Yukon
Energy, Mines and Resources

Department of Energy, Mines and Resources
Keno Hill Property
Yukon Territory

# Preliminary Terms of Reference for Field and Laboratory Studies of Mine Water Treatment Options at the Keno Hill Property, Yukon

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January 2004

HATCH

Rescan™

# KENO HILL PROPERTY, YUKON

## Preliminary Terms of Reference
## for
## Field and Laboratory Studies
## of Mine Water Treatment Options

Prepared for:

**Yukon Dept. Energy, Mines and Resources**
**Government of Yukon**
Whitehorse, Yukon

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# Preliminary Terms of Reference for Field and Laboratory Studies of Mine Water Treatment Options at the Keno Hill Property, Yukon

## 1. Introduction

In July, 2003, Hatch Associates Ltd. (Hatch) and Rescan Environmental Services Ltd. (Rescan) evaluated the major safety and environmental issues of the Keno Hill Property (Hatch/Rescan, 2003). The report identified metal loading of the aquatic ecosystem from mine water discharge as the most important environmental issue requiring immediate attention, and recommended that studies should be conducted to develop cost effective long-term methods for water treatment. This document describes preliminary Terms of Reference for a program of field investigations, bench scale laboratory tests and conceptual engineering to be completed in 2004.

## 2. Background

### 2.1 History

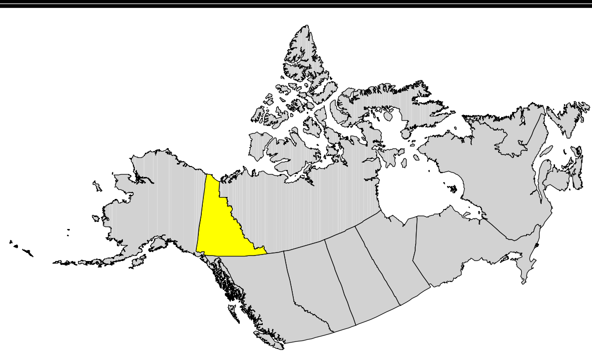
The Keno Hill property in central Yukon Territory has been the site of silver, zinc and lead mining since the early 1990's (see Figure 1 for project site location). The property covers approximately 15,000 ha in an east-west belt that is 29 km long and 8 km wide. The ore occurs in irregular shoots within narrow veins. As a result, the property includes at least 93 separate abandoned mine workings (*e.g.*, adits, pits, waste rock piles, tailings storage areas, *etc*.). In 1989, the last mining operations, United Keno Hill Mines Ltd. (UKHM), closed and the property was placed on care and maintenance. An attempt to reopen the mine in 1996 was unsuccessful and UKHM went bankrupt in 2000.

As of June 12, 2003, the Yukon Government has been overseeing interim care and maintenance of the Keno Hill property. The property is classified as a Type II site under the terms of the Devolution Transfer Agreement between the Yukon and federal governments, meaning that should the site be abandoned, and there is no responsible party to remediate the site, then the federal government will retain responsibility for funding the historical environmental liabilities that existed prior to April 1, 2003.

### 2.2 Previous Research

Five previous studies described the environmental liabilities of the Keno Hill property:

1. ***Yukon Territory Water Board (1997)***. On July 25, 1996, UKHM submitted an application to the Board for a Type A water licence to reopen the mine complex. The documents

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# Elsa/Keno Hill Site Location

Figure 1

supporting the application, plus the interventions of Indian and Northern Affairs Canada (INAC), Environment Canada (EC), and other stakeholders, were compiled in a seven-volume report. Although the bankruptcy of UKHM halted the reopening of the mine, the supporting documents in this report contain useful information on the local aquatic ecosystem;

2. ***PWGSC (2000)***. In March, 2000, Public Works and Government Services Canada (PWGSC) published a five-volume Environmental Baseline Assessment of the Keno Valley and the adjacent Dublin Gulch area;

3. ***CANMET (2002a, 2000b)***. In 2001, CANMET Mining and Mineral Sciences Laboratory completed two reports on metal-bearing drainage issues of the Keno Hill area based on a site investigation and a review of the scientific literature; and

4. ***Hatch and Rescan (2003)***. In 2003, Hatch/Rescan evaluated and prioritized the safety and environmental issues of the Keno Hill property. The report identified metal loading of the aquatic ecosystem as the most important environmental issue, and recommended short-term and long-term action plans. The short-term plan was to continue lime treatment of mine water from the principal sources. The long-term plan was to develop effective methods of water treatment that are less expensive than lime treatment, require less intervention, and can be applied to widely-scattered sources.

## 2.3 Mine Water Issue

Five sites in the Keno Hill area (Galkeno 300, Galkeno 900, No Cash 500, Silver King and Bellekeno) continue to release significant volumes of metal-enriched, but mostly neutral pH mine water. Figure 2 depicts the location of the various workings on the Elsa Keno Hill property. Other sites have no discharge or limited seasonal discharge. Generally the site does not have a major acid drainage issue associated with waste rock piles. One exception is a small acid drainage associated with the Husky waste rock pile.

Prior to 1993, there was no treatment of any mine water discharges in the Keno Hill area. At present, the drainages from Galkeno 900 and Bellekeno are intermittently treated on site by mixing mine water with slaked lime slurry to precipitate dissolved metals, allowing some of the metal-rich sludge to settle in small ponds near the adits, and discharging the overflow effluent downslope to the receiving environment. The sludge retained in the small ponds is excavated and moved to the tailings impoundment area. The drainage from that tailings impoundment is also treated with lime on an as-needed basis to reduce dissolved metals. The drainages from Galkeno 300, No Cash 500 and Silver King are not currently treated. Discharge from these adits is allowed to flow downslope with the expectation that metals are adsorbed to soils. This is commonly referred to on site as "natural attenuation". This process consists of both co-precipitation of metals with iron and manganese precipitation and metal adsorption on plants and soils.

## 2.4 Heavy Metal Contamination and Its Ecological Consequences

Zinc is the key marker heavy metal in the Keno Hill area. It has the highest concentrations in water, sediment and fish tissue of any of the heavy metals, and is therefore used as a sentinel metal. The CCME guideline for the protection of freshwater aquatic life is 0.03 mg/L total zinc (CCME, 1999). That concentration has been regularly exceeded in receiving water samples taken from Christal Lake, Christal Creek, Flat Creek and those reaches of the South McQuesten River that are immediately downstream of the confluences of Christal and Flat Creeks. Christal and Flat Creeks are the primary routes by which mine water enters the South McQuesten River. The South McQuesten River, a tributary of the Stewart River (which is a tributary of the Yukon River), is the principal drainage route for the north slopes of the Keno Hill complex. Zinc concentrations in stream sediments are elevated in the same areas in which zinc concentrations in water are elevated.

Elevated concentrations of zinc have reduced the abundance and taxonomic diversity of benthic invertebrates and fish. For example, fish abundance and diversity are highest in the South McQuesten River upstream of the confluence of Christal Creek and lowest in Christal and Flat Creeks. Zinc concentrations in muscle and liver tissues of Arctic grayling (*Thymallus arcticus*) and slimy sculpin (*Cottus cognatus*) are elevated in the same areas with elevated water and sediment zinc concentrations.

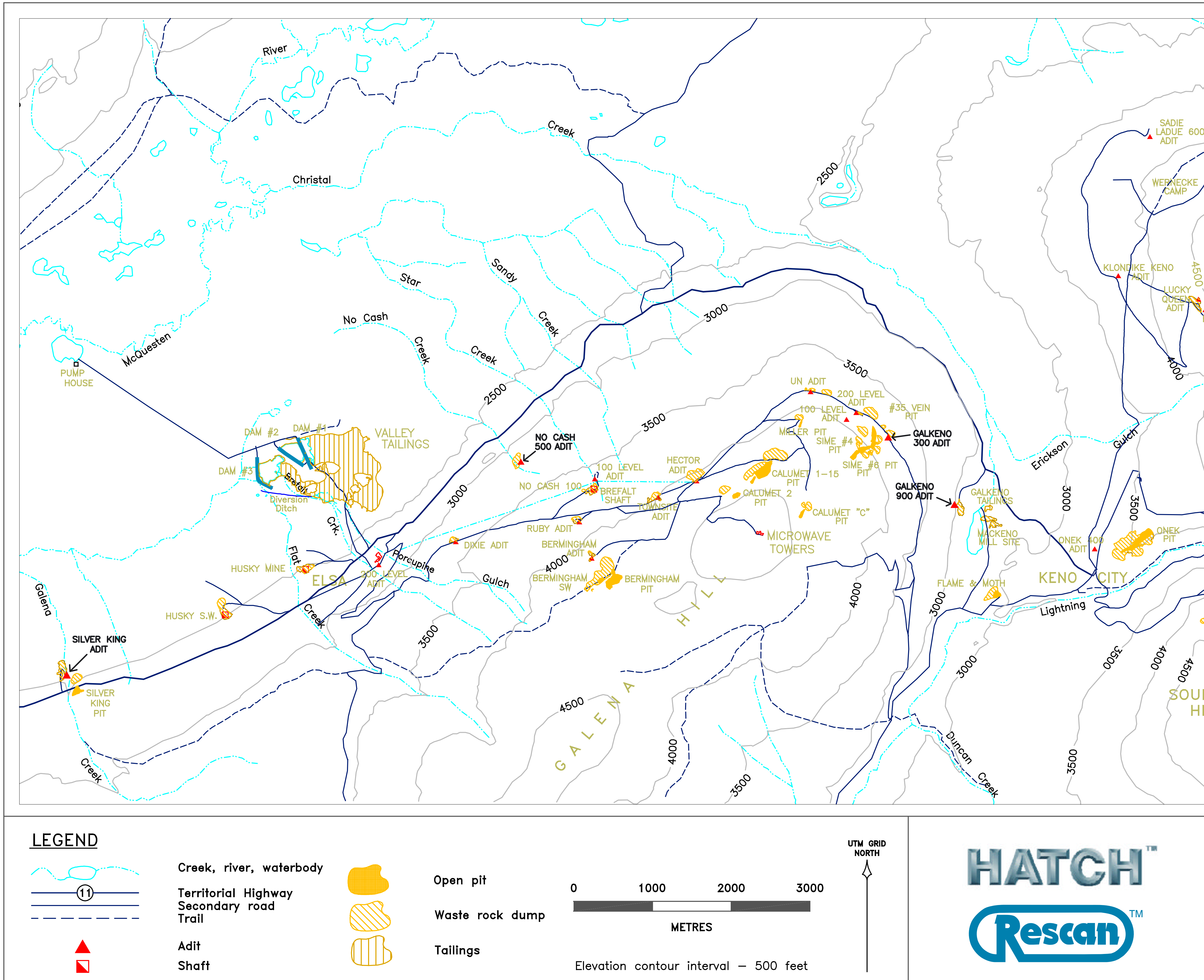
The elevated zinc concentrations in the Keno Hill area are believed to be due mainly to current discharges of mine water (CANMET, 2002b). Hence, the aquatic ecosystem of the Keno Hill area can begin to recover by natural processes only if the concentrations of heavy metals in mine water discharges are first reduced to levels approaching background. For this reason, the successful treatment of mine water is the key first step in restoration of the aquatic environment in the Keno Hill area.

## 2.5 Potential Water Treatment Methods

The analyses by CANMET (2002a, 2000b), and the observations made by the Hatch/Rescan team during their on-site evaluation in June, 2003, provided a list of potential treatment methods. They can be divided into three groups: active, semi-passive and passive.

**The active treatment method:**

> This method involves chemical treatment by the addition of slaked lime to the discharge in order to precipitate dissolved metals as metal hydroxides and gypsum. This method is currently used at the Galkeno 900 and Bellekeno sites (and at the Elsa tailings impoundment on an as-needed basis). It also was used at the Silver King site. Its principal limitation is the cost of reagents, maintaining the treatment facilities and sludge handling. For that reason, it is




**Elsa/Keno Hill Property Map**

Figure 2

viewed as an expensive measure that could be replaced once long-term, low-cost, semi-passive treatment methods were developed.

**The semi-passive treatment methods:**

*The redox-driven oxy-precipitation* of iron and manganese process with co-precipitation of zinc, copper and arsenic should be developed as a semi-passive method. The waters in the underground workings in the area are anoxic and as such are very high in dissolved iron and manganese. Upon exposure to fresh air (oxygen) the dissolved iron and manganese precipitate and in the process scavenge significant amounts of zinc, copper and arsenic as co-precipitates. Sorption occurs on hydrated metal oxides (oxy-hydroxides), most notably those of $Mn^{+4}$ and $Fe^{+3}$ which are present once the dissolved species $Mn^{+2}$ and $Fe^{+2}$ and are exposed to air and oxidized. These oxy-hydroxides usually undergo de-protonation (loss of $H^+$ ion) yielding a net negatively charged surface, which attracts and binds metal cations similar to clay surfaces as:

$$2\,\mathrm{MnO(OH)} + \mathrm{Zn}^{+2} = \begin{matrix}\mathrm{Mn-OO} \diagdown \\ \mathrm{Mn-OO} \diagup\end{matrix}\,\mathrm{Zn} + 2\mathrm{H}^{+}$$

The metal-oxide hydration and the associated sorption process also release hydrogen ions which contributes to acidity as shown by the above equation. The sorption ability of manganese oxide is higher than that of iron oxide, and especially pronounced for relatively fresh metal oxides precipitates which is the case in the adit flows.

This natural process is occurring at the site and may be a significant contributor to dissolved metal attenuation. The zinc, copper and arsenic enriched oxy-hydroxide precipitates subsequently deposit on the vegetated slopes downstream of the underground portals. Over the long term as these iron and manganese precipitates are buried. Buried, these precipitates could be exposed to anoxic conditions and resolubilize releasing the co-precipitated metals. This natural redox-driven precipitation process is potentially a treatment method provided that metal scavenging is efficient and that the solids can be retained and encapsulated to prevent resolubilization of the co-precipitated metals.

A preliminary evaluation should be conducted to assess whether this natural process warrants further investigation as a semi-passive treatment system. The advantages over lime treatment include no reagent cost and a significant reduction in precipitate volume.

*Constructed or artificial wetlands* are used primarily in temperate zones as bio-reactors to remove nutrients and to a lesser extent dissolved metals. Nutrients and metals are taken up by plants and micro-organisms and then exported in organic complexes or buried in sediments. The area of wetlands required to handle a given flow depends on the volume of flow, the porosity of the substrate, the type of contaminant and the average water temperature. The last factor is a key issue in the Keno Hill area because of the very low average annual temperature (about -3°). Wetlands would cease to function during the 8 months of the year that they are frozen, and would function at a low rate compared to temperate zone systems during the other 4 months of the year. The only way to compensate for temperature-dependence is to increase the surface area of a wetlands. Based on data collected from an experimental wetlands constructed downstream of the Galkeno 900 site in 1995, CANMET (2000b) estimated that a wetlands with a minimum area of 53.4 ha would be required for that site alone. That is far too large to fit into the local terrain. Therefore, CANMET (2000b) concluded that a primary treatment system based on constructed wetlands "is neither feasible nor practical, and is not recommended";

*Freeze crystallisation* occurs when water is gradually frozen. During this process relatively pure ice crystals grow on the surface and contaminants are extruded into the water layer below. The end result of the freezing process is a block of ice containing a vertical gradient of contaminants. When the ice thaws, the relatively clean surface water can be decanted, leaving behind a sub-surface water layer containing most of the contaminants. This method would require the construction of storage ponds for each site with control structures to decant clean water and treat the residual water with lime. There are clearly substantial engineering issues with this treatment: (1) the ponds must be large enough to hold all of the mine water produced by a site over an entire winter period; (2) it will be difficult to prevent mixing of surface and sub-surface water during the spring thaw; (3) the ponds and the control structures would require significant maintenance and (4) the remaining contaminated water would require lime treatment to precipitate the elevated dissolved metals.

**The passive treatment method:**

*Natural attenuation* occurs on the site when mine water flows over or through natural soils. Dissolved metals are retained in the soils through various chemical and biochemical mechanisms. The short-term effectiveness of natural attenuation in the Keno Hill area was studied at the Galkeno 300 site in the summer of 2000 (CANMET, 2000b). Long-term stability has yet to be determined. Certain obvious facts are known:

(1) natural attenuation ceases at freeze-up in October and does not re-initiate until break-up in June, and (2) any type of soil will eventually become fully charged with metals and lose its ability to remove more metals. Dispersal of mine water over larger areas of soil/vegetation can only delay the date at which time the soils become fully saturated. This method could be useful as part of an integrated approach in which natural attenuation is a secondary or tertiary treatment method.

Table 2-1 presents a summary of the various treatment methods identified in the CANMET reports.

## Table 2-1
## Summary of Mine Water Treatment Options for Keno Hill

| Method | Comments |
|---|---|
| Active treatment using slaked lime | Currently used at the Galkeno 900 and Bellekeno sites and at the Elsa tailings impoundment on an as-needed basis. Its principal limitation is the cost of reagants, manpower to maintain treatment facilities and handling sludge. |
| Semi-passive treatment using constructed wetlands | Preliminary studies at the Galkeno 900 adit indicate that the area of wetlands that would be required to treat mine water in the low-temperature, short-growing-season Keno Hill area is far too large to fit into the available terrain. |
| Semi-passive treatment using freeze crystallization | Substantial engineering issues related to storage of water, effective spring decantation of clean surface water, and lime treatment of residual water need to be overcome to make this a practical method. |
| Semi-passive treatment using redox-driven oxyprecipitation | This method is occurring naturally as part of the "natural attenuation" method. It is a potentially a semi-passive method provided that metal scavenging can be shown to be efficient and that precipitated metals can be contained. |
| Semi-passive treatment using anoxic limestone drains | This method is not practical for the Keno Hill area because the drains will freeze solid during the first winter and thereafter remain a permanent part of the permafrost layer. |
| Passive treatment using natural wetlands | There are no natural wetlands in the Keno Hill area that are large enough for this purpose. Even if there were, it would not be appropriate to use them because the purpose of mine water treatment is to rehabilitate the local aquatic environment. |

**(continued)**

**Table 2-1**
**Summary of Mine Water Treatment Options for Keno Hill (Completed)**

| Method | Comments |
|---|---|
| Passive treatment using permeable reactive barriers | Primarily used for remediation of slow-flowing groundwater, hence are not suitable for the large-volume surface flows from Galkeno 300 and 900 sites. Also, permafrost conditions create significant problem. |
| Passive treatment using natural attenuation in soils and on vegetation | Currently used at Galkeno 300 and Silver King sites. The long-term environmental acceptability of this method has yet to be confirmed. |

In summary, the long-term treatment of mine water at the Keno Hill property may consist of a combination of active, semi-passive and passive methods installed in sequence. The most practical combinations may differ among sites depending on seasonal flow variations and the chemical composition of the discharge. Regardless of what combinations are ultimately found to be feasible, there will be a need for maintenance and monitoring over the long term.

# 3. Objectives

The study should be staged into two phases. The first phase should be a more definitive evaluation of various treatment alternatives identified in the CANMET study and possibly others for the long-term control of metal contamination of the South McQuesten watershed from the Keno Hill historical mining works. This phase should also compile all existing water quality and water flows from the area. Potential semi-passive treatment options such as the redox-driven oxy-precipitation should be evaluated in a preliminary manner.

This initial phase of the work should be completed by May 1, 2004. The deliverable for this work should be a compilation of existing water quality and hydrology and identification of data gaps from the five main water discharge areas which are Silver King Adit, No Cash 500 Adit, Galkeno 300 Adit, Galkeno 900 Adit and Bellekeno 600 Adit. A more in depth review of treatment options with a cognizance of the remote location and extreme climate should be developed.

Phase 2 of the study would be a field program to fill any data gaps and complete a basic evaluation of semi-passive treatment options identified in Phase 1. The second phase of the study could involve the following:

- conduct field studies at the Keno Hill area in the summer of 2004 to assess the ability of semi-passive methods and the passive methods to individually or in combination treat mine drainage at the five major mine sites to reduce downstream impacts;

- conduct bench-scale laboratory tests to evaluate the potential for semi-passive treatment systems identified in the Phase 1 evaluation for the five major Keno Hill mine sites that currently discharge water;
- prepare conceptual engineering descriptions and process flowsheet for the full-scale versions of these systems;
- estimate the capital costs and operating costs for each of these systems;
- evaluate risk of failure for each type of system; and
- recommend which system(s) would provide the best treatment of mine water for the lowest long-term cost with the highest reliability.

# 4. Evaluation of Potential Semi-Passive Treatment

The work planned for the summer of 2004 should consist of some basic field investigations, bench scale laboratory testwork, conceptual engineering, cost estimates and risk evaluation of the selected treatment option. The program should be initiated in June 2004 and focus on five major discharges; Galkeno 300, Galkeno 900, No Cash 500, Silver King and Bellekeno 600. The work, from field investigation to risk evaluation, should be completed by October 2004. The work that might be involved for each component of the study is described in general terms below. The Phase 1 program should provide the definitive Phase 2 field program.

## 4.1 Field Program

Water quality and quantity should be evaluated for the five major underground workings namely Galkeno 300, Galkeno 900, No Cash 500, Silver King and Bellekeno 600. The effort should focus on the water quality of each discharge to assess the potential application of a semi-passive treatment process. Most of the water quality field investigation should be performed using insitu probes. Redox potential, pH and dissolved metal concentrations under an anoxic environment should be evaluated. Metal loading rates should be determined. For example, the Galkeno 300 flows are 40-50 L/s with dissolved zinc concentration of 100-150 ppm.

## 4.2 Laboratory Test Program

A bench scale test program should be set-up at the Elsa site to evaluate the effectiveness of semi-passive treatment methods to remove zinc, copper and arsenic from the discharge stream. The initial bench scale testwork should be completed in the field due to liable water quality conditions. Detailed analytical work should be performed in an approved laboratory on samples prepared and preserved in the field. The principal investigation should be to determine the efficiency of metal removal for zinc, copper, cadmium, arsenic, *etc*. In addition, settling tests should be performed on the metal precipitates to provide information for the conceptual engineering evaluation.

### 4.3 Conceptual Engineering

An engineering conceptual design should be completed to take the semi-passive treatment option to a pilot scale application in 2005. The engineering work should include a process flow sheet for metal removal. Method to collect the metal precipitates should also be evaluated. Secure disposal of the metal precipitates should be investigated.

### 4.4 Cost Estimate

An order of magnitude cost estimate for a semi-passive treatment system should be developed. The cost for a pilot scale application at one of the discharge areas such as Galkeno 300 should be developed. A broader cost estimate for a full scale semi-passive treatment system for the five major discharge areas should be provided.

### 4.5 Risk Evaluation

A risk evaluation of the proposed semi-passive treatment option should be completed. The risk should consider the reliability and effectiveness of the application in a combination of a semi-passive and passive treatment system.

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