BELLE ELDRIDGE MINE SITE REMEDIATION

Karl L. Ford,* Toxicologist
BLM National Applied Resource Sciences Center
Bldg. 50, Denver Federal Center
Denver, CO 80225-0047

Peter Bierbach, HazMat Coordinator
BLM Montana State Office
Granite Tower, 222 N. 32nd Street
Billings, MT 59107

Dex Hight, Hydrologist
BLM Miles City Field Office
111 Garryowen Road
Miles City, MT 59301

Russ Pigors, Natural Resource Specialist
BLM South Dakota Field Office
310 Roundup Street
Belle Fourche, SD 57717-1698

Cate Webb
South Dakota School of Mines
Rapid City, SD

Jeremy Gilbert
Colorado School of Mines
Golden, CO 80401

INTRODUCTION

The Bureau of Land Management has over 100,000 abandoned mine sites located on public lands. Field inventories have shown numerous sites to be releasing heavy metals to the environment. The Belle Eldridge Mine is a site that BLM is characterizing and planning for remediation in 1999. The site is located in the Black Hills near Deadwood, SD. Site characterization activities were performed by BLM and the South Dakota School of Mines (SDSM). The site has 3,300 cubic yards of acidic tailings with high concentrations of arsenic and lead located in the stream and the stream floodplain, waste rock dumps, a flowing adit, and seeps. The adit water has zinc concentrations well above ambient water quality criteria for the protection of aquatic life.

An engineering evaluation and cost analysis (CCJM, 1998) was performed for the site to address removal of the tailings, stabilization of the waste rock pile, and treatment of the adit and seep flows using constructed wetlands. Cleanup criteria were established using a risk assessment approach. A treatability study and design for the wetlands was prepared by the Colorado School of Mines (CSM). The design will optimize the metal loading with the highly variable water flows.

SITE DESCRIPTION

The Belle Eldridge Mine is located in Spruce Gulch approximately 1.5 miles from Deadwood, SD. The site lies at an elevation of 4,913 feet above sea level in the Black Hills. The principal features of the site are a flowing adit, two seeps, waste rock dumps, old mill foundations, and approximately 3,000 cubic yards of tailings, primarily located in Spruce Gulch, Figure 1. Figure 1 also delineates the 100-year floodplain as determined by SDSM. The tailings were once impounded in an old tailings dam that has been breached. Downstream on Spruce Gulch are several residences with 0.5 mile and more residences as one approaches Deadwood.

Mining at the site may have begun before the turn of the century; however, the Deadwood Zinc and Lead Company began mining the site in 1911. Activity was sporadic until 1941, when the war effort prompted a greater demand for metals. Belle Eldridge Mines installed a flotation concentrator in 1942 which had a capacity of 50 tons/day. During 1942-43, 11,382 tons of lead zinc ore, 200 oz. gold, and 9,960 oz. silver were produced. Operations may have continued into the 1950s. The ore body lies between two porphyry sills and consists of quartzite, shale and dolomite of the Deadwood formation. The most common minerals in the ore were galena, sphalerite, pyrite, arsenopyrite, and quartz.

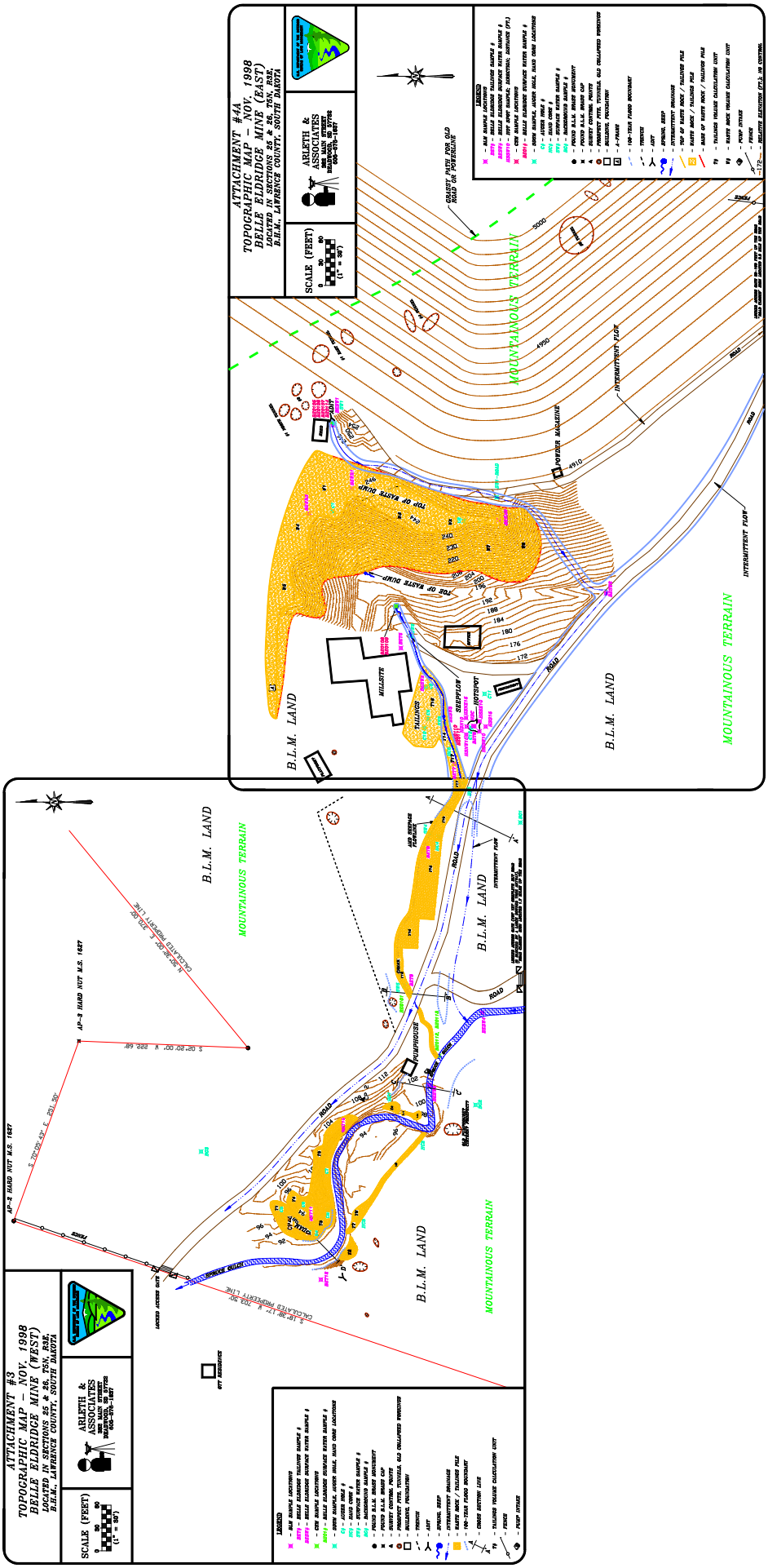

ATTACHMENT #3
TOPOGRAPHIC MAP – NOV. 1998
BELLE ELDRIDGE MINE (WEST)
LOCATED IN SECTIONS 25 & 26, T5N, R3E,
B.H.M., LAWRENCE COUNTY, SOUTH DAKOTA
SCALE (FEET)
0 30 60
(1" = 30')
ARLETH & ASSOCIATES
MINE MAPS SERVICES
BOX 1000, RAPID CITY, SD 57709
605-376-1487
B.L.M. LAND
MOUNTAINOUS TERRAIN
AP-2 HARD HOT M.S. 1487
S 50°20'00" E 231.30'
S 50°20'00" E 270.00' CALCULATED PROPERTY LINE
S 50°20'00" W 222.68'
S 18°28'15" W 703.90' CALCULATED PROPERTY LINE
LOCKED ACCESS GATE
OFF ENCLOSURE
PUMPHOUSE
ROAD
INTERMITTENT FLOW
ATTACHMENT #4A
TOPOGRAPHIC MAP – NOV. 1998
BELLE ELDRIDGE MINE (EAST)
LOCATED IN SECTIONS 25 & 26, T5N, R3E,
B.H.M., LAWRENCE COUNTY, SOUTH DAKOTA
SCALE (FEET)
0 30 60
(1" = 30')
ARLETH & ASSOCIATES
MINE MAPS SERVICES
BOX 1000, RAPID CITY, SD 57709
605-376-1487
GRASSY PATH FOR OLD ROAD OR POWERLINE
TOP OF WASTE DUMP
TOP OF WASTE DUMP
HILLSITE
TAILINGS
SUMPLOW
HOTSPOT
POWDER MAGAZINE
INTERMITTENT FLOW
ROAD
FENCE
B.L.M. LAND
MOUNTAINOUS TERRAIN
LEGEND
BLM SAMPLE LOCATIONS
BELLE ELDRIDGE TAILINGS SAMPLE #
BELLE ELDRIDGE SURFACE WATER SAMPLE #
CDS SAMPLE LOCATIONS
SHOW SAMPLE, AUGER HOLE, HAND CHAR LOCATIONS
CS – AUGER HOLE #
BAND CORE #
STORAGE WATER SAMPLE #
SURFACE WATER SAMPLE #
FOUND B.L.M. BRASS CAP
SURVEY CONTROL POINTS
PROSPECT PITS, TRENCHES, OLD COLLAPSED WORKINGS
BUILDING, FOUNDATION
TRENCH
ADIT
SPRING, SEEP
INTERMITTENT DRAINAGE
WASTE ROCK / TAILINGS PILE
100-YEAR FLOOD BOUNDARY
CROSS SECTION LINE
TAILINGS VOLUME CALCULATION CUT
FENCE
PUMP STRAIN
WASTE ROCK VOLUME CALCULATION CUT
PUMP STRAIN
FENCE
PROJECTED ELEVATION (FT.) TO CONTOUR

Figure 1.

SITE CHARACTERIZATION

Site characterization was initiated by BLM in 1997 and continued in 1998 by SDSM. Table 1 summarizes characteristics of the waste at the site:

Table 1. Site Characterization Summary

Source	Approximate Volume	Hazardous Substances/Mean Concentrations (mg/kg)
Cumulative Mill and Channel Tailings Deposits	3,320 yards	Arsenic: 5,894 Cadmium: 3.95 Lead: 6,205 Zinc: 1,129 Acid Base Potential: -63.3 tons/kiloton
Upper Seep (SW2)	11 kg/yr (mass load of metals)	Arsenic: 0.003 mg/L Cadmium: 0.087 mg/L Lead: 0.023 mg/L Zinc: 7.67 mg/L
AMD Seep (SW3) (unfiltered); n=3	296 kg/yr aggregate metals	Arsenic: 2.4 mg/L Cadmium: 0.11 mg/L Lead: 14.7 mg/L Zinc: 8.9 mg/L
Adit Effluent (unfiltered) n=9	3,897 kg/yr aggregate flow	Arsenic: 0.12 mg/L Cadmium: 0.11 mg/L Lead: 1.09 mg/L Zinc: 6.0 mg/L
Contaminated Soil	8 cubic yards	Arsenic: 16,500 Lead: 48,700 Silver: 225 Thallium: 4.2
Waste Rock	12,600 cubic yards	Arsenic: 757 Cadmium: 3.39 Lead: 781 Zinc: 637

Spruce Gulch is not covered by South Dakota water quality criteria because of its ephemeral nature; however, criteria for the receiving stream, Whitewood Creek, are established: arsenic 0.19 mg/L, cadmium 0.01 mg/L, lead 0.07 mg/L, and zinc 0.1 mg/L. The adit flow and seeps exceed these levels for most of the criteria.

Based on several years of field observations by BLM, the adit flow is known to dry up during the late summer through winter months. For the months the adit normally flows, Table 2 shows the monthly precipitation in inches for Deadwood and the adit flow in gpm. A linear regression was performed for the precipitation and adit flow data sets. A significant relationship was found between the two data sets (multiple R = 0.985). Adit flow can be predicted from the following equation:

Adit flow (gpm) = 52.3 x Monthly Precipitation (inches) - 106.6

Based on 49 years of record, the average monthly precipitation for the period April-July is 3.65 inches. This would yield an average adit flow according to the regression equation of 84.7 gpm. This is practically the same mean value as measured by SDSM during 1998 (87.5 gpm).

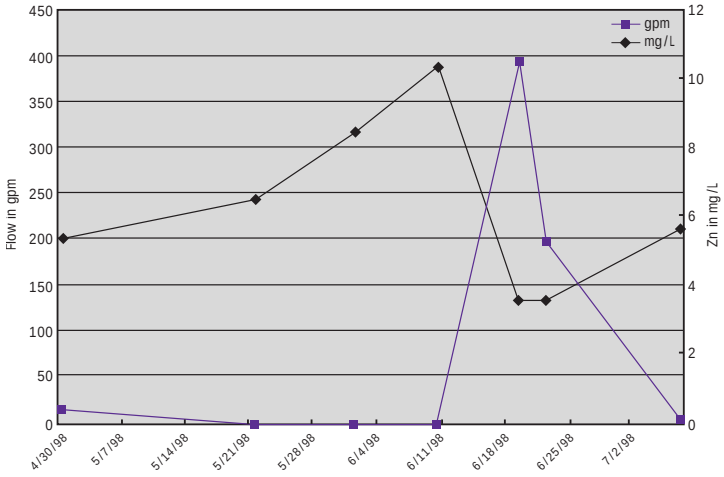
Table 2. Monthly Precipitation and Adit Flow Rates

Period	Precipitation (inches)	Period	Adit Flow (gpm)
April 1997	5.93	May 7, 1997	222*
April 1998	1.8	April 30, 1997	12.7
June 1998	8.74	June 19, 1998	345
July 1998	2.85	July 1998	3.8 (mean of 3)
NA		August 1998	NA ?

* 80 gpm was measured at road. Based on SDSM, road flow is about 36% of the adit flow, so the adit flow was about 222 gpm.

There is an important relationship between metals loading and adit flow rates. A time trend analysis plot of the adit zinc concentrations versus the adit flow rate is shown in Figure 2. It may be seen the during high flow conditions, zinc concentrations decrease and during low flow conditions, zinc concentrations increase. This information was used to design the size of the wetland.

Figure 2. Belle Eldridge Adit Flow and Zinc Concentrations

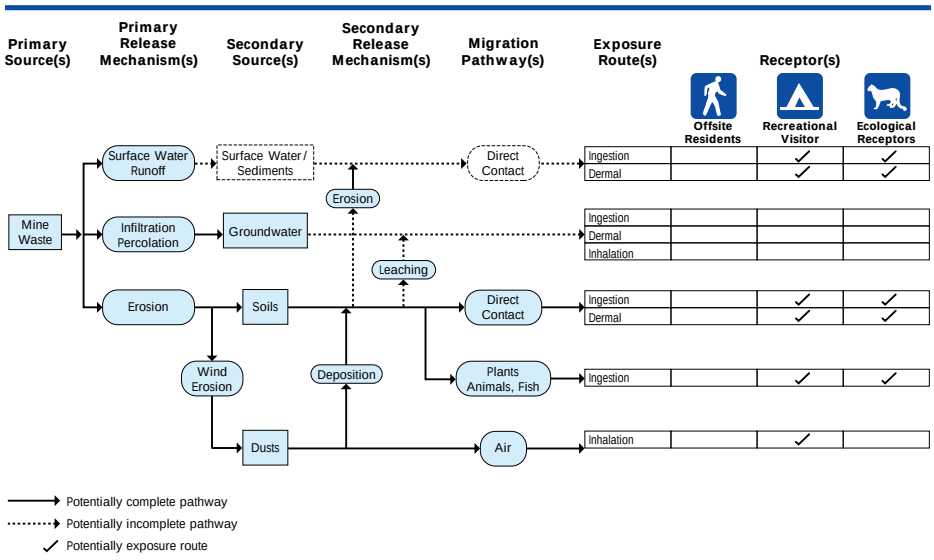


STREAMLINED RISK ASSESSMENT

BLM developed acceptable multimedia risk management criteria (RMC) for the chemicals of concern (COCs) as they relate to human use and wildlife habitat on or near BLM lands (Ford, 1996). The primary objective of this section was to perform a streamlined risk assessment for the site and to establish the magnitude of risk to human health and wildlife. RMCs for soil, sediment, fish and water protective of human receptors for the metals of concern were developed using available toxicity data and standard U.S. Environmental Protection Agency (EPA) exposure assumptions. Acceptable soil and sediment concentrations protective of wildlife receptors (ecological RMCs) for the metals of concern were developed using toxicity values and wildlife intake assumptions reported in the current ecotoxicology literature.

The COCs and migration pathways were identified from historical information and site evaluation and presented in the site conceptual model, Figure 3. The COC selection process utilized chemicals documented to have been released to surface water and observed contamination in tailings at Belle Eldridge Mine tailings. Human and ecological COCs for Belle Eldridge Mine are: arsenic, cadmium, lead, and zinc. Potential receptors, receptor exposure routes, and exposure scenarios were identified from on-site visits and discussions with BLM personnel. Representative wildlife receptors at risk were chosen using a number of criteria, including likelihood of inhabitation, and availability of data.

Figure 3. Mine Waste Conceptual Site Model for Human and Ecological



Human Health Risk Assessment

The human exposure scenarios were developed to provide realistic estimates of the types and extent of exposure that individuals might experience to the metals of concern in the water, soils, and sediments on BLM property. Such exposures might occur to individuals who use BLM lands for camping or all-terrain vehicle (ATV) driving, or individuals who work on BLM lands. Contamination may migrate from the BLM tracts to adjoining property.

The RMCs correspond to either a target excess cancer risk level of 1×10^5, or a target noncancer hazard index of 1.0. In the case of metals posing both carcinogenic and noncancer threats to health, the lower (more protective) concentration was selected as the RMC. The concept behind the RMC is that people will not experience adverse health effects from metal contamination on BLM lands in their lifetimes, while exposure is limited to soil, sediments, and waters with concentrations at or below the RMC. A target excess cancer risk of 1×10^5 means that for an individual exposed at these RMCs for 30 years, there is only a one in a hundred thousand chance that that person would develop any type of cancer in a lifetime as a result of contact with the COCs. A hazard index of <1.0 means that the dose of noncancer metals assumed to be received at the site by any of the receptors in a medium is lower than the dose that may result in any adverse noncancer health effects. The RMCs are protective for exposures to multiple chemicals and media. Lead RMC for the child receptors were determined from EPA's Integrated Exposure Uptake Biokinetic Model (USEPA, 1993) and other EPA regulations and guidance.

EPA has developed criteria for residential exposure in their Soil Screening Guidance (EPA, 1996). The criteria, or soil screening levels (SSLs) are shown along with the BLM RMCs in Table 3. These criteria do not account for multiple chemicals.

Ecological Risk Assessment

Wildlife in Spruce Gulch may be exposed to metal contamination via

several environmental pathways. The potential exposure pathways include soil and sediment ingestion, vegetation ingestion, surface water ingestion, and inhalation of airborne dust. Ecological RMCs have been established for metals in soil and sediments. This has been accomplished using the best data available, including: ecotoxicological effects data for the metals of concern, wildlife receptors representative of the Black Hills ecosystem, body weights and food intake rates for each receptor, and soil ingestion rates for each receptor (Ford, 1998).

The site is part of the Black Hills Coniferous Forest Province. The selected wildlife receptors are: deer mouse, mountain cottontail, bighorn sheep, white-tailed deer, mule deer, elk, mallard, Canada goose, and trumpeter swan.

The literature was surveyed for toxicity data relevant to either wildlife receptors at the site or to closely related species. In the absence of available toxicity data for any receptor, data were selected on the basis of phylogenetic similarity between ecological receptors and the test species for which toxicity data were reported. Soil ingestion data for each receptor were obtained from a recent study on dietary soil content of wildlife from the U.S. Fish and Wildlife Service. Where no dietary soil content data were available for a particular receptor, the soil content was assumed to be equal to that of an animal with similar diets and habits. The amount of soil ingested by each receptor was estimated as a proportion of their daily food intake. The food intake in grams for each receptor was calculated as a function of body weight.

RMCs were calculated for each chemical of concern in soil based upon assumed exposure factors for the selected receptors and species- and chemical-specific toxicity reference values (TRVs). Essentially, the TRVs represent daily doses of the metals for each wildlife receptor that will not result in any adverse toxic effects. TRVs were computed by metal of concern for each wildlife receptor/metal combination for which toxicity data were available. Phylogenetic and intraspecies differences between test species and ecological receptors have been taken into account by the application of uncertainty factors in derivation of critical toxicity values. These uncertainty factors were applied to protect wildlife receptors which might be more sensitive to the toxic effects of a metal than the test species. The uncertainty factors were applied to the test species toxicity data in accordance with a method developed by BLM. In accordance with this system, a divisor of two was applied to the toxicity reference dose for each level of phylogenetic difference between the test and wildlife species, i.e. individual, species, genus, and family.

For aquatic life protection, AWQC (EPA, 1986) and sediment criteria (Effects Level-Medium) were used (NOAA, 1990).

Risk Assessment Results

Table 3 compares the maximum media concentrations at the site with the selected appropriate RMCs. The ratio of the environmental media concentration to the RMC is analogous to a hazard quotient of 1.0; that concentration that should present negligible risk. The arsenic RMC has been modified to reflect the *in-vitro* bioaccessibility of 3.5%. Media concentrations exceeding RMCs for humans or wildlife greater than 1.0 are flagged "+"; these occurrences may pose a chronic threat. Media concentrations exceeding RMCs by more than 10 and 100-fold for humans or wildlife are flagged as moderate risk “++” and high risk “+++”, respectively. Most significant are the 29 and 919-fold exceedances of arsenic and lead RMCs, respectively, in the tailings. Residential RMCs and SSLs are shown for comparison.

Cadmium and zinc in the adit flow at this site exceed ambient water quality criteria for Whitewood Creek by 17- and 130-fold, respectively. Containment or removal of the tailings and treatment of the adit and seep flows will eliminate risks from direct contact and will reduce release of cadmium, lead and zinc to Spruce Gulch and help achieve ambient water quality criteria.

Removal Action Criteria

The camper RMCs (including the modified arsenic RMC) shown in Table 3 are proposed to be the removal criteria for soils and tailing materials. Since these criteria are based on ingestion and inhalation, mean surficial concentrations of areas exceeding these criteria will be removed or covered. The elk

RMC is similar to other large wildlife species that have a home range much larger than the site; the elk RMC may be modified by the size of their home range. This modification, called an area use factor, is the quotient of the site area (4 acres) divided by the home range (640 acres) is 0.006 for elk. With the area use factor, all the elk RMC are greater than the camper RMC.

The Whitewood Creek water quality standards shown in Table 3 are proposed as the removal criteria for water discharging from the site. The NOAA (1990) sediment criteria (Effects Level-Medium) shown in Table 3 are proposed for removal criteria for sediment.

Table 3. Belle Eldridge Mine Tailings Comparison of Analytical Results and Risk Management Criteria (RMC) Surface Tailing Results (mg/kg or ppm)

ANALYTE	BET6	Elk RMC	Camper RMC	Residential RMC	Residential SSL	Sediment RMC
Antimony	107+	NA	50	13	31	25
Arsenic	16500++	328	570a	28a	11a	85
Cadmium	2.0+	3	70	3	78	9
Copper	79.6+	131	5000	250	NA	390
Lead	48700+++	127	1000	400	400	110
Mercury	1.2+	11	40	960	NA	1.3
Nickel	8.3	NA	2700	135	1,600	50
Selenium	ND	NA	700	35	390	NA
Silver	225	NA	700	35	390	2.2
Zinc	417+	275	40000	2000	23,000	270

Surface Water (µg/l)

ANALYTE	BE-SW-1	AWQC*
Aluminum	ND	NA
Antimony	ND	NA
Arsenic	ND	190
Cadmium	69.5++	10
Copper	ND	80
Lead	ND	70
Mercury	ND	0.8
Nickel	ND	160
Selenium	ND	20
Silver	ND	20
Zinc	5940++	100

* South Dakota Administrative Code Criteria for Whitewood Creek
a - Criteria modified for 3.5% bioaccessibility

IDENTIFICATION AND SCREENING OF REMOVAL ALTERNATIVES

A list of alternatives that would prevent or minimize the release of metals from the mine site were developed and screened against the criteria of effectiveness, implementability, and cost. Effectiveness is defined as how effective the alternative is in protecting human health and the environment (by meeting removal action criteria) and reducing risks to human health and the environment. Effectiveness also includes compliance with applicable, relevant, and appropriate requirements (ARARs), which include various local, State, and Federal standards. Implementability includes a screening of the technical and administrative feasibility, including legal considerations. Cost includes direct capital cost, engineering and design cost, and operation and maintenance cost.

The following presents a brief description of the alternatives and a summary of the screening against the above criteria:

1. No Action—No removal or treatment measures would be taken and the tailings, waste rock, contaminated soil, and adit/seep flows would remain in their current state.

This alternative would not prevent or reduce the releases of hazardous substances to the environment at Belle Eldridge, nor reduce the risks to human health or the environment; hence, this alternative was screened from further consideration.

2. Institutional Controls—The site would be fenced, gated, and posted. This would reduce traffic on the site and reduce BLM liability for exposure or injury. However, there would be no reductions in water quality metal concentrations and the tailings in the creek still would be still subject to erosion.

This alternative would reduce health risks from direct contact with the mine site wastes, but would not reduce releases of hazardous substances from the site into Spruce Gulch, air, or groundwater; hence, this alternative was screened from further consideration.

3. Physical Removal of Tailings to Onsite Repository—The tailings in the creek and below mill and millsite debris would be removed to an onsite (within 2 miles) repository. The stream channel would be restored.

This alternative is a partial removal action and would be effective in eliminating releases of hazardous substances into Spruce Gulch from the seepage and erosion of the tailings. This alternative is retained for further consideration.

4. Physical Removal of Tailings to Offsite Repository—Tailings in the creek and below mill and millsite debris would be removed to an offsite repository (within 30 miles), and the stream channel would be restored. This alternative may be modified to include removal of tailings to an operating mine for reprocessing. Assay results on the tailings indicate significant gold and silver values that may make reprocessing feasible.

Like alternative 3, this alternative is a partial removal action and would be effective in eliminating releases of hazardous substances into Spruce Gulch from the seepage and erosion of the tailings. This alternative is retained for further consideration.

5. Capping of Tailings—Stream tailings would be pulled back from the stream, graded 3:1, and covered with 2' of soil plus capillary barrier. The surface would be revegetated and the stream channel would be restored. Millsite tailings would be covered in the same fashion.

This alternative would reduce the releases of hazardous substances into Spruce Gulch from the seepage and erosion of the tailings. However, there is not enough space outside of the 100-year floodplain to place the tailings and cap them. The tailings could be armored from flooding with gabion walls, for instance, but there would be no assurance that the tailings would not be released in a large flood event. This alternative is screened from further consideration.

6. Constructed Wetland for Adit Flow and Seeps—An anaerobic constructed wetland would be installed to treat these flows. This system relies on the use of sulfate reducing bacteria to reduce the metals to sulfides and render them insoluble in the wetland substrate. The wetland would be placed and designed to prevent infiltration into rock dumps. Run-on controls would be constructed above the adit to minimize infiltration. The wetland design assumptions developed by CSM are shown in Table 4:

Table 4. Wetland Design Assumptions

	Seep	Adit
Flow (gpm)	4	150
Moles Metal/Day	17	173
Substrate Volume (m^3)	346	575
Substrate Loading (ft^2/gpm)	800	50
Substrate Depth (ft)	3.8	2.7
Area (ft^2)	3,200	7,500
Construction Cost ($$)	69,000	109,000

Further monitoring of the adit and seep flows is planned to assist in the final design of the wetland systems. An advantage of this alternative is that it does not require active operation and maintenance while effectively reducing releases of hazardous substances into Spruce Gulch from the adit flow and seepage to levels less than aquatic life protection stream standards. This alternative is retained for further consideration.

7. Regrade and Revegetate Waste Rock and Run-on Control—The alternative involves regrading the waste rock pile to reduce the slope and make room for the wetland. Portions of the waste rock pile not covered with the wetland would be covered with clean soil and revegetated or covered with clean rock. The drainage above the adit will be routed around the waste rock pile and the prospects/subsidence areas near the adit will be filled to prevent infiltration.

This alternative is effective in minimizing direct contact with the metals in the waste rock, reducing erosion, and preventing infiltration from run-on into the waste rock. It also makes alternative 5 more implementable and cost-effective as it will reduce the amount of flow from the adit and seeps that requires treatment. This alternative is retained.

COSTS

Table 5 summarizes the estimated costs for each alternative:

Table 5. Estimated Costs

Alternative	Description	Estimated Cost
Alternative 3	Onsite Repository	$200,000
Alternative 4	Offsite Repository	$275,000
Alternative 6	Constructed Wetland	$100,000-$150,000
Alternative 7	Reclaim Waste Rock	$58,000

PREFERRED ALTERNATIVES

Based on the selection criteria, alternatives 3, 6, and 7 are the preferred alternatives. Work is scheduled to begin during the summer of 1999.