DIRECT REVEGETATION OF ACIDIC MINE TAILINGS AT THE IDARADO MINE SITE IN SOUTHWEST COLORADO[1]

E. F. Redente[2]

Abstract: The Idarado Mining Company (Idarado) mined gold, silver, copper, lead and zinc in the Red Mountain and Telluride mining districts in southwest Colorado between the 1940s and 1978. In 1983, the State of Colorado filed a natural resource damage claim against Idarado to address historic environmental impacts linked to past mining and milling activities. After prolonged negotiation and litigation, Idarado and the State of Colorado agreed on a comprehensive plan to improve water quality in local streams and reclaim historic mining sites. Six tailing storage facilities that were constructed during 65 years of ore processing were reclaimed between 1993 and 1995. The elevation of the tailing facilities range from 2,709 to 3,208 m. A direct reclamation approach was implemented by using the tailings as the primary plant growth media and amending the upper 45 cm of the tailings with lime, limestone, manure, and straw. Plant cover was monitored annually for the past 12 years (1997-2008), along with metal uptake by the dominant plant species. Plant cover was determined using permanent and random point-line transects on both the top surface and side slopes of each tailing facility. The four most dominant grasses and two most dominant forbs on each tailing facility were collected for metal analysis, using both washed and unwashed samples. The State of Colorado established specific standards associated with plant cover and species diversity that will be applied after 15 growing seasons to determine reclamation success. Plant cover and species diversity exceed the State standards in all years where precipitation is average or above average, based on long-term climate records. However, in years where precipitation is below average, plant cover falls below expectations. Plant metal concentrations (i.e. Cd, Cr, Cu, Pb, and Zn) are consistently below levels considered to be phytotoxic, regardless of the year and species tested.

Additional Key Words: organic amendment, liming, high elevation, heavy metals.

---

[1]Paper was presented at the 2009 National Meeting of the American Society of Mining and Reclamation, Billings, MT ***Revitalizing the Environment: Proven Solutions and Innovative Approaches*** May 30—June 5, 2009. R.I. Barnhisel (Ed.) Published by ASMR, 3134 Montavesta Rd., Lexington, KY 40502.

[2]Edward F. Redente is Vice President and Principal Ecologist, MWH Americas, Inc., 3665 JFK Parkway, Suite 206, Fort Collins, CO 80525

Proceedings America Society of Mining and Reclamation, 2009 pp 1087-1106

DOI: 10.21000/JASMR09011087

Introduction

Mining in the Red Mountain and Telluride mining districts in southwest Colorado began in the mid 1800s and left behind a vast array of facilities and structures including old town sites, railroads, bridges, power plants, mining and milling structures, and mine rock and tailing piles. In the wake of more than 100 years of mining, there was a legacy of mine and mill features scattered along the Telluride and Red Mountain landscapes requiring reclamation, remediation or source-control measures.

The Idarado Mining Company (Idarado) was founded in 1939 and consolidated a number of other active mines in the Red Mountain and Telluride mining districts of the San Juan Mountains, concluding in 1953 with the acquisition of Telluride Mines (Hardy et al., 1999). Idarado produced Au, Ag, Cu, Pb and Zn. During the 1940s, the Idarado Mine provided base metals to support the Allies efforts during World War II. In 1978, the last ore was mined from the underground workings and milling operations ceased.

In 1983, the State of Colorado filed a natural resource damage claim against Idarado to address the historic environmental impacts in the two mining districts. After intense and prolonged negotiations and litigation, Idarado and the State of Colorado agreed on a comprehensive plan to improve the water quality in the regions streams and rivers and reclaim historic mining sties, which have been accomplished. The entire effort was a successful collaboration between a number of stakeholders, including the local communities of Telluride and Ouray, local town and county governments, the State of Colorado and Idarado. The plan successfully achieved a balance between historic preservation and environmental protection.

Between the Telluride and Red Mountain operations, six significant tailing storage facilities were constructed during the 65 years of ore processing at the Pandora and Red Mountain mills. Idarado recognized that development of a closure and land-use plan would require a collaborative effort to address the district mining community's historic character and minimize disruption to the tourist driven local economy. Traditional reclamation methods would employ extensive removal and/or cover-type activities that require substantial disruption of the local communities and additional land resource disturbance. Exportation of mine and mill-related waste materials would have involved thousands of truck trips through local communities, causing disruption and increased traffic. Importing cover materials would also result in disruption to the community unless the cover materials were mined locally. Idarado sought a better solution based upon evolving reclamation technology; converting the tailing materials into viable soil substrate that would support a self-sustaining plant community capable of resisting wind and water erosion.

This approach departed from traditional techniques and became the primary remedial choice based upon extensive input Idarado sought from this author, along with local community and government agencies. As a precursor to final reclamation, Idarado established field-scale testing of direct, in-situ revegetation in the mid 1980s (Redente and Baker, 1996). Based on the results of field-scale testing, a plan was designed and implemented for full-scale reclamation beginning in the mid 1990s. The Remedial Action Plan (RAP) that was developed between Idarado and the State of Colorado established revegetation success standards for live plant cover, total cover (i.e. live vegetation and litter), and species diversity (U.S. District Court, 1992). Revegetation success will be determined after 15 years of monitoring or as early as 2011 for some tailing facilities. Monitoring of revegetation success has continued on an annual basis and is the subject of this paper. The following presents a summary of plant cover and metal uptake data collected over a 12-year period to measure revegetation success of the direct revegetation program initiated by Idarado on tailing piles in the Telluride and Red Mountain mining districts.

Methods and Materials

Site Description

The Idarado mine is located between the towns of Telluride (population 1,950) and Ouray (population 750) in San Miguel and Ouray Counties. A mountain ridge separates the Telluride District from the Red Mountain District. The mine extends beneath this ridge, with the western portal located about 2 miles east of Telluride. In the Telluride District, there are historic buildings, inactive mines and 6 tailings ponds. The eastern portal of the mine in the Red Mountain District is located about 11 miles south of Ouray. This District consists of historic buildings, inactive mines and 4 tailings ponds along Red Mountain Creek.

Average annual precipitation is 58 cm in Telluride and 59 cm in Ouray. Since the Red Mountain tailing facilities are about 350 m higher in elevation than the town of Ouray, annual precipitation at the tailings facilities is most likely greater than the average reported for Ouray. The plant community types in the Telluride area are coniferous forest dominated by Douglas fir (*Pseudotsuga menziesii*) on hillsides surrounding the San Miguel Valley and meadows with scattered cottonwoods (*Populus* spp.) and aspen (*Populus tremuloides*). The plant community type in the Red Mountain area is coniferous forest dominated by Englemann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*).

The tailing piles in the Telluride District range in elevation from 2,709 m to 2,725 m. Telluride Tailing Piles 1 through 4 were amended and revegetated as separate piles, but because the four piles are physically adjoined to each other they have been monitored as one large tailing pile and referred to as TT 1-4. These four tailing piles cover a combined surface area of approximately 10 ha. Telluride Tailing Piles 5&6 (TT 5&6) were amended and revegetated as one large pile and have also been monitored as one tailing pile. TT 5&6 cover a combined surface area of approximately 30 ha. All of the Telluride Tailing Piles have both top and side slope segments that were amended and revegetated. Side slopes on TT 1-4 and TT 5&6 were graded to approximately 3h:1v.

The tailing piles in the Red Mountain District are situated in different locations that range in elevation from 2,972 m to 3,208 m. Red Mountain Tailing Pile 1 (RM 1) is approximately 0.2 ha in size, RM 2 is approximately 2.6 ha, RM 3 is approximately 1.2 ha, and RM 4 is approximately 10 ha. RM 1 through 3 have both top and side slope segments that were revegetated and monitored. However, the side slopes of RM 4 were covered with rock and therefore this tailing pile only has a top segment that was revegetated and monitored. The side slope segments on RM 1 through 3 were graded to 3h:1v or less.

Soil chemical analysis of the Telluride and Red Mountain tailings prior to amendment and revegetation showed that pH varied greatly from pile to pile and within a pile. pH ranged from approximately 2.0 to 7.0 in the upper 30 cm. Tailings were also assessed for total Cd, Cr, Cu, Pb, and (Zn). Mean concentrations across all tailing piles ranged from 10 to 80 mg/kg for Cd, 7 to 18 mg/kg for Cr, 65 to 750 mg/kg for Cu, 1,700 to 5,840 mg/kg of Pb, and 2,120 to 12,000 mg/kg for Zn.

Revegetation Methods

Telluride Tailing Pile 1. Telluride Tailing Pile 1 (TT 1) was revegetated in 1993. The revegetation process included the incorporation of: 1) limestone, at an application rate of 195 MT/ha; 2) manure at 90 dry MT/ha; 3) hay or straw, at 45 MT/ha; and 4) fertilizer, at 140 kg N/ha, 289 kg P/ha, and 92 kg K/ha. Limestone, manure and hay were mixed to a depth of 45 cm in June 1993 and fertilization was completed at the end of September. The tailing pile was then seeded in October with the seed mixture presented in Table 1. The site was mulched with straw immediately after seeding, at a rate of 4.5 MT/ha.

Table 1. Plant species mixture seeded on Telluride Tailing Piles 1-6.

Common Name	Scientific Name	Native (N) Introduced (I)	Seeding Rate kg PLS/ha
Grasses			
Slender wheatgrass	*Elymus trachycaulus*	N	5.6
Smooth brome	*Bromus inermis*	I	2.2
Mountain brome	*Bromus marginatus*	N	5.6
Orchardgrass	*Dactylis glomerata*	I	2.2
Common Timothy	*Phleum pretense*	I	3.4
Canada bluegrass	*Poa compressa*	N	1.1
Kentucky bluegrass	*Poa pratensis*	I	1.1
Creeping wildrye	*Leymus triticoides*	N	3.4
Hard fescue	*Festuca ovina duriuscula*	I	2.2
Forbs			
Cicer milkvetch	*Astragalus cicer*	I	3.4
Sainfoin	*Onobrychis viciaefolia*	I	3.4
Rocky Mountain penstemon	*Penstemon strictus*	N	2.2
Red clover	*Trifolium pretense*	I	3.4
Lewis flax	*Linum lewisii*	N	1.1
Alfalfa	*Medicago sativa*	I	3.4
Western yarrow	*Achillea millefolium*	N	2.2

Telluride Tailing Pile 2. Telluride Tailing Pile 2 (TT 2) was revegetated at approximately the same time as TT 1. The revegetation process included the incorporation of: 1) limestone, at an application rate of 244 MT/ha; 2) manure, at 90 dry MT/ha; 3) hay or straw, at 45 MT/ha; and 4) fertilizer, at 140 kg N/ha, 289 MT P/ha, and 92 MT K/ha. Limestone, manure and hay were mixed to a depth of 45 cm in July 1993 and fertilization was completed at the end of September. The tailing pile was then seeded in October 1993 with the seed mixture presented in Table 1. The site was mulched with straw immediately after seeding, at a rate of 4.5 MT/ha.

Telluride Tailing Pile 3. Telluride Tailing Pile 3 (TT 3) was revegetated at approximately the same time as TT 1 and TT 2. The revegetation process included the incorporation of: 1) limestone, at an application rate of 217 MT/ha; 2) manure, at 90 dry MT/ha; 3) hay or straw, at 45 MT/ha; and 4) fertilizer, at 140 kg N/ha, 289 kg P/ha, and 92 kg K/ha. Limestone, manure and hay were mixed to a depth of 45 cm in August 1993 and fertilization was completed at the end of September. The tailing pile was then seeded in October with the seed mixture presented in Table 1. The site was mulched with straw immediately after seeding, at a rate of 4.5 MT/ha.

Telluride Tailing Pile 4. Telluride Tailing Pile 4 (TT 4) was revegetated one year after TT 1-3. The revegetation process included the incorporation of: 1) limestone, at an application rate of 249 MT/ha; 2) manure, at 90 dry MT/ha; 3) hay or straw, at 45 MT/ha; and 4) fertilizer, at 57 kg N/ha, 274 kg P/ha, and 90 kg K/ha. Limestone, manure and hay were mixed to a depth of 45 cm in June 1994 and fertilization was completed in October. The tailing pile was then seeded in October 1994, with the seed mixture presented in Table 1. The site was mulched with straw immediately after seeding, at a rate of 4.5 MT/ha.

Telluride Tailing Piles 5&6. The revegetation of Telluride Tailing Piles 5&6 (TT 5&6) was begun in 1995 and completed in 1996. The revegetation process included the incorporation of: 1) lime, at an application rate of 3 MT/ha; 2) limestone, at a rate of 757 MT/ha; 3) manure, at 90 dry MT/ha; and 4) hay, at 45 MT/ha; and 4) fertilizer, at 57 kg N/ha, 274 kg P/ha, and 90 kg K/ha. Amendments were mixed to a depth of 45 cm. One portion of the tailing piles was seeded in the fall of 1995 and the remaining portion of the piles was seeded in the fall of 1996 using the seed mixture in Table 1. Seeding took place at difference times because of the size of the tailing piles and reclamation schedule which was dictated by weather. Seeding was followed with straw mulching at a rate of 4.5 MT/ha.

Red Mountain Tailing Pile 1. Red Mountain Tailing Pile 1 (RMT 1) was revegetated in 1993 and 1994. The revegetation process included the incorporation of: 1) lime, at an application rate of 4 MT/ha, 2) limestone, at a rate of 181 MT/ha; 2) manure, at 90 dry MT/ha; 3) hay or straw, at 45 MT/ha; and 4) fertilizer, at 56 kg N/ha, 277 kg P/ha, and 90 kg K/ha. Limestone, manure and hay were mixed to a depth of 45 cm in September 1993 and fertilization was completed at the end of September 1994. The tailing pile was then seeded in October 1994, with the seed mixture presented in Table 2. The site was mulched with straw immediately after seeding, at a rate of 4.5 MT/ha.

Table 2. Plant species mixture seeded on Red Mountain Tailing Piles 1-4.

Common Name	Scientific Name	Native (N) Introduced (I)	Seeding Rate kg PLS/ha
Grasses			
Slender wheatgrass	*Elymus trachycaulus*	N	5.6
Smooth brome	*Bromus inermis*	I	2.2
Mountain brome	*Bromus marginatus*	N	6.7
Orchardgrass	*Dactylis glomerata*	I	4.5
Common Timothy	*Phleum pretense*	I	4.5
Canada bluegrass	*Poa compressa*	N	1.1
Kentucky bluegrass	*Poa pratensis*	I	1.1
Creeping wildrye	*Leymus triticoides*	N	3.4
Forbs			
Cicer milkvetch	*Astragalus cicer*	I	4.5
Sainfoin	*Onobrychis viciaefolia*	I	5.6
Rocky Mountain penstemon	*Penstemon strictus*	N	4.5
Red clover	*Trifolium pretense*	I	4.5

Red Mountain Tailing Pile 2. Red Mountain Tailing Pile 2 (RMT 2) was revegetated in 1996. The revegetation process included the incorporation of: 1) lime, at an application rate of 12 MT/ha; 2) limestone, at a rate of 528 MT/ha; 3) manure, at 90 dry MT/ha; 4) hay, at 45 MT/ha; and 5) fertilizer, at 56 kg N/ha, 277 kg P/ha, and 90 kg K/ha. Amendments were mixed to a depth of 45 cm. The tailing pile was seeded in the fall of 1996 with the seed mixture presented in Table 2. The site was mulched with straw immediately after seeding, at a rate of 4.5 MT/ha.

Red Mountain Tailing Pile 3. Red Mountain Tailing Pile 3 (RMT 3) was revegetated in 1994. The revegetation process included the incorporation of: 1) lime, at application rates of 0.5 MT/ha; 2) limestone, at a rate of 672 MT/ha; 3) manure, at 90 dry MT/ha; 3) hay or straw, at 45 MT/ha; and 4) fertilizer, at 56 kg N/ha, 277 kg P/ha, and 89 kg K/ha. Limestone, manure and hay were mixed to a depth of 45 cm in August and September 1994 and fertilization was completed in October 1994. The tailing pile was then seeded in October 1994, with the seed mixture presented in Table 2. The site was mulched with straw immediately after seeding, at a rate of 4.5 MT/ha. The top segment of this tailing pile was reseeded in July 1995 because of poor plant growth in June and July. Poor plant growth was attributed to extended periods of standing water on the tailing pile in late spring of 1995 which resulted in high seed mortality.

Red Mountain Tailing Pile 4. Red Mountain Tailing Pile 4 (RMT 4) was revegetated in 1995. Prior to the application of amendments to the top surface of RMT 4, the pile was tilled, sampled, and analyzed for pH and acid generation potential. In order to accomplish this task, the top surface of RMT 4 was divided into a network of sampling grid cells that were approximately one acre in surface area to account for the high variability in acidity. The testing for pH indicated that 21 of the 29 grid cells would require the addition of lime. Lime was added to these 21 cells at a rate of 3.5 MT/ha. Similarly, based on tests for acid generation potential, limestone was added at a rate of 755 MT/ha to the 21 cells. In addition to lime and limestone, manure was spread over the surface of the tailing pile at a uniform rate of 90 dry MT/ha and tilled into the surface. Hay was also spread and incorporated at a uniform rate of 45 MT/ha. Inorganic fertilizer was applied to the top surface of RMT 4 at the following rates: 66 kg N/ha, 336 kg P/ha, and 106 kg K/ha. All amendments were applied between the period of September 14 and October 14, 1995 and incorporated to a depth of 45 cm. The tailing pile was then seeded in late October 1995, with the seed mixture in Table 2. The site was mulched with straw immediately after seeding, at a rate of 4.5 MT/ha.

Sampling Methods

In August of each year, plant cover was measured on Telluride Tailing Piles 1-6 and Red Mountain Tailing Piles 1-4. Live canopy cover was measured by the point method, using a vegetation sighting scope mounted on an adjustable tripod with a level. Cover was measured for each species encountered, as well as litter, rock, and bareground. Cover measurements were made along two permanent and four randomly placed transects that traversed the length of each pile on both top and slope segments. A total of 100 points were randomly sited along each transect to collect cover data in the categories of live vegetation, litter, rock, and bareground. An adequate number of cover points were observed to estimate the population mean at a 90 percent level of confidence following sample adequacy calculations described by Bonham (1989).

Plant tissue samples of leaves and stems were randomly collected for metal analyses at the time of cover sampling. Composite samples were collected from the most abundant grass and forb species (4 grasses and 2 forbs) growing on each tailing pile segment. Plant samples were split and one half of each sample was washed in deionized water to provide tissue metal concentrations for washed and unwashed samples to separate plant uptake from surface deposition that would occur from soil splash associated with rainfall events. All samples were analyzed for total concentrations of cadmium, chromium, Cu, Pb, and Zn at the Colorado State University Soil, Water and Plant Testing Lab using a nitric perchloric digestion and Inductively Couple Plasma-Atomic Emission Spectroscopy.

Revegetation Success Standards

Revegetation success on Telluride and Red Mountain Tailing Piles will be determined by applying certain criterion, stated in the RAP, for total cover, live cover, and species diversity. Final determinations of success will be based on vegetation data collected during the last two years of the evaluation period. Reclamation of the top surface of each pile will be judged successful if the following criteria are met: 1) total cover (i.e. live vegetation and litter) is equal to or greater than 80%; 2) live cover is equal to or greater than 60%; 3) no single species contributes more than 50% of the live cover; and 4) at least four perennial species each contribute a minimum of 3% of the live cover. The revegetation of the side slopes will be deemed successful if the following criteria are met: 1) total cover is equal to or greater than 70%; 2) live cover is equal to or greater than 60%; 3) no single species contributes more than 50% of the live cover; and 4) at least four perennial species each contributes a minimum of 3% of the live cover.

Results and Discussion

Cover on Telluride Tailing Piles 1-4

Percent canopy cover of live vegetation varied over the 12 years of monitoring between 35% and 86% on the top segment and between 35% and 82% on the slope segments of TT 1-4 (Fig. 1). Live cover fell below the success standard of 60% in three of the 12 years (2000, 2002 and 2003) on both the top and slope segments of these tailing piles. These three years represented below average precipitation for the site. In fact the years 2000 through 2005 represented below average precipitation years based on a 100 year average precipitation of 58 cm for Telluride. In general, live cover was similar or somewhat lower on slope segments compared to the top segment of these tailing piles. The only exception to this long-term trend was in the year 2002, when mean live cover on the slope segments was greater than on the top segment. Total cover (i.e. live vegetation and litter) on TT 1-4 met or exceeded the success criteria of 80% and 70% in each year of monitoring for both top and slope segments, respectively.

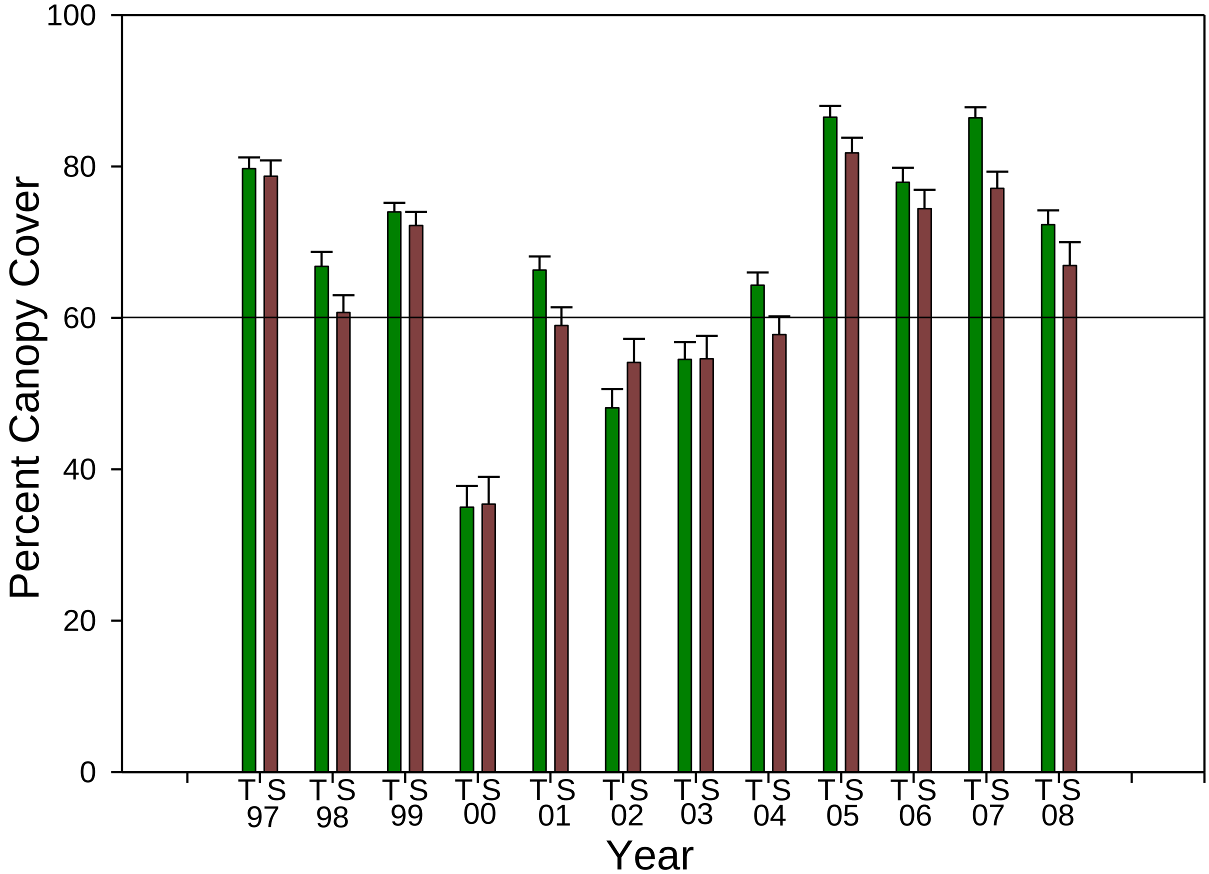

Figure 1. Percent canopy cover for the top (T) and side slopes (S) of Telluride Tailing Piles 1-4 (monitored as one tailing facility) for the years 1997 through 2008. Standard errors are shown at the top of each bar. The horizontal line at 60% canopy cover represents the criteria for live plant cover that must be met for revegetation success.

<u>Cover on Telluride Tailing Piles 5&6</u>

Percent canopy cover of live vegetation varied over the 12 years of monitoring between 45% and 92% on the top segment and between 44% and 84% on the slope segments of TT 5&6 (Fig. 2). Live cover fell below the success standard of 60% in 2000 and 2003 on the top segment and in 2000, 2002 and 2003 on the slope segments. In general, live cover was greater on the top segment compared to slope segments of these tailing piles. The only year in which live cover on the slope segments was greater than the top segment was in 2008. Total cover (i.e. live vegetation and litter) on TT 5&6 met or exceeded the success criteria of 80% and 70% in each year of monitoring for both top and slope segments, respectively.

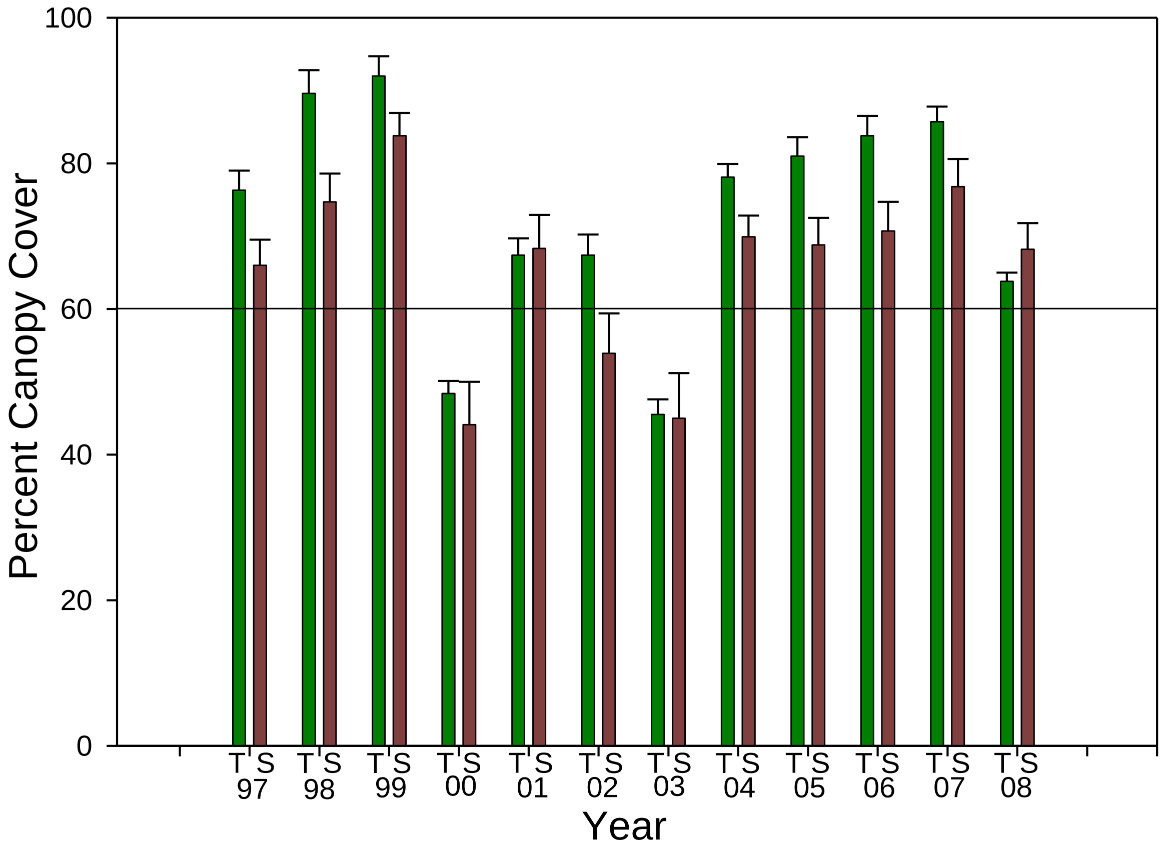

Figure 2. Percent canopy cover for the top (T) and side slopes (S) of Telluride Tailing Piles 5&6 (monitored as one tailing facility) for the years 1997 through 2008. Standard errors are shown at the top of each bar. The horizontal line at 60% canopy cover represents the criteria for live plant cover that must be met for revegetation success.

Cover on Red Mountain Tailing Pile 1

Percent canopy cover of live vegetation varied over the 12 years of monitoring between 64% and 93% on the top segment and between 40% and 90% on the slope segments of RM 1 (Fig. 3). Live cover fell below the success standard of 60% in two of the 12 years (1997 and 1998) on the slope segment of this tailing pile and exceeded the success standard on the top segment of the pile in all years. These two years represented the first two growing seasons and were unrelated to precipitation. In general, live cover was similar or somewhat lower on the slope segment compared to the top segment of this pile in all years except 2000 and 2003, when live cover on the slope segment was greater than on the top segment. Total cover (i.e. live vegetation and litter) on RM 1 met or exceeded the success criteria of 80% and 70% in each year of monitoring for both top and slope segments, respectively.

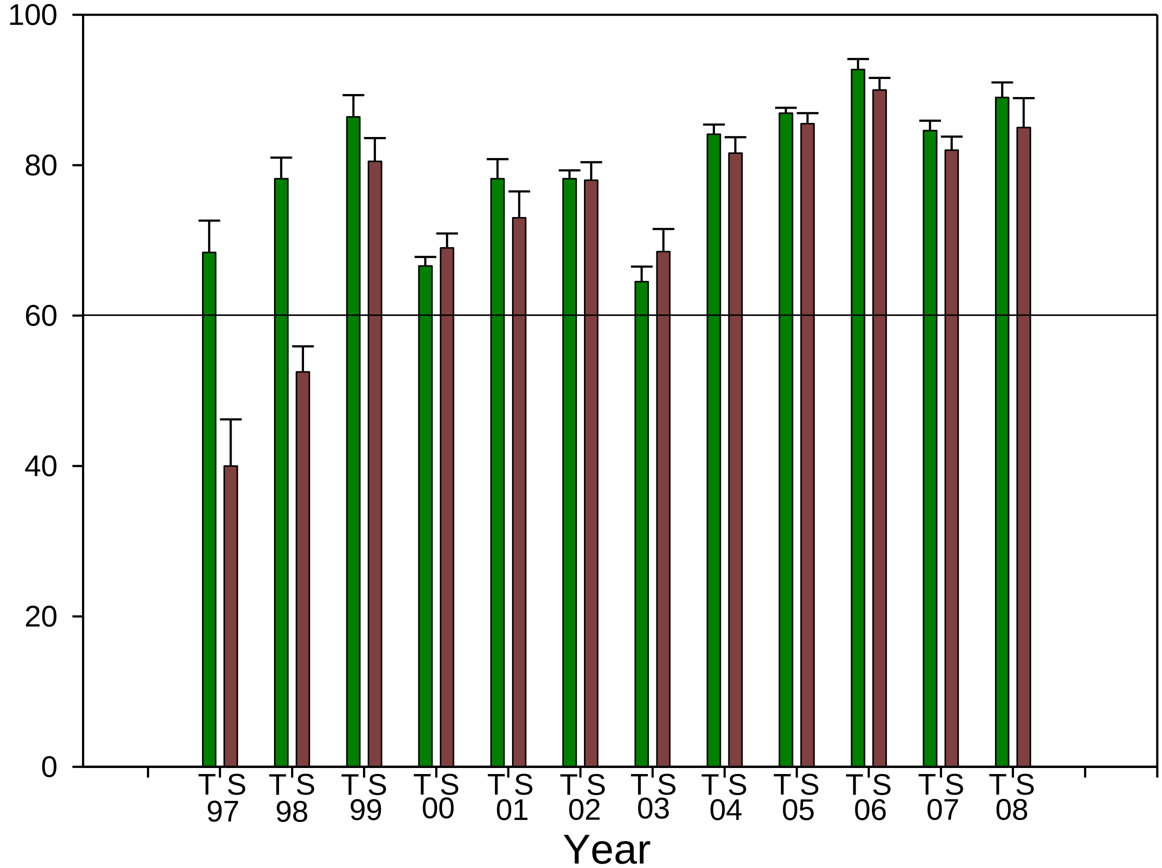

Figure 3. Percent canopy cover for the top (T) and side slope (S) of Red Mountain Tailing Pile 1 for the years 1997 through 2008. Standard errors are shown at the top of each bar. The horizontal line at 60% canopy cover represents the criteria for live plant cover that must be met for revegetation success.

Cover on Red Mountain Tailing Pile 2

Percent canopy cover of live vegetation varied over the 12 years of monitoring between 30% and 91% on the top segment and between 43% and 87% on the slope segments of RM 2 (Fig. 4). Live cover fell below the success standard of 60% in two of the 12 years (1997 and 2003) on both the top and slope segments of this tailing pile. 1997 was the first growing season and 2003 represented an average precipitation year for the Red Mountain District. However, precipitation during May through July of 2003 was nearly 60% below the long-term average for the site. In general, live cover was similar or lower on slope segments compared to the top segment of this tailing pile. The only exception to this long-term trend was in the first growing season (1997), when mean live cover on the slope segments was greater than on the top segment. Total cover (i.e. live vegetation and litter) on RM 2 met or exceeded the success criteria of 80% or 70% for both top and slope segments in all years except in 1997, when both top and slope segments fell below the success criteria for total cover.

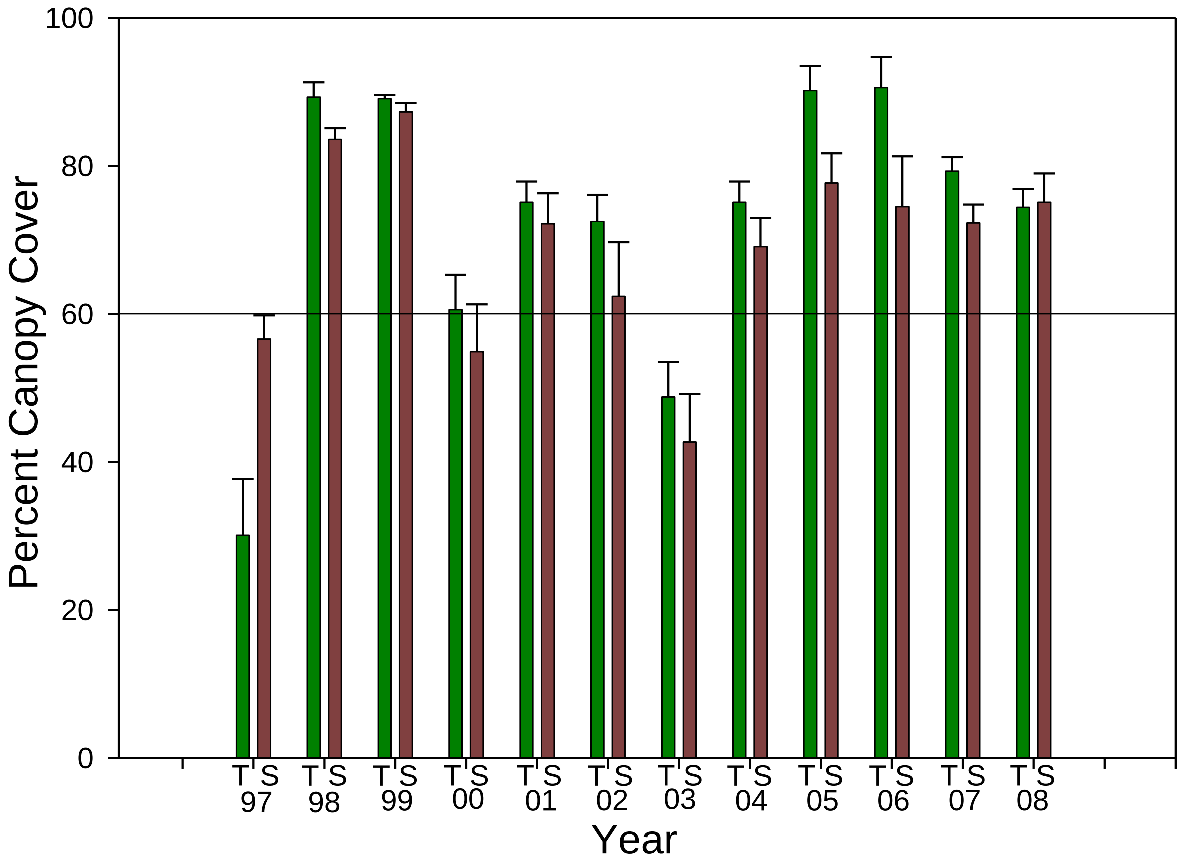

Figure 4. Percent canopy cover for the top (T) and side slopes (S) of Red Mountain Tailing Pile 2 for the years 1997 through 2008. Standard errors are shown at the top of each bar. The horizontal line at 60% canopy cover represents the criteria for live plant cover that must be met for revegetation success.

Cover on Red Mountain Tailing Pile 3

Percent canopy cover of live vegetation varied over the 12 years of monitoring between 44% and 90% on the top segment and between 32% and 75% on the slope segments of RM 3 (Fig. 5). Live cover fell below the success standard of 60% in four of the 12 years (2000, 2001, 2002 and 2003) on the slope segments of this tailing pile and in years 2000 and 2003 for the top segment. All of these years represented below average annual precipitation or below average precipitation during the growing season. In most years, live cover was lower on slope segments compared to the top segment of this tailing pile. Total cover (i.e. live vegetation and litter) on RM 3 met or exceeded the success criteria of 80% and 70% for both top and slope segments in all years, respectively.

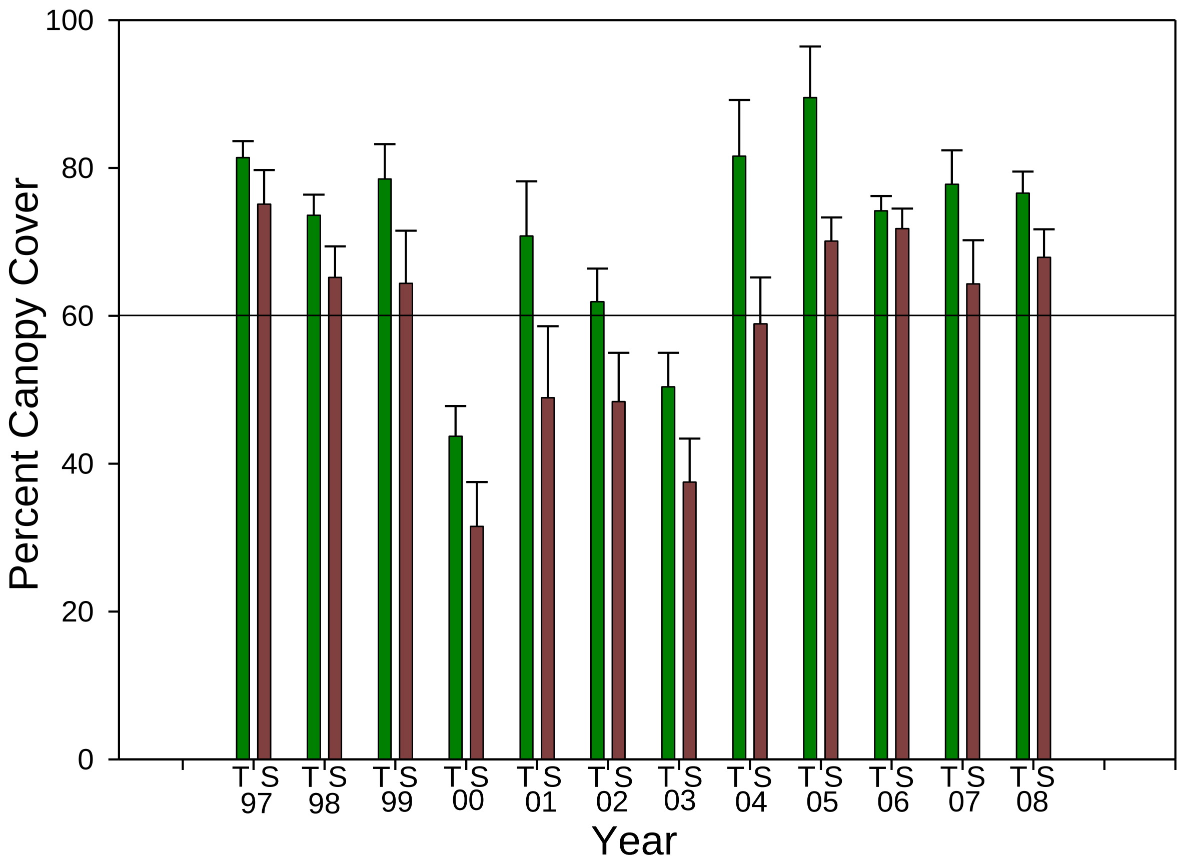

Figure 5. Percent canopy cover for the top (T) and side slopes (S) of Red Mountain Tailing Pile 3 for the years 1997 through 2008. Standard errors are shown at the top of each bar. The horizontal line at 60% canopy cover represents the criteria for live plant cover that must be met for revegetation success.

Cover on Red Mountain Tailing Pile 4

Percent canopy cover of live vegetation varied over the 12 years of monitoring between 45% and 85% on the top segment of RM 4 (Fig. 6). Since the side slopes were covered with rock, monitoring of RM 4 was limited to the top portion of the pile. Live cover fell below the success standard of 60% in four of the 12 years (2000, 2001, 2002 and 2003). All of these years represented below average annual precipitation or below average precipitation during the growing season. Total cover (i.e. live vegetation and litter) on RM 4 met or exceeded the success criteria of 80%.

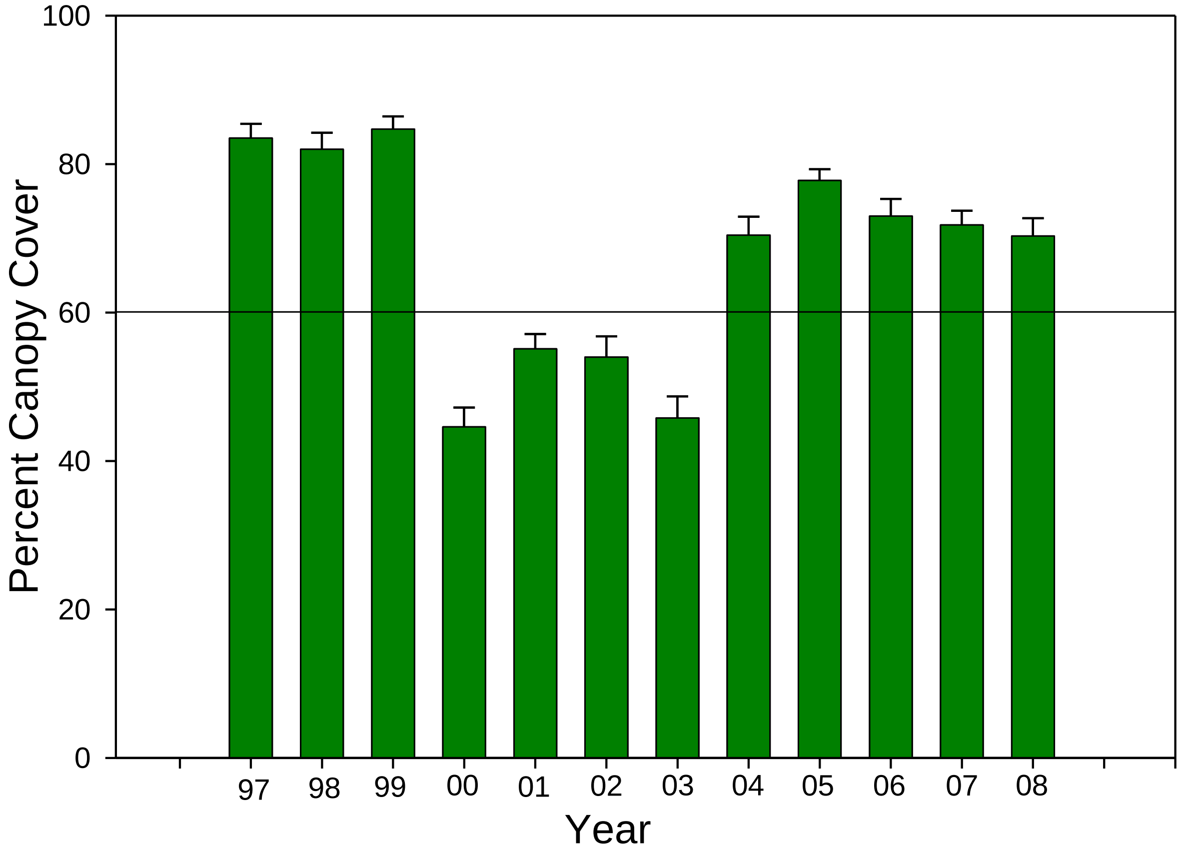

Figure 6. Percent canopy cover for the top of Red Mountain Tailing Pile 4 for the years 1997 through 2008. Standard errors are shown at the top of each bar. The horizontal line at 60% canopy cover represents the criteria for live plant cover that must be met for revegetation success.

Species Performance Across Tailing Piles

The tailing piles in the Telluride District were seeded with 16 species (Table 1) and the tailing piles in the Red Mountain District were seeded with 12 species (Table 2). Both seed mixtures were comprised of native and introduced species adapted to high elevation sites in the Rocky Mountain region. The seed mixture used on the Telluride Tailing Piles included nine grasses and seven forbs. There were four legumes (*Astragalus cicer, Onobrychis vicifolia, Medicago sativa, and Trifolium pretense*) included among the seven forbs seeded on the Telluride Tailing Piles. The seed mixture used on the Red Mountain Tailing Piles included eight grasses and four forbs. Three of the four forbs seeded on the Red Mountain Tailing Piles were legumes (*Astragalus cicer, Onobrychis vicifolia, and Trifolium pretense*). All species in both seed mixtures consisted of only cool season species because of the short growing season and shrub and tree species were not selected for seeding or planting because of their general deep rooting nature that was not considered compatible with the depth in which the tailing piles were amended.

All species that were seeded on both the Telluride and Red Mountain Tailing Piles became established and have shown persistence over the 12 years of monitoring. Some species are only present in trace amounts (i.e. less than 0.5 percent cover) and not all species are present on all tailing piles. The establishment of non-seeded species has been limited to a *Juncus* species on most tailing piles and *Achillea lanulosa* on the Red Mountain Tailing Piles. *Achillea* was seeded on the Telluride Tailing Piles but was not included in the seed mixture for the Red Mountain Tailing Piles. There have been a number of annuals that have invaded in small amounts over time (including *Lepidium* and *Brassica* species), but no annual invader has contributed more than a trace amount of cover in any year or on any tailings pile.

A listing of the best performing species for both Telluride and Red Mountain Tailing Piles are presented in Table 3. Beginning in 1998, the most dominant species are listed in Table 3 for alternate years to provide a summary of those species that showed the best performance. The number of species from year to year that contributed at least two percent cover is relatively consistent, with some decline in 2008 from previous years. In addition, there has been a great deal of consistency in species dominance over time, with both grasses and forbs/legumes contributing to the plant communities that have become established.

Table 3. Listing of the best performing species on tailing piles in the Telluride and Red Mountain Districts for alternate years during the years 1998 through 2008. Each species contributed at least two percent live cover in each year listed. Order of species is alphabetical and not related to level of dominance.

1998	2000	2002	2004	2006	2008
Achillea lanulosa	*Achillea lanulosa*	*Achillea lanulosa*	*Achillea lanulosa*	*Achillea lanulosa*	*Achillea lanulosa*
Bromus inermis	*Bromus inermis*	*Astragalus cicer*	*Astragalus cicer*	*Agrostis alba*	*Bromus inermis*
Bromus marginatus	*Bromus marginatus*	*Bromus inermis*	*Bromus inermis*	*Astragalus cicer*	*Dactylis glomerata*
Dactylis glomerata	*Dactylis glomerata*	*Bromus marginatus*	*Bromus marginatus*	*Bromus inermis*	*Elymus trachycaulus*
Elymus trachycaulus	*Elymus trachycaulus*	*Dactylis glomerata*	*Dactylis glomerata*	*Bromus marginatus*	*Festuca ovina var. duriuscula*
Medicago sativa	*Festuca ovina var. duriuscula*	*Elymus trachycaulus*	*Elymus trachycaulus*	*Dactylis glomerata*	*Juncus spp.*
Melilotus officinalis	*Juncus spp.*	*Festuca ovina var. duriuscula*	*Festuca ovina var. duriuscula*	*Elymus trachycaulus*	*Medicago sativa*
Penstemon strictus	*Medicago sativa*	*Juncus spp.*	*Juncus spp.*	*Festuca ovina var. duriuscula*	*Phleum pretense*
Phleum pretense	*Phleum pretense*	*Medicago sativa*	*Medicago sativa*	*Juncus spp.*	*Poa pratensis*
Poa compressa	*Poa compressa*	*Poa compressa*	*Penstemon strictus*	*Medicago sativa*	*Trifolium pretense*
Poa pratensis	*Poa pratensis*	*Poa pratensis*	*Phleum pretense*	*Penstemon strictus*	
Trifolium pretense	*Trifolium pretense*	*Penstemon strictus*	*Poa pratensis*	*Phleum pretense*	
		Trifolium pretense	*Trifolium pretense*	*Poa pratensis*	
				Trifolium pretense	

Meeting Revegetation Success Standards

The Remedial Action Plan (RAP) established between Idarado and the State of Colorado lists several criteria for revegetation success. These criteria include the following: 1) total cover (i.e. live vegetation and litter) is equal to or greater that 80% for the top surface of the tailing pile or 70% for the side slopes; 2) live cover is equal to or greater than 60% for the top and side slopes of the tailing pile; 3) no single species contributes more than 50% of the live cover; and 4) at least four perennial species each contribute a minimum of 3% of the live cover.

Live and total cover has been addressed above and with the exception of below average precipitation years, the criterion for live cover was consistently met for the top and side slopes of all tailing piles. Total cover was met in all years and on all tailing piles for both top and side slopes, except for RM 2 in 1997, which was the first growing season for this tailing pile.

The criteria that no single species contributes more than 50% of the live cover and that at least four perennial species each contribute a minimum of 3% of the live cover were met in every year and on every tailings pile, with few exceptions. If an exception to either criterion occurred, it was always isolated to a single year and long-term trends indicate that these criteria are achievable.

Plant Tissue Metal Concentrations

Plant tissue samples collected for metal analyses consistently provided three findings across years and tailing piles. The first was that washed plant samples had metal concentrations that were almost always lower than non-washed samples. Secondly, metal concentrations were below levels considered to be phytotoxic for Cd, Cr, Cu, Pb, and Zn based on published values (Kabata-Pendias,2001; Levy et al., 1999; Paschke and Redente, 2002; Paschke et al., 2000; Paschke et al., 2006). Finally, forb and legume tissue concentrations were consistently higher than concentrations in grass tissue. Table 4 presents plant metal concentration data for 2008. This data set represents just one year of data and is presented to provide a snap shot of plant tissue metal concentrations for grasses and forbs/legumes as distinct life form groups after 12 years of plant growth. These concentrations represent washed samples, which were typically about 10 percent lower than unwashed samples.

Table 4. Plant tissue metal concentrations for grasses and forbs averaged over the Telluride and Red Mountain tailing facilities in 2008. Concentrations for grasses and forbs represent means for all washed grass and forb samples collected in 2008. All values are means reported in mg/kg and standard deviations are shown in parentheses.

	Cadmium	Chromium	Copper	Lead	Zinc
Telluride Tailing Piles					
Grasses	0.60 (0.19)	0.42 (0.33)	0.48 (0.31)	1.90 (0.90)	200 (67)
Forbs/Legumes	1.53 (0.26)	0.85 (0.66)	1.49 (0.95)	3.30 (1.50)	255 (40)
Red Mountain Tailing Piles					
Grasses	0.98 (0.99)	0.80 (0.39)	2.12 (1.52)	4.68 (2.67)	182 (71)
Forbs/Legumes	1.72 (1.05)	1.62 (0.52)	3.46 (2.19)	6.69 (3.56)	221 (59)

The issue of potential toxicity to native ungulates was investigated during field-scale testing of direct in-situ revegetation in the mid 1980s. Data were not published from this investigation, but results indicated that plant metal concentrations would not pose a risk to native grazers that might use the tailing facilities for forage.

Conclusions

The direct revegetation approach implemented by Idarado has been successful to date in establishing relatively diverse and sustainable plant communities on acid-generating tailings at elevations above 2,700 m. The incorporation of lime and/or limestone along with manure and hay has created a non-acidic growth medium capable of supporting plant cover and species diversity at levels to meet success criteria established by the State of Colorado. As noted earlier, traditional reclamation methods would have employed extensive removal and/or cover-type activities, thus disrupting local communities and requiring additional land resource disturbance. Direct revegetation approaches similar to what was implemented in the Telluride and Red Mountain mining districts appear to have promise for other sites where soil cover is limited or unavailable.

Acknowledgements

The author extends his gratitude to Idarado Mining Company for the opportunity to contribute to this project, for their long-term support, and progressive approach towards reclamation.

Literature Cited

Bonham, C.D. 1989. Measurement for Terrestrial Vegetation. John Wiley & Sons, New York, NY.

Hardy, A.J., J.V. Redmond, R.A. River, and C.S. Davis. 1999. High altitude mine waste remediation—implementation of the Idarado Remedial Action Plan. p. 120-131 *In* S.A. Bengson and D.M. Bland (eds.). 1999 Proceedings of the 16th Annual National Meeting of the American Society for Surface Mining and Reclamation. *Mining and Reclamation for the Next Millenium*, (Scottsdale, AZ, August 13-19, 1999).
https://doi.org/10.21000/JASMR99010120

Kabata-Pendias, A. 2001. Trace Elements in Soils and Plants. CRC Press. Boca Raton, FL.

Levy, D.B., E.F. Redente, and G.D. Uphoff. 1999. Phytotoxicity assessment of native grasses growing in Pb-Zn tailings Tri-State Mining District, USA. Soil Science 164:363-375. http://dx.doi.org/10.1097/00010694-199906000-00001.

Paschke, M.W. and E.F. Redente. 2002. Copper toxicity thresholds for important reclamation grass species of the western United States. Environmental Toxicology and Chemistry 21:2692-2697. http://dx.doi.org/10.1897/1551-5028(2002)021<2692:CTTFIR>2.0.CO;2.

Paschke, M.W., E.F. Redente, and D.B. Levy. 2000. Zinc toxicity thresholds for important reclamation grass species of the western United States. Environmental Toxicology and Chemistry 19:2751-2756. http://dx.doi.org/10.1002/etc.5620191120.

Paschke, M.W., L.G. Perry, and E.F. Redente. 2006. Zinc toxicity thresholds for reclamation forb species. Water, Air and Soil Pollution. 170:317-330.
https://doi.org/10.1007/s11270-006-3139-3

Redente, E.F. and D.A. Baker. 1996. Direct revegetation of mine tailing: a case study in Colorado. p. 183-191. *In* F.F. Munshower and S.E. Fisher (eds.). Planning, Rehabilitation, and Treatment of Disturbed Lands. Reclamation Research Unit Publication No. 9603. Montana State Univ. Bozeman, MT.

United States District Court for the State of Colorado. 1992. State of Colorado v. Idarado Mining Company and Baumgartner Oil Company: Remedial Action Plan (RAP), Volumes I, II, and III: Civil Action No. 83-C-2385. May 21, 1992.