REVEGETATION MONITORING AT BLOCK P MILL AND TAILINGS SITE, MONTANA[1]

J. Gant Massey,[2], and William H. Thompson

Abstract. In 1929, the Block P Mill and Tailings Site (Block P) near Monarch, MT was the largest lead producer in Montana. When the mill finally closed in 1943 the site left behind a legacy of barren, phytotoxic soil and an ongoing transport of hazardous trace elements into nearby streams. Problems included areas of soil acidity as low as 1.8 pH, and zones with highly elevated concentrations of arsenic, cadmium, copper, lead, zinc and manganese in both soils and tailings materials. As a result, much of Block P, which would have been fully covered with vegetation if undisturbed, was nearly devoid of plant life. In 2001, however, it was decided to clean up and restore Block P to a functional site with natural vegetation. In 2004 and 2005, waste materials were consolidated to a centralized repository. Then, soil amendments (compost, slow-release fertilizer and lime) were added to areas from which tailings were removed, leave-area soils and imported fill materials. In 2005 and 2006, the project site was replanted with native grass and forb seeds, as well as containerized woody plant species that had been propagated from local stock.

In July 2008, scientists from ESG monitored the status of revegetation at Block P. Monitoring included assessments of containerized woody plant survival, herbaceous cover, and overall cover on the nine revegetation units at the site. The monitoring results show a continued trend toward successful revegetation. The average containerized woody plant survival, weighted for unit size, was 74 percent, which exceeds the 70 percent project goal. Average herbaceous canopy cover and average total canopy cover of all plants across the entire project site are respectively 46 and 49 percent. The canopy cover of native species far exceeds non-native canopy cover, the cover of weedy exotic species is minimal, and hundreds of woody volunteer plants are appearing. The improvements in vegetation, environmental, and aesthetic values of the Block P Mill and Tailings site are clear and palpable, and demonstrate the efficacy of using appropriate soil amendments and site-adapted native plant species to restore even the most challenging of disturbed sites.

Additional Key Words: soil amendment, mine restoration, native plant species

---

[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]J. Gant Massey, Ph.D., and William H. Thompson are Founding Members and Plant Ecologists at Ecological Solutions Group, Stevensville, Montana 59870.

Proceedings America Society of Mining and Reclamation, 2009 pp 743-767
DOI: 10.21000/JASMR09010743

http://dx.doi.org/10.21000/JASMR09010743

Introduction

Revegetation and Mine Land Reclamation

Reestablishing vegetation on mined land is an important step in the overall reclamation process. In particular, vegetation aids in stabilizing the soil surface from erosion, thereby helping reduce the off-site transport of contaminants of potential concern (Strock 1998). Plant evapotranspiration also helps reduce the infiltration of water into mine wastes, thereby reducing the volume of mine drainage generated (Strock 1998). In restoration planning, however, the substrates of mine sites often present significant environmental challenges. This can include extremes of pH, the presence of trace elements in potentially phytotoxic concentrations, a dearth of organic materials and soil nutrients, and an absence of soil microbiological activity (Kabata-Pendia 2001, Munshower 1994).

Many researchers have recommended the use of soil amendments customized to site conditions (Schafer and Associates and MSU 1989) and site-adapted native plant species (Ballek 1999) to optimize the chances of successfully revegetating heavily-contaminated mine sites. This paper presents a case study in which these restoration techniques were utilized in an effort to revegetate the Block P Mill and Tailings Site (Block P) near Monarch, Montana, a heavily-contaminated Pb mill site, whose soils had been nearly barren for over 60 years. The paper presents the results of revegetation monitoring two years after restoration activities were completed on the site. As such, this case study examines the efficacy of using site-customized soil amendments and site-adapted native plant species in restoring extremely contaminated mine sites.

Site Location

The Block P Mill and Tailings Site is located in Section 13, Township 15N, Range 8E, near the confluence of Galena Creek and the Dry Fork of Belt Creek in Judith Basin County, Montana. Access is via Forest Service Road 120 (FS 120) approximately 16 kilometers (10 miles) east from U.S. Highway 89 at Monarch, Montana. The site lies at an elevation of approximately 1,655 meters (5,430 feet).

Background Information

Block P is a central point of the Barker-Hughesville Mining District of the Little Belt Mountains, Montana. Following the 1879 ore discovery in the Galena Creek drainage by

E. A. "Buck" Barker and Patrick H. Hughes, hundreds of mining claims were established in the district with several smelters constructed by 1881 (Robertson and Roby 1951, Wolle 1963). By the early 1900s, T. C. Power of Helena acquired the Barker, Grey Eagle, and Belt mines, operating them under the name of the Block P mine (Fig. 1). Power built a mill at Barker in 1910-1911, subsequently selling it to St. Joseph Lead Company in 1927 (Sommer 1991). By 1928, the St. Joseph Lead Company built a 400-ton selective flotation mill (Fig. 2), making it the largest producer of Pb in the state by 1929 (Robertson and Roby 1951, Sommer 1991). Economic difficulties of the Great Depression shut down the mill by late 1930, and although reopened briefly in the early 1940s, the site has not operated since 1943 (Sommer 1991).

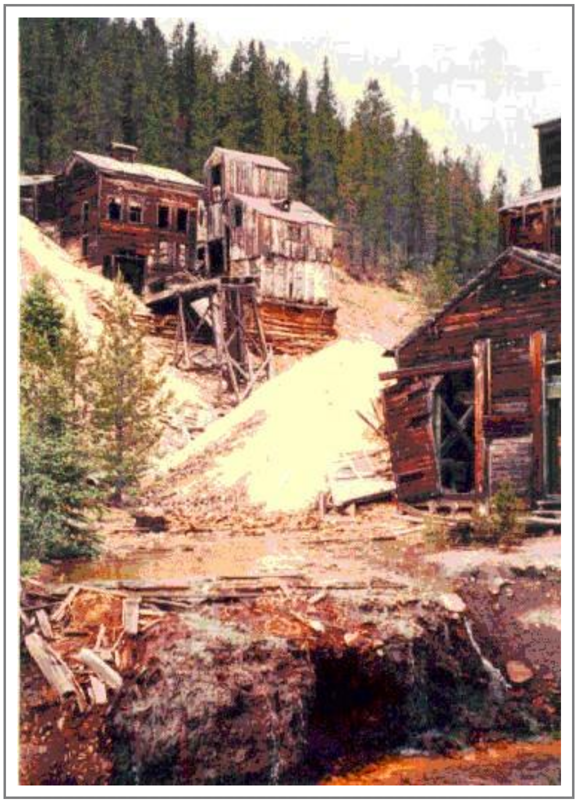

Figure 1. Block P mine (MT DEQ 1996)

Site soil samples in the mid-1980s revealed soil acidity at the Block P Mill Tailings site with averaging 5.8 pH, but in some cases as falling as low as 1.8 pH. The soil samples also contained elevated levels of As, Cd, Cu, Fe, Pb, Mn and Zn, as well as several other hazardous substances. As a result, much of Block P, entirely surrounded by completely vegetated land, was nearly devoid of plant life. The problem areas contained approximately 141,500 cubic meters (185,000 cubic yards) of mostly exposed and decayed waste rock located on approximately 6.6 hectares

(16.2 acres) near and along Galena Creek and the Dry Fork of Belt Creek (EPA 2007) (Fig. 3 and 4).

Figure 2. Block P mill site, 2005

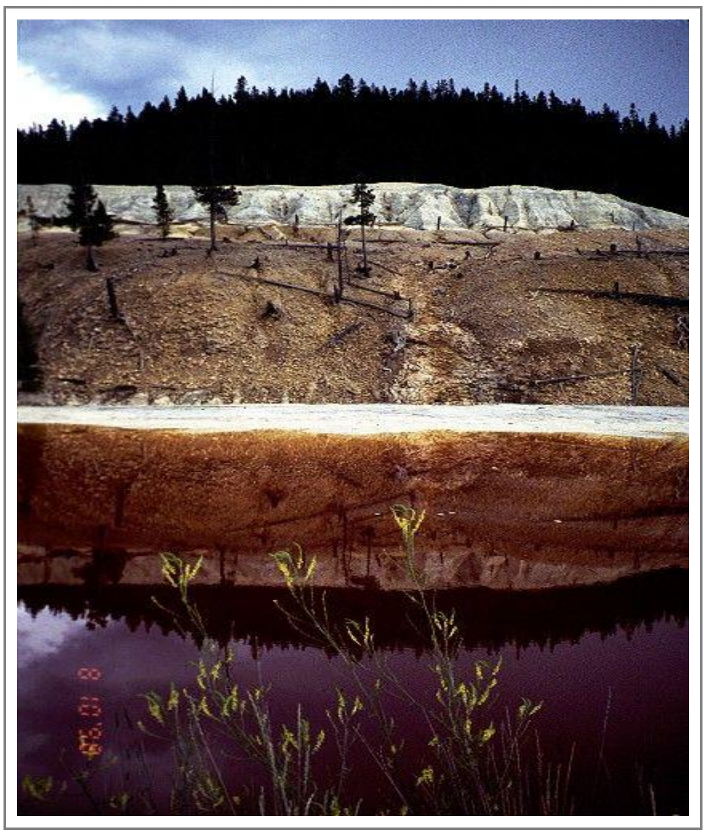

Figure 3. Block P mill tailings pile and diked tailings ponds, 1998

Figure 4. Dry Fork of Belt Creek near Bender Creek, 2005

Between 1998 and 2001, The Doe Run Company (Doe Run), the direct corporate successor to the St. Joseph Lead Company, prepared an Engineering Evaluation I Cost Analysis (EEICA) for the Block P Mill Tailings site. The June 2001 final EEICA recommended consolidation of mill tailings and other mining wastes into an onsite repository, followed by reclamation and revegetation of the areas disturbed by excavation and construction activities. The USDA-FS approved the EEICA, and Doe Run implemented the recommended removal alternative between 2004 and 2006. Work related to the excavation and onsite consolidation of over 38,000 cubic meters (50,000 cubic yards) of waste materials was performed by Shumaker Trucking and Excavating of Great Falls, MT.

Nonetheless, it was known prior to construction that sub-soils underlying areas of tailings removal and some leave areas (from which contaminated soils would not be removed) would remain strongly acidic and contain potentially phytotoxic concentrations of trace elements. In addition, these areas would be generally devoid of organic materials and soil nutrients. These soils were to be amended with compost, slow-release fertilizer, and lime to create a suitable planting medium for native species (Thompson and Massey 2005). Two additional areas would receive uncontaminated, if nutritionally impoverished, fill. This fill material also would be amended to create a suitable planting medium. The goal of the restoration was to create self-sustaining, site-appropriate native plant communities that would require no long-term maintenance, and that would be self-sustaining.

Soil amendment and revegetation protocols were tailored for nine (9) separate revegetation units at the Block P Mill Tailings site, based upon individual site conditions. These units are listed in Table 1, and shown in Fig. 5 and 6.

Table 1. Revegetation units and habitats at the Block P Mill and Tailings Site, Montana

Revegetation Unit	Hectares	Habitat
Repository Cap*	0.9	Upland
Skirt Slope	0.7	Upland
Mill Site	0.2	Upland
Diked Tailings	1.6	Upland/Wetland
Borrow Area*	1.0	Upland/Wetland
Migrated Tailings Area North of Rd 120	0.7	Upland/Wetland
Bender Creek Streamside Area	0.9	Wetland
Galena Creek Riparian Zone	0.4	Wetland
Migrated Tailings Area South of Rd 120	0.04	Wetland
Total Hectares	6.6	

*These revegetation units' soils are uncontaminated, but nutritionally deficient fill material. All other revegetation units contain soils with acidity and elevated trace element concentrations.

All revegetation units received slow release fertilizer (Biosol™ with N:P:K of 7:2:3) was added at the constant rate of 2.47 megagrams per hectare (1 U.S. ton/acre). Further, all containerized (rooted) tree and shrub plants were installed with an RTI Restoration Pak™ (N:P:K of 11:17:9) to provide additional soil nutrients. Compost rates were designed to increase the organic material fraction of the soil to approximately 2 to 3 percent of the soil dry weight. Due to inherent site differences of revegetation units, these targets resulted in different application rates (Table 2).

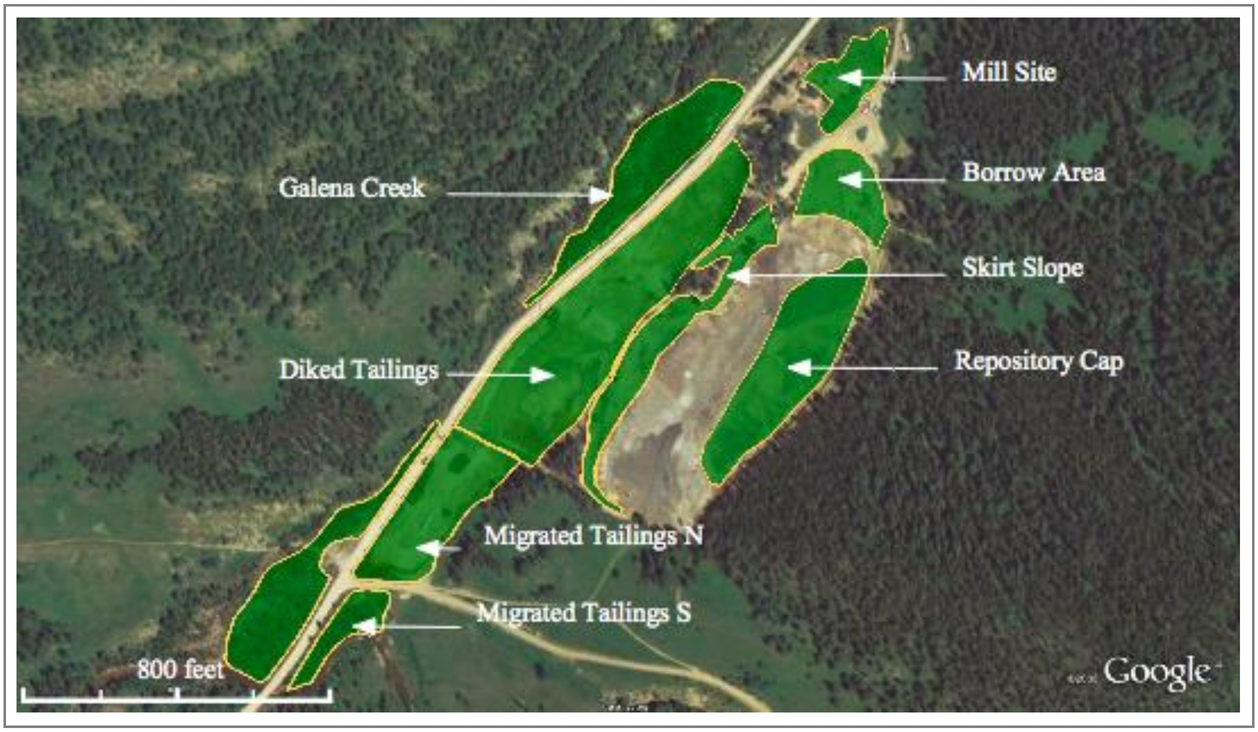

Figure 5. Revegetation Units, main Block P mill and tailings site (Google 2009)

Figure 6. Bender Creek revegetation units, Block P (Google 2009)

Table 2. Soil amendments by revegetation unit

Revegetation Unit	Compost Rate (megagrams/hectare)	Lime Rate (megagrams/hectare)
Repository Cap	277	4
Skirt Slope	189	39
Mill Site	79	211
Diked Tailings	278	119
Borrow Area	277	3
Migrated Tailings Area North of Rd 120	189	164
Bender Creek Streamside Area	208	26
Galena Creek Riparian Zone	232	56
Migrated Tailings Area South of Rd 120	189	291

Lime addition rates, as expressed in megagrams of lime to be added per 1,000 megagrams of mine waste, were calculated using the following formula (Equation 1):

Lime Rate (megagrams/ 1,000 megagrams) = [{(HNO3 extractable sulfur % + residual sulfur %) *31.25} + {HCl extractable sulfur % * 23.44} + {SMP lime requirement single buffer method in megagrams CaCO3 / 1,000 megagrams waste}] *1.25 **(1)**

This formula was developed to derive the quantity of lime necessary to neutralize both active and potential acidity in mine wastes (Schafer and Associates and MSU 1989). As shown in Table 2, this resulted in lime addition rates ranging from 2.47 megagrams/heactare (1 U.S. ton/acre) to over 321 megagrams/hectare (130 U.S. tons/acre). All soil amendments were chisel-plowed to a depth of 20 to 30.5 centimeters (8 to 12 inches), and all planting units in which soil acidity was of significant concern were given 6 months to mellow after the incorporation of lime.

Approximately 20 percent of the Block P site vegetation potential was categorized as riparian habitat, 30 percent upland habitat and 50 percent mixed riparian and upland. As shown in Tables 3, 4, 5 and 6, separate species palettes were developed for planting in each of the habitats in the nine revegetation units. These palettes include different grass and forb seed mixes for wetland

and upland zones, as well as different species of containerized (rooted) stock (Table 3). These seed mixes were spread by hydromulching.

Table 3. Grass and forb species and seeding application rates, Block P, Montana

Riparian (mesic to moist) Sites		Upland (dry) Sites	
Grasses	PLS kg/ha	Grasses	PLS kg/ha
Agrostis alba (redtop)	0.2	*Elymus trachycaulus* (slender wheatgrass)	3.6
Agrostis scabra (ticklegrass)	0.4	*Festuca idahoensis* (Idaho fescue)	2.7
Bromus marginatus (mountain brome)	5.4	*Festuca ovina* (sheep fescue)	1.3
Calamagrostis canadensis (bluejoint reedgrass)	0.5	*Koeleria macrantha* (Prairie junegrass)	0.6
Deschampsia cespitosa (tufted hairgrass)	0.4	*Pseudoregneria spicata* (blue bunch wheatgrass)	5.4
Elymus trachycaulus (slender wheatgrass)	3.6	Sterile Triticale cover crop	8.9
Phleum alpinum (alpine timothy)	0.4		
Sterile Triticale cover crop	8.9		
Forbs		Forbs	
Aster laevis (smooth aster)	0.2	*Achillia miulliflorum* (yarrow)	0.1
Solidago rigida (rigid goldenrod)	0.1	*Penstemon strictus* (Rocky Mountain penstemon)	0.2
Thermopsis montanus (golden banner)	0.9	*Potentilla gracilis* (slender cinquefoil)	0.3
Total PLS kg/ha:	21.0	Total PLS kg/ha:	23.0

Table 4. Planting palettes: containerized woody plants installed by species and habitat type, Block P, Montana

Species	Mixed	Riparian	Upland	Totals
Alnus incana (mountain alder)	n/a	144	n/a	144
Arctostaphylos uva-ursi (kinnikinnick)	403	72	1,120	1,595
Berberis repens (creeping Oregongrape)	403	n/a	214	617
Betula occidentalis (water birch)	149	108	n/a	257
Cornus stolonifera (red-osier dogwood)	258	163	n/a	421
Juniperus communis (common juniper)	n/a	n/a	283	283
Juniperus horizontalis (creeping juniper)	n/a	n/a	283	283
Prunus virginiana (common chokecherry)	142	189	109	440
Rosa woodsii (Woods rose)	636	225	695	1,556
Salix bebbiana (Bebb willow)	n/a	144	n/a	144
Salix boothii (Booth willow)	n/a	144	n/a	144
Salix drummondiana (Drummond willow)	n/a	108	n/a	108
Salix exigua (sandbar willow)	n/a	144	n/a	144
Shepherdia canadensis (Canada buffaloberry)	77	n/a	123	200
Spiraea betulifolia (Shiney-leaf spiraea)	403	n/a	497	900
Symphoricarpos album (common snowberry)	366	72	283	721
Picea glauca (white spruce)	290	105	n/a	395
Pinus contorta (lodgepole pine)	823	98	21	942
Populus tremuloides (quaking aspen)	341	7	n/a	348
Populus trichocarpa (black cottonwood)	98	98	n/a	196
Pseudotsuga menziesii (Douglas fir)	1,107	105	21	1,233
Totals	5,496	1,926	3,649	11,071

Table 5. Planting palette species counts by life form, Block P, Montana

Revegetation Unit	Trees	Shrubs	Grasses	Forbs	Total
Repository Cap	0	6	6	3	15
Skirt Slope	0	6	6	3	15
Mill Site	2	4	6	3	15
Diked Tailings	4	8	16	6	34
Borrow Area	4	8	16	6	34
Migrated Tailings Area North of Rd 120	3	7	16	6	32
Bender Creek Streamside Area	4	9	10	3	26
Galena Creek Riparian Zone	0	8	10	3	21
Migrated Tailings Area South of Rd 120	3	7	10	3	23

Table 6. Planting palettes: containerized woody plant counts and spacing, Block P, Montana

Revegetation Unit	Trees	Shrubs	Total Woody Plants	Spacing (m)
Repository Cap	0	2,419	2,419	1.9
Skirt Slope	0	1,099	1,099	2.6
Mill Site	42	89	131	3.9
Diked Tailings	1,621	1,216	2,837	2.4
Borrow Area	867	650	1,517	2.6
Migrated Tailings Area North of Rd 120	294	848	1,142	2.5
Bender Creek Streamside Area	392	1,047	1,439	2.5
Galena Creek Riparian Zone	0	396	396	3.2
Migrated Tailings Area South of Rd 120	21	70	91	2.1
Totals	3,237	7,834	11,071	2.4

Woody plant materials were specified as 164 cubic centimeter (10 cubic inch) or 10x10x36 centimeter (4x4x14 inch) Tree-pots. Woody propagules for this project were grown from site-adapted seed or cuttings collected in the vicinity of Block P, with plant production shortfalls being supplemented by stock from other western Montana sources of similar ecological setting. Planting densities were designed to meet immediate concerns (i.e., expected planting survival rate and the need for quick establishment of cover on the site), as well as the ultimate goal of a natural community appropriate for each unit.

Soil amendment and revegetation work was performed by Bitterroot Restoration, Inc. of Corvallis, MT, with assistance by Arrowhead Reclamation of Whitehall, MT. Revegetation work began in fall 2005 and was completed in June 2006.

Methods and Materials

On July 19-21, 2007 and on July 18-19, 2008, scientists from ESG monitored revegetation efforts at the Block P Mill Site near Monarch, MT, using the following methods. Except as specified below, ESG established in 2007 one transect in each of the nine revegetation units (length of app. 50 meters), with the Bender Creek, the Tailings Repository Cap and the Lower Diked Tailings Area each receiving two transects, due to their large size. Each end of the transects was staked and monumented via sub-meter GPS.

For the purposes of making multi-year observations of plant survivability and vigor, three quadrats were established along each transect at the randomly selected points of 5, 28 and 42 meters (respectively, 16, 91 and 139 feet). Each quadrat was 6-meters by 6-meters (19.7 feet by 19.7 feet) in size, and was randomly placed to a side of the transect (see Fig. 7 and Fig. 8). The quadrat size was chosen to capture vegetation data from approximately 2 percent of the entire project area.

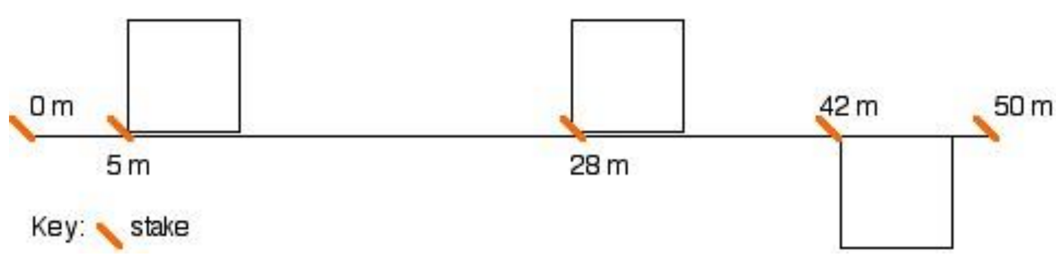

Figure 7. Transect layout

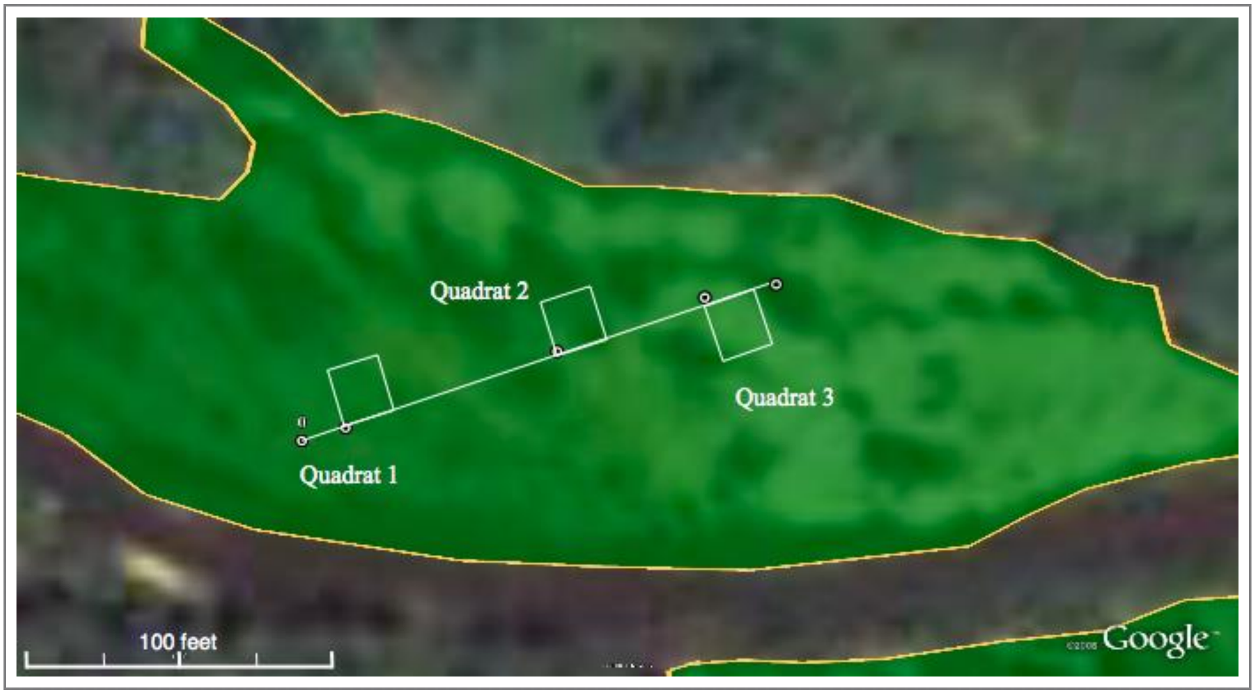

Figure 8. Transect layout on Bender Creek NW planting unit
(Google 2009)

Due to the small sizes and non-homogenous shapes of revegetation units within the Galena Creek and Migrated Tailings Area South of Route 120, it was not possible to establish transects consistent with the other units. Instead, within the Galena Creek area, three 6-meter by 6-meter (19.7 feet by 19.7 feet) quadrats were randomly placed in the revegetation unit to capture the three major areas of soil amendment and planting work. Within the Migrated Tailings Area South of Route 120, two 6-meter by 6-meter (19.7 feet by 19.7 feet) quadrats were established at the north end of the unit, and a 2-meter by 18-meter quadrat (6.6 feet by 59.0 feet) was placed parallel to Forest Road 120 at the southern end of the unit.

Within all quadrats, ESG recorded these data, with plant canopy cover as a percent of quadrate area collected per Daubenmire (1959): woody species count, vigor, and canopy cover; herbaceous species canopy cover; total canopy cover. Each revegetation unit was also inspected for general signs of plant survival and vigor, as well as general site conditions (i.e., bare ground, noxious weed presence, uncontrolled erosion, etc.)

Results and Discussion

Plant Cover

Table 7 shows the results of monitoring for woody plant cover, herbaceous cover, and total cover. These data have been averaged for each revegetation unit, so as to not give double weight to a unit that had more than one transect, and the final totals are weighted by area, so as to ensure equal influence of large and small area units.

Table 7. Average plant canopy cover: 2008

Revegetation Unit	Woody Cover (percent)	Herbaceous Cover (percent)	Total Cover (percent)
Tailings Repository Cap	1	16	17
Skirt Slope and Haul Road	1	26	28
Mill Foundation Area	2	24	26
Lower Diked Tailings Area	2	57	59
New Stream Channel north of Repository	4	34	38
Migrated Tailings Area north of Rd 120	1	56	57
Bender Creek Streamside Area	7	76	83
Galena Creek Riparian Zone	9	49	57
Migrated Tailings Area south of Rd 120	5	100	106
Average Cover	4	49	52
Average Cover Weighted for Unit Size	3	46	49

These cover values show a major increase in plant cover from pre-restoration conditions, in which little to no plant cover was present. As one of the long-term goals of the restoration plan was the development of self-sustaining vegetation communities, this data seems to bode well for the future of the Block P Mill and Tailings site.

On every revegetation unit but one (the Migrated Tailings Area north of Rd 120), the species encountered in 2008 exceeded the number of species seeded and installed due to natural recruitment (Table 8). Native species cover far exceeded non-native species. Further, weedy, exotic invasive plant species had gained no more than a slight presence (0.8 percent average average cover) on the revegetated plots. Nonetheless, weed encroachment will remain one foci of continued monitoring. Within the upland sites, new grasses and forbs equally accounted for the increase in species count, while in the wetland/upland and wetland sites, forb species accounted for most of the increase in species count. Further, hundreds of volunteer woody plants (i.e., seedlings not planted as part of the study) are appearing in the wetland revegetation units.

Table 8. Plant species count by revegetation unit

Revegetation Units	Installed Species Count	2008 Species Count
Tailings Repository Cap	15	23
Skirt Slope and Haul Road	15	27
Mill Foundation Area	15	31
Lower Diked Tailings Area	34	35
New Stream Channel north of Repository	34	38
Migrated Tailings Area north of Rd 120	32	25
Bender Creek Streamside Area	26	32
Galena Creek Riparian Zone	21	40
Migrated Tailings Area south of Rd 120	23	46

Among forb species, common sagewort (*Artemisia absinthium*) had the greatest cover (2.1 percent) when present in a quadrat, but only a moderate constancy (45 percent of quadrats). By contrast, common yarrow (*Achillea millefolium*) was present in 61 percent of quadrats, but its average cover when present was only 0.5 percent. Among grass species, redtop (*Agrostis stolonifera*) had the greatest cover (27 percent average), although it was found in only two-thirds (67 percent) of quadrats. Bearded wheatgrass (*Elymus trachycaulus*) had the greatest constancy (94 percent of quadrats), but had only a 7.9 percent average cover.

Among shrub species, mountain alder (*Alnus incana*) had the greatest average cover when present, although at 1 percent, this is not a dominant species. Further, mountain alder (*Alnus incana*) had a constancy of only 15 percent, trailing far behind wood’s rose (*Rosa woodsii*), which had a constancy of 61 percent and almost an equal cover of 0.8 percent when present in a quadrat. Among tree species, black cottonwood (*Populus trichocarpa*) had the greatest average cover (4 percent) when present, followed by lodgepole pine (*Pinus contorta*) at 2 percent. These two species also shared the greatest constancy among trees, appearing in 18 percent of quadrats.

Containerized Woody Plant Survival

Table 9 shows how many woody plants were expected within the sampling quadrats, as well as the survival monitoring results for 2007 and 2008. In the final column, the 2008 data have been averaged for each revegetation unit, so as to not give double weight to an area that had more than one transect; and weighted by area, so as to not give the data from small units disproportionate influence over larger ones.

Table 8. Containerized woody plant survival: 2007 and 2008

Restoration Unit	Expected Count	2007 Count	2008 Count	2008 Percent Survival by Unit	2008 Area-Weighted Percent Survival
Tailings Repository Cap	29.3	18.5*	22	75	10
Skirt Slope and Haul Road	16.3	13	15	92	10
Mill Foundation Area	7	2	3	43	1
Lower Diked Tailings Area	18.9	15.5*	12	63	16
Borrow Area	16.2	6	5	31	5
Migrated Tailings Area north of Rd 120	16.9	14	9	53	6
Bender Creek Streamside Area	16.7	18	17	102	14
Galena Creek Riparian Zone	10.6	20	18	170	10
Migrated Tailings Area south of Rd 120	24.3	33	35	144	1
Totals	156	140	136	87	74

*Averaged from two transects

These monitoring results show very strong survival trends for the containerized woody plant material. The 74 percent average survival across all units (as weighted for unit size) in 2008 is a slight drop from the survival rate of 81 percent that was measured in 2007, but still surpasses the 70 percent project goal for woody plant survival. Ninety-nine percent of the plants that were still present were vigorous in 2008, versus 95 percent of the plants examined in 2007. Given the project goal of 70 percent cumulative survival across all revegetation units, the containerized plant survival data indicate that project goals are currently being met.

Water Availability

Water availability is the strongest environmental factor in governing plant growth and survival at Block P. As shown in Table 10, dry upland areas, such as the Mill Foundation, Tailings Repository Cap and Skirt Slope, had the lowest plant cover and species count, while wetland areas, such as Bender Creek and the Migrated Tailings Area South of FS Road 120, have the highest plant cover and species count.

Table 10. Average plant canopy cover and species count by habitat: 2008

	Woody Percent Cover	Herbaceous Percent Cover	Total Percent Cover	Expected Species Count	2008 Species Count	Containerized Plant Count
Upland	1.3*	22.0	23.7	15	27	70
Upland/Wetland	2.3	49.0	51.3	33	33	49*
Wetland	7.0*	75.0	82.0	23	39	139*

*Statistically significant difference in categories using ANOVA and Bonferroni/Dunn post-hoc test at alpha = 0.05

Interestingly, the mixed upland/wetland sites had lower containerized woody plant survival than either the upland or wetland habitats. Although an experimental explanation is not available, observation suggests that a combination of herbivory and less than optimal mixing into the soil of amendments that had been stockpiled in these units may have contributed to containerized plant mortality in the mixed upland/wetland habitats.

Conclusion

As indicated in the monitoring results, and as may be seen in Fig. 11-22, the post-restoration improvements in vegetation, environmental and aesthetic values of the Block P Mill and Tailings site are apparent. Vegetation cover has increased from nearly nothing to nearly 50 percent, and plants are now growing in areas that had been barren for over 60 years. Of course, the true measure of this project’s success will not be known for several decades. Residual acidity and presence of trace elements, browse animal damage and weed invasions are some of the long-term issues with which the vegetation of the site must contend. Nonetheless, in the short term, these revegetation efforts have not just taken root, they are flourishing. As such, the monitoring results support the efficacy of using soil amendments customized to specific site conditions and site-adapted native plant species to restore even the most challenging of contaminated sites.

Figure 12. Lower Diked Tailings Unit and Skirt Slope, 2008

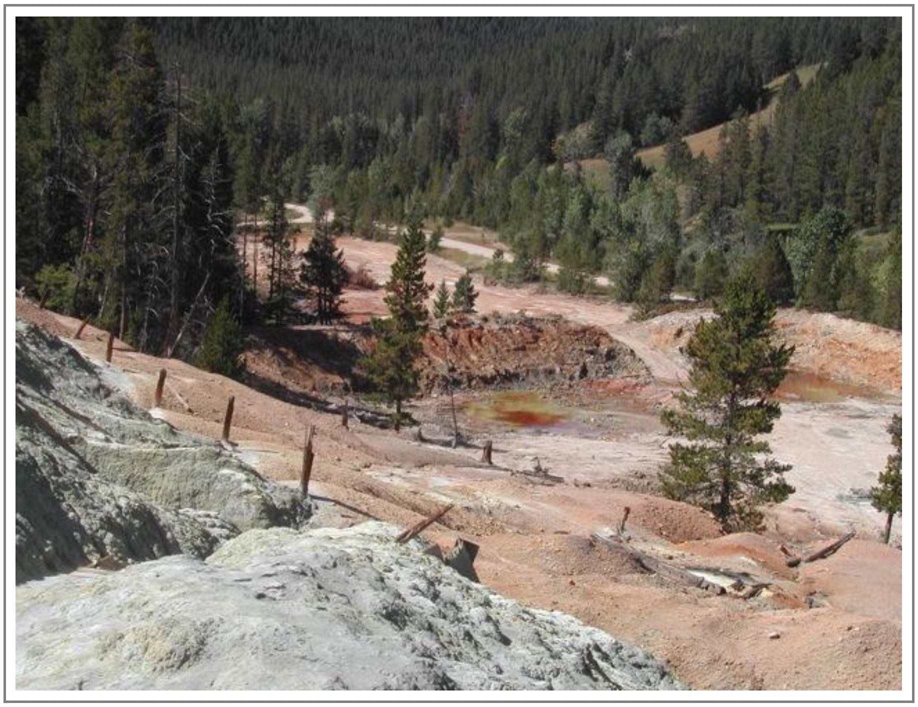

Figure 13. Migrated Tailings Unit North of FS 120 and Lower Diked Tailings Units, 2005

Figure 14. Migrated Tailings Unit North of FS 120 and Lower Diked Tailings Units, 2008

Figure 15. Migrated Tailings Unit North of FS 120, 2004

Figure 16. Migrated Tailings Unit North of FS 120, 2008

Figure 17. Migrated Tailings Unit South of FS 120, 2005

Figure 18. Migrated Tailings Unit South of FS 120, 2008

Figure 19. Bender Creek Unit, 2005

Figure 20. Bender Creek Unit, 2008

Figure 21. Tailings Repository Cap Unit, 1998

Figure 22. Tailings Repository Cap Unit, 2008

Acknowledgements

The authors would like to acknowledge the long-term support and funding of Mr. John Hunt of Barr Engineering Company, Minneapolis, Minnesota, and Mr. John Carter of The Doe Run Company, Viburnum, Missouri, for all work at the Block P Mill and Tailings site. The authors would also like to acknowledge the support and involvement of the management and staff of Bitterroot Restoration, Inc., Corvallis, Montana, and Arrowhead Reclamation, Whitehall, Montana, in creating and implementing restoration plans at the site. Thanks are also extended to Mr. Tom Parker, now of Geum Consulting, who, over 10 years ago, introduced Dr. Massey to the complex puzzle that is Block P.

Literature Cited

Ballek, Len. 1999. Montana: Site adapted container grown woody plants for mine reclamation. *In* Proceedings of the enhancement of reforestation at surface coal mines--Technical Interactive Forum, held March 23-24, 1999 at the Drawbridge Inn and Convention Center in Fort Mitchell, Kentucky, U.S.A. U.S. Department of the Interior, Office of Surface Mining, Coal Research Center, Southern Illinois, University, Carbondale, Illinois, U.S.A. 274 p.

Bonham, C. D. 1989. Measurements for terrestrial vegetation. John Wiley & Sons, New York, New York, U.S.A.

Coulloudon, B., K. Eshelman, J. Gianola, N. Habich, L. Hughes, C. Johnson, M. Pellant, P. Podborny. A. Rasmussen, B. Robles, P. Shaver, J. Spehar, J. Willoughby. 1999. Sampling vegetation attributes. BLM Technical Reference 1734-4, Denver, Colorado, U.S.A.

Daubenmire, R. D. 1959. A canopy-coverage method of vegetation analysis. Northwest Science 33: 43-66.

EPA (Environmental Protection Agency). 200NPL site narrative for Barker-Hughesville Mining District. (http://www.epa.gov/superfund/sites/npl/nar1617.htm, January 23, 2009). Washington, D.C., U.S.A.

Google. 2008. Google Earth Pro. 4.3.7284.3916 (beta). Google, 1600 Amphitheatre Parkway, Mountain View, California, U.S.A.

Kabata-Pendias, Alina. 2001. Trace elements in sols and plants. Third edition. CRC Press. Boca Raton, Florida, U.S.A. 315 p.

MT DEQ (Montana Department of Environmental Quality). 1996. A Guide to abandoned mine reclamation. Helena, Montana. U.S.A. 35 p.

Munshower, F. F. 1994. Practical handbook of disturbed land revegetation. CRC Press, Inc., Boca Raton, Florida, U.S.A. 288 p.

Robertson, Almon F., and Robert N. Roby. 1951. Mines and mineral deposits (except fuels), Judith Basin County, Montana. Information Circular 7602. United States Department of the Interior, Bureau of Mines. n.p. *In* Montana Department of Environmental Quality. 2004. Historical narrative of the Barker-Hughesville mining district. (http://deq.mt.gov/abandonedmines/linkdocs/techdocs/90tech.asp, January 23, 2009). Montana Abandoned Mine Program, Montana Department of Environmental Quality, Helena, Montana, U.S.A.

Schafer and Associates and Reclamation Research Unit (MSU). 1989a. Streambank Tailings and Revegetation Study-Phase I. Montana Department of Health and Environmental Sciences Final Report, Helena, Montana, U.S.A.

Sommer, Barbara. 1991. Cultural resource inventory and assessment of the Barker/Hughesville Mining District. Prepared by GCM Services, Inc. for Chen-Northern, under contract with the Montana Department of State Lands. *In* Montana Department of Environmental Quality.

2004. Historical narrative of the Barker-Hughesville mining district. (http://deq.mt.gov/abandonedmines/linkdocs/techdocs/90tech.asp, January 23, 2009). Montana Abandoned Mine Program, Montana Department of Environmental Quality, Helena, Montana, U.S.A.

Strock, Nevin. 1998. Reclamation and revegetation. *In* Coal Mine Drainage Prediction and Pollution Prevention in Pennsylvania: Pennsylvania Department of Environmental Protection, Brady, B.C., Kania, T., Smith, W.M., and Hornberger, R.J., eds., 398 p. http://www.ott.wrcc.osmre.gov/library/pub/cmdpppp.htm

Thompson, William H. and Gant Massey. 2005. Block P mill tailings site revegetation plan. Bitterroot Restoration, Inc., Corvallis, Montana, U.S.A. 23p.

Wolle, Muriel Sibell. 1963. Montana Pay Dirt: A guide to the mining camps of the treasure state. Sage Books, Denver, Colorado. n.p. *In* Montana Department of Environmental Quality. 2004. Historical narrative of the Barker-Hughesville mining district. (http://deq.mt.gov/abandonedmines/linkdocs/techdocs/90tech.asp, January 23, 2009). Montana Abandoned Mine Program, Montana Department of Environmental Quality, Helena, Montana, U.S.A.