HIGH ALTITUDE TAILING RECLAMATION[1]

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Abstract: Tailing, if present, is the most difficult aspect of mine reclamation. Physical characteristics of tailing often provide good soil-plant water relations, but that characteristic is frequently overshadowed by its high erodability. Chemical characteristics such as high acidity, alkalinity, salinity, and heavy metal concentrations are common in metal mine tailing and can prohibit direct revegetation of the tailing. When detrimental physical and chemical characteristics exist, an accepted tailing reclamation technique is to place a cover material over the tailing and revegetate that material. The cover material should: 1) be relatively inert; 2) be deep enough for an adequate root zone for vegetation; 3) possess good soil-plant water and nutrient relations; 4) be resistant to erosion; and, 5) minimize capillary movement of water and contaminanats from the tailing into the cover material. In some instances, the cover material must also act as a barrier to movement of oxygen and water to and from the tailing.

Specific case studies of high elevation tailing reclamation are discussed; including relative difficulties, successes, and costs, along with data for 18 years of vegetation monitoring at the reclaimed Urad Mine tailing ponds. The data indicate that production and diversity on the Urad tailing ponds has always exceeded that of the control and that vegetation cover on the ponds initially exceeded that of the control, but is now below that of the control.

Additional Key Words: Revegetation; cover; production; diversity; heavy metals; reclamation costs

Introduction

Some general distinctions will be helpful before describing various tailing reclamation projects.

High Elevation or High Latitude

Not many examples of truly high elevation tailing ponds exist, and only a few of those have been reclaimed. For purposes of this paper, high elevation will be defined as above approximately 2,450 meters (8,000 feet). Distinctions vary with latitude because high latitude sites exhibit somewhat similar climatic conditions at lower elevations. An equivalent north latitude to a 2,750 meter (9,000 foot) elevation in Colorado would be a low elevation site north of the 60th parallel, i.e., the Yukon or Northwest Territories in Canada, and most of Alaska.

High elevation or high latitude sites are not necessarily more difficult to reclaim than other sites that have severe climates. Harsh winters and shorter, colder growing seasons at high altitude or latitude sites are not necessarily more limiting than conditions of a desert environment, they are simply different. Different species are required, planting times are different, mulches may be more important in the desert, and erosion control measures may differ. The major problems in revegetating tailing are chemical and physical limitations, and these problems are universal irrespective of climate.

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Closure, Remediation, Reclamation, and Revegetation

Some distinctions in terminology and differences among the terms closure, remediation, reclamation, and revegetation should be considered. The terms are primarily hierarchical. Closure of a site are all activities and plans that resolve the environmental and safety issues of a site. Closure includes reclamation and revegetation, and such things as the collection and treatment of acid mine water. It will dictate the long term activities at the site such as monitoring, maintenance, and security. The term closure is usually associated with the closing of an active site. Remediation is a term generally used in association with Superfund clean-up activities at a site that has not been active in recent years. These sites must be studied to determine how they can best be remediated, and Superfund triggers extensive studies as well as additional involvement of lawyers to comply with very complex legal and governmental requirements.

Reclamation and revegetation are often used synonymously, when in fact they are different. Reclamation is a major part of closure and remediation, and revegetation is a part of reclamation. Reclamation includes site modifications, revegetation, and the establishment of functional ecosystems. Revegetation is simply the successful establishment of a permanent, self-sustaining stand of vegetation.

Definition of Reclamation. When reclamation includes revegetation of a disturbed site to a natural system, it is defined as the activity that artificially initiates and accelerates the natural continuous trend toward ecological recovery (Brown, 1982).

Mother nature will reclaim all disturbed sites, in time, without man's intervention. Some sites will recover faster than others, but all sites will recover. Man's intervention in the form of reclamation simply speeds up the process of recovery. In most cases, the site will not return to the exact ecological composition it was before disturbance because slopes, aspects, and soils will have been changed. The area will, however, recover and function in a manner somewhat similar to that prior to the disturbance.

The natural continuous trend toward ecological recovery is initiated and accelerated by stabilizing the physical and biological aspects of the disturbed land. Regrading, growth medium amendment, and revegetation are the basic reclamation activities that serve to stabilize the physical, chemical, and biological aspects of the ecosystem.

Problems in Reclaiming Tailing

Tailing, if present, is the most difficult component of mine reclamation. The major problems to be overcome in reclaiming tailing are erodability and potential toxicities, including acid producing potential.

Physical Characteristics. Physical characteristics of tailing often provide good soil-plant water relations, but that characteristic is frequently overshadowed by its high erodability. The texture of mill tailing typically is that of silt. A significant percentage of the material will pass a 200 mesh screen.

These fine, relatively uniformly sized materials are very susceptible to both wind and water erosion. Unless physically stabilized, the tailing will blow when dry and will gully with a very small concentration of runoff. Besides the obvious problems of particulate pollution, blowing tailing will drift down-wind into revegetated areas. The blowing tailing can injure or sheer down-wind vegetation. In addition, tailing does not provide a very stable matrix for roots of woody vegetation.

Chemical characteristics. Chemical characteristics such as acidity, alkalinity, salinity, and concentrations of heavy metals are common in tailing from metal mines. These chemical characteristics often result in sufficient toxicity to prohibit direct revegetation of tailing. Acid production is the most common problem. Oxidation of the sulfides produces acid, which in turn dissolves heavy metals from the tailing. These heavy metals may then be taken up by roots of terrestrial vegetation or carried into the watershed where they could cause chronic or acute poisoning of aquatic life.

Tailing Reclamation Projects

Partially or totally reclaimed high elevation tailing ponds that the authors have had involvement with include:

- Alma-American Mill, 3,500 m (11,500 ft), Alma, CO
- Climax Mine, 3,175 to 3,975 m (10,400 to 13,000 ft), Leadville, CO
- Urad Mine, 3,200 m (10,500 ft), Empire, CO
- Keystone Mine, 3,050 m (10,000 ft), Crested Butte, CO
- Henderson Mill, 3,000 m (9,500 ft), Kremmling, CO
- Idarado Mine, 2,750 to 3,200 m (9,000 to 10,500 ft), Telluride and Ouray, CO
- Black Eagle Mill, 2,500 m (8,200 ft), Idaho Springs, CO.

Some lower elevation tailing ponds, either partially or totally reclaimed, include:

- McLaren Mine, 2,150 m (7,000 ft), Cooke City, MT
- Sheldon Mine, 1,975 m (6,500 ft), Prescott, AZ
- Annie Creek Tailing 1,975 m (6,500 ft), Lead, SD
- Nevada Gulch Mine, 1,825 m (6,000 ft), Lead, SD
- Inco Mine, 300 m (1,000 ft), Sudbury Ontario, Canada
- Contwoyto Lake Mine, 300 m (1,000 ft), NWT Canada
- Copper mines in Arizona, Utah, and Montana
- Iron mines in Minnesota.

Case Studies

The two basic approaches to reclaiming tailing ponds are: 1) revegetate the bare tailing, or 2) cover the tailing with overburden, waste rock, or soil and revegetate that material.

Revegetating Bare Tailing

Bare tailing has been successfully revegetated at Idarado, Nevada Gulch, Inco, various copper mines in Arizona, Utah, and Montana, and at iron mines in Minnesota.

Idarado Mine. The Idarado Mine, located near the towns of Ouray and Telluride, CO, has a number of tailing ponds, all of which are being reclaimed under a settlement agreement in a Superfund lawsuit initiated by the state of Colorado in 1982.

Revegetation research projects and successful bare tailing revegetation demonstrations have been ongoing at the mine for many years, each adding to the body of knowledge on revegetation of tailing. The final revegetation recipe that is being implemented is the application of lime as necessary (generally <10 tonnes per hectare [5 tons per acre]) to neutralize the pH of the tailing, about 225 tonnes per hectare (100 tons per acre) of limestone to maintain a neutral pH in the future, 90 tonnes per hectare (40 tons per acre) of manure (dry weight), 45 tonnes per hectare (20 tons per acre) of hay, and inorganic fertilizer at an approximate rate (N-P-K) of 56-284-90 Kg per hectare (50-253-80 lbs per acre). The tailing is effectively being transformed into a soil. Incorporation of these quantities of amendment into the top 25 cm (10 in) of tailing requires about seven passes with a large farm rototiller. A nurse crop is grown and incorporated, then the area is reseeded and mulched with two more tons of hay, the dam faces are netted, and the area is irrigated as necessary for germination and plant establishment. This is the most elaborate revegetation recipe in our experience.

The large quantities of organic matter effectively convert the tailing to a soil, and revegetation has been successful. The vegetation and litter effectively control both wind and water erosion on the tailing surface and dam faces.

The cost of the reclamation effort at the Idarado Mine could be determined in a number of ways. The highest estimate could be the total sum of the $ millions being spent by all entities on the law suits plus the $ millions being spent on the reclamation itself, divided by the number of acres being reclaimed. That number could eventually be in the range of $432,000 to $556,000 per hectare ($175,000 to $225,000 per acre).

Nevada Gulch. Wharf Resources' successfully reclaimed bare tailing in Nevada Gulch, near Lead South Dakota. The small 1.6 hectare (4 acre) tailing pond was a remnant left from gold mining during the early 1900's. The tailing was neither acidic nor toxic, and the primary concern was erosion control.

A water course adjacent to the pond was cleaned, reconstructed, and rip-rapped; all slopes were reduced; and, the bare tailing was revegetated. The only soil amendments used in the program were 4.5 tonnes per hectare (2 tons per acre) of hay mulch and some inorganic fertilizer. The project was completed in 1986, and the material has been successfully stabilized. The cost of reclamation was about $35,000 per hectare ($14,000 per acre).

Inco. The International Nickel Company in Sudbury, Ontario has reclaimed in excess of 1,010 hectares (2,500 acres) of tailing during the last 42 years, and continues to reclaim tailing with ongoing production at the mine. This is the premier example of bare tailing revegetation. The techniques for revegetating the Sudbury tailing have evolved through the years (Peters, 1984). In early years, limestone was applied every second year, or so, for some years to maintain a high enough pH to support vegetation. Acidification potential of the Inco tailing and the concomitant amount of limestone required to neutralize the tailing are within the realm of economic realism.

The sequence currently followed in revegetating the tailing at Inco is: surface preparation (contouring), discing, liming, seeding, fertilizing, tree planting, and a follow-up maintenance program (Heale, 1991). On the average, 25 tonnes per hectare (11 tons per acre) of finely ground agricultural limestone is mixed into the tailing surface prior to seeding. At the time of seeding, additional limestone (no specified quantity) is spread and disced into the surface. After seeding, vegetation growth and development is monitored and a follow-up application of approximately 11 tonnes per hectare (5 tons per acre) of limestone may be applied to the more difficult areas, as necessary. This approach eliminates the need for maintenance liming. It is estimated that Inco applies an average of 34 to 38 tonnes per hectare (15 to 17 tons per acre) of limestone to the tailing. The results have been astonishingly good. The vegetation is healthy, permanent, and self-sustaining. Trees are planted and have invaded, and species diversity is high.

Covering the Tailing

Another accepted tailing reclamation technique, especially when the physical and chemical characteristics of the tailing are detrimental to plant growth, is the placement of a cover material over the tailing and revegetation of that material. The cover material should: 1) be relatively inert; 2) be deep enough to act as an adequate root zone for vegetation; 3) possess good soil-plant water relations; 4) be resistant to erosion; and, 5) not facilitate capillary movement from the tailing surface into the cover material. In some instances the cover material must also act as a barrier to the movement of oxygen and water to and from the tailing.

Climax Mine. The Cyprus Amax Climax Mine dates from 1918. Since that time, more than 360 million tonnes (400 million tons) of molybdenum ore have been milled and tailing has been deposited in ponds covering nearly

810 hectares (2,000 acres). The mine is located near Leadville, Colorado, and the mine permit encompasses nearly 49 square kilometers (19 square miles). The elevation of the site ranges from 3,175 to 3,975 m (10,400 to 13,000 ft) and straddles the Continental Divide at the headwaters of three major watersheds.

The overall tailing reclamation plan at Climax is very similar to the Urad plan discussed later. In essence, the plan is to cover the tailing with waste rock and revegetate the rock with the aid of organic and inorganic amendments.

Much reclamation has been implemented at the Climax Mine in recent years. However, the mine is so large and spread out that much of the progress is either not very obvious or is out of view of the general public. In an effort to consolidate and modernize the ore processing facilities, a large number of the old buildings and conveyors have been dismantled and salvaged. Two of the five major tailing ponds have been covered with overburden and are in various stages of revegetation. One of the dams required extensive regrading and slope reduction for stabilization.

A complicating problem at Climax is that not only is the tailing an acid generator, but some of the waste rock also generates acid. Much of the waste rock cover has been treated with limestone or kiln dust. In addition, a large number of lessor disturbances throughout the mine site have been reclaimed.

An estimated average cost of reclaiming all disturbances at the mine is in the range of $25,000 to $37,000 per hectare ($10,000 to $15,000 per acre). Reclamation of the tailing is more expensive, however, than reclaiming most of the other types of disturbances.

Keystone Mine. The Keystone Mine is a relic silver-lead-zinc operation acquired by AMAX Inc. when the Mount Emmons Project was purchased in the late 1970's. The 22 hectare (54 acre) mine site is located near the town of Crested Butte, Colorado, at an elevation of about 3,035 m (9,000 ft). Four small but highly acidic and erosive tailing ponds existed at the site.

AMAX implemented state-of-the-art reclamation of the ponds in 1981, including the use of filter fabrics, installation of extensive water diversion facilities, construction of a $16 million water treatment plant, and the placement of an engineered, compacted, low-permeability cap over the tailing (AMAX Inc. 1981). Upon completion, the surface of the cap had all the characteristics of a pavement. The cap was successfully revegetated by simply ripping the surface 8 to 15 cm (3 to 6 in) with a crawler tractor and revegetating the material with the aid of hydromulch, sawdust, manure, limestone, and hay mulch.

A gross comparison of closure, reclamation and revegetation costs for this project is possible. Revegetation cost was approximately $3,700 per hectare ($1,500 per acre); reclamation cost about $74,000 per hectare ($30,000 per acre) for the tailing ponds including drainage systems to the water treatment plant; and, closure of the Keystone Mine has cost about $2.5 million per hectare ($1 million per acre) to date. However, this cost continues to increase because of the continuing cost of treat the mine water.

Henderson Mine. Mining at Henderson was initiated in 1976. To date, the mine has processed approximately 105 million tonnes (115 million tons) of molybdenum ore. The mine, located on the eastern slope of the Continental Divide, is connected to the mill, located on the western slope, by a 15.5 kilometer (9.6 mile) railroad-haulage tunnel. The tailing is a weak acid generator. Because the mine is isolated from the mill, no waste rock is available within a reasonable distance to serve as a cover for the tailing. The most available cover material is soil in the area. Therefore, a sufficient quantity of soil is being stripped and stockpiled from within the tailing basin to cover the tailing to a depth of 30 cm (1.0 ft).

The tailing dam has been covered with soil and revegetated as the tailing pond has grown through the years. In addition, tailing revegetation plots were established in 1982 to test the validity of the reclamation plan. The plots have been monitored carefully for the past 12 years, including analysis of the soil at different depths.

All indications are that 30 cm of soil over the tailing will be sufficient to successfully revegetate the tailing (Trlica, Brown, Jackson, and Jones 1994).

The tailing deposition area is presently about 405 hectares (1,000 acres) in extent and the estimated cost of reclaiming the tailing is presently about $10,000 per hectare ($4,000 per acre).

Sheldon Mine. The Sheldon Mine is located near Prescott, Arizona, in an historic (1863-1940) gold and silver mining area similar to many other mine camps in the West. A small (1.6 hectare, 4 acre) tailing pond was the source of significant sediment to a reservoir and the objective of the reclamation project was to eliminate the sediment source.

In this instance, the tailing was highly acidic. Reclamation consisted of the installation of interceptor channels, applying 74 tonnes per hectare (33 tons per acre) of limestone to the tailing, and covering the tailing with about 15 cm (6 inches) of topsoil.

Much was learned from this relatively early (1970's) project. Recommendations after the completion of the project included the application of significantly more lime or limestone, incorporation of the lime material into the surface of the tailing, and a greater depth of soil cover. Thames (1984) summarized the results of the project by stating: "Two follow-up treatments of lime were required after the initial work and maintenance of peripheral drainage channels has been necessary. Despite the excellent appearance of the site after treatment, it is anticipated that annual maintenance of this type will be necessary for several years before the site can be declared successfully reclaimed."

Contributions and volunteer help kept the costs of reclaiming this tailing to about $5,000 per hectare ($2,000 per acre).

Black Eagle Mill. The Black Eagle Mill tailing were one of about twenty sites deemed to be contributing sediment to the watershed in the Clear Creek/Central City Superfund Site (which essentially entailed the entirety of Clear Creek and Gilpin Counties, CO). Ms. Fabyan Watrous inherited the Black Eagle site (and the concomitant liability), and voluntarily cooperated to prepare all the required engineering and reclamation plans and legal documents associated with Superfund, and to implement and pay for the remediation. The tailing was regraded to 3:1 slopes, the base of the tailing was rip-rapped to protect the stream against a 100 year flood, runoff interceptors were installed, the tailing was covered with 51 cm (20 inches) of imported overburden material and 10 cm (4 inches) of imported soil, and the site was revegetated.

The total cost (including attorneys, etc.) of remediation for the approximately 1.4 hectare (3.4 acre) site was about $220,000 to $250,000 per hectare ($90,000 to $100,000 per acre). Ongoing monitoring and maintenance will be required for years, as is the case with all Superfund sites, but costs should not be excessive for this site because remediation was done correctly.

Contwoyto Lake. The Echo Bay, Inc. Contwoyto Lake project is a relatively large modern gold mine located just south of the Arctic Circle in the Northwest Territories of Canada. The elevation at the site is low, but the latitude is high. The authors know very little about the project, but the reclamation plan is worth mentioning because of it's uniqueness.

The original reclamation plan was to deposit the tailing in a natural depression, allow it to freeze, cover the tailing with overburden, and revegetate the overburden. The tailing, which was potentially toxic, would become a part of the permafrost, forever frozen in place. The plan was implemented, but problems were encountered in permafrost integrity, and a more conventional disposal system had to be designed and constructed.

Annie Creek Tailing. Wharf Resources, as with many modern mines, inherited another small relic tailing pond near Lead, South Dakota referred to as the Annie Creek Tailing. The pond contained about 109,000 tonnes (120,000 tons) of tailing and occupied less than 0.5 hectare (1 acre). The area is high is arsenic and some of the tailing had eroded down the drainage since being placed there between 1903 and 1916. Wharf had voluntarily isolated this tailing from the environment from 1987 to 1990 by stabilizing it with a rock buttress, isolating subsurface drainage from the material with a French drain, and by covering the tailing with a low permeability cap. In the meantime, the site was brought into the Superfund process and in 1991 was proposed for the National Priorities List (i.e., the list of the approximately 1,300 most contaminated sites in the USA).

The Superfund process is unrelenting. Once a site is brought into the process, there is essentially no way out even if the threat to human health and the environment is negligible. Richard Long (1994) of the EPA stated "once scored and proposed for the Superfund national priority list, EPA is obligated to characterize the site, assess the risk, and implement controls necessary to mitigate the risks." At the onset, the Annie Creek tailing appeared to pose negligible threat to human health and the environment and the EPA and Wharf worked very hard to minimize bureaucratic and legal entanglements. The effort to minimize the bureaucracy was very successful, but extensive biological studies were still required.

Now, nearly four years later, the studies have been completed, the threat to human health and the environment was deemed to be negligible, and the remediation plan has been implemented. The final remediation required at the site consisted of capping one part of the tailing, about 0.2 hectares (0.5 acres), that had eroded down the watershed. The studies cost an estimated $ 2 million, but the final remediation cost was estimated at only $35,000. Ten million dollars per hectare ($ 4 million per acre) makes this the most expensive of our reclamation examples. Without the joint agency-company effort, to minimize the bureaucratic and legal entanglements, the costs to Wharf could easily have been twice this amount. But, the final remediation probably would have been the same. Long (1994) stated "Although Wharf Resources incurred substantial costs, it is a fraction of what would have been spent under the normal circumstances (and in one third of the time)."

Urad Reclamation Project

The Urad Reclamation Project has been singled out for a much more thorough discussion because it was the first large scale and comprehensive reclamation project of its kind. Also, both authors have been intimately involved with the project from inception in 1974 to present. In addition, vegetation and soils have been monitored fairly extensively through the years.

History

Molybdenum became a high priority metal with the U.S. Government during World War I. The molybdenum orebody within Red Mountain, about 80 kilometers (50 miles) west of Denver, Colorado near the Continental Divide, was first developed and mined from 1914 to 1919 by the Primos Exploration Co. Later, the Urad Mine was worked intermittently by the Molybdenum Corporation of America during World War II. Climax Molybdenum Company (then a Division of AMAX Inc.) purchased the property in 1963 and put the mine back into production in 1967. The orebody was depleted and the mine closed in 1974 after processing about 12.7 million tonnes (14 million tons) of ore and producing 22 million Kg (48 million lbs) of molybdenum. The ore grade and processing efficiency resulted in the recovery of about 1.8 Kg per tonne (3.5 lbs per ton) of molybdenum.

Tailing produced in the milling process during World War I was deposited directly into Woods Creek. Most of the tailing was contained in a pond during the World War II period of production. There was no reclamation law in effect when Climax reopened the mine in 1967. Still, the company made a commitment to the local community to stabilize, revegetate, and reclaim disturbed areas at the end of mining.

Two tailing ponds, (totaling about 50 hectares or 125 acres) posed the most difficult reclamation problem when mining was completed in 1974 (Brown 1974). This was the first full-scale program to stabilize and reclaim tailing at a high elevation. Little was known about reclaiming sterile tailing at a 3,175 m (10,400 ft) elevation and with a frost free growing season of only about 20 days per year. There were no examples to follow, so the entire reclamation program was experimental.

Reuse of Waste Products

Three major waste products were used to reclaim the tailing:

- Development waste rock from the new Henderson Mine;
- Sewage sludge from the Denver metropolitan area; and,
- Wood chips from a sawmill in Fraser, Colorado.

The source of the Henderson Mine waste rock was 1,200 to 1,525 m (4,000 to 5,000 ft) underground where it was being excavated to develop access to the Henderson ore body. The granitic rock was a sterile growth medium that would require addition of organic matter and nutrients to create a plant growth medium. The Urad reclamation project utilized 1.4 million tonnes (1.5 million tons) of waste rock, 3,800 tonnes (4,200 tons) of sewage sludge (dry weight), and 18,350 cubic meters (24,000 cubic yards) of wood chips to provide a surface material suitable for plant growth.

Adding these amendments resulted in an increase in organic matter, nitrogen, and phosphorus, all essential for plant growth and development. The effort was quite successful, and the project resulted in Climax Molybdenum Company receiving the 1981 National Environmental Industry Award from the Presidents' Council on Environmental Quality.

Bare Tailing or Waste Rock

This first and most important decision in the reclamation plan was whether to attempt revegetation of the bare tailing or to cover the tailing with rock and revegetate the rock. Both rock and tailing were initially sterile, but rock offered several advantages over tailing as a plant growth medium. Waste rock provided a capillary barrier to potential migration of acids or salts from the tailing. The rock eliminated wind and water erosion, thus stabilizing the tailing and eliminating drifting and sand sheer of vegetation by tailing. Rock also provided a rooting zone for tap roots of trees and shrubs. Darker colored waste rock absorbed more heat and maintained higher surface temperatures than the white colored tailing. The rock material also acted as a mulch reducing water loss from the surface.

The rock was available from the Henderson Mine, and stabilizing the Urad tailing with rock was deemed the best approach. In addition to the above characteristics, using waste rock for tailing reclamation provided the added benefit of eliminating the rock as a reclamation liability at the Henderson Mine site.

Wood chips mixed into the surface provided additional mulch, organic matter, and storage for some of the excess nitrogen from the sewage sludge for future plant use. The added sewage sludge provided the necessary nutrients and more organic matter to form the complete waste growth medium. Because of the high C:N ratio of this organic matter, additional ammonium nitrate fertilizer was projected to be necessary for some years, but has been applied only twice in the 19 years since inception of the project.

Monitoring Objectives

The waste rock growth medium, heavy metal uptake by the plants, and vegetation characteristics on the tailing ponds at the Urad Mine have all been monitored through the years. The objective in monitoring the waste rock was to determine to what extent chemical constituents of this plant growth medium had been modified as a result of additions of sewage sludge, wood chips, inorganic fertilizers, and vegetation; to follow waste material development into a soil; and to observe trends that might cause the revegetation effort to fail in the long term. The objective in monitoring heavy metal uptake by the plants was early detection of potential vegetation and animal toxicities. The objective in monitoring vegetation characteristics was to quantify the development of the plant community, as related to soil development and metal uptake, and included quantifying the rate of plant invasion from the surrounding area.

Waste rock used in reclamation of the Urad tailing was expected to be high in molybdenum (Mo) and some other metals, as some of this waste material came from the orebody itself. High concentrations of Mo in plants can cause molybdenosis in ruminants and may cause molybdenum toxicity in plants (Dye and O'Harra 1959). Forage with molybdenum levels as low as 5 ppm have been reported to cause molybdenosis in cattle. Generally, forage containing concentrations greater than 10 ppm Mo are considered toxic to cattle. Availability of Mo to plants is highly correlated with soil pH. Under the slightly basic conditions of the plant growth medium covering the Urad tailing reclamation areas, molybdenum solubility and uptake by plants could be appreciable. Since deer and elk sometimes utilize forage on the tailing reclamation areas, molybdenosis or other toxic chemical constituents could potentially become a problem to these ruminants. For these reasons, a study was initiated to determine if certain toxic compounds, elements, and heavy metals were being concentrated in vegetation established on the waste rock growth medium covering the Urad tailing. It was also possible to determine whether older plants with deeper root systems were concentrating more toxic constituents than were younger plants.

AMAX Inc. had a significant amount of high elevation reclamation to conduct in the future and it was important for the Company to know whether seeded species at Urad were increasing, decreasing, or simply maintaining themselves in stands. It is probable that introduced species will eventually be replaced with invading or planted native species on reclaimed areas. Therefore, species composition, cover, diversity, and production on various reclaimed areas as related to length of time since seeding were studied. This information was compared with data from a nearby native community to establish successional trends within the stands.

Soil trends and heavy metal uptake by vegetation are reported elsewhere (Trlica and Brown 1992). We will concentrate on characteristics of the plant community through time in this paper.

Methods and Procedures

The two tailing ponds were covered with the waste mine rock from 1974 through 1978. The rock was spread 0.9 m (3 ft) deep on the surface and 1.5 to 6.1 m (5 to 20 ft) on the dam faces. Some small hills were created from the rock to break the flat contour of the surface for purposes of aesthetics, provide wind breaks for vegetation, and for avalanche protection for the road. Eighteen tonnes per hectare (20 tons per acre) of wood chips (dry weight) and 67 tonnes per hectare (30 tons per acre) of sewage sludge (dry weight) were then applied and mixed (by ripping) into the rock surface with a crawler tractor. Dead timber was also spread onto the surface for additional wind protection. Reclamation efforts followed the preparation of the plant growth medium with successive areas being seeded from 1975 through 1979.

The tailing areas were seeded with a mixture of grass and forb species at a density of 56 Kg per hectare (50 lbs per acre). The seed mixture included smooth bromegrass *(Bromus inermis)*, timothy *(Phleum pratense)*, meadow foxtail *(Alopecurus pratensis)*, creeping foxtail *(Alopecurus arundinaceus)*, orchard grass *(Dactylis glomerata)*, red top *(Agrostis alba)*, red fescue *(Festuca rubra)*, hard fescue *(Festuca ovina)*, Kentucky bluegrass *(Poa pratensis)*, cicer milkvetch *(Astragalus cicer)*, white clover *(Trifolium repens)*, and an annual ryegrass *(Secale cereale)*. Only one of the species (hard fescue) was native to the area. Native species would have received greater emphasis, however commercial quantities of seed of other native high altitude species were unavailable in the late 1970's.

Seeded areas were irrigated during the first growing season to ensure good germination and plant establishment. The areas were hand planted with trees and shrubs the second year. Approximately 40,000 seedlings were planted through the years. Seedlings of Engelmann spruce *(Picea engelmannii)*, lodgepole pine *(Pinus contorta)*, bristlecone pine *(Pinus aristata)*, limber pine *(Pinus flexilis)*, subalpine fir *(Pseudotsuga menziesii)*, aspen *(Populus tremuloidies)*, and willows *(Salix spp.)*, all of which are native to the area, were planted on the tailing ponds. Survival of tree seedlings was poor the first season, primarily because high winter winds resulted in ice abrasion and desication of exposed foliage and buds in this open and harsh environment. If a seedling survived the first winter, it generally was established well enough to continue to survive. However, tree seedlings in this environment only maintain themselves for 15 to 20 years before putting on much height growth. Even then, growth rate is very slow.

Vegetation Sampling. Data collected for vegetation on reclaimed and control areas included species composition, frequency, cover, and production. Sampling was done using two different methodologies. A 0.1-m^2 rectangular quadrat (Daubenmire, 1959) was used to sample composition, cover, frequency and production. Individual species encountered within 50 quadrats in each of two replications per stand were recorded, cover and production estimated, and 10 percent of the quadrats were randomly chosen and clipped to determine actual production. This double sampling procedure (Pechanec and Pickford, 1937) for estimating production was employed to determine total community standing crop. The U.S. Forest Service paced transect technique (Range Analysis Handbook, 1979) was used as another measure of species composition and frequency of occurrence over larger areas of the stands. The 0.1-m^2 quadrats were used within 10x10-m plots on the reclaimed tailing ponds, whereas paced transects covered more total area of these stands.

Vegetation on segments of the Urad tailing ponds seeded in 1975, 1976, and 1977 were all sampled in 1979, 1985, and 1992. In addition to reclaimed tailing ponds, the vegetation on a south-facing road cut near the Henderson Mine office building that had been seeded in 1972 was sampled. A native community in a circa 1879 burned-over area above the Urad tailing ponds was also sampled as a control to compare vegetation of a native community with that on reclaimed sites.

Data Analysis. Data for the vegetation sampling were analyzed using standard analysis of variance and t-test techniques (Steel and Torrie, 1980). When significant differences ($p < 0.05$) were detected among variables or years of seeding, Newman-Keul's Range Test was used to separate these differences. Some data were not appropriate for statistical analyses (frequency and diversity), but were summarized and means calculated.

Results and Discussion

Aerial Cover. Aerial cover for grasses and forbs of each stand was sampled using a slight modification of the Daubenmire (1959) technique. Total cover on tailing ponds (Fig. 1) exceeded that of the control and roadcut areas in 1979 and 1985, but cover of the control area exceeded that of all reclaimed areas in 1992. This was probably caused by the increase in forb cover in 1992 in the control area, with little change occurring on reclaimed areas (Fig. 2).

The summer of 1992 was excellent for wild flowers in the Rocky Mountains because there was no extended period of drought. The control appears to have reacted more positively to the continuous moisture than did the reclaimed areas. Forbs were more prevalent on the control in both 1979 and 1985 than on any of the seeded stands (Fig. 2). In 1985, forb cover was less than 2 percent on all tailing reclaimed areas compared with more than 13 percent on the control area. Forb cover was greater on the control than on reclaimed areas during each sample year (Fig. 2). In addition, visual observation of the vegetation and analyses of the growth medium both indicated that vegetation on the ponds was suffering from nitrogen deficiency. The tailing ponds were fertilized with ammonium nitrate at 112 Kg per hectare (100 pounds per acre) of 33-0-0 during the summer of 1992. This was only the second time the ponds had been maintenance fertilized since inception.

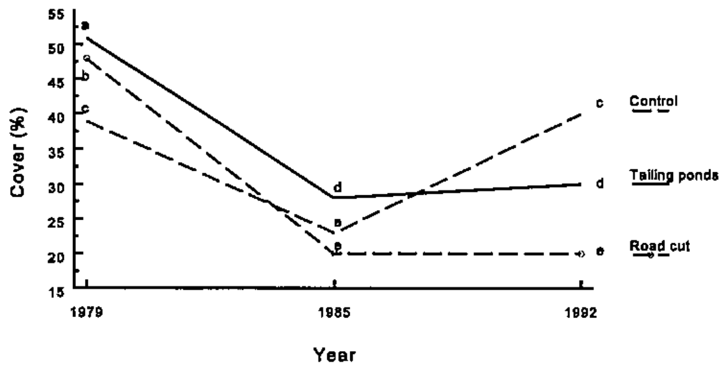

Figure 1. Average Vegetation Cover for Tailing Ponds, Road Cut, and Control Area.

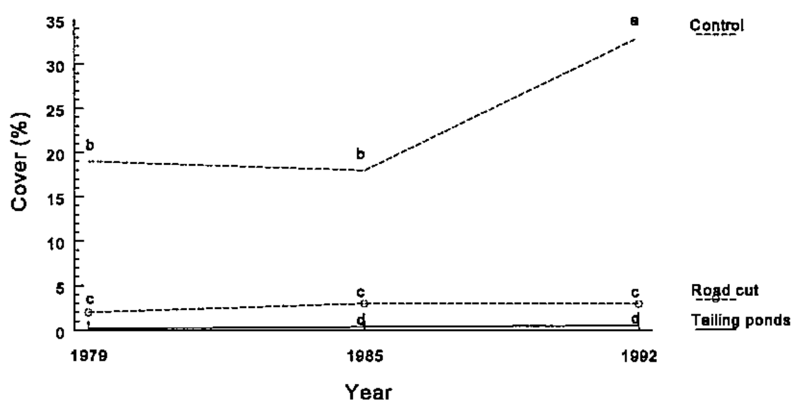

Figure 2. Average Forb cover for Tailing Ponds, Road Cut, and Control Area.

Hard fescue *(Festuca ovina)* was the only seeded species common to both seeded stands and the control. Of the various areas sampled, total cover of hard fescue on the tailing remained fairly constant between 1979 and 1985 and increased by 1992 (Fig. 3). Cover of this species declined between 1979 and 1985 on the roadcut, but then showed a small increase in 1992. Cover of fescue was low and constant through time in the control. The taller introduced grass, smooth bromegrass *(Bromus inermis)* declined through time on all reclaimed areas (Fig. 4). The greatest rate of decline was between 1979 and 1985.

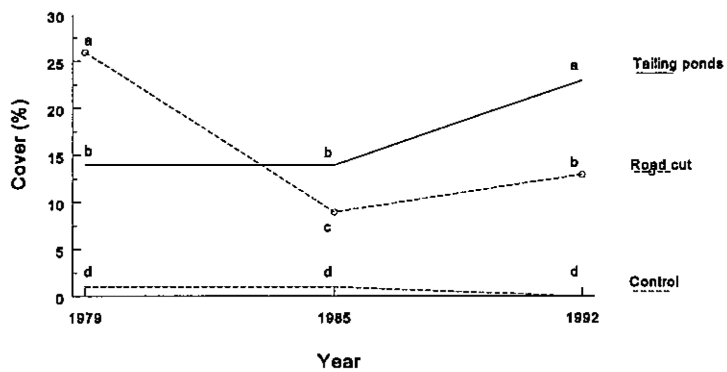

Figure 3. Average *Festuca ovina* Cover for Tailing Ponds, Road Cut, and Control Area.

Smooth bromegrass, hard fescue, and timothy *(Phleum pratense)* dominated the cover of the seeded areas in 1979 and 1985. There was always a concern that the tall introduced species would continue to dominate. Some hypothesized that the taller grasses would eventually shade out the shorter stature species, such as hard fescue. This could cause the shorter stature species to decrease in importance and, theoretically, might lead to a situation similar to that of intensively managed mesic meadows or irrigated pastures. Conversely, it might be hypothesized that withholding nitrogen fertilizer would allow for better expression of shorter stature species.

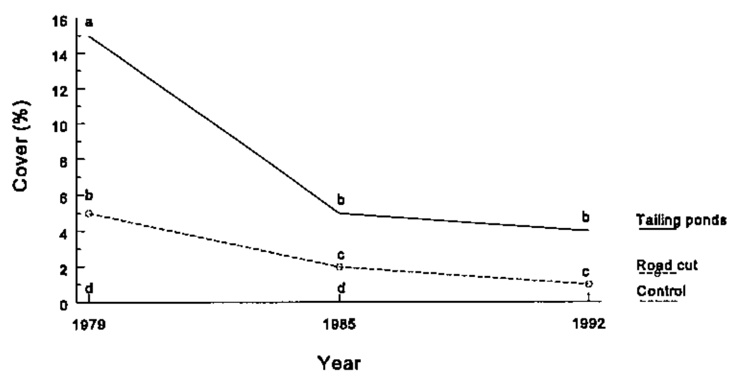

Figure 4. Average *Bromus inermis* Cover for Tailing Ponds, Road Cut, and Control Area.

The latter hypothesis appears to be correct. Hard fescue increased in cover between 1979 and 1992 on the seeded areas, probably because supplemental nitrogen was not applied between 1979 and 1992. By 1992, the tall introduced species had decreased leaving the tailing reclamation area dominated by the native hard fescue. However, this has resulted in reduced total cover on tailing ponds (Fig. 1).

Production. The seeded Urad tailing ponds and the road cut area have consistently produced significantly more aboveground biomass than the control (Fig. 5). Production on the reclaimed tailing ponds was much greater than for the control area in all three years of sampling. In general, there was an increase in production on the tailing reclamation area between 1979 and 1985 even though vegetation cover declined somewhat. Production on the tailing ponds and road cut area was similar to that of shortgrass prairie in 1985; whereas, production of the control area was more like that of a desert grassland or sagebrush-grassland type (Sims, Singh, and Lauenroth 1978).

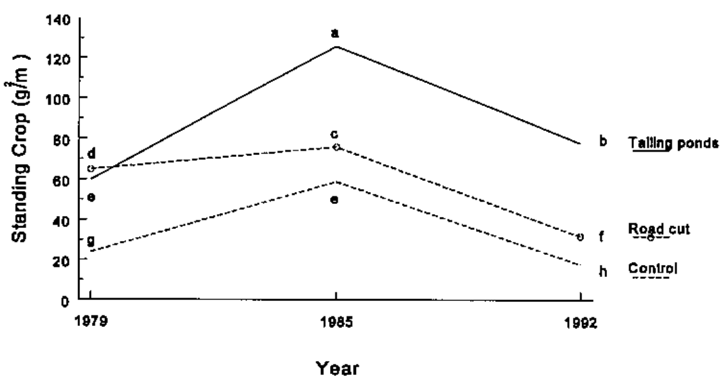

Figure 5. Average Standing Crop for Tailing Ponds, Road Cut, and Control Area.

Production at all three sites increased from 1979 to 1985 and decreased from 1985 to 1992. The reason for this trend was the decrease (die back) of the introduced species on reclaimed areas and differences in weather. The reason the introduced species decreased was that the relative nitrogen requirement of introduced species is greater than that for native species. Production of the native grass species has increasing with time, but that increase will never equal the high production initially exhibited by the introduced species.

Frequency of Occurrence. Using the U.S. Forest Service pace transect method (Range Analysis Handbook, 1979), rock and litter were frequently encountered on the reclaimed tailings during the 1985 and 1992 sampling years. Bare soil and moss cover were not encountered on transects in these seeded stands in 1979. Moss was encountered on seeded areas by 1985 and increased through 1992. Litter encountered in 1979 was not as evident during the 1985 and 1992 samplings, as the wood chips were decomposing.

With an increase of occurrence of vascular plants and moss in 1985 on seeded areas, there was a corresponding decrease in the occurrence of rock on the surface. The amount of erosion pavement and bare soil did not vary greatly between 1979 and 1985. The pattern of frequency of occurrence of plants on seeded areas compared much more favorably with that of the 1879 burned area (control) by 1985, indicating that seeded areas had definitely improved between 1979 and 1985. Frequency of occurrence of plants decreased somewhat from 1985 to 1992 on all sites (Fig. 6).

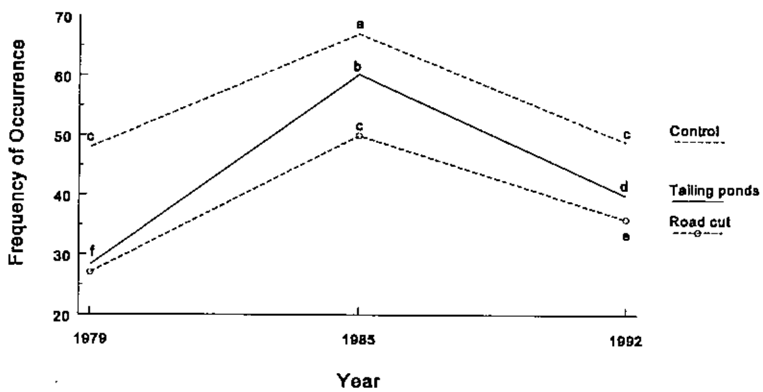

Figure 6. Average Frequency of Occurrence for Plants on Tailing Ponds, Road Cut, and Control Area.

Diversity. Species diversity was estimated by recording invading species occurrence along transects through the study areas. Species that were planted at each particular site were not included in diversity determinations. When the planted species were excluded from the analysis, the data indicated that the burn area (control) was the most diverse community. Twenty-six species occurred along transects through this community in 1979, and 30 species were recorded in 1985. The Urad tailing ponds seeded in 1975 had 19 invading species in 1979 and was thus slightly less diverse than the control, and frequency of occurrence of these species was low. Species diversity of other stands was low, but increased between 1979 and 1985. No invasion of stands seeded in 1977 was noted in 1979. By 1985, however, 15 species had invaded the 1977 seeded area. Some of these species might be considered by some to be weeds.

These data indicated that invasion was fairly rapid within five years of seeding and that improvement continued through 1985 and 1992. It will be interesting to determine whether the invading species increase in cover and production in the future, as their importance was still fairly low in 1992. If both invading and planted species are considered, then diversity of reclaimed areas has consistently exceeded that of the control in every year.

Costs. An approximate breakdown of the reclamation and revegetation costs as of the end the reclamation project in 1980 for the entire Urad Mine are:

Item	$ (millions)
o Rock Haul	$2.2
o Flood Control	$2.9
o Structure Salvage	($0.3)
o Revegetation	$0.5
o Taxes, mgmt, etc.	$0.9
Reclamation	$6.2
o Post 1980 costs (est)	$1.0
Closure to date	$7.2

The total acreage reclaimed was about 95 hectares (234 acres), plus about 24 kilometers (15 miles) of road. Therefore, the overall average reclamation cost was about $62,000 per hectare ($25,000 per acre). However, most of the money was expended on the 125 acres of tailing, providing a value in the range of $111,000 to $124,000 per hectare ($45,000 to $50,000 per acre) to reclaim the tailing. The average cost for revegetating the tailing was about $5,200 per hectare ($2,100 per acre) in mid-1970's dollars.

Closure costs have been ongoing since 1980. The property has required maintenance; the Urad portal was plugged; a water treatment plant has recently been constructed; and, water treatment will continue indefinitely. Therefore, the closure costs of the mine are greater than the reclamation costs, and continuously increasing.

Summary and Conclusions

Generalizations

Bare tailing can be reclaimed, or tailing can be covered and the cover material revegetated. Reclamation of tailing ponds at high elevations is usually much more difficult than reclaiming similar ponds at lower elevations, mainly because of restriction presented by the severe climate and short growing season. There are, however, some advantages to working in cold climates. Equipment access onto unstable or wet pond surfaces is often a problem. The tailing freezes during winter months in cold climates. This allows heavy equipment to work the surface with little or no problem. Another advantage of revegetating tailing at the very high elevations is that weed control usually is not necessary because most 'weeds' are not adapted to this environment.

Introduced species may have difficulty maintaining vigor over long time periods at high elevations because they may require more nitrogen than is commonly available in cold climates with thin and rocky soils and slow mineralization rates. Therefore, the use of native species appears to be more important at high elevations than at low elevations. More high elevation native species should be included in seed mixes today because high elevation natives are now commercially available. Tree seedling survival is low and the survivors can take as long as 15 to 20 years to initiate 'significant' growth.

The costs of tailing reclamation (including closure, etc.) can vary by a factor of about 2,000; from as low as $2,000 per acre to as high of $4,000,000 per acre. Superfund status adds another dimension to the costs. It is safe to say that none of the mines with extraordinarily high reclamation costs ever made that amount in net profit.

Urad Summary and Conclusions

Reclamation of waste rock material over Urad tailing, where sewage sludge and wood chips were used to construct a growth medium, has been effective. Wind and water erosion of tailing has been essentially eliminated. Seeded grasses are well established and produce more forage than in a nearby burned-over spruce-fir community. Cover of vegetation on reclaimed tailing often equaled or exceeded that of the native plant community.

Vegetation on the tailing ponds and road cuts is more diverse than naturally occurring communities, if the planted species are included in the analysis. Reclaimed areas have matured from domination by introduced species to domination by a native species. Forbs continue to occur infrequently, but are increasing. Species diversity has increased with time since the areas were seeded in 1974-1979. Invasion of the seeded stands by native species is occurring and diversity may be expected to continue to increase with time. However, diversity of the nearby undisturbed area in this habitat is not high. Fertilization with inorganic nitrate fertilizer should be used sparingly to prevent the tall introduced grasses from regaining dominance and competing with native invading species. For a more thorough discussion of Urad reclamation data, please refer to the paper by Trlica and Brown (1992).

Acknowledgments

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