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Underground Hydrologic Preliminary Evaluation

2008 Closure Studies

Prepared by:

Alexco Resource US Corp
For ERDC

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ERDC

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1. INTRODUCTION

Earlier closure studies performed by SRK (March 31, 2008 Memo titled "Outcomes from 2007/08 Keno Hill Adit Closure Studies") included an assessment of closure options for 70 known adits in the United Keno Hill Mines district on behalf of Elsa Reclamation and Development Company Ltd. (ERDC). Closure options were considered for each adit, with objectives for each adit closure including preventing public access, water control, and water treatment. For eight adits, adit plugs were recommended for primary consideration. An adit plug would provide the ability to control mine drainage rate, timing and location, potentially allowing for treatment in seasonal campaigns or for temporary control of drainage during maintenance of treatment projects outside of the adit. An adit plug may also be part of an underground water treatment project where the underground mine pool behind the adit plug could be the vessel for water treatment.

The eight adits where adit plugs were recommended were Silver King 100, No Cash 500, Galkeno 300, Galkeno 900, Bellekeno 625, Onek 400, Keno 700, and Sadie Ladue 600. At each of these locations there is an existing discharge that is being treated or may be treated in the future. Due to the active development of the Bellekeno deposit, this mine is not included in this analysis. The preliminary analysis in this document is intended to define some factors that would affect the potential for water storage or treatment in the adits and mine workings and evaluate the potential effects to the environment were an adit plug to be installed in each location. Special attention is placed on the Hector-Calumet mine workings because it is the dominant system generating zinc loading in the district, and because of its potential to drive long term water treatment costs during closure.

Work performed includes evaluating output from 3-D geological evaluations Alexco is currently undertaking in the district to define mineral resources in the Keno Hill mining district. Much of what is shown in this document is the work product of Alexco geologists whose objectives were not specifically for the purpose of evaluating closure options, and these work products were generated at Alexco's cost. However, it is believed that the information presented here is an accurate depiction of the mining records digitized and put into AutoCAD or MineSite programs.

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2. NORTH EAST END OF GALENA HILL: GALKENO 900, GALKENO 300, HECTOR-CALUMET WORKINGS, AND NO CASH 500

Three adits located on the north and east end of Galena Hill currently drain the primary zinc loading of the entire Keno Hill mine district, comprising over 90% of the point sources known in the district, Galkeno 300, No Cash 500, and Galkeno 900. This first section examines some hydrologic factors affecting closure of these adits.

2.1. CONNECTION OF HECTOR CALUMET WITH OTHER GALENA HILL MINES

The Hector and Calumet (H-C) mines are one continuous mine from which the majority of ore and waste rock was removed within the entire Keno Hill mining district. However, no surface discharge of water is observed to emanate from this mine. Mines with adit drainage that are within a few thousand feet of the H-C workings include No Cash 500, Galkeno 300, and Galkeno 900.

Table 1 shows the tons of ore and total rock removed from each mine and recent annual loading of zinc from each mine. What can be observed are both the effects of rock types (e.g., host rock neutralization potential) on zinc loading, but also that the total zinc loads in the district can only be explained logically if Hector Calumet drainage reports to Galkeno 300 adit drainage. It is also possible to explain the relatively high loading (2nd highest concentration in the district) at No Cash 500 by postulating a distant connection of No Cash with Hector Calumet mine pool. It is also important to note that there are no direct observation points to the Hector Calumet pool, so all of the information in this report infers connections and mine pool elevations from mine records.

TABLE 1. ZINC LOADING COMPARED TO ORE AND WASTE ROCK REMOVAL IN THE KENO HILL DISTRICT.

Site Name	Ore Removed (tons)	Estimated* Total Rock Removed (tons)	Zinc Loading (kg)
Galkeno 300 (+Sime)	214,000	716,000	55,000
Hector Calumet	2,710,000	4,166,000	
No Cash 500	167,000	313,000	2,400
Onek 400	95,000	703,000	890
Galkeno 900		120,000	680
Bellekeno 600	40,500	104,500	520
Sadie Ladue 600	244,000	288,000	340**
Keno 700	284,000	326,000	330
Bermingham	7,800	186,000	270
Silver King	201,000	364,000	260

*some waste rock not accounted for, used for road construction or other activities
**derived from very few data points

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2.1.1. Connection of Hector Calumet with Galkeno 300 Adit Drainage

Figures 1, 2, and 3 show different views of the connection between the Galkeno 300 level with the H-C 775 level. At the connection of the H-C 775 level with the Galkeno 300 level, H-C 775 elevation is 1149.8 m. At the connection of the Galkeno 300 level with the H-C 775 level, the Galkeno 300 elevation is 1128.04 m. This 21.7 m difference is assumed to be an underground waterfall overflowing from the H-C mine into the Galkeno mine.

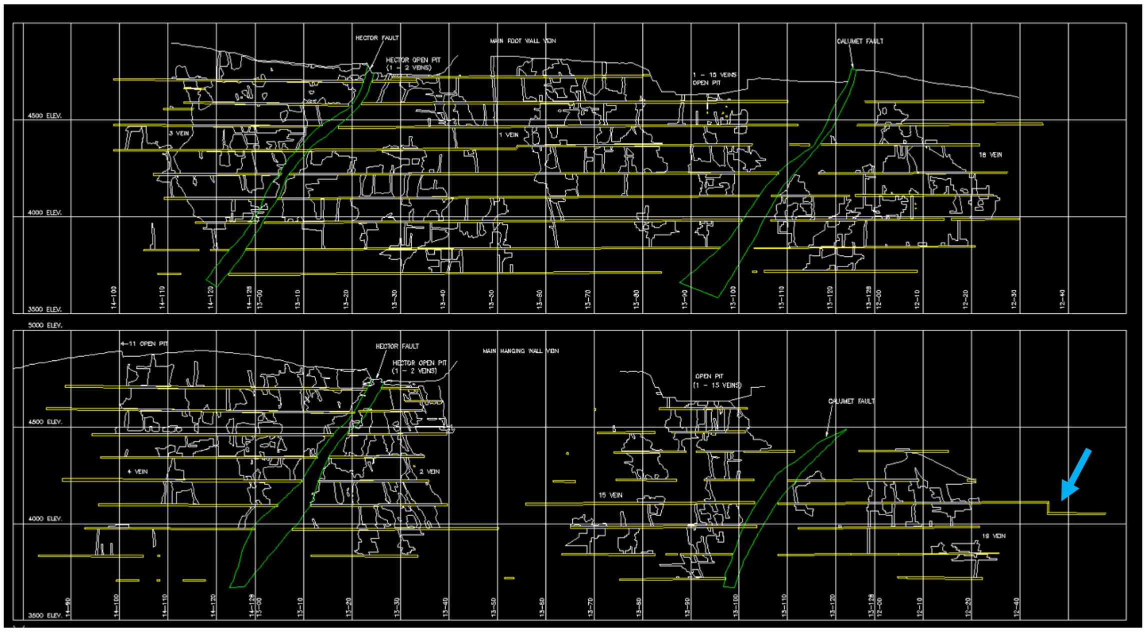

FIGURE 1. LONGSECTION OF HECTOR CALUMET WORKINGS (CALUMET WORKINGS ON RIGHT SIDE) WITH BLUE ARROW POINTING TO THE H-C 775 LEVEL. THE DROP IS 21.7 METERS.

There is no direct connection of the Hector Calumet workings with the Galkeno 900 system (Figure 3). However, the Sime cross cut and McLeod fault are suggested to provide an indirect route whereby drainage from the H-C workings could contribute flow and metals mass to the Galkeno 900 drainage.

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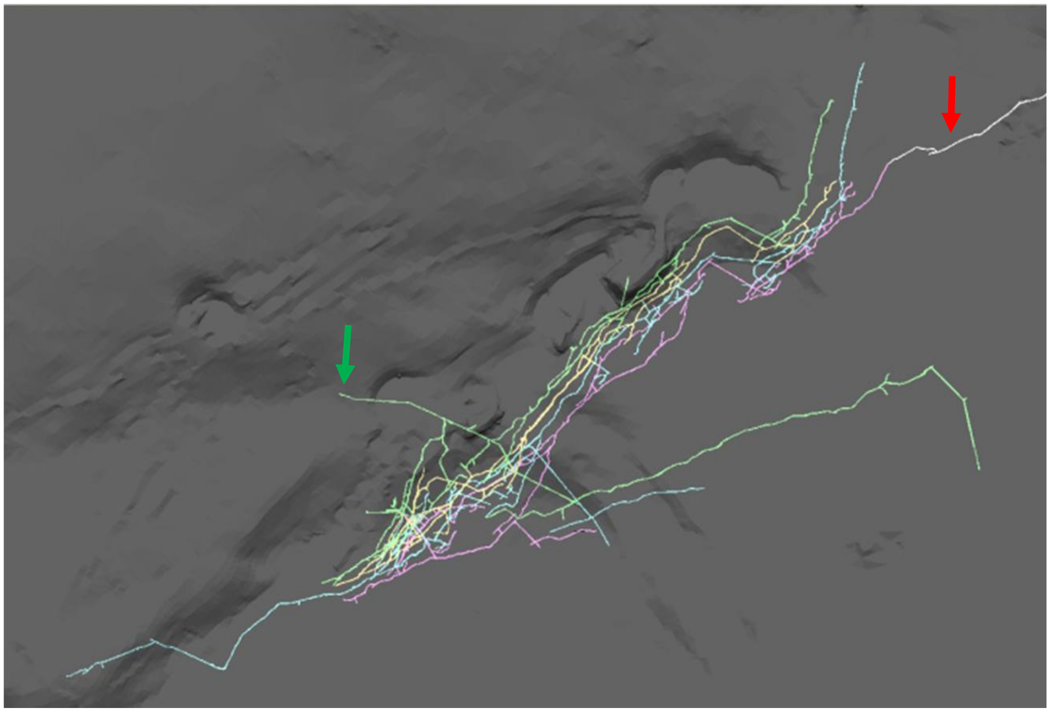

FIGURE 2. HECTOR CALUMET MINE. THE MINE LEVELS SHOWN ARE THE 400 L– GREEN, 500 L– ORANGE, 650 L– TEAL, AND 775 L– MAGENTA. THE GREEN ARROW IS THE HECTOR 400 ADIT. THE RED ARROW IS THE LOCATION OF THE CONNECTION OF THE 775 LEVEL TO THE GALKENO 300 LEVEL. SOME OF THE OPEN PITS THAT ARE AT THE SURFACE OF THE HECTOR CALUMET MINES ARE VISIBLE ABOVE THE WORKINGS.

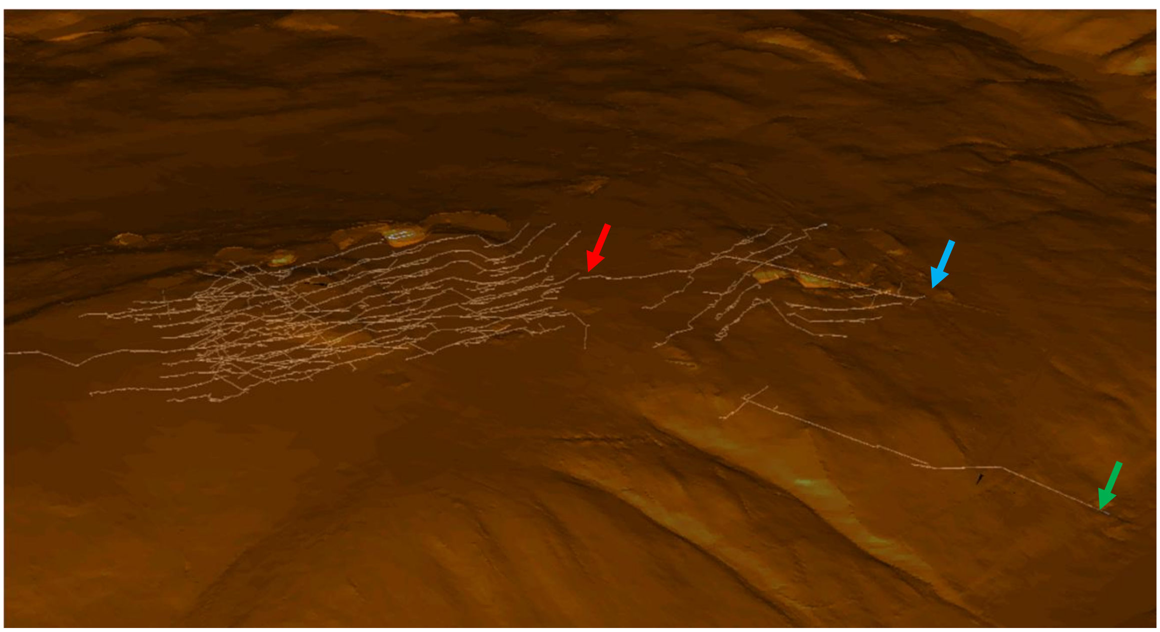

FIGURE 3. NORTHERN END OF GALENA HILL, SHOWING HECTOR CALUMET MINE ON LEFT SIDE, GALKENO MINES ON THE RIGHT SIDE. RED ARROW SHOWS LOCATION OF CONNECTION BETWEEN THE HECTOR CALUMET MINE AND GALKENO MINE. BLUE ARROW SHOWS LOCATION OF GALKENO 300 ADIT AND GREEN ARROW SHOWS LOCATION OF GALKENO 900 ADIT.

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2.1.2. Mass Loading and Drainage from Hector Calumet Affecting Galkeno 300

While the mass loading of zinc from the Hector Calumet mines almost certainly represents the vast majority of the zinc exiting Galena Hill at Galkeno 300, it is less certain what fraction of the flow is contained in the H-C 775 overflow, or what fraction of the water is dilution from other sources, including water bearing faults that intersect and drain into the Galkeno 300 level, open pits above the Galkeno workings, or other catchment/recharge from surface to the Galkeno mines. As part of the care and maintenance activities and 2009 spring freshet, Alexco dug a series of diversion ditches around the Hector Calumet and Sime Pits in April 2009 in an effort to reduce the volume of water exiting the Galkeno 300 adit during freshet. The peak flows historically experienced (25 – 30 lps) were not exhibited in 2009 and the peak flow during the freshet period reached a high of 18 lps. It is reasonable to conclude that the majority of the freshet volumes emanating from the Galkeno 300 adit are from the direct connection of the Hector Calumet open pits into the underground workings.

To assess the immediate catchment area associated with the Hector Calumet mine above the 775 level, the north end of Galena Hill above the 1305 m elevation was selected and the area assessed in AutoCAD. Figure 4 shows this assessment. The outlined area was selected to be the north and western side of Galena Hill under which some of the H-C workings lie.

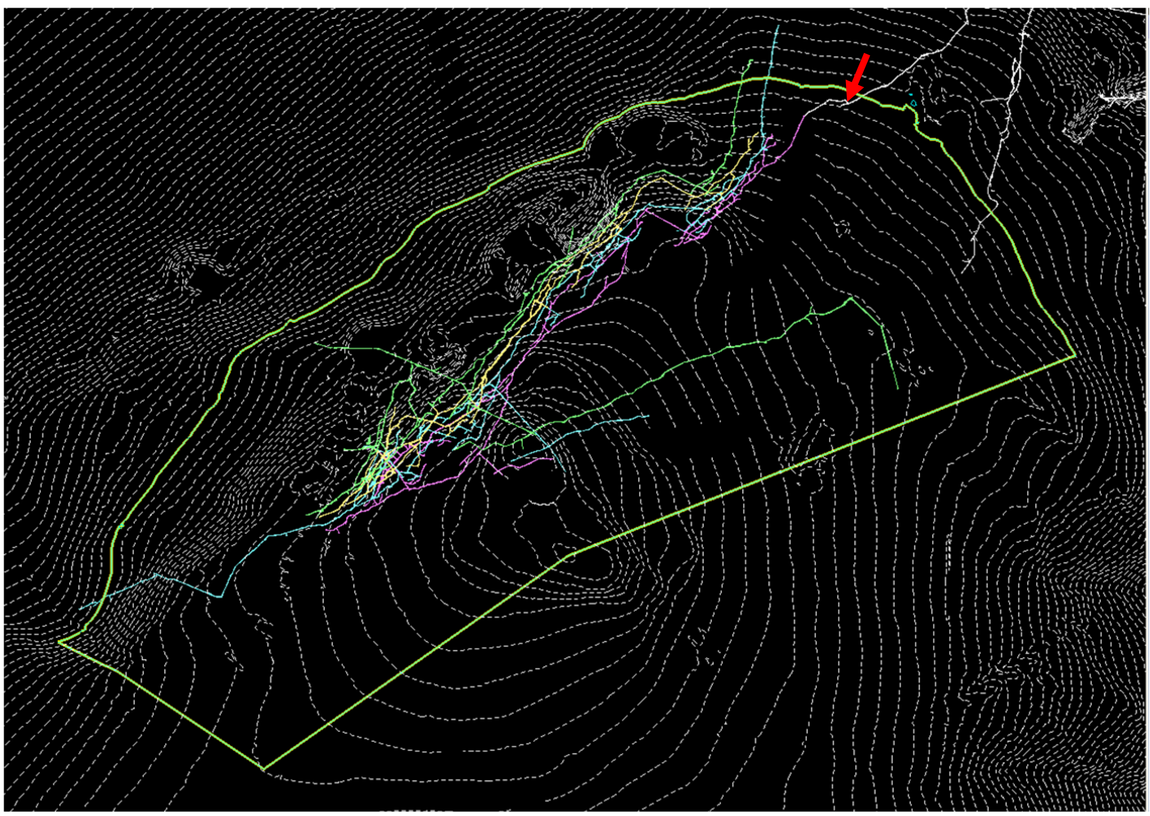

FIGURE 4. CATCHMENT AREA ASSUMED TO POTENTIALLY DRAIN INTO THE HECTOR CALUMET WORKINGS. AREA OF THE OUTLINED AREA IS 1,859,157 M^2. RED ARROW SHOWS H-C TO G300 CONNECTION.

The catchment area that could logically receive precipitation that could become infiltration into the mine workings is 1,860,000 m^2. This does not mean that water bearing faults with a greater catchment area don't intersect the mine and add to the mine drainage, but this analysis cannot account for those uncertainties. That said if 30% of the estimated 300 mm precipitation that falls on Galena Hill near the summit were to enter the mine, then the annual drainage from the H-C mine that were exiting from H-C 775 could be in the range of 167,000 m^3, or approximately 5.3 l/second. If we assume that some meteoric inputs such as falls into open pits is 100% captured by the mine, and increase the overall precipitation capture to 50%, these estimated drainage amounts increase to 279,000 m^3 or 8.85 m^3/second.

This calculated flow is a significant fraction, approximately 50-80%, of the annual drainage treated at Galkeno 300. However, as noted above, the concentrations of metals in the H-C mine pool may be substantially higher than the drainage treated at G300, and the other water entering the Galkeno 300 mine may primarily act as dilution water. If this calculation is accurate, effective pretreatment in the mine pool may substantially reduce or even eliminate the need for treatment at Galkeno 300.

2.1.3. Characteristics of the Hector Calumet Mine Pool

Examination of Figure 1 and inferring that the overflow of the H-C pool out the 775 level into Galkeno 300 level leads to the conclusion that there is a mine pool of substantial size in the H-C mine, and that there is a substantial proportion of the mine that is currently unsaturated. By assuming standard size tunnels on each level and interpolating vein thickness from mine records, Alexco developed the following volume estimates associated with each mine level (Table 2).

TABLE 2. HECTOR CALUMET MINE POOL VOLUMES AND RESIDENCE TIMES CALCULATIONS

H-C Mine Level	Volume (ft^3)	Volume (m^3)	Cumulative Volumes	Pool Residence Time (5.3 l/s)*
100 level	1,360,000	38,080	Mine void volume above Hector 400 adit=6,580,000 ft^3 or 184,240 m^3	
300 level	2,460,000	68,880		
400 level	2,760,000	77,280		
525 level	2,480,000	69,440	Potential additional pool volume = 5,530,000 ft^3 or 154,840 m^3	154,840/116.2 m^3/d = 1333 days or ~3.6 yr
650 level	3,050,000	85,400		
775 level	2,600,000	72,800	Mine pool volume = 14,200,000 ft^3 or 397,600 m^3	397,600/116.2 m^3/d = 3,420 days or ~9.4 yrs
900 level	5,950,000	166,600		
1040 level	4,900,000	137,200		
1165 level	750,000	21,000		
Totals	26,310,000	736,680		

*It is recognized that this is an averaged number of an estimated volume; residence times on particular levels may vary greatly.

Based on these calculations, the residence time in the mine pool is at least several years, and may be 10 years or more. If the 525 and 650 levels were to be flooded, the incremental volume added to the mine pool may allow for several more years residence time to be added. This additional volume would likely take several years to fill.

The Galkeno 300 adit did not have any water flowing from the adit until a significant flow was discovered in 2004. There have been a number of hypothesis on why the Galkeno 300 suddenly began to produce water in the 7 – 10 lps range after it had remained dry for a number of decades. Given the fact that the Hector Mine pool is estimated to have several years of retention and has not been in operation for at least 30+ years, it is unlikely that the mine pool finally filled in 2004 and began reporting to the Galkeno 300 adit. A more likely explanation that has been offered previously is that a ground fall occurred in the Galkeno 300 adit and resulted in water being diverted out the adit rather than previously directing it to the Sime X-C and eventually into the Galkeno 900 system through the McLeod fault system.

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2.1.4. Connection of Hector Calumet Workings with No Cash Drainage

As noted in the discussion of Table 1, No Cash 500 drainage represents the second most significant discharge of zinc to the environment in the Keno Hill district. The proximity of the mine to the H-C workings and the suggestion that the Jock Fault and the No Cash Fault are the same or related faults, provides an explanation of a route of subsurface transport of drainage from H-C to No Cash mine.

The assumed elevation of the mine pool in H-C mine is 1149.8 m. The elevation of No Cash 100 adit at portal is 1075.3 m, or approximately 75 m lower. The elevation of No Cash 500 at the portal (mapped by the bench adjacent to the portal) is 955 m. There is currently no pool at No Cash because the 500 level is the lowest level in the mine. As a consequence, there is a lot of hydraulic head capable of driving flow from the H-C pool to the No Cash mine through the Jock/No Cash Fault system. However, the distance separating the mine pool at H-C from the No Cash mine workings is several kilometers, which is ample distance to provide for flow resistance due to lower permeability zones and attenuation of mass migration from the H-C mine pool toward No Cash during passage through country rock. Consequently it is impossible to say definitively the contribution of the H-C mine pool to the mass flux from the No Cash mine. Figure 5 illustrates the elevation of the Hector 775 level and the No Cash 100 level (the closest potential connection point) and the Jock Fault connected to the H-C mine and No Cash Fault connected to the No Cash mine.

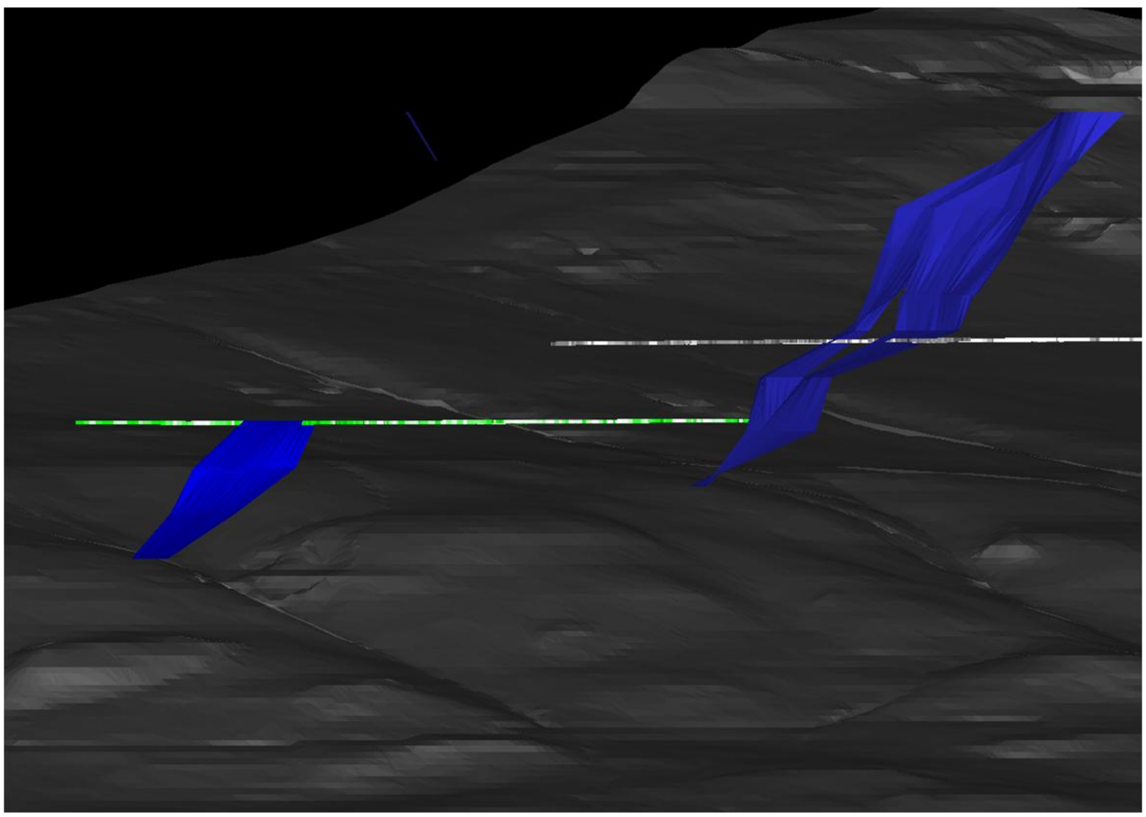

FIGURE 5. THE NO CASH FAULT (BLUE LOWER LEFT), NO CASH 100 LEVEL (GREEN), HECTOR CALUMET 775 LEVEL (PURPLE), AND JOCK FAULT (UPPER RIGHT).

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2.1.5. Discussion Related to Hector Calumet System

The direct connection of the H-C 775 level to the Galkeno 300 level and the recharge assessment, combined with the overall disturbance associated with the H-C mine, provide strong circumstantial evidence that the mine pool at H-C is the dominant mass loading and flow that currently requires treatment at Galkeno 300 portal. The connection with Galkeno 900 and No Cash 500 drainage is less direct and requires flow through natural faults/fractures that provide opportunity for attenuation of metals prior to discharge.

Figure 6 illustrates a summary of some key features of the Hector Calumet connections with other mines in the northeast end of Galena Hill. The connectivity of the H-C mine pool to the main long term closure cost of the Keno Hill mine district, i.e., long term water treatment at Galkeno 300, points to the benefit of directly managing the H-C pool, potentially with source control technologies including mine pool treatment.

Isolation of the H-C mine pool from the Galkeno 300 would not be easy. A hydraulic bulkhead installed in the area of connection between the two mines would be an engineering challenge due to its depth (approximately 180 meters below ground surface at the connection, 1330 m at surface, 1150 m at connection). Installation of a hydraulic bulkhead within the Galkeno 300 level tunnel that connects to H-C 775 level would require over 2 km of mine adit rehabilitation. Both of these would be costly.

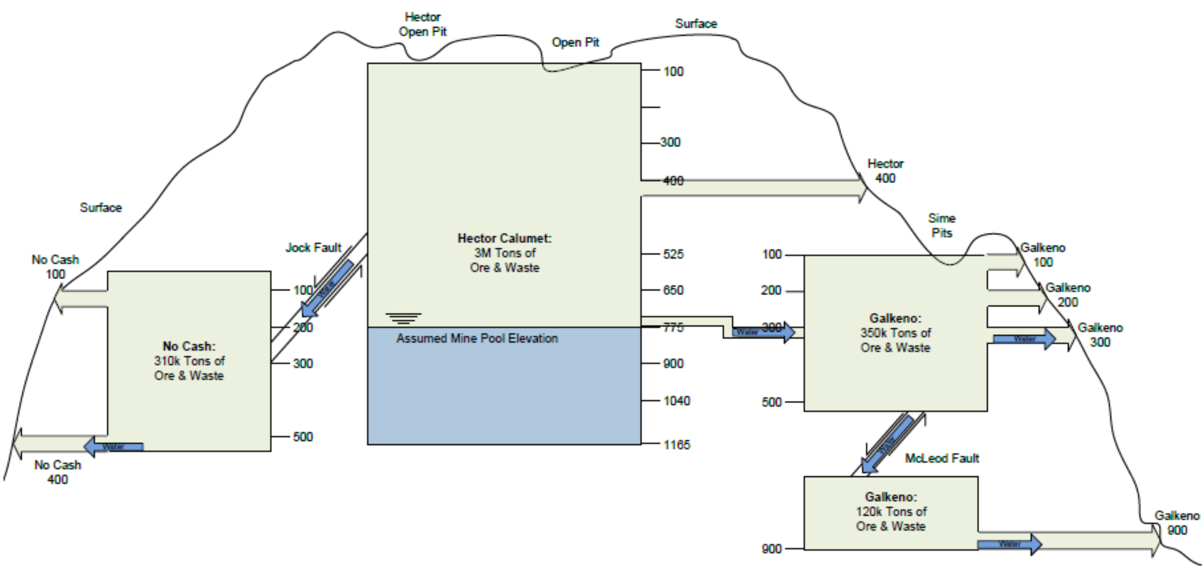

FIGURE 6. SIMPLE ILLUSTRATION OF THE RELATIONSHIP OF THE HECTOR CALUMET MINE SYSTEM WITH OTHER GALENA HILL MINES. ELEVATIONS ARE NOT TO SCALE.

However, the potential benefits of isolation of the H-C pool are numerous:

- Several years hydraulic residence time in the H-C mine pool provides ample opportunity for mine pool treatment either by alkaline or organic carbon reagent addition. Source control within the H-C mine pool would allow natural leakage from H-C to no longer contain high concentrations of metals that may alleviate the need for active treatment at Galkeno 300, and perhaps reduce metals loads at Galkeno 900 and No Cash 500.
- Mine pool filling could allow flow from the H-C mine to discharge from the Hector 400 adit, which could allow placement of an active water treatment facility, if chosen as a

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closure option for the district, on the Elsa side of Galena Hill, rather than at the difficult to access and maintain Galkeno 300 end of Galena Hill. Gravity drainage from Hector 400 could also be combined with No Cash 500 in a single pipe or other drainage way to bring the drainage to a more easily managed location with better access, including passive treatment options on the broad flat areas in the bog areas below No Cash.

- Flooding the additional levels in the mine pool could provide short term changes to water quality due to oxidation products in the mine levels dissolving into the mine pool. However, flooding mine workings typically by itself significantly reduces long term loading from mines. For long term closure, increasing the H-C pool to at least the 400 level could reduce long term operational costs, and may also allow for lower capital costs for a treatment system if the mass loading were lower due to the reduction in oxidation processes.
- Utilization of the H-C mine pool for storage could allow for seasonal treatment campaigns that would operate in months where operational costs are lower due to warmer temperatures.

In conclusion, Alexco recommends further assessment of the H-C mine pool to evaluate the costs and feasibility of isolating this mine pool from the other mine systems on Galena Hill.

2.2. GALKENO MINE SYSTEM

The clear likelihood of influence of the H-C mine pool on the Galkeno 300 drainage is discussed in Section 2.1. The other factors that affect the potential for an adit plug to be installed in Galkeno 300 are discussed in this section.

The Galkeno mine immediately connected to the Galkeno 300 adit drainage is depicted in Figure 7.

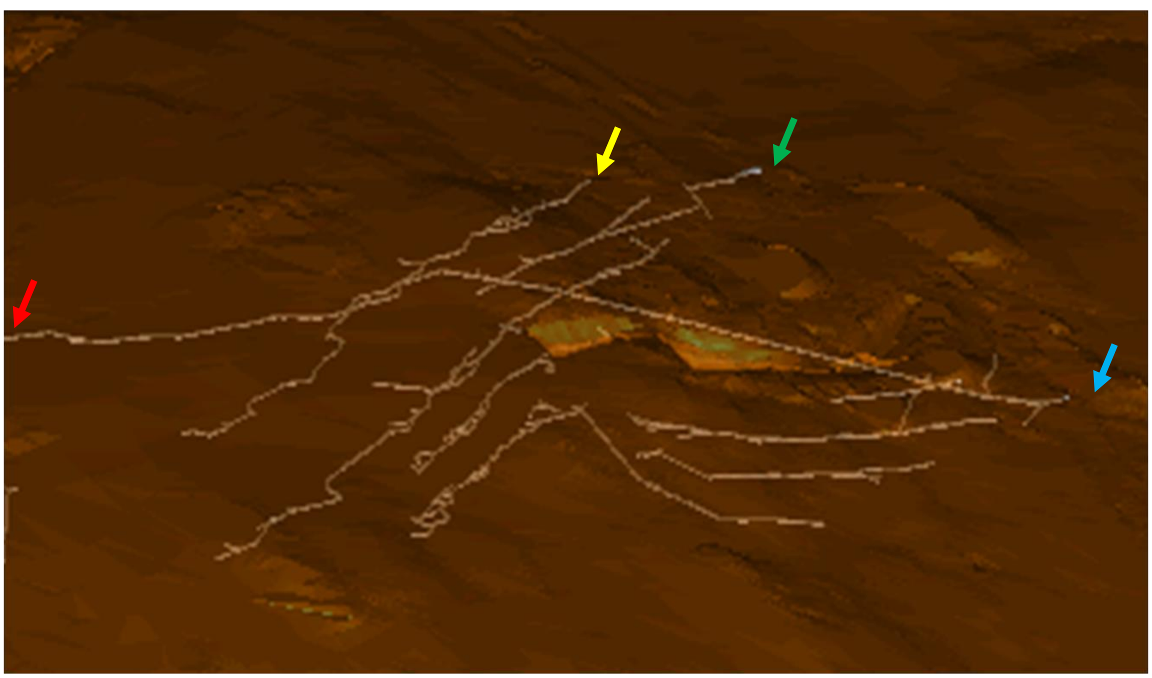

FIGURE 7. GALKENO MINE WORKINGS. BLUE ARROW IS LOCATION OF GALKENO 300 ADIT, GREEN ARROW IS 200 ADIT, YELLOW ARROW IS 100 ADIT, AND RED ARROW IS APPROXIMATE LOCATION OF CONNECTION WITH H-C MINE. NOTE EXTENSIVE PITS ABOVE GALKENO 300.

2.2.1. Adit Plug Factors for Galkeno 300

The potential for an adit plug at Galkeno 300 is affected by the many surface connections near the Galkeno 300 portal. Key openings and their elevations are listed below in Table 3.

TABLE 3. KEY FEATURES AND ELEVATIONS NEAR GALKENO 300.

Feature	Elevation (m)	Elevation above G300 Portal
Galkeno 300 portal	1128.0 m	
Hector Calumet 775 level	1149.8 m	21.8 m
Galkeno 200 portal	1165.5 m	37.5 m
Galkeno 100 portal	1201.1 m	73.1 m
UN adit portal*	1184 m	56 m
Sugiyama Pit bottom elevation	1155 m	27 m
Sime East Pit	1195 m	67 m
Sime West Pit	1240 m	112 m

* UN workings do not seem to be connected with Galkeno workings.

As can be seen from Table 3, the first main surface discharge location if Galkeno 300 were to be plugged with a hydraulic plug is the Sugiyama pit approximately 27 meters higher than the G300. However, the elevation of the H-C 775 level is lower than the Sugiyama pit, indicating that the water would likely back up into the H-C mine if Galkeno 300 were to have an adit plug installed. Examination of the Galkeno longsection (Figure 8) shows that there are workings and stoping near the base of the Sugiyama and Sime pits off the 200 level, making a surface pit filling a likely scenario if G300 hydraulic adit plug were to be installed.

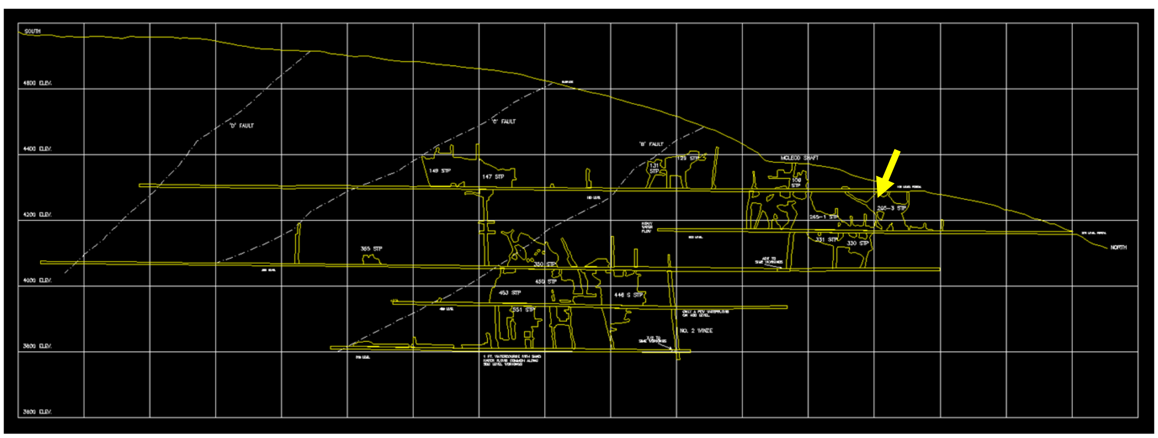

FIGURE 8. GALKENO LONGSECTION, SHOWING 5 LEVELS OF WORKING AND EXTENSIVE INTERCONNECTIONS BETWEEN LEVELS NEAR THE BASE OF PITS. YELLOW ARROW IS GENERAL PROJECTED AREA OF SUGIYAMA AND SIME EAST PITS.

Calculation of the residence time of Galkeno 300 discharge in the Galkeno workings is not a simple problem. The potential for backfilling water into Hector Calumet mine through the 775 level is likely. Prior to water continuously discharging from Galkeno 300, Dan Cornett and others observed a significant flow coming from Galkeno 300 level and cascading down the Sime crosscut. The discharge location for the Sime crosscut is likely to the lower Galkeno and Sime workings, and eventually through Galkeno 900 adit or surface seeps that are extensive on the East end of Galena Hill. However, the historic mass loading from Galkeno 900 is not anywhere close to the mass loading from Galkeno 300 since it began continuously discharging in 2002-3.

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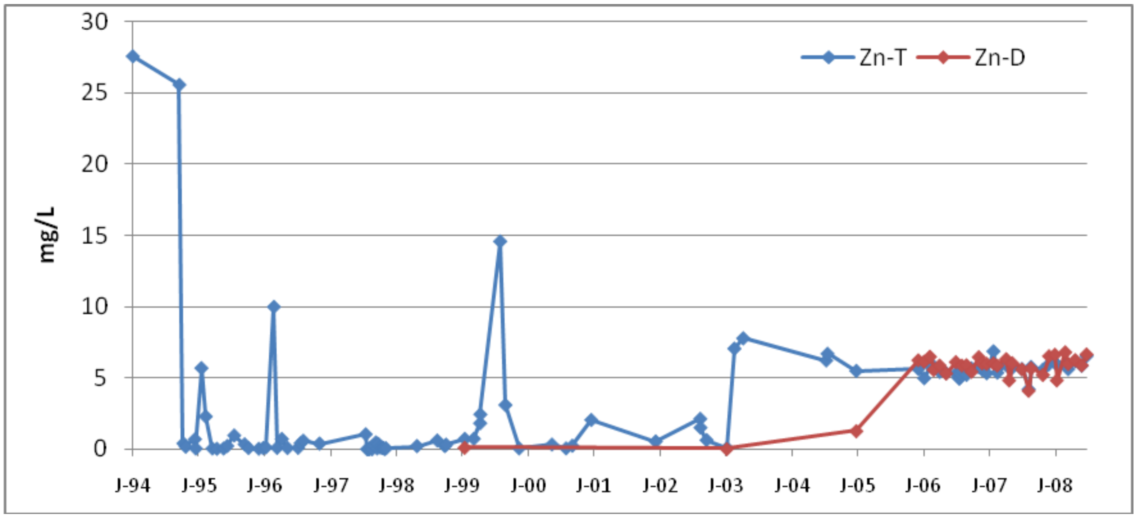

FIGURE 9. GALKENO 900 ZINC CONCENTRATIONS OVER TIME.

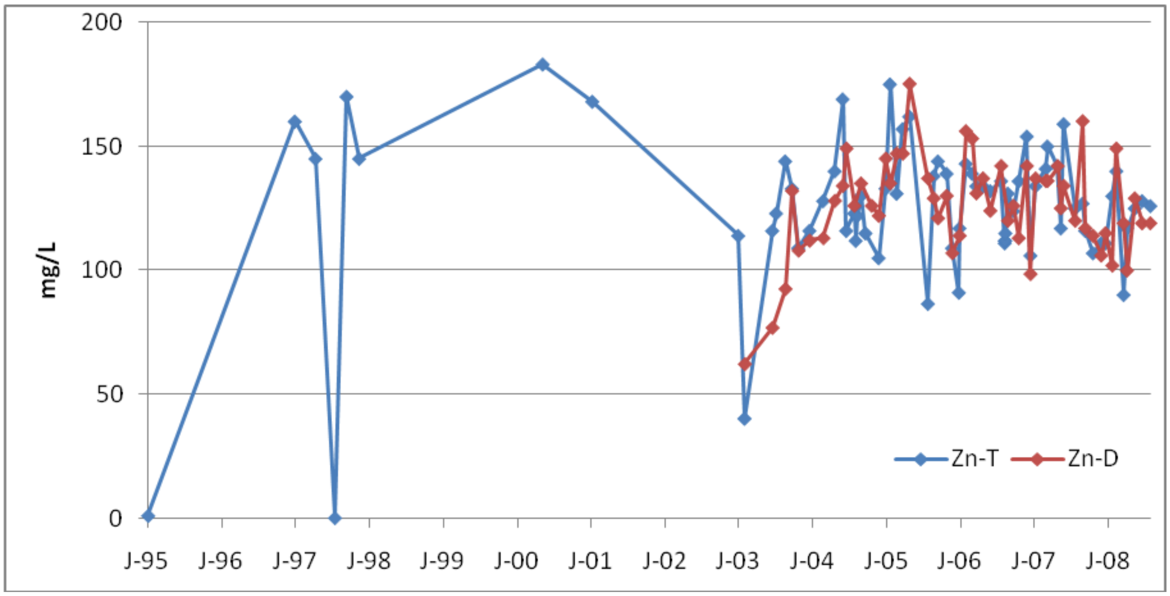

FIGURE 10. GALKENO 300 ZINC CONCENTRATIONS OVER TIME. NOTE GALKENO 300 ONLY HAD INTERMITTENT SEEPAGE PRIOR TO 2002/2003.

The likely locations for drainage from Galkeno 300 to go if a hydraulic adit plug were installed are in order:

- Filling into lower Galkeno 400/500 levels, Sime 400 and 500 levels, and potentially through faults into Galkeno 900 adit.
- Backfilling into the Hector Calumet 775 level.
- Filling into Sugiyama pit.
- Galkeno 200 portal.
- Sime East Pit.
- Galkeno 100 portal.

It should be recognized that the extensive workings near the surface around Galkeno 300 portal make placement of a hydraulic plug that would back water up any significant distance or height highly uncertain as to effectiveness, with the potential for fugitive flows to become a bigger issue around the Galkeno 300 area.

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It is our preliminary conclusion that an adit plug should not be considered for Galkeno 300 that would back water up more than 20 meters. The amount of additional residence time that would be gained by installing that type of plug could be great (if all of the discharge were to then come out of Galkeno 900). Alternatively, once the lower Galkeno and Sime workings were filled, the volume of the potential pool on the Galkeno 300 level would be limited to the stoping and adit volume on the 300 level. Crude estimates of this volume are in the range of 30,000 m^3, which would give a residence time of approximately 1 month at the average flow rates from the Galkeno 300 adit. It may help manage springtime freshet flows but beyond that it is uncertain if it would have any long-term value.

2.2.2. Adit Plug Options for Galkeno 900

The 1996 Site Characterization Report has extensive discussion of the existing adit plug in Galkeno 900. One option for consideration for additional management of flow out of the Galkeno 900 adit is installation of a second plug, which could reduce fugitive flows around the existing plug by an order of magnitude or more. While this would reduce point source flows to a manageable level (existing flow from Galkeno 900 is in the range of 4 l/s) that could potentially be treated in a passive treatment system, it should also be recognized that there are many mapped and unmapped seepage locations on the eastern end of Galena Hill, and that the additional plug may redirect additional flow to these surface seeps.

2.3. No Cash Mine

No Cash mine has surface drainage in the range of 5-10 l/s discharging from the 500 level adit. Other significant surface potential drainage points include No Cash 100 adit. The elevation of the 500 adit is 955 m, and the elevation of the 100 adit is 1075.3 m. The No Cash workings are depicted in Figures 11 and 12.

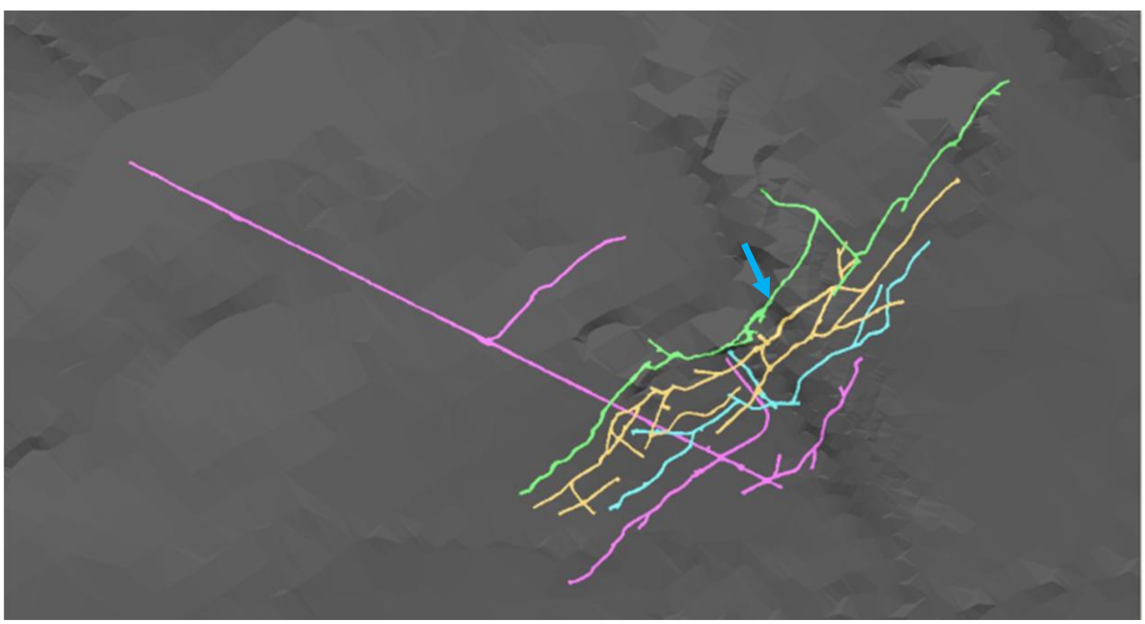

Figure 11. Plan view of No cash workings. 500 level portal is upper left. 100 level– green, 200 level– orange, 300 level—teal, 500 level— magenta. Blue arrow shows location of surface stream near 100 level workings.

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A significant feature of the No Cash workings is the close proximity of a stream that passes over the top of the workings. 100 level workings come close to the surface near the stream, making recharge of the stream into the mine a significant likelihood in the future. The volume of drainage from the mine is not consistent with the relatively small area of the mine, pointing to either surface recharge or to connections with faults or other features that provide significant subsurface recharge. The drainage from No Cash is representative of several km^2 recharge by surface precipitation, far greater than the area of the mine. It is reasonable to believe that rerouting or lining the stream that passes over the mine workings would substantially reduce the discharge rate from No Cash mine.

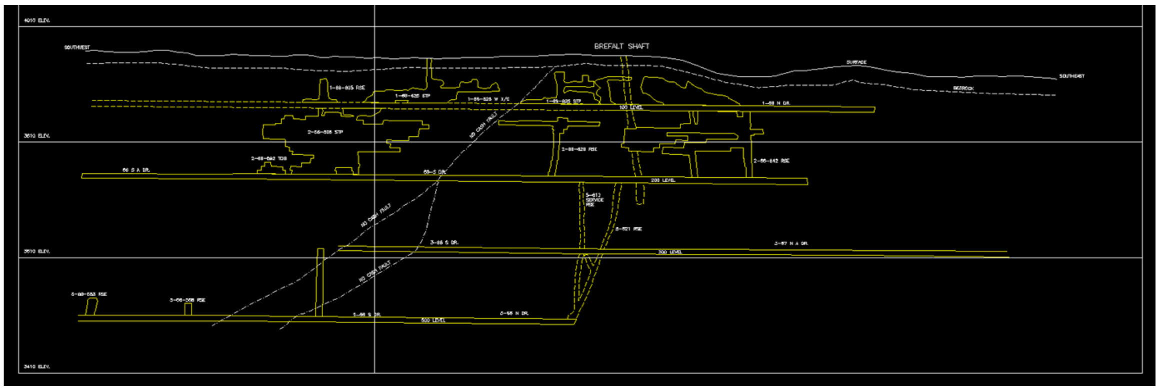

FIGURE 12. NO CASH MINE LONGSECTION. NOTE 100 LEVEL WORKINGS NEAR SURFACE. 500 LEVEL ADIT CONTINUES 3000 FEET OFF TO THE LEFT OF THE FIGURE.

No Cash mine is a candidate for a hydraulic adit plug. There are approximately 3000 feet from the 500 level portal until significant workings are encountered, which could allow for a hydraulic plug of significant length to be constructed. The 120 meters of difference between the 100 and 500 levels and the volume of rock removed from the mine provides the potential for substantial residence time to be achieved in the mine pool. With the assumption of 4 tons/m^3, and 80% of the mine workings that could be flooded, there are 33,300 m^3 available to be filled. At an average flow rate from No Cash of 6 l/s (Figure 13), the residence time that could be achieved in the No Cash workings is approximately 60 days.

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FIGURE 13. FLOW AND ZINC CONCENTRATION FROM NO CASH 500 ADIT.

Another fruitful area of investigation would be to see if diversion and lining surface stream(s) that cross No Cash workings would reduce flow from the mine. The potential for managing the mine drainage within the mine could be substantially improved if the flow rate could be decreased.

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3. SILVER KING MINE

Key features and elevations of the Silver King Mine are listed in Table 4.

TABLE 4. SILVER KING FEATURES AND ELEVATIONS.

Feature	Elevation	Difference from Discharge Elevation
100 adit at portal	745.7 m	
100 adit at 300 decline	747.0 m	-1.3 m
100 adit at 4-6 vein end	748.8 m	-3.1 m
75 adit at portal	765.5 m	+ 19.8 m
200 level	728.8 m	-16.9 m

The 100 level of Silver King connects to the 300 level on the #4, #5, and #6 veins. There is also a 100 level on the #1 and #2 veins that is not directly connected in the mine plans to the 100 level on the #4-#6 veins. The discharge directly flows from the 100 adit associated with the #4, #5, and #6 veins. This may represent two largely separate pools. The 100 level on the #1 and #2 veins is closely connected to the surface pit.

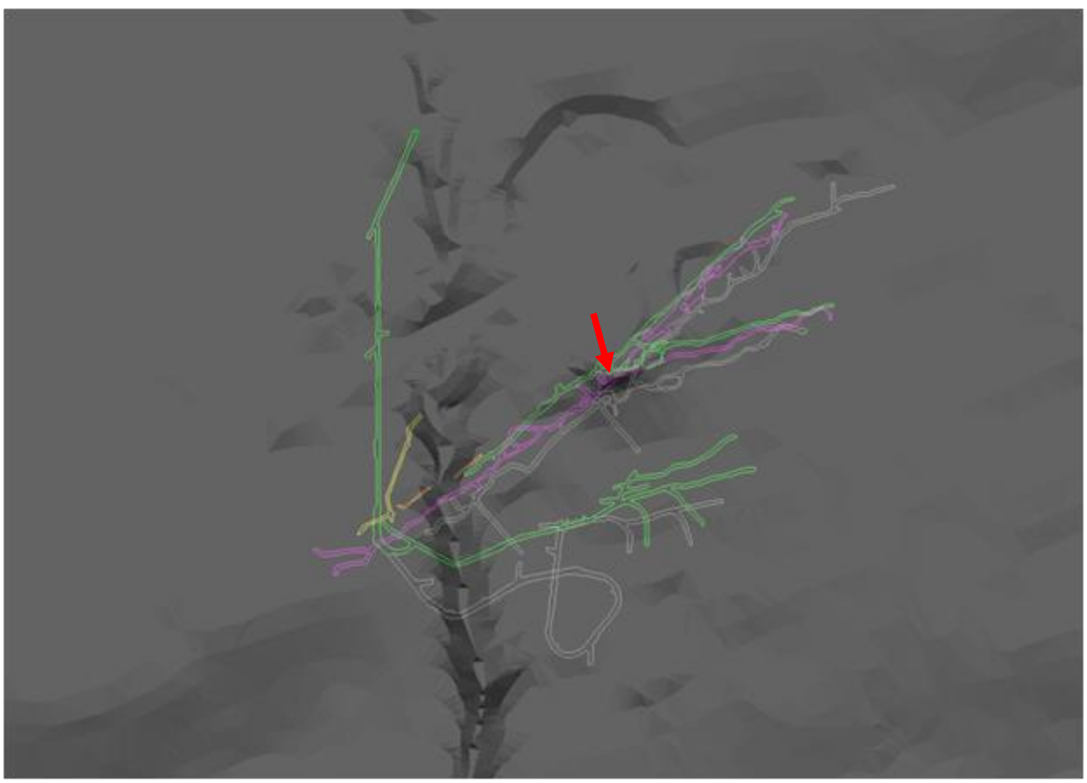

FIGURE 14. SILVER KING MINE WORKINGS, PLAN VIEW. 50 LEVEL– ORANGE, 75 LEVEL– YELLOW, 100 LEVEL– GREEN, 200 LEVEL– MAGENTA, 300 LEVEL—GREY. SILVER KING 100 ADIT IS TOP OF PICTURE. #1 AND #2 VEINS ARE WORKINGS NEAR THE TOP OF MINE WORKINGS (RED ARROW—WHICH IS ALSO LOCATION OF SURFACE PIT), #4, #5, AND #6 VEINS ARE TOWARD THE BOTTOM. NOTE GALENA CREEK CUTS IMMEDIATELY OVER THE MINE WORKINGS.

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If a hydraulic adit plug were installed, water would be backed up into the 100 level into the 4-6 vein area, and would eventually fill in the shaft that connects the 75 level to the 100 level. If water were to be backed up 19.8 meters, water would emanate from the 75 level.

It is unclear if there is direct hydraulic connectivity between the 100 level at the portal and the 100 level at the pit (Figure 14). As can be seen in Figure 15, there is not a direct connection in the mine records between the 100 level on the east side of Galena Creek and the 100 level on the west side of Galena Creek.

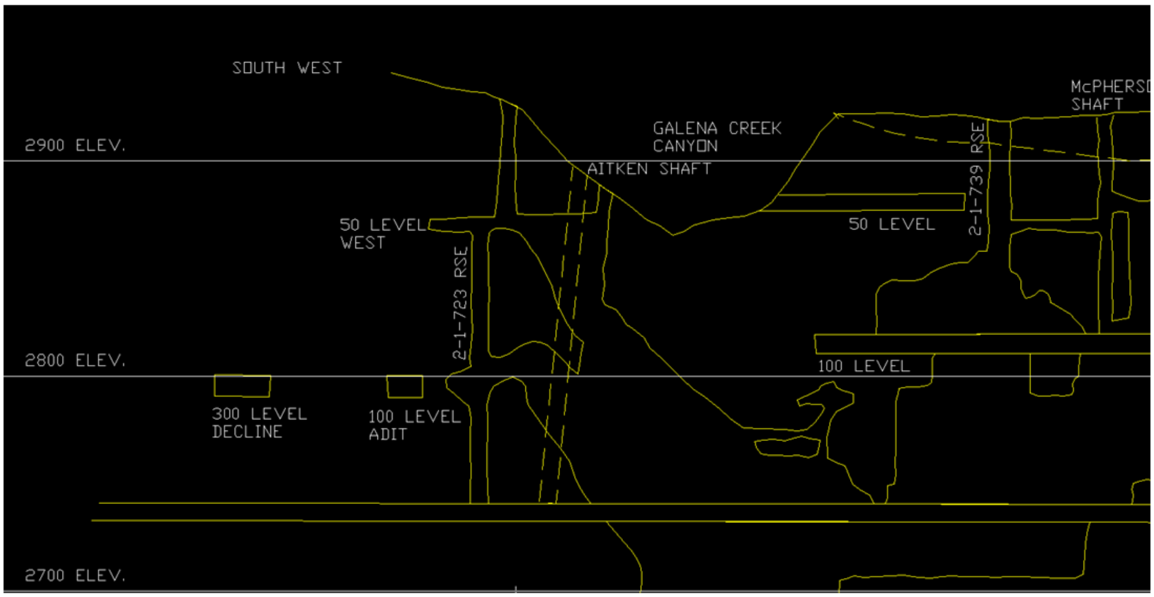

FIGURE 15. CLOSE UP OF SILVER KING LONGSECTION.

Similar to No Cash, the most significant issue affecting long term management of mine water behind an adit plug is the apparent close connection of Galena Creek with Silver King Mine. The very low concentrations of metals in Silver King mine may be partially due to a large component of surface water recharge, and also that the 100 adit may only drain the part of the mine associated with the #4, #5, and #6 veins. The recent average discharge rate from Silver King 100 is 5 l/s, a flow rate equivalent to half of Galkeno 300 discharge. This flow rate represents a much larger catchment than the area of the Silver King mine workings. Using 30% subsurface recharge rates and precipitation representative of the Silver King mine elevation, approximately 2 km^2 is the expected recharge area to produce 5 l/s. If the open pit were connected to the discharge from the adit, approximately 1.8 l/s could be produced if the open pit represented a 100% recharge basin. However, as noted before, the mine maps do not show a direct connection of the Silver King pit with the 100 adit discharge.

If a hydraulic plug were installed in Silver King the mine location that would receive discharge is the 75 level adit, almost 20 meters higher. However, the base of Galena Creek is lower than this level, making the first discharge location likely fugitive flow to the creek base. It is unlikely that there is enough residence time that could be created in the mine workings at a flow rate of 5 l/s to provide anything more than an opportunity for some in situ treatment; it is not a candidate for a storage and campaign treatment.

However, the 75 level adit may provide an ideal location for reagent addition, where the approximately 320 m length from the portal to the connection with the 75 level would provide some reaction time for treatment and settling of metal precipitates. The adit volume in this area

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may be in the range of 3,000 m^3, or approximately 1 week of potential residence time at 5 l/s. This is a typical range of some bioreactors' residence time.

FIGURE 16. NOTE ADIT DISCHARGE NEAR PONDS (AT TOP OF PICTURE), GALENA CREEK LOCATION (GREEN ARROW), SILVER KING PIT (RED ARROW).

Figure 17 shows a simple illustration of the Silver King system. This is a largely flooded mine already, and consequently an adit plug would not provide substantial reduction in oxidation reactions. The lack of storage volume also limits the usefulness of the mine for mine drainage storage and treatment only during warmer seasons. Therefore a hydraulic adit plug may not provide much value.

An observation of the relatively low mass loading of the Silver King mine compared to the volume of ore removed from the mine may point to several factors. One possible explanation is that the largely flooded mine limits oxidation reactions due to air exchange into the mine workings. Other explanations could include a lack of complete capture of discharge of metals from the mine from the 100 level adit, with the portion of the mine pool connected to the #1 and #2 veins emanating by fugitive flow. Elimination of surface recharge from Galena Creek may decrease the flow rate from Silver King 100, but may leave a slower discharge with the same metals load. These are factors to be assessed during the development of final closure alternatives for Silver King Mine.

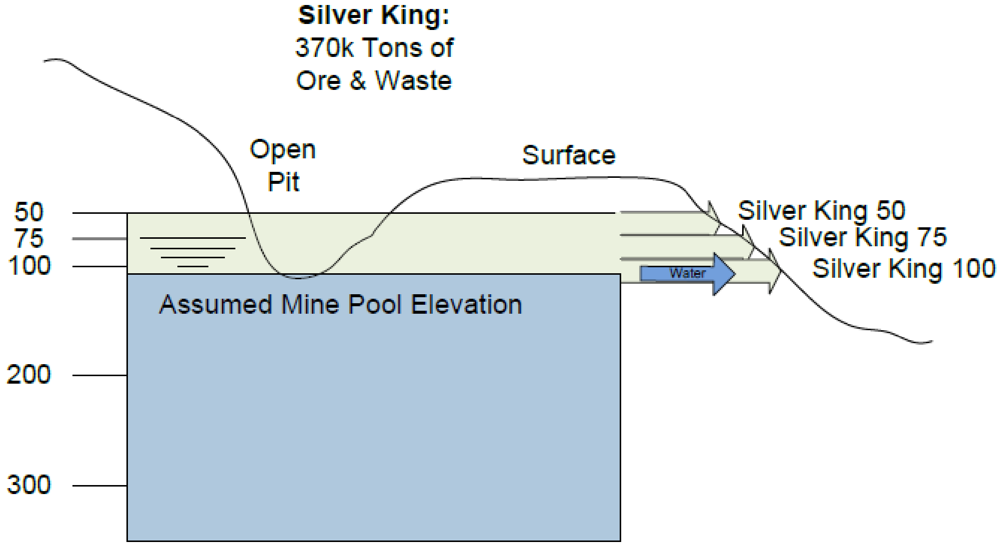

FIGURE 17. SIMPLE ILLUSTRATION OF SILVER KING MINE.

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4. ONEK MINE

Onek mine is a relatively simple mine to understand. The 400 level drains the entire mine, with 2 shafts and many raises providing ample vertical connection with the 200 and 300 levels, and the Fisher pit and 100 level immediately associated with the Fisher pit. See Figures 18 and 19.

There is very imperfect flow records associated with the Onek mine. However, the range of recorded flows is from 0.1 l/s up to 7.3 l/s. This range is consistent with freshet or stormwater rapidly transporting through the mine and reporting to the adit discharge. Assumptions of mass loading based on this sparse information indicate that Onek is a significant discharge in the Keno Hill district.

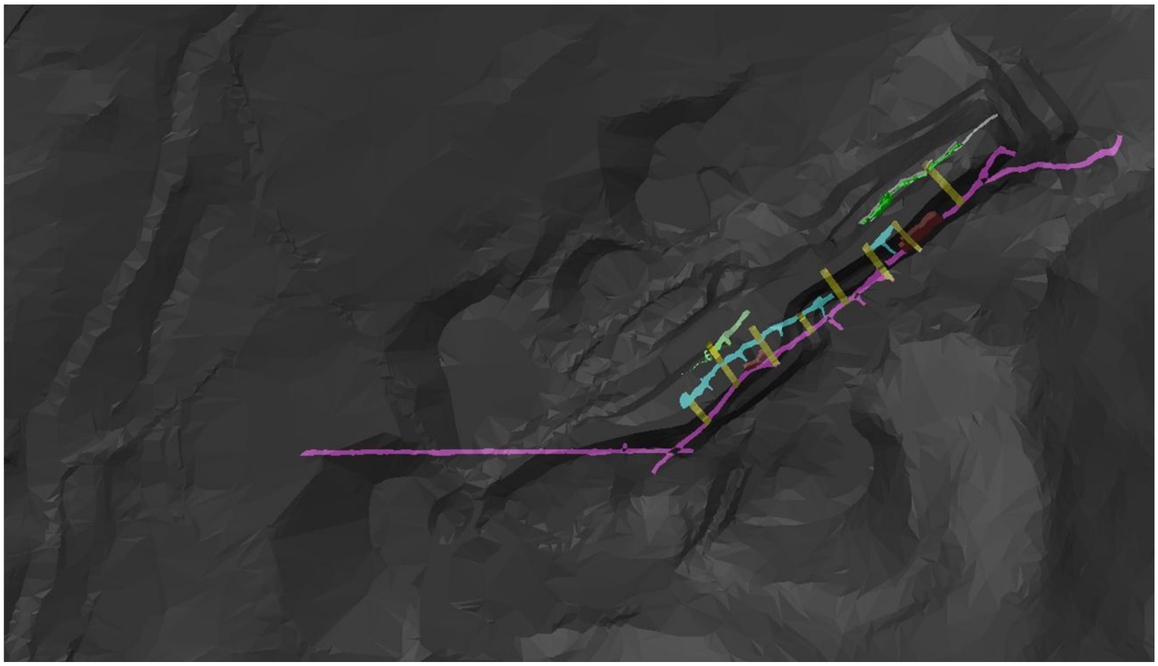

FIGURE 18. ONEK MINE SHOWING 100 LEVEL (GREEN), 200 LEVEL (YELLOW), 300 LEVEL (BLUE), 400 LEVEL (MAGENTA), RAISES FROM THE 400 LEVEL (GOLD). 100 LEVEL IS AT FISHER PIT LEVEL.

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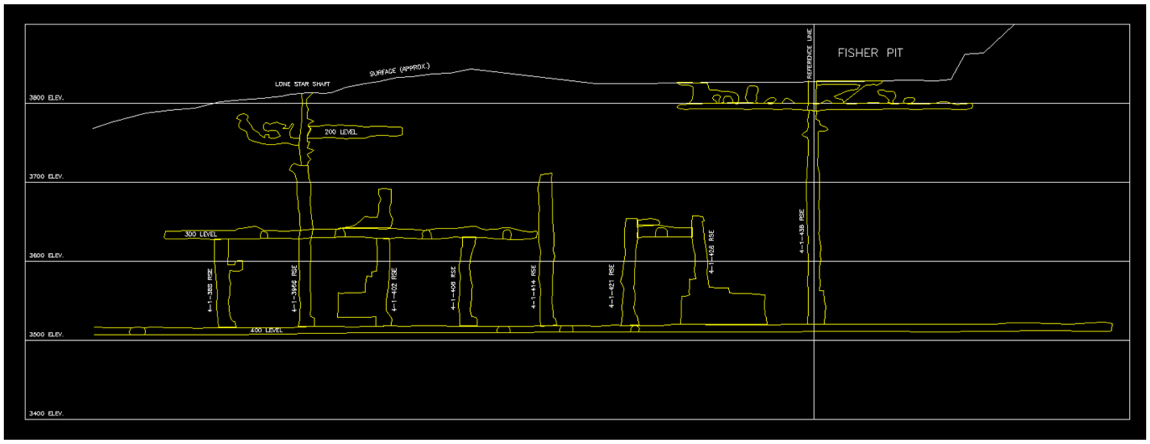

FIGURE 19. LONGSECTION OF ONEK MINE. NOTE LONESTAR SHAFT AND CONNECTIONS FROM FISHER PIT TO 400 LEVEL.

Key elevations for Onek Mine are listed in Table 5. The majority of the open space in the mine is contained in the 300 and 400 levels and associated workings. If a hydraulic adit plug were installed in the Onek mine the water could be backed up approximately 40 meters and the vast majority of the mine voids would be flooded.

TABLE 5. KEY FEATURES OF ONEK MINE.

Feature	Elevation	Elevation difference from Onek 400 adit
400 adit	963.7 m	
400 adit at end (~376 meters)	966.5 m	+ 2.8 m
Pit lowest elevation	1039 m	+ 75.3 m

The residence time in the mine pool is difficult to estimate due to the infrequent measurements of flow from the Onek adit. A conservative estimate of flow and residence time in the Onek mine is shown in Table 6, based on two weeks of high flow associated with the freshet, and 50 weeks associated with base flow. This estimate shows that half of the flow that enters the Onek mine may enter the mine during the freshet.

TABLE 6. RESIDENCE TIME ESTIMATE OF ONEK MINE IF HYDRAULIC PLUG IS INSTALLED.

Production	Ore Tons	Waste Rock Tons	Total Tons	Volume m^3	Flow Rate l/s	Total Flow m^3	Residence Time
Underground	33,036	7,500	40,536	11,259	0.2 avg, 8 freshet	6,134 + 6,912 = 13,046	11,259/13,046=0.863 years in underground
Pit	62,245	600,000	662,245				

There are several possible reasons to use a hydraulic adit plug during closure of the Onek mine. Treatment of the mine workings seems feasible given the reasonably simple layout of the mine. There are two shafts, the Fisher shaft and Lone Star shaft that connect the Fisher pit with the other mine workings. These shafts may be good locations for recirculating water and perhaps to add treatment reagents to the mine workings if the mine is allowed to fill. It may also be reasonable to use the mine to store water to be removed for treatment using an active treatment system or a wetland based treatment system operated only in the warmer season.

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Figure 20 shows a simple illustration of the Onek mine system. In summary Onek mine is a good candidate for an adit plug, with multiple reasonable closure scenarios with a hydraulic adit plug as an integral part of the closure scenario. There is a good volume of potential storage and a reasonable likelihood that an adit plug could be installed that would hold enough water to allow for a variety of treatment alternatives to be employed. In summary, Alexco recommends further investigation of an adit plug for the Onek mine.

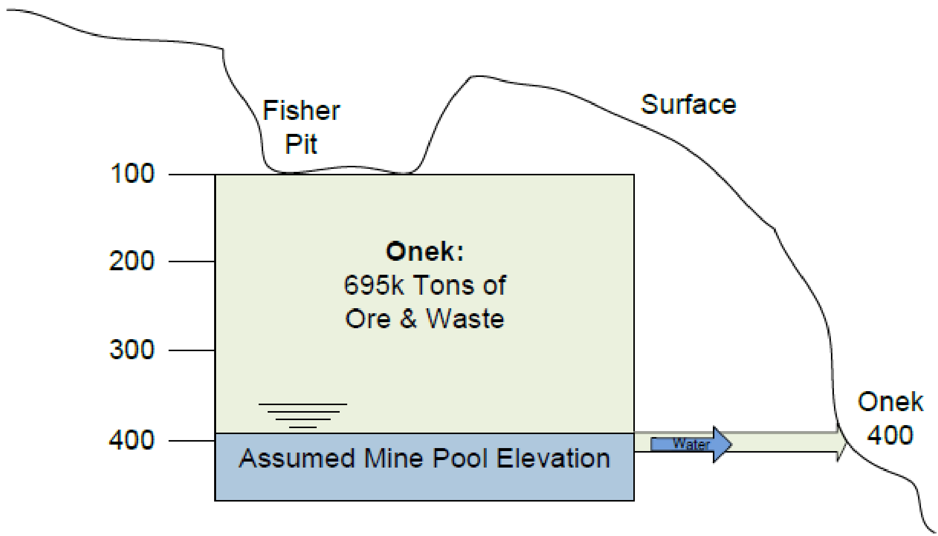

FIGURE 20. SIMPLE ILLUSTRATION OF ONEK MINE.

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5. KENO MINE

The Keno mine (Figure 21) is a large mine with many levels and interconnections with other mines on Keno Hill. Shamrock J and the Comstock-Keno-Porcupine mines have connections on the 400 and 700 levels. The Keno 700 level adit drains all of these mines to Hope gulch.

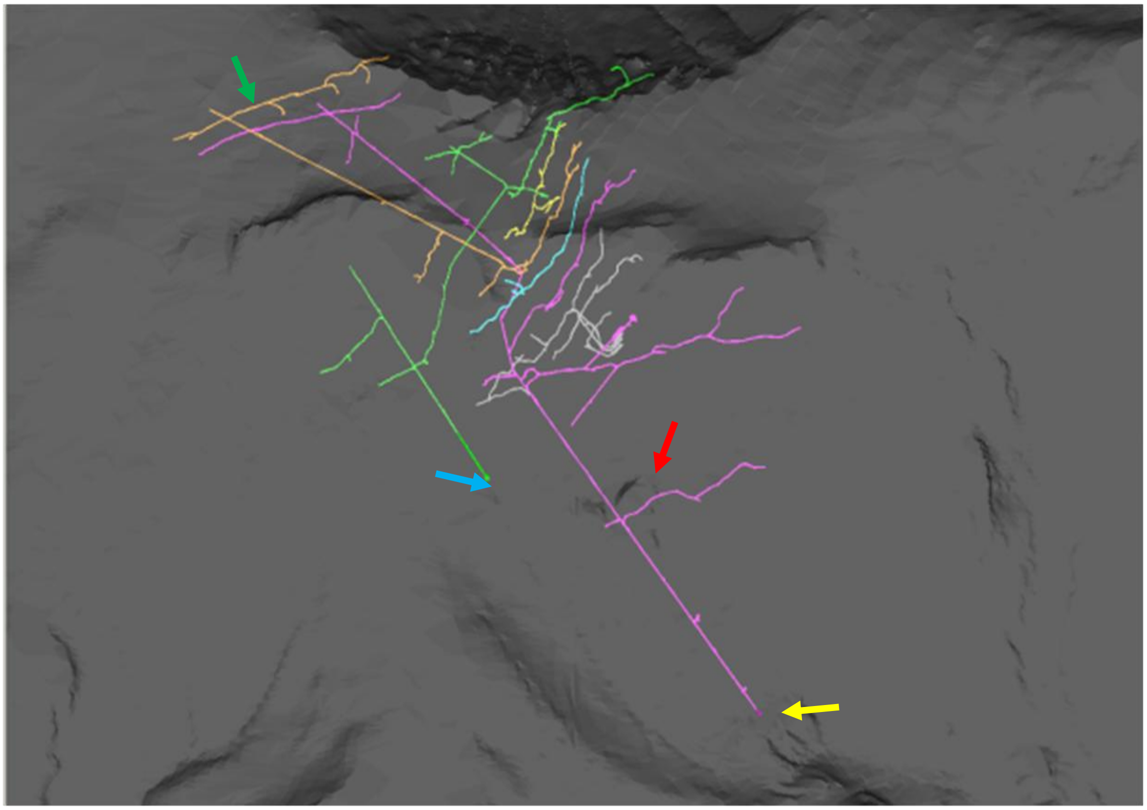

FIGURE 21. KENO MINE, SHOWING 200L– ORANGE, 300L– YELLOW, 400L– ORANGE, 500L– TEAL, 700L– MAGENTA, DEEPER WORKINGS– GREY. YELLOW ARROW POINTS TO KENO 700 DISCHARGE, BLUE ARROW POINTS TO KENO 200 ADIT, GREEN ARROW POINTS TO SHAMROCK J-18 MINE, RED ARROW POINTS TO PORCUPINE PIT.

Table 7 shows some key features and elevations. The connection of the Keno 700 level to the #14 vein makes the flooding of the Porcupine pit the first possible location of surface drainage as a result of hydraulically plugging the Keno 700. The Porcupine pit is approximately 109 meters higher than the Keno 700 adit. After the Porcupine pit, the Keno 200 on Hope gulch is 146.4 meters higher than the Keno 700 level, or 37 meters higher than Porcupine pit.

TABLE 7. KEY FEATURES AND ELEVATIONS OF KENO HILL MINES.

Feature	Elevation	Difference from Discharge Elevation
Keno 700L at portal	1470.6 m	
Porcupine pit base	1580 m	
200 adit at portal (estimated)	1615 m	
200 adit at portal on Faro Gulch	1617 m	

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There is some uncertainty about the available volume of mine workings due to uncertainty about the connections with the Shamrock J-18 mine and the Porcupine mine workings. Table 8 presents an estimate based on the volume associated with the Keno workings only. This analysis indicates that there are many months of potential storage in the Keno workings. The depth within the mountain of the primary Keno workings and the length of the Keno 700 crosscut between the vein workings and the Keno 700 portal presents good location to install a hydraulic adit plug.

TABLE 8. RESIDENCE TIME ESTIMATE OF KENO MINE IF HYDRAULIC PLUG IS INSTALLED.

Production	Ore Tons	Waste Rock Tons	Total Tons	Volume m^3	Flow Rate l/s	Total Flow m^3	Residence Time
Underground	283,557	42,100	325,667	87,729	3 avg	94,608	87,729/94,608=0.9273 years in underground

Figure 22 shows a simple illustration of the Keno mine system. In summary Keno mine is a good candidate for an adit plug, with multiple reasonable closure scenarios with a hydraulic adit plug as an integral part of the closure scenario. There is a good volume of potential storage and a reasonable likelihood that an adit plug could be installed that would hold enough water to allow for a variety of treatment alternatives to be employed. In summary, Alexco recommends further investigation of an adit plug for the Keno mine.

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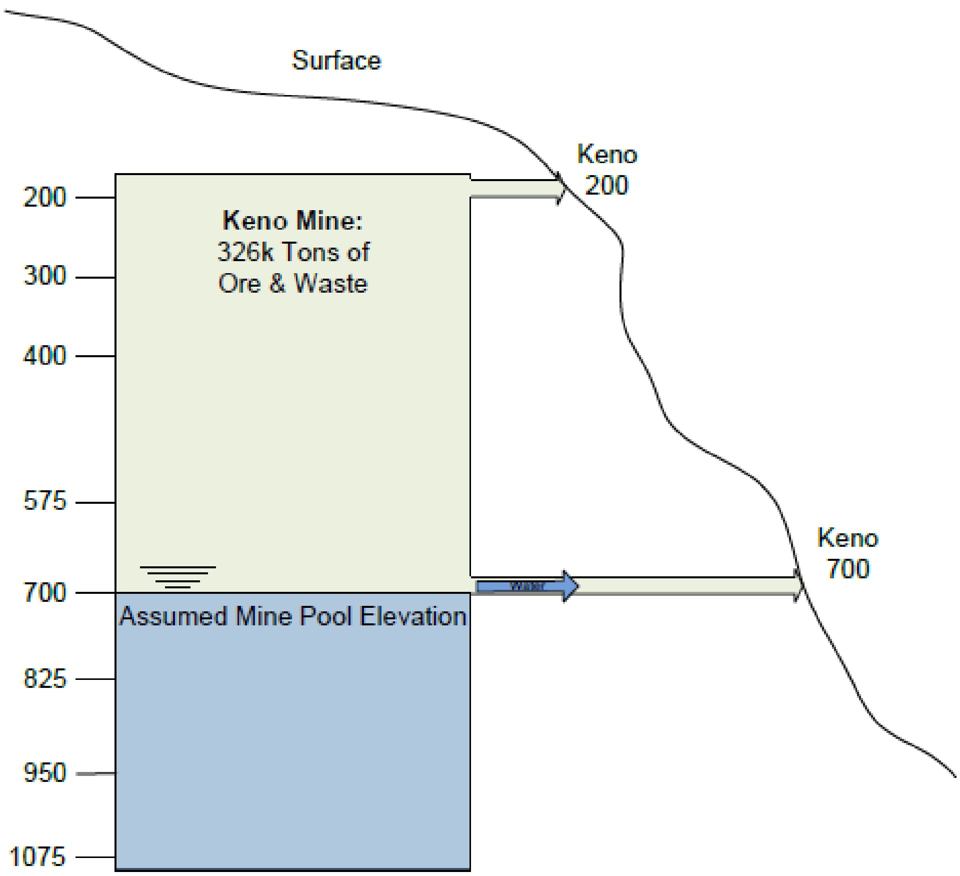

FIGURE 22. SIMPLE ILLUSTRATION OF KENO MINE.

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6. SADIE LADUE MINE

Sadie Ladue mine comprised of the Sadie Mine and the Ladue Mine which were joined together after each was started separately. There are two shafts that connect the levels on both the Ladue and the Sadie sides. The Ladue 600 level drains the entire mine, and there are many raises providing ample vertical connection in each side of the mine. Connections between the Sadie and Ladue sides occur on the 200 and 400 levels. See Figure 23.

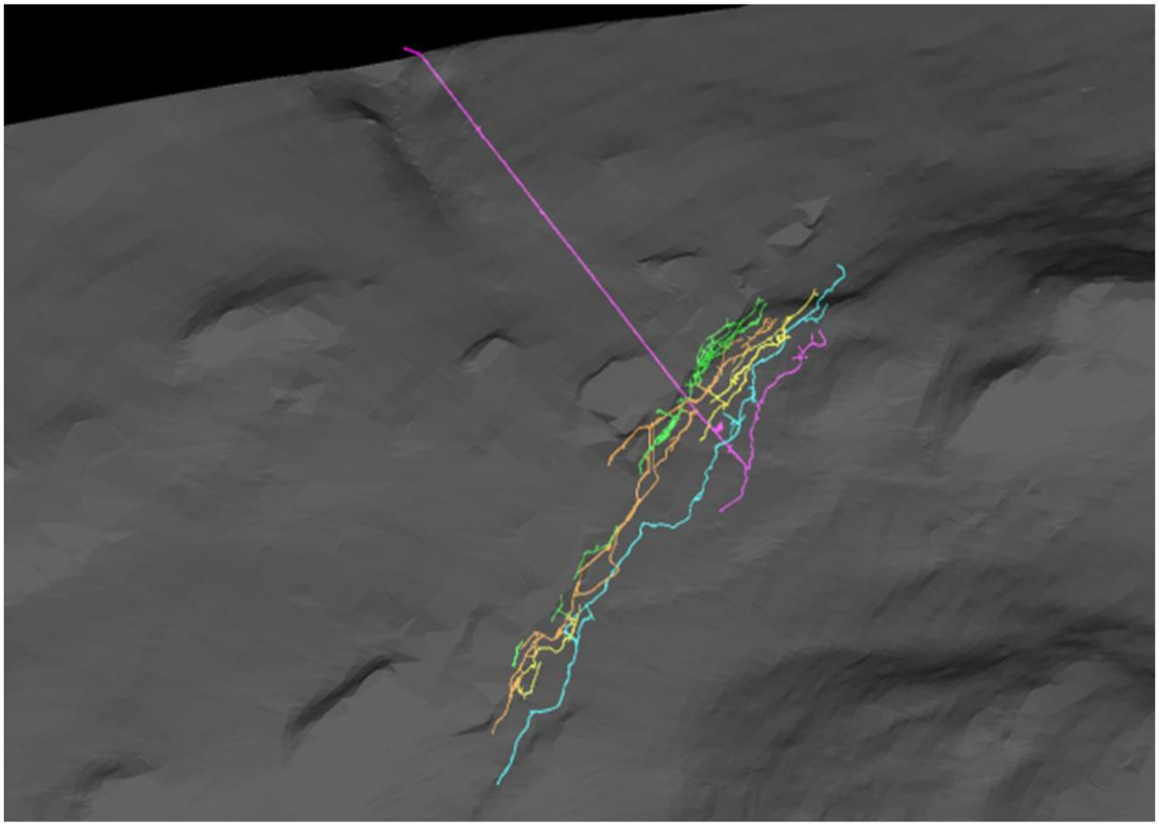

FIGURE 23. SADIE LADUE PLAN VIEW, 50L, 100L, 150L– GREEN, 200L— ORANGE, 250L, 300L—YELLOW, 400L –TEAL, 600L—MAGENTA

Table 9 presents some key features and elevations associated with Sadie Ladue mine.

TABLE 9. KEY FEATURES AND ELEVATIONS OF SADIE LADUE MINE.

Feature	Elevation	Difference from Discharge Elevation
Ladue 600 adit near portal	1118.3 m	
400 level elevation at #2 shaft	1166.7 m	+48.4
400 level at Sadie shaft	1169.6 m	+51.3
300 level at #2 shaft	1190.5 m	+72.2
200 level at #2 shaft	1214.2 m	+95.9
200 level below pit	1216 m	+97.7
100 level at #2 shaft	1235.3 m	+117
Pit	1250 m	+131.7

The long tunnel on the 600 level presents a good opportunity for a hydraulic adit plug long enough to minimize flow around the plug. The distance from portal to junction is 830 m. The

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adit near the portal has been partially collapsed and has in the past been partially plugged with ice. Similar to Onek, the data are scarce regarding flows from the adit, with a wide range of values having been measured at the mine, from 0.5 l/s to 17 l/s. The average flow rate from Sadie Ladue mine is highly uncertain, but if the estimated rate in Table 10 (averaged from 8 values over 6 years) is correct, there are only a few months of hydraulic residence time in the mine were the adit to be plugged.

TABLE 10. HYDRAULIC RESIDENCE TIME IN SADIE LADUE MINE IF HYDRAULIC PLUG WERE INSTALLED

Production	Ore Tons	Waste Rock Tons	Total Tons	Volume m^3	Flow Rate l/s	Total Flow m^3	Residence Time
Underground	244,000	44,000	288,888	78,600	12	378,400	78600/378400=0.21 yrs in underground

Figure 24 shows a simple illustration of the Sadie Ladue mine system. In summary Sadie Ladue mine may be good candidate for an adit plug, with the uncertainty regarding flow rates from the mine being a key factor affecting the usefulness of a hydraulic plug. There is a good volume of potential storage and some chance that an adit plug could be installed that would hold enough water to allow for a variety of treatment alternatives to be employed. One key factor that would affect what closure scenarios could be employed that would utilize the underground workings is the true flow rate from the mine. In summary, Alexco recommends further investigation of an adit plug for the Sadie Ladue mine that focuses on assessment of the true loading from the mine (to assess relative need of closure measures at the mine) and to determine total annual mine flow.

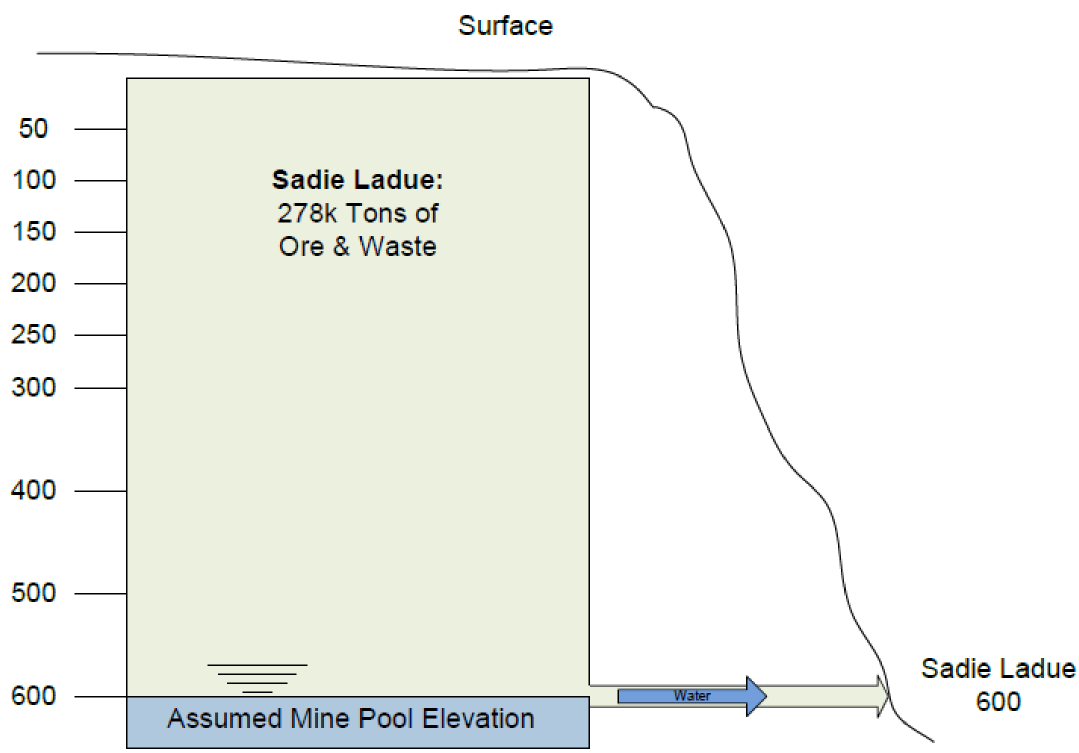

FIGURE 24. SIMPLE ILLUSTRATION OF SADIE LADUE MINE.

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7. ADDITIONAL DISCUSSION

There are several potential reasons to consider placing a hydraulic plug in a mine adit. This section discusses several reasons and issues related to them as they apply to the Keno Hill Mining District.

7.1. PREVENTION OF METALS LEACHING

Metals generation from underground mine workings is a function of oxidation and dissolution of metals from metal sulfides. This requires both air and water contact the sulfides. At the Keno Hill mining district, the drainage from the underground mines is typically neutral, but metals that are still soluble in neutral pH conditions, especially zinc and cadmium, are often elevated as a result of this process. Treatment of drainage from the underground mines discussed herein will necessarily focus on zinc and cadmium. However, other metals, including manganese and iron will affect reagent demand during treatment, and may also add to the toxicity profile of the mine drainage. Thus inhibiting the formation of metals by preventing the dissolution of metal sulfides within the mine workings is an objective that should be considered during closure. Installation of hydraulic plugs and flooding underground mine workings can be part of a closure approach that prevents metals dissolution, rather than simply relying on long term treatment.

At other mine sites with similar metals issues, flooding of historic ore bodies where successful reduced metals loading from mine workings by 65% (Brittania mine, BC) to 85% (Eagle mine, CO). While these mines had substantially different chemistry than that typically encountered in the mining district, especially far higher acidity, fundamentally the exclusion of oxygen by exchanging the voids with 20% oxygen with voids with 8 ppm oxygen saturated in water still will have a great benefit to preventing metals leaching.

There are several current discharges (Silver King, Sadie Ladue, Keno 700) whose concentrations is less than 3 mg/L on average. It is possible that by flooding these workings that in time the concentrations will decrease and will not require long term treatment simply as a consequence of flooding the mine workings.

7.2. MANAGEMENT OF PEAK FLOWS

Where water treatment is required, either active or passive, capital costs will be higher if sized to treat peak flows related to freshet. For several of the mines, flow varies by factors of 2 to greater than 10. In designing treatment systems, this variability of sizing of treatment systems will have a major effect on capital costs, requiring sizing systems for peak flows with a larger safety factor, rather than for annual mean flow with a relatively smaller safety factor. For this reason alone, hydraulic plugs must be assessed as part of an overall mine water treatment system.

It has also been observed that the overall flow from a mine will decrease with the installation of an adit plug and the flooding of a portion of the mine workings. This can be due to the reduction in head differential from water bearing features around the mine such as fractures and faults. Since flow is affected by gradient, reducing the gradient toward the mine by flooding the workings will overall decrease the recharge rate to the mine.

7.3. DRAWBACKS OF HYDRAULIC PLUGS

The one example of a hydraulic plug in the Keno Hill mining district is located at Galkeno 900. It has a leakage rate of 4 l/s annual average. Factors affecting the leakage rate include the

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competence of the host rock, steps taken to grout the rock around the adit plug, and the length of the overall plug. However, a single plug of any length if water is backed up with substantial head pressure will leak and the rate of leakage cannot be predicted with great certainty.

Several approaches can be taken to counteract this.

- One reasonable approach is to plan to have followup work to enhance the competence of the adit plug either by additional grouting, or installation of a secondary plug with lower required head.
- After a hydraulic plug is installed, the management of the height of water behind the plug can be used to understand the relationship of leakage around the plug to pressure. It is possible that leakage is faster after a threshold water elevation is reached, for example.

If the adit plug is used to manage water on a seasonal basis, dramatic changes in water elevations in the mine may be necessary to manage the flows. This can have a negative effect on the chemistry in the mine by periodically saturating and draining metal bearing rubblized rock in the mine. This can have a leaching effect on the metals in the mine unless care is taken to exclude oxygen from the mine workings.

It should also be noted that in nearly every case, the initial flooding of mine workings that have been unsaturated for some time leads to a dimunition of water quality for a period of time, from a few months to several years. In time, this effect is reversed as the avoidance of oxidation of metals becomes the dominant effect of mine pool creation.

7.4. OTHER OBSERVATIONS

Comparison of the Keno Hill mines with other mines that have had adit plugs installed has led to several other observations:

- Keno Hill mining district is a very high grade district. Consequences of this include a relatively low volume of mine workings and potentially higher grade wastes left behind. The lack of more than 1 year residence time except for the Hector Calumet system is one fact that stands out from this study.
- Beyond the scope of this assessment were mine dewatering records which could help understand true recharge rates. It would be useful to study these records and the filling rate of especially the Hector Calumet system to provide a second check on estimated flow rates from this system.
- There is extensive fugitive flow described in some areas, and suspected in other areas. The effect of mine filling on creating or enhancing non-point source pollution is a concern that should be considered at every stage of the closure planning process.

7.5. POTENTIAL FOR IN MINE TREATMENT

This author has participated in more than 15 in mine pool treatment projects, including pit lakes and underground workings. It is my opinion that creation of mine pools and treatment within the mine pool by addition of alkaline or organic carbon reagents would provide benefits to the Keno Hill mine district closure.

Some benefits of in mine treatment include:

- Creation of a clean mine pool minimizes concerns related to fugitive or non-point source discharge of mine waters.

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- Exclusion of oxygen in the mine pool and atmosphere above the mine pool minimizes metals leaching. Any inexpensive method that minimizes long term leaching will pay dividends in either avoiding the need for active treatment, or in minimizing costs associated with active treatment.
- Pretreatment of mine discharge will deposit sludge within the mine workings, rather than externally where it requires management.
- Pretreated mine water may be amenable to passive treatment external to the mine if discharge standards are not met within the mine workings.

Currently, mine pools are only present in Silver King, Hector Calumet, Galkeno 900, and Keno 700, of the mines that are studied in this analysis. All of these mine pools are not easily accessed and are poorly understood. Placement of a mine plug and filling of the mine workings provides a good tool to study the nature of the mines during filling.

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8. RECOMMENDATIONS

A few recommendations are proposed from this study for broader consideration:

1. Evaluate further potential methods for isolating Hector Calumet from the mines around it, especially Galkeno 300. An adit plug installed between these mines is one method that would allow flooding the H-C workings and minimizing the source of metals from the biggest mine in the district.
2. Evaluate potential for storage of water within Hector Calumet by flooding it to the Hector 400 level. Similar to recommendation #1, this would likely involve an adit plug between Hector Calumet and Galkeno.
3. Evaluate a low pressure adit plug at Galkeno 300, both for its effects at gaining temporary storage during freshet flows, and to determine if flows are redirected down the Sime crosscut toward Galkeno 900.
4. Evaluate a second adit plug at Galkeno 900 to further reduce flows from Galkeno 900.
5. Do a comprehensive survey of fugitive flow from Galena Hill to assess the water balance and ratio of point source to non-point source flow.
6. Evaluate a high pressure adit plug for No Cash 500 as a component of in-mine treatment or mine pool storage for active treatment at No Cash.
7. Evaluate redirecting surface stream flow or lining the creek to minimize recharge into No Cash.
8. Evaluate a low pressure plug at Silver King as a component of in-mine treatment at Silver King.
9. Evaluate redirecting surface stream flow or lining the creek to minimize recharge into Silver King.
10. Evaluate a high pressure adit plug for Onek 400 as a component of in mine treatment or mine pool storage for active treatment at Onek.
11. Evaluate creation of a free draining pit at Onek and/or surface diversions to minimize recharge through the Fisher pit.
12. Evaluate a high pressure adit plug for Keno 700 as a component of in mine treatment or mine pool storage for active treatment at Keno 700.
13. Evaluate a high pressure adit plug for Sadie Ladue 600 as a component of in mine treatment or mine pool storage for active treatment at Sadie Ladue 600.
14. As part of the adit plug assessment for the above noted adits, the following work should be completed as part of an underground mine adit hydraulic plug inspection:
    - Adit accessibility to determine the adit access and logistics to gain entry to the adit.
    - Geological review of mine adit – a review of the rock types and possible locations for a mine adit plug would be undertaken by mine geological staff
    - Adit excavation and entry – physical works would be undertaken to safely gain entrance to the mine workings for underground inspection
    - Inspection Team – team of mine engineer and geologist to inspect and document underground conditions at a potential hydraulic plug site
    - Inspection Report to document the underground mine adit hydraulic plug assessment for each site