to ameliorate limiting soil-spoil conditions (e.g., lime, organic matter, fertilizer, etc.). This step helps provide a relatively Anatural@ growth media, free of limiting or exclusionary conditions to any plant establishment.

Observe and study natural succession on disturbances (e.g., natural plant colonization on old road cuts and fills, old mine spoils, other disturbed areas) in the immediate area to identify adapted native seral species.

Select adapted seral plant species identified in 5. above and collect seeds and other propagules (e.g., early successional grasses and forbs normally dominate disturbances, and these provide evidence of those species most suitable for survival on severe disturbances). This gives some assurance that species are genotypical suited to the site. The same species grown elsewhere may not have the hardiness shown by local representatives.

Schedule restoration and revegetation procedures to coincide with native plant phenology and climate (e.g., the season when natural seed maturity and seed-fall occur prior to the on-set of dormancy; normally August-September-early October in northern Hemisphere).

Use seeding and planting techniques appropriate for the physiological requirements of the selected species, and that most closely simulate natural processes (e.g., broadcasting more closely approximates natural seed distribution).

Apply surface mulch to minimize erosion, evaporation, temperature extremes, and wind re-distribution of seed and soil, and to promote seed trapping.

Refertilize site for 3 to 5 consecutive years after initial installation to promote organic matter build-up, soil genesis, and nutrient cycling.

Application Steps in Revegetation for New World Restoration

Three different environmental and soil classes are used, based on the kind and location of disturbance. Though the revegetation research applies to all minewaste and acidic disturbed areas above 9000 feet in elevation, road cuts and fills and repository site reclamation are generally treated with different methods, because of differing environments and soils.

Note that we do not recommend taking high-quality surface soil or sub-soil from repository excavations to use on minewaste areas. This is because they are radically different materials, and plant communities adapted to one material will not survive well in the other. Also, considerable plant material may be present in that soil, retarding appropriate community growth with Aweeds@ better adapted for lower elevations and fertile, non-acid soils. This kind of "gardening" approach has been shown to result in plant communities that require long-term maintenance as we have changed the ecological parameters of that particular environment. Finally, the look of this area will be significantly different, emphasizing the reclamation process, rather than blending the area into the surrounding landscape.

Repository Sites at Lower Elevations

Surface soils at the proposed repository sites (and similar areas) are of higher quality than at higher elevations. Grassland vegetation will be re-established by using saved surface soil for re-spreading on the repository site; seeding with appropriate native species; raking in seed to 2 inch; fertilizing with a balanced fertilizer (e.g., 16-16-16 N-P-K) at 100 lbs N ac^{-1}; and surface mulch with erosion blanket or equivalent, approved hydromulch on slopes over 30% gradient.

Road Cuts and Fills at All Elevations

Road cuts and fills at all elevations will be re-vegetated by seeding with appropriate native species; raking in seed to 2 inch; fertilizing with a balanced fertilizer (e.g., 16-16-16 N-P-K) at 100 lbs N ac^{-1}; and surface mulch with erosion blanket or equivalent, approved hydromulch. This applies to road disturbances created in the New World Restoration Project. Older cuts are generally stable and should not be re-disturbed. This applies ONLY to disturbances NOT in material fitting the criteria for minedump restoration. Road cuts and fills in minewaste having acid characteristics and elevation higher than 9000 feet should be treated as minedumps and revegetated as described below.

Minedumps, Minewaste, and other Disturbed Areas above 9000 feet

The techniques described below are appropriate for any kinds of minewaste or tailings in the higher elevations of the New World District. They can be applied to minedumps left in place, to re-contoured disturbed areas (such as the Como Basin), to natural ground surfaces below and downstream of removed dumps, roadbeds, or re-contoured road prisms. Applicable sites are at higher elevations (greater than 9000', where forb/sedge/grass communities are dominant.) Since all research was completed on soils developed from rock fragments derived from intrusive bedrock, sites on rocks having sedimentary influence may require some modifications of these techniques. For example, soil material with significant limestone will require less lime amendment.

Yellowstone National Park has proposed using products from their proposed composting facility near West Yellowstone. This material has been evaluated as an organic amendment. It appears to be satisfactory for this use. It can be obtained at a low cost and will make a high quality addition to the surface material. It should be applied at rates equivalent to those recommended in this publication.

1. Site preparation will include re-contouring the spoil area to a relatively Anatural@ topography, leaving the most favorable soil materials on top. Compacted areas such as road beds will be tilled to improve tilth if no lime incorporation is indicated. Disturbed areas under removed minedumps should be ripped and smoothed to improve infiltration. We do not recommend removal of any material below the natural ground surface from the area below removed-minedumps. There is not likely to be enough leaching of acidic materials to preclude reclaiming using the standard techniques described below, since they already allow for acid additions.

2. Incorporate lime: based on lime incubation and/or ABA test.

Procedure:

-hydrated lime [$Ca(OH)_2$] for active acidity
-crushed limestone [$CaCO_3$] for potential acidity from unweathered sulfides.
-incorporate to 15 cm (6 inches) depth, or more.

Advantages:

-neutralize acidity to pH of about 5.5 to 6.5.
-decreases availability of metals and other toxic chemicals.
-promotes availability of nutrients.

Disadvantages:

-acquisition, transportation, and application costs.

3. Incorporate organic matter:

Procedure:

-0.25 to 0.5 % by wt. with fine particle OM (e.g., peat).
-up to 1% by wt. with manure or coarse OM (e.g., manures, compost, plant residues, etc.). High quality compost from Yellowstone National Park should meet these specifications.
-incorporate to 15 cm (6 inches) depth, or more.

Advantages:

-complexes metals.
-improves nutrient and water holding.
-improves aeration, bulk density, infiltration, etc.

Disadvantages:

-acquisition, transportation, and application costs.

4. Incorporate fertilizer:

Procedure:

-Apply balanced granular fertilizer (e.g., 16-16-16 N-P-K) at 100 lbs N ac^{-1}.
-Apply P_2O_5 at 200 lbs/ac P.
-incorporate to 15 cm (6 inches) depth.

Advantages:

-provides essential plant nutrients.
-promotes root and shoot development, and reproduction.

Disadvantages:

-may promote ?luxury consumption@ by low-seral species (e.g., grasses and sedges), but effect is short-lived.
-potential nitrate leaching.
-acquisition, transportation, and application costs.

5. Broadcast seed with mixture of native successional species and lifeforms:

Procedure:

-observe natural succession.
-collect seed of native seral species (or purchase from reputable merchant).
-broadcast at rate of 250-400 seeds ft^{-2} (50-75 lbs ac^{-1}).
-lightly cover to 0.5 cm by packing.

Advantages:

-enhances succession.
-ecologically compatible and adapted.
-promotes reproduction.
-promotes invasion and colonization.

Disadvantages:

-acquisition costs.

-potential lower viability and germination.
-may require higher seeding rates.
-expensive.

6. Surface mulch with erosion blanket:

Procedure:

-use straw-woven in cotton string netting or equivalent.
-especially appropriate on:
- - slopes steeper than 3:1;
- - all areas at high elevations (above 9000 ft.);
- - exposed high-wind impact areas.
-apply immediately after seeding.
-apply uniformly, use high-density pinning.
-Hydromulch has been shown to retard community development because it tends to raise seedlings from the soil with the frequent frost events. However, new hydromulch technology and development may have overcome this limitation. Hydromulch techniques will be evaluated as a replacement for the costly erosion blanket procedure.

Advantages:

-minimizes evaporation.
-minimizes erosion, sediment movement.
-minimizes wind re-distribution of seed, soil-fines, etc.
-minimizes temperature extremes (e.g., frost).
-enhances seed trapping.

Disadvantages:

-acquisition, transportation, and application cost.

7. Re-fertilize yearly for 3 to 5 years :

Procedure:

-apply with spreader
-use 32-5-5 at 100 lbs N ac^{-1} or equivalent.

Advantages:

-provides high-pulses of readily available nutrients.
-?pushes@ plant root and shoot development.
-enhances biomass and organic matter formation.
-may enhance nutrient cycling.

Disadvantages:

-may favor grass sward (?luxury consumers@), but this effect is

short-lived.
-discontinuation leads to biomass-cover ?crash@.
-higher cost.

Long-term effects:

-eventual enhancement of diversity through invasion, colonization, and establishment of other lifeforms.
-leads to enhanced rate of successional development, and community formation.
-promotes soil genesis and nutrient cycling.

References

to be completed.