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Remediation Options for Galkeno 300 Adit Drainage at the United Keno Hill Mines, Yukon Territory

Nand K. Davé

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EXECUTIVE SUMMARY

This report reviews and evaluates the available remediation options for mitigating the environmental impacts of metal bearing drainage from the Galkeno 300 adit at the United Keno Hill Mining District near Elsa in central Yukon. The options evaluated include: Do Nothing – Present Status Quo; Hydraulic Plugging of the adit; Collection and Treatment at the adit site or at a downstream or other locations; and Passive Treatments provided by constructed wetlands or by Natural Attenuation through native organic and inorganic soil substrates. Based on the financial implications of short and long-term water quality objectives and environmental compliance, a comprehensive waste water management strategy for the site is recommended.

The report also identifies the natural attenuation processes of metal retention by organic and inorganic soil horizons of the mineralized native soils as a promising technology, unique to the site, for passive treatment of metal bearing mine effluents. Also identified are knowledge gaps in the passive treatment technologies using constructed and/or natural wetlands and natural attenuation processes related to their performance in the cold climatic conditions of northern Canada.

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INTRODUCTION

This report reviews and evaluates the available remediation options for mitigating the environmental impacts of metal bearing drainage from the Galkeno 300 adit at the United Keno Hill Mines, Elsa, Yukon. The work forms a part of a broader project titled "Review of Mine Drainage Issues in the United Keno Hill Mining District", which is undertaken for the Department of Economic Development, Government of Yukon, and Canada Centre for Mineral and Energy Technology (CANMET), Natural Resources Canada, under a jointly funded agreement.

For this purpose, all available reports pertaining to the facility operation during its care and maintenance mode, reports prepared for submission to the Yukon Water Board for Class A Water Licence and the various environmental study reports related to passive treatments by constructed and natural wetlands, and natural attenuation processes were reviewed. These include: United Keno Hill Mines Limited - Site Characterization (United Keno Hill, 1996a), Closure Plans for Current Conditions (United Keno Hill, 1996b) and Mine Reopening – Operating Plan (United Keno Hill, 1996c); Design of a Passive System for Treatment of Discharges from Galkeno 900 Adit at the United Keno Hill Mine Camp (Microbial Technologies, 1995); Investigations into Passive Wetlands Treatment of Mine Drainage to Remove Heavy Metals at the Various Sites at the United Keno Hill Mines, Central Yukon (Laberge, 2000); Possible Mechanisms of Natural Attenuation of Metal-Bearing Waters in Soils in Northern Climates (MacGregor, 2000); and Field Investigations of Natural Attenuation of Mine Drainage-Borne Zinc in Shallow Soils Over Permafrost, Central Yukon, Canada (MacGregor and Li, 2001a and 2001b). A field visit to the site was also undertaken during the third week of October 2001 to familiarize with the site settings and existing conditions. While conducting this review, special attention was paid to the geographical location of the site and its rigorous northern climatic conditions.

BACKGROUND

A brief description of site conditions, mineralization, and mining and current environmental conditions etc. are briefly presented below for reference only. Details about these topics are found in the United Keno Hill Mines Limited - Site Characterization Report (United Keno Hill, 1996a).

Site Conditions

The United Keno Hill Mining District is located approximately 63º 55´N and 135º 25´W, in the vicinity of the villages of Elsa and Keno City in the central Yukon Territory, approximately 45 km northeast of the town of Mayo and 450 km north of Whitehorse (Figure 1). The mining property, covering claims and leases, is approximately 15,000 ha in size in a roughly east-west belt, about 29 km long and 8 km wide, encompassing the area containing Keno Hill, Galena Hill and Sourdough Hill (Figures 2-4). The property lies along the broad McQuesten River valley within the Yukon plateau just south of the Wernecke mountains.

The terrain consists of concordant, rolling upland areas separated by wide valleys. Alpine mountain peaks extend above the uplands locally. Valley bottoms and slopes have dense boreal forest cover, but the upland commonly extend above the tree line and is tundra covered. The tree line is at an elevation of approximately 1,370 m. The mine site is wholly contained within the catchment basin of the Stewart River (Figure 1).

The climate of the area is rigorous. The mean annual temperature at Mayo is –3 ºC, ranging from the recorded coldest winter temperature of -55 ºC and warmest summer temperature of 32 ºC. Because of the northern latitude of the site, there is no true daylight in December, and in June, there is no true darkness. The average annual precipitation in the area is ~285 mm. The site is underlain by permafrost so run-off is complete.

The vegetation is dominantly low brush and mountain alder (willow) with black spruce in the McQuesten valley seldom exceeding a height of four metres, and scattered spruce and black birch on hillsides.

Mineralization

Silver is predominant within the central lode deposits of the district. The mineralization consists of discontinuous bands and lenses of silver bearing deposits bottomed out in zinc. Gold is present, although it has never been viewed as an important constituent within the lodes. There is a history of the recovery of substantial placer gold from drainage systems throughout the mining district.

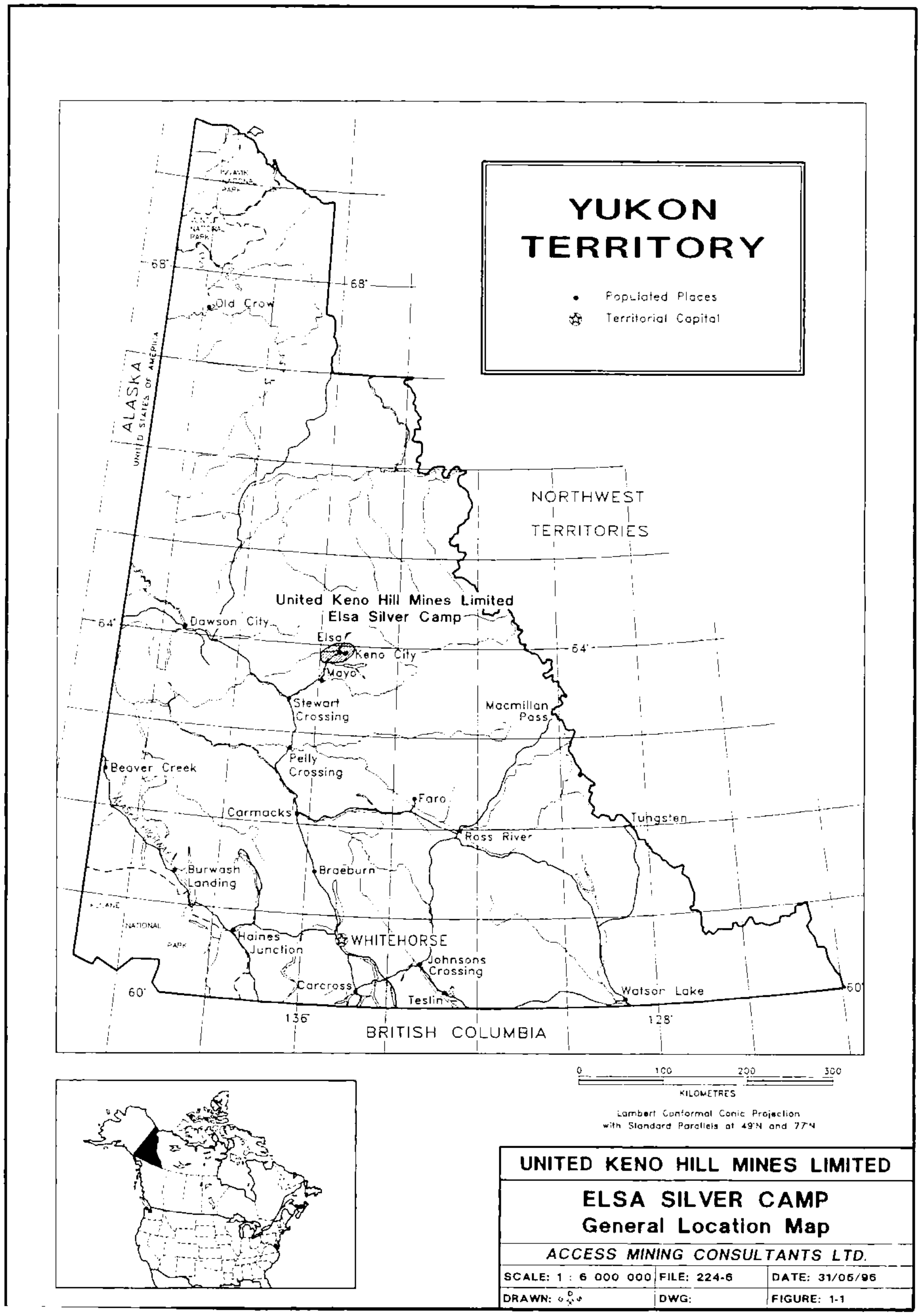

Figure 1 – Generalized location of United Keno Hill Mines Limited, Elsa, Central Yukon.

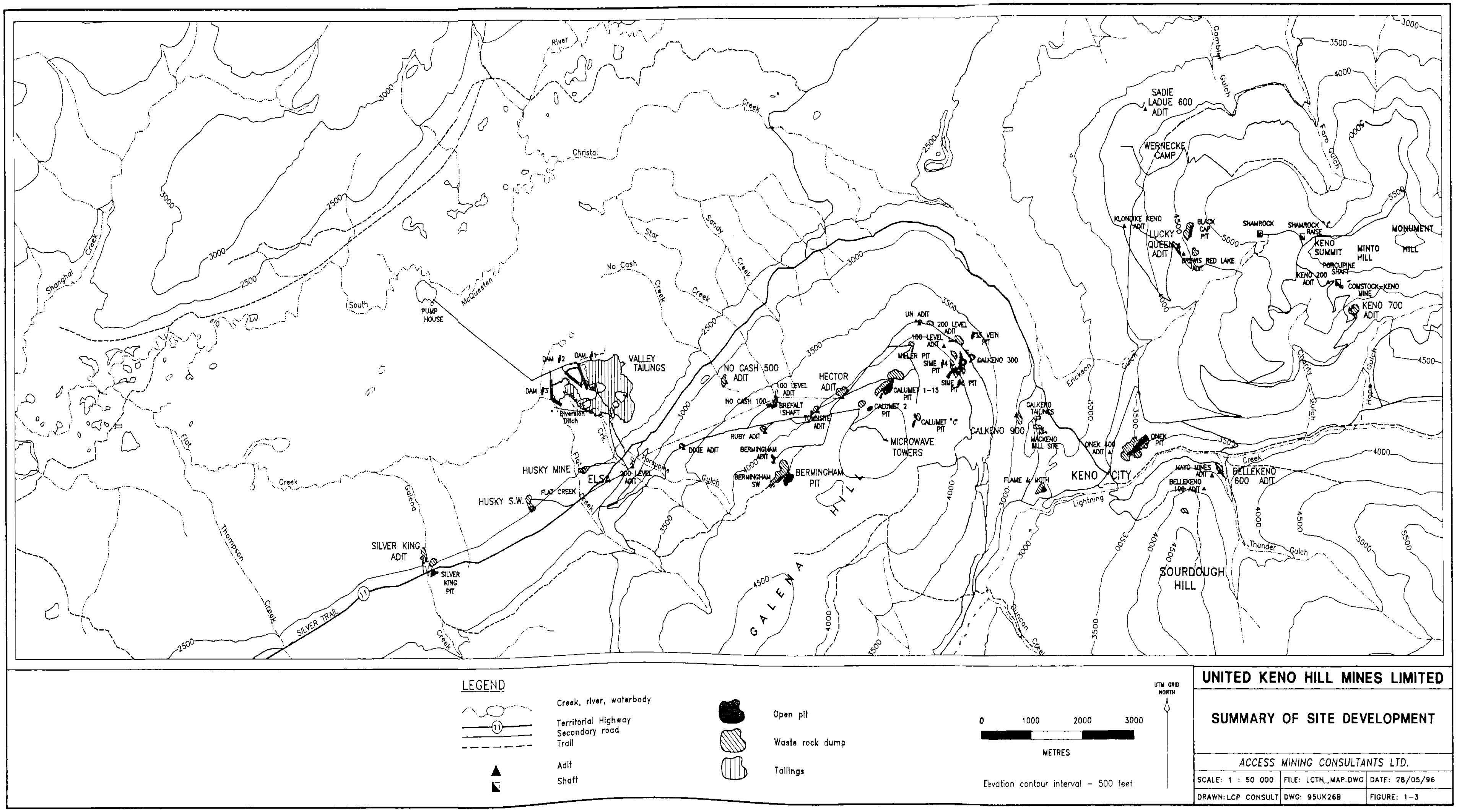

Figure 2 – General location of various mines, adits, open pits, waste rock piles and tailings impoundments at the United Keno Hill Mines site.

Figure 3 – View of valley and tailings impoundments at the United Keno Hill Mines, looking north-east from the Elsa townsite.

Figure 4 – View of Christal Lake and surroundings, looking north-east from the Galkeno 900 adit

The ore zones are in the shape of simple veins, sheet zones and breccia zones, ranging in thickness from 0.3 to 30 metres. Strike length and dip extensions of individual ore shoots ranged from 30 to 335 m. It is common for several ore shoots to occur in a single vein fault.

The principal ore minerals in the mining camp are: argentiferous galena [Pb(Ag)S], freibergite (argentiferous tetrahedrite – "grey copper") [$(Cu,Fe,Zn,Ag)_{12}(Sb,As)_4S$], and pyrargyrite ("ruby silver") [Ag_3SbS_3]. polybasite [$(Ag,Cu)_{16}Sb_2S_{11}$], stephanite [Ag_5SbS_4], native silver [Ag], argentite [Ag_2S], sphalerite [ZnS], jamesonite [$Pb_4FeSb_6S_{14}$], bournonite [$PbCuSbS_3$], and boulangerite [$Pb_5Sb_4S_{11}$] occur locally in minor amounts.

Associated vein minerals occurring in different deposits include greenockite, hawleyite, pyrite, arsenopyrite, marcasite, cerussite, anglesite, malachite, azurite, chalcopyrite, copper sulphate, limonite, pyrolusite, jarosite, bindheimite, beudantite and scorodite. Gangue minerals associated with the vein structures include siderite, quartz, barite and calcite.

An oxidation zone is found to extend from surface to approximately 150 m below the surface. Zinc is depleted within this zone and increases significantly at depths contributing to apparent silver-zinc zonation within the deposit. Within the oxidized zone minerals such as limonite, pyrolusite, cerrusite and anglesite are common.

The detailed geology, mineralogy and geochemistry of the Keno Hill district are found in Boyle (1965).

Mining and Current Environmental Conditions

Mining in the area started in the early 1900 for silver and continued for approximately 70 years, producing silver, zinc and lead through small to large scale mining. The last full scale mining ended in 1989 with the closure of the United Keno Hill mining operations. The property has been on care and maintenance basis since. Recently, the property has been purchased by Advanced Mineral Technology (AMT) Inc. of Fairfield, Idaho, USA.

The site has several inactive and/or abandoned open pits and underground silver/lead/zinc mines, having many adits and mined-out workings, as well as waste rock piles, tailings impoundments and some unconfined older tailings deposits.

Mostly neutral, metal bearing drainages occur at several adits at the site, most notably Galkeno 300, No Cash, Galkeno 900 and Onek, and from Bellekeno and Silver King mine openings or adits. Acid rock drainage occurs from a small waste rock pile at Husky mine. The drainages from Galkeno 900, Bellekeno and Silver Kings adits are treated on site by mixing the adit/mine discharge stream with slaked lime slurry, allowing the treatment sludge to settle in two settling ponds, and the clear effluent is discharged to the receiving environment downstream. The treated effluent flows either directly to receiving lakes or streams or percolates through natural forested lands and/or bogs and wetlands. No treatments are provided to discharges from No Cash, Galkeno 300 and Onek adits (although the former two have significant flows and high metal contents), and to occasional discharges, if any, from other adits at the site. Table 1 provides a comparative water quality, compiled from United Keno Hill (1996a), of the various adit discharges at the site.

Table 1 – Water quality of various adit discharges at the United Keno Hill Mines site.

Location	**pH**	**Cond. µSi/cm**	**TDS mg/L**	**Alk. mg/L $CaCO_3$**	**SO_4 mg/L**	**Ca mg/L**	**Fe mg/L**	**Mn mg/L**	**Mg mg/L**	**Pb mg/L**	**Zn mg/L**
Galkeno 900	7.5	2000	2400	170	1400	480	2.8	60	40	0.01	28
Galkeno 300	7.2	1800	2000	60	1200	250	0.1-3.0	150	40	<0.1	120
No Cash	7.9	1000	1000	170	600	200	0.05-0.1	14	22	0.01-0.02	13-15
Onek	7.5	1050	1000	120	500	200	0.02	5.5	20	0.03	55
UN	8.0	550	380	180	120	100	0.02-0.6	0.3	10	0/01	0.1
Bellekeno	8.1	1130	1030	170	540	225	0.03	0.6	48	0.01	4.5
Silver King	6.9	900	800	60	500	130	1-16	4	35	0.01	1-2
Husky SW	6.9	1300	1100	130	700	240	10-30	15-20	32	0.01	0.4-0.8
Sadie Ladue	8.0	420	320	140	120	70	0.02	0.04	22	0.01	0.5
Ruby	8.0	450	300	120	140	80	0.05	4	12	<0.01	1-1.5

Hydraulic Plugging of Galkeno 900 Adit

Prior to installation of the present water treatment system at the Galkeno 900 adit, a hydraulic (concrete) plug was installed in the adit in 1993 by the United Keno Hill Mines, approximately 360 m from the opening. This was done to seal the adit and stop the discharge of nearly neutral, but high zinc containing effluent to the receiving waters of Christal Lake and Christal Creek located immediately downstream.

The hydraulic plug resulted in flooding of the old mine workings and water back-up in the mine, creating a hydrostatic pressure of approximately 1.17 MPa (170 psi) at the bulkhead by 1995, corresponding to a vertical rise of water column in the Galena Hill by ~110 m (360 ft) above the Galkeno 900 adit. These conditions led to by-passing of the installed bulkhead, and flow soon resumed from the adit through the various fractures and fault zones. The aggravating flow and its elevated zinc content necessitated the installation of the present water treatment system at the adit.

Thus, the sole purpose of stopping the zinc enriched discharge from the Galkeno 900 adit by installation of a hydraulic plug has been completely lost. In fact, the rise of hydrostatic head within the mine workings might have exacerbated the flow and drainage water quality elsewhere from the hillside and other adits. Based on the observations of site personnel at the United Keno Hill Mines and information received from them, MacGregor (2001a) has indicated that the increasing flow with time at the Galkeno 300 adit might be linked to the elevated water level within the inter-linked mine workings in the Galena Hill. This stipulation, however, could not be ascertained by the observed water pressure at the bulkhead, which corresponds to a water elevation of approximately 100 m below the Galkeno 300 adit elevation of 1160 m.

Drainages from other Adits

The drainages from other adits travel above ground for short distances from the adits, depending upon site conditions and topography, and percolate through ground eventually reporting to the Christal Creek drainage system. In this process, a majority of the metals in the drainage are attenuated and retained through various interactions within the naturally occurring and partially decomposing organic cover layers, mineralized soils and detritus material above the permafrost, and/or naturally occurring wetlands (MacGregor 2000 and 2001a & b, and Laberge 2000). The overall impact of these drainages to Christal Creek is reported to be either low or indistinguishable from its water quality monitoring history.

Passive Treatment Investigations

Constructed Wetlands

The suitability of a constructed wetland in providing treatment to the various metal rich adit drainages at the United Keno Hill Mines was evaluated by Microbial Technologies of Vancouver in 1995 by constructing a small, 18.5 m x 9.0 m x 0. 5 m, experimental wetland plot downstream of the Galkeno 900 adit. The constructed plot was established using substrate and vegetation excavated from a naturally occurring wetland in the area and transplanting them in the plot. A small inflow, at the rate of ~0.3 L/min, from the Galkeno 900 adit discharge was directed towards the constructed wetland and its performance in removing zinc and other metals was assessed during the summer of 1995 (Microbial Technologies 1995).

After overcoming the various flow channelling and short circuiting difficulties, the constructed wetland plot was shown to remove more than 80% of zinc, and to a certain extent other metals such as cadmium, manganese, nickel, during its short monitoring period from mid August to mid September 1995. Most of the metal retention occurred in the wetland substrate through microbial reduction of dissolved sulphate, resulting in production of hydrogen sulphide gas and precipitation of insoluble metal sulphides. Some retention of metals with iron and manganese oxides and oxyhydroxides, as adsorbed species, was also suggested.

Although, the passive wetland treatment data at the site are limited to a very short time interval of warm summer period, and year-around monitoring data of the plot performance, and specifically during the prolonged cold winter months are yet to be obtained, a full-scale wetland treatment system for the Galkeno 900 adit discharge has been suggested by Microbial Technologies. Furthermore, based on the mesocosm studies within the constructed plot, a 26 day effluent retention period in the wetland treatment area is recommended for complete removal of zinc and other metals. However, the suggested size of 450 m x 20 m x 0.5 m of the constructed wetland appears to be too small for handing the observed flow of ~ 860 m^3/d from the Galkeno 900 adit. This size would only provide a retention period of ~2 days, requiring the actual size of the constructed wetland to be 15 times larger, corresponding to an area of approximately 15 ha, for the desired retention period. This estimate does not include the additional retention time required for the reduced microbial activity and decreased kinetic reaction rates during cold climatic conditions, which would further require a much enlarged constructed wetland area.

Natural Wetlands

The pilot wetland treatment plot at the Galkeno 900 adit was re-evaluated in 1999, together with other natural wetlands providing treatments to various drainages and effluent streams at the United Keno Hill site, by Laberge Environmental Services (Laberge 2000). The study concluded that due to insufficient volume flowing through the examined wetlands, their performance in treatment of waste water could not be fully evaluated. However, sediment analyses showed that metals had been attenuated by all sites examined, and metal uptake in the plant species was low. Overall, based on the preliminary results, the investigators concluded that there was a good potential for the use of natural and constructed wetlands to treat metal contaminated mine drainages at the United Keno Hill site.

Natural Attenuation by Native Soils

The natural attenuation of metals in the drainage from the Galkeno 300 adit by native soils at the United Keno Hill Mines was investigated by MacGregor and Li of the Department of Civil Engineering, University of British Columbia, during the summer field season of 2000 (MacGregor 2000 and MacGregor and Li 2001a&b). The discharge effluent from the adit, on its downward migration, percolates laterally through layers of local soils comprised of partially decomposed organic material underlain by poorly sorted mineral soils and some detritus sand before discharging to Christal Creek. The study concluded that progressive zinc and manganese removal was occurring from the drainage waters in the down-slope direction; typically reducing zinc from concentration of ~150 mg/L at the adit mouth to approximately 2-3 mg/L where the drainage discharges to the creek, a reduction by a factor of 50-75. Manganese was also removed in the process (MacGregor and Li 2001a&b).

The sorption of zinc ions on to the organic material was identified from the observed zinc attenuation. The coincidental removal of zinc and manganese suggested that manganese oxides are forming along the flow path and zinc removal is occurring by co-precipitation and adsorption mechanisms. The investigators indicated a good potential for natural attenuation mechanisms to remove zinc and other metals from mine drainages at the United Keno Hill site, although this investigation was also limited to a short time period during the warmest part of the year. No mention is given in the study of the impact of cold temperature and near freezing conditions on the reaction kinetics in the natural attenuation processes, as the first order reaction rates are typically temperature dependent. The long-term viability of the natural attenuation process and its continued removal and binding of metals on to the organic and inorganic components of the local soil at low ambient temperatures remain to be demonstrated.

GALKENO 300 ADIT – DISCHARGE CASE HISTORY

The Galkeno 300 adit is situated on the east-northeast facing side of the Galena Hill at an elevation of 1160 m (3800 ft) above the main sea level (AMSL), approximately 300 m (1000 ft) above the valley floor below. The Galena 900 adit is located southeast of Galkeno 300 at an elevation of 950 m (3,120 ft), as seen from Figures 2 and 5

From the cessation of mining to the mid 1990's, the Galkeno 300 adit was observed to have metal contaminated discharge only during period of rapid snow melt in the spring. Table 1, provides a comparative water quality of Galkeno 300 and other adits at the United Keno Hill site, complied from the company's site characterization report (United Keno Hill 1996a). In 1997, four years after the hydraulic plugging of the Galkeno 900 adit, small volumes of drainages were observed to be constantly discharging from the Galkeno 300 adit. In 1998, the discharge was slightly greater, and again in 1999 and 2000, the discharge volume was reported to be increasing according to the information obtained by MacGregor from the United Keno Hill Mines site personnel (MacGregor 2001a). In August 2000, the average flow and zinc concentration of the Galkeno 300 adit discharge were measured by MacGregor as ~8 L/s and 170 mg/L, respectively. During the October 2001 field visit, the adit flow was estimated to be between 10-15 L/s.

As mentioned previously, MacGregor and Li associated the increased flow from the Galkeno 300 adit to the hydraulic plugging of the Galkeno 900 adit, causing flooding of the Galkeno workings close to the 300 level. However, from the bulkhead pressure readings at the Galkeno 900 adit, the water level in the mine working should be approximately 100 m below the Galkeno 300 adit elevation. Regardless of the cause, larger flows than had previously been observed, with high dissolved zinc contents are exiting the Galkeno 300 adit. Percolation of incoming drainage water through the old mine workings, where no flow existed previously, is contributing to increased zinc leaching and hence higher levels in the adit discharge. In addition to high levels of dissolved zinc, the adit discharge also contains dissolved iron, manganese, cadmium and low levels of arsenic, as seen from Table 2. The effluent is nearly neutral to very weakly acidic having a pH of ~ 6.3.

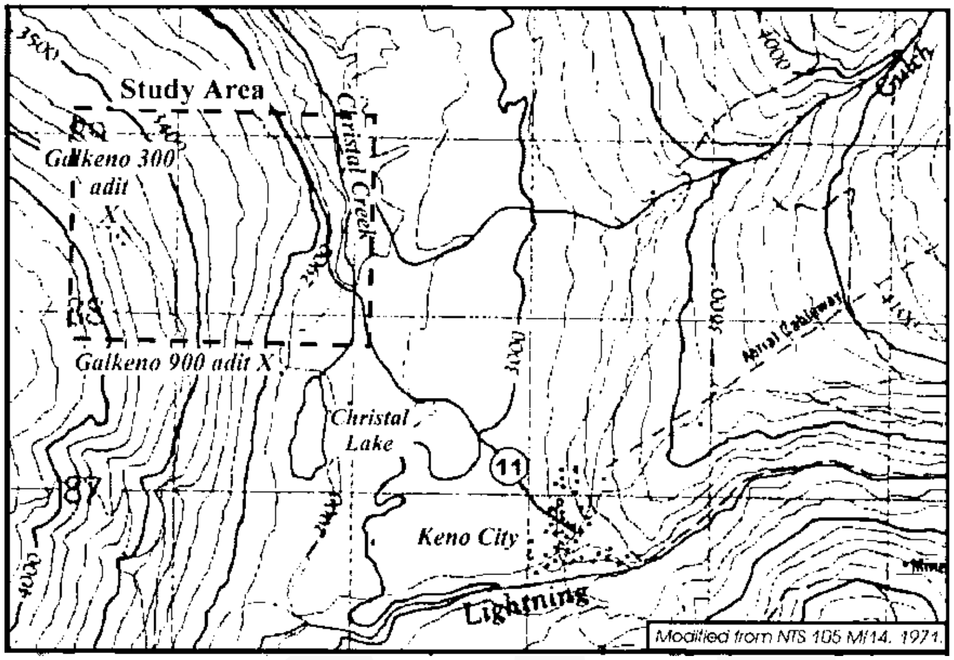

Figure 5 – Location of Galkeno 300 and 900 adits at the United Keno Hill Mines (adapted from MacGregor and Li 2001).

The drainage from the Galkeno 300 adit flows across the haul road, then down-gradient as surface flow over a short distance, percolating as subsurface flow through the hillside soils towards Christal Creek. Figures 6-12, show the flow exiting the adit and the observed flow paths, constructed by MacGregor, as it advanced towards Christal Creek. During the October field visit, no subsurface flow was seen exiting the collection ditch constructed downstream of the adit near Christal Creek and Highway 11 culvert (Figure 9).

Natural attenuation of zinc, manganese, and to a certain extent cadmium and arsenic, was seen by MacGregor from the adit discharge as it migrated through the local soils towards Christal Creek. Near the adit discharge, some dissolved iron hydrolyzed and precipitated along the surface flow path (Figures 6 and 7). Spatially, aqueous metal concentrations decreased with increasing distance from the adit; the rate of decrease was greater after the flow entered subsurface ~150 m down slope of the adit discharge. These results are illustrated in Table 2 and Figure 13, showing continuous removal of zinc and manganese over a distance of approximately 1.7 km along the subsurface length of the flow path as it progressed towards Christal Creek. The estimated metal removal factors for zinc and manganese were, respectively, ~ 110 and 460, with complete removal of the dissolved cadmium and arsenic (MacGregor and Li 2001a).

Figure 6 – Galkeno 300 adit discharge, surface flow pattern at the adit.

Figure 7 – Galkeno 300 adit discharge, surface flow pattern near the adit and settling of iron hydroxide precipitate.

Figure 8 – Galkeno 300 adit discharge, surface flow pattern on the adit road onwards to its downward migration.

Figure 9 – General area of sub-surface drainage from the Galkeno 300 adit in the vicinity of Christal Creek confluence.

Figure 10 – General view of the Galkeno 300 adit site from Silver Trail Highway #11.

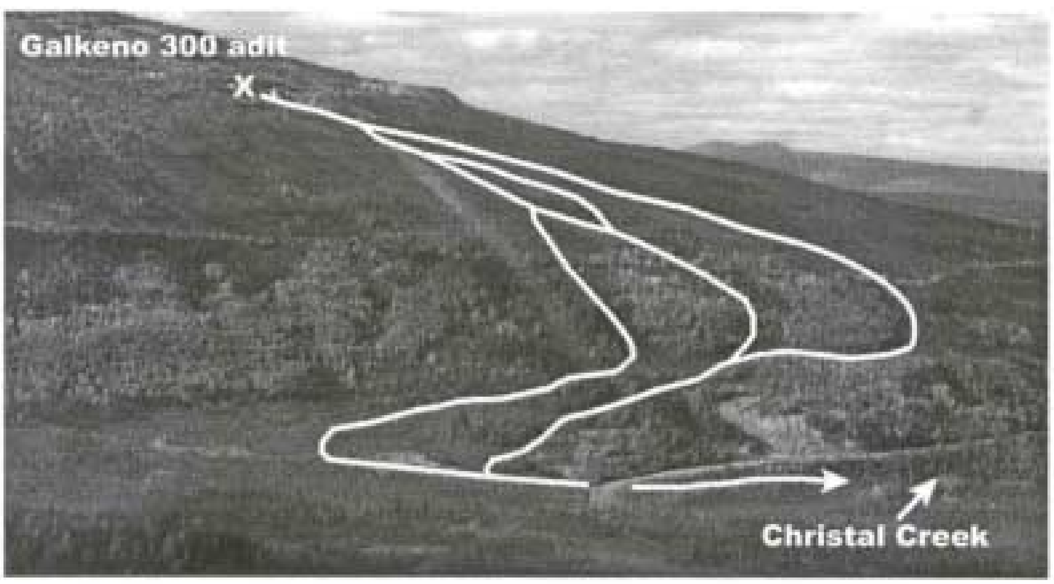

Figure 11 – Generalized pattern of surface and sub-surface flow paths from the Galkeno 300 adit to Christal Creek (adapted from MacGregor and Li 2001a).

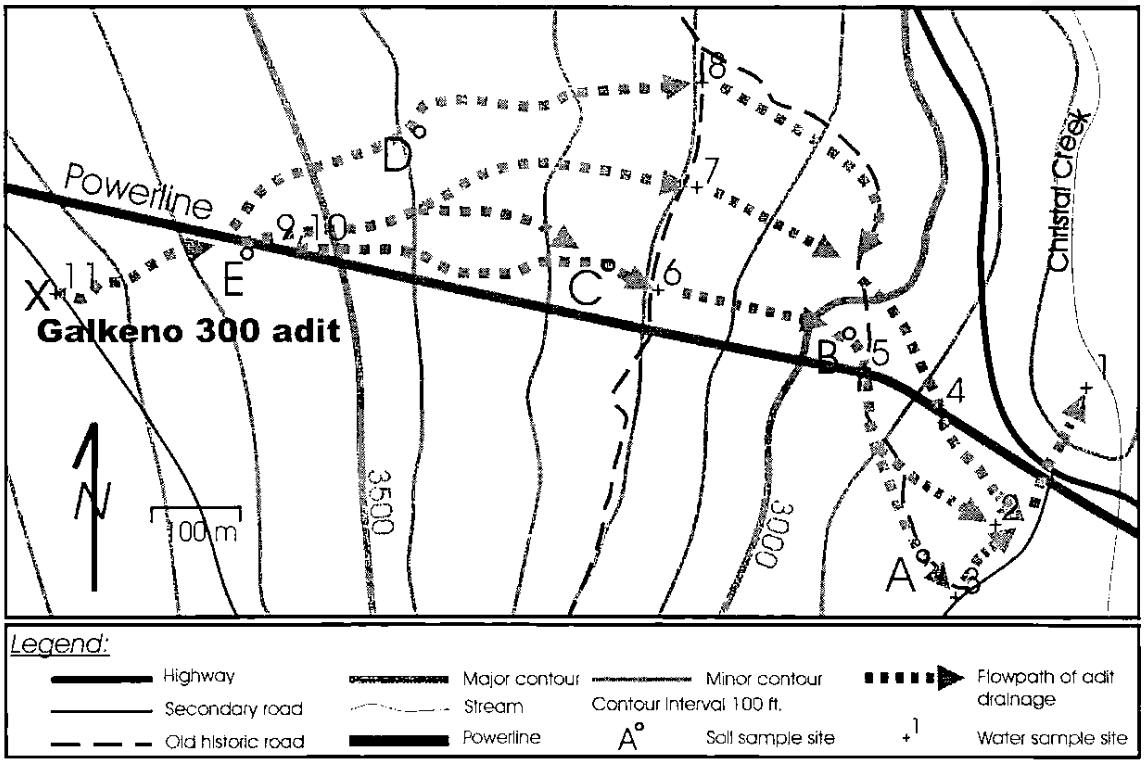

Figure 12 – Observed surface and sub-surface flow paths between the Galkeno 300 adit and Christal Creek, and soil sampling locations (adapted from MacGregor and Li 2001a).

Soil samples taken along the Galkeno adit flow path contact showed elevated metal concentrations compared to background metal levels in similar soils adjacent to, but isolated from the mine drainage along the flow path (Table 3). Both the upper organic and the lower soil horizons showed metal retention and uptake, the highest attenuation, however, resulted in the organic layer.

These results are very encouraging, although no performance evaluation of the natural attenuation processes at the site or elsewhere is available to judge the year-around and long-term performances of the underlying mechanisms.

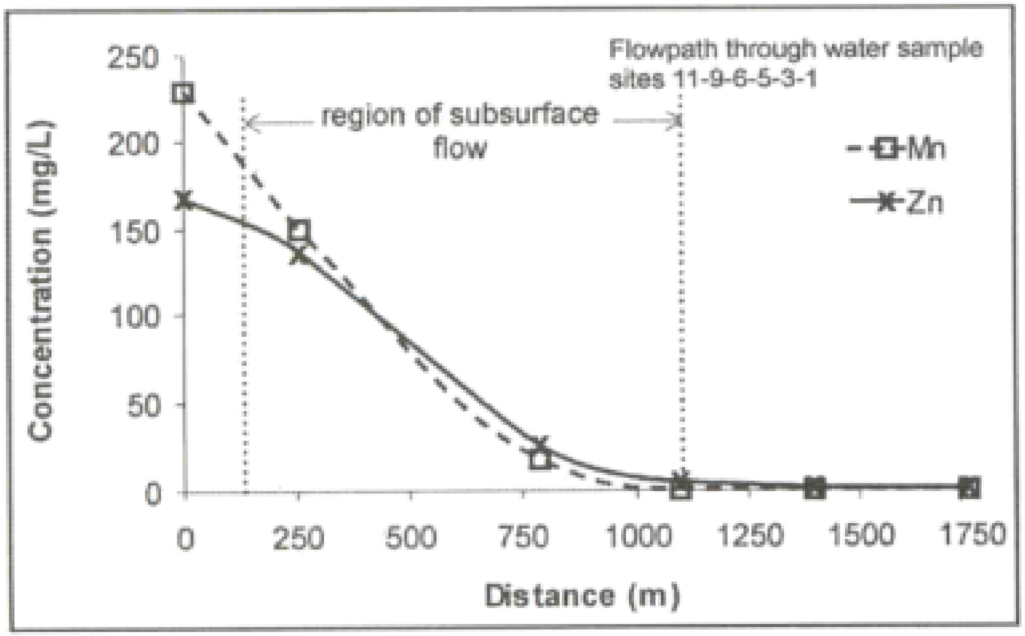

Figure 13 – Concentrations of zinc and manganese in surface and sub-surface flows along the flow paths from the Galkeno 300 adit to Christal Creek (adapted from MacGregor and Li 2001a).

Table 2 – Effuent water quality at the Galkeno adit and immediately upstream of the sub-surface flow confluence with Christal creek (adapted from MacGregor and Li , 2001a).

Parameter	Galkeno 300 Adit	Above confluence with Christal Creek	Metal Reduction Factor
Discharge Flow (L/s)	7.8	8.3	-
pH	6.34	7.26	-
Zn (mg/L)	168	1.55	108
Mn (mg/L)	255	0.49	461
Cd (mg/L)	0.59	<0.006	complete removal
As (mg/L)	0.20	<0.06	complete removal

Table 3 – Soil concentrations of zinc and manganese at background and Galkeno 300 subsurface flow study area locations (adapted from MacGregor and Li , 2001a).

Sample Site	Horizon	Zn Conc. (mg/kg)		Mn Conc. (mg/kg)	
		Background	Study Site	Background	Study Site
Near adit, E	upper organic	156	13800	61	61318
Near adit, E	lower mineral	312	4590	479	3344
Mid point, C	upper organic	90	28571	4860	224000
Mid point, C	lower mineral	237	1370	170	418
Near creek, A	upper organic	315	3010	1160	1210
Near creek, A	lower mineral	289	277	532	482

The sorption of zinc is reported to occur on to the organic matrix and co-precipitation with manganese oxides and oxyhydroxides, which are very important and dominant processes of metal retention at the adit site, and probably elsewhere on the property, where such subsurface flow of metal rich effluents is occurring through the organic and inorganic soil substrates. It should, however, be emphasized that these sorption type soil-metal interactions are dependent on pH, temperature and reduction-oxidation (redox) potential, and are reversible when equilibrium conditions change. For example, with increasing aqueous acidity or redox potential the adsorbed metals could be easily de-sorbed and released, and with decreasing temperatures the adsorption reaction kinetics may slow down considerably impacting the system performance.

Adsorption on the organic matrix having a limited adsorption capacity may further result in a high metal concentration plume migrating downwards, along the flow path, and eventually reaching Christal Creek at some point in time. Continuous production of new organic matter and its yearly deposition and degradation provides new adsorption sites, which could continue the adsorption process indefinitely, provided there are no drastic changes to other conditions or increased flow. Further investigations regarding the maximum adsorption capacity of the soils for metal retention, stability of the co-precipitated and/or adsorbed metal species with time, and the overall long-term performance of the various processes need to be undertaken.

In the interim, the quality and quantity of the drainage exiting from the Galkeno 300 adit are of concern. Natural attenuation processes remove zinc in the subsurface flow by two orders of magnitude, from approximately 170 mg/L to ~2 mg/L, over a distance of 1.7 km before the seepage flow enters Christal Creek. Although, no significant impact on zinc levels is seen in Christal Creek at the confluence of the creek and subsurface flows, removal of zinc to a level of ~1 mg/L appears to be the limit over the short flow path. These levels may increase at the confluence point during winter months. Thus, the process as such cannot be considered as sufficient for meeting the discharge water quality objectives of 0.5 mg/L zinc at the point of discharge in the creek.

It should, however, be mentioned that water at ~ 1 mg/L zinc may be entering the creek through seepages elsewhere and from the old tailings, submerged or partially submerged, near Christal Lake from other or past mining operations. In fact, zinc has been historically depleted in the oxidized orebody and translocated elsewhere (Boyle 1965), which has been used for fingerprinting of the silver-zinc zonation. To a certain extent, these processes are still ongoing and are contributing to overall background zinc levels in the mineralized belt. Seventy odd years of mining in the area has increased the anthropogenic metal load of the local watershed, and to a certain extent downstream. Thus , it is very probable that the background zinc and other metals entering the Christal Creek drainage system through various surface and subsurface flows may be relatively high, and may have increased progressively during period of no or lax environmental controls.

Location of Final Point of Discharge for Galkeno 300 Adit

The issue of providing treatment, whether conventional or passive, to the Galkeno 300 adit discharge becomes important depending upon the location of its final point of discharge, which could vary from the mouth of the adit to some place downstream between the adit and before the confluence of the subsurface seepage flow with Christal Creek. For the purpose of defining the final point of discharge from a waste management facility, the following relevant word definitions are provided, for reference only, from the Canada Gazette Part 1 (July, 2001) pertaining to the Metal Mining Effluent Regulations (MMER) of the Department of Fisheries and Oceans.

<u>Deleterious Substance</u>

A "deleterious substance" means a substance prescribed under Section #3 (As, CN, Cu, Pb, Ni, Zn, Total Suspended Solids and Ra-226, and any acutely lethal effluent) as listed in Table 4, except as other wise prescribed by the Metal Mining Effluent Regulations,

<u>Effluent</u>

An "effluent" means mine water effluent, mill process effluent, tailings impoundment area effluent, treatment pond or treatment facility effluent, seepage and sub-surface drainage that contains a deleterious substance,

<u>Final Discharge Point</u>

The "final discharge point" in respect of an effluent means an identifiable discharge point of a mine beyond which the operator of the mine no longer exercises control over the quality of the effluent.

The MMER authorized limits of deposition of non-lethal effluents containing deleterious substances are provided in Table 4.

Generally, the final point of effluent discharge is identified by the owner/operator of a mine, mill or waste management facility, and approved by regulatory authorities. Before the final point of discharge, the owner/operator has the discretion of providing a single or a series of primary and secondary treatments including any chemical and/or passive treatments to meet the final effluent discharge guidelines. Thus, any area used for waste storage and for providing treatments, including polishing and/or passive, is designated as a waste management and treatment facility and has to be managed accordingly.

In context of the above defined terminology for the final point of discharge and the new Metal Mining Effluent Regulations (MMER), the existing Galkeno 300 adit discharge is judged to be in non-compliance irrespective of the designation of its final point of effluent discharge, located anywhere between the adit and Christal Creek. Thus, some form of effluent treatment and/or other remediation measures are required.

Table 4 – MMER authorized limits of deposition of non-lethal effluents containing deleterious substances.

Parameter	MMER Requirements		
	Monthly	Composite	Grab
As (mg/L)	0.5	0.75	1.0
CN (mg/L)	1.0	1.5	2.0
Cu (mg/L)	0.3	0.45	0.6
Ni (mg/L)	0.5	0.75	1.0
Pb (mg/L)	0.2	0.3	0.4
Zn (mg/L)	0.5	0.75	1.0
pH	In range of 6.0 to 9.5		
Ra-226 (Bq/L)	0.37	0.74	1.11
TSS (mg/L)	15	22.5	30
% Non-acutely lethal effluent	100%		

GALKENO 300 ADIT – REMEDIATION OPTIONS

Provided below are some of the possible remediation options considered for handling the short and long-term drainage issues from the Galkeno 300 adit.

1. Do Nothing – Present Status Quo

As the Galkeno 300 effluent does not meet the regulatory water quality objectives for final discharge anywhere from the discharge point at the adit to the confluence of Christal Creek, this option would be highly irresponsible of the owner/operator to suggest, and for the regulatory authorities to approve. Although there is credible evidence from the study of MacGregor and Li (MacGregor 2001a&b) that natural attenuation of zinc, manganese and other metals is occurring along the sub-surface flow path from the adit to Christal Creek, the discharge water quality at the Christal Creek confluence is still containing zinc levels 2 to 4 times above the regulatory discharge limits of 0.5 mg/L based on a monthly average. Thus no credible argument can be made in defence of the present status quo, and hence this option is considered to be a non-starter.

Furthermore, the do-nothing option fortifies the pre-conceived biased perception and negative image of the mining industry, based on its past operational history and legacy, which the modern industry and regulatory agencies alike are trying so hard to dissociate by increasingly developing and implementing environmentally sound policies and safeguards. In fact, a more proactive program of environmental protection and habitat management is require to demonstrate the commitment of the industry to sustainable development of mineral resources.

2. Hydraulic Plugging of the Adit

A hydraulic plug, similar to that installed in the Galkeno 900 adit, could be installed in the Galkeno 300 adit to stop its discharge with medium to high cost implications, depending upon the location of the plug, structural and ground competence of the adit access and working areas, and efforts required in removal of fallen rocks and clearing of cave-ins etc. Although hydraulic plugging is an acceptable method of sealing adits, mine shafts and other openings, the experience gained at the Galkeno 900 adit testifies to a very poor performance to complete failure of the installed plug in meeting the desired objectives of sealing the adit and stopping the discharge of the contaminated effluent.

Additionally, the Galkeno 900 plug has raised the water level in the mine workings and in the hillside, which may have exacerbated the flow situation and contaminants load elsewhere. In the long-term, leaks around the installed bulk-head and its foundation, and the increased bulkhead pressure have the potential of progressively weakening the structural integrity of the adit seal, which in the absence of a proper care and maintenance program may result in a catastrophic plug failure having disastrous consequences for human life, property and the environment in general.

Thus, hydraulic plugging of the Galkeno 300 adit should not be considered, except for the purpose of holding water temporarily during winter months for other options, such as pumping of the effluent to the mill at Elsa or a large scale wetland or natural attenuation passive treatment option as discussed below.

3. Collection and Treatment of the Effluent at the Galkeno 300 Adit Site

This option is very feasible and could be quickly implemented at the adit site in a manner similar to those at other on site treatment locations. It would, however, require construction of a heated water-treatment facility and sludge setting ponds, appropriately sized for the required flow and residence time, at a higher elevation and in a difficult hilly terrain, which would have low to medium cost implications. On-site treatment of the effluent would also require year-around maintenance of roads for lime delivery, sludge management and operation of the facility itself, adding to the increased operational cost.

In the long-term, it would be disadvantageous to have too many individual effluent treatment facilities at the site, which would increase the overall operational and maintenance costs.

This option may be suitable for an immediate or interim period, but is not recommended for a continuous long-term facility management.

4. Collection and Treatment of the Effluent at a Downstream Location

This option requires collection of the sub-surface seepage from the adit at a suitable downstream location close to Christal Creek, and installations of a heated treatment facility and sludge settling ponds, both having easy access from the Silver Trail Highway #11. The seepage may be intercepted and collected in a ditch running parallel to the hillside contour and gravity fed to the downstream located treatment and sludge settling facility.

This option is very feasible and is considered to be better than providing treatment at the adit. Depending upon the locations of the intercepting ditch and sludge settling ponds, the initial construction cost for this option would be comparable or slightly higher than that at the adit, however, the long-term operational costs would be lower. The treatment facility would also require proper operational planning of handling a low or no flow during winter months and increased flow during spring thaw and periods of heavy rainfall.

5. Diversion Towards and Treatment at the Galkeno 900 Adit

This option takes the advantage of the natural terrain between Galkeno 300 and 900 adits and the existing treatment and sludge settling facilities at Galkeno 900, and utilizes the natural attenuation and retention of metals by native soils. It consists of diverting the Galkeno 300 effluent towards the Galkeno 900 adit by constructing a semi-impervious diversion ditch along the hillside and access road to the Galkeno 300 adit from the south-east, bringing the drainage effluent at the Galkeno 900 adit for treatment. The ditch should not be lined, but made semi-impervious by lightly compacting its bed to permit gradual dispersion of a part of the down flowing effluent as sub-surface seepage through natural soils over a wide area of the hillside for natural attenuation and metal retention. The remainder of the effluent reaching the Galkeno 900 adit is collected and treated there.

A slow flowing sub-surface seepage distributed over a wide area between the north-east facing hillside and Christal Creek would provide long retention and increased contact times with organic and inorganic components of the native soils for enhanced metal attenuation and retention through the various adsorption and/or co-precipitation processes.

The construction of a long diversion ditch from Galkeno 300 to Galkeno 900 adits would require proper engineering feasibility and design to handle the increased run-off and drainage from the hillside during spring and periods of heavy rainfall, including events of maximum probable precipitation (MPP), as well as silt and erosion protections. The treatment and sludge handling facilities at the Galkeno 900 adit would also require upgrading to handle the increased flow and contaminant load. It might be advantageous, in the long-term, to construct a properly designed and engineered modern-effluent-treatment facility at Galkeno 900 for metal removal, effluent filtration and final pH control of the effluent to between 7 and 9 within the facility itself. The existing sludge settling ponds would also require to be enlarged for further dewatering, consolidation and storage of the filtered sludge from the treatment plant.

Modernization of the effluent treatment and sludge handling facilities at Galkeno 900 is strongly recommended, as it would be cost effective over the anticipated long treatment period. This would be achieved by providing an efficient pH control and lime/alkali usage for metals precipitation and removal as well as adjustment of the final effluent pH for regulatory compliance using carbon di-oxide or a dilute solution of sulphuric acid. The practice of discharging the final effluent at pH 10, required for zinc precipitation, may not be permitted for the continuous long-term operation of the treatment facility. In this repect, no justifiable argument could be made for the continued exceedance above the regulatory limits and/or the effluent may not meet the 100% non-lethal requirements.

This option could be implemented at a reasonably low to very moderate cost, and is believed to be the most suitable for handling the adit related discharge issues at both Galkeno 300 and Galkeno 900 adits until other passive wastewater treatment technologies are fully evaluated for year-around fulltime operation at the United Keno Hill site. Moreover, even in the case of long-term successful-field trials and implementation of one or a combination of passive treatment technologies at the site, the designed treatment facility at Galkeno 900 would serve as a back-up chemical system in the event of poor performance or failure of the implemented passive systems or when remediation work is required. Thus, a feasibility study and implementation of this option is strongly recommended.

With the construction of a new water treatment facility at Galkeno 900, arrangement should also be made to drain the adit for relieving the built-up hydrostatic pressure on the bulkhead and lowering the water elevation within the mine workings. As the hydraulic plug has lost its utility, holding of a huge quantity of water behind the bulkhead serves no purpose, except aggravating the drainage situation at the adit and elsewhere, and in any event all this accumulated water has to be treated. Draining of the Galkeno 900 adit may re-channel the flow infiltration from higher elevations, thus reducing and/or alleviating the discharge flow conditions at other adits including Galkeno 300, to the pre-plug conditions. If that happens, the drainage problem at Galkeno 300 would eliminate itself, and the drainage diversion ditch then would serve to handle any occasional flow from the adit.

In case a direct ditch linkage between Galkeno 300 and 900 adits is not feasible, drainages from the two adits could be brought, by similar semi-impervious diversion ditches, to a centrally convenient location between the two adits for collection and treatment in a newly constructed facility as proposed for the Galkeno adit above.

Alternatively, to decrease the treatment load of a large quantity of water in the Galkeno 900 adit, this water could be pumped to the Elsa mill for usage as process water during warm summer periods by installing a suitable pipeline for seasonal operation. Once the Galkeno 900 adit has been drained, and if there is no flow from the Galkeno 300 adit, any cracks in the vicinity of the hydraulic plug in the Galkeno 900 adit could be sealed enabling the storage of the wastewater in the adit during winter months for a seasonal treatment. This treatment could be chemical and/or a combination of chemical and passive treatments provided by constructed wetlands or natural attenuation processes at suitable downstream locations, or recycling and/or treatment through the Elsa mill during the warm summer period.

Pumping of the drainage water to the Elsa mill, when in operation and/or refurbished, would decrease the freshwater demand for milling. It would further facilitate the centralization of waste water handling and treatment on a seasonal basis at the mill, and handling of the treated effluent through the tailings management facility after cessation of mining at the site. The wastewater treatment facility at the Galkeno 900 adit could then be mothballed , contingent upon the flow situations at Galkeno 300 and Galkeno 900 adits after complete drainage of the later adit and mine workings.

6. Passive Treatment by Constructed Wetlands Downstream of Galkeno 300

A passive treatment by constructed wetland downstream of the Galkeno 300 adit is feasible, but in the absence of any year-around performance data of the constructed wetland plot at this site or at any other site having similar location and climatic conditions, specially during prolonged periods of sub-zero temperatures and freezing of the substrate that supports the biological activity and provides treatment, the suitability of this option cannot be judged, and hence cannot be recommended as a stand alone system at the site.

Based on the very limited monitoring and performance data of the constructed wetland plot at the Galkeno 900 site, a 26-day retention time has been suggested by Microbial Technologies to decrease the dissolved zinc level in the effluent from approximately 30 mg/L to 0.2 mg/L, achieving a reduction factor of ~ 150. For the current dissolved zinc concentration of approximately 150 mg/L in the Galkeno 300 adit discharge, a five times longer retention period of ~ 130 days would be required for the constructed wetland to provide an adequate treatment to lower the dissolved zinc levels in the final effluent to near regulatory discharge limits. This long retention period, equalling more than one and half times the frost free period of ~ 75 days at the site, appears to be excessively too long and unachievable given the short duration of warm temperatures favourable to enhanced biological activity in the wetland substrate.

Additionally, this long retention period corresponds to a constructed wetland area of approximately 56 ha for treating the observed discharge flow of ~ 10 L/s (865 m^3/d) at the Galkeno 300 adit. Given the hilly terrain, it would be difficult to clear a reasonable flat area downstream of the Galkeno 300 adit for accommodating such a large sized constructed wetland between the adit and Christal Creek, at the same time maintaining adequately uniform flow, free from channelling and short circuiting, through the site for optimal performance. Furthermore, in the event of a wetland malfunction or poor performance or a complete failure, this large area would then have to be managed as a conventional waste management area, requiring rehabilitation and effluent control measures. And in the extreme case, a clean-up of the site consisting of removal and transportation of the contaminated material to the tailings management area may be required.

For the aforementioned reasons, the constructed wetland option is judged to be unsuitable for providing both short and long-term passive treatments to the Galkeno 300 adit discharge, unless proven otherwise by long-term monitoring and favourable performance of a reasonably sized constructed wetland at the site.

7. Passive Treatment by Natural-Attenuation Downstream of Galkeno 300

Based on the studies of MacGregor and Li (MacGregor 2001a&b), the natural attenuation and retention of metals by organic and mineralized soil horizons downstream of Galkeno 300 is judged to be the best passive treatment option available at the site. Although in the this study also, the site monitoring and performance data are limited to a single field season, there is credible evidence of the retention of zinc and other metals that could be further enhanced by distributing the downward migrating flow over a large distance along the hillside contour to increase the contact time with the soil matrix and improve its long-term metal retention characteristics. There is almost no construction or maintenance cost and the entire hillside terrain could be utilized.

As there are no performance data for cold temperature conditions and freeze-up of the shallow soil substrate above the underlain permafrost, this option is also not recommended as a stand alone system. It should, however, be incorporated with a backup chemical treatment system, as suggested in Option #5. Additionally, during the winter period of freeze-up and glaciation, the advancing freezing front leads to concentration gradient and enhancement of the dissolved solute in the liquid phase, away from the freezing layers, resulting in eventual crystallization of solute species in micro-liquid droplets just prior to their freezing. In the spring, the outer clean ice layers melt first before dissolution of the crystallized solute species within the frozen matrix, thus providing a retention mechanism unique to the northern cold climatic conditions (Nagashima and Furukawa 1997, Marion et al. 1999, Wakisaka et al. 2001 and Ostroumov et al. 2001). The contribution of this freeze-thaw mechanism to the natural attenuation process still remains to be fully evaluated.

In addition to the options considered above, there are a few other engineering considerations for collection and treatment of all adit discharges such as: plugging of all the adits for short-term storage of effluents during winter months and their pumping during summer months to a centralized water recycling or treatment facility; and diamond drilling of interconnecting underground mine workings, if accessible, to establish a good hydraulic connection amongst all workings in Galena Hill and pumping of the effluent from a single adit nearest to a centralized water handling facility for recycling or treatment. The Elsa mill, upon refurbishing, would be most suited as the centralized waste water handling facility, where the effluents could be recycled within process water streams or be chemically treated with other wastewater streams. These options are not considered further based on an incremental cost benefit analysis.

RECOMMENDED APPROACH

Based on the above considered options, the following integrated approach is recommended for handling the combined environmental issues of managing drainages from both Galkeno 300 and Galkeno 900 adits. The suggested steps may be implemented progressively depending upon the issue-priority and resource-allocation/availability analysis.

1. Divert the Galekeno 300 adit discharge through a semi-impervious ditch towards the Galkeno 900 adit for collection and treatment there,

2. Allow slow infiltration and dissipation of the drainage effluent, on its downward migration, through natural soils on the hillside for natural attenuation and metal retention within the organic and soil matrices over a wide length of the interconnecting terrain between the two adits,

3. Construct new and modern wastewater treatment and sludge management facilities at the Galkeno 900 adit for pH controlled precipitation, treated effluent filtration and final pH adjustment to < 9,

4. In the absence of significant acid mine drainage, investigate the feasibility of using sodium hydroxide for precipitation of dissolved metals and recovery of zinc from the treatment sludge,

5. Drain the Galkeno 900 adit via either the new wastewater treatment plant at the adit or recycle the water through the Elsa mill,

6. Progressively reclaim the open pits on Galena Hill by back-filling them with the available waste rock from nearby waste rock piles, and re-contour the back-filled pit surfaces for improved surface drainage of infiltrating precipitation to minimize water accumulation within the pits and its drainage to mine workings below,

7. Construct a new or rejuvenate and expand the existing experimental wetland test plot at the Galkeno 900 adit site and evaluate its performance at regular intervals on a year-around basis for a few years using flow through as well as mesocosm studies. The evaluation should include the impact of seasonal changes on microbial activity and metal removal efficiency, winter freeze-up of the shallow substrate above the permafrost, precipitation and/or co-precipitation or adsorption of the dissolved ionic species, long-term physical and chemical stability of the precipitated secondary minerals and precipitates in the substrate, and metal up-take by the established vegetation,

8. Select a natural wetland area receiving effluent from a drainage site such as the No Cash adit and monitor its performance as above in #7,

9. Select a natural attenuation and treatment area, similar to that existing downstream of the Galkeno 300 adit or the waste rock pile at the Husky mine and evaluate its performance for the seasonal variables and other stability factors listed above in #7, as well as the maximum metal retention capacity of the organic and inorganic components of the soil substrate,

10. Investigate the role of freeze-thaw dynamics in removal of dissolved ionic species by crystallization and/or precipitation during cold-front advance and their re-dissolution during ice melting,

11. Based on the long-term performance evaluation of the these passive treatment technologies, re-visit their suitability and possible incorporation in the long-term waste management strategy at the United Keno Hill site,

12. Evaluate the feasibility of diamond drilling for interconnecting the various mine working to facilitate mine drainage through a common adit close to Elsa Mill for recycling and/or treatment there, and

13. Evaluate the feasibility of holding drainages within the adits for a seasonal operation or recycling of the waste water through a centralized treatment facility.

SUMMARY AND CONCLUSIONS

At the United Keno Hill mining district near Elsa in central Yukon, mining for the past seventy years or so has left several adits, and inactive/or abandoned open pits and silver/lead/zinc underground mines, as well as tailings and waste rock piles. Whereas the effluents from the tailings and some adits and mine shafts are collected and treated with lime, metal bearing drainages from several adits and underground workings remain untreated, and are of significant cause of environmental concern at the site. One of such concern is the drainage from the Galkeno 300 adit, located on the north-northeast side of Galena Hill.

Several remediation options available for mitigating the environmental impacts of metal bearing drainage from the Galkeno 300 adit were reviewed and evaluated for their suitability at the site. These include: Do Nothing; Hydraulic Plugging of the adit; Collection and Treatment at the adit site or at a downstream or other locations; and Passive Treatments provided by constructed wetlands or by Natural Attenuation through native organic and inorganic soil substrates.

Based on the financial implications of meeting short and long-term water quality objectives and environmental compliance, a comprehensive waste water management strategy consisting of the utilization of the natural attenuation process and capacity of the native soil substrates in combination with the diversion of the Galkeno 300 effluent to the treatment facility at the Galkeno 900 adit for both passive and active chemical treatment has been suggested.

The natural attenuation process of metal retention by organic and inorganic soil horizons of the mineralized native soils has been identified as a promising technology, unique to the site, for passive treatment of metal bearing mine effluents. Also identified were existing knowledge gaps in the passive treatment technologies using constructed and/or natural wetlands and natural attenuation processes related to their performance in the cold climatic conditions of northern Canada.

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