STATE OF COLORADO

Eschberger - DNR, Amy <amy.eschberger@state.co.us>

# Times Mine Bulkhead Evaluation TM Stamped[11625]

1 message

**Mark Steen via Adobe Document Cloud** <noreply@acrobat.com> Wed, May 15, 2019 at 9:59 AM
Reply-To: goldhillbooks@yahoo.com
To: amy.eschberger@state.co.us

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DEERE & AULT
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# TECHNICAL MEMORANDUM

COLORADO LICENSED PROFESSIONAL ENGINEER
CHRISTOPH MICHAEL GOSS
38427
5/15/2019

**TO:** Mark A. Steen (Colorado Milling Company LLC)

**FROM:** Christoph Goss PhD, P.E.

**DATE:** May 15, 2019

**RE:** Times Mine Bulkhead Evaluation
D&A Job No. 0788.001.00

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This technical memorandum is in response to a request by Colorado Milling Company, LLC to evaluate the Times Mine Bulkhead at the Gold Hill Mill site.

## BACKGROUND

The Gold Hill Mill is an existing mineral processing facility in Boulder County, Colorado, near the town of Gold Hill (MLRD Limited Impact 110(2) Permit No. M-1994-117). The general location is shown in **Figure 1**. In December 2017, Colorado Milling Company, LLC (CMC) submitted an amendment to add several components to the permitted site. These include the Left Hand Creek Pump Station, Gold Mill Pipeline Easement, and Times Mine Adit Portal. Since the amendment application submittal, the Colorado Division of Reclamation, Mining, and Safety (DRMS) has issued three Adequacy Review letters dated 1/26/2018, 12/21/2018, and 1/14/19. CMC has responded to Adequacy Review letters 1 and 2 on 12/8/2018 and 1/4/2019, respectively. Based on this correspondence, there are various outstanding issues to be evaluated and addressed. Deere & Ault Consultants Inc, (D&A) has evaluated those issues related to the Times Mine Bulkhead.

In 1986, the owners of the Gold Hill Mill prepared the site for water storage in support of milling operations. The work included cleaning, surveying, and rehabilitating the upper level of the Times Mine, drilling a monitoring/pumping well into the Times Mine directly above the winze to the Wynona Mine, installing a concrete bulkhead with piping in the Times Mine, and installing a well casing into the Wynona Mine Shaft. The components are shown in **Figure 2**. The general proposed operations plan consists of pumping fresh water into Times Mine through the bulkhead and then pumping it out through the Wynona Shaft to the mill. **Figure 3** provides a plan and profile view of the Times and Wynona mines. A key feature of the project that becomes apparent in the profile is the hydraulic connection between the Times and Wynona Mines. Through the Wynona Winze, 150 Level, and shaft, the two mines act as a single mine pool with drainage at the Times Mine bulkhead and an overflow at the Wynona Shaft collar.

600 S. Airport Road, Building A, Suite 205
Longmont, CO 80503
Phone: 303-651-1468 ● Fax: 303-651-1469

## SITE VISIT

D&A staff visited the site on April 22, 2019 to document conditions and take measurements. Select photos are found attached. D&A measured water levels in both the Times Mine Well and the Wynona Shaft using a water level indicator. These levels were then used in the figures and analysis. Locations were geo-referenced using a Trimble R1 GNSS Receiver coupled to a tablet. Surface elevations were within a foot of those provided in documents by CMC and their survey consultant, Mountain Surveying LLC. D&A used the professionally surveyed elevations where available.

D&A entered the Times Mine to document the adit and bulkhead condition. The first 50 feet of adit consisted of a relatively new 5-foot diameter corrugated metal culvert pipe. Past the pipe, the rock of the adit was somewhat blocky with the main joints dipping moderately to steeply west. Nominal adit dimensions were 6-foot high by 5-foot wide. Ground support consisted of one timber set and several timber props. After 30 feet, the adit intersected a vein striking west and dipping steeply to the north. The vein and alteration halo ranged from 1 to 3 feet wide. The altered rock was soft while the surrounding rock was fractured but generally hard and competent. No ground support was in place. Conditions were dry. Two new PVC pipes ran the length of the adit and entered the bulkhead. Both had closed valves. **Figure 4** shows a profile of this drift.

The bulkhead was installed in this drift, approximately 20 feet from the adit intersection. Visible were the wooden concrete forms from the bulkhead placement. The forms were covered in iron precipitant. The bulkhead concrete was not visible. Seepage was noticeable along the back and upper edges of the contact between the bulkhead and the rock. The seepage consisted of a wet sheen with no concentrated flows. No flow was visible on the invert. No concentrated flow was observed at the pipe penetrations. Seepage and iron precipitant extended two and three feet past the bulkhead in the back, along the vein. See attached photos and **Figure 5** for additional detail.

Using site measurements, public data, and documentation from CMC and Mountain Surveying LLC, D&A developed a plan and profile of the site to better understand and explain the project. This is shown in **Figure 3**. Key elevations are summarized on the table below. Note that the difference in the water elevations at the Times Well and Wynona Shaft are mostly due to field measurement limitations. The elevations do appear to reflect the same mine pool.

| Feature | Elevation (ft) | Notes |
|---|---|---|
| Wynona shaft top of Manhole | 8450.0 | D&A 4/22/19 estimated |
| Times Well Top of Casing | 8449.3 | Swift 2/10/2019 |
| Times Well Ground | 8446.8 | Swift 2/10/2019 |
| Collar of Wynona Shaft | 8445.0 | Swift 2/10/2019 |
| Top of Wynona Winze in Times Mine | 8364.5 | Swift 2/10/2019 |
| Bulkhead Pressure Design Elevation | 8360.0 | CMC 1/4/2019 |
| Water Level in Times Well at D&A Site Visit | 8357.6 | D&A 4/22/19 |
| Water Level in Wynona Shaft at D&A Site Visit | 8356.5 | D&A 4/22/19 |
| Water Level in Times Well noted by others | 8354.6 | Swift 2/10/2019 |
| Top of Times Mine Bulkhead | 8348.3 | D&A 4/22/19 |
| Floor of Wynona Winze in Times Mine | 8347.7 | Swift 2/10/2019 |
| Bottom of Times Mine Bulkhead | 8342.4 | Interpolated 95 ft at 1.7% grade |
| Floor of Times Mine Portal | 8340.8 | Swift 2/10/2019 |

## BULKHEAD EVALUATION

Based statements by CMC in the permit documents, the bulkhead consists of a three-foot-thick concrete structure with some steel reinforcing where the concrete was cast directly against clean rock but not grouted. While no documentation of the structure exists, the design described is typical for underground mines and can be assumed to be correct. There are five loading conditions (water levels behind bulkhead invert) that were evaluated: proposed typical operational water level (4.5 ft), current water level (15.2 ft), design water level (17.6 ft), maximum proposed operational level (22.1 ft), and maximum possible water level where the mine pool overflows through the Wynona Shaft (102.6 ft).

When designing or evaluating mine bulkheads, one must consider the possible failure modes. These include hydraulic jacking of the surrounding rock mass, shear failure around the plug, structural failure of the plug, long term disintegration (chemical decomposition) of the concrete, and excessive seepage or piping past the plug (Lang, 1999; Abel, 1998).

Hydraulic jacking occurs when the water pressure behind the bulkhead is higher than the confining pressure of the ground in the area. The hydraulic jacking causes joints in the rock mass to open up, allowing more flow through them. This can be avoided by locating the bulkhead deep underground where the confining pressure (weight of rock above and related horizontal stresses) is high enough to resist the water pressure.

The Times Mine Bulkhead has approximately 26 feet of cover. Based in its location near the inside road edge, most of the cover is likely rock. Assuming 20 feet of rock cover with a density of 165 pcf results in an overburden pressure of 3300 psf (23 psi). Abel (1998) suggests that under typical circumstances, the pressure required to hydraulically jack rock is twice the overburden pressure. Hence, the Times Mine bulkhead could be subjected to 6600 psf (46 psi) of water pressure from the mine pool without hydraulically jacking. As shown below, hydraulic jacking becomes a likely failure mode only under the maximum possible mine pool level.

**Hydraulic Jacking**

| Condition | Head (ft) | Pressure (psi) | Allowable Pressure (psi) | Factor of Safety |
|---|---|---|---|---|
| Operation | 4.5 | 1.9 | 46 | 24.2 |
| Current | 15.2 | 6.6 | 46 | 7.0 |
| Design | 17.6 | 7.6 | 46 | 6.1 |
| Max Op | 22.1 | 9.6 | 46 | 4.8 |
| Maximum | 102.6 | 45 | 46 | **1.0** |

Perimeter shear failure occurs when the bulkhead moves along the concrete/rock interface or adjacent rock due to water pressure from the mine pool. This failure can be avoided by locating the bulkhead in good ground, roughening the surface at the rock/concrete interface, keying into the rock, and grouting the interface.

The shear capacity of the Times Mine Bulkhead can be calculated by multiplying the shear strength of the concrete by the total area that the concrete is in contact with the wall rock. Unless the ground is heavily altered, the weakest shear strength is in the concrete. Based on the rock visible directly in front of the bulkhead it appears that the altered rock was mostly removed from the perimeter. Per ACI 318, the design shear strength of concrete is twice the square root of the compressive strength. Assuming a conservative compressive strength of 2000 psi, the design shear strength is 89 psi or 12,880 psf. Multiplying the perimeter of the bulkhead face (19.4 ft) by the length of 3 ft results in an area of 58.2 sf. Multiplying that by 12,880 psf results in a design shear load capacity of 749,602 pounds. The load on the bulkhead is a function of the water pressure on the face area. With a face area of 22 sf and a maximum water pressure of 45 psi (6480 psf), the driving force is 142,560 pounds. Dividing 749,602 by 142,560 gives a factor of safety of 5.3. Hence, shear is not a likely failure mode under any loading condition.

Structural failure occurs when the concrete plug itself fails due to deep beam bending or shear failure through the reinforced concrete due to water pressure or earthquake induced water hammer. It can be avoided by making the bulkhead long enough and adding rebar reinforcement at both faces.

The Times Mine Bulkhead structural strength can be calculated per ACI 318 deep beam analysis, as described in Abel 1998. This analysis compares the tensile bending stresses on air side face to the allowable concrete tensile strength. The rather involved calculations were done on a spreadsheet and the results are summarized below. For the proposed operational, current, design, and maximum operational conditions, a three-foot-thick unreinforced concrete bulkhead is acceptable. For the maximum load condition, rebar consisting of at least number 5 bars 12 inches on center each way would be required. Based on statements by CMC, rebar was used in the construction but the size and spacing are not known (no documentation available). Based on this, a structural failure is unlikely yet possible. Please note that these calculations do not take earthquake loading or water hammer effects into account. Should those be requested, D&A will have to research appropriate earthquake loads for the site.

**Structural Failure**

| Condition | Head (ft) | Bulkhead Length (ft) | Minimum Required Bulkhead Length (ft) | Factor of Safety |
|---|---|---|---|---|
| Operation | 4.5 | 3 | 0.9 | 3.3 |
| Current | 15.2 | 3 | 1.6 | 1.9 |
| Design | 17.6 | 3 | 1.7 | 1.8 |
| Max Op | 22.1 | 3 | 2.0 | 1.5 |
| Maximum | 102.6 | 3 | 4.2 | **0.7** |

Concrete degradation occurs when the acidic mine waters chemically break down the concrete. It can be avoided by using sulfate resistant cement (ASTM C-150 Type V), pozzolans like flyash and microsilica, and possibly permeability reducing admixtures in the mix. It is also common to place lime in the tunnel upstream of the bulkhead to neutralize the acidic mine waters in the vicinity of the bulkhead. This technique is effective in the short term but may provide only limited beneficial use in the long term.

For the Times Mine Bulkhead, there is no information on the concrete mix design used. Hence, one must assume that it contained standard Type-I cement. The quality of the water behind the bulkhead is not known. If it is mostly fresh water, per the operations plan, then degradation is not an issue. If the water becomes more acidic, due to contact with the existing mine pool, then degradation could be a problem. If water testing reveals sulfate concentrations above 150 ppm, we suggest conducting a mortar bar test (ASTM C1038) using the mine water and standard Type-I cement to evaluate the reactivity.

The most likely failure mode of a bulkhead is seepage and piping. Excessive seepage past the plug occurs when the higher upstream head finds fractures in the downstream rock mass or concrete-rock interface and bypasses the bulkhead. The worst case would be where the gradient and seepage are high enough to wash out material in joints or shears, leading to a piping failure. Seepage and piping can be avoided by placing the bulkhead in good ground, contact grouting the concrete-rock interface, and ring grouting the rock mass prior to installing the bulkhead. This requires a detailed geological investigation with a particular focus on joints, shears, and faults upstream and downstream of the bulkhead that could become water conduits. If seepage is excessive, it can often be reduced by pressure grouting the affected joints. Seepage and piping are a direct function of the pressure gradient across the bulkhead.

The design of most mine bulkheads in the United States is based on relationships developed by Garrett and Campbell-Pitt (1961) and adapted by Chekan (1985). The relationships came from full scale testing in South Africa where an experimental bulkhead was constructed in quartzite inside the deep West Driefontein Mine. The researchers installed an un-grouted bulkhead and pressurized the space behind it until water leakage around the bulkhead became excessive. They repeated the experiment each time after grouting the contact between the concrete and rock, grouting the rock mass, and chemical grouting the rock mass. They then calculated the pressure gradient (pressure at leakage/length of bulkhead) for each case. Finally, they recommended applying a Factor of Safety between 4 and 10 to these gradients. Their results are summarized on the table below:

**Allowable Pressure Gradient (psi/ft of Bulkhead Length) per Garrett and Campbell-Pitt**

| Bulkhead Grouting | Factor of Safety | | |
|---|---|---|---|
| | 1 | 4 | 10 |
| None | 10 | 2.5 | 1 |
| Contact Grouting Only | 228 | 57 | 23 |
| Rock Mass Grouting | 400 | 100 | 40 |
| RM Chemical Grouting | 887 | 222 | 89 |

The three-foot-thick Times Mine Bulkhead was designed and constructed without grouting, leading to a maximum allowable pressure gradient of 10 psi/ft. Pressure gradients and associated factors of safety for each loading scenario are summarized below. For the proposed operational and current conditions, the pressure gradient is acceptable. For the design and maximum operational conditions, the pressure gradient is somewhat unconservative (3.9 and 3.1 vs 4). For the maximum loading condition, the pressure gradient factor of safety is below 1, hence excessive leakage should be expected.

**Seepage Failure**

| Condition | Head (ft) | Pressure (psi) | Pressure Gradient (psi/ft) | Factor of Safety |
|---|---|---|---|---|
| Operation | 4.5 | 1.9 | 0.6 | 16.6 |
| Current | 15.2 | 6.6 | 2.2 | 4.5 |
| Design | 17.6 | 7.6 | 2.5 | **3.9** |
| Max Op | 22.1 | 9.6 | 3.2 | **3.1** |
| Maximum | 102.6 | 45 | 15 | **0.7** |

The limitation of the West Driefontein Mine seepage experiment and calculations is that they only consider leakage through the bulkhead, concrete-rock contact, and immediate rock mass. They do not consider seepage or piping through joints or shears parallel to the tunnel, across the plug. The Times Mine Bulkhead is located on a vein that was not pressure grouted. Under high head, this is the most likely seepage path.

## CONCLUSIONS

- The Times Mine Bulkhead is currently holding back a head of 15.2 feet of water (6.6 psi). The stated design capacity is 17.6 feet (7.6 psi).
- The water may have been pumped into the mine in the past or groundwater may be seeping in and raising the mine pool.
- The maximum head possible behind the bulkhead, when water overflows through the Wynona Shaft well casing, is 102.6 feet (45 psi)
- Based on our calculations, the bulkhead should perform adequately under the design, current and proposed operational conditions.
- Under the maximum proposed operational conditions, the bulkhead area should be observed and conditions documented on a regular basis with a particular focus on any increases in seepage or the development of any concentrated areas of flow. Should a significant flow or seepage increase be observed, the mine pool would need to be lowered rapidly.
- Based on our calculations, the bulkhead would most likely fail under the maximum loading condition where water overflows at the Wynona Shaft. The likely failure mode would be excessive seepage and water flow past the bulkhead, possibly through the vein in the back.
- The total volume of water stored at or above the elevation of the bulkhead is unknown. If the Wynona 100 Level is lower than the bulkhead, the additional volume from the Wynona Shaft is negligible and water behind the bulkhead is limited to the Times Mine volume of approximately 25,000 cubic feet (187,000 gallons). If the Wynona 100 Level is higher than the bulkhead, most of its unknown volume would be stored behind the bulkhead (i.e. it would drain out if the bulkhead was opened).
- Minor seepage is visible along the contact between the bulkhead and the rock. The seepage continues 3 feet past the air side face.
- The presence of oxidized iron precipitate on the bulkhead face, rock interface and vein suggest mine pool water is seeping around the bulkhead. This is typical.
- Total flow past the bulkhead is negligible. No concentrated flows were observed.
- The bulkhead appears to be performing adequately. There are no visible signs of distress.

## RECOMMENDATIONS

- Develop a system where water levels will be limited to acceptable levels. This could include a pressure relief valve at the bulkhead pipes that discharges into an acceptable location.
- Monitor water levels in both the Times Well and Wynona Shaft well regularly. Consider installing a pressure transducer and datalogger if site will be unmanned for longer periods.
- Install a stainless-steel fluid filled pressure gauge (0-50 psi range) on the bulkhead pipes. It should be installed on a tee between two valves and include a sampling/air bleed port.
- While we generally recommend removing the bulkhead forms to better observe and assess the condition of the concrete, we do not suggest doing that on this site due to the high risk of damaging the PVC pipes.
- Investigate elevation of Wynona 100 Level to evaluate its effect on storage behind the Times Mine bulkhead. If the level is higher than the Times Mine, it could drain out through the bulkhead. If the level is lower, it would be dead storage. A potential method would be to pump the Wynona Shaft at various elevations. A quick drop in water level would show it to be only shaft volume. A slow drop would indicate a connection to a mine pool.
- While the PVC pipes and valves are not susceptible to corrosion, they are brittle and can crack. Consider sleeving the pipes with stainless steel and replacing the PVC valves with stainless steel. This should be done when there is no water behind the bulkhead.
- Remove the stuck pump from the Wynona Shaft and survey the top of casing to allow regular and accurate water level readings.
- Develop a plan to draw down the water in the mine.
- Monitor water quality/chemistry to evaluate potential concrete degradation

## LIMITATIONS

Deere & Ault Consultants Inc. work on this project is limited to the analysis described in this report. Specifically, our services do not include the evaluation of any outstanding adequacy review issues other than those addressed herein.

## REFERENCES


Abel Jr., J.F., 1998, "*Bulkhead Design for Acid Mine Drainage*," in Proceedings Western U.S. Mining-Impacted Watersheds, Joint Conference on Remediation and Ecological Risk Assessment Technologies, 36 Pages, Denver, Colorado, USA

Chekan, Gregory J, 1985, "*Design of Bulkheads for Controlling Waters in Underground Mines*," Bureau of Mines Information Circular, 9020

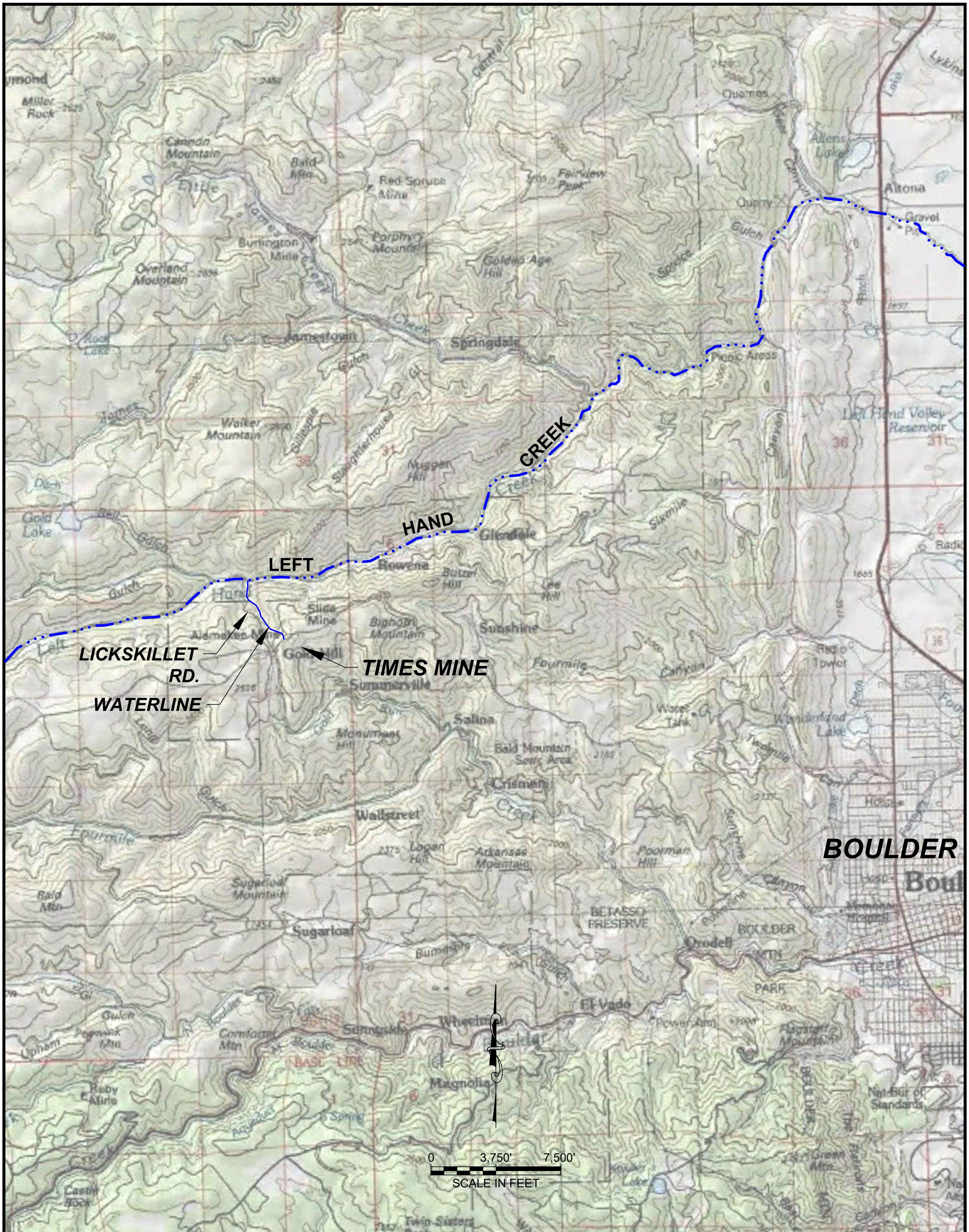
Einarson, D.S., and Abel Jr., J.F., 1990, "*Tunnel Bulkheads for Acid Mine Drainage*," in Proceedings International Symposium on Unique Underground Structures, Vol. 2, Pages 71-1 to 71-20, Denver, Colorado, USA

Garrett, W.S., and Campbell-Pitt, L.T., 1961, "*Design and Construction of Underground Bulkheads and Water Barriers*," Seventh Commonwealth Mining and Metallurgy Congress, Vol. 3, Pages 1283 to 1301

Kirkwood, D.T., and Wu, K.K., 1995, "*Technical Considerations for the Design and Construction of Mine Seals to Withstand Hydraulic Heads in Underground Mines*," Society for Mining, Metallurgy and Exploration Annual Meeting Preprint 95-100

Lang, Brennan, 1999, "*Permanent Sealing of Tunnels to Retain Tailings or Acid Rock Drainage*," in Mine, Water, and Environment, 1999 IMWA Congress, Sevilla, Spain

# FIGURES

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| TIMES MINE BULKHEAD EVALUATION | | FIGURE NO. |
|---|---|---|
| VICINITY MAP | | 1 |
| JOB NO. 0788.003.00 | SCALE: AS NOTED | |

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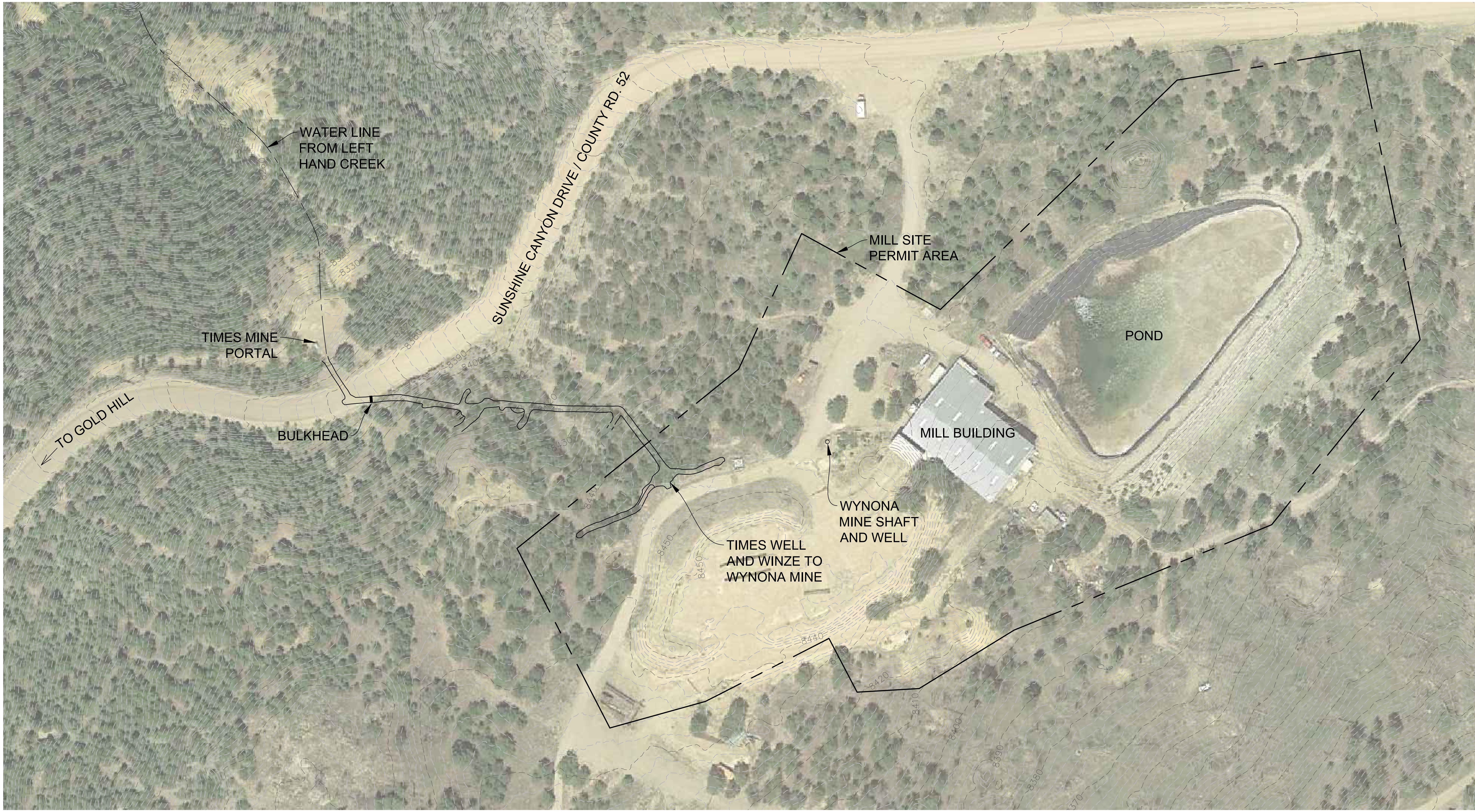


***NOTES:***

1. TOPOGRAPHY FROM THE STATE OF COLORADO POST FLOOD LIDAR.
2. TIMES MINE SURVEY BY KARL G. SWIFT PLS IN 1986, UPDATED WHERE ACCESSIBLE 4/27/2019
3. TIMES MINE GEOLOGIC MAP PLAN VIEW BY RUSSELL R. MCLELLAN, 1947

0 50 100
SCALE IN FEET

JOB NO. 0788.001.00

**TIMES MINE BULKHEAD EVALUATION**

**AREA MAP**

DEERE & AULT CONSULTANTS, INC.

| | | | |
|---|---|---|---|
| **FIGURE NO.** | **2** | | |
| **DATE:** | **MAY 2019** | **SCALE:** | **AS NOTED** |

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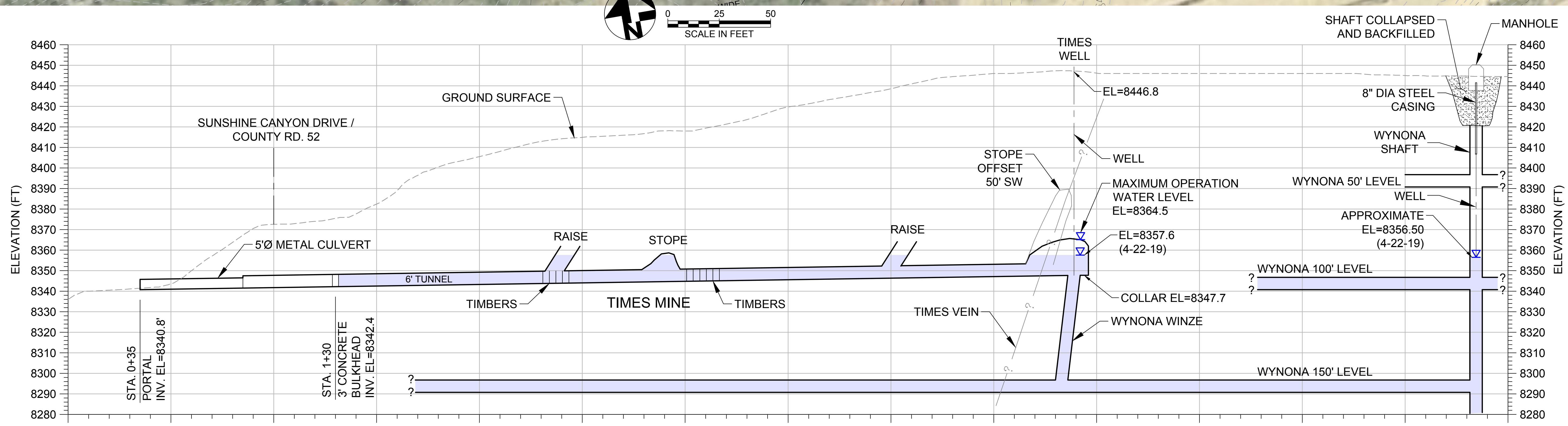


***NOTES:***

1. TOPOGRAPHY FROM THE STATE OF COLORADO POST 2013 FLOOD LIDAR.
2. TIMES MINE SURVEY BY KARL G. SWIFT PLS IN 1986, UPDATED WHERE ACCESSIBLE 4/27/2019
3. TIMES MINE GEOLOGIC MAP PLAN VIEW BY RUSSELL R. MCLELLAN, 1947
4. TIMES AN WYNONA MINE PROFILE PROVIDED BY COLORADO MILLING COMPANY BASED ON MAPS BY J.E. BYRON AND A.E. REARDON 1934 AND 1947

JOB NO. 0788.001.00

| | |
|---|---|
| **TIMES MINE BULKHEAD EVALUATION** | |
| **PLAN AND PROFILE** | |
| DEERE & AULT CONSULTANTS, INC. | **FIGURE NO.** 3 |
| **DATE:** MAY 2019 | **SCALE:** AS NOTED |

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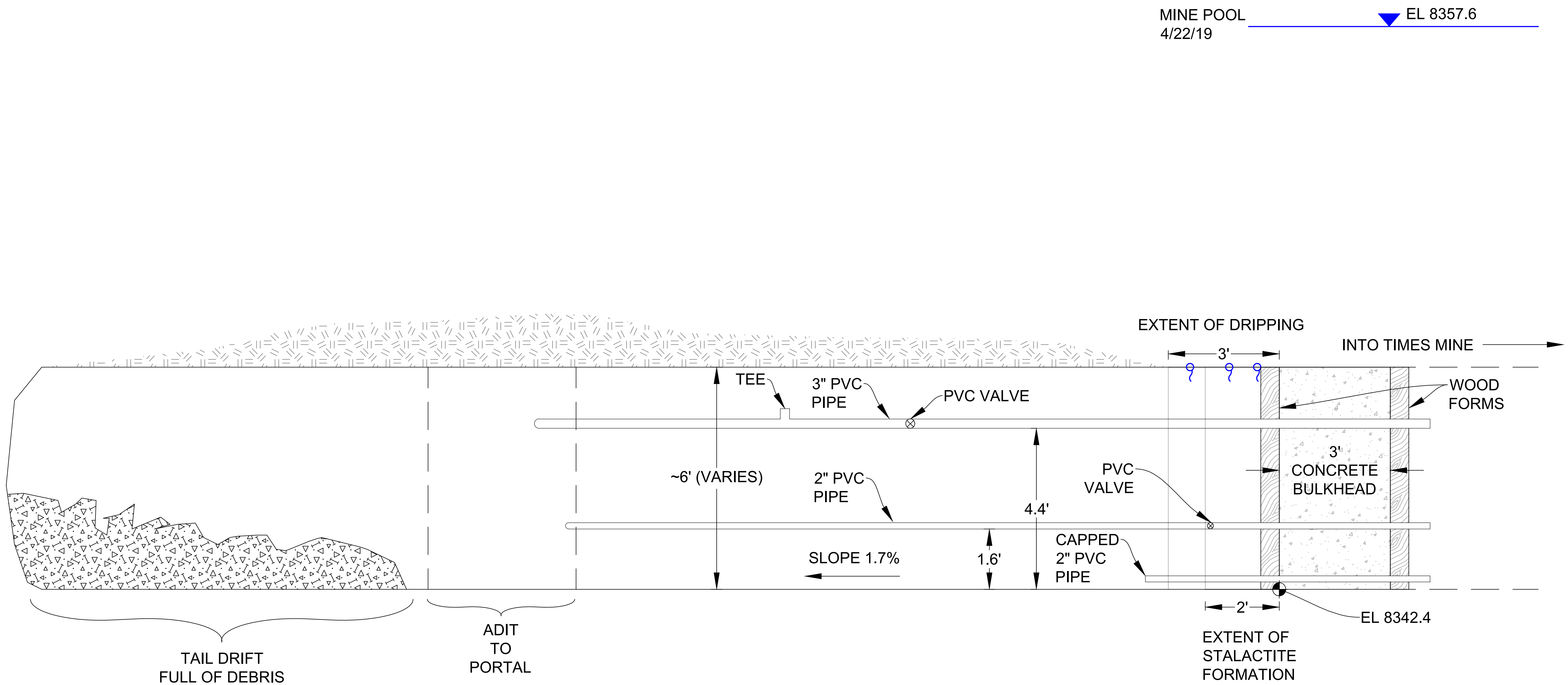



## *PROFILE OF BULKHEAD*

0 1.5' 3'
SCALE: 1" = 3'

JOB NO. 0788.003.00

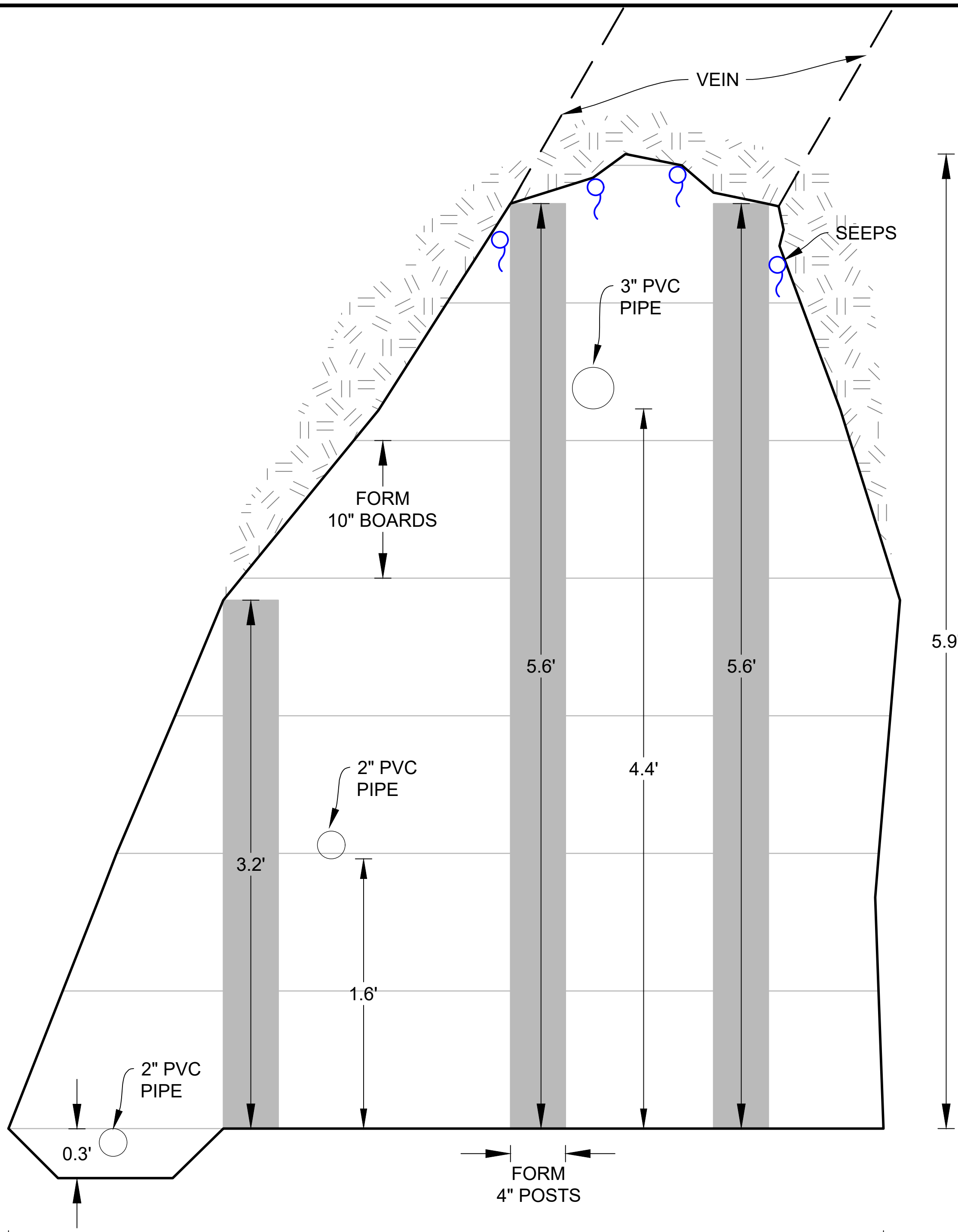
**TIMES MINE BULKHEAD EVALUATION**

**PROFILE AT BULKHEAD**

DEERE & AULT CONSULTANTS, INC.

**FIGURE NO.** 4

**DATE:** MAY 2019 **SCALE:** AS NOTED




# *FACE OF BULKHEAD*



NOTES:

1. PIPES ARE ONE 3" SCHEDULE 40 PVC RATED TO 260 PSI, AND TWO 2" SCHEDULE 40 RATED TO 280 PSI.
2. WOOD FORM FROM BULKHEAD INSTALLATION STILL IN PLACE.



| | | | |
|---|---|---|---|
| DEERE & AULT CONSULTANTS, INC. | TIMES MINE BULKHEAD EVALUATION | | FIGURE NO. |
| | BULKHEAD AIR SIDE FACE CROSS SECTION | | 5 |
| | JOB NO. 0788.001.00 | SCALE: AS NOTED | |

# PHOTOGRAPHS

**Photo 1: Shed around the Times Mine Well**

**Photo 2: Times Mine Well head**

**Photo 3: Concrete manhole around the Wynona mine shaft (collapsed and backfilled)**


**Photo 4: Inside Wynona Mine Shaft manhole; Well casing into shaft at upper left**

**Photo 5: Portal entrance into the Times Mine; County Road 52 above**

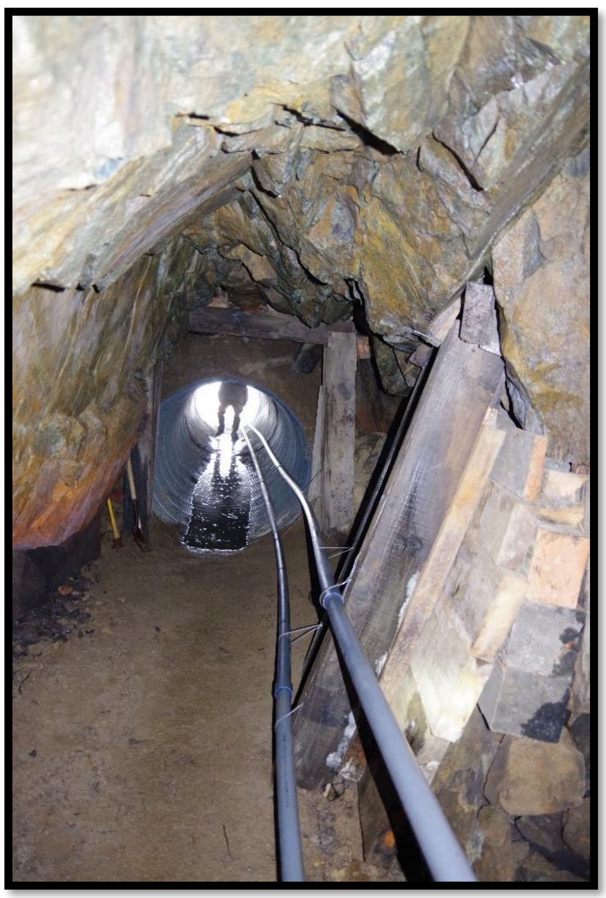


**Photo 6: Piping from portal into adit as seen from drift**

**Photo 7: Upper pipe in Times Mine drift along vein; Note closed valve and Tee**

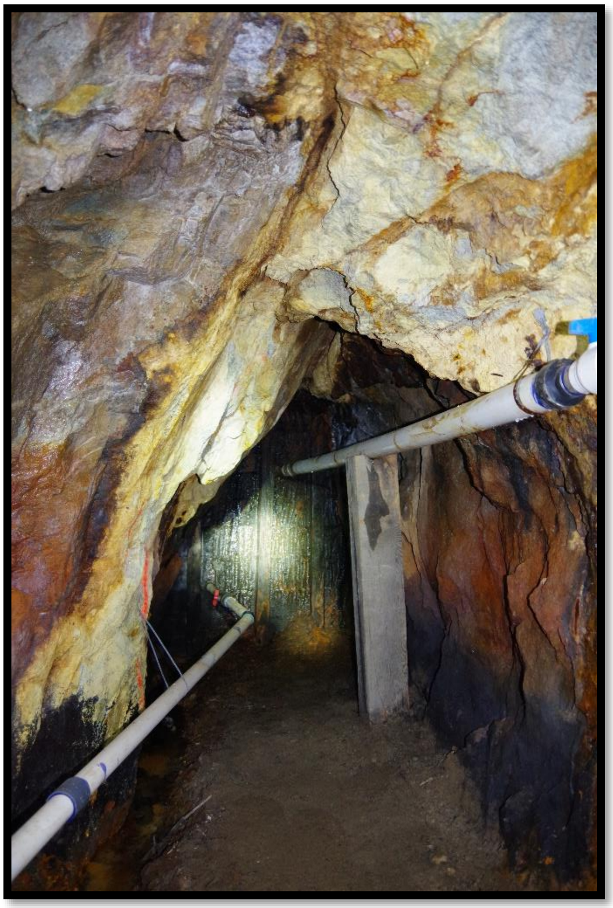


**Photo 8: Piping in drift and into bulkhead; Note off-white alteration zone**

**Photo 9: Bulkhead overview; Note wood forms remain in place and altered rock removed**

**Photo 10: Lower piping in bulkhead; Note closed valve and precipitant on floor**

**Photo 11: Seepage and precipitant at top of bulkhead**

**Photo 12: Upper bulkhead piping and extent of dripping along vein in back**

**Photo 13: Seepage along right side of bulkhead**

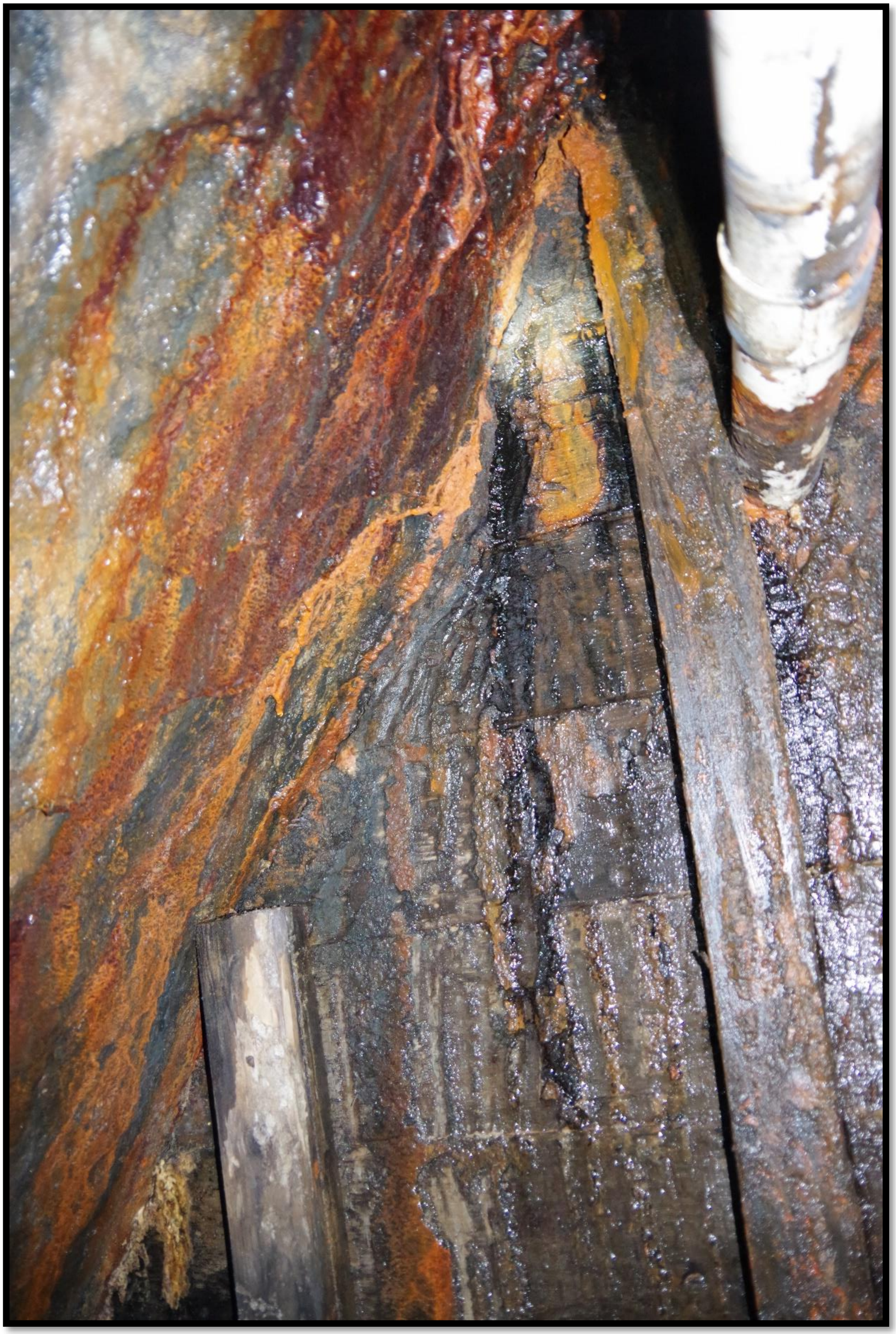


**Photo 14: Seepage along left side of bulkhead**