Passive Treatment of Mining Influenced Water: From Bench Scale to O & M

BIOCHEMICAL REACTOR CONSTRUCTION, MINE POOL CHEMISTRY CHANGES, & O & M GOLINSKY MINE, CALIFORNIA

Jim Gusek, Sovereign Consulting Inc., and
Rick Weaver, US Dept. of Agriculture**,** Forest Service

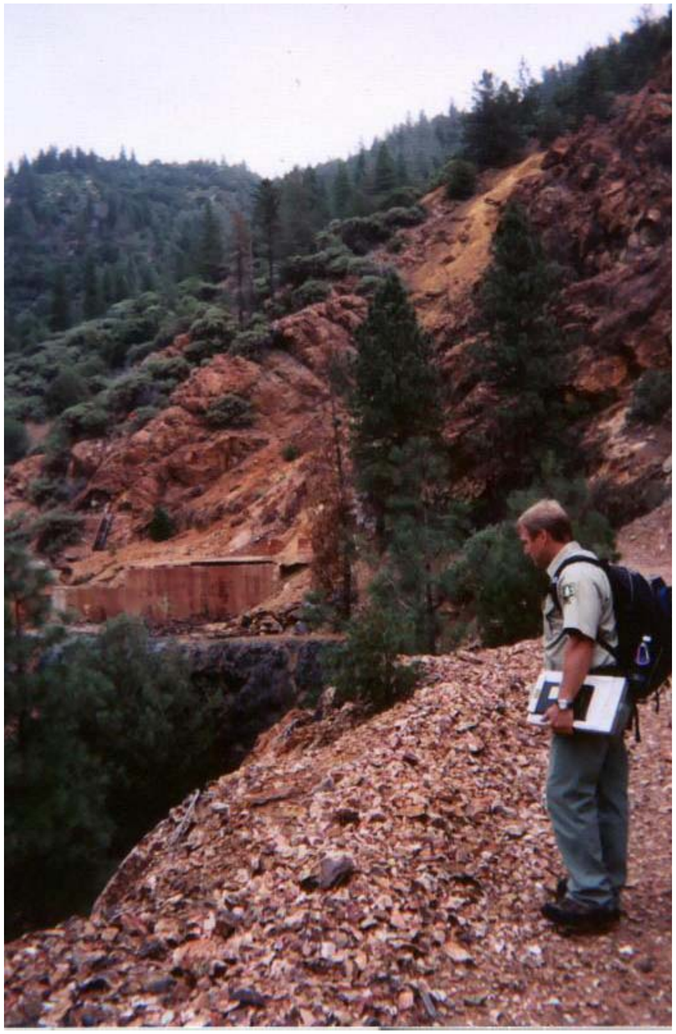
SOVEREIGN CONSULTING INC.
AN ENVIRONMENTAL SERVICES FIRM

Golinsky Mine, Trinity National Forest

I. BCR Design & Construction

II. Mine Pool Improvements

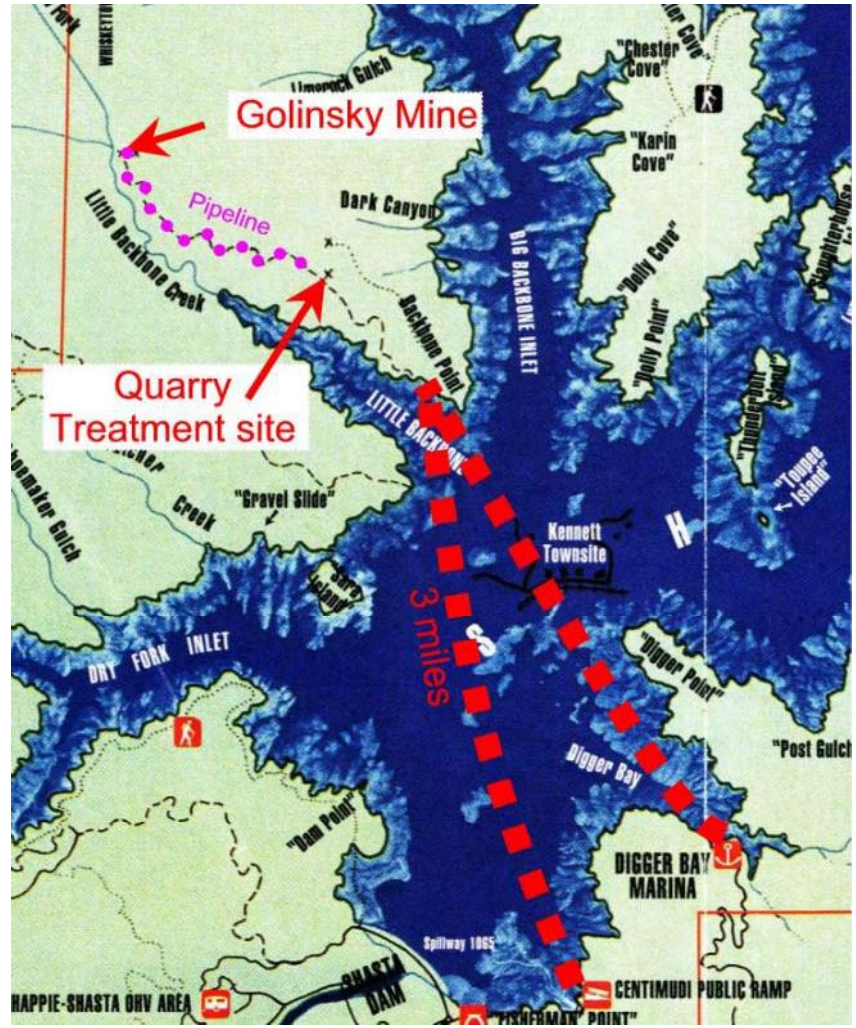
III. Operation & Maintenance



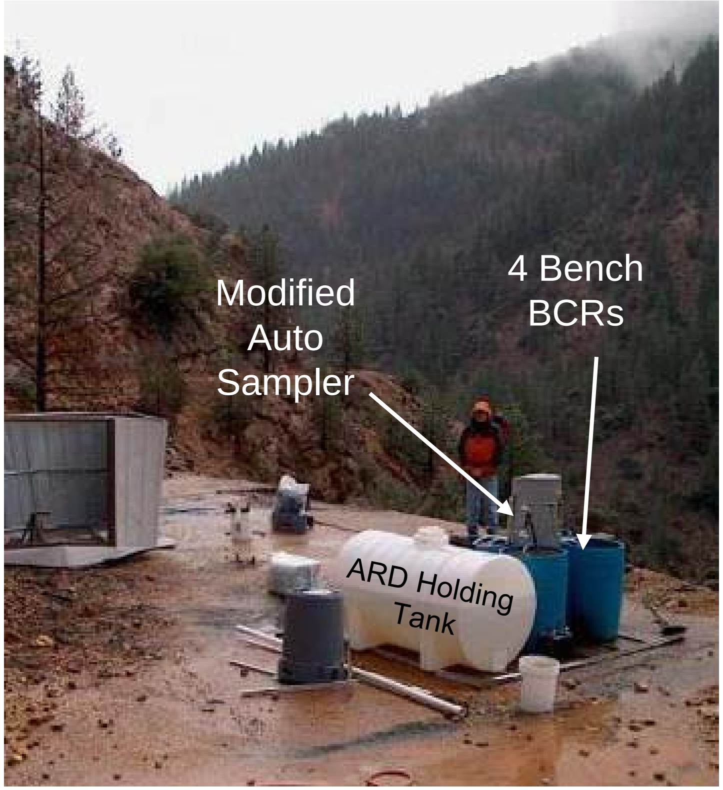
Site Location & Project History

Site/Project History

- ❑ Mine Operates 1904 to 1938 (copper & gold)
- ❑ USFS acquires property in 1944 through purchase
- ❑ 2004 - Bench Test Construction & Operation
- ❑ 2004 – Design/build buried pipeline
- ❑ 2004 – 2006 Pilot Scale Construction & Operation
- ❑ 2006 – Pilot decommissioning
- ❑ 2007 - Full Scale Module 1 Design
- ❑ **2010 – Full Scale Construction**
- ❑ **2011 – Full Scale Start-up**
- ❑ **2012-2016 Vicinity Drought**
- ❑ **2016 – O&M Activity**



Bench Test & Pilot Test Setup



17 Weeks Bench Flow Range:

8.5 to 16.4 Liters/day

Pilot Average Flow:

0.9 gpm

Mine Water Chemistry – Pilot Testing

Influent Water (Lower Portal)

pH – 2.7

Fe – 73 mg/L

Al – 23 mg/L

Mn – 0.85 mg/L

Zn – 37 mg/L

Cu – 12 mg/L

Ni – 0.031 mg/L

Cd – 0.47mg/L

SO_4 – 664 mg/L

Pilot BCR Effluent

pH – 7.2

Fe – 0.8 mg/L

Al – 0.06 mg/L

Mn – 2.5 mg/L

Zn – 0.1 mg/L

Cu – <0.003 mg/L

Ni – 0.007mg/L

Cd – 0.006 mg/L

SO_4 – 488 mg/L

Passive Treatment Chemistry 101

REDUCING/ ANAEROBIC CONDITIONS

$$SO_4^{-2} + 2\,CH_2O \rightarrow \mathbf{HS^-} + 2HCO_3^- + H^+$$

(Sulfate reduction and neutralization by bacteria)

$$Zn^{+2} + \mathbf{HS^-} \rightarrow ZnS\,(s) + H^+$$

(Sulfide precipitation)

OXIDIZING CONDITIONS

$$Fe^{+3} + 3\,H_2O \rightarrow Fe(OH)_3\,(s) + 3\,H^+$$

(Hydroxide precipitation)

ALL CONDITIONS

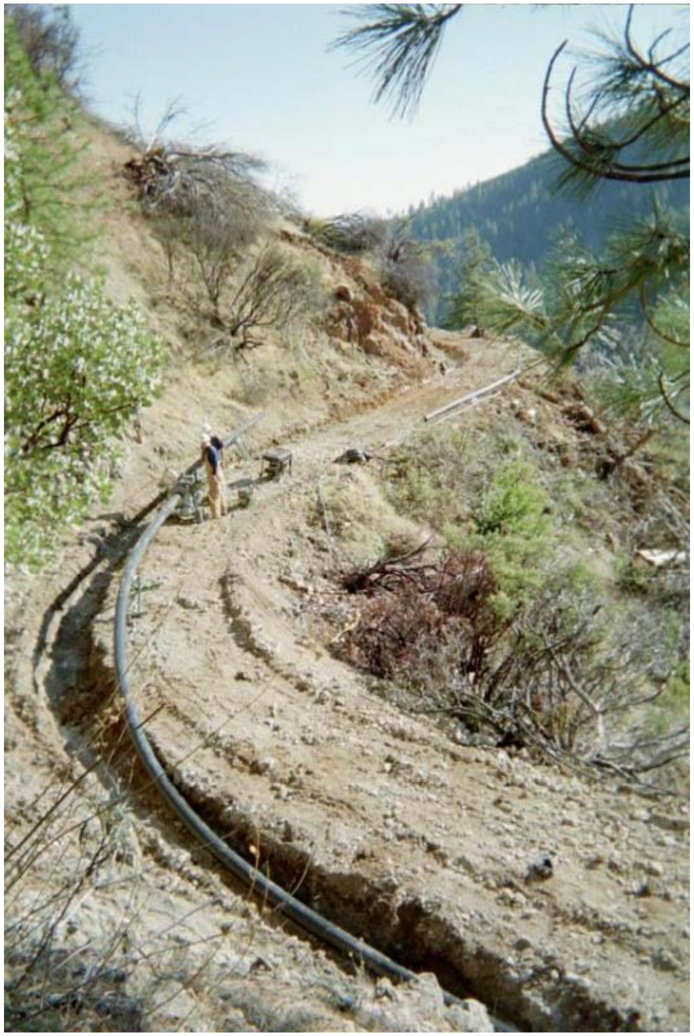
$$H^+ + CaCO_3 \rightarrow Ca^{+2} + HCO_3^-$$

(Limestone dissolution)

Module 1 Design Chemistry

Parameter	Lower Portal Estimate for Design (2007 data)	Lower Portal (Pilot average for 27 months - 2004 to 2006)
Flow, L/min	37.8	3.6
Flow, gpm	10	0.9
pH S.U.	3.0	2.7
Fe, mg/L	27	73
Cu, mg/L	14	12
Zn, mg/L	67	37
Cd, mg/L	0.73	0.47
Al, mg/L	31	23
Mn, mg/L	0.42	0.85
Sulfate mg/L	<500	664

Mine, Pipeline, and Abandoned Limestone Quarry



Phased Module Implementation

- Portal flow data suggests peak of 90 gpm during wet months
- No available space at the mine site itself
- Available space at the quarry only has room for 30 gpm
- Site access is restricted; it’s difficult to build full PTS capacity in a single construction season
- Limited funding supports design of 10 gpm “starter” module and monitor to see if addition modules are necessary

Overall Design Philosophy

- All flows by gravity
- Biochemical reactor sized for 10 gpm / 38 liters minute
- Any by-passed flow (>10 gpm) would be neutralized by treated water in a mixing pond
- Mixing pond effluent would be infiltrated into native ground in a “Flow Dispersion Zone”
- “Tweak” substrate recipe based on experience at other sites

BCR Substrate Modification

Component	Pilot BCR	Full BCR
Rice Hulls	10%	10%
Wood Chips	40%	50%
Hay	10%	10%
Limestone	30%	30%
Manure[1]	10%	<0.1%

Manure (and 6 cy of depleted pilot substrate) rototilled into upper 12 inches of substrate

Construction Challenges

- Lake levels are the lowest in years due to drought
  - Good news: mobilization site close to Shasta Dam (2.4 miles from beach head)
  - Bad news: off-loading barges will be difficult on sloping shore at beach head
- Drought ends from El Nina rains as bid walk is conducted (March 2010)
- Lake levels rise, and rise, and rise some more…
- Preferred mobilization site is submerged; alternate site is 6.9 miles from beach head

Lake level recovery: too much of a good thing

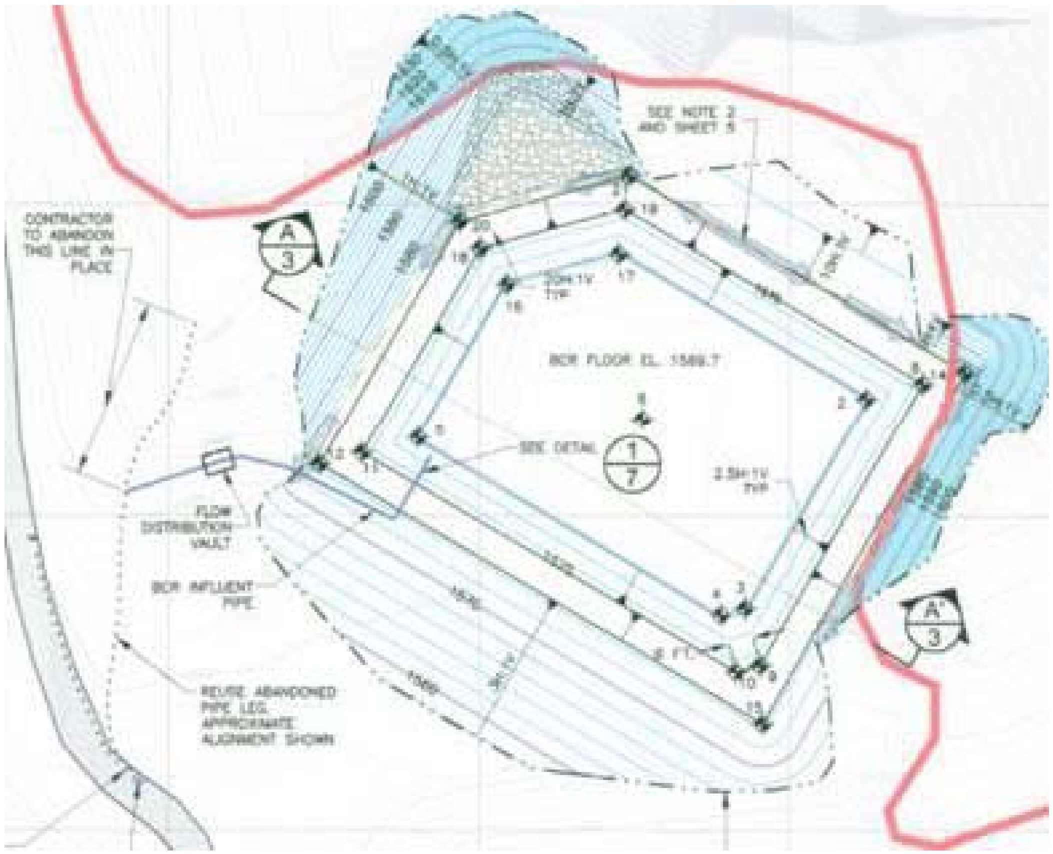
Initial Contractor
Mobilization Site (2.4 miles)

Construction Challenges (Continued)

- Storing materials at a very constricted site

Construction Challenges (Continued)

- Ground conditions in one corner of the quarry require field modification

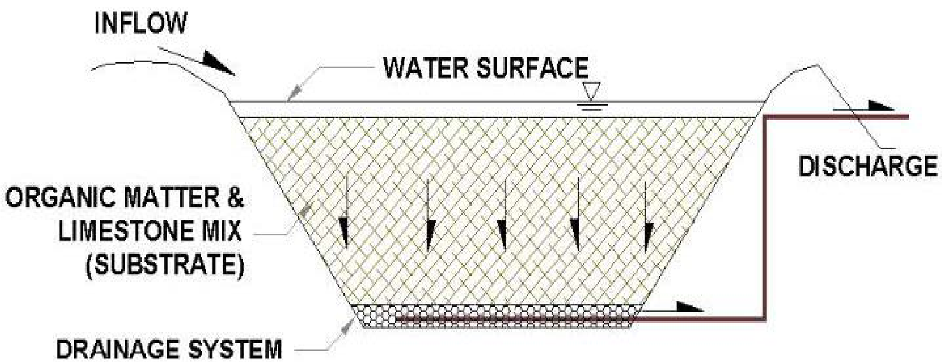


BCR Footprint reduced by 3.6%

Construction Challenges (Continued)

- Delayed start due to weather and storm water BMP's puts project behind schedule and reduced available construction budget
- Ground conditions in the mixing pond footprint spook contractor
- Mixing pond is dropped from the contractor's work scope (see paper [Gusek, 2011] for details)
- Flow Dispersion Zone design is modified to minimize imported riprap

Golinsky BCR Construction, 2010 (with ARRA Funding)



Construction Cost: $1.3 million (about $0.012 per gallon for 20-yr life)

Final BCR As Built (January, 2011)

BCR Module 1 Commissioning Challenges

- Portal 3 is the only mine pool plumbed into the quarry when the BCR is ready for commissioning (we used it for soil moisture, dust control)
- ***Portal 3 sulfate concentration is only 8 to 10 mg/L***
- Lower Portal pipeline is plugged with iron precipitates;
- Inclement weather prevented LP maintenance and the BCR filled with rain water

Solutions

- ❑ Added 20 lbs or 9.1 kg of Epsom salt to BCR inflow
- ❑ Added a 30 lbs or 13.4 kg “teabag” of agricultural gypsum to flow distribution vault
- ❑ Influent sulfate 14 mg/L; effluent 4 mg/L
- ❑ Lower Portal plumbed in January 25th 2011, no “transition” (sulfate @1,127 mg/L; pH 2.7)

BCR Receiving Lower Portal MIW
(May 2011)

BCR Receiving Lower Portal MIW (October 12, 2016)

BCR Results
(6 Lower Portal MIW events)

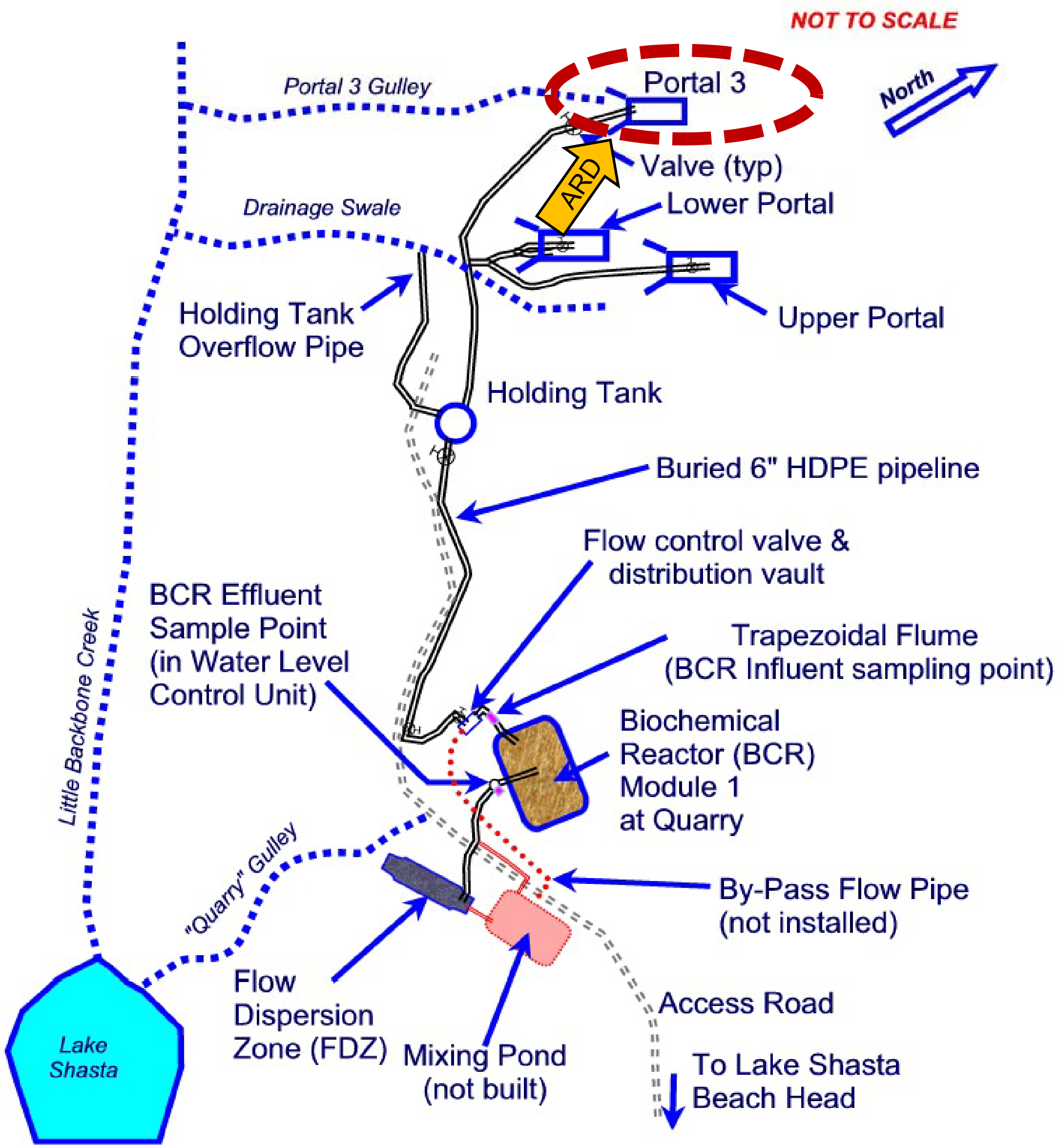
Parameter	Influent	Effluent
pH	2.7 s.u.	6.45 s.u.
Iron	97.2 mg/L	6.1 mg/L
Aluminum	28.6 mg/L	0.03 mg/L
Copper	19.3 mg/L	0.005 mg/L
Zinc	40.0 mg/L	0.5 mg/L
Cadmium	0.40 mg/L	0.005 mg/L
Calcium	19 mg/L	206 mg/L
Manganese	0.6 mg/L	2.1 mg/L
Sulfate	728 mg/L	324 mg/L
ORP	354 mv	-217 mv

97% metal removal efficiency in May 2011

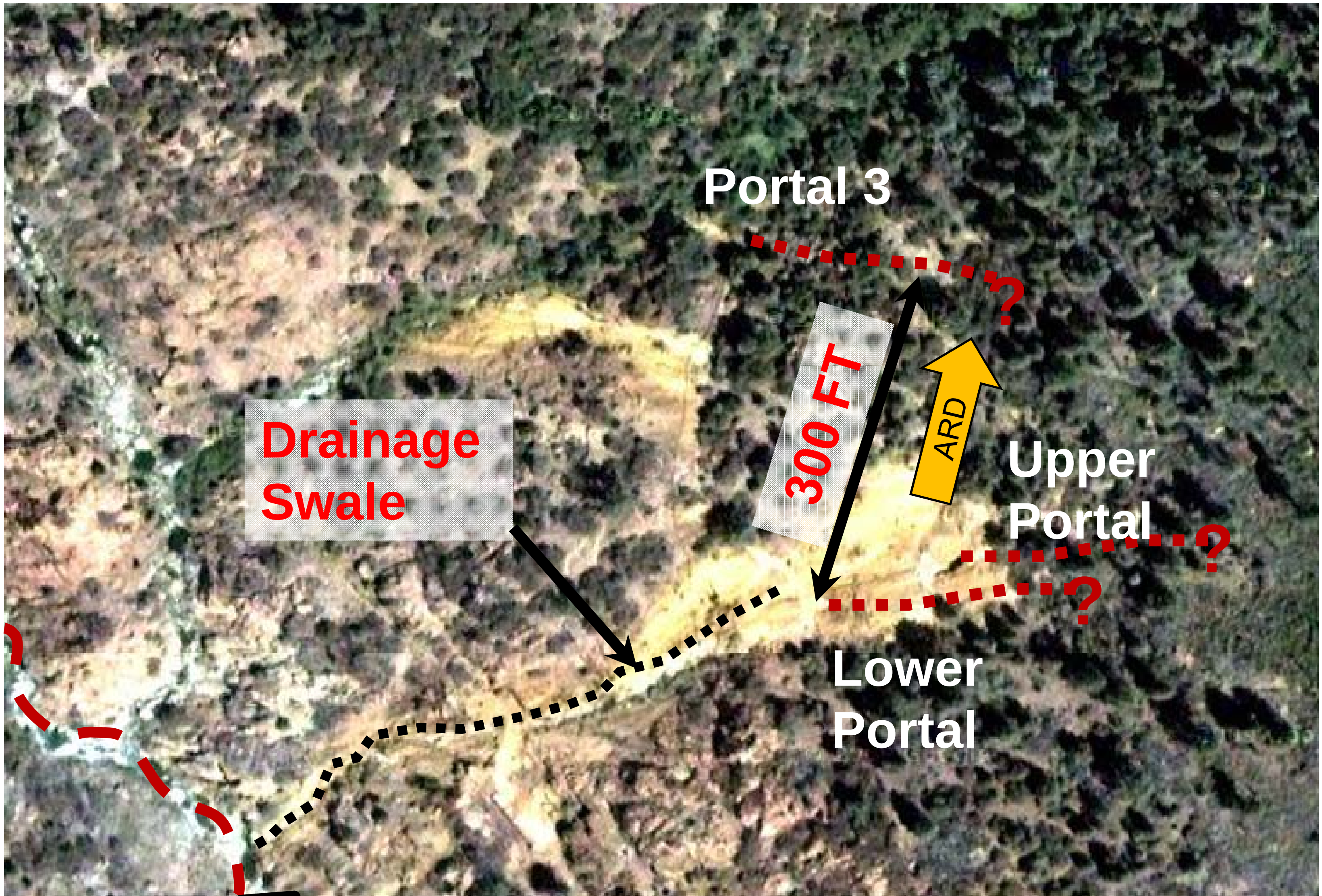
PART II

PORTAL 3 MINE POOL IMPROVEMENTS

Full Scale Passive System Schematic Layout



Portal 3 and Lower/Upper Portal Proximity



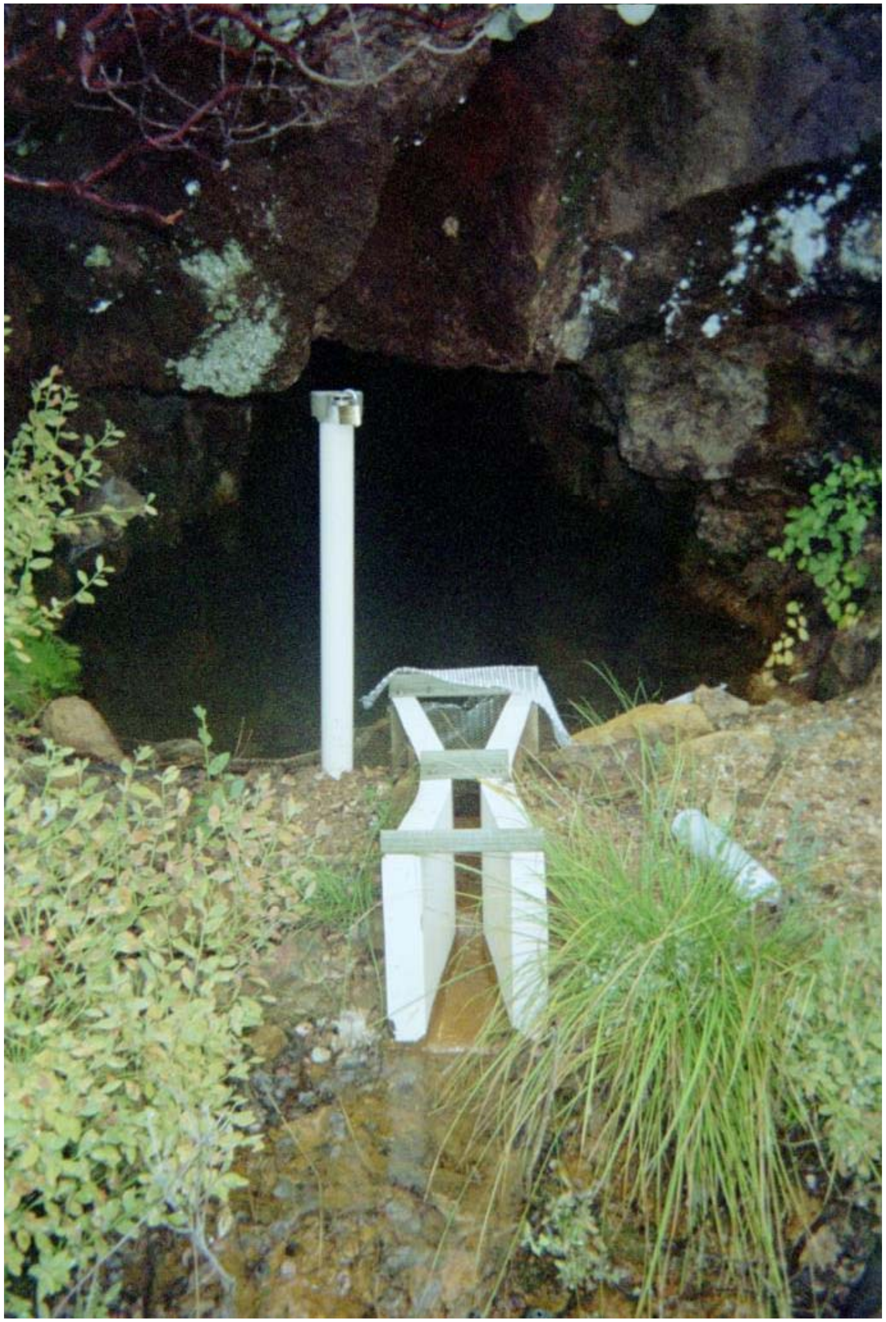
Little Backbone Creek

Changes in Portal 3 Chemistry 2004-2016

Changes in Portal 3 Chemistry 2004-2016

Changes in Portal 3 Chemistry 2004-2016

Changes in Portal 3 Chemistry 2004-2016

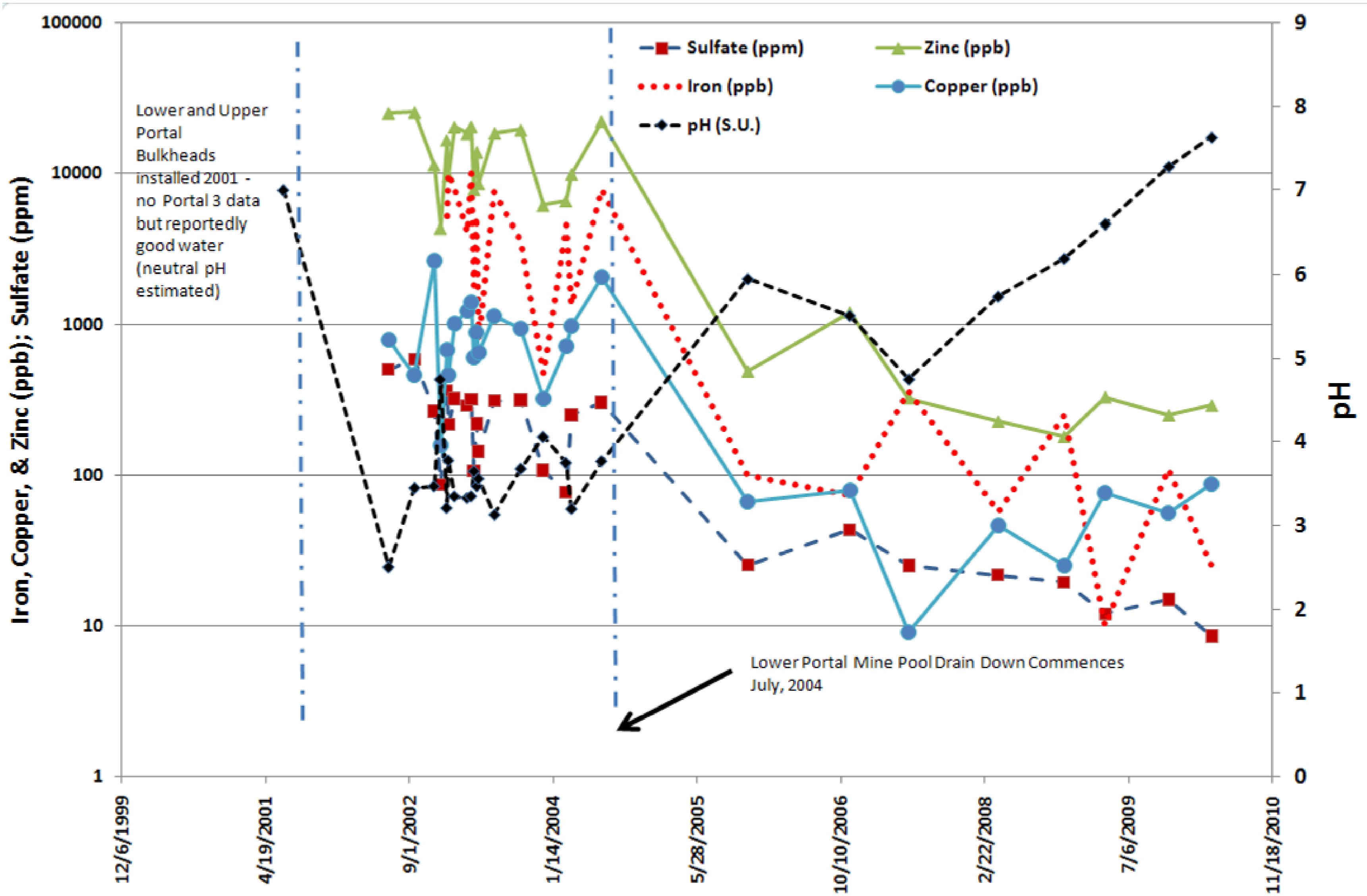


2007

Changes in Portal 3 Chemistry 2004-2016

Changes in Portal 3 Chemistry 2004-2016

Portal 3 Water Chemistry Improvements



0.07 to 0.11 gpm of Lower Portal MIW satisfies metal load in Portal 3 based on sulfate, zinc, and copper

Final Thoughts (Parts I & II)

- Construction Cost: $1.3 million – ARRA funding with supplementary USFS funds
- Seven year span from initial bench tests in late 2003 to startup in late 2010 – fully commissioned in June 2011
- Safety record exemplary for remote site, heat stress, multiple water crossings
- After five years, system appears to be performing as intended – no surprises (yet)
- No ill effects due to prolonged drought

PART III

OPERATION & MAINTENANCE

BCR Commissioned in June 2011 & function as designed through 2013

In 2012 following dry season, flow data logger malfunctioning at BCR

Equipment mobilized to site with Landing Craft

Influence of vegetation potentially adversely affecting iron removal

Mini excavator used to pull willows

Mini excavator moving vegetation removed from BCR

BCR after willow removal

Repairing BMPs on access road using hand tools and mini excavator

Clearing access road of vegetation

Pipelines from Lower adit. Iron hydroxide sludge blockage

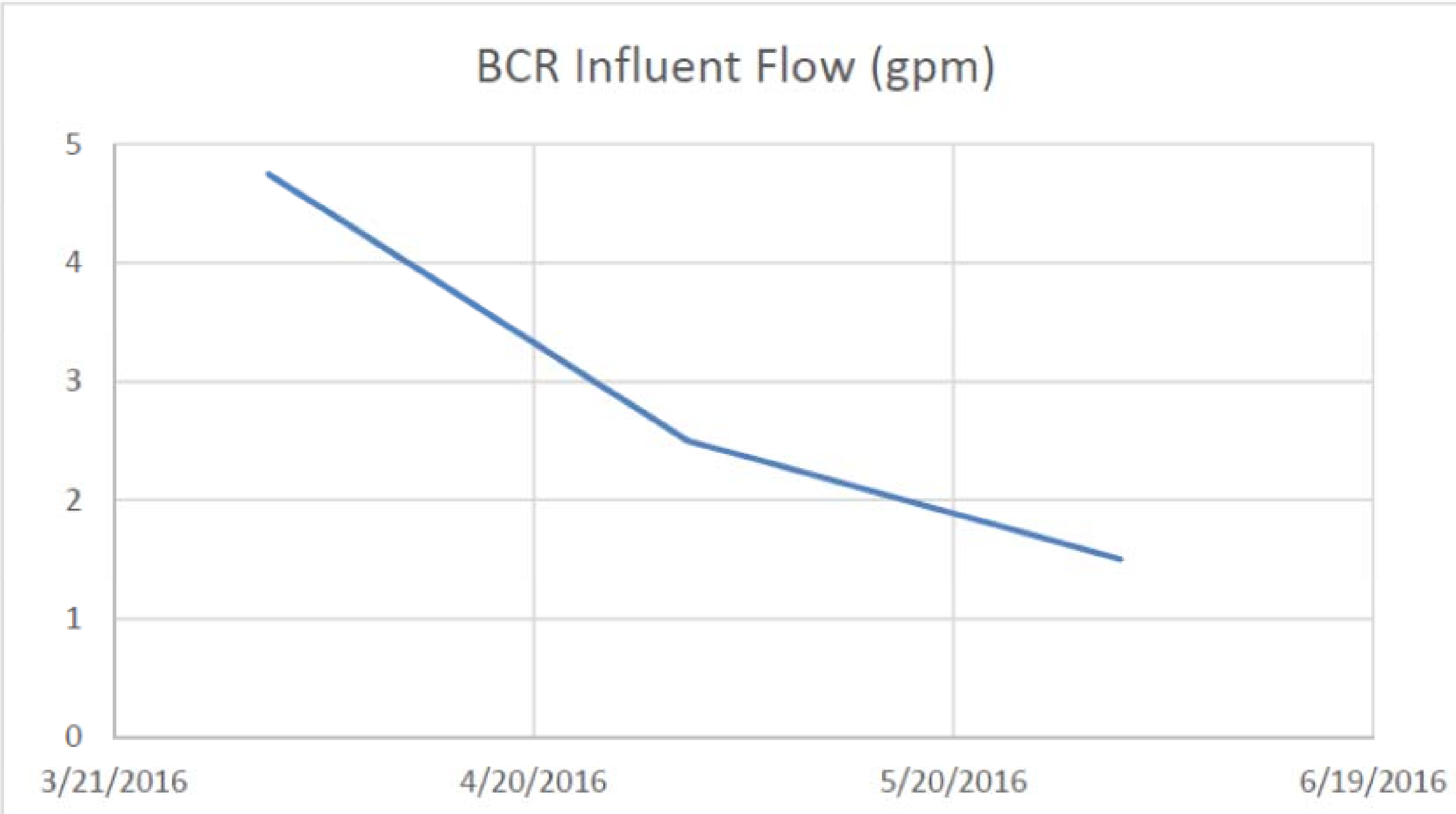
Upper Adit
Link Seal and Stainless Steel Flexible Coupling installed to repair leak & stabilize pipe at bulkhead

Leak at Saddle Tee on Upper Adit Pipe
Repairing Saddle Tee with Romax Clamp

Trash bag stuck in pipe causing plug

Lower Adit Bat Gate
Sock Filter over Floor Drain

Winter to summer flow rate decrease from 4.5 gpm to 1.5 gpm between April 25 and June 6, 2016. Estimated cumulative total of 233,000 gallons received by the BCR.



Changing battery in data logger at BCR influent flume. Flow was 0.75 GPM on 10/12/16

Pipes replaced due to excessive iron hydroxide deposition

BCR at low water level on October 16, 2016 at end of dry summer

BCR on October 19, 2016
after 4 to 5 inches of rain in four days

Mass Removal Rates from Spring Monitoring

Parameter	BCR Influent	BCR Effluent	Pounds Removed During Reporting Period	Pounds Removed per day During Reporting Period	Removal Efficiency During Reporting Period
Sulfate (mg/L)	1,400	1,500	See Note 1 Below		
Dissolved Aluminum (µg/L)	34,000	<50	66.1	1.57	100%
Dissolved Iron (µg/L)	85,000	150,000	See Note 2 Below		
Dissolved Cadmium (µg/L)	710	1.8	1.4	0.03	99.7%
Dissolved Copper (µg/L)	27,000	2.5	52.5	1.25	100%
Dissolved Manganese (µg/L)	920	3,300	See Note 2 Below		
Dissolved Zinc (µg/L)	76,000	13,000	122.5	2.92	83%

Notes:

1. Increase in sulfate concentrations may be attributable to reduced biological activity (as a result of no flow to the BCR) and associated sulfate reduction. If this is the case, future samples events should see increased sulfate reduction.
2. It is suspected that increased dissolved iron and manganese concentrations are the result of iron precipitate collecting in the discharge piping.

Conclusion of Spring Monitoring Report

- Monitoring observations and data collected by ECM have concluded that the BCR is operating within design parameters and is effectively removing metals from mine impacted water.

- The BCR appears to be treating the mine drainage successfully and the efficiency of removal for aluminum, cadmium, and copper is close to 100%, with zinc near 83% removed.

Are the exposure assumptions, toxicity data, cleanup levels, Removal Action Objectives used at the time of the removal action (RA) still valid?

- *Reduce or eliminate the release of acidity and heavy metals from the Site to surface water and meet ARARs,*

- *Reduce or eliminate the release of acidity and heavy metals to from the Site to groundwater and meet ARARs, and*

- *Reduce or eliminate the potential for exposure to humans, aquatic and terrestrial biota from ingestion or direct contact with AMD and potentially contaminated aquatic life.*

Data indicate that the BCR is effective at treating MIW at the design flow rate of 10 gpm. The exposure assumptions, toxicity data, cleanup levels, and RAOs used at the time of the RA are still valid & the BCR system that was installed is protective.

Storm water runoff in swale only MIW discharged from site

Final Thoughts

- Phased design approach minimizes risk
- Bulkheading underground mine workings is not always a good idea (ARD is going to find its way out)
- Passive treatment is ***LOW*** maintenance, not **NO** maintenance
- Removal Action assumptions still valid; BCR system is protective
- Special thanks to:
  - Brad Shipley (ret.), USFS P.O. 2003? to 2016, and
  - ECM Consultants, the current site monitoring and O & M contractor

Questions/Discussion??

SOVEREIGN CONSULTING INC.
AN ENVIRONMENTAL SERVICES FIRM

FOREST SERVICE
U S
DEPARTMENT OF AGRICULTURE