BIOCHEMICAL REACTOR CONSTRUCTION AND MINE POOL CHEMISTRY CHANGES, GOLINSKY MINE, CALIFORNIA[1]

James Gusek[2], Joel Kelsey, Ryan Schipper, and Brad Shipley

Abstract. In early 2010, American Recovery and Reinvestment Act funds were available to implement the “shovel-ready” design package for a biochemical reactor (BCR) module that was planned at the abandoned Golinsky Mine site in northern California. The design was based on bench and pilot studies that were documented in previous ASMR papers. The construction site, located near Lake Shasta, is only accessible by boat followed by a 1.6 km (1-mile) trip on a narrow dirt road. During construction, the typically restricted site access was further complicated by the highest lake levels in years which required the relocation of the construction contractor’s mobilization site.

The construction of the BCR within the footprint of an abandoned limestone quarry required a few minor design modifications. However, the logistics of moving about 1,000-plus tons of organic substrate, drainage gravel, HDPE liner, rip rap, pipes, plus construction equipment safely across Lake Shasta in a coordinated barge and ground transportation program was probably the greatest project accomplishment.

The commissioning of the pilot treatment bioreactor in mid-2004 resulted in the drain-down of an acidic mine pool. This action appears to have caused significant improvements in the drainage chemistry of a mine adit adjacent to, but not directly connected to the acidic mine pool. This unintentional outcome allowed the use of the improved mine water source for fire suppression, dust control, and moisture control in earthwork compaction efforts.

Additional Key Words: BCR, mining influenced water, passive treatment, abandoned underground copper mine, mine pool drain-down effects

---

[1] Paper was presented at the 2011 National Meeting of the American Society of Mining and Reclamation, Bismarck, ND ***Reclamation: Sciences Leading to Success*** June 11 - 16, 2011. R.I. Barnhisel (Ed.) Published by ASMR, 3134 Montavesta Rd., Lexington, KY 40502.

[2] James Gusek and Ryan Schipper are with Golder Associates Inc., 44 Union Blvd #300, Lakewood, CO 80228, Joel Kelsey is with Golder Associates Inc., Roseville, CA and Joel Kelsey is with USDA Forest Service, Nevada City, CA

Proceedings America Society of Mining and Reclamation, 2011 pp 253-268
DOI: 10.21000/JASMR11010253

`http://dx.doi.org/10.21000/JASMR11010253`

Introduction

The Golinsky Mine is an abandoned underground base metal mine near Lake Shasta in Shasta County, California in the Shasta-Trinity National Forest (see Fig. 1). The mine was last active in the early part of the 20th century (SHN, 2004) when Cu, Zn, and minor amounts of precious metals were recovered. The mine and an associated milling/smelting complex are in rugged, mountainous terrain. The site and previous activities on this project are further described in Gusek et al., 2005 and Gusek, et al., 2008.

The remote site can only be reached by boat, about a three-mile (4.8 km) trip from either of two boat launch sites. The mine complex is about a two-mile (3.2 km) hike from the landing site in Little Backbone Bay. The mine complex is at an elevation of 1,800 ft. (549 m); the shoreline of Lake Shasta is at an elevation of about 980 ft. (300 m). There are three adits, two of which have concrete bulkheads. The third adit workings are not connected to the workings that are bulkheaded. The geochemistry of the "main" Golinsky Mine ore is dominated by sulfides, including pyrite. This condition leads to the inevitable production of acid rock drainage (ARD). The main mine pool chemistry exhibits a pH of 2.5 to 4 and contains heavy metals including Fe, Al, Cu, Zn, Cd, and Mn. The bulkhead construction was intended to flood the mine workings and suppress pyrite oxidation/ARD by perpetual submergence. The bulkheads were installed in 2001; the third adit (Portal 3) reportedly exhibited neutral-pH drainage with trace metal content prior to the bulkhead installation; this condition deteriorated soon after the bulkheads were constructed.

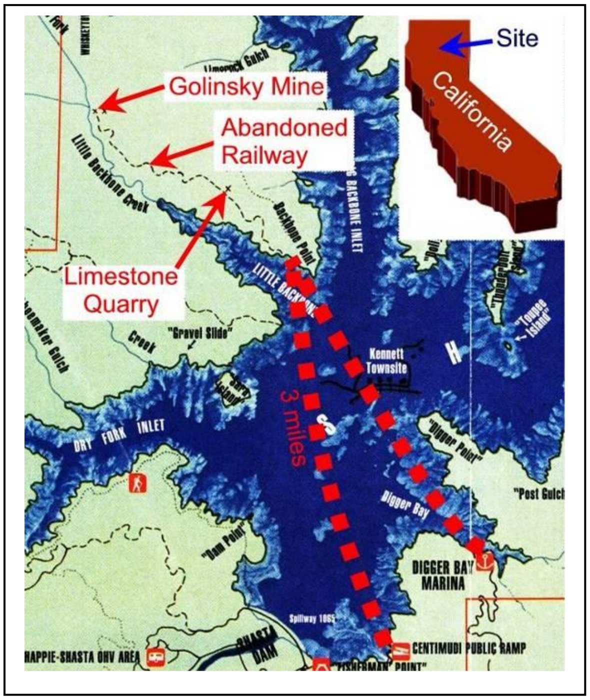

Figure 1. Site Vicinity

From 2001 to 2004, Portal 3 discharged ARD that failed to meet water quality standards, the pH dropped to about 3 S.U. and dissolved metals concentrations increased. It was hypothesized that contaminated "main" mine pool water was mixing with the otherwise clean water that discharged historically from Portal 3 prior to the bulkheads' construction.

In late 2003, Region 5 of the U.S.D.A. Forest Service elected to investigate methods of treating and discharging the main Golinsky Mine pool water behind the bulkheads and collect and treat the ARD discharging from the third adit. These measures would help to protect Little Backbone Creek, which is a tributary to Lake Shasta. Due to the site's inaccessibility and total lack of infrastructure (i.e., electricity), passive treatment methods were viewed as especially attractive.

Phased Treatability Study and Supplemental EE/CA

A two-phased treatability study was commissioned to determine if a sulfate reducing biochemical reactor (BCR) was an appropriate technology for passively treating the main mine pool ARD commingled with Portal 3 ARD. Bench scale tests were conducted in late 2003 to early 2004 (Gusek, 2005). A pilot scale BCR was operated from mid-2004 to early-2006; it was decommissioned in 2006. Results of this phase of the treatability study were presented in Gusek, et al., 2008. The pilot scale results and the conclusions of a supplementary Engineering Evaluation and Cost Analysis (EE/CA) (Golder, 2007) supported the concept of a passive treatment system (PTS) at the Golinsky site.

ARD Collection and Delivery Pipeline

Unfortunately, there was little space to construct a PTS at the mine site proper. The USDA Forest Service recognized this situation early in the planning process. In late 2004, it commissioned the construction of a 2,400 m (1.5 mile) long pipeline system to collect the ARD from the two bulkheaded adits and Portal 3 and convey it by gravity to the only practical site for a full scale PTS, an abandoned limestone quarry (see Fig. 1).

The system schematic layout is presented in Fig. 2. The original design included a flow distribution vault, BCR Module 1, a mixing pond, and a flow dispersion zone. Of these, the mixing pond was not constructed. The circumstances that lead to that omission are discussed subsequently.

Design of the First BCR Module

The pilot BCR system treated about 4,277 m^3 (1.13 million gallons) of Lower Portal ARD from the main Golinsky mine pool from July 2004 to October 2006. Key pilot BCR observations included average metal removal of greater than 95% and pH improvements sufficient to satisfy regulatory requirements (Golder, 2007). This performance was the design basis for the full-scale system.

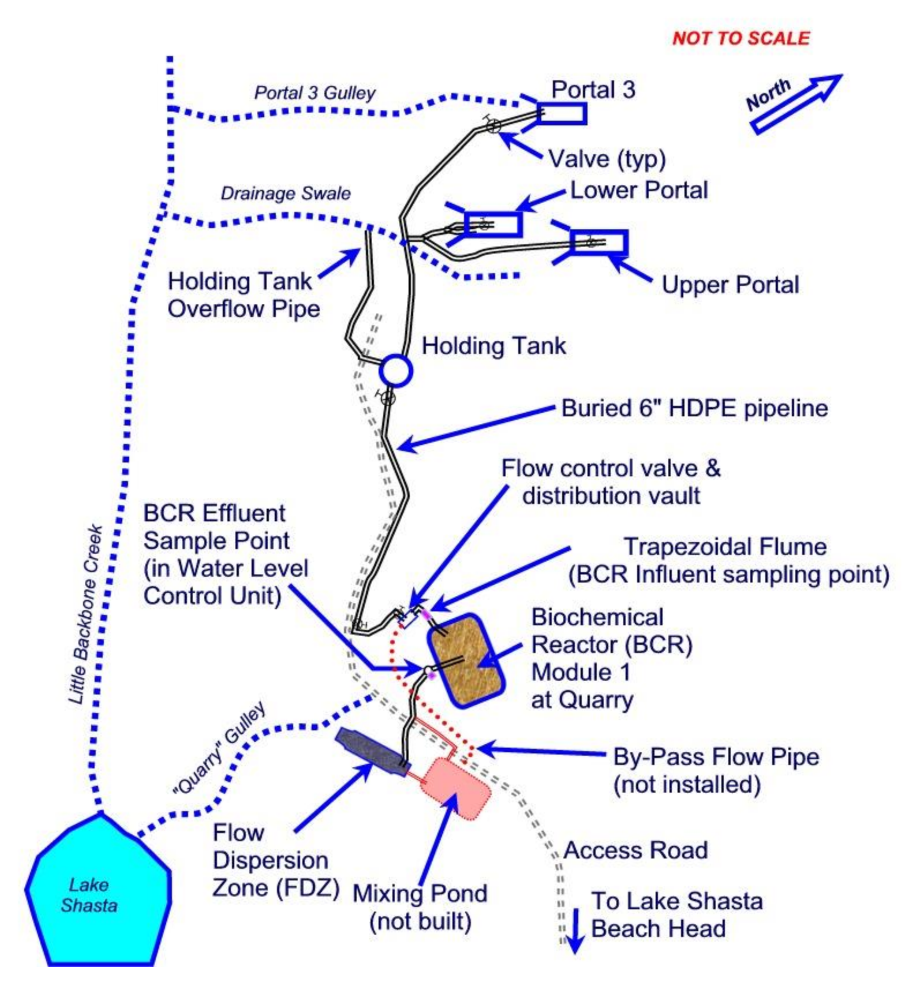

Figure 2. Golinsky Passive Treatment System Schematic Layout

Flow Rate

The peak design flow of ARD for a full scale PTS was somewhat uncertain because the flow data may have inadvertently included some surface runoff at the mine and seepage flows through fractured rock adjacent to the Lower Portal bulkhead. Since the 2004 drain down of the main mine pool, peak flows appear to have been attenuated through temporary storage behind the Lower Portal bulkhead.

Some post-bulkhead available data suggest that flows approaching 340 L/min (90 gpm) could occur briefly during wet months. Preliminary PTS sizing of the available construction area at the abandoned limestone quarry revealed that the maximum treatment capacity would only be about one-third of the estimated peak or 114 L/min. (30 gpm). Mixing treated ARD with by-passed flow was evaluated in the field and the results discussed in Gusek et al., 2008. Due to the uncertainty of the magnitude of peak flows, a mixing basin was included in the final design.

Phased Modular Implementation

The final design assumed that the system would be constructed near the limestone quarry site to eventually treat the total flow from the Golinsky Mine but it would be implemented in "modular" phases. Each phase would consist of a single BCR cell to treat a near constant flow rate. This approach was followed for several reasons:

- A phased modular design approach allowed further flow and water chemistry data to be collected. The chemistry and flow regime of the site is complex and vary seasonally. A full scale design would be based on both the flow and water chemistry. Additional characterization of both, to occur concurrently with design and construction of the first treatment cell module, would provide greater confidence in the design of additional modules until the cumulative treatment capacity matches site needs.
- Site access is very difficult and limited to boat access via Lake Shasta. Mobilizing a construction crew and materials to the site would be a major challenge if the construction of an entire full scale system was scheduled to occur in a single construction season. Constructing the full scale system in modular phases would allow site access challenges to be resolved on a smaller scale.
- Lastly, a phased modular design approach was embraced by the USFS as an effective means of dealing with sporadic budgeting issues.

Following this approach, the limestone quarry site could be developed first into at least two modules. Transient flow or loading peaks would be by-passed and commingle with the BCR Module 1-treated water in a mixing pond prior to infiltration into the local soil profile. If additional BCRs were required, they might be located in the vicinity of the quarry, but further away. A more detailed discussion of the phased modular system's development follows.

Assumed Influent Chemistry

When the original BCR system concept was considered, it was assumed that flows from all three portals would be commingled and the mixed ARD would be treated. However, as the project evolved, it appeared that the chemical characteristics of Portal 3 and the main mine pool were improving to the point that perhaps only the discharge from the main mine through the Lower Portal would be treated. The characteristics of Portal 3 ARD chemistry would be monitored over time and including this component of the site ARD loading would be considered optional. Changes in Portal 3 chemistry are subsequently discussed in greater detail.

When the final BCR Module 1 design process was initiated in 2007, it appeared that the

Portal 3 chemistry was indeed improving and it was assumed that only the Lower Portal ARD would require treatment. The assumed design chemistry compared to the 27-month average observed during the pilot test is provided in Table 1.

Table 1. Design Flow and Chemistry of Golinsky BCR Module 1 and Pilot BCR Cell

Parameter	**Lower Portal Estimate for Design**	**Lower Portal (Pilot Average for 27 months)**
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

BCR Design

During the pilot system's operation, the average sulfate and metals removal rates exhibited values of 0.088 moles/day/m^3 and 0.25 moles/day/m^3, respectively. During portions of the pilot test, loading of 0.35 moles/day/m^{3}was observed. For the Module 1 design, a metals removal rate of 0.3 moles/day/m^{3}was assumed. If the main mine pool chemistry continues its established trend to improve, this bulkhead assumption should be conservative.

As suggested in Table 1, the Module 1 design emulates the successful BCR with an approximate order of magnitude scale-up from 3.6 L/min to about 38 L/min. Similar to the pilot, the Module 1 cell was configured as a vertical flow reactor with flow entering the top of the cell and flowing out the bottom. The substrate recipe was similar to the pilot recipe with the exception of the "Cogen Fuel", a local feedstock for an electric generating station. Cogen Fuel was replaced by wood chips in Module 1 to reduce the overall construction cost. In addition, experience at other BCR projects revealed that a recipe containing 10% animal manure as a bacterial inoculum was excessive. A minor amount of manure tilled into the surface of the BCR was found to provide the necessary initial bacterial community necessary for BCR startup.

As a result, the Module 1 BCR substrate recipe was:

- Rice hulls (10% by weight) [same as pilot],
- Wood chips (50%) [pilot plus 10%]

- Hay (10%) [same as pilot], and
- Limestone (30%)

As part of the pilot BCR de-commissioning, about 1.53 m^3 (2 yd^3) of substrate was saved for future use as a scale up inoculum in the belief that microbes present in the pilot substrate would have adapted somewhat to the site conditions. To this material, about 3.06 m^3 (4 yd^3) of composted and/or fresh manure would be added and roto-tilled into the upper 150 mm (6 in.) of the BCR substrate surface. About 1,264 m^3 (1,652 yd^3) of installed organic substrate was required for construction.

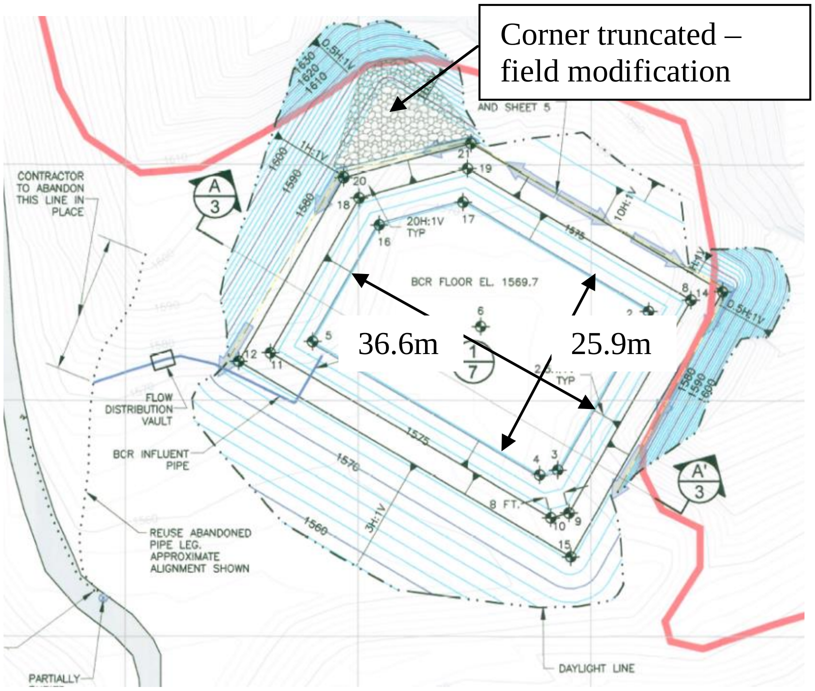

Figure 3. BCR Module 1 earthwork in limestone quarry

The Module 1 BCR was configured to be enclosed by earthen berms within the limestone quarry footprint as shown in Figure 3. The organic substrate layer would be 0.9 m (3 ft) thick, underlain by a 150 mm (6-in) gravel drainage layer containing a network of perforated pipes. The pipe network sub-divided the floor of the BCR into four equal collection zones to minimize short circuiting. The final design would include 150 mm (6-inches) of standing water above the substrate and 0.5 m (1.5 ft) of freeboard. The earthwork would be lined with a geomembrane comprised of linear low density polyethylene (LLDPE), 60 mil (1.5 mm) thick. Figure 3 reflects an as-constructed field modification that was required to accommodate local geotechnical conditions. It resulted in a reduction of about 34 m^2 (365 ft^2) or 3.6% of the total floor footprint of about 948 m^2 (10,200 ft^2). As the treatment capacity is a function of BCR bottom area, the reduction in theoretical flow capacity reduction of 1.4 L/min falls within the level of confidence in the original design.

Figure 4. Flow splitter boxes and concrete distribution vault during construction

The Module 1 BCR would receive ARD through a concrete distribution vault designed to allow the eventual splitting of ARD into three equal flows. This was accomplished using off-the-shelf splitter boxes typically used in domestic septic systems (See Fig. 4).

Because of the potential for wide variations in flow rates in response to wet weather, two "settings" (high and low flow) for the flow splitter boxes were required. Because of their low cost, two separate splitter boxes were installed for each module; either box could be quickly engaged or disengaged by operating a knife gate valve. Due to the remoteness of the site, this would have to be accomplished manually in response to an extended period of wet weather when flows could peak shortly thereafter. Whether this design feature needs to be periodically implemented will be evaluated during the first year of the system's operation.

A geotechnical investigation of the limestone quarry vicinity (CGI, 2007) did not reveal conditions that would restrict this plan. However, observations on site during rainy weather revealed that several springs on the floor of the quarry emerge in response to localized infiltration. These springs would be buried by the BCR earthwork so subsurface drains were included in the final design.

Mixing Pond Design

Typical BCR systems require aerobic polishing cells (APCs) to elevate depressed concentrations of dissolved oxygen, remove excess biochemical oxygen demand, and remove manganese. The pilot BCR discharged a flow of about 3.6 L/min (0.9 gpm) into a typically dry gully which functioned as an APC and infiltration gallery (see Fig. 2). The full-scale design involved the construction of a mixing/holding basin. This basin was designed to mix the effluents of up to three BCR cells with by-passed raw AMD portal discharge water from the Golinsky Mine during high-flow/loading episodes. From the pilot testing data (Gusek et al., 2008), the following assumptions were used to size the mixing pond.

- a two- hour mixing zone hydraulic retention time (HRT),
- a 24 hour settling zone HRT,
- a mixing ratio of 2 parts BCR effluent to 1 part by-passed ARD,

- settled solids have 2% solids by weight or 0.024 grams solids/liter of water
- 0.007 liters of sludge is generated for every liter of water (mixed)

The mixing pond design volume was 528 m^3 (139,500 gal). This volume included room for sludge accumulation. To maintain the pump-free, gravity-flow requirement of the design, the mixing pond needed to be located on a sloping hillside. The geotechnical investigation (CGi, 2007) for this structure involved backhoe test pits, soil characteristic testing, geophysical testing, and a seismic assessment. The mixing basin earthwork design (CGi, 2008) included a rock and fill slope stability assessment under static and earthquake loading conditions.

The final design included a 60 mil (1.5mm) thick LLDPE geomembrane liner and interior side slopes of 2H:1V. One end of the pond had a more-shallow slope to allow vehicular access during sludge cleanout events; the LLDPE geomembrane was specified to be textured for safety concerns. The outer slope face of the fill was 1.5H:1V.

Flow Dispersion Zone Design

As originally designed, the mixing pond discharge would infiltrate into local soils in an unlined percolation trench or flow dispersion zone (FDZ), similar to the protocol observed during the pilot's operation. This pH neutral, metal-free, infiltrated water would likely travel subsurface in bedrock fractures or along the bedrock/colluvial contact before entering Shasta Lake as a non-point source, which was the typical situation while the pilot BCR was operating.

The design investigation included several standard percolation tests along an abandoned access road down-gradient from the mixing pond site. The design included using standardized flow infiltration chambers typically used in residential septic systems.

Construction Plans and Specifications and Project Kickoff

In 2008, preliminary construction plans and specifications were prepared and submitted for review and comment. As with any similar project, securing funding for construction was an inherent challenge. As of late 2009, the Module 1 BCR plans and specifications were considered "shovel ready" when funding became available through the American Recovery and Reinvestment Act (ARRA) legislation. Minor revisions in the plans and specifications were completed in early 2010; the construction commenced in May, 2010.

Construction Challenges

As with the pilot BCR system (see Gusek et. al, 2005), all equipment and materials were hauled by barge or boat across Lake Shasta. While the scale of the Module 1 BCR increased only by a factor of 10, the logistical effort seemed to be magnified by 100. The first challenge was identifying a suitable lake-side mobilization site. In contrast to the depressed and rapidly-changing lake levels that hampered the construction of the pilot BCR in 2004, the wettest spring in recent history raised levels in the lake to submerge an ideal equipment and mobilization area on the lake shore near the Shasta Dam. Consequently, the construction contractor was required to utilize a USFS boat ramp 7.4 km (4.5 mi) further away, which added to travel times and prolonged the project schedule.

Most of the construction equipment and materials were transported on a pre-fabricated barge (see Fig. 5) as well as the World War II landing craft that was used in the construction of the pilot BCR in 2004. Due to the near-normal lake levels, supersacks filled with construction materials could be off-loaded with a grade-all with a fork lift attachment or a mini-excavator and transferred to a flat bed truck for the 1.6 km (1 mi) trip from the beach head to the quarry site.

Figure 5. Barge delivery of supersacks filed with organic substrate or other construction materials (e.g., drainage gravel and rip rap)

At the quarry site, storage space for stockpiling materials was in short supply. The construction contractor was forced to store over 2,000 supersacks of mixed organic substrate, various gradations of gravel and rip rap along the access road from the quarry to the mine. In places, the supersacks were stacked three high (see Fig. 6).

Due to the unavoidable construction delays, the construction of the mixing pond was deferred to the future. The BCR effluent was plumbed directly into a field-modified FDZ that included the septic system infiltration chambers.

Figure 6. Stockpiled supersacks of construction materials

In October, 2010, supersacks of mixed rice hulls, wood chips, and limestone were proportioned and mixed with hay and placed in the geomembrane-lined BCR (Fig. 7). Subsequently, the 4.6 m^3 (6 yd^3) of composted manure and residual pilot BCR substrate were rototilled into the upper surface of substrate. The construction effort was essentially complete by late-October, 2010.

<u>Changes in Portal 3 Chemistry 2004-2010</u>

When the pilot BCR was first commissioned in 2004, the main Golinsky mine pool was effectively drained at a steady rate of about 5,450 L/day. Data from mine maps and post-construction bulkhead static pressure data (SHN, 2004) suggest that the main mine pool has a volume of about 1,440 m^3 (354,000 gal). During the summer months, typical pre-bulkhead ARD flow from the Lower Portal was less than 4 L/min. Flow spikes in response to precipitation events appeared to be common during January to April. While the bulkheads were virtually waterproof, the surrounding wall rocks were sufficiently fractured that wintertime accumulations of ARD bled off by mid-summer. Consequently, prior to 2004, the main mine pool static pressure head varied from about 21.3 meters of water to 10.1 meters (70 ft to 33 ft). This meant that about 11.2 m (36.7 ft) of vertical mine workings were being flooded and repeatedly drained. The dissolved oxygen concentrations in the main mine pool did not change in response to the bulkhead installation (SHN, 2004); the desired anoxic conditions did not form.

Figure 7. Filling BCR with organic substrate

In response to the initial filling of the main Golinsky Mine pool in 2001, the chemistry of Portal 3 deteriorated as visually exhibited in Fig. 8 (left).

Figure 8. Portal 3 ARD in mid-2004 (left) and fall 2008 (right)

Changes in Portal 3 chemistry are shown graphically in Fig. 9. After the bulkheads were installed, Portal 3 pH dropped to about 3 S.U. and the Fe, Cu and Zn and SO_4^{2-} concentrations increased. Not surprisingly, this trend was reversed once the main Golinsky mine pool was drained in 2004. However, it took about five years for the Portal 3 pH values to rebound to estimated pre-bulkhead conditions; concurrently, the Portal 3 appears to visually improve (see Fig. 8, right) as the chemistry begins to rebound.

Unfortunately, there are no pre-bulkhead analyses of Portal 3 water chemistry for comparison. The pre-bulkhead Portal 3 pH of 7.0 plotted on Fig. 9 is an educated estimate based on anecdotal information.

Figure 9 reflects downward trends in dissolved Fe, Cu and Zn (ppb values) in concert with the increasing pH. The SO_4^{2-} trend exhibits less noise than the metals and the most recent analytical result (spring of 2010) of 8 mg/L suggests that the primary source of water in Portal 3 is likely to be very clean and the residual concentrations of Fe, Cu and Zn are being contributed by a very small mass contribution from continued leakage from the main Golinsky mine pool to the Portal 3 adit, which are estimated to be about 61 to 91 m (200 to 300 ft) apart.

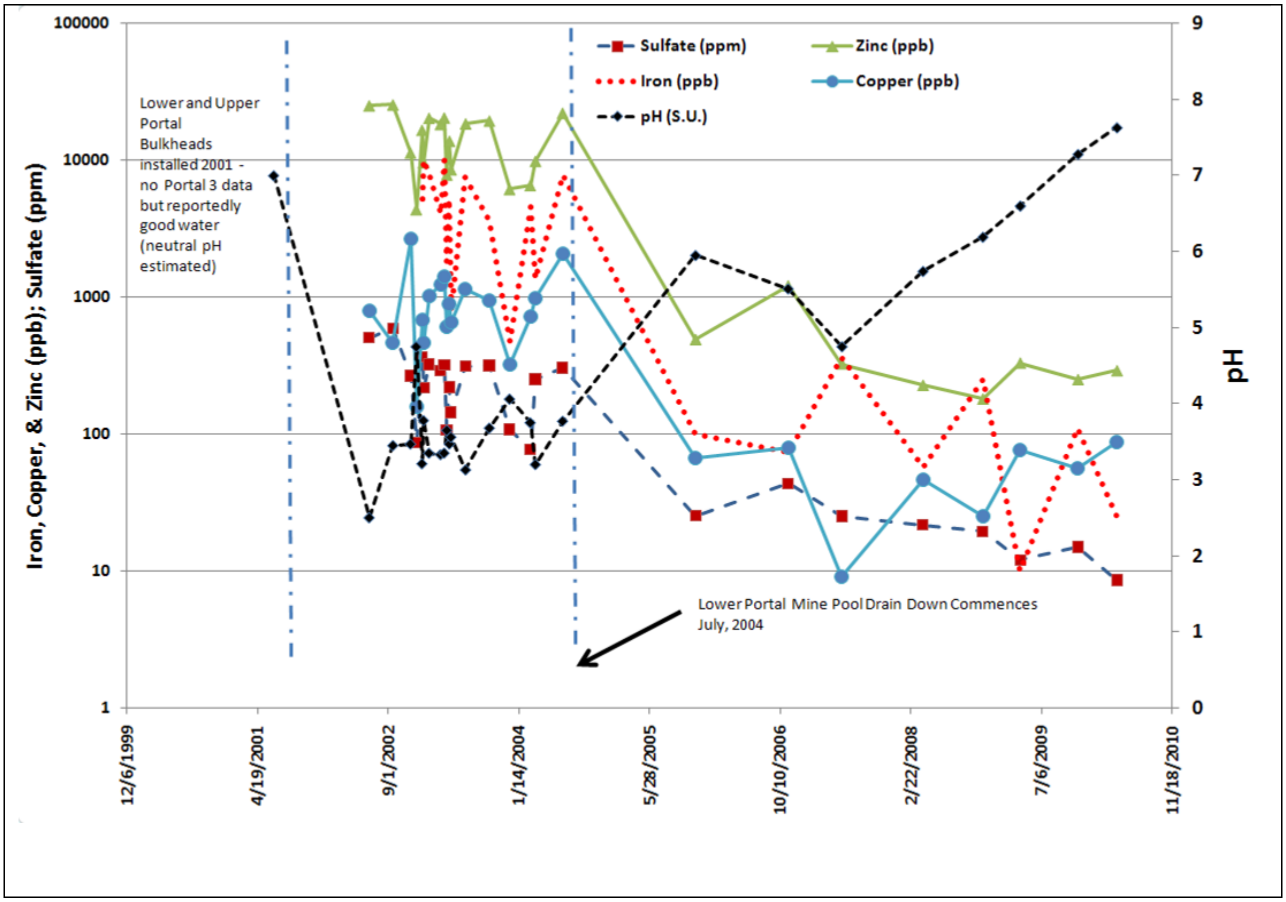

Figure 9. Changes in Portal 3 chemistry after main Golinsky adits received bulkheads

The falling concentrations of SO_4^{2-}, Cu and Zn in the Portal 3 samples allowed an interesting mass balance estimate to be conducted. The SO_4^{2-}, Cu and Zn loads from Portal 3 in April of 2010 samples were estimated to be 218, 2.4, and 7.9 grams per day, respectively. If the source of this loading was assumed to be the main Golinsky mine pool, exhibiting concentrations of 370, 0.088, and 0.29 mg/L for SO_4^{2-}, Cu and Zn, respectively, the inter-adit flow required to satisfy the Portal 3 loading is only 264 to 442 ml/min (0.07 to 0.11 gpm). The mass loading agreement between the three parameters considered was remarkably good. This close agreement for both metals and sulfate would suggest that re-dissolution of metals from the precipitates on the floor of Portal 3 is not the source of the Portal 3 loading.

The beneficial and unintended consequence of the improvements in Portal 3 chemistry allowed its use during construction of the Golinsky Module 1 BCR. The Portal 3 “ARD” was diverted to the abandoned limestone quarry construction site through the buried pipeline that had been installed in 2004. There, it was available for fire suppression, dust control on haul roads, and for moisture control in earthwork fill placement. If the Portal 3 water was insufficient for project requirements, construction water from Lake Shasta, about 1.6 km (1.0 mi) away, was hauled by truck. To accomplish this diversion, the ARD delivery pipe from the main Golinsky Mine pool was temporarily disconnected from the buried pipeline system and the summertime ARD flow (about 2 L/min or less) was allowed to infiltrate into the waste rock dump on the steeply sloping hillside as it had done prior to the bulkhead construction.

BCR Module 1 Commissioning Challenges

From October 23, 2010 to about mid-November, the site received about 280 mm (11 in) of rainfall. The original intention was to fill the BCR with a mixture of Portal 3 and Lower Portal ARD and allow bacterial incubation to commence. However, when the weather improved and allowed access to the site to initiate BCR filling with ARD in early December, it was found that the BCR was already full of water – rain water.

The inclement weather pattern persisted to the extent that it was not feasible to reconnect the delivery pipeline to the Lower Portal, so the BCR was commissioned with Portal 3 “ARD” which had very low concentrations of sulfate (8 mg/L) and no acidity. To encourage SO_4^{2-} reducing bacteria propagation, about 9.1 kg (20 lbs.) of Epsom salt were added to the flow distribution vault in a single dose and a 13.6 kg (30 lbs.) “tea bag” of agricultural gypsum was suspended in the vault as well. The first sampling event in January 2011 revealed an influent sulfate concentration of 14 mg/L and an effluent concentration of about 4 mg/L. The overall volumetric SO_4^{2-} reduction rate associated with these results was estimated to be 0.0013 moles/day/m^3.

The ARD from the Lower Portal was connected and the flow from Portal 3 suspended on January 26, 2011 at which time the teabag of agricultural gypsum was removed. Results from a sampling event in late March, 2011 indicated that the sulfate reduction rate was 0.09 moles/day/m^3 which was coincidentally greater than the metals loading of 0.07 moles/day/m^3. These preliminary performance values co-incidentally agree with the pilot BCR data. In late March, 2011 the BCR removed about 91% of the influent combined metals load; pH increased from about 2.8 to 6.6 S. U. in the BCR as well.

The deferral of the mixing pond construction necessitated the installation of a temporary 25 mm (1-inch) reinforced hose to convey BCR effluent from the BCR outfall pipe to the FDZ. This installation plugged quickly, not due to any particulate obstruction, but due to apparent damage from a curious bear, as evidenced by telltale bite marks. The hose was subsequently replaced with solid 76 mm (3-in) PVC pipe.

The germination of vegetation from seed in the hay component of the substrate occurred soon after the onset of inclement weather in October, 2011. If necessary, this vegetation may be suppressed if the oxidizing micro-environments in the plant root zone are found to be suppressing sulfate reduction.

Other minor system adjustments will likely occur as the system matures. A photo of the BCR in early 2011 is shown in Fig. 10.

Figure 10. – Golinsky Module 1 BCR – January, 2011

Closing Remarks

The construction cost of the Module 1 BCR was about \$1.3 million. The advancement of this project from the first bench scale investigations into BCR practicality in 2003 to construction of a full scale module in 2010 spanned seven years. The challenges of implementing this project included confronting numerous safety issues: remoteness of the activity (sometimes out of cellular telephone range), heat stress from elevated summer temperatures (over 100ºF/38ºC), and the multiple water crossings (sometimes in foul weather). Thankfully, the project was completed without incident. The authors appreciate the support of the US Department of Agriculture, Forest Service, the ARRA funding allocated to the project, and the numerous engineering and construction companies that contributed to the project's successful implementation.

References

CGI Technical Services Inc., 2007. “Geotechnical Investigation Golinsky Mine, Lake Shasta California” prepared for the USDA Forest Service, Region 5. January 24, 2007.

CGI Technical Services Inc., 2008. Letter Report: “Mixing Basin Fill Slope Design, Golinsky Mine, Shasta County, California”, prepared for Golder Associates Inc., February 25, 2008.

Golder Associates Inc., “Supplemental Engineering Evaluation/Cost Analysis, Golinsky Mine Site, Shasta-Trinity National Forest, California”, August, 2007.

Gusek, J.J., B. Shipley, and D. Lindsay, 2005. "Overcoming Access Issues at a Remote Passive Treatment Site Near Lake Shasta, CA", Proceedings America Society of Mining and Reclamation, 2005 pp 443-453. http://dx.doi.org/10.21000/JASMR05010443.

Gusek, J.J., T. Rutkowski, E. Blumenstein, and B. Shipley, 2008. "Two-Year Sulfate Reducing Bioreactor Pilot Test Results at the Golinsky Mine, California, Proceedings America Society of Mining and Reclamation, 2008 pp 424-441. http://dx.doi.org/10.21000/JASMR08010424.

SHN Consulting Engineers & Geologists, Inc., 2004. “Data Summary Report, June 2002 to June 2004, Golinsky Mine Shasta-Trinity National Forest, California”, July, 2004.