Proceedings Tailings and Mine Waste 2011
Vancouver, BC, November 6 to 9, 2011

Burlington Mine VCUP Case History: an Ecological Approach to Mine Site Remediation

Maureen O'Shea-Stone

Director, Ecological Solutions and Natural Systems
Walsh Environmental Scientists and Engineers, LLC, Boulder, USA

Abstract

This paper discusses the ecological approach and long-term results of remediation of the Burlington Mine, Boulder County, Colorado under a Voluntary Clean Up (VCUP) action.

Located in the eastern Rocky Mountain foothills, this mine produced fluorspar from 1920 to 1973. Prior to the VCUP action, the vacant mine property was dominated by an unvegetated slope covered by a large, acidic waste rock pile, with unprotected mine adit and shaft openings, and numerous subsidence features. An intermittent creek crossed the waste rock, capturing and conducting surface water drainage from the waste rock downstream to confluence with James Creek.

Remediation goals integrated an ecologically-based approach to create a self-sustaining local system that would:

- establish a naturalistic and functional, self-sustaining plant community,
- improve water quality in down gradient receiving streams by reducing surface and ground water interaction with waste rock;
- limit potential for future subsidence; and
- reduce onsite safety hazards and liability.

The VCUP design integrated several innovative techniques that resulted in exceeding basic requirements, met multiple project goals, and accommodated the abundant physical constraints and challenges of remediating a high-altitude mine site. The paper reviews details of the remediation actions and presents monitoring results four years after completion of the VCUP.

Introduction

Site History

The Burlington Mine site is approximately one mile northwest of Jamestown, at the intersection of County Roads 94 and 87, in Boulder County, Colorado. The site is located on the western side of Porphyry Mountain at an elevation of about 7,300 feet (2,225 meters) and was considered part of the Jamestown Mining District, at the northeast end of the Colorado mineral belt. The district began as primarily a gold-producing area. Silver, lead, and other minerals were also produced. Uranium is present in the ores from the district but does not appear to have been a major product. In later years, the district became one of the chief fluorspar producers in the western United States, of which the Burlington Mine represented the largest deposit in the district. At least eight other mines occur within a half-mile (805 meters) of the Burlington site.

The history of the Burlington Mine site is taken from Walsh (2002). Records indicate that Frank and James Warren originally patented the Burlington claim in 1920. General Chemical Corporation, later a division of Allied Chemical Corporation, began mining the Burlington fluorspar ore body in 1942 and remained a large producer for more than 30 years.

Extensive development began in the early 1940s when General Chemical Company purchased the mine (Photo 1). Between 1943 and 1973, the mine was enlarged from a single 150 foot (46 meter) shaft with workings on two levels to a depth of over 1,500 feet (457 meters), reportedly the deepest mine in the district, with more than 10,000 linear feet (3,048 meters) of workings on 14 levels. A small, open cut mine was begun on the hillside above the Balarat Hill Road and the surface structures of the mine about 1971, but was only worked for a short time. Throughout the period of ownership by General Chemical and Allied, ore from the Burlington Mine Site was shipped to Boulder for production of acid-grade fluorspar. It does not appear that milling ever occurred at the mine site.

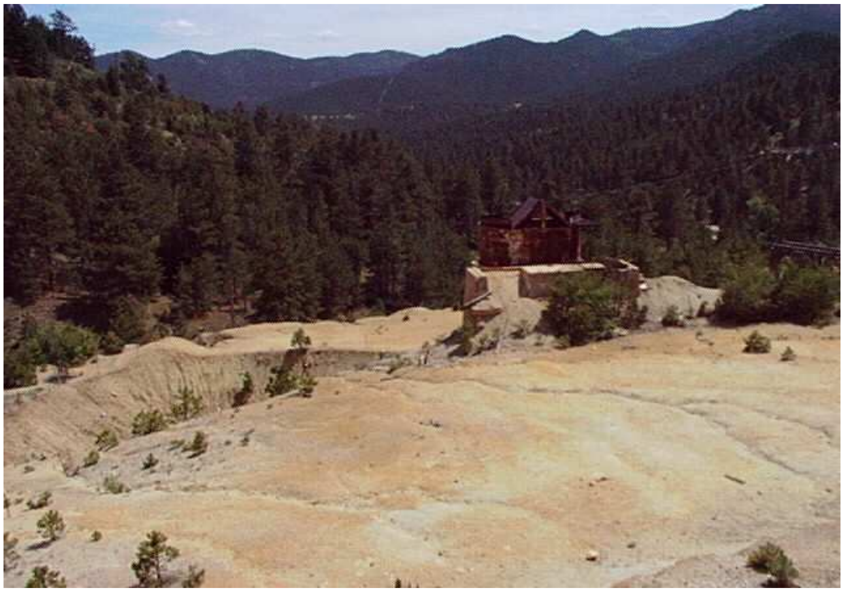

Photo 1. View of the Burlington fluorspar mine complex, around 1940, including the mine adit, waste rock pile, residences, and a hoisting tower.

According to a 1975 mine inspector's report, the Burlington Mine Site was shut down in 1973. It was reported that 16 acres (6.5 hectares) were reclaimed that year. In addition, buildings on site were torn down and the collar of the shaft was filled with concrete. The report stated that one-fourth acre (0.16 hectares) of land was mined and two acres (0.8 hectares) were used as a mine waste rock disposal area.

In 1982, Boulder County nominated the site (as part of the larger mining district) for listing as an uncontrolled hazardous waste site. The Environmental Protection Agency (EPA) performed a Preliminary Assessment of the Golden Age Mine in 1993 and an Expanded Site Inspection (ESI) in 1997. The Burlington Mine Site was included in the study area with three other local mines, the streamside, and a tailings deposit in the Jamestown town park. No notifications for hazardous substances were required. The site was found to not be eligible for listing on the National Priorities List (NPL) of Superfund sites established under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

Existing Conditions

At the time of the VCUP, the site was a vacant mining property, dominated by an unvegetated waste rock feature (Photo 2). Two subsidence pits and a large mine shaft opening presented significant hazards and impacts to water quality. A concrete and steel ore bin and loading structure and several building foundations remained on the property. The Balarat Hill Road (County Road 82) crossed the site on the north, between the main mine site and the secondary open cut mine to the north (Photo 3). The largest subsidence pit was intercepting flows in Balarat Gulch and creating direct flow path into mine workings. Interaction with mine workings and waste rock resulted in potential water quality impacts downstream to Little James Creek (Photo 4) and ultimately to Left Hand Creek. A pond at the southern toe of the waste rock pile also drained into Balarat Gulch (Photo 5).

Impetus for VCUP

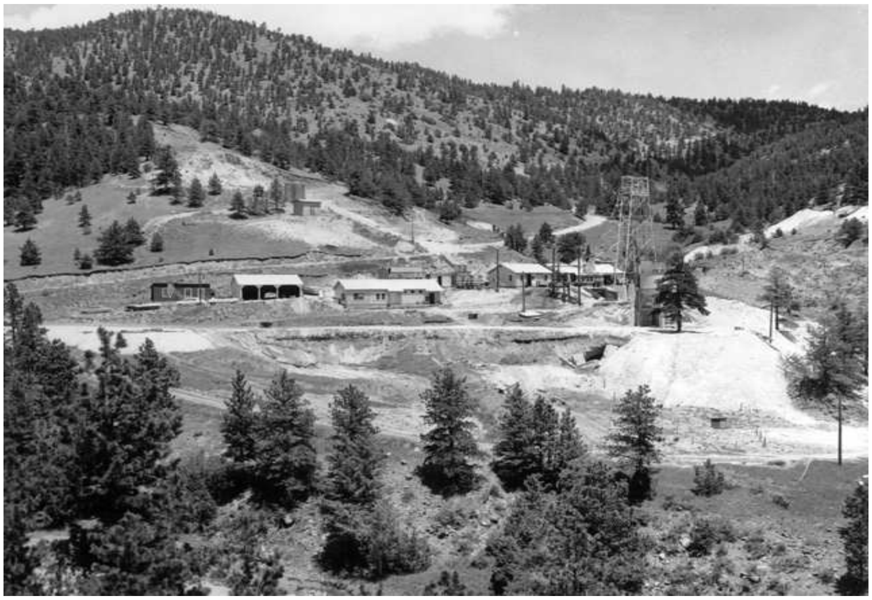

Photo 2. Ore bin and loading structure amidst waste unvegetated waste rock pile.

The Voluntary Cleanup and Redevelopment Act (VCRA), effective July 1, 1994, is a program designed to foster a cooperative relationship between applicants and the Colorado Department of Public Health and the Environment (CDPHE). It is designed to solve problems to the mutual benefit of both parties, and avoid sometimes inefficient enforcement actions. Properties must not fall within the authority of other environmental enforcement programs, and the program has no enforcement authority. The owner of a property in the program may choose not to implement cleanup and no referral to any other regulatory program would occur. The program encourages voluntary cleanups of contaminated industrial and commercial properties by providing a framework for determining site-specific clean-up responsibilities and an expedited review and approval process.

Remediation Goals

Primary goals for the VCUP included: use an ecological approach,

- improve water quality in downstream receiving streams,
- establish a naturalistic and functional, self-sustaining plant community,
- reduce surface and groundwater interaction with contaminated materials,
- limit the potential for future subsidence, and
- reduce onsite safety hazards and liability.

Remedial activities consisted of consolidating acid-generating waste rock, closure of onsite adits and shafts, subsidence pit fill and mounding, realignment of an intermittent tributary, surface water runoff management, and site-wide revegetation.

Engineering Actions and Results

The use of more natural and naturally functioning systems was a project goal that exceeded basic requirements. Their successful implementation at the Burlington Mine Site faced notable challenges to accommodate multiple project goals, as well as the abundant physical constraints at the mine site. In regards to site drainage, the use of natural systems is an important improvement over more traditional mine site remediation, which has always addressed safe conveyance of onsite water, but not necessarily how to restore natural form and function or how to use the water to maximize habitat value for wildlife.

Photo 3. Secondary open cut mine.

Water Quality Improvement

The goal of water quality improvement was addressed through a combination of diverse treatments, each of which served to reduce the interaction of surface and groundwater with the contaminated mine waste materials and underground mine workings located onsite.

Sitewide Treatments

Activities to correct sitewide surface and groundwater interactions included surficial waste rock consolidation, subsidence pit fill and mounding, soil amendments and topdressing, and revegetation with native species. The waste rock consolidation reduced the footprint of contaminated materials onsite, which reduced the area of potential contact and interaction.

Photo 4. Interception of Balarat Gulch by largest subsidence pit.

Under existing conditions, the subsidence pits were providing direct flow paths into the mine workings. Of particular concern was the pit that intercepted Balarat Gulch, an intermittent drainage that drains to Little James Creek and ultimately to Left Hand Creek. Backfilling this pit was the first step in eliminating the direct flow path for the gulch into the mine workings. Final grading included substantial mounding over the backfilled pits to create a minimum two percent slope. The positive slope created by the mounding discourages infiltration – and potential contact with mine workings – by promoting runoff. In anticipation of backfill settling, the area was overmounded by a minimum of 4 feet (1.2 meters).

Soil amendment included an agricultural lime application to neutralize the acid generation potential of the waste rock. All areas slated for revegetation were capped with a native soil layer and covered with compost. These topdressing layers serve two purposes: 1) they create a physical barrier to precipitation contacting the potentially acid generating materials below and 2) they provide a suitable growth medium for the revegetation effort. The physical barrier is actually a second level of protection against acid mine drainage generation because the waste rock was neutralized by the lime treatment. Revegetation helped stabilize the site and promote evapotranspiration and interception of precipitation over infiltration.

Photo 5. Mine pond at toe of waste rock pile.

Balarat Gulch Treatments

Activities to correct the surface and groundwater interactions associated with Balarat Gulch included control of subsurface flows and construction of a diversion channel that realigned the drainage to avoid mine workings. A projection to ground surface, created from 3-D mine mapping developed for the site, was used to identify the optimal centerline location and inverts for the diversion channel. The realignment routes flows to the east of the old subsidence areas. The diversion channel was sized to contain the 100-year storm event (plus 20 percent) within the protected main channel banks. The 100-year design reasonably protects against surface water re-accessing the mine workings by overflowing the diversion channel.

The critical upper reach of the diversion channel, where the channel makes a sharp bend away from its historic path, was lined with a PVC liner to force water to stay in the channel and further reduce the potential for piping failure behind the channel's boulder wall bank protection. The two lower reaches of the diversion channel were left unlined to allow hillslope groundwater to access the new channel, rather than being forced underneath where it could potentially reach the underground mine workings.

While the diversion channel adequately rerouted surface flows in the Gulch, a substantial portion of the total flow was being conveyed below the surface through the alluvium and along the bedrock contact. This subsurface flow had to be intercepted along with surface flows to successfully prevent water from reaching the mine workings. A primary alluvial water control structure, extending down to bedrock, was installed at the top of the diversion channel. Depth to bedrock was determined by a geotechnical drilling program.

Two main components comprised the alluvial control structure – a curtain drain and an impermeable liner. The curtain drain was constructed of prefabricated drainage panels with perforated PVC pipe threaded through bottom sleeves. The drain conveys the intercepted water. The impermeable lining traps the intercepted water, preventing it from bypassing the structure and forcing it into the curtain drain system. As a secondary control, a scavenger drain installed to protect the pit closures was located where it could capture water not intercepted by the upslope primary control. The scavenger drain also captures local groundwater flowing toward the closed features.

The combination of rerouting flows, pit backfill, and subsurface water control provides solid protection against flows re-accessing the mine workings. By preventing contact with the workings, cleaner water is delivered downstream.

Erosion and Sedimentation Controls

Additional measures were implemented to control erosion and sedimentation at the site long-term. Site grading and drainage included construction of a surface water control channel network, which conveys runoff through the site in a controlled manner and prevents the formation of rills or gullies to minimize sediment entrainment. Construction best management practices (BMPs) were employed to provide interim protection until vegetation becomes fully established at the site.

The sitewide revegetation also assists with erosion and sediment control. Vegetation stabilizes the soil, decreasing erosion from stormwater runoff. Site grading followed a maximum 3H:1V slope wherever possible to assist the revegetation efforts and prevent excessive runoff velocities.

Reduction of Future Subsidence Potential

The Burlington Mine site has experienced consistent subsidence for at least 30 years. A beneficial side effect of the aforementioned water quality improvement activities is the notable reduction of future subsidence potential. The closure of shafts and subsidence areas combined with the realignment of Balarat Gulch away from the mine workings will inherently reduce the future risk of subsidence in the areas historically plagued with this problem. Similarly, by controlling and intercepting subsurface flows that would otherwise access the closed mine features, the water quality improvements mitigate the risk of future subsidence on the site.

Ecological Approach

Methods for incorporating natural form and function and enhancing wildlife habitat were utilized in all feasible aspects of the remediation. The most notable features are the bed and bank treatments for the diversion channel, use of natural materials for all visible structures, waterfowl protection measures, and sitewide revegetation with native species.

Channel Bed and Bank Treatments

An innovative channel design was employed for the Balarat Gulch diversion channel. The design imitated natural channel form and function, incorporated naturalizing elements, and created aquatic and riparian habitat.

Photo 6. Balara Gulch Diversion Channel, 2004.

A step-pool configuration was built into the channel because this channel form is typical of high-gradient alpine streams. These systems use frequent drops to dissipate energy, as opposed to flatter gradient, valley floor systems that dissipate energy by meandering. The ranges for height and spacing of drop structures, which were used to create the step-drops, were determined based on observations and measurements of the step-drops in the reaches above and below the diversion channel. The closely spaced step-drops achieve flatter between-drop slopes and they create natural flow variability with areas of faster and slower moving water.

While the channel was designed to withstand flows in excess of the 100-year storm, a mobile bed utilizing soil and rock gradations found in the natural channel was specified as a surface treatment. The surface material is mobilized frequently by lower intensity, higher recurrence interval storms. This mobility allows natural scour and deposition cycles to occur, which can form localized pools and develop a low flow channel. The creation of deeper water prevents overly wide, shallow flow, which is a common constraint to aquatic habitat. The mobile bed treatment was underlain by a resistive grouted riprap layer to provide vertical protection against lowering of the channel invert. Channel lowering could not be allowed due to the mine workings below.

The development of a low flow channel was further encouraged by creating small notches in the tops of the drop structures. Notches were designed to follow a random, alternating pattern down the channel to promote low flow sinuosity. Natural materials were given preference during design of the bed and bank treatments. Concrete or grouted riprap were avoided as surface layers, favoring natural rock and boulders to provide the required surface protection. The resulting natural appearance was enhanced by the establishment of woody and herbaceous vegetation along the channel two years later in 2006.

The comprehensive revegetation plan, utilizing all native species, benefited the newly created channel by restoring riparian vegetation wherever possible. Native riparian trees were specified along the lower reach of channel, where impermeable lining or exposed bedrock did not preclude their use. Restoring the riparian zone along the channel provides shading and cooling of streamflows, protective overhead cover, and terrestrial habitat. Streamside vegetation also helps to stabilize banks and functions as a detritus source for the aquatic system, forming the base of the aquatic food chain.

Waterfowl Protection

An old mine tunnel at the southern end of the site has become permanently flooded and causes a constant discharge from the overlying pond. The flooded area is known as the “mine pond”. Water in the pond has a low pH and heavy iron staining exists along the discharge path from the pond.

While the pond and its discharge had to be excluded from this VCUP project due to point source discharge issues, concerns for the health of waterfowl that would be tempted to land in the pond were addressed. Bird Balls™, which were recommended by the U.S. Fish and Wildlife Service, were used to cover the pond surface, preventing waterfowl from landing or residing in the pond, and removing potential contamination pathways.

Engineering Results

The ecological approach employed for the Burlington Mine Site remediation resulted in more natural and functional systems that help soften the harsh aesthetics of the old mine site and improve wildlife habitat. Some of the most notable natural features at the site are the bed and bank treatments along the diversion channel. Woody and herbaceous vegetation is successfully establishing along the new channel, in the flat benches between drop structures, as intended. The riparian vegetation is helping to stabilize the channel under lower flow conditions and functions as a detritus source for the aquatic system, forming the base of the aquatic food chain. Restoration of the riparian corridor will ultimately provide shading and cooling of streamflows, protective overhead cover, and terrestrial habitat.

The biggest challenge associated with the Balarat Gulch diversion channel turned out to be stabilization of the extensive eastern sideslope, which had to be excavated to a 2 to 2.5H:1V sideslope. These slopes are steeper than typically desired, but were unavoidable due to the underlying mine workings. The alternative approach to maintain a 3H:1V sideslope would have dramatically increased the total disturbance area (due to the steep existing hillslope and difficulty in catching grade), to the extent that the additional loss of mature ponderosa and lodgepole pines would have been more detrimental than helpful.

The steep sideslope was seeded with a native seed mix, which included native shrub seed selected specifically for optimal establishment on micro-niches within the bedrock face. The slope was then mulched and tackified prior to installation of a biodegradable, woven coconut coir erosion control fabric.

Early in the monitoring phase, problematic drainage conditions were identified along the hillslope that were exacerbating the already severe conditions and hindering revegetation. First, the excavation along the hillslope had intercepted several small drainages that were concentrating surface runoff and creating deep rills down the hillslope, under the erosion control fabric. Second, the excavation had intercepted a groundwater seep that was contributing to local instabilities. In some areas, the fabric was stretched to failure by the underlying erosion.

The points of concentrated flow were stabilized by rerouting flows where possible and using woody material as supplemental velocity breaks to reduce the erosive energy of flows before they accessed the hillslope. Water from the seep was collected in a below-ground drain system and routed safely around the vulnerable hillslope to more stable, vegetated areas. This system is similar to the curtain drain employed at the top of the Balarat Gulch diversion to capture alluvial flows. Concurrent with these corrective measures, the larger rills were regraded as best possible on the steep, tall hillslope and erosion control fabric was re-installed in problem areas. These corrective measures were very successful and significant rilling has not occurred since the treatments.

Today, the sideslope shows signs of slow progress towards revegetation. Three growing seasons after construction, vegetative coverage is currently as low as five percent in some sections of the hillslope, but as high as 85 percent in other sections. Due to the severe conditions, revegetation of this hillslope is expected to take 10 to 20 years, as opposed to the 3-year window that can be expected under milder conditions.

Biological Actions and Results

Amendment Test Plot

Walsh was fortunate to have time and budget to establish a plot to test the relative merits of soil amendments (no organic amendment, topsoil, and four application rates of compost) in terms of plant germination and establishment. Waste rock was scraped from sides of the existing waste rock pile and redistributed across the top of a third-acre (0.13 hectare) test site in a 12-inch (0.3 meter) lift. This material was previously tested for pH to determine lime application rates sufficient to neutralize acid-forming potential of the material. An appropriate rate of lime was applied (4 tons/ 1,000 ft^2[92.9 square meters)) and ripped into the upper 6 inches (0.15 meter) of waste rock across the entire test site. Compost applications were ripped into the upper 6 inches (0.15 meter) of the waste rock.

Treatments were applied to six test plots, each approximately 50 feet (15.2 meters) by 20 feet (6.1 meters), laid out in parallel, contiguous strips, across the lime-treated waste rock site, as described below:

- Treatment 1 – Compost applied at rate of 30 tons / acre (0.4 hectare), with lime.
- Treatment 2 – Compost applied at rate of 40 tons / acre (0.4 hectare), with lime.
- Treatment 3 – Compost applied at rate of 50 tons / acre (0.4 hectare), with lime.
- Treatment 4 – Compost applied at rate of 60 tons / acre (0.4 hectare), with lime.
- Treatment 5 – Positive Control – 15 inches (38 cm) of subsoil + 3 inches (7.6 cm) of local topsoil.
- Treatment 6 – Negative Control – lime treatment, with no organic material.

The site was seeded with the same mix proposed for project waste rock repository. All treatments were broadcast seeded at a rate of 120 seeds/ square foot (0.9 square meter). The site received nothing more than ambient precipitation for the entire 2003 growing season. Success parameters were measured using three replicate samples per treatment cell per sample date. Germination success was measured by counting seedlings per 25 cm^2 sample frame approximately one month after seeding. Establishment was sampled twice during the growing season. Establishment parameters measured included: 1) ocular estimation of percent cover, by life form (graminoid or forb) per 25 cm^2 sample frame, 2) height of tallest specimen per life form in each replicate quadrat, and 3) total species richness per treatment.

Not unexpectedly, the poorest performing treatment for any parameter was no subsoil with no organic amendment. The best performing treatment for germination and establishment was subsoil + 50 tons compost/acre or 60 tons compost/acre (0.4 hectares). This combination of subsoil plus compost at these rates resulted in cover estimates more than double those for the subsoil + topsoil treatment. It was therefore concluded revegetation success would be most likely achieved using a 15 inch (38 centimeters) subsoil layer, amended with commercial compost at a rate of 60 tons/acre (0.4 hectares), over the lime amended waste rock material.

Revegetation Design Details

Revegetation addressed the waste rock repository, native, disturbed soils, and undisturbed native soils as well as the riparian corridor and other wetland mitigation areas, and an extensive and steep native rock/soil slope on the north-west side of the new channel.

Final grading was done perpendicular to new slopes. Final grade surfaces were intentionally left rough. No rock or pebble debris were removed. Upon achievement of final grade the different areas were treated as follows:

Waste Rock

- Waste rock was moved and consolidated into a central repository
- Agricultural lime (Effective Calcium Carbonate Equivalent [ECCE] of 87 percent) was applied at 30 tons/acre (0.4 hectares) and ripped to a depth of 12 to 15 inches (30 to 38 centimeters). This was allowed to cure for three months.
- Reserved subsoils were spread over the waste rock to a depth of 15 inches (38 centimeters).
- Commercial (Type A) compost applied at a rate of 60 tons per acre (0.4 hectares), ripped/tilled into subsoil to a depth of 9 to 12 inches (22.9 to 30 centimeters). All areas were hydroseeded at a rate of 120 seeds per square foot (0.9 square meter), using the site-specific upland seed mix detailed in Table 1. This was followed with a hydromulch treatment of all seeded areas.
- Erosion Control Fabric (ECF) was installed on the slopes greater than 2.5:1 after final grading, seeding, and mulching.

Disturbed Native Soils

- These soils were uncovered when waste rock was moved and consolidated. Agronomic tests showed these samples had considerable lower pH values than surrounding native, undisturbed soils.
- Agricultural lime applied at 5 tons/acre (0.4 hectare) and ripped to a depth of 12 to 15 inches (30 to 38 centimeters). This was allowed to cure for almost three months.
- All areas were hydroseeded at a rate of 120 seeds per square foot (0.9 square meter), using the site-specific upland seed mix detailed in Table 1. This was followed with a hydromulch treatment of all seeded areas.
- Erosion Control Fabric (ECF) was installed on the slopes greater than 2.5:1 after final grading, seeding, and mulching.
- Upland trees and shrubs were planted following the schedule detailed below.

Wetland Mitigation Areas

- These areas were graded to final contours, and hydroseeded at a rate of 120 seeds per square foot (0.9 square meter), using the site-specific wetland mitigation seed mix detailed in Table 2. This was followed with hydromulch treatment of all seeded areas.
- Riparian shrubs were planted following the schedule detailed in Table 3.

Upland Tree and Shrub Planting

In addition to seeding, containerized shrub and tree stock was strategically planted to benefit from appropriate created habitat conditions for screening and wetland compensatory mitigation, following the schedule detailed in Table 4.

Photo 7. Ore bin and revegetated waste rock pile, three full growing seasons following VCUP completion (comparison to Photo 1).

Biological Results

Revegetation ogressed as expected over the first three full growing seasons following completion. Quantitative monitoring results are summarized in Table 5. Average foliar cover was approximately 61 percent across the upland portions of the site by the end of the first growing season. By the end of the third full growing season, this value had increased to almost 65 percent (Photo 7).

Relative cover by native species was approximately 81 percent after the first growing season. This has been dramatically reduced to 44 percent by the end of the third growing season. This is despite the gradual reduction in the diversity of non-native species on the site (12 to 5.5) over the three years.

Weeds have been a relatively minor problem on the site. Control is being accomplished primarily by mechanical controls.

Conclusions

The use of natural and naturally functioning systems appear to have supported all of the desired project goals. The water quality engineering features have operated as designed. No significant surficial erosion is observed in any of the revegetated areas. Water samples collected after VCUP completion indicate a strong improvement in water quality in downstream recieving streams, supporting conclusions that these features have reduced surface and groundwater interaction with contaminated materials. Onsite safety hazards have been completely removed. No surface subsidence has been observed since project completion.

Selected soil treatments and amendments appear to have performed as anticipated to create a suitable substrate for the establishment of a naturalistic and functional, self-sustaining plant community. This established vegetation cover, contributes to the stability of the site as well as contributes to a reduction in surface precipitation interaction with covered waste rock contaminants. Wetland mitigation revegetation was deemed successful by the US Army Corps of Engineers and the site was released from monitoring conditions in 2008.

State and Federal regulating agencies concurred with these conclusions and released the VCUP as successful in 2008.

Table 1. Upland Seed Mix

Binomial	Common Name	Life Form	Season*	% of Mix**
Bromopsis marginatus	mountain brome 'Bromar'	bunch	C	10
Deschampsia cespitosa	tufted hairgrass 'Peru Creek'	bunch	C	10
Elymus canadensis	Canada wildrye	bunch	C	10
Elymus trachycaulus	slender wheatgrass 'San Luis'	bunch	C	10
Poa fendleriana	mutton bluegrass	bunch	C	10
Koeleria cristata	Junegrass	bunch	C	10
Poa canbyi	Canby bluegrass 'High Plains'	bunch	C	10
Aster chilensis	Pacific aster	forb	NA	3
Gaillardia aristata	blanketflower	forb	NA	2
Linum lewisii	Lewis flax	forb	NA	2
Lupinus argenteus	silver lupine	forb	NA	4
Monarda fistulosa	bee balm	forb	NA	3
Penstemon strictus	Rocky Mountain penstemon	forb	NA	3
Vicia americana	American vetch	forb	NA	4
Thermopsis rhombifolia	golden banner	forb	NA	4
Ceanothus fendleri	buckbrush	shrub	NA	1
Cercocarpus montanus	mountain mahogany	shrub	NA	1
Purshia tridentata	bitterbrush	shrub	NA	1
Ribes cereum	wax current	shrub	NA	1
Rosa woodsii	wild rose	shrub	NA	1
			Total	100

*C = cool season grass

**rate of 120 pure live seed (PLS) per foot^{2} ((0.9 square meters)

Table 2. Wetland Mitigation Seed Mix

Binomial	Common Name	Indicator Status*	% of Mix**
Juncus balticus	Baltic rush	FACW	20
Carex nebrascensis	Nebraska sedge	OBL	30
Carex aquatilis	water sedge	OBL	20
Deschampsia cespitosa	tufted hairgrass	FACW	15
Phleum alpinum	alpine timothy	FAC	15
		Total	100

*FACW = Facultative Wetland SPecies, OBL = Obligate Wetland Species

**rate of 120 pure live seed (PLS) per foot^2 (0.9 square meters)

Table 3. Riparian Shrub Schedule

Binomial	Common Name	Size	Spacing	Number
Acer glabrum	Rocky Mountain maple	# 5	5’ o.c.	38
Alnus incana	thinleaf alder	# 5	5’ o.c.	46
Betula occidentalis	river birch	# 5	5’ o.c.	46
Lonicera involucrata	twinberry	# 5	5’ o.c.	37
Prunus virginiana	chokecherry	# 5	5’ o.c.	18
Ribes aureum	golden currant	# 5	5’ o.c.	37
			Total	222

Table 4. Upland Tree and Shrub Schedule

Binomial	Common Name	Size	Number
Pinus ponderosa	ponderosa pine	# 5	20
Cercocarpus montanus	mountain mahogany	# 5	30
Juniperus scopulorum	Rocky Mountain juniper	# 5	20
Padus virginiana	chokecherry	# 5	30
Physocarpus monogynus	ninebark	# 5	20
Purshia tridentata	bitterbrush	# 5	15
Ribes cereum	wax current	# 5	20
Rosa woodsii	wild rose	# 5	15
		Total	170

Table 5. Annual Revegetation Monitoring Results Summary

Percent Cover*	**2005**	**2006**	**2007**	**Mean**
Vegetation	61.0	61.6	64.8	62.5
Bare Ground	35.6	29.3	27.2	30.7
Rock	4.6	9.2	8.1	7.3
Relative Cover				
Native Species	80.8	40.8	43.7	55.1
Non-native Species	19.3	20.8	21.1	14.4
Species Diversity				
Native Species	16.8	21	21.5	19.8
Non-native Species	12	8.3	5.5	8.6
Total # Species	28.8	29.3	27.3	28.5

* percent cover totals include weeds

References

Walsh, 2002. Voluntary Cleanup Plan Application, Mine waste rock piles, Burlington Mine Site, Jamestown, Colorado. February 27.