Mine Closure 2023 - Behrooz Abbasi, Jeff Parshley, Andy Fourie & Mark Tibbett (eds)

doi:10.36487/ACG_repo/2315_060

# Determination of groundwater-pit lake interactions, Liberty Pit, Tonopah, Nevada, USA

**RJ Bowell** *SRK Consulting, UK*

**B Anderson** *Piteau Associates, USA*

**R Kruger** *SRK Consulting, USA*

**B Clarkson** *SRK Consulting, USA*

**N Chutas** *Pathfinder Minerals, USA*

**A Carpenter** *Pathfinder Minerals, USA*

**J Parshley** *SRK Consulting, USA*

## Abstract

*This paper presents a case study of an open pit acting as a terminal sink in a net evaporative environment. The Liberty Pit, located on the Tonopah project in Nye County, Nevada, hosts a small permanent body of water. Currently, this body was approximately 12 m deep with a diameter of approximately 20 m in a crude circular shape. The geology of the pit is dominated by a Quartz Monzonite Porphyry (QMP) that hosts copper-molybdenum mineralization in a porphyry style deposit. Additional mineralization is also hosted within fingers of a mineralized host rock, potassic altered hornfels, that also outcrop in the pit. The most striking geological feature in the pit is the Liberty fault, which is a listric fault, that occupies the western portion of the pit and separates overlying Neogene-Quaternary alluvium from the underlying Mesozoic bedrock.*

*In terms of hydrogeological setting, water in the pit area is separated from the regional groundwater, which is compartmentalized by bedrock faults. Water chemistry of the monitoring boreholes on the perimeter of the pit show distinct chemistry including isotopic signature compared to an in-pit shallow borehole and the pit lake. Trace element and isotopic signature of the groundwater indicates it may be a source for the pit lake water demonstrating the pit is acting as a hydrologic sink. This is further confirmed by hydrogeological calculations that demonstrate the pit lake is isolated from the main bedrock groundwater through the presence of an aquiclude, the Liberty fault.*

*Geochemical modelling of the pit lake, coupled with hydrogeological estimates of inflows, demonstrate how the pit lake chemistry can be described in terms of inflow groundwater coupled with meteoric flushing of secondary salts and evapoconcentration. The lake body appears to currently be homogeneous with little evidence of zonation.*

*This study demonstrates the merits of field data and actual monitoring data in the evaluation of a pit lake. Despite the location on the side of basin and range topography, the lake is isolated from regional groundwater through the presence of natural aquicludes and, thus, does not present a risk to regional groundwater.*

**Keywords:** *Pit Lake, Stable Isotopes, Hydrogeology, Groundwater Interaction*

## 1 Introduction

The Liberty Pit at Tonopah, Nevada has hosted a permanent body of water since cessation of mining in the 1990's (SRK, 2022). In common with many pits in the western USA, the lake has formed in response to an end of dewatering and collection of water from inflowing groundwater and surface water pit wall runoff (Bowell, 2002). Evaporation appears to be the strongest control on the extent of the lake, like many lakes (Castendyk & Eary, 2009). This study has utilized pit water and groundwater monitoring well chemistry including stable isotope ratios. Although stable isotopes are relatively common in such assessments, there have been few documented studies for pit lake-groundwater environments in Nevada (Pellicori et al., 2005; Gammon et al., 2010; Newman et al., 2020).

The mine site is located about 40 kilometers northwest of Tonopah, Nevada, and accessed by the Gabbs Pole Line Road. The site is situated within the southern Big Smoky Valley on the western flanks of the San Antonio Mountains. The waste rock dumps cover approximately 782 acres and were constructed by end-dumping on a gently west-sloping (5%) alluvial fan.

The site climate is characterized as arid with hot summers and cold winters. The nearest weather station to the project is at the Tonopah Airport, located in Ralston Valley approximately 48 kilometers to the southeast. The elevation of the weather station is 1,800 m above mean sea level (amsl), similar to the site elevation at approximately 1,900 m amsl. Due to the similarities in site elevation and proximity to the mine, data from the Tonopah AP weather station is considered representative of the site.

# 2 Site geology

The Hall Mine Complex, where the Liberty Pit is located, is centred on a porphyry Cu-Mo system in the western flanks of the San Antonio Mountains. The Hall Stock Complex comprises predominantly quartz monzonite porphyry and hosts much of the Cu-Mo mineralization. The information provided here is taken from Shaver (1984) and Mears et al. (2000). The geology of the area is shown in Figure 1.

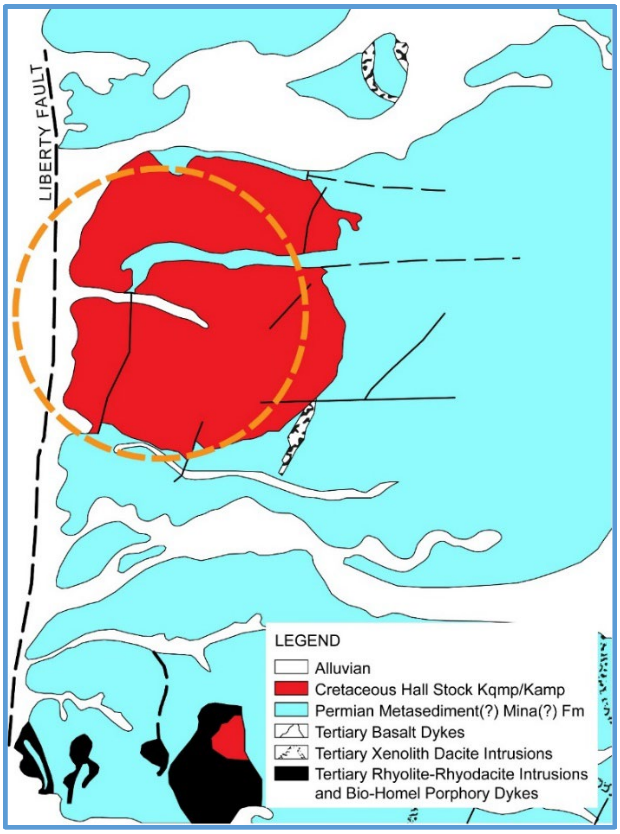


**Figure 1 Geology map of Tonopah Copper Project, orange circle shows outline of pit area**

Pit geology is dominated by Permian age metasediments which have undergone significant deformation (isoclinal folding) and faulting, as well as low-grade metamorphism. These units have been variously described as tuffs, pyroclastics, siltstones, argillites, schists, and limestones within this package of rocks, which are largely undifferentiated and now grouped as hornfels.

The Hall Stock Complex intruded the sedimentary/metasedimentary sequence of rocks in the Late Cretaceous Period (66-70 Ma), based on K/Ar and U/Pb age dates. The 762 m-diameter stock complex consists of two spatially- and temporally distinct bodies: 1) the earlier North stock and 2) the younger South stock, which is reported to truncate the Molybdenum mineralization hosted by the North stock (Shaver, 1984).

Felsic dikes are late-stage cross-cutting intrusives, consisting of varying amounts of quartz and orthoclase (85% combined) in a matrix of plagioclase and mafic phases (15% biotite/hornblende). Extrusive Tertiary-age rocks in the deposit area unconformably overlie the metasediments and the Hall stocks. The oldest unit is a basal mafic-rich ignimbrite that has been K/Ar dated at 24 million to 29 million years old.

**Structural geology**

The site is in the Great Basin of Nevada, which is an extensional tectonic regime characterized by normal faulting with down dropped valley floors and uplifted mountain blocks. Exposed in the western wall of the Liberty Pit is the westward-dipping Liberty Fault, which is a normal fault with a north-south strike. This Fault is the contact between the bedrock and the overlying alluvium. Additional faulting has been observed in the bedrock with the North Fault striking sub perpendicular to the Liberty Fault toward the southeast, and the low angle Basement Fault, which strikes sub parallel to the Liberty Fault but exhibits a perpendicular dip angle. Bedrock faulting may be related to emplacement of the Hall stock, or coeval with extensional tectonics.

# 3 Methodologies

Methodologies and procedures for the geochemistry program were completed at WET Lab, Sparks, Nevada. Samples of pit lake at various depths, groundwater samples from monitoring wells and pit wall rocks and sediments were analysed. Groundwater samples from wells were analyzed for Nevada Dept Environmental Protection (NDEP) Profile I constituents. Pit lake water was analyzed for NDEP Profile III constituents for both filtered and unfiltered fractions.

Isotopes of oxygen and hydrogen were analyzed in water samples, and oxygen and sulfur isotopes in sulfate molecules in water by Isotech Laboratory, Champaign, Illinois.

Water sample isotope analyses were performed by cavity ring-down spectroscopy (CRDS). Oxygen isotopes of dissolved nitrate were determined using ion exchange techniques, followed by mass spectrometry. Sulfur isotope analysis of organic solids and liquids were analyzed using an elemental analyzer (EA) coupled to an isotope ratio mass spectrometer (IRMS). Carbonates are analyzed by acid digestion followed by dual inlet IRMS.

Hydrogen isotopic compositions were determined for many types of samples. Water samples are analyzed using the CRDS. Reproducibility is generally 1.0 per mil or better. Tritium analysis of groundwater is done by radiometric measurement of the water. Landfill leachates or other samples with concentrations of 15 TU or higher, are analyzed by direct counting of the purified water. Detection levels of 1 TU are achieved by electrolytic enrichment of the sample, followed by radiometric analysis.

Assessment of the pit wall solids was undertaken using Nevada Dept of Environmental Protection protocols for assessment of mine waste geochemistry including acid base accounting and kinetic testing (NDEP 2014).

Hydrogeological evaluation relied on historic information provided by the mining company and utilized this to assess water depth, piezometric surfaces and flows coupled with calculations.

# 4 Results

## 4.1 Pit wall geochemistry

There is potential for acid generation in the pit wall rocks (Figure 2). The acid generating potential is likely overestimated in these results, which could be because of the following:

- The small potential observed within the oxide material most likely relates to poorly designated samples (i.e., contains residual sulfide) or lack of neutralization, as well as low acid generation creating a false positive anomaly.
- Some contamination by historic mine waste that is extensive on site (four waste rock piles with approximately 40 million tons of mineralized waste) has possibly impacted some of the alluvium samples as they also report sulfide concentrations.

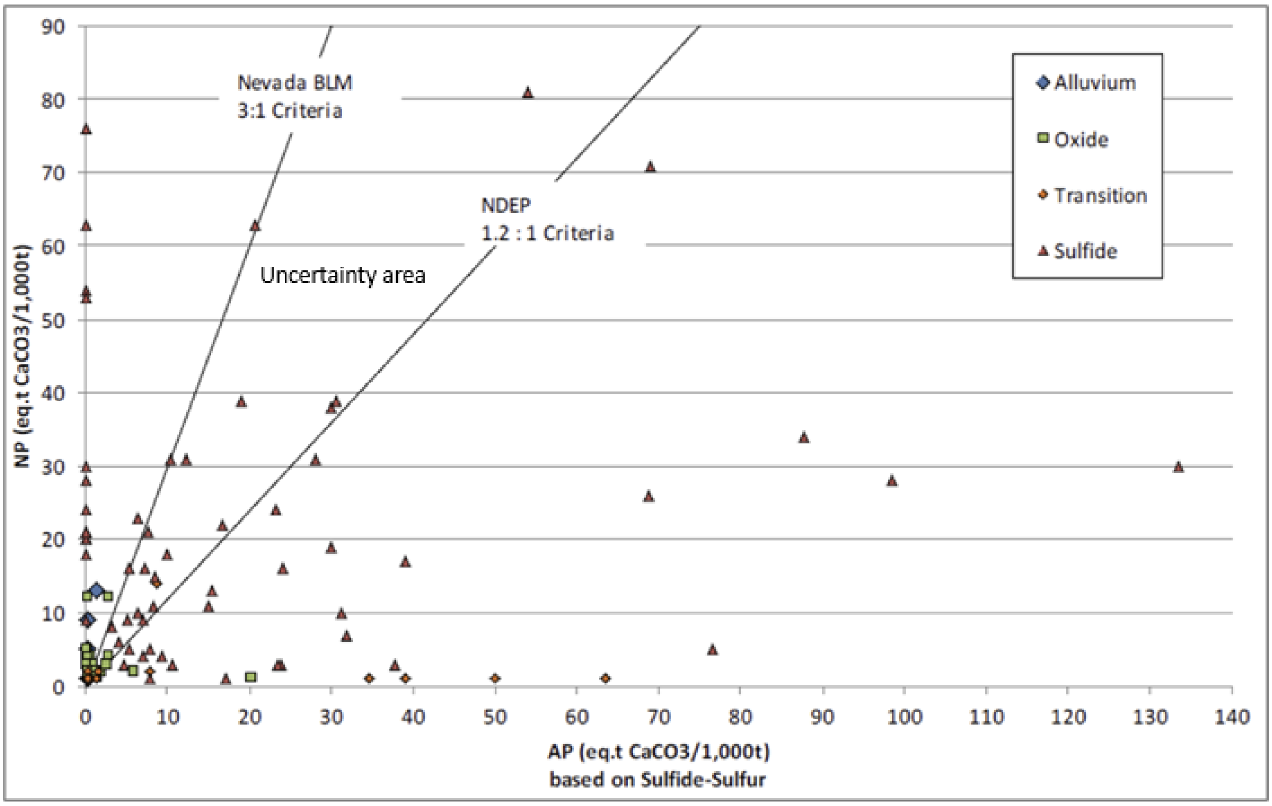


**Figure 2 Neutralization Potential (NP) vs Acid Generation Potential (AP) categorized as oxidation types**

As observed in Figure 2, the sulfide facies material and much of the transitional (partly oxidized sulfides) bearing wall rocks show net potential for acid generation or are uncertain (wedge between ratio of 3:1 to 1.2:1). The only material that is systematically net neutralizing is the oxide material and the non-sulfide bearing primary material that plots along the y axis. Determination is given in Price (2009).

The main reason for the overestimate of acid generation potential for the Tonopah Hall mine material types is the lack of carbonate buffering in the system, however, with titration analysis demonstrating a large potential for acid neutralization by silicate buffering.

In the assessment of metal leaching, short term HCT testing was undertaken for 20 weeks. The effluent pH over 20 weeks predicts an acidic pH (4.3) with elevated levels of aluminium, cadmium, copper, iron, manganese and zinc (Table 1).

**Table 1 Summary of constituent release in humidity cell after 20 weeks**

| Parameter | Units | MWMP Extract | Week 1 Effluent | Week 10 Effluent | Final Effluent | Nevada Reference Value |
|---|---|---|---|---|---|---|
| Alkalinity, Total | mg/L | <1 | <1 | <1 | <1 | N/A |
| Aluminum | mg/L | 11.2 | 22.5 | 5.93 | 3.00 | 0.05 |
| Antimony | mg/L | 0.004 | 0.008 | <0.003 | <0.003 | 0.006 |
| Arsenic | mg/L | <0.005 | <0.005 | <0.005 | <0.005 | 0.01 |
| Barium | mg/L | 0.063 | <0.020 | <0.020 | <0.020 | 1.0 |
| Beryllium | mg/L | <0.002 | 0.002 | <0.002 | <0.002 | 0.004 |
| Boron | mg/L | <0.10 | <0.10 | <0.10 | <0.10 | |
| Cadmium | mg/L | 0.172 | 0.342 | 0.043 | 0.066 | 0.005 |
| Calcium | mg/L | 25.0 | 88.1 | 17.9 | 18.0 | 200 |
| Chloride | mg/L | 7.0 | 22.1 | 0.6 | 1.6 | 250 |
| Chromium | mg/L | <0.005 | <0.005 | <0.005 | <0.005 | 0.05 |
| Copper | mg/L | 12.2 | 51.6 | 15.4 | 17.5 | 1.3 |
| Fluoride | mg/L | 19.8 | 47.7 | 10.7 | 14.0 | 2.0 |
| Iron | mg/L | 0.044 | 0.041 | <0.005 | <0.005 | 0.3 |
| Lead | mg/L | 0.009 | 0.012 | <0.007 | <0.007 | 0.015 |
| Magnesium | mg/L | 9.28 | 45.7 | 6.67 | 7.00 | 125 |
| Manganese | mg/L | 0.586 | 2.85 | 0.350 | 0.422 | 0.05 |
| Mercury | mg/L | <0.0005 | <0.0005 | <0.0005 | <0.0005 | 0.002 |
| Nickel | mg/L | 0.041 | 0.184 | 0.031 | 0.031 | 0.10 |
| Nitrate As Nitrogen | mg/L | <0.1 | 0.5 | 0.1 | 0.1 | 10.0 |
| Nitrite As Nitrogen | mg/L | <0.1 | <0.1 | 0.4 | 0.4 | 1.0 |
| Nitrate + Nitrite As N | mg/L | <0.1 | 0.5 | 0.5 | 0.5 | 10.0 |
| pH | s.u. | 5.36 | 5.02 | 5.13 | 4.30 | 6.5 – 8.5 |
| Potassium | mg/L | 2.95 | 24.2 | 5.73 | 6.30 | N/A |
| Selenium | mg/L | <0.010 | 0.014 | <0.010 | <0.010 | 0.050 |
| Silver | mg/L | <0.010 | <0.010 | <0.010 | <0.010 | 0.10 |
| Sodium | mg/L | 7.21 | 16.2 | 0.57 | 0.70 | N/A |
| Sulfate | mg/L | 162 | 702 | 103 | 164 | 250 |
| Thallium | mg/L | <0.001 | 0.002 | <0.001 | <0.001 | 0.002 |
| TDS | mg/L | 266 | 865 | 162 | 190 | 500 |
| WAD Cyanide | mg/L | <0.025 | ----- | ----- | ----- | 0.200 |
| Zinc | mg/L | 2.94 | 8.77 | 1.80 | 2.30 | 5 |

## 4.2 Hydrogeology of the open pit area

Groundwater at the site occurs in two major regimes. The regional alluvial groundwater system flows southward past the site, sub-parallel to the Liberty Fault. This system is separate from the bedrock groundwater, which occurs in the much lower hydraulic conductivity and fault divided bedrock of the San Antonio Mountains. Physiography suggests the alluvial groundwater system is recharged by precipitation at higher elevations in the Toiyabe and Toquima ranges bounding the northern reaches of the valley.

The bedrock groundwater is recharged by precipitation infiltration in the nearby San Antonio Mountains. The bedrock groundwater is impounded at the range front by the nature of the Liberty Fault as a strong hydraulic barrier. Monitoring wells completed in the alluvium show a very shallow southwest gradient, whereas monitoring wells 6001 and 6002 drilled through the alluvium and completed beneath the Liberty Fault (in bedrock) show an absence of water in the alluvium with the bedrock piezometric levels more than 160 m above the fault (as the alluvium-bedrock contact) (Barranca Group, 2011). Location of the monitoring wells used in the mine site area are shown in Figure 3 along with the bedrock piezometric surface in the mining area. The elevation of water has not changed significantly over time.

The large gradient in piezometric levels in the alluvium compared to the bedrock system has initiated questioning regarding the state of the pit as a groundwater flow-through system.

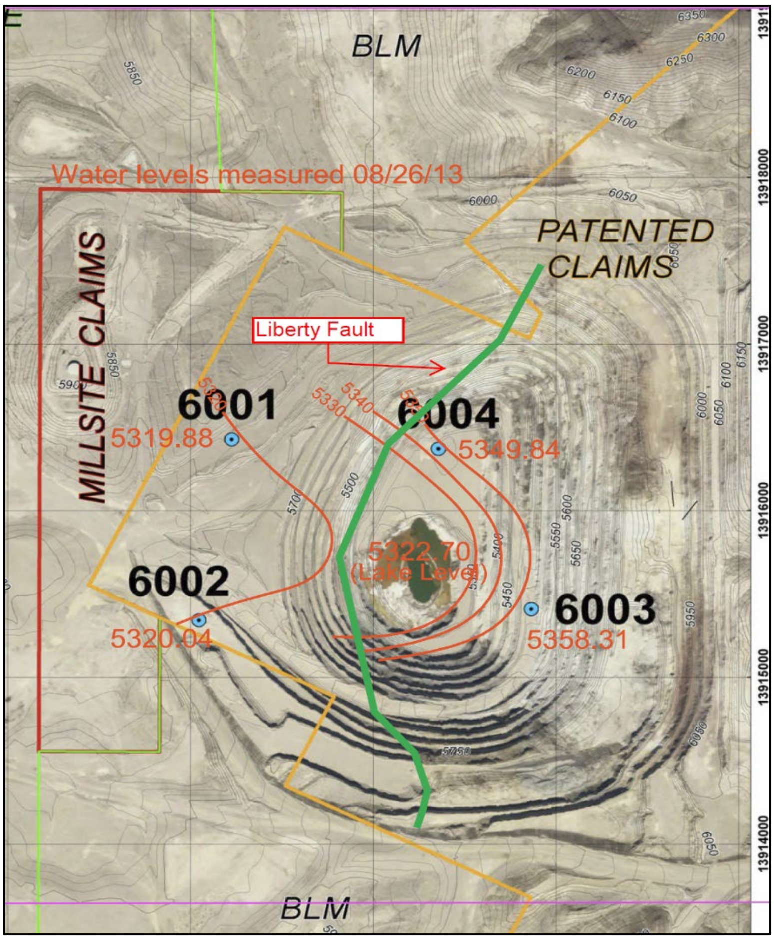


**Figure 3 Plan view of Liberty pit area showing location of dewatering wells (6001-6004)**

Wells 6003 and 6004 are upgradient of the pit and wells 6001 and 6002 are downgradient. The pit lake head elevations are generally 1–3 m lower than the downgradient groundwater elevation. This relationship is also observed in the elevations shown in Figure 4. Historic groundwater elevation is generally static.

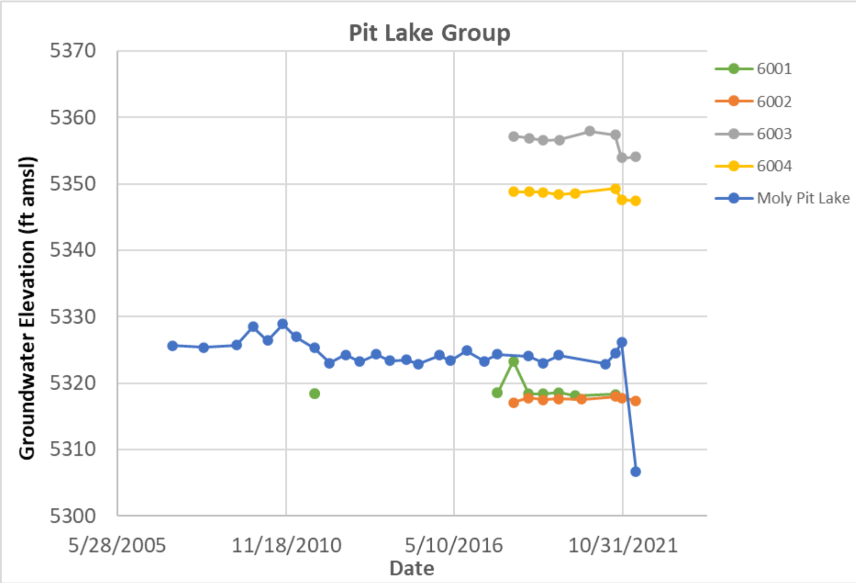


Figure 4 Elevation in monitoring wells and pit lake

## 4.3 Groundwater hydrogeochemistry

Macro chemistry, major element, and trace element data were collated and plotted to aid in establishing whether a link exists between the pit lake and aquifer. Water quality samples from the pit lake have been collected since 1991. Water quality samples have been collected routinely for wells in the vicinity of the pit since 2005.

Groundwater quality in the wells tend to show higher magnesium and alkalinity ($CO_3$+$HCO_3$), lower sodium, potassium, sulfate and chloride. Thus, the pit lake water has Na-K-SO4 characteristics, but groundwater is more of a mixed Ca-Mg-$HCO_3$-$SO_4$ type of water (Figure 5).

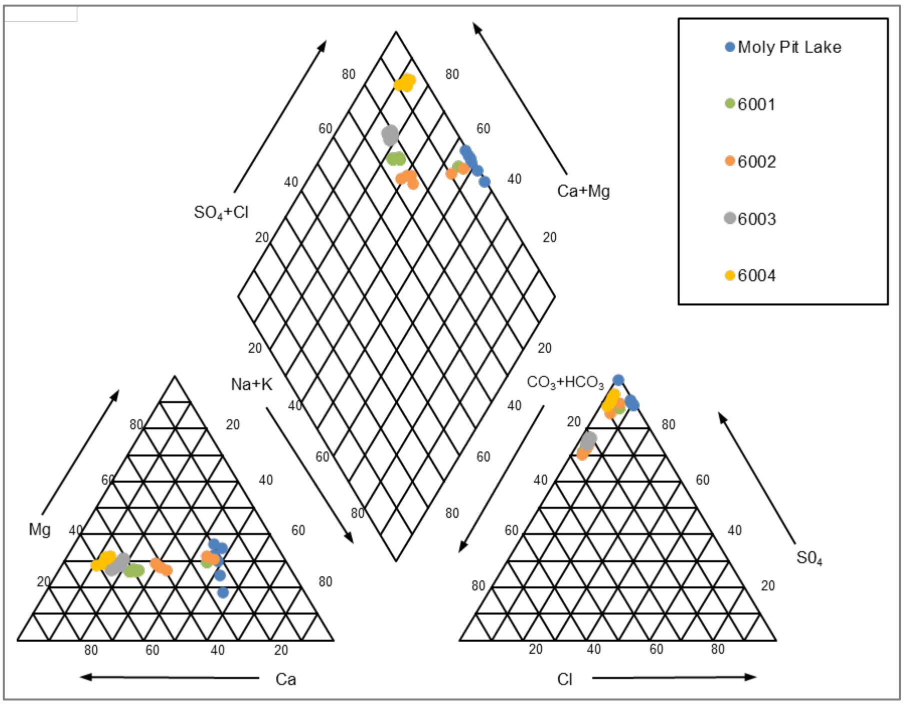


Figure 5 Piper plot for groundwater wells and pit lake Liberty pit area

Variation in pH over time within the groundwater wells and pit lake is shown in Figure 6. The groundwater samples display a higher overall pH compared to the pit lake water. The pit lake pH shows an overall decreasing trend from the late 80's to 2001, dropping from approximately 8.4 to approximately 4.6. This trend is likely related to a combination of low groundwater recharge, increased precipitation in the lake, and increased acid generation from weathering of pit walls. Following 2001, the pit lake pH remains somewhat stable and buffered between 5.8 and 4.3.

A sharp increase in pH is seen in the pit lake sample obtained in October of 2018, rising from 4.9 to 7.0. This is likely associated with the October 2018 event responsible for the alkalinity increase observed in the pit lake during that time. A similar spike is also seen in the 6001 and 6002 well samples from the spring of 2019, indicating that some connection with a degree of lag time may exist between the pit lake and these wells. Most groundwater samples fall within a pH of 6.5 to 8.0, which is the NDEP reference range for pH. The exceptions include samples obtained from well 6001 in the fall of 2018 and well 6002 in the fall of 2021, which both exceeded 8. Waters from the pit lake have consistently remained below 6.5 since 1996, except for samples obtained prior to 1994, in the fall of 2018, and spring of 2019.

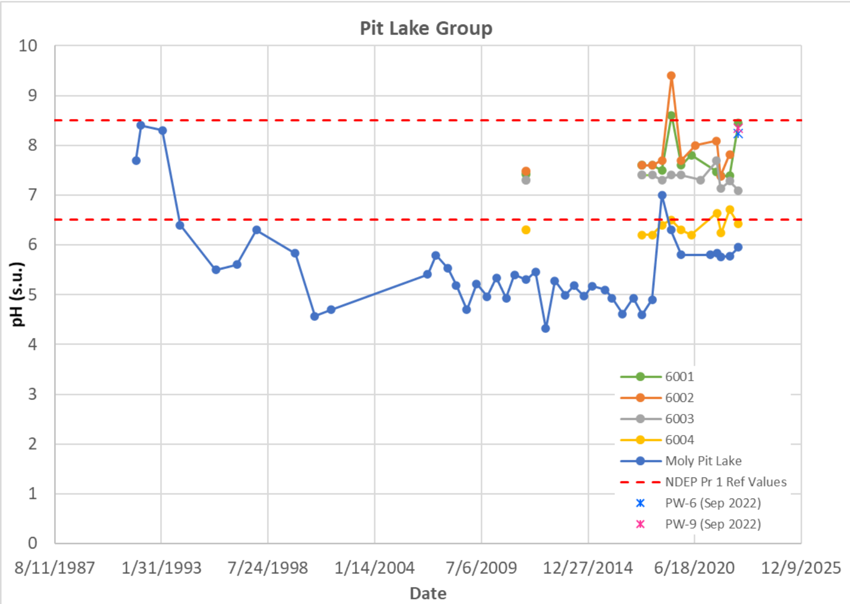


**Figure 6 Variation in pH over time, groundwater wells and pit lake, Liberty pit area**

The TDS within the pit lake group samples is shown to be dominated by sulfate (Figure 7). Samples obtained from wells and the pit lake are shown to consistently exceed the NDEP reference values for TDS at 1,000 mg/L. The pit lake has displayed a steady increase in TDS since 1993. This is likely a result from a combination of increased contribution from wall rock salts, acid generation, and evapoconcentration.

Since 2006, the pit lake TDS has remained between 5,890 and 12,700 mg/L. All pit area groundwater samples have maintained TDS values between 302 mg/L and 2,320 mg/L, suggesting there is no apparent hydrological connection to the pit late.

Pit lake water level elevations have remained relatively steady, with seasonal variations ranging between 1-3 m, from 2003 to 2021. The water level is shown to drop by approximately 6 m in 2021. This may be related to pumping of water for drilling on site, or evaporation, or a combination of the two.

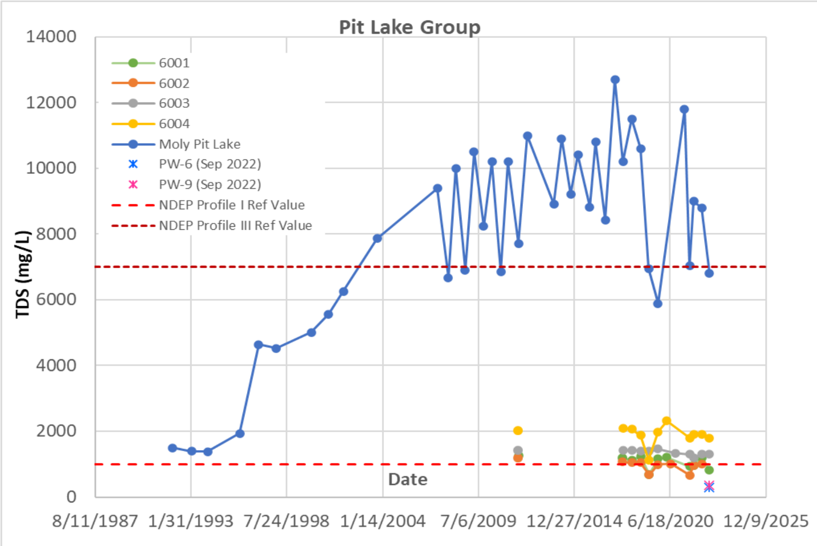


**Figure 7** **Variation in total dissolved solids (TDS) over time, groundwater wells and pit lake, Liberty pit area**

In terms of trace elements, copper is largely undetectable in wells 6001, 6002, and 6003. Samples from well 6004 contain copper concentrations exceeding detection limits with some measurements surpassing the NDEP threshold of 1 mg/L (Figure 8). Copper concentrations in the Liberty pit lake range from 0.14 to 79 mg/L and overlap with those from well 6004.

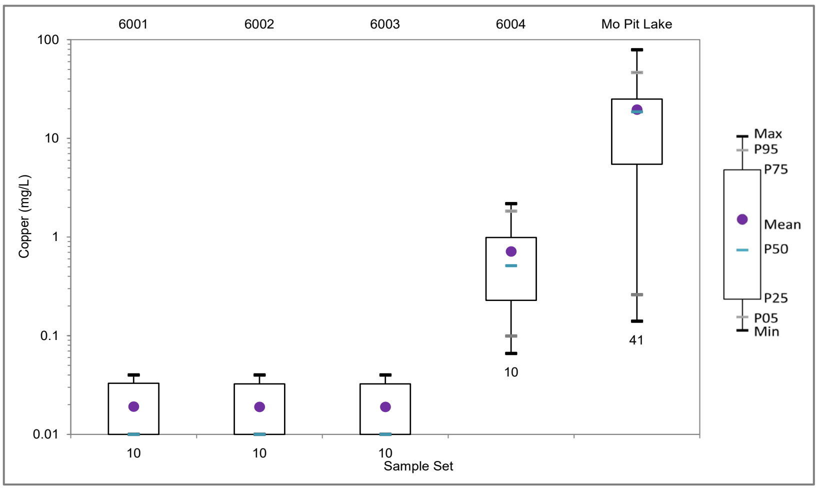


**Figure 8** **Box and whisker plot showing range and statistics, copper concentration groundwater wells and pit lake, Liberty pit area**

In terms of variation over time, the pit lake has shown considerably higher concentrations of copper than any of the monitoring wells (Figure 9). The distribution of fluoride concentrations in the pit lake group samples is similar to those observed with copper and aluminium. Wells 6002 and 6003 have consistently displayed undetectable amounts of fluoride. Samples obtained from well 6004 show a range of 16 to 51 mg/L and consistently exceed NDEP water quality criteria. This range overlaps with the distribution displayed in the pit lake samples, which fall between 8.6 and 512 mg/L (Figure 10). Interestingly, detectable fluoride in 6001 may point towards a connection from 6004, which is upgradient of 6001.

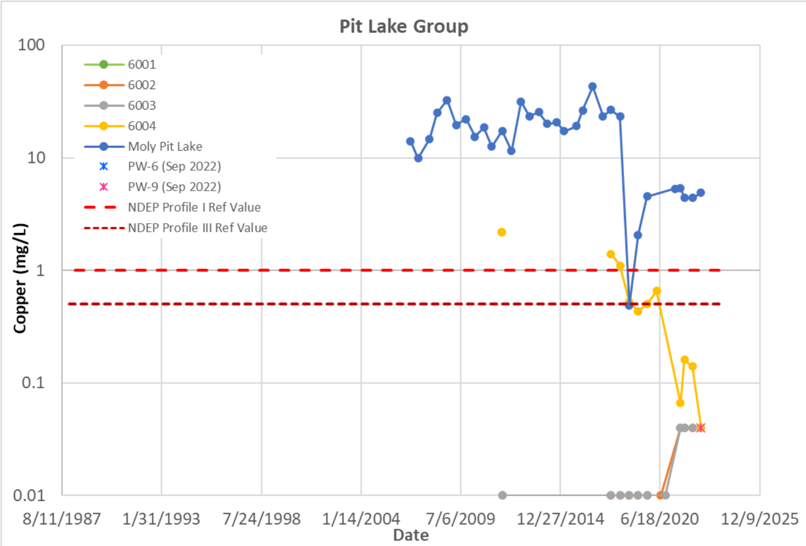


**Figure 9 Variation in copper concentration over time, groundwater wells and pit lake, Liberty pit area**

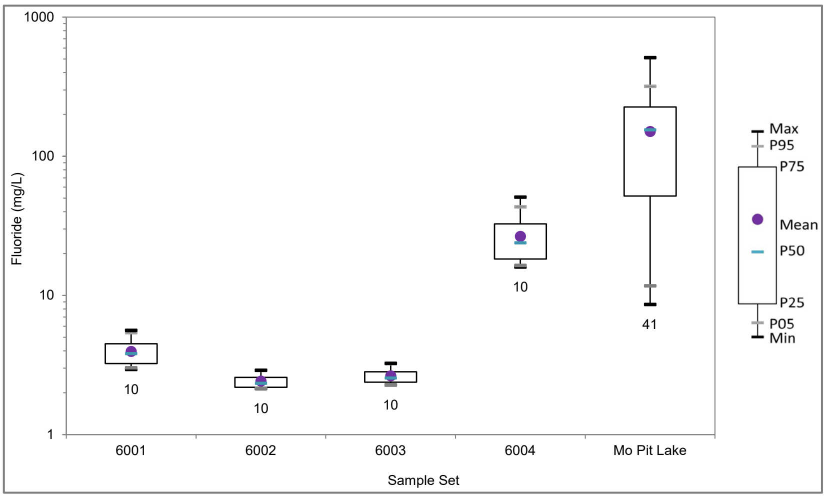


**Figure 10 Box and whisker plot showing range and statistics, fluoride concentration groundwater wells and pit lake, Liberty pit area**

Water samples were taken from the pit lake at various depths in September 2023 (Figure 11). The pH is slightly acidic, with values ranging between 5.7 at 6 m to 5.96 at 3 m below surface level (bsl) with the highest concentrations of parameters observed just above the bottom of the lake, at 11 m, for sulfate, calcium, iron, copper, manganese and aluminium. However, during sampling, sediment was disturbed and therefore contamination of this sample cannot be ruled out. The lowest concentrations were observed at surface level for calcium, magnesium, iron, fluoride, copper, manganese and aluminium. Also, there is no obvious systematic variance in the elements, the lake is likely not stratified at present, and can be seen as a homogeneous body of water. A chemocline may develop over time at the base, but it is currently not mature or stable.

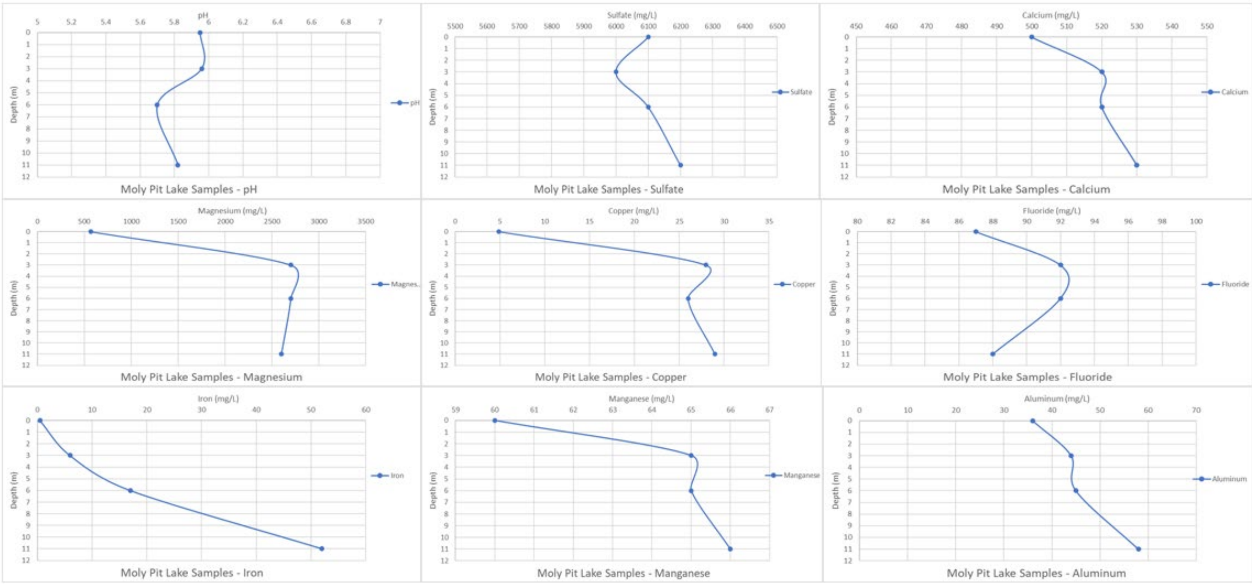


**Figure 11 Selected parameters, pit lake chemistry with depth, Liberty pit area**

Stable isotope analyses were undertaken on pit lake and groundwater samples to investigate potential relationships between the two. The pit lake waters are different to that of the district-wide groundwater, plotting closer to the Global Meteoric Water Line. There is separation between the two sets of data, indicating different sources (Figure 12). The groundwater displays a wall rock reaction or mixing trend, whereas the pit lake water is interpreted as having an evaporation trend.

The sulfur isotopes demonstrate that the pit lake water is lighter than the groundwater, even though concentrations are higher. This is interpreted as fractionation of groundwater as a source to the pit lake and evapoconcentration. This supports the hypothesis that the pit is acting as a local groundwater sink.

# 5 Discussion

Monitoring wells downgradient of the pit lake (6001 and 6002) appear to be hydrologically separated from the pit by the Liberty Fault and presumably not affected by the pit lake chemistry. In addition, oxygen and sulfur isotope chemistry appear to indicate that groundwater is a contributor to pit lake chemistry.

The Liberty Fault isolates the bedrock groundwater system east of the fault from the alluvial groundwater system west of the fault. Although the surface locations for wells 6001 and 6002 are located west of the westward-dipping Liberty Fault, their screened intervals fall east of the fault drawing water from the bedrock groundwater system (Figure 13). Because these wells are screened in the bedrock system, it is erroneous to indicate that the Liberty Fault separates these wells from the bedrock groundwater system and waters of the existing pit lake.

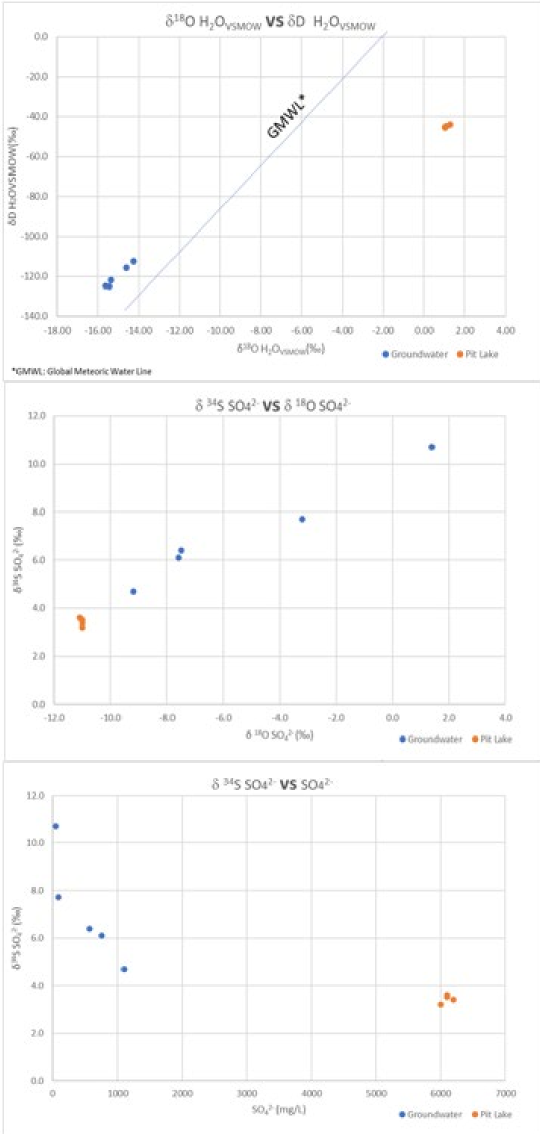


**Figure 12 Stable isotope results, pit lake and groundwater wells, Liberty pit**

Wells 6001, 6002, 6003, 6004, and the existing pit lake, share similar chemistries because they all reside in the bedrock groundwater system. Despite this chemical similarity, constituent concentrations in the existing pit lake are elevated due to evapoconcentration and other chemical processes unique to the existing pit lake environment. The lack of connectivity between the existing pit lake chemistry and the "6000" series wells is consistent with the pit lake functioning as a hydraulic sink where groundwater gradients are toward the existing pit lake. A comparison of the isotope chemistry in the existing pit lake and surrounding monitoring wells indicates that groundwater is flowing down gradient toward the pit lake driven by evaporation as the only outflow mechanism. Similar conclusions have been published by other studies (Newman et al. 2020).

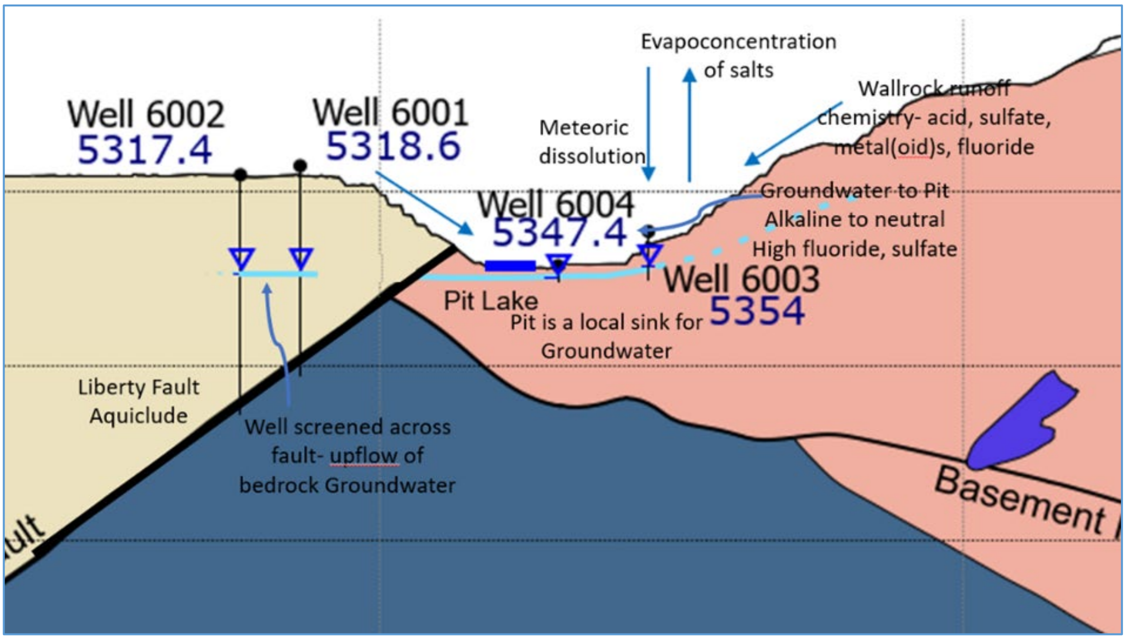


**Figure 13 Conceptual hydrogeological-hydrogeochemical model of the Liberty pit**

From the hydrogeological work of Piteau (2022) the Liberty Fault is acting as an aquiclude. This is also seen in the field geology observed in the pit where mineral salts form only on the footwall side of the fault zone (Figure 14).

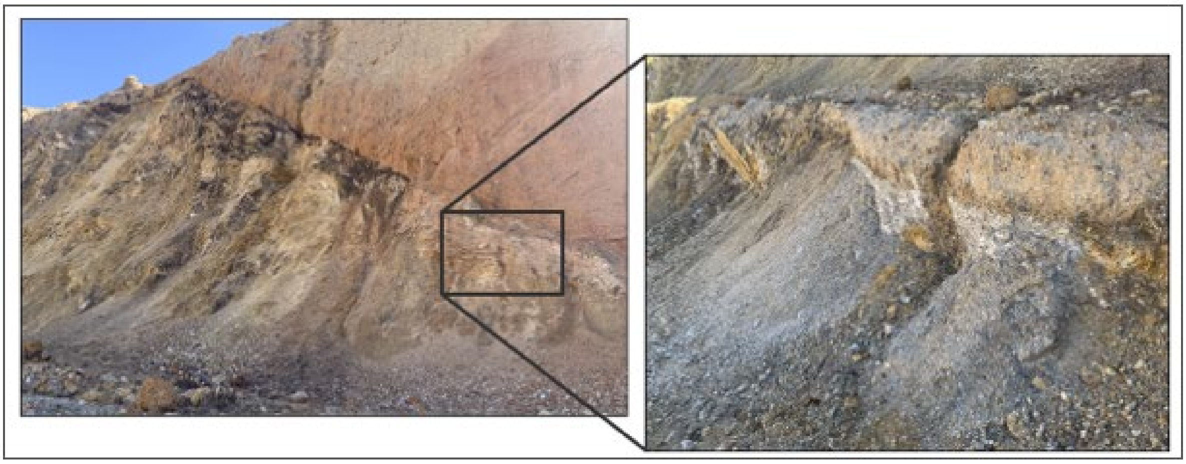

**Figure 14 Salts form on lower side or footwall of Liberty Fault on Hornfels and alluvium scree but not on the in-situ alluvium**

Iron staining on the hanging wall alluvium possibly reflects percolation of meteoric water through the alluvium and redox control at the fault boundary where water ponds as it cannot migrate further.

From the hydrogeochemistry of the pit lake and, particularly from oxygen and sulfur isotopes in sulfate molecules, the groundwater appears to be the source of sulfate in the pit and not the other way around, confirming the sink mechanism active in the current pit. The isotopically light sulfate in the lake could not be the source of groundwater sulfate that is isotopically heavier in both oxygen and sulfur isotope ratios. In addition, significant dilution would be required to the water chemistry if the pit lake was a source of down gradient borehole water.

Wallrock geochemistry of the pit walls and floor sediments reflect a pit lake chemistry that is heavily influenced by evaporation of the secondary salts within those units. By comparison, MWMP chemistry of the weathered sulfides does not show similar concentrations of parameters and thus, coupled with ABA, NAG and paste pH indicate that it is secondary salts that currently dominate the pit lake chemistry rather than direct active sulfide oxidation. On the whole, sulfides are coarse crystalline phases and, in the pit, show only minor evidence of oxidation. The relative continuity in pit lake chemistry reflects the current chemical stability of the system, with meteoric water rinsing and evapoconcentration being the main controls on pit lake chemistry.

Water in the downgradient boreholes completed in bedrock are identical and support the fact that when the wells were constructed, screens were placed across the bedrock-alluvium boundary (the Liberty Fault) and thus confined groundwater from bedrock is the source of water in the monitoring holes. There is no evidence of significant downgradient connection between the alluvial aquifer and the pit lake environment. Rather, it appears that the pit is currently acting as a local groundwater sink contained within the bedrock aquifer. Monitoring chemistry of the downgradient wells 6001 and 6002 in historic and current monitoring data indicates these wells host the same water chemistry as the upgradient well 6003. The well in the pit, 6004, appears to be monitoring an “isolated” zone of water within the fracture zone of the pit that has little or no connection to other waters but may be part of the groundwater that is contributing seepage to the existing pit lake.

# 6 Conclusion

The pit lake at the Liberty Pit hosts a small permanent body of water. In September 2022 this body was approximately 12 m deep with a diameter of approximately 20 mm in a crude circular shape. The geology of the pit is dominated by a Quartz Monzonite Porphyry (QMP) that hosts copper-Molybdenum mineralization in a porphyry-style deposit. Additional mineralization is also hosted within fingers of a mineralized host rock, potassically altered hornfels, which also outcrops in the pit. The most striking geological feature in the pit is the Liberty Fault which is a listric fault that occupies the western portion of the pit and separates overlying Neogene-Quaternary alluvium from the underlying Mesozoic bedrock.

In terms of hydrogeological setting, it appears that water in the pit area is separated from the regional groundwater, which is also compartmentalized by the Basement and Liberty Faults. Water chemistry of the boreholes installed into bedrock – 6001, 6002, 6003 (thus intersecting groundwater in the aquifer beneath the Liberty fault) appears to be distinctly different from the waters of the Liberty Pit Lake and 6004. Macro-, trace- and isotope chemistry of groundwater support the distinctive nature of groundwater in the existing Liberty Pit Lake from surrounding groundwater and the difference between groundwater immediately beneath the pit to that intersected in wells 6001, 6002 and 6003. Although well 6001 is collared in alluvium on the west side of the fault but completed in the bedrock unit. Samples from the well are identical to the bedrock groundwater and indicate that water in this well is confined bedrock groundwater upwelling due to screening across the lithological divide. Trace element and isotopic signature of the groundwater indicates it may be a source for the pit lake water but not the other way round, thus conclusively demonstrating the pit is acting as a hydrological sink.

The Liberty Fault appears to act as an aquiclude/barrier, with no evidence of water moving from the alluvium above the fault, through the fault and into the bedrock below the fault through the presence of oxidized iron staining. Along the footwall of the fault, ponding of mineralized solutions has created a zone of secondary copper and iron sulfate precipitation, indicating the aquitard nature of the Liberty Fault.

Static geochemical testing of the wallrock indicates that the QMP and Hornfels lithologies in the pit are potentially acid generating (although not particularly reactive); and, although several regulated parameters were measured (arsenic, manganese, selenium), no concentration exceeded the Nevada reference values. The pit has been continuously monitored over the past 25 years, providing real time data which provides a more representative assessment of lake chemistry. In addition, the chemical changes in the lake are minor over this period with relatively consistent chemistry indicating that the current system is in some form of chemical equilibrium with a strongly evaporative control through evapoconcentration in the dry season and dissolution in the wet season. In addition, the hydrogeochemical and hydrogeological studies demonstrate that the pit is a sink.

## Acknowledgement

Pathfinder Minerals are acknowledged for funding this study and approving publication of this paper.

## References

Bowell R.J. 2002 Hydrogeochemical dynamics of Pit Lakes. In: Younger, P.L. and Robins, N. (eds) Mine Water Hydrogeology and Geochemistry. Geological Society of London Special Publication, 159-187.

Barranca Group 2012 Monitor Well Construction, Sampling, & Testing – Liberty Project. February 2012. 82p.

Castendyk DN & Eary LE 2009 Mine Pit Lake: Characteristics, Predictive Modelling and Sustainability, v.3. SME, Denver,Colorado. 316p.

Gammons, C.H., Duaime, T.E., Parker, S.R., Poulson, S.R., Kennelly, P., 2010. Geochemistry and stable isotope investigation of acid mine drainage associated with abandoned coal mines in central Montana, USA. Appl. Geochem. 31, 100–112.

Mears J Huffman E, Terhune B 2000 Geology of the Tonopah Copper Deposit, Nevada. Proceedings of Geology in the Great Basin, May 15-18 2000. GSN, Reno. 1149-1155.

Nevada Dept of Environmental Protection (NDEP) 2014 Waste rock, overburden, and ore evaluation Bureau of Mining Regulation and Reclamation. NDEP. February 28, 2014. 5 p.

Newman, Connor P., Poulson, Simon R., Hanna, Braden, 2020. Regional isotopic investigation of evaporation and water-rock interaction in mine pit lakes in Nevada, USA, Journal of Geochemical Exploration, 210, 106445

Pellicori, D.A., Gammons, C.H., Poulson, S.R., 2005. Geochemistry and stable isotope composition of the Berkeley pit lake and surrounding mine waters, Butte, Montana.Appl. Geochem. 20 (11), 2116–2137

Piteau Associates. 2022. Liberty Complex Liberty - Pit Lake Water Balance Analysis and Hydrogeologic Summary. December 2022. 50p.

Price WF 2009 Prediction Manual for Drainage Chemistry from Sulfidic Geologic Materials. MEND Report 1.20.1. Natural Resources Canada. 579p.

Shaver, S.A., 1984, The Hall (Nevada Liberty) Molybdenum deposits, Nye County, Nevada: Geology, alteration, mineralization and geochemical dispersion: Stanford, California, Stanford University, Ph.D. dissertation, 261 p

SRK Consulting. 2022 Tonopah Copper-Liberty Project Geochemistry- Schedule of Compliance Study. USPR000803. December 2022. 105p.

State of Nevada, Department of Conservation and Natural Resources, Division of Environmental Protection and Bureau of Mining Regulation and Reclamation. February 15, 2022. Water Pollution Control Permit, NEV0088029.