Final Report
Evaluation of Containerized Legumes for Revegetation of Molycorp Overburden Piles–1996 Trial of Source-Identified Germplasm

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by:

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Executive Summary:

The objective of this experimental planting in 1996 was to evaluate 16 source-identified legume species not typically commercially available to determine which species exhibit superior survival and growth on overburden. Several species (*Oxytropis campestris v. cusickii*, *Oxytropis besseya v. fallax*, *Astragalus utahensis*, and *Oxytropis multiceps*) had vigor and survival equivalent to the best performing commercially available herbaceous legumes tested in an earlier study. Two species (*Oxytropis campestris v. cusickii* and *Oxytropis splendens*) had stature comparable to some of the better performing commercial varieties tested.

Objective:

The objective of this experimental planting was to evaluate legumes for their potential to survive and grow when planted directly into overburden as transplants. The species tested were grown from seed collected in the wild from known locations in Colorado, Wyoming, Arizona, and Utah. Survival, vigor, stature, and seedhead production for source-identified species were compared with commercially available legumes evaluated in an earlier study (Dreesen 2002). To assess nitrogen fixation potential, no fertilizer was applied to the legume seedlings at planting or during later growth.

Introduction and Application:

The Molycorp open pit molybdenum mine near Questa, NM operated an open pit from 1965 to 1983 that required the removal of 300 million metric tons of overburden. The overburden piles are situated at elevations from 8,000 to 9,800 ft with surrounding vegetation of ponderosa pine, mixed conifer, and mountain shrub communities. Southerly aspects and steep slopes are the predominant natural site features and overburden pile characteristics. The overburden piles consist of mixed volcanic rocks (rhyolitic and andesitic types sometimes referred to as acid rock) as well as black andesite and aplite intrusives (referred to as neutral rock) (Steffen, Robertson, and Kirsten, Inc. 1995). The mixed volcanic rocks are highly fractured and weathered typically with low pH and high salinity from pyrite oxidation. The mixing of rock types during overburden pile construction has resulted in heterogeneous substrates with a range of pH and soluble salt levels.

Several herbaceous and suffretescent species have invaded the mine overburden piles and road cuts (*Eriogonum sp., Artemisia frigida, Penstemon sp.*, and *Solidago sp.*) and many herbaceous species are components of the surrounding mountain shrub community and mixed conifer forest. No native legume species have invaded overburden areas; however, yellow sweet clover (*Melilotus officinalis*) has established on spots where lowland topsoil has been brought in and placed on the overburden. The surrounding natural plant communities contain a paucity of legume species. An occasional *Lupinus sp*. has been observed. Results from a legume species trial installed in 1995 using commercially available species revealed a number of species with superior performance. Native herbaceous legumes in the *Petalostemum* genus appear better suited to more xeric overburden sites (Dreesen 2002). *Thermopsis montanus* and *Thermopsis rhombifolia* seem to hold some promise as revegetation species based on their persistence and spread by rhizomes. Although *Hedysarum boreale* had relatively poor survival, the vigor of the few plants that survived would make it a reasonable selection to include in a legume species mix. Two species with relatively good early performance but only poor to fair later performance, *Dalea aurea* and *Astragalus missouriensis*, could only be recommended under the presumption that they could set and disseminate viable seed before their demise. The native woody legume *Amorpha fruticosa* showed good overall performance. The long-term performance of *Amorpha fruticosa* is still unresolved because the Molycorp environment is outside its typical area of adaptation (i.e., lower elevation and riparian). *Robinia neomexicana* tested in earlier species trials exhibited excellent growth and vigor but highly variable survival (Dreesen 2001). Thus,

Robinia neomexicana would be the better woody legume to include in a revegetation species mix. Two forb species tested in the 1995 planting, *Penstemon barbatus* and *Solidago sp.,* would be recommended. However, while *Penstemon barbatus* is a perennial based on performance at these sites, it appears to function as a "short-lived" species with a decline in vigor and survival after several years. The introduced herbaceous legume *Astragalus cicer* had good performance at both sites and would be recommended for inclusion in revegetation specifications if exotic species are deemed appropriate. *Medicago sativa* appears to be another worthwhile exotic species on more mesic sites like the Blind Gulch site.

The woody legume, *Robinia neomexicana*, was installed in early species trials and was one of the few species that showed good vigor without nutrient additions. This response substantiates that nitrogen is deficient in the overburden. This lack of nitrogen in the overburden materials has been assumed by the poor growth of transplants that did not receive fertilizer application at planting (Dreesen 2001). The establishment of legumes capable of nitrogen fixation through symbiosis with *Rhizobium sp.* would provide a natural mechanism for introducing nitrogen into the nutrient cycle of revegetated plant communities on the overburden.

The poor germination of seed broadcast or incorporated into overburden negates the suitability of species trials established from seed. Therefore, containerized transplants were used to establish the evaluation plots to determine which species have superior survival and growth characteristics sufficient to justify their use in cost effective large scale reclamation efforts.

Methods:

Source-identified seed of 16 legume species was obtained from ALPLAINS seed company, Kiowa, Colorado (see Table 1 for species list and origin) and propagated in the late spring of 1995. The seed was scarified by abrasion with fine grit sandpaper and planted in plug trays. Plug seedlings were transplanted in mid summer 1995 into Ray Leach Super Cells containers (10 cubic inch).

The planting took place on August 7, 1996 at 2 locations on the Molycorp mine site (Blind Gulch 9300 ft. and Spring Gulch 9000 ft.) on the flat top of overburden piles. The Blind Gulch overburden surface materials are a heterogeneous mix of low pH mixed volcanic rock and neutral aplite and black andesite. The Spring Gulch plots were all situated on neutral rock. The Blind Gulch site is more mesic due to greater precipitation (higher elevation and orographic influences) as well as generally having overburden with a higher proportion of fines. Dibbles specifically designed for Ray Leach Super Cell containers (10 cubic inch) were used. Planting holes were placed approximately 8 to 12 inches apart in ripped rows.

In August 1996, August 1997, and August 1998 the vigor, survival, and presence of seedheads (not 1997) were recorded. The vigor ratings based on visual comparisons were scaled as follows: 4 = excellent, 3 = good, 2 = fair, 1 = poor, and 0 = dead. In August 2000, the number of live plants, individual heights, and individual crown widths were recorded. The height and width were estimated by observation.

The species included in the 1996 planting are listed in Table 1 along with the origin, seed source, number of row plots, and number of seedlings per row plot.

Table 1. Species tested at Blind Gulch and Spring Gulch overburden piles.

Genus	Species	Origin (Seed Source)	Elevation of Seed Collection	Number of Plants at Spring Gulch	Number of Plants at Blind Gulch
				(rows x reps.)	(rows x reps.)
Astragalus	*barrii*	Johnson Co., WY	4,750	3 x 7	
Astragalus	*crassicarpus*	Park Co., CO	9,250	3 x 7	
Astragalus	*detritalis*	Duchesne Co., UT	5,400	3 x 7	3 x 6
Astragalus	*kentrophyta v. jessiae*	Fremont Co., WY	6,100	3 x 2	
Astragalus	*kentrophyta v. kentrophyta*	Weld Co., CO	6,600	3 x 6	
Astragalus	*saurinus*	Uintah Co., UT	5,550	3 x 4	
Astragalus	*spatulatus*	Albany Co., WY	7,300	3 x 2	
Astragalus	*utahensis*	Sevier Co., UT	6,300	3 x 7	3 x 7
Lotus	*mearnsii*	Navajo Co., AZ	5,950	3 x 5	
Oxytropis	*besseya v. fallax*	Fremont Co., WY	5,710	3 x 6	
Oxytropis	*campestris v. cusickii*	Lake Co., CO	12,050	3 x 6	
Oxytropis	*multiceps*	Weld Co., CO	6,600	3 x 7	3 x 2
Oxytropis	*nana*	Carbon Co., WY	6,400	2 x 2	
Oxytropis	*splendens*	Lake Co., CO	10,200	3 x 7	
Trifolium	*dasyphyllum*	Park Co., CO	12,000	3 x 7	3 x 4
Trifolium	*parryi*	Park Co., CO	12,200	3 x 4	

Results:

The overall survival of the 16 entries as well as the mean vigor of live plants is reported in Table 2. The composite mean survival for all species at Spring Gulch decreased from 67 to 68% in 1996 and 1997 to 29% by 2000. Several species had survival percentages greater than respective composite means for all four years, *Astragalus utahensis, Oxytropis besseya v. fallax, Oxytropis campestris v. cusickii, Oxytropis multiceps* and *Trifolium dasyphyllum.* During earlier years *Astragalus kentrophyta v. jessiae* and *Astragalus saurinus* survival exceeded the composite means. During later years *Astragalus barrii, Astragalus crassicarpus,* and *Oxytropis splendens* survival exceeded the composite means for later years. Both *Astragalus utahensis* and *Oxytropis multiceps* exhibited fair to good survival at the Blind Gulch site during the later years' evaluations.

A number of species at Spring Gulch showed mean vigor ratings greater than the composite means for all evaluations from 1996 through 1998: *Astragalus barrii, Astragalus kentrophyta v. jessiae, Astragalus utahensis,* and all the Oxytropis species (*Oxytropis besseya v. fallax,*

Oxytropis campestris v. cusickii, *Oxytropis multiceps*, *Oxytropis nana*, and *Oxytropis splendens*). The vigor ratings were rather consistent over the years for most species (i.e., poor performers remained poor from 1996 to 1998). At Blind Gulch, *Astragalus utahensis* and *Oxytropis multiceps* had fair to good vigor for all evaluation years.

The mean heights and widths in 2000 are reported in Table 3. The species at Spring Gulch with mean heights and widths approximately equal or greater than the composite means include *Oxytropis besseya v. fallax*, *Oxytropis campestris v. cusickii*, *Oxytropis multiceps*, and *Oxytropis splendens*. *Astragalus crassicarpus* and *Astragalus utahensis* had canopy widths close to the composite mean widths, but had short stature. *Oxytropis multiceps* had superior height and width at Blind Gulch whereas *Astragalus utahensis* had superior width.

The overall ratings presented in Table 3 are calculated by multiplying the survival (as a decimal fraction) by the vigor ratings. These results for Spring Gulch closely parallel the vigor results. Two *Astragalus* species (*Astragalus kentrophyta v. kentrophyta* and *Astragalus utahensis*), all the *Oxytropis* species (*Oxytropis besseya v. fallax*, *Oxytropis campestris v. cusickii*, *Oxytropis multiceps*, *Oxytropis nana*, and *Oxytropis splendens*), and *Trifolium dasyphyllum* had overall ratings in all 3 years which exceeded the species composite means. *Astragalus utahensis* and *Oxytropis multiceps* exhibited fairly good overall ratings for all 3 years at Blind Gulch. A number of species exhibited seedhead production (see Table 3) in one or both evaluation years (1996 and 1998): *Astragalus crassicarpus*, *Astragalus utahensis*, and all Oxytropis species (*Oxytropis besseya v. fallax*, *Oxytropis campestris v. cusickii*, *Oxytropis multiceps*, *Oxytropis nana*, and *Oxytropis splendens*).

Conclusions:

Seven species had vigor values greater than or equal to 2.50 in 1998, the final year of vigor evaluation: *Astragalus kentrophyta v. kentrophyta*, *Astragalus utahensis*, *Oxytropis besseya v. fallax*, *Oxytropis campestris v. cusickii*, *Oxytropis multiceps*, *Oxytropis nana*, and *Oxytropis splendens*. In the 1995 planting of commercially available herbaceous legumes, 5 species had 1998 vigor values greater than or equal to 2.50: *Hedysarum boreale*, *Astragalus cicer*, *Astragalus missouriensis*, *Astragalus lonchocarpus*, and *Petalostemum purpureum* (Dreesen 2002). Of the source identified entries, 6 species had at least 50% survival in 2000: *Astragalus barrii*, *Astragalus crassicarpus*, *Astragalus utahensis*, *Oxytropis besseya v. fallax*, *Oxytropis campestris v. cusickii*, and *Oxytropis multiceps*. In comparison, 5 herbaceous legumes had greater than 50% survival in the 2000 evaluation of commercially available legumes : *Petalostemum purpureum*, *Petalostemum candidum*, *Thermopsis rhombifolia*, *Thermopsis montana*, and *Astragalus cicer*.

Overall rating results for 1998 show 5 species in the source identified planting with values of at least 1.75: *Astragalus kentrophyta v. kentrophyta*, *Astragalus utahensis*, *Oxytropis besseya v. fallax*, *Oxytropis campestris v. cusickii*, and *Oxytropis multiceps*. The commercial legume planting had 5 species with 1998 ratings greater than 1.75: *Astragalus cicer*, *Petalostemum purpureum*, *Thermopsis montana*, *Petalostemum candidum*, and *Thermopsis rhombifolia*. In 1998, 5 species of the source-identified material had at least 25% of live plants with seedheads: *Astragalus crassicarpus*, *Oxytropis besseya v. fallax*, *Oxytropis campestris v. cusickii*, *Oxytropis nana*, and *Oxytropis splendens*. A similar summary of commercial material reveals 3 herbaceous species with at least 25% of live plants with seedheads: *Astragalus missouriensis*, *Hedysarum boreale*, and *Medicago sativa*. The source-identified materials with the largest average height and width were *Oxytropis campestris v. cusickii* (12 cm x 20 cm) and *Oxytropis splendens* (11 cm x 14 cm). The maximum individual size (maximum height x maximum width) for these 2 species was 15 cm x 36 cm and 20 cm x 20 cm, respectively. The commercially available species that exceeded these 2 source-identified species in average height and width include *Hedysarum boreale* (36 cm x 43 cm), *Astragalus cicer* (14 cm x 33 cm), and *Medicago sativa* (10 cm x 30

cm). The commercial materials with the greatest maximum individual heights and widths include *Hedysarum boreale* (56 cm x 76 cm), *Astragalus cicer* (25 cm x 61 cm), *Thermopsis montana* (41 cm x 30 cm), and *Petalostemum candidum* (25 cm x 41 cm).

The source-identified species with superior performance for one or more attributes can be summarized as follows:

- *Oxytropis campestris v. cusickii* – superior vigor, survival, overall rating, seedhead production, and stature;
- *Oxytropis besseya v. fallax* - superior vigor, survival, overall rating, and seedhead production;
- *Astragalus utahensis* - superior vigor, survival, and overall rating;
- *Oxytropis multiceps* – superior vigor, survival, and overall rating;
- *Oxytropis splendens* – superior vigor, seedhead production, and stature;
- *Astragalus kentrophyta v. kentrophyta* – superior vigor and overall rating;
- *Oxytropis nana* – superior vigor and seedhead production;
- *Astragalus crassicarpus* - superior survival and seedhead production; and,
- *Astragalus barrii* – superior survival.

Several source-identified species (*Oxytropis campestris v. cusickii*, *Oxytropis besseya v. fallax*, *Astragalus utahensis*, and *Oxytropis multiceps*) had vigor and survival equivalent to the best performing commercially available herbaceous legumes tested in the earlier study. Two species (*Oxytropis campestris v. cusickii* and *Oxytropis splendens*) had stature comparable to some of the better performing commercial varieties tested. The species within the *Oxytropis* genus seemed to have generally better performance than the other genera, although a few Astragalus species had superior performance. The elevation of the collection site did not appear to be related to performance; 2 of best performers were of alpine origin (*Oxytropis campestris v. cusickii* and *Oxytropis splendens*) while *Oxytropis besseya v. fallax*, *Astragalus utahensis* and *Oxytropis multiceps* were collected at 5,700 to 6,600 feet.

Because seed of these source-identified species are generally collected in the wild and are not produced commercially, the cost of seed for these species will be extreme. If a diverse herbaceous legume component is desired in the revegetation species mix, then a small fraction of seed of these species could be included in a seed mix to target this goal.

Literature Cited:

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Table 2. Overall Survival Percentage and Mean Vigor of Live Plants at Spring Gulch and Blind Gulch Sites

Site	Species		1996 Overall Survival Percentage (%)	1997 Overall Survival Percentage (%)	1998 Overall Survival Percentage (%)	2000 Overall Survival Percentage (%)	1996 Overall Mean Vigor of Live Plants	1997 Overall Mean Vigor of Live Plants	1998 Overall Mean Vigor of Live Plants
Spring Gulch	ASBA		62	62	**62**	**52**	**2.31**	**1.92**	**2.00**
Spring Gulch	ASCR		38	71	33	**62**	1.00	1.67	1.14
Spring Gulch	ASDE		38	48	0	0	1.25	1.00	
Spring Gulch	ASKEJE		**83**	**100**	33	0	1.60	1.17	1.00
Spring Gulch	ASKEKE		56	56	**61**	17	**2.70**	**2.60**	**3.27**
Spring Gulch	ASSA		**83**	**83**	17	0	**2.10**	1.60	1.00
Spring Gulch	ASSP		33	17	33	0	1.00	1.00	1.00
Spring Gulch	ASUT		**90**	**95**	**86**	**52**	**2.84**	**2.25**	**2.61**
Spring Gulch	LOME		47	40	33	0	1.57	1.67	1.40
Spring Gulch	OXBEFA		**100**	**100**	**89**	**75**	**2.17**	**1.89**	**2.56**
Spring Gulch	OXCACU		78	72	**61**	**58**	**3.14**	**2.69**	**3.64**
Spring Gulch	OXMU		**95**	**100**	**90**	**64**	**2.90**	**2.48**	**3.05**
Spring Gulch	OXNA		67	67	**67**	17	**2.25**	**2.25**	**2.50**
Spring Gulch	OXSP		62	62	**52**	**38**	**3.00**	**2.31**	**3.09**
Spring Gulch	TRDA		**95**	**95**	**81**	29	**2.15**	1.75	1.71
Spring Gulch	TRPA		42	25	17	0	1.00	1.00	1.00
	mean		**67**	**68**	**51**	**29**	**2.06**	**1.83**	**2.06**
Blind Gulch	ASDEBA		22	22	11	0	1.75	1.25	1.50
Blind Gulch	ASUT		71	67	57	29	2.07	1.79	2.58
Blind Gulch	OXMU		67	83	67	67	2.75	2.40	3.00
Blind Gulch	TRDA		67	75	17	0	1.38	1.00	1.00

Table 3. Mean Height and Width in 2000, Overall Rating (Survival x Vigor), and Percentage of Plants with Seedheads at Spring Gulch and Blind Gulch Sites

Site	Species	2000 Mean Height (cm)	2000 Mean Width (cm)	1996 Overall Rating	1997 Overall Rating	1998 Overall Rating	1996 Overall Percentage of Plants with Seedheads (%)	1998 Overall Percentage of Plants with Seedheads (%)
Spring Gulch	ASBA	3	6	1.43	1.19	1.24	0	0
Spring Gulch	ASCR	3	8	0.38	1.19	0.38	**75**	**57**
Spring Gulch	ASDE			0.48	0.48		0	0
Spring Gulch	ASKEJE			1.33	1.17	0.33	0	0
Spring Gulch	ASKEKE	3	3	**1.50**	**1.44**	**2.00**	0	0
Spring Gulch	ASSA			**1.75**	**1.33**	0.17	0	0
Spring Gulch	ASSP			0.33	0.17	0.33	0	0
Spring Gulch	ASUT	3	8	**2.57**	**2.14**	**2.24**	**21**	6
Spring Gulch	LOME			0.73	0.67	0.47	0	0
Spring Gulch	OXBEFA	4	7	**2.17**	**1.89**	**2.28**	**50**	**50**
Spring Gulch	OXCACU	**12**	**20**	**2.44**	**1.94**	**2.22**	**64**	**64**
Spring Gulch	OXMU	3	8	**2.76**	**2.48**	**2.76**	**20**	0
Spring Gulch	OXNA	3	5	**1.50**	**1.50**	**1.67**	0	**25**
Spring Gulch	OXSP	**11**	**14**	**1.86**	**1.43**	**1.62**	**85**	**82**
Spring Gulch	TRDA	3	6	**2.05**	**1.67**	**1.38**	0	0
Spring Gulch	TRPA			0.42	0.25	0.17	0	0
	mean	**4**	**9**	**1.48**	**1.31**	**1.28**	**20**	**18**
Blind Gulch	ASDEBA	0	0	0.39	0.28	0.17	0	0
Blind Gulch	ASUT	3	13	1.48	1.19	1.48	0	0
Blind Gulch	OXMU	4	15	1.83	2.00	2.00	0	0
Blind Gulch	TRDA	0	0	0.92	0.75	0.17	0	0