Water Quality Predictions and Impacts at Mine Sites: Case Studies Beal Mountain, MT; Stillwater, MT; Phoenix, NV

Characterizing, Predicting, and Modeling Water from Mine Sites

STRATUS CONSULTING

USGS science for a changing world

Kuipers & Associates, LLC

Water Boards Training Academy

Beal Mountain Mine, Montana

- Located in Southwest Montana on Forest Service and private land
- Pegasus Gold Mining Company – 1989 to1998.
- Gold and silver from open pit mining and heap leach
- 1998 Bond $6.3 Million
- 1999 Leach Pad overtopped, cyanide into GW,SW
- Site Investigations led to Forest Service CERCLA site in 2003 and has been the subject of on-going remediation efforts since that time.
- Funds spent to date = $15M
- Estimated additional funds to close = $25-$200M

Beal Mountain Mine – Water Quality Predictions, 1988 EA

- Sulfide content of the ore ranged from 3 to 8% (pyrrhotite, pyrite, chalcopyrite, with traces of molybdenite and arsenopyrite)
- Rind of clay and /or iron oxides enclosing fresh sulfides in a cherty matrix account for low acid production
- Geochemical characterization tests conducted included whole rock analysis, ABA and EP Toxicity tests
- Constituents of concern identified included arsenic, cadmium and lead
- Results of the acid-base testing indicated the waste rock would not generate acidic waters and would not be a significant source of metals due to the low sulfide content of the waste material and the large acid-buffering capacity of the majority of the waste rock
- Tests on waste rock indicated that a leachate developed under acidic conditions would be innocuous

Beal Mountain Mine – Water Quality Predictions, 1988 EA

- Mitigation identified in the EA included:
  - diversion of stormwater and collection of pit water for process use
  - leach pad and solution ponds would be lined and have either a blanket drain or leak detection system that would be monitored
  - pit would be backfilled, underlain by a layer of limestone and gravel and be free-draining, resulting in no pit lake
  - leach pad would be rinsed to address residual cyanide followed by natural degradation, dilution and "mobilization"
  - water quality impacts from the leach pad were expected to be minor and probably unpredictable
  - FONSI (Finding of No Significant Impact)

Beal Mountain Mine – Water Quality Predictions, 1993 Expansion EIS

- Included geochemical characterization testing, including static ABA, short term leach tests (EPA Method 1310), kinetic tests (15 week humidity cell tests) and trace element analysis
- Constituents of concern identified include nitrate, sulfate, cyanide, increased sediment and TDS
- Due to the presence of pyrite, pyrrhotite and iron disulfides associated with the deposit, the potential for acid production exists
- Geochemical material characterization tests for the main Beal and South Beal deposits indicate a low potential for acid formation – However, the release of sulfates and metals into surface waters is still considered to be a possibility, and these substances could become mobile regardless of acid production

Beal Mountain Mine – Water Quality Predictions, 1993 Expansion EIS

- Samples of main Beal waste with higher sulfide content were chosen to test a worst-case scenario, and static tests showed that the potential for acid generation exists for these samples
- Leachate extraction tests resulted in no metals concentrations exceeding regulatory limits, and metals mobility was predicted to be minimal
- Results from static tests on heap leach material suggested an uncertainty as to whether sulfate release and metals leaching would eventually become a concern
- Results from kinetic tests on the heap leach material showed sulfate release for all samples, indicating a possibility for oxidation of pyrite
- A chemical analysis of humidity cell leachate after week nine indicated the possibility of arsenic mobility.

Beal Mountain Mine – Water Quality Predictions, 1993 Expansion EIS

- Mitigation included:
- successful reclamation would minimize any potential for impacts to groundwater from the release of sulfate and would reduce infiltration
- addition of main Beal waste rock as backfill material into South Beal pits could provide a new source of potentially acid generating material, but testing of backfill material before placement, segregating acid producing material and keeping the pit floor above the water table were expected to prevent negative impacts to water
- if pyrite oxidation occurs, waste would be segregated in order to isolate reactive waste and cap it.
- The LAD (land application discharge) system for disposal of excess leach solution demonstrated that all contaminant levels, including arsenic, are successfully attenuated prior to discharge.

Beal Mountain Mine – Actual Water Quality, 2004 EECA Existing Conditions

- Groundwater quality monitoring well data indicated that groundwater in the LAD area exceeded standards for nitrate, iron and cyanide and had elevated total dissolved solids concentrations
- Springs below the LAD area also showed appreciable increases in cyanide and selenium concentrations
- Concentrations of selenium, sulfate, nitrate and total dissolved solids were elevated in seeps sampled at the toe of the waste rock dump

Beal Mountain Mine – Actual Water Quality, 2004 EECA Existing Conditions

- Water emanating from the toe drain collection system is pumped to a storage pond and has elevated selenium, sulfate and nitrate concentrations and cannot be discharged directly to surface water or groundwater without treatment
- Alkalinity and pH values have decreased somewhat following cessation of leaching operations, indicating that the neutralizing capability of the heap is slowly being depleted
- Current leach pad water quality has elevated concentrations of sulfate (2,600 mg/l), selenium (0.38 mg/l), arsenic (0.16 mg/l), iron (4.0 mg/l, copper (0.42 mg/l), total cyanide (9.5 mg/l) and WAD cyanide (0.061 mg/l) Alkalinity values have decreased to about 100 mg/l ($CaCO_3$ equivalent)

Beal Mountain Mine – Main Pit

Beal Mountain Mine – Pit Slide Area and Heap Leach Pad

Beal Mountain Mine – Heap Leach Pad

Figure 5. Downstream profile of streamflow at synoptic sampling sites.

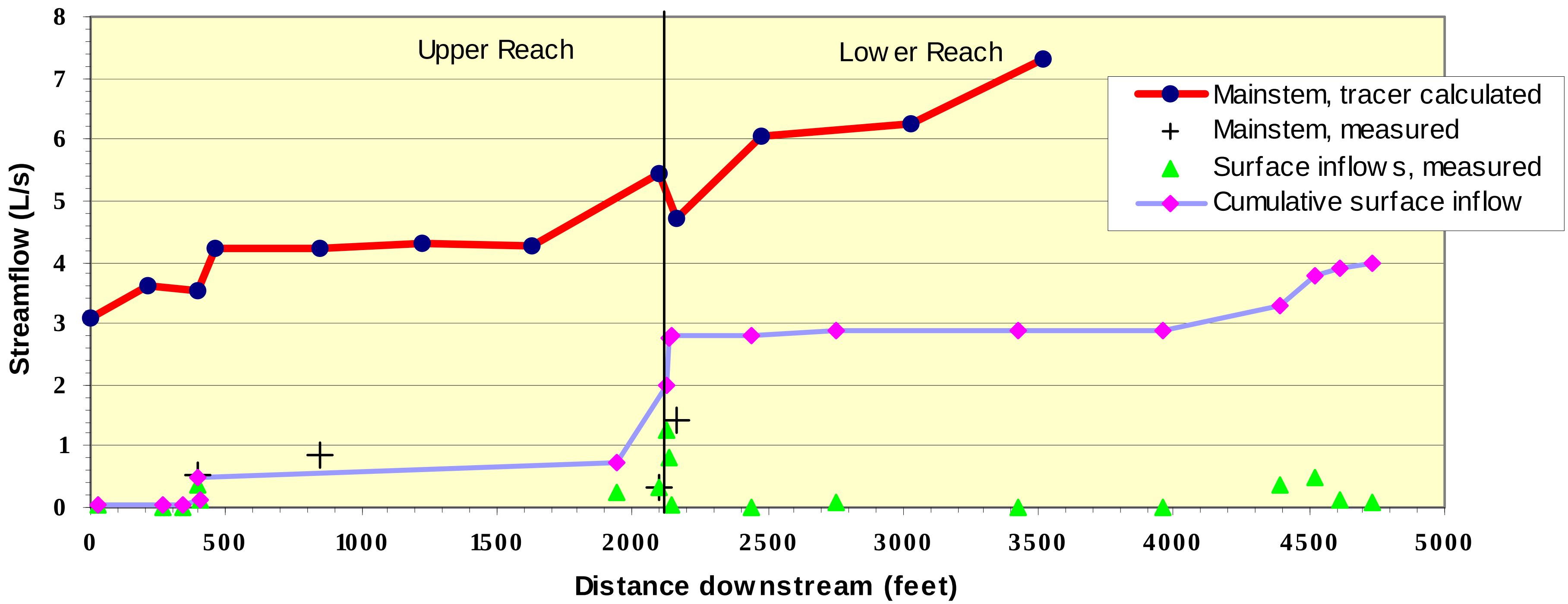
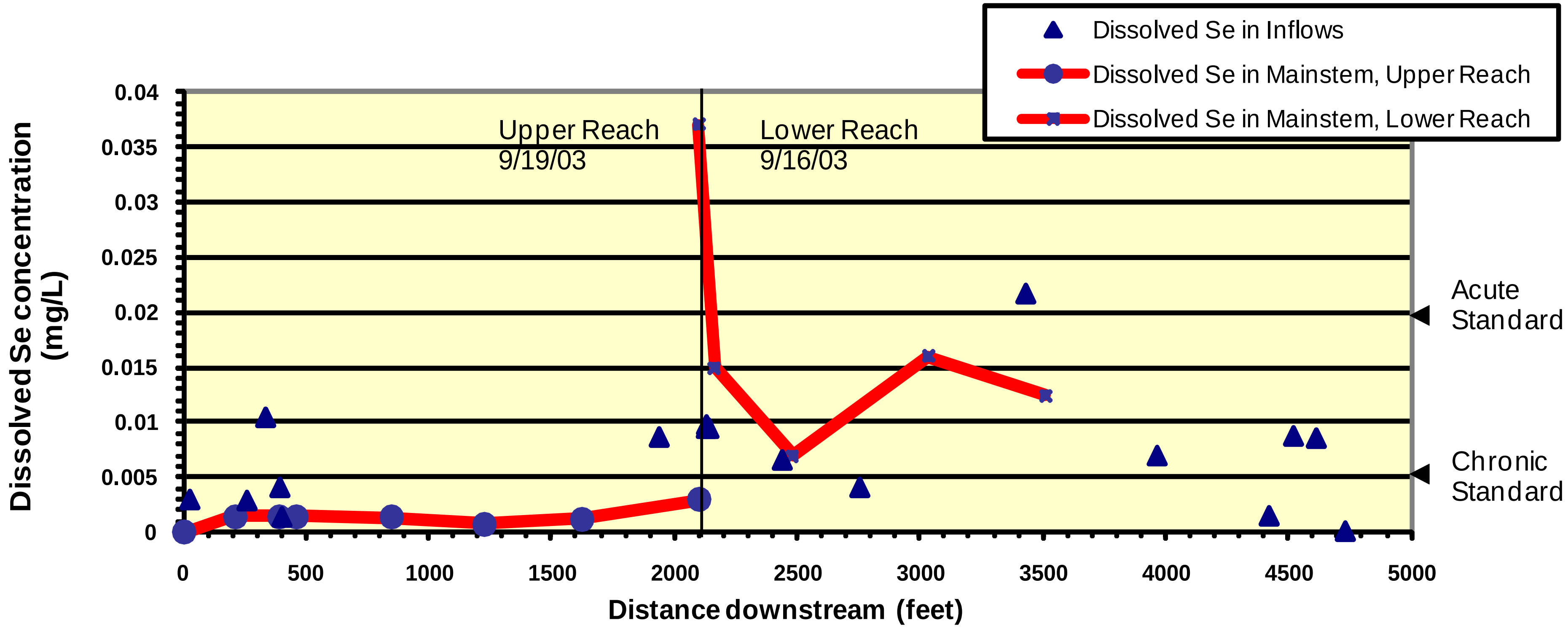
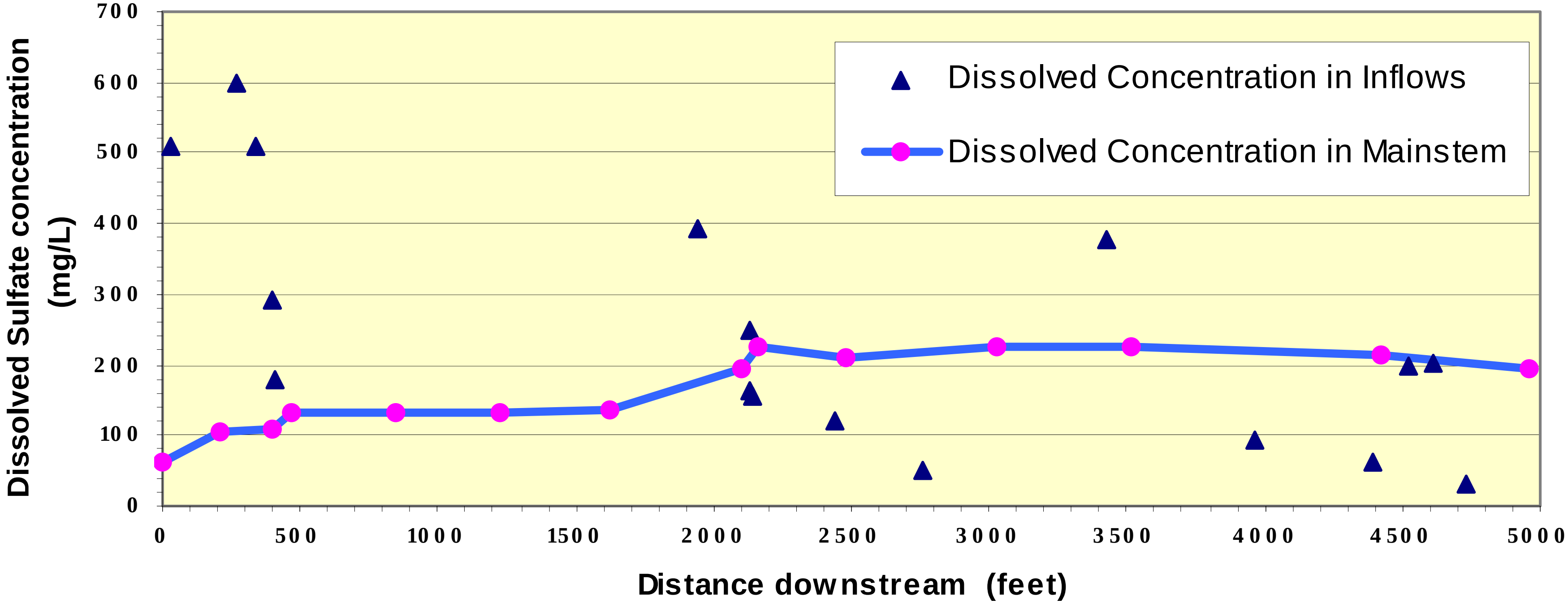


Figure 6. Downstream profile of selenium concentrations in synoptic samples from the German Gulch watershed.



STRATUS CONSULTING

Figure 7. Downstream profile of sulfate concentrations in synoptic samples from the German Gulch watershed.



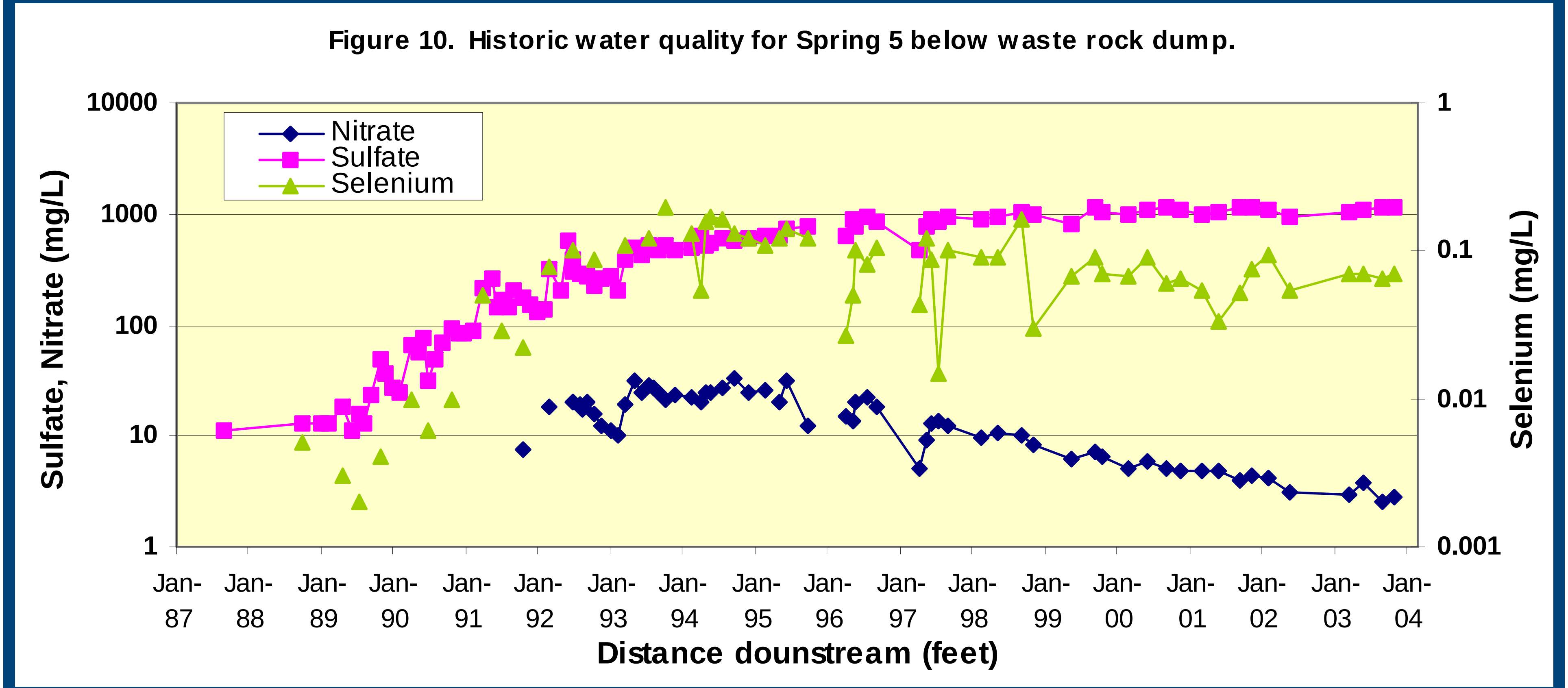
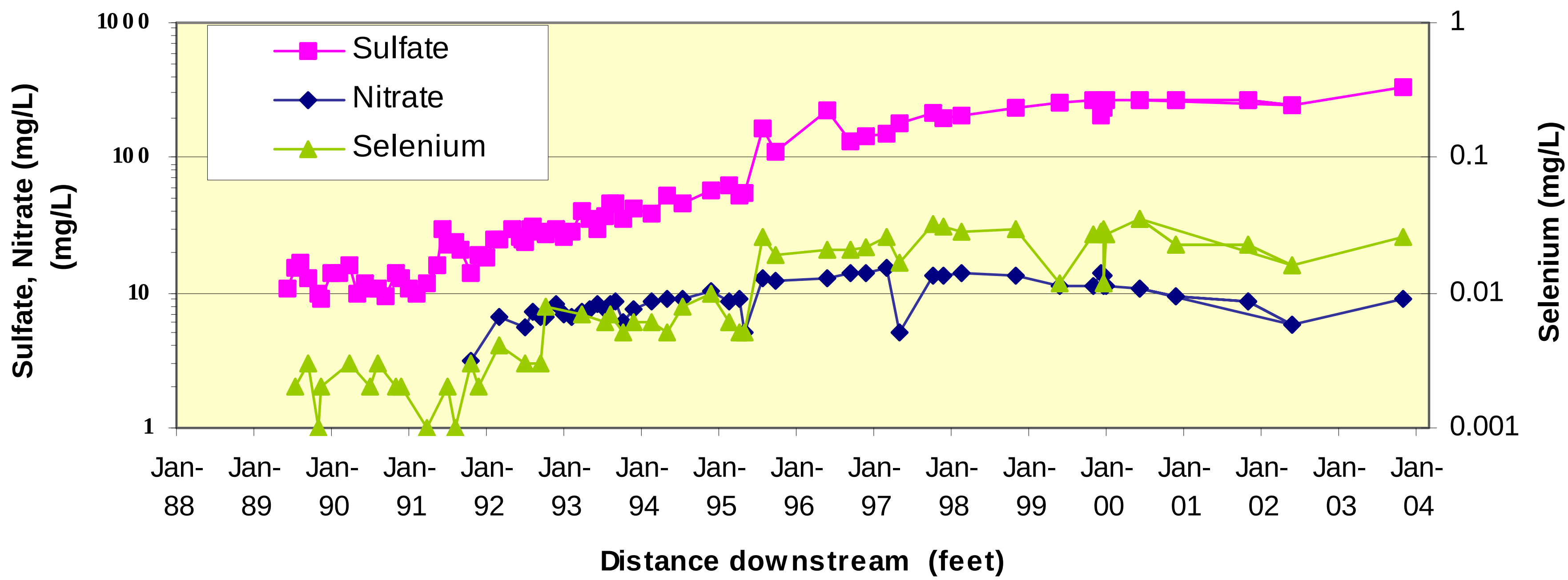


Figure 10. Historic water quality for Spring 5 below waste rock dump.
Nitrate
Sulfate
Selenium
Sulfate, Nitrate (mg/L)
Selenium (mg/L)
10000
1000
100
10
1
1
0.1
0.01
0.001
Jan-87
Jan-88
Jan-89
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Jan-00
Jan-01
Jan-02
Jan-03
Jan-04
Distance dounstream (feet)

Figure 11. Historic water quality for Well SBB-88-20 near leach pad dike.



DRAFT ALTERNATIVES
BEAL MOUNTAIN MINE ENGINEERING EVALUATION/COST ANALYSIS

Issue Identified	Alt. No.	Alternative Name	Mechanism Used to Address Identified Issue	Alternative Elements	Alt. Considered But Not Carried Forward
MAIN BEAL PIT					
1. Instability of Leach Pad Dike Resulting from Future Movement of Clay/Sill Slide	MB-1	Monitoring	Continue evaluation of slide movement	Monitor slide movement using survey and inclinometers; monitor water levels in dewatering wells; implement contingency plan if necessary	1. Backfill pit to buttress slide
	MB-2	Dewatering	Reduce or eliminate movement by lowering water table	Lower water table by pumping existing dewatering wells; dispose of water by infiltration	
	MB-3	Partial Removal	Move spent ore and leach solution from instable area; reduce loading above instable area	Move spent ore from southwest corner of Leach Pad to north; repair cover on removal area and disposal area	
SOUTH BEAL PIT					
None	SB-1	Monitoring	Monitor to evaluate meeting of reclamation goals	Monitor water quality in German Gulch; monitor revegetation; monitor erosion	None
WASTE ROCK DUMP					
1. Impacts to Water Quality in German Gulch from Waste Rock Dump Seepage **2. Potential for Waste Rock Dump to Produce Acid Rock Drainage**	WR-1	Monitoring	Monitor existing condition and impacts	Monitor SPR-5 and SPR-10A water quality, monitor surface water and groundwater quality in German Gulch	1. Move waste rock dump off-site to engineered facility 2. Move waste rock dump to engineered on-site facility 3. Reactive barrier at waste rock dump toe to treat seepage
	WR-2A	Removal	Remove identified source of selenium	Remove waste rock from above SPR-10A (20% of Se load in German Gulch); place removed waste rock in Leach Pad; pipe water around south side of dump; recover upper dump area; reduce snow drifting on waste rock dump	
	WR-2B	Removal/Reconstruct Cover	Remove identified source of selenium; replace entire cover on dump to limit infiltration	Remove waste rock from above SPR-10A (20% of Se load in German Gulch); place removed waste rock in Leach Pad; pipe water around south side of dump; regrade entire dump to slopes <2.5:1; recover dump with geosynthetic/soil cover system; reduce snow drifting on waste rock dump	

DRAFT ALTERNATIVES
BEAL MOUNTAIN MINE ENGINEERING EVALUATION/COST ANALYSIS

Issue Identified	Alt. No.	Alternative Name	Mechanism Used to Address Identified Issue	Alternative Elements	Alt. Considered But Not Carried Forward
WASTE ROCK DUMP(continued)					
1. Impacts to Water Quality in German Gulch from Waste Rock Dump Seepage 2. Potential for Waste Rock Dump to Produce Acid Rock Drainage	WR-3A	Complete Soil Cover	Reduce infiltration above identified selenium source	Reclaim upper portion of waste rock dump per existing closure plan; incorporate organics into soil cover to increase moisture holding and reduce oxygen; reduce snow drifting on waste rock dump; install upgradient lined diversions	4. Install oxidation/reduction controls in waste rock dump to reduce contaminants in solution 5. Collect seepage; pump and store solutions in leach pad; treat with pad solutions and LAD 6. Collect seepage; treat in constructed wetlands on pit floor 7. Collect seepage and land apply in Silver Bow Creek Floodplain
	WR-3B	Complete Cover With Geomembrane	Reduce infiltration above identified selenium source	Construct composite geomembrane cover on upper portion of waste rock dump to reduce infiltration; reduce snow drifting on waste rock dump; install upgradient lined diversions	
	WR-4A	Seepage Water Treatment	Treat water to remove contaminants	Evaluate variety of water treatment options to remove identified contaminants; use land application discharge as part of treatment process; use groundwater standards for treatment effluent; meet surface water standards after land application	
	WR-4B	Discharge to German Gulch	Contaminant dilution using mixing zone	Use existing pipeline and infiltration galleries; define compliance point (infiltration galleries?)	
	WR-4C	Discharge to German Gulch	Contaminant dilution using mixing zone	Extend existing pipeline; add infiltration galleries, define compliance point (infiltration galleries?)	
LEACH PAD					
1. Water Collecting in Pad Cannot be Released to Environment due to Elevated Contaminant Concentrations 2. Infiltration Through Cover Increasing Volume of Pad Solution	LP-1	Monitoring	Monitor existing condition and impacts	Monitor water quality and volume in pad; monitor groundwater quality; monitor leach pad underdrain ponds; monitor revegetation; install new well in leach pad?	1. Gravity drain pad solution to German Gulch and discharge to groundwater using mixing zone
	LP-2	Pad Solution Water Treatment	Treat water to remove contaminants	Evaluate variety of water treatment options to remove identified contaminants; use land application discharge as part of treatment process; use groundwater standards for treatment effluent; meet surface water standards after land application	
	LP-3	Replace Existing Cover	Reduce or eliminate infiltration into leach pad	Salvage soil on existing cover; remove synthetic membrane; replace with new geosynthetic membrane; construct drainage layer on the cover; recover with salvaged soil; revegetate	

DRAFT ALTERNATIVES
BEAL MOUNTAIN MINE ENGINEERING EVALUATION/COST ANALYSIS

Issue Identified	Alt. No.	Alternative Name	Mechanism Used to Address Identified Issue	Alternative Elements	Alt. Considered But Not Carried Forward
LAND APPLICATION DISPOSAL (LAD) AREAS					
1. Reduce Contaminant Concentrations in Soil	LAD-1	Monitoring	Monitor existing condition and impacts	Monitor soil and water quality in springs in LAD area	None
	LAD-2	Rinsing	Reduce elevated constituent concentrations in soil	Rinse LAD areas with fresh water to minimize effects to soil	
GERMAN GULCH					
1. Exceedance of Water Quality Standards 2. Potential Selenium Source Identified in Road Fill Crossing German Gulch	GG-1	Monitoring	Monitor existing condition and impacts	Monitor surface water and groundwater quality in German Gulch	None
	GG-2	Removal	Remove potential selenium source	Excavate waste rock from road fill; Replace culvert/fill material	
ACTIONS COMMON TO ALL ALTERNATIVES				**DESCRIPTION**	
1. Meet Existing Closure Requirements	AC-1	Main Beal Pit		Construct lined interceptor and diversion ditches; revegetate as required	
		South Beal Pit		Repair erosion problems; revegetate as required	
		Maintenance Shop, Process Plant, Office Building		Remove facilities; regrade and revegetate	
		Roads		Narrow roadway, revegetate fill slopes; remove temporary bridge over German Gulch and raise existing bridge; obliterate road across private property	
		Ponds		Closure depends on short term use	

Stillwater Mine, Montana

- Stillwater Mining Company
- In operation since 1986
- Primary commodities mined are platinum group minerals from underground mining, using flotation processing methods
- Disturbs 255 acres on private and U.S. Forest Service lands Mine
- New mine EIS was completed in 1985
  - 1992 EIS mine expansion
  - 1998 an EIS was conducted for a new tailings disposal facility and revised waste management

Phoenix Mine, Nevada
General Project Description

- Owner/Operator: Newmont Mining Corp.
- Location: Battle Mountain, Nevada – mine located on Bureau of Land Management and private land.
- Operations: Historic mining district, modern large-scale mining initiated 1970's, planned large expansion encompassing five existing mines. Open pit, carbon-in-leach, heap leach
- Total Disturbance: 676 acres (existing)
  4,295 acres (proposed)
- Financial Assurance $34,152,000 (phase 1 surface disturbance)
  $918,500 (treatment in perpetuity)

Phoenix Mine, Nevada
Reclamation Plan – Phase 1

Disturbance	Area (acres)	Reclamation Plan
Pit	576	Partial pit backfill and complete backfill (prevent pit lake)
		Cover with 5 ft capping material
		Revegetate
		Construct stormwater controls
Waste Rock Dumps	1,942	Regrade slopes to 2H:1V and 3H:1V
		Cover with 2 ft ET layer, 1 ft growth medium
		Revegetate
		Construct stormwater and erosion control structures
Tailings Impoundments	1,396	Regrade slopes to 2H:1V and 3H:1V
		Cover with 2 ft ET layer, 1 ft growth medium
		Revegetate
		Construct stormwater and erosion control structures
Miscellaneous (includes Roads)	3,159	Grading, ripping, revegetation, stormwater controls
Water Treatment		Amend submerged waste rock with hydrated lime
		Lime precipitation and membrane separation
		Construct seepage capture systems

Phoenix Mine, Nevada
Long-Term Groundwater Management Plan

- One View on ARD (Yes)
- Three Views on Requirements and Cost Estimate
  - Newmont $918,500 (from $408,000)
    - Based on treatment beginning in 60 years
    - 9% net discount rate
  - EPA $33.5 million
    - Based on treatment beginning in 20 years
    - 5% net discount rate
  - NGO's $60 million
    - Based on existing treatment requirements
    - 3% net discount rate
- BLM/State of Nevada decision for Newmont
  - Long-term Contingent Fund Agreement
  - Irrevocable Trust Agreement