One- and Three-Year Transplant Performance of Container Grown Stock Planted at a High Elevation, Disturbed Site[4]

J. T. Harrington[1], A. M. Wagner[2], and D. R. Dreesen[3]

ABSTRACT

The Molycorp, Inc. Questa mine is located in northern New Mexico in an area of steep topography. Rock pile construction from overburden during open pit operations utilized steep canyons to create the piles. The resulting rock pile slopes are relatively shallow, steep and high (over 500 feet). A state highway and river, located near the toe of the slopes preclude reshaping of the piles. The angle (steepness) of the slopes is similar to the natural topography, which supports primarily a mixed conifer ecosystem. Standard forestry techniques have been adapted for the revegetation program. In general, seedlings of the overstory and shrub species are hand planted on the slopes, directly into the overburden using hoedads. Development of a self-sustaining ecosystem appropriate to the site is the underlying goal of the revegetation program. The relatively rapid physical weathering of the overburden rock creates a suitable planting medium for the seedlings. Both the fast growing early successional overstory species (*Populus angustifolia, Robinia neomexicana,* etc.) and the slower growing, later successional overstory species (*Pinus ponderosa, P. flexilis, Abies concolor,* etc.) are planted simultaneously along with appropriate understory species. The differential growth of the two types of overstory species is intended to shorten the time frame to achieve a more stable, later successional plant community. First year survival for transplants has averaged 80% and 3 year stocking rates are between 80% and 97% of the original planting rates. This survival rate has been attributed to three main features of the program: 1) using site adapted (genetic) stock; 2) planting pre-conditioned container grown stock; and 3) proper planting techniques. The expanded revegetation program is in its fourth year with over 130,000 seedlings planted.

Additional Key Words: reforestation, reclamation, direct revegetation

[1]Associate Professor, Mora Research Center, New Mexico State University, Mora, NM 87732
[2]Environmental Coordinator, Molycorp, Inc., Questa, NM, 87556
[3]Agronomist, Los Lunas Plant Materials Center, Natural Resources Conservation Service, Los Lunas, NM 87031.
[4]This research was funded through grants from Molycorp, Inc. Questa, NM

INTRODUCTION

The Molycorp Inc., Questa Molybdenum Mine has been in operation since 1921. The mine is located in an area of steep, mountainous topography in narrow canyons adjacent to the Red River five miles east of the town of Questa, New Mexico in Taos County. Underground mining occurred from 1921 to the early 1960s when open pit development of the ore body began. The open pit mine operated from 1965 through 1983. From 1983 to the present mining is an underground block caving operation.

The open pit period of extraction generated 328 million tons of overburden. Deposition of this overburden material utilized the natural steep, long slopes and narrow canyons for the development of the overburden rock piles. Today, the rock pile surfaces are steep and long, in some cases exceeding 500 feet in length. Unlike other mining operations where rock piles are situated on relatively flat ground and the height of the piles is indicative of pile depth, the depth of the rock piles at Molycorp range from 60 to 125 feet in thickness (depth) (Robertson GeoConsultants, Inc. 1999). The resulting overburden depth was a function of several factors including underlying topographic features including slope, slope length and overburden structural composition and its influence on angle of repose. The resultant surface of the rock piles has similar slope intensity to the adjacent natural topography.

The terrain surrounding the mine supports primarily coniferous ecosystems with riparian ecosystems in the bottoms of many canyons having perennial streams or rivers. The conifer dominated ecosystems range from ponderosa pine (*Pinus ponderosa*), to mixed conifer (*P. flexilis*, *Pseudotsuga menziesii*, *Abies concolor*) to spruce-fir (*Picea engelmannii* and *Abies concolor*) stands. Topographic features, specifically elevation and aspect strongly influence species distribution (Wagner and Harrington, 1994). Also, edaphic features, which include rooting mantle thickness, water holding capacity and nutrient availability, likely influence vegetation distribution in the area. Areas in which the coniferous overstory have been disturbed, various shrub (*Quercus* spp., *Cercocarpus montanus*, *Ribes* spp.), aspen (*Populus tremuloides*) and narrowleaf cottonwood (*P. angustifolia*) dominated communities occur.

The other natural feature which appears to strongly influence vegetation distribution in this region are hydrothermal scars. These naturally occurring areas have highly erodible, and acidic "soils" (Meyer and Leonardson 1990). During the open pit-mining operations, hydrothermal scars were excavated along with intervening areas of more neutral geologic materials. Heterogeneous overburden piles resulted with a wide range of particle sizes, and chemistries (specifically pH).

Consistent with the variability in vegetation surrounding the mine, the mine itself offers a broad range of planting sites. For example, elevation ranges from 8,000 feet to 10,000 feet and almost every aspect occurs. In addition to the variability in the overburden thickness, overburden particle size ranges from clay-sized fines to large cobble, and overburden pH ranges from neutral (pH 7) to very acidic (pH 3). This site diversity will require a range of revegetation techniques be employed to revegetate the site.

Goals of Revegetation Program

Traditional approaches to revegetation of overburden materials often involves drastic recontouring and capping with various materials to support plant growth, and in several cases manipulate water movement. However, many features of this site indicate that developing

new revegetation techniques and technologies or modifying existing ones would be more advantageous to both Molycorp and the overall watershed. Some of the technologies and techniques developed from the *in situ* revegetation of the overburden would be applicable to other, natural areas in the watershed which are actively eroding.

The goals of the reclamation program at the mine site are to stabilize the site and reduce erosion, to reduce water infiltration and increase evapotranspiration and to establish a productive plant ecosystem compatible with the adjacent plant communities. The rationale behind using forestry as a post-mining land use a the mine site is that this is a consistent land use to the previous as well as surrounding current land use. This post-mining land use is also consistent with the underlying principles of restoration ecology (Bradshaw, 1987). Further, using a mixture of plant types (trees, shrubs, forbs and grasses) will broaden the depth and quality of the overall root system, thereby improving site stability (Gray and Sotir, 1996). The reclamation program is also based on the natural regeneration and establishment of conifers on the low pH, highly erodible scar areas surrounding the mine site.

The mine site revegetation is focused on the concept of using a nurse tree crop along with an economic (or crop) tree and establishing both simultaneously. The nurse trees are trees and sometimes shrubs that make the site more suitable for crop tree (or the long term tree) establishment and growth. The nurse trees also aid and expedite site stabilization and uses early successional species.

The operational revegetation is based on site-specific and published research results as well as a technique's ability to meet the specific goals for the planting unit. Research areas have included species and seed source screening on overburden pHs, stock type suitability, local seed source propagation, planting windows, and fertilizer incorporation (Harrington et al., 2000). The operational plantings utilize hand planting of tree and shrub seedlings that have been produced form local seed sources whenever possible. This process is consistent with the regeneration ecology of adjacent stands. Hand planting reduces the compaction and does not impede deep root exploration.

Previous Revegetation Research

Beginning in the mid-1970s Molycorp has been actively funding revegetation research at their Questa mine. Initially, this research effort began with the then Soil Conservation Service Plant Materials Center in Los Lunas, New Mexico (currently, the Natural Resource Conservation Service, Los Lunas Plant Materials Center (NRCS-LL-PMC). This research effort continues today. In 1992, Molycorp expanded this effort by expanding funding to include New Mexico State University researchers at the Mora Research Center (NMSU-MRC). This research effort also continues today.

MATERIALS AND METHODS

The plants used in these studies and the operational program are container grown seedlings produced in greenhouses. The majority of seedlings are produced in 10 in ^{3} containers ® (Steuwe and Sons, Inc. Corvallis, OR). Other containers used have included D-16, D-40 and styroblocks. The NMSU-MRC and NRCS-LL-PMC facilities have produced the plant materials used in the operational plantings under appropriate production regimes. When possible and depending on availability, local seed sources have been used. Planting of seedlings uses traditional container planting techniques (dibble bars, hoedads, etc.) adjusted to accommodate unique site features such as rockiness and steep slopes.

Operational Planting Techniques

In September of 1996, the first operational planting was conducted on the top portion of one of the lower (elevation) rock piles, (Spring and Sulphur Gulch rock pile, SSG). The elevation of this rock pile ranges from 8,200 ft. to 8,650 ft with a field pH of >6.0 and is composed of aplite and black andesite rock (SRK, 1995). The planting was done by hand using a contract planting crew. The plant material consisted of a wide range of plant species (Table 1). In general the relative proportion of plant forms was as follows: 35% deciduous trees; 40% coniferous trees; and, 25% shrubs. All plant materials were grown in reforestation containers as described above at the NMSU-MRC Research Nursery or the NRCS-LL-PMC. Planting crews were told to select plant materials to maximize diversity at the planting site. (Note: some members of the planting crew were better at this than others.) The planting crews were given instructions to plant seedlings 3 ft apart within rows and the rows were to be 4 ft apart (1.0 m X 1.2 m).

The following year, June 1997, two additional sites were planted in the same manner. The first site was the lower level of the Middle rock pile immediately to the west of the 1996 planting and this site is similar in elevation, pH and rock type. The second site was the Capulin rock pile, one of the highest locations on the site ranging from 9,250 ft. to 9,800 ft. in elevation, with a field pH of 3.6 to 3.8 and composed of mixed volcanic rocks (SRK 1995). Approximately 30,000 to 35,000 seedlings were planted (total) using the same method described for the 1996 planting. Species for these plantings are listed in Table 1 and percentages of life forms were similar to the 1996 planting. Species mixes were adjusted to the planting site conditions. For example, fewer pinyon or junipers (evergreen shrubs) were planted at the Capulin site because of its elevation.

Vegetation Analysis

In August of 1997, nine $100m^2$ (50m x 2m) transects in the 1996 planting area were randomly selected and measured to evaluate survival and stocking (number of plants / hectare). Species composition and frequency were recorded. Status categories included: living, dead, living and partially covered, dead and partially covered. No interpretations of the vigor of the seedlings were made. For ease of installation and consistency, all transects were placed perpendicular to the slope direction.

In May, 2000 stocking levels were determined for the three planting sites discussed in this report. Transects were placed as described for the August 1997 survival measurements. At the Capulin rock pile, 3 transects were placed, 3 transects were placed for the Middle rock pile and 6 transects for the SSG rock pile. Species composition and frequency were recorded. Status categories included number of living seedlings, number of covered seedlings (living), and number of seedlings with broken tops (browse damaged). These status categories were used to quantify the condition of the established seedlings. Covered indicates that there have been movement of rocks, small particles or other material over the seedling. This category includes plants that appear to be unaffected by the covering (small amount of stem covered) to those with a larger portion of the stem covered but still living. The number of living seedlings per hectare is reported as adjusted and non-adjusted stocking levels. The adjusted stocking level accounts for areas with large cobble or scree slopes that were deemed unplantable by the planting crew and therefore no seedlings were transplanted in these areas. Stocking levels are determined by multiplying the numbers in the transect by

100 for non-adjusted rates. Adjusted levels reflect the shortened transects due to the presence of cobble.

Data were analyzed using descriptive statistics including means and standard deviation (SAS Institute, Inc. 1996). Sums were generated from the raw data for plot by species combinations.

RESULTS

Overall, first year survival of the 1996 planting was 81% (Table 2). Survival by plant category ranged from 94% for coniferous shrubs (juniper and pinyon pine) to 63% for deciduous trees. Observations indicate that the narrowleaf cottonwood planted in the fall of 1996 was likely planted without sufficient dormancy for an early frost. Percentage of covered seedlings ranged from 5% for deciduous trees to 16% for coniferous shrubs. Overall, only 9% of the seedlings showed signs of covering.

Stocking levels were also evaluated, for the SSG site both one and three years after planting and for the other two sites, three years after planting (Table 3). All life forms were represented in all the areas. Plant density ranged from 6856 plants per hectare to 8833 plants per hectare when adjusted for cobble areas. The target planting rate was 9075 plants per hectare (unadjusted for cobble). The stocking rate for the SSG site is higher in 2000 than in 1997. There are two possible explanations for this change, one is that some of the seedlings evaluated as dead in 1997 may have root sprouted subsequently. The increase in stocking is evident for both deciduous trees and deciduous shrubs. The other explanation is that natural encroachment from the surrounding area is occurring at the site and some of these new seedlings may be volunteers.

The number of seedlings affected by cover and browse varies greatly (Table 4). In the 2000 evaluation, all the seedlings noted as covered or browsed were still alive. Conifer seedlings at the Capulin rock pile appear to be the most affected by browse. Covering varies from site to site. The Spring and Sulphur Gulch rock pile shows the least evidence of covering (717 plants/ha), with the Middle and Capulin rock piles showing similar levels of covering (2000 and 1700 plants/ha respectively).

SUMMARY

The initial results and three year stocking rates demonstrate that the planting techniques and planting stock used at the site allow for successful establishment of forest seedlings. All three sites are still stocked at 80% of the target planting rate. Capulin, the rock pile at the highest elevation and the lowest pH shows stocking at 97% of the planting rate. However, it was noted that some planters planted closer than the 1 m by 1.2 m spacing standard which could in part explain the higher stocking levels at Capulin.

The target stocking rates for evaluation of the reclamation to determine successful establishment is currently proposed at 150 to 275 crop trees per acre depending upon the site conditions. There is also provision for measuring the understory and/or nurse crop trees with a separate standard. These evaluations do not take place until a minimum of twelve years post planting or fertilization (if applicable).

While there is evidence of browse damage and covering of seedlings, this does not yet appear to be at a level to significantly impact the revegetation efforts. These conditions should continue to be monitored in these plantings as well as in future plantings. In many cases observed, while the seedling is impacted by either browse or covering, the seedling continues to survive.

Growth has not yet been measured or used as an indicator of success. At this site previous plantings (early 1990s) and the natural regeneration on surrounding slopes seems to indicate that growth lags behind establishment. From unpublished data collected to date, seedlings (both transplanted and natural regeneration) appear to put energy into root development and little into shoot growth for the first four to six years after establishment (Harrington 2000, unpublished data). After four to six years shoot growth becomes evident on an annual basis. It is anticipated that within the next two years, shoot growth will be measured to assist in determination of successful establishment at these sites.

The successful establishment of seedlings at the site has been attributed to three factors. As noted above, whenever possible, site adapted (genetic) plant material is used in the planting program. For some species this appears to be a critical component of successful establishment (Harrington et al., 2000). The second factor is using pre-conditioned, container grown stock. The higher than expected mortality of the narrowleaf cottonwood in the 1996 Fall planting was in part because the plants were not conditioned properly and were susceptible to an early frost kill. Lastly, proper planting techniques, as is seen in any forestry planting, are critical to successful establishment of the seedlings. The 80% survival and the subsequent stocking levels three years after transplanting are evidence that the seedlings are planted properly.

This reclamation program is in the early stages of implementation with approximately 15% of the disturbed acreage planted to date. The program is intended to plant incremental areas over the period of anticipated mine operations (30 years) which will allow for continued development and research of plant material, planting techniques and post-planting maintenance. The reclamation program has a long term objective of establishing a self-sustaining forest ecosystem at the site that is appropriate to the area.

LITERATURE CITED

Bradshaw, A.D. 1987. Restoration: an Acid Test for Ecology. In: Restoration Ecology. Chapter 2. M.E. Gilpin and J.A. Aber (eds.). Cambridge University Press. 342 pp.

Gray, D.H. and R.B. Sotir. 1996. Biotechnical and Soil Bioengineering Slope Stabilization. John Wiley and Sons, Inc. New York. 378 pp.

Harrington, J.T., A.M.Wagner and D.R. Dreesen. 2000. Successful Techniques for High Altitude Steep Slope Revegetation. Proceedings: 2000 Billings Land Reclamation Symposium. March 20-24, 2000. Billings, MT.

Meyer, J. and R. Leonardson. 1990. Tectonic, Hydrothermal and Geomorphic Controls on Alteration Scar Formation near Questa, New Mexico. New Mexico Geological Society Guidebook, 41st Field Conference, Southern Sangre de Cristo Mountains, New Mexico, 1990.

Robertson GeoConsultants, Inc. 1999. Interim Report: Questa Waste Rock Pile Drilling, Instrumentation and Characterization Study. Interim Report 052007/1. Prepared for Molycorp, Inc. September 6, 1999.

SRK. 1995. Questa Molybdenum Mine Geochemical Assessment. Prepared for Molycorp, Inc. April 13, 1995. Steffen Robertson and Kirsten (U.S.), Inc. Project No. 09206.

Wagner, A. M. and J. T. Harrington. 1994. Revegetation Report for Molycorp, Inc. Report prepared for Molycorp, Inc. – New Mexico Mine Permit TA001RE.

Table 1. List of species and plant form category by year of planting.

Plant Species		Plant Form Category	Year	
Common Name	**Scientific Name**			
Bristlecone Pine	*Pinus aristata*	Coniferous tree	1996	1997
Ponderosa Pine	*Pinus ponderosa*	Coniferous tree	X	
Southwestern White Pine	*Pinus strobiformis*	Coniferous tree	X	X
Limber Pine	*Pinus flexilis*	Coniferous tree	X	X
Douglas fir	*Psuedotsuga menziesii*	Coniferous tree		X
White Fir	*Abies concolor*	Coniferous tree	X	
Engelmann Spruce	*Picea engelmannii*	Coniferous tree	X	
Blue Spruce	*Picea pungens*	Coniferous tree		X
Rocky Mountain Juniper	*Juniperus scopulorum*	Coniferous shrub	X	
Pinyon Pine	*Pinus edulis*	Coniferous shrub	X	X
New Mexico Locust	*Robinia neomexicana*	Deciduous tree	X	X
Chokecherry	*Prunus virginiana*	Deciduous shrub		X
Oak	*Quercus gambelii*	Deciduous shrub		X
Kinnikinnik	*Arctostaphylus uva-ursi*	Deciduous shrub	X	
Narrowleaf cottonwood	*Populus angustifolia*	Deciduous tree	X	
Fringed Sage	*Artemisia frigida*	Deciduous shrub	X	X
Rubber Rabbitbrush (Chamisa)	*Chrysothamnus nauseosus*	Deciduous shrub	X	X
Four-wing Saltbush	*Atriplex canescens*	Deciduous shrub	X	
Mountain Mahogany	*Cercocarpus montanus*	Deciduous shrub	X	X
Fernbush	*Chamaebatiaria millefolium*	Deciduous shrub	X	X
Alder	*Alnus tenuifolia*	Deciduous tree		X
Currant	*Ribes spp.*	Deciduous shrub		X

Table 2. One year survival for September 1996 planting at Spring and Sulphur Gulch rock pile (SSG). Plot was measured in August 1997. The target planting rate based on a 3 ft. by 4 ft. (1.0 X 1.2 m) spacing was 9075 seedlings per hectare.

Plant Category	Evaluation for Planted [1]	Mean	Std. Deviation	Evaluation for Planted[2]	Mean	Std. Deviation
Coniferous trees	Planted (#/Ha)	4870	1388	Planted (#/Ha)	4656	1536
	% Live	87.4	1.6	% Live	87.4	1.6
	% Covered	9.5	1.4	% Covered	9.5	1.4
Coniferous shrubs	Planted (#/Ha)	204	187	Planted (#/Ha)	189	183
	% Live	94.1	5.7	% Live	94.1	5.7
	% Covered	5.9	5.7	% Covered	5.9	5.7
Deciduous Shrubs	Planted (#/Ha)	1179	759	Planted (#/Ha)	1133	786
	% Live	92.2	2.7	% Live	92.2	2.7
	% Covered	15.7	3.6	% Covered	15.7	3.6
Deciduous Trees	Planted (#/Ha)	2638	722	Planted (#/Ha)	2478	728
	% Live	63.2	3.2	% Live	63.2	3.2
	% Covered	4.5	1.4	% Covered	4.5	1.4
Total	Planted (#/Ha)	8930	1263	Planted (#/Ha)	8489	1771
	% Live	80.8	1.4	% Live	80.8	1.4
	% Covered	8.8	1.0	% Covered	8.8	1.0

[1]Planted is the number of seedlings counted (dead and alive) based on a 2 m by 50 m transect.

[2]Planted is the number of seedlings counted (dead and alive) based on the actual transect measured. Some transects were shortened because of the presence of cobble and those areas were unplantable.

Table 3. Stocking levels of planting sites (number per hectare) at Spring and Sulphur Gulch (SSG), Middle and Capulin rock piles. Plantings occurred in 1996 and 1997.

Planting Site	Plant Category	Years in ground at evaluation	Stocking [1]	Std. Deviation	Stocking [2]	Std. Deviation
SSG	Coniferous tree	1	4232	1553	4067	1667
	Coniferous shrub	1	187	184	178	186
	Deciduous shrub	1	1090	692	1044	714
	Deciduous tree	1	1662	546	1567	563
	Total	1	7171	1414	6856	1797
SSG	Coniferous tree	3	3778	918	3550	701
	Coniferous shrub	3	56	62	50	55
	Deciduous shrub	3	1228	777	1217	791
	Deciduous tree	3	2226	449	2133	524
	Total	3	7288	752	6950	1106
Middle	Coniferous tree	3	3907	140	3567	321
	Coniferous shrub	3	421	312	367	252
	Deciduous shrub	3	1644	600	1533	666
	Deciduous tree	3	1541	581	1433	666
	Total	3	7513	667	6900	1253
Capulin	Coniferous tree	3	5167	1595	NA	NA
	Coniferous shrub	3	67	58	NA	NA
	Deciduous shrub	3	1767	351	NA	NA
	Deciduous tree	3	1800	755	NA	NA
	Unknown	3	33	58	NA	NA
	Total	3	8833	2312	NA	NA

Stocking[1] is stocking levels (no./ha) not adjusted for areas of cobble that are unplantable.
Stocking[2] is stocking levels (no. / ha) adjusted for areas of cobble that are unplantable.
NA: Not applicable, for the Capulin rock piles no areas of cobble were found that were unplantable.

Table 4. Condition of plants as measured in the field 1 and 3 years post-planting. Numbers are reported in number of plants per hectare.

Planting Site	Plant Category	Covered[1]	Std. Dev.	Covered[2]	Std. Dev.	Browsed[1]	Std. Dev.	Browsed[2]	Std. Dev.
SSG (1997 evaluation)	Conif. tree	463*		442*					
	Conif.shrub	12*		11*					
	Decid.shrub	185*		178*					
	Decid. tree	119*		112*					
	Total	786*		747*					
SSG (2000 evaluation)	Conif. tree	494	332	467	327	193	121	183	117
	Conif.shrub	18	43	17	41	0	0	0	0
	Decid.shrub	83	98	83	98	0	0	0	0
	Decid. tree	155	163	150	164	0	0	0	0
	Total	750	398	717	407	193	121	183	117
Middle	Conif. tree	1038	529	969	569	187	76	167	58
	Conif.shrub	227	131	200	100	77	7767	67	58
	Decid.shrub	658	285	600	265	0	00	0	0
	Decid. tree	250	145	233	153	0	00	0	0
	Total	2173	870	2000	900	264	143	233	115
Capulin	Conif. tree	1133	513	NA	NA	1600	872	NA	NA
	Conif.shrub	33	58	NA	NA	33	58	NA	NA
	Decid.shrub	1133	379	NA	NA	33	58	NA	NA
	Decid. tree	900	889	NA	NA	33	58	NA	NA
	Unknown	33	58	NA	NA	0	0	NA	NA
	Total	3233	1644	NA	NA	1700	954	NA	NA

[1] Indicates numbers are not adjusted for cobble areas that are unplantable.
[2] Indicates numbers are adjusted for cobble areas that are unplantable.
* Indicates numbers estimated from Table 2.
NA: Not applicable, for the Capulin rock piles no areas of cobble were found that were unplantable.