

Ecological Approach Used to Remediate Former Mining Site

Cleanup of the inactive Burlington Mine site in Boulder County, CO, was initiated in 2003 as a voluntary cleanup overseen by the Colorado Department of Public Health and Environment (CDPHE) pursuant to the Colorado Voluntary Cleanup Redevelopment Act of 1994. An ecological approach was used to improve downstream water quality, reduce surface- and ground-water interaction with contaminated materials, and limit potential for subsidence. Activities included the filling and mounding of subsidence pits, realignment of intermittent tributaries, management of surface-water runoff, and revegetation of barren areas.

The 11-acre property was used by several companies from 1920 to 1973 to produce fluorspar (calcium fluoride), an active ingredient of fluorinated compounds commonly needed for water fluoridation and ceramic manufacturing. In the 30 years prior to cleanup, the site experienced significant and increasing subsidence. Site investigations in 1999 indicated acidic and metals contamination in waste rock onsite and in the adjacent surface-water drainage. Geotechnical investigations indicated a 12- to 15-foot layer of alluvium overlying bedrock at a depth of 25 feet below ground surface. Ground water is encountered at a depth of 8-10 feet.

Field preparation began with consolidation of 25,000 yd³ of acid-generating waste rock and closure of three onsite adits and shafts. Activities then focused on addressing three subsidence pits that provided direct paths for flow of contaminated material from the subsurface mine workings to surface and ground water. Of particular concern was a 1/3-acre pit that intercepted intermittent drainage from Balarat Gulch in the Lefthand Canyon watershed. Approximately 17,000 yd³

of uncontaminated or neutralized onsite soil was used to backfill the pits. Sufficient material was added to create a minimum 2% slope for discouraging infiltration and promoting runoff. In anticipation of the backfill settling, the area was over-mounded 4 feet.

Significant water interactions associated with Balarat Gulch were addressed by constructing a 500-ft diversion channel to realign drainage away from mine workings. The design used a step-pool configuration typical of high-gradient alpine streams, whereby system stability relies on closely spaced, low-profile drop structures (i.e., elevation reductions) to dissipate flow energy. Construction of the channel bed in this way helped to more closely imitate natural channel form and function, incorporate naturalizing elements, and create aquatic and riparian habitat.

Three-dimensional mining maps were used to identify the channel's optimal centerline location and inversions. The channel design accommodated sizing and configuration sufficient to contain the design discharge of 264 cfs, which is 120% of a 100-year storm event. In an upper reach of the diversion channel, where realignment required a sharp bend away from the historic surface-water path, a PVC liner was installed to fully confine water and reduce potential for piping failure behind a constructed 10-ft-wide, 2-ft-high boulder wall. Two lower reaches of the channel were left unlined to allow hillslope ground water to access the new channel rather than flowing beneath it and potentially accessing the mine workings below.

The Balarat Gulch diversion channel required excavation at a steep (2:1- 2.5:1 horizontal:vertical) 1/2-acre sideslope. To prevent erosion, the slope was stabilized with a native seed mix including mountain mahogany (*Cercocarpus montanus*) and

bitterbrush (*Purshia tridentata*) shrubs suited for optimal establishment on bedrock face microniches. Following seeding, the slope surface was amended with Biosol® prior to installing a biodegradable woven-coconut coir erosion control fabric.

A primary alluvial water control structure extending to bedrock was installed at the top of the diversion channel to address subsurface flow. The engineered structure comprises a 75-ft-long, 25-ft-deep impermeable liner and curtain drain consisting of prefabricated drainage panels with perforated PVC pipe threaded through bottom sleeves. The impermeable lining intercepts alluvial water and forces it into the curtain drain system. Localized ground water and surface water not intercepted by the primary control system are captured in a secondary, downstream "scavenger" drain.

Revegetation focused on stabilizing the site, promoting evapotranspiration, and preventing precipitation and subsurface infiltration. Preparations required surface application of agricultural lime to neutralize acid generation potential of the waste rock. Approximately 15 tons of lime were applied per 1,000 tons of waste rock throughout the backfilled areas. These areas were covered with 12-18 inches of native subsoil and topdressed with "type A" commercial compost at a rate of 60 tons per acre. This created a physical barrier to precipitation reaching the waste rock and provided a suitable medium for plant growth. A seed mix of native grasses, wildflowers, and shrubs was broadcast seeded at a rate of 240 pure live seed (PLS) per square foot. Shrub and tree plantings included over 220 riparian species such as thinleaf

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Figure 2. The ecological approach used to address AMD in the Balarat Gulch relies on revegetation with native plants to help stabilize banks of the diversion channel constructed four years ago.



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alder (*Alnus incana*), 150 upland shrub species such as wax currant (*Ribes cereum*), and 20 ponderosa pine trees (*Pinus ponderosa*).

A mobile bed of soil and rock gradations in the natural channel was used to allow mobilization by low-intensity storms, as in a natural, dynamic system. Material mobility results in natural scour and deposition cycles capable of forming localized pools or overly wide water flow. The mobile bed is underlain by a resistive, grouted riprap layer providing vertical protection against channel lowering. To replicate native conditions, natural rock and boulders were given preference over concrete during construction of the bed and bank treatments. Creating small notches in the tops of the drop structures in an alternating alignment encouraged development of low-flow channels with increased sinuosity.

After 12 months of remedy operation, corrective measures were required to address unanticipated drainage along

the hillslope of Balarat Gulch. Deep rills had developed under the erosion control fabric due to interception of several small drainages and a ground-water seep caused by remedial excavation; in some areas, the fabric was stretched to failure by underlying erosion. Woody material was installed where possible to reroute flows and serve as supplemental breaks to drainage flows, and a subsurface drain system was installed to collect and route seep water around the vulnerable hillslope to more stable, vegetated areas. Large rills were regraded to the extent possible and erosion control fabric was re-installed in problem areas.

Wildlife protection methods included installation of Bird Balls™ recommended by the U.S. Fish and Wildlife Service to

prevent waterfowl from landing or residing in a pond receiving constant discharge from underlying mine tunnel. After three growing seasons, vegetative coverage is as low as 5% (in sections of the steep 2:1 hillslope), but as high as 85% in other areas (Figure 2). Complete revegetation is expected to require 10-20 years. CDPHE estimates a total cleanup project cost of \$1.5 million, or about \$140,000 per acre.

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Interagency Study Examines Impacts of Mine Spoil Types on Reforestation Efforts

The University of Kentucky, in cooperation with the U.S. Department of Interior (DOI) Office of Surface Mining, the Kentucky Department of Natural Resources, and the coal industry has initiated a research program to examine reforestation techniques on surface mined lands. Research plots were established on the Bent Mountain surface mine in Pike County, KY, for the purpose of evaluating

the influence of three different loose-graded spoil types on tree performance, water quality, and hydrology.

Historically, reforestation was used to reclaim sites impacted by surface mining in the Eastern U.S. The passage of the Surface Mining Control and Reclamation Act of 1977 required that mined lands be returned to their approximate original contour (AOC).

Spoil compaction involved in reconstructing sites to the AOC often hinders reforestation efforts, contributing to a decline in the amount, diversity, and productivity of forestland in coal-producing areas. Compacted soil and inappropriate geochemical characteristics often lead to high seedling mortality, slow plant

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