Dept. of Energy Mines & Resources, Gov't of Yukon

Preliminary Site Evaluation and Prioritisation of Safety and Environmental Issues of the Keno Hill Property, Yukon

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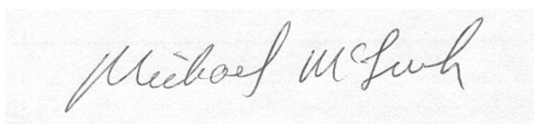
Prepared by: July 2003

Rob Henderson, P.Eng. (Hatch) Date



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1. Executive Summary

The Keno Hill property in central Yukon Territory has been the site of silver, zinc and lead mining since the early 1900s. In 1989, the last mining operation, United Keno Hill Mines Ltd. (UKHM), closed, and the property was placed on care and maintenance. An attempt to re-open the mine in 1996 was unsuccessful and UKHM went bankrupt in 2000.

As of June 12 2003, the Yukon government is overseeing interim care and maintenance of the United Keno Hill mine site. The United Keno Hill site is defined as a Type II site, meaning that should the site be abandoned, and there is no responsible party to remediate the site, the federal government will retain responsibility for funding the historical environmental liability which existed prior to April 1, 2003.

On June 02 2003, the Government of Yukon requested that Hatch Associates Ltd. (Hatch) and Rescan Environmental Services Ltd. (Rescan) provide an independent evaluation of the environmental and human health and safety issues in the immediate vicinity of the Keno Hill property. Hatch/Rescan's assessment and ranking of the Keno Hill issues indicated that the most important items requiring immediate attention are:

Metal loading of the aquatic system (in particular Galkeno 300). The Galkeno 300 adit is currently discharging water containing approximately 123 ppm Zn to the environment at a rate of 40-50 L/sec. The flow in 1996 was negligible. The pressure at the Galkeno 900 bulkhead should be checked to determine if excess water pressure is causing the Galkeno 300 flows. Short term action plans are to quantify the effect of this flow on Christal Creek and immediately commission an engineering study to treat the water. Primary water treatment option studies (including costs) for the Keno Hill site should be completed by Dec 2003 and appropriate treatment methodology should be in place for the 2004 freshet. The lime treatment systems at Silver King and Bellkeno should be maintained in working condition should treatment be required at short notice. In the longer term, an effective water treatment method for all the sites at Keno Hill is required. Lime treatment appears to be acceptable in the short term, however it is expensive and requires intensive management. Studies on natural attenuation and other passive systems should be continued.

Public access to dangerous sites. A listing of Keno Hill physical hazards by the CS&I Mines Inspector presents details of 26 sites with safety issues including open shafts and adits. Many of the sites are easily accessible to the public and are not fenced or identified as dangerous. The immediate action plan should be to limit public access to hazardous areas and install gates, locks and danger signs at all dangerous sites. The medium to long term action plan is to complete a site closure plan, demolish old buildings, seal up mine openings and complete clean-up of the site. Any buildings of historic value or facilities that may be useful to future mining operations should be identified and rehabilitated. Most of the old adits are unlikely to be used again due to their poor condition and small size and should be permanently closed.

Potential failure of the tailings dam. The tailings dam is built on permafrost using inadequate construction methods and was classified as "marginally stable" in 1996. The short term action plan is to obtain geotechnical advice as to the stability of the dam, monitor the subsidence of the dam and complete repairs as necessary. If the site is to be maintained under care and maintenance, the dam will likely require modifications as specified in the Water License QZ96-001. If the site is to be abandoned then the dam should be closed and rehabilitated.

Potential PCB contamination. The Keno Hill site has significant quantities of electrical equipment manufactured prior to 1977 when Canadian PCB regulations were introduced. Keno Hill has a small registered PCB storage building and it is likely that additional PCB material is still present in unused equipment scattered around the site. A comprehensive audit of the site should immediately be done to test old equipment and soils for PCBs and to determine if the current PCB storage site is compliant. If PCB contaminated material is on site it has to be stored correctly or removed and destroyed.

Essential studies. In order to develop an appropriate care and maintenance program, a better understanding of the meteorological and hydrological conditions of the site are required. A valid water balance and contaminant loading is required to evaluate the effects of elevated metals on the aquatic environment. An aquatic effects monitoring program should be developed for Christal Creek, Flat Creek, Lightning Creek and the South McQuesten River. Natural purification processes such as redox-driven oxy-precipitation of iron and manganese with associated adsorption of metals such as zinc, cadmium, copper and arsenic should be investigated. Freeze-purification of contaminated water should be evaluated. Further investigation of wetlands treatment should be de-emphasized until a primary treatment method is established. Wetlands may be appropriate as a reliable secondary treatment method.

The other important issues to be addressed in the short to medium term are the removal of chemicals from Elsa Mill, repairs to the Elsa Mill building, formation of ice plugs in adits, the potential for failure of the Porcupine Diversion Ditch, the potential for contamination of the Keno City water supply, the presence of asbestos in old buildings and the generation of dust from Elsa tailings.

2. Acknowledgements

This report was produced by Hatch Ltd. (Hatch) and Rescan™ Environmental Services Ltd. (Rescan). Paul Hosford (C.Eng., Hatch) was Project Manager, and Clem Pelletier (B.Sc., Rescan), Robert Henderson (P. Eng., Hatch) and Michael McGurk (Ph.D., R.P.Bio., Rescan) wrote the report. Bill Dunn P.Eng. was the project co-ordinator for the Yukon Government department of Energy Mines and Resources. The following individuals attended meetings with Clem Pelletier and Robert Henderson during their visit to Whitehorse and the Keno Hill property (June 10-13, 2003):

Al von Finster	Fisheries and Oceans Canada
Sandra Orban	Fisheries and Oceans Canada
Bengt Petterson	Yukon Envionment
Frank Patch	Yukon Envionment
Vic Enns	Environment Canada
Eric Soprovich	Environment Canada
Naresh Prasad	Yukon Occupational Health and Safety
Robert Thomson	Yukon Energy Mines and Resources
Hugh Copland	Yukon Energy Mines and Resources
Anne Leckie	First Nation of Na-Cho Nyak Dun
Robert McIntyre	Access Consulting Group
Dan Cornett	Access Consulting Group
Ross Zawada	Nevada Pacific Gold Ltd

3. Introduction

On June 02 2003, the Government of Yukon requested that Hatch and Rescan provide an independent evaluation of the environmental and human health and safety issues in the immediate vicinity of the Keno Hill Property. The terms of reference specified that the report will:

1. Identify Health and Safety risks and evaluate significance.
2. Prioritise these risks in terms of which should be dealt with immediately and those that can be dealt with in the mid or long term.
3. Identify risks to the environment/environmental quality at the site or in the receiving environment and evaluate significance.
4. Prioritise these risks in terms of which should be dealt with immediately and those that can be dealt with in the longer term.
5. Identify future studies or monitoring programmes which should be instituted to measure cumulative effects, potential long term impacts or which are required to better characterize the risks.
6. Identify significant changes which have occurred since the Environmental Baseline Assessment done by PWGSC in 2000.

This report prioritises those issues and identifies future studies or monitoring programs that may be required to better characterise the issues.

On June 10, 2003, Clem Pelletier (Rescan) and Rob Henderson (Hatch) flew from Vancouver to Whitehorse and spent the day discussing the Keno Hill area with territorial and federal regulators. On June 11, they drove to Keno City and inspected the project area. On June 12, they returned to Whitehorse for additional meetings with regulators and then flew back to Vancouver.

4. Background Information

4.1 Location, Access and Physiology

The Keno Hill property in central Yukon Territory (63°55'N and 135°25'W) has been the site of silver, zinc and lead mining since the early 1900s. The site is approximately 354 km due north of Whitehorse in the vicinity of the communities of Keno City and Elsa. Keno City is a hamlet populated by 30-50 residents and Elsa village is currently unoccupied. A general site location map and a detailed site plan is provided in Appendix A.

Access to the area is via a 407 km, two lane paved road from Whitehorse to Mayo and a 45 km, all weather gravel road from Mayo to Keno City. Total distance to site by road from Whitehorse is 452 km.

The Keno Hill camp is considered to be Canada's second largest producer of silver. From 1914 to 1989, approximately 6.8 million kg (218 million ounces) of silver was produced from over 34 mine sites. The many old mining operations are spread over an area approximately 26 km long by 6 km wide located on three hills.

Keno Hill (1,825 m) is one of three prominent hills located to the south of McQuesten Lake. Galena Hill and Sourdough Hill rise to elevations of about 1,400 m and 1,370 m respectively. The broad McQuesten River valley is located north of the three hills and has an elevation of approximately 600 m. Lightning Creek drains to the south of the hills towards the Mayo River. Both the Mayo River and the South McQuesten River report to the McQuesten River and ultimately to the Stewart River.

The climate of the area is rigorous with cold winters and short summers. Mean annual temperature in Mayo is –3 ^{o}C. Winter temperatures have been recorded to –55^{o}C and summer temperatures to 32 ^{o}C. Because of the northern latitude of the site, there is no true daylight in December and no true darkness in June. The area is underlain with irregular regions of permafrost and its occurrence is dependent on elevation, hillside exposure, depth of overburden, vegetative cover and presence of water.

4.2 Site Development History

The Keno Hill area has a long history of occupation and development. The area has been used for centuries by the local First Nations for their traditional lifestyle. In 1885, prospectors entered the area looking for placer gold. The first recorded discovery of silver-lead was the Silver King vein on Galena Hill in 1903 and mining commenced in 1913. In 1919, silver vein discoveries on Keno Hill led to a staking rush in the area.

The Treadwell Yukon Company Limited entered the area in 1921, acquired the better showings and began shipping hand-cobbed ore. Treadwell constructed a 110 tonne per day mill at the townsite of Werneke on Keno Hill in 1924. The Wernecke Mill produced until 1933 and then was relocated to Elsa on Galena Hill. In 1936, the 136 tonne per day Elsa Mill was put into operation. The Elsa Mill capacity was further expanded to 450 tonnes per day in 1951.

In 1945, Conwest Exploration Co. Limited and Frobisher Exploration Co. Limited acquired all former Treadwell Yukon Co. Limited's interest and formed Keno Hill Mining Company Limited. In 1948, this company was reorganized as United Keno Hill Mines Limited (UKHM). Falconbridge Limited acquired control of UKHM in 1962 and operated the properties until January 9, 1989, when production was suspended due to falling silver prices, high production costs and an inability to meet production targets.

Ore was obtained from a total of 34 UKHM underground mines and open pit operations. The majority of the ore, 4,420,000 tonnes, was produced from underground mines. Average ore grade from 20 different deposits was 1,440 g/t Ag, 7 % Pb and 4.4 % Zn. Over half of the underground production of UKHM silver came from the Hector-Calumet Mine (1935-1972). Open pit production commenced in 1977 and produced a relatively small quantity of 425,600 tonnes of ore grading about 580 g/t Ag, 3 % Pb and 0.4 % Zn from 14 different deposits.

The village of Elsa originated in 1929 with the opening of the Elsa Mine. The population of the village varied with the level of mining activity and approximately 400 people lived in Elsa prior to the shutdown in 1989. The unoccupied village is now comprised of many wooden industrial buildings in relatively poor condition. A school, recreation (curling) center, swimming pool building and a bunkhouse at the east end of Elsa appear to relatively new and in fair condition.

Keno City is currently inhabited by 30-50 people and is a cluster of log structures, a 12-room hotel, cabins, café, museum and bakery. The hamlet has a fire hall including a well and pump for the potable water supply. Keno City is a Yukon tourist destination on the Silver Trail and popular sights are the signpost on Keno Hill, alpine butterflies and the Keno Mining Museum. There are designated hiking trails in the area and a hotel, a campsite plus several log cabins exist for tourist accommodation.

A small townsite previously existed at Calumet and the houses have long since been removed and the sites flattened. There is a public road passing through Elsa to Calumet and on to Keno City via the Duncan Creek road. Small industrial buildings, cabins or bunkhouses exist at most of the old workings.

Electric power is currently supplied to site from a Yukon Energy Corporation 5 megawatt hydro dam located near Mayo. The hydro dam was originally constructed in 1952 by UKHM and there are numerous old power lines, transformers and steam lines on the site.

4.3 Recent Ownership

About 75% of the claims in the United Keno Hill area are registered to UKHM. The UKHM property consists of two Crown Grants, 674 mining leases and 289 mineral claims covering an area of approximately 15,000 ha. Since the Elsa Mill was closed in 1989 there has been very little subsequent mining activity.

The Keno Hill property is considered by the Yukon Government to have potential for future exploration and mining for silver. A 1996 engineering study estimated that the property had measured and indicated resources of approximately 22 million ounces of silver.

In July 1990, BLM Mines Inc. purchased the 44.8% interest in UKHM formerly held by Falconbridge Ltd. In 1991, Rosmith Investments and Stephen Powell each acquired 50% of the issued and outstanding common shares of BLM. In January 1998, UKHM was issued a Class A water license, however production did not start. In September 1999, the Supreme Court of the Yukon ordered that the mine assets and property be sold and in February 2000, UKHM applied for creditor protection.

In September 2001, AMT Canada Inc. agreed to purchase the Elsa property and assets for $3.6 million and proposed to reprocess the tailings at Elsa. Terms of the purchase agreement were not met and on February 14, 2003, the Supreme Court of the Yukon ordered AMT Canada Inc to be divested of its mining claims and assets at Elsa.

In February 2003, Nevada Pacific Gold Ltd. announced their intention to purchase the property from a group of secured creditors subject to completion of due diligence. On May 29, 2003, Nevada Pacific elected not to complete the purchase of the Keno Hill assets.

As of June 12, 2003, the Yukon government is overseeing interim care and maintenance of the United Keno Hill mine site. The United Keno Hill site is a Type II site under the terms of the Devolution Transfer Agreement (DTA) defined by the Yukon government as follows:

"*On April 1, 2003, lands that were controlled previously by the federal government's Department of Indian Affairs and Northern Development (DIAND) were transferred to the Yukon government along with legislative and regulatory authority. Seven mines were identified as Type II sites under the Devolution Transfer Agreement. These are existing mine sites that, if abandoned without proper closure, could pose substantial financial liability to the government and result in long term environmental impacts.*"

"Should the United Keno Hill site be abandoned under terms of the DTA, and there is no responsible party to remediate the site, the federal government will retain responsibility for funding the historical environmental liability which existed prior to April 1, 2003."

5. Previous Research and Documentation

5.1 Application for Water License QZ96-001

On July 25, 1996, UKHM submitted an application to the Yukon Territory Water Board for a Type A water license to re-open the Keno Hill mine complex. The documents submitted by UKHM in support of that application, the correspondence between the Board and UKHM, the interventions by Indian and Northern Affairs Canada (INAC), Fisheries and Ocean Canada (FOC), Environment Canada (EC), and the screening report prepared under the *Canadian Environmental Assessment Act* (CEAA) by INAC were compiled in a seven-volume file (Yukon Territory Water Board, 1997). Apart from correspondence, application forms, information sheets and public notices, the file contained several reports prepared by UKHM and its consultants, including:

- a mine reopening and operating plan (UKHM, Exhibit 1.4);
- a spill contingency and emergency response plan (UKHM, Exhibit 1.5);
- a conceptual design for tailings disposal (Bruce Geotechnical Consultants Inc., Exhibit 1.6);
- a site characterisation report with 10 technical appendices (Access Mining Consultants Ltd., Exhibit 1.7), including a report on fish and fish habitat of the area (White Mountain Environmental Consulting, 1995, Exhibit 1.7.5);
- a mine closure plan (UKHM, Exhibit 1.8);
- supplementary water licence information (UKHM, Exhibit 1.9);
- an intervention by the Water Resources Division of INAC (Exhibit 5.1) and a joint intervention by FOC and EC (Exhibit 5.2); and
- a screening report of the proposed mine re-opening from INAC (Exhibits 9.1-9.3).

Although the mine plans have been superseded by the bankruptcy of UKHM, some of the environmental information provided by UKHM and its consultants was useful in this study. For example, the study of fish and fish habitat by White Mountain Environmental Consulting remains the only study on fisheries resources in the project area. The interventions by INAC and DFO and INAC's CEAA report provide useful perspectives on the environmental liabilities of the area.

Water licence QZ96-001 was granted to UKHM on January 26, 1998 (Yukon Territory Water Board, 1998). On March 20, 2002, the Yukon Territory Water Board re-assigned the licence to Advanced Mineral Technology Canada Inc., the new owners (at that time) of the Keno Hill property. With the Government of Yukon's acceptance of responsibility for care and maintenance of the property in 2003, the water licence is assumed to have been voided.

5.2 Environmental Baseline Assessment

In March, 2000, Public Works and Government Services Canada (PWGSC) published a five-volume Environmental Baseline Assessment of the Keno Valley and Dublin Gulch areas (PWGSC, 2000). The objective was to provide baseline environmental information for the Waste Management Program of INAC. The report provided an overview of the environmental setting and land use of the area and site assessments reports for each of 93 separate exploration and mining sites on Galena Hill, Keno Hill, Sourdough Hill and the northern half of the Gustavus Range. It also included two appendices: water quality monitoring data for the area and a copy of the 1994-1995 fish and fish habitat assessment of the area (White Mountain Environmental Consulting, 1995).

At each of the 93 sites, the assessment report described location and access, site physiography, geology and mineralisation, site history, mine development, potential contaminants of concern, water quality, and reclamation activities. Maps, photographs and results of water quality analyses were shown for each site.

At the request of INAC, the authors of PWGSC (2000) did not draw comparisons or make references to environmental quality criteria or make recommendation for future action. Hence, their report is primarily a source of data.

5.3 Review of Mine Drainage Options

In 2001, CANMET Mining and Mineral Sciences Laboratory completed two reports on metal-bearing drainage issues of the Keno Hill area. The first report, Davé (2002a), reviewed the issues and the available treatment options. It reported that:

- significant drainage of metal-enriched, but mostly neutral-pH, mine water occurs from adits at five sites: Galkeno 300, No Cash 500, Galkeno 900, Silver King and Bellekeno. Other adits have no discharge or limited seasonal discharge. Acid rock drainage occurs from a small waste rock pile at the Husky Mine site;

- the drainages from Galkeno 900, Bellekeno and Silver King are treated on site by mixing mine water with slaked lime slurry, allowing the sludge to settle in ponds and discharging the clear effluent to the receiving environment. (Note: treatment of the drainage at Silver King has stopped since Davé (2002a) was completed);

- the Christal Creek–Flat Creek–South McQuesten River area has been most affected by metal-mine drainage from the site. The majority of the zinc, other metals, and dissolved sulphate load in the receiving water system originates from adits of three sites: Galkeno 300, No Cash 500 and Galkeno 900, and to a lesser extent from the Onek adit. However, the overall metal load to the system remains high because of untreated and/or unconfined discharges from other sites;

- a hydraulic (*i.e.*, concrete) plug was installed in the Galkeno 900 adit in 1993, (Exhibit 1.7 of Yukon Territory Water Board, 1997) but it has failed to stop the flow of metal-enriched water. Instead, the water levels in the old mine rose and some of it is now believed to be flowing out of the Galkeno 300 adit;

- a wetland treatment system is probably inappropriate for the sub-Arctic conditions of central Yukon where temperatures are below freezing for 9 months of the year. In addition, the area required for such a treatment system at Keno Hill is estimated to be on the order of 54 hectares, which is excessive considering the area that is available. Therefore, a stand-alone wetland treatment system is not feasible and is not recommended;

- two methods appear to have some promise and could be combined with other passive systems, but both require further investigation. Anoxic limestone drains might be considered to remove zinc in the form of smithsonite ($ZnCO_3$), but the efficiency of such systems is only about 20-50%. A freeze-crystallisation purification system, which naturally occurs at the site during winter, could also be used; and

- long-term management of metal-bearing drainages may require both chemical and passive treatment operated sequentially or in parallel depending on seasonal flow and climatic conditions.

The second report, Davé (2002b) dealt with specific remediation options for mine water exiting the Galkeno 300 adit. It considered four options:

- ***do nothing*** – this was considered unacceptable because the effluent does not meet CCME guidelines for the protection of freshwater aquatic life;

- ***hydraulic plugging of the adit*** – this was also considered unacceptable because of the failure of the hydraulic plug in the Galkeno 900 adit and because of the danger that a plug may fail without constant care and maintenance;

- ***collection and treatment of mine water at the adit or at a downstream site*** – this option is feasible because it is now being done at Galkeno 900, but it would require construction of a diversion to the Galkeno 900 treatment facility or construction of a heated water treatment facility and settling ponds and year-round maintenance at or near the adit. However, it is not a long-term solution; and

- ***Passive treatment of mine water with constructed wetlands or by natural attenuation through soil*** – constructed wetlands are not feasible because of the large area of wetland that would be required. Natural attenuation occurs but is not recommended as a stand-alone system, but could be combined with backup chemical treatment system.

5.4 Closure Considerations by Na-Cho Nyak Dun First Nation

On May 30, 2003, the director of the Lands and Resources Department of the First Nation of Na-Cho Nyak Dun (NND), issued a memo that listed a number of environmental issues that needed to be considered for closure of the Keno Hill property (Leckie, 2003). They are:

- ***Water treatment strategies*** – aquatic resources should be protected from high levels of metals and low pH using Canadian Council of Ministers of the Environment (CCME) guidelines. Effluent from the tailings facility and from adits of Silver King, Bellekeno, Galkeno 900 and possibly Onek sites should undergo long-term treatment. Engineered wetlands or other kinds of active or passive methods should be put in place;

- ***Treatment of effluent from waste rock dumps*** – run-off from waste rock dumps should be monitored for acid generation, and waste rock dumps should be re-contoured and re-engineered for stability;

- ***Treatment of sludge*** – sludge produced by water treatment plants is currently dumped in the tailings facility. This sludge contains heavy metals and may become a long-term source of heavy metals if weathered or dissolved by water flowing through the facility. The sludge should be de-watered and treated properly according to environmental standards;

- ***Ice plugs*** – monitoring of ice plugs should continue because they may be a source of heavy metals when they melt;

- ***Physical stability of the tailings dams*** – at least two failures of the tailings dams have occurred since 1972;

- ***Reclamation of open pits and closing of adits and mine shafts***; and

- ***Waste management strategies*** – waste dumps need to be consolidated and removed from the area north and below of the Elsa townsite. The material in the dumps may contain electrical transformers and PCBs. Chemicals, reagents, fuel and PCBs on that site should be disposed of in accordance with guidelines.

5.5 Recent Water Quality Data

The pH and concentrations of zinc and sulphate in water samples continue to be taken from a variety of stations in the study area on a weekly basis (Access Consulting Group, unpublished data 2001-2003). These stations are primarily the outfalls from mine sites rather than stations in receiving waters.

5.6 Summay

A substantial literature has accumulated that describes the environmental issues of the Keno Hill area. Although the human health and safety problems and the environmental problems of the area are well-documented, there is, at present, no consensus on the solutions to those problems.

6. Current Land Use

Land tenure is currently comprised of various mining claims and leases and commercial, recreational and residential properties. With the decline in mining, tourism and recreation are now the most significant economic activities in the study area. The Keno Valley is part of the historic Silver Trail mining area and Keno City maintains a mining museum. Tourists can visit many of the 93 mine sites described by PWGSC (2000). Keno City is readily accessed by a paved road.

There are at least two guiding-outfitting operations in the area that are based out of Whitehorse, and two territorial campgrounds at Hanson Lake. Eight trapping concessions are partially or completely within the Keno Valley area, and trapping continues to be an important way of life for many residents and for the Na-Cho Nyack Dun First Nation.

The primary sport fish in the South McQuesten River and its tributary creeks is Arctic grayling. Other sport fish such as lake trout and northern pike are found in lakes. Chinook salmon are also present in the South McQuesten River, but in 1994 and 1995, the years of the only fish and fish habitat survey in the study area (White Mountain Environmental Consulting, 1995), chinook fry were found only below the confluence of Haggart Creek. At that time, access to the upstream reaches of the South McQuesten River was blocked by a log jam about 1 km upstream of the confluence of Haggart Creek. Since 1995, a bypass channel around the log jam was constructed that allows chinook salmon movement upstream (W. Dunn, personal communication). At this time, it is not known whether chinook salmon have taken advantage of the bypass, but it is reasonable to assume that they have and that they are now present in the Keno Hill study area.

The region once supported small-scale logging operations, mainly in support of the mines. Although there are no active logging operations, the potential for further logging exists now that the forests have largely regenerated.

7. Overview of the Aquatic Environment

The UKHM Site Characterisation Report described the historical data on the water quality, sediment quality, benthic invertebrate community, and fish and fish habitat of the study area (Exhibit 1.7 of Yukon Territory Water Board, 1997). The conclusions derived from the study of each of those four components of the aquatic environment paint a common picture of the historical impacts of mine activity on the local aquatic ecosystem.

The key heavy metal in the area is zinc because it is has the highest concentrations of any of the other heavy metals. It is used in this report (as it has been in other reports) as a sentinel metal. The CCME zinc guideline for the protection of aquatic life is 0.03 mg/L. Changes in zinc concentration over time and space are assumed to reflect changes in concentration of the other, less-common heavy metals. Two other water quality variables, dissolved sulphate and pH, are also important because they are indices of historical or residual impacts of mine activity.

Concentrations of zinc and sulphate show that the main areas of aquatic habitat that have been impacted by mine activities are Christal Lake, Christal Creek, Flat Creek and those reaches of the South McQuesten River immediately downstream of the confluences of Christal and Flat Creeks. The South McQuesten is a tributary of the Stewart River which, in turn, is a tributary of the Yukon River. Although zinc is elevated in Lightening Creek, which is tributary to the Mayo River (also a tributary to the Stewart River), average zinc concentrations are lower than those in Christal and Flat Creeks.

The majority of the zinc, other metals, and dissolved sulphate load originates from adits of Silver King, No Cash 500, Galkeno 300, Galkeno 900 and Bellekeno sites, and to a lesser extent from the adit of the Onek site. Mine water from No Cash 500 flows into No Cash Creek and thence though soil and natural wetlands to the South McQuesten River. There is no evidence that metals from No Cash 500 water enter the South McQuesten River. Although the effluent from the Galkeno 900 adit and the Elsa Tailings decant are treated with lime, the overall metal load to the system remains high because of the cumulative impact of many, small untreated and/or unconfined discharges from other sites (Davé, 2002a, 2000b). There is also a potential contribution from tailings deposited in Christal Lake and Christal Creek, from tailings that have been deposited into Flat Creek, and from weathering of tailings stored within the Porcupine Gulch north of the Elsa townsite.

Mine water from the Silver King adit flows into Galena Creek and thence into Flat Creek and the South McQuesten River. Mine water from the Galkeno 300 and 900 adits flows into Christal Creek. Water from the Bellekeno 625 level exfiltrates from the second settling pond into Lightning Creek.

7.1 Water Quality

Concentrations of total zinc are typically low in the South McQuesten River upstream of the confluence of Christal Creek, and are believed to represent near background concentrations. The pH is around 8.0, sulphate averages about 50 mg/L, and most metals are less than the detection limit. Total zinc ranged from <0.002 to 0.033 mg/L over the 1974 to 1996 period. It is not known if there are water quality data for this reach for any time after 1996, but it is not expected to have changed since 1996.

Zinc concentrations in Christal Creek are substantially higher than background levels, occasionally exceeding 1.5 mg/L in 1996 at the Elsa/Keno Road station, just downstream of Christal Lake. Zinc concentrations appear to decline with distance along Christal Creek because concentrations further downstream at the Hanson Lake Road station averaged about 0.2 mg/L in 1996. This indicates that the major sources of metals to Christal Creek are in its headwaters close to Christal Lake. Zinc concentrations have remained above the CCME guideline for protection of aquatic life in Christal Creek despite treatment of mine water from Galkeno 900 since 1994 and the use of natural attenuation to reduce metal concentrations in mine water from Galkeno 300. For example, a total zinc concentration of 0.15 mg/L was recorded at the Hanson Lake Road station on February 2, 2001.

Zinc concentrations in the South McQuesten River downstream of the confluence with Christal Creek (*i.e.*, at the pumphouse) have been highly variable, but are typically greater than the background levels found upstream of the Christal Creek confluence. Concentrations occasionally exceeded 0.3 mg/L in the early 1990s, and average zinc concentrations in 1996 were slightly lower than 0.05 mg/L. Concentrations just upstream of the confluence with Flat Creek have ranged from below detection limits to 0.07 mg/L. Concentrations in the South McQuesten River have remained above CCME levels since 1996. For example, on February 2, 2001, they ranged from 0.031 mg/L at the pumphouse (mid-way between the Christal and Flat Creek confluences) to 0.034 mg/L at the "UK3" station 350 m downstream of Flat Creek.

Total zinc loadings in Flat Creek tend to vary seasonally depending on water flow and the amount of releases from the tailings impoundment. They are typically high immediately below the diversion ditch and tailings impoundment. Zinc concentrations in Flat Creek 200 m upstream of the confluence with the South McQuesten River on February 2, 2001, were 0.025 mg/L, which was slightly below the CCME guideline.

Zinc concentrations in the South McQuesten River downstream of Flat Creek were generally less than 0.1 mg/L in 1996. They still exceeded the CCME guideline in 2001, being 0.034 mg/L on February 2, 2001, at station "UK3". Average zinc concentrations in the river generally decline with downstream distance from the Flat Creek confluence.

In summary, heavy metal concentrations in creeks and rivers of the study area, as indexed by zinc concentrations, have continued to exceed CCME standards since mining activities ceased in 1989. As late as 2001, zinc concentrations in Christal Creek and the South McQuesten River exceeded the CCME standard.

It is not clear whether concentrations have significantly decreased or increased with time in the affected areas since mining ceased in 1989 and since treatment began at the major sources of metal contamination (*e.g.*, lime treatment began at Galkeno 900 in 1994). The time series of zinc concentrations shown for receiving water stations in UKHM's site characterisation report do not show clear temporal trends, and there has been no statistical analyses of the available data (Yukon Water Board, 1997: Exhibit 1.7).

Although the metal concentration of selected mine water is currently sampled on a weekly basis, receiving waters do not appear to be regularly sampled. The latest data for stations in Christal Creek, Flat Creek the South McQuesten River and Lightning Creek were apparently taken on February 2, 2001, over 2 years ago.

It is important before initiating any changes in methods of mine water treatment to establish whether metal concentrations have remained constant in the system (apart from possible seasonal cycles associated with freezing and thawing) or whether they are changing significantly over time. If concentrations are decreasing over time, then the metal-loading problem may involve, in part, residual metal loading from tailings and contaminated sediments that were deposited before 1989. Alternatively, it may indicate the success of mine water treatment. However, if concentrations are constant over time or increasing, then they must be due to ongoing metal loading. If so, then current treatment methods are largely ineffective.

7.2 Sediment Quality

A study in 1994 showed that sediment zinc concentrations followed a similar spatial distribution as zinc concentrations in water samples. Zinc concentrations were lowest (310 μg/g dry weight) in the South McQuesten River upstream of the confluence of Christal Creek. Zinc concentrations were much higher in Christal Creek, ranging from 2,090 μg/g at the Keno highway station to 1,950 μg/g at the Hanson Road station. As a result, zinc concentrations in the South McQuesten River below the Christal Creek confluence were over four times greater than background levels (1,640 μg/g). The highest zinc concentrations in the study area were measured in Flat Creek just upstream of the confluence with the South McQuesten River – 5,180 μg/g). Zinc concentrations in the South McQuesten downstream of Flat Creek ranged from 1,640 μg/g just downstream of the confluence to 1,150 μg/g 9 km further down.

There is apparently no information on sediment metal concentrations in receiving waters of the study area since 1994, hence it is not known if the cessation of mining activities in 1989 or the initiation of water treatment at some sites since then has had any significant effect on the level of heavy metals in sediments. As with water quality, it is important to ascertain whether sediment metal levels have changed significantly over time.

7.3 Benthic Invertebrates

The density and taxonomic diversity of benthic invertebrates in the South McQuesten River both show a direct, positive correlation with zinc concentrations in water and sediments. For example, in 1990, density was greatest upstream of the confluence of Christal Creek (>6,000 organisms) and fell to <1,000 organisms downstream of the confluence of Christal Creek. Density remained low until 9 km downstream of Flat Creek where it climbed back to ~2,500 organisms. By a distance of 27 km downstream of Flat Creek density reached ~3,000 organisms. Taxonomic diversity followed a similar pattern: high (>60 taxa) upstream of Christal Creek, low in the reaches between Christal Creek and Flat Creek (<50 taxa) and highest 27 km downstream of Flat Creek (>80 taxa). A study conducted in 1994 showed similar results, suggesting that the cessation of mining activities in 1989 did not significantly affect the level of metal loading to which benthic invertebrates were exposed.

7.4 Fish and Fish Habitat

The only study to date of fish and fish habitat in the study area was conducted in 1994 and 1995 (White Mountain Environmental Consulting, 1995). Eleven species were found in the area. Slimy sculpin was found in the greatest number of habitats. Arctic grayling was the most abundant species. Chinook salmon fry were found in the South McQuesten River, but only downstream of the log jam near the confluence with Haggart Creek. It is reasonable to assume that they have since moved through the recently constructed bypass around the log jam and have re-colonised the South McQuesten River and its tributaries as far east as McQuesten Lake or that they will do so within the near future. The following discussion is restricted to the results of the 1994 and 1995 survey.

The abundance and diversity of fish followed the same spatial pattern observed for zinc concentrations in water and sediment (*i.e.*, highest in the South McQuesten River and lowest in Christal and Flat Creeks), suggesting a causal relationship between abundance and metal contamination. However, the relationship between metal contamination and fish distribution is undoubtedly more complex than that because of the differences in physical habitat between the river and its two tributaries.

7.4.1 Christal Lake and Christal Creek

Christal Lake is a small, shallow (maximum depth = 3 m), spring-fed lake at the head of Christal Creek. It contains only slimy sculpin. The substrate of the lake consists of silt overlying tailings. Some of the tailings have washed out of the lake because fragments of hardened tailings sludge are found along the length of Christal Creek.

Reach 5 of the creek is 5 km long and narrow (1-3 m), and has excellent pool and riffle habitat for juvenile grayling and sculpin, but it contains only slimy sculpin due to barriers to fish passage in reach 4. Reach 4 a narrow, 700 m-long, steep-sided canyon. Two collapsed bridges in this reach are barriers to fish passage. There is evidence of placer mining in this reach. Adult grayling were found in pools in the downstream part of this reach. Reach 3 is 3-5 m wide and shallow with gravel substrate and many beaver ponds. No fish were found, but grayling and sculpin probably move through the reach during periods of high flow. Reach 2 flows through a wide, flat area with many pools and beaver dams. Adult Arctic grayling were found in some large pools. Reach 1 is the shortest reach (30 m) and is actually the confluence of Christal Creek and the South McQuesten River. It supported the greatest number and variety of fish species in the creek. The confluences of creeks and the South McQuesten River provide the highest quality habitat and highest fish densities and species richness in the study area.

7.4.2 Flat Creek

Flat Creek has five reaches. The uppermost (number 5) is too steep to be fish-bearing and was not surveyed. Reach 4 is a 5 km-long, narrow (0.5 m), deep (1 m) channel in wet meadows. Its substrate appears to consist partly of tailings sludge. The quality of fish habitat is poor and no fish were found. Reach 3 is 4.2 km long and has a mainly silty substrate suggestive of tailings sludge with occasional sections of gravel. Log jams were found but no permanent barriers to fish migration. However, no fish were found. Reach 2 is a 700-m long, narrow channel with occasional deep pools that may support fish, however no fish were found. Reach 1 is 40 m long and is the confluence with the South McQuesten River. It is the only reach in Flat Creek that supports a diverse fish community.

7.4.3 South McQuesten River

The South McQuesten River is a meandering, mountain river with a wide variety of habitat types. It contains abundant habitat for all life stages of grayling and suitable rearing habitat for juvenile chinook salmon. The reach of the river near the outlet of McQuesten Lake is believed to be suitable habitat for chinook salmon spawning because of the presence of old spawning dunes. (The dunes are created by repeated nest digging by chinook salmon females.) Eleven species of fish were found in the reaches of the river within the study area, and grayling was the numerically dominant species. Grayling dominated the community upstream of Christal Creek, grayling and slimy sculpin together dominated the community between the confluences of Christal Creek and Flat Creek, and slimy sculpin dominated the reaches downstream of Flat Creek.

7.4.4 Lightning Creek

The reaches of this creek in the Keno Hill area have been extensively placer mined and contain only low quality fish habitat. The reach above the confluence with Thunder Creek contained adult grayling. The reach below Thunder Creek is turbid and contains only sub-adult grayling, perhaps displaced there by older and more aggressive conspecifics. The reach between Keno City and Duncan Creek was largely empty of fish except near Duncan Creek where adult and sub-adult grayling were found. Slimy sculpin were not present in Lightning Creek.

7.5 Metal Body Burden in Fish

Analysis of metal concentrations in the muscle and liver tissue taken from grayling and slimy sculpin in 1994 and 1995 showed a spatial distribution of metal concentrations similar to that shown by metal concentrations in water and sediment samples. The lowest concentrations of zinc, lead and copper were found in fish caught in the South McQuesten River upstream of the confluence with Christal Creek. The highest concentrations of zinc were found in slimy sculpin of Christal Lake and Christal Creek. One sculpin had a concentration of 835 ppm, which is over eight times greater than the threshold level established by the Canadian government for edible fish tissue (100 ppm). Average zinc concentrations in slimy sculpin from the mouth of Flat Creek were 30% lower than those from Christal Creek, but lead and copper concentrations were higher than those in Christal Creek. Grayling are known to avoid zinc-contaminated water, hence the presence of grayling in Christal Creek with relatively high tissue zinc concentrations suggests that the fish may have developed tolerance for high metal concentrations.

7.6 Fish Habitat Restoration

No aquatic habitat restoration activities have occurred in the study area.

7.7 Summary

The spatial distribution of metal concentrations in water, sediment and fish tissues and the spatial distribution of benthic invertebrate and fish density and species diversity all show a similar pattern. It is clear that mine drainage from the Keno Hill sites has had a major impact on the aquatic resources of the study area. It has reduced the abundance and diversity of benthic invertebrates and fish in both Christal and Flat Creeks and shifted the species composition of the fish community of the most impacted reaches of the South McQuesten River (*i.e.*, downstream of Christal Creek and particularly downstream of Flat

Creek) away from grayling, a valued sport fish, to slimy sculpin, a hardier fish of no recreational or food value. It has increased the tissue metal concentrations of fish within the impacted reaches.

From the perspective of the aquatic ecosystem, the most significant issues that must be dealt with at the Keno Hill area are those that allow the continued discharge of heavy metals into the affected watersheds. Habitat restoration is of no value as long as metal loading continues.

The single most important waterbody is the South McQuesten River itself. Although it has been contaminated by heavy metals, its physical habitat has not been damaged, hence the river can be eventually restored to a state resembling its pre-impact condition through natural processes once metal loading is reduced or eliminated. In contrast, both Christal Creek and Flat Creek have been physically damaged by the release of tailings and, in the case of Christal Creek, by placer mining in reach 4. Lightning Creek has been heavily damaged by placer mining. That damage will take time to repair by natural processes even after metal loading stops.

Fortunately, Christal and Flat Creeks are not essential for the production of grayling and chinook salmon in the area. The grayling population in the study area can be supported entirely by the wide range of habitat types present in the South McQuesten River. In fact, the shallow depths of Christal and Flat Creeks indicates that the South McQuesten River is the major overwintering habitat for grayling and chinook salmon in the study area. Chinook salmon typically spawn and rear in the mainstem of large rivers rather than in streams (Healey, 1991), although chinook fry will make opportunistic excursions into small streams during summer in search of prey and cover. Christal and Flat Creeks provide mainly ancillary spring spawning habitat for grayling and summer rearing habitat for grayling and chinook fry.

One important unanswered question is whether metal loading to the study area has changed significantly over time. The fact that mining activities ended in 1989 and that treatment of mine water has been done for almost 10 years would suggest that metal concentrations may have declined over the last decade. On the other hand, there may be substantial residual metal loads stored in stream sediments and in old tailing sludge that may take a long time to be released. Also, as stressed by Davé (2000a), metal loading is probably occurring from many small, unmonitored sources as well as from the four of five large, known sources. This issue bears directly on the question of the effectiveness of current mine water treatment techniques and it should be resolved before large investments are made in future remediation and mitigation activities.

8. Environmental Issues

The most significant environmental issue in the study area is the deleterious effect of metal-contaminated mine water on the aquatic ecosystem. The most valued components of the aquatic ecosystem are Arctic grayling and chinook salmon. The following issues all impact on the potential for release of metals to the environment.

8.1 Silver King Discharge

Silver King is the westernmost mine in the Keno Hill complex. It was the first mine in the area and was still active in the 1980's. UKHM planned to re-open it in the late 1990's. Until recently, water flowing out of the Silver King adit was treated using lime slurry to raise the pH and precipitate metals. The precipitated sludge was temporarily stored in settling ponds and the treated supernatant flowed into Galena Creek and thence into Flat Creek. The water is now allowed to flow untreated down the slope north of the mine into Flat creek using a "natural attenuation" approach. The concept is that metals will be absorbed by soil and organic matter as the water percolates downslope. The success of the natural attenuation process at the Silver King site has not been rigorously assessed.

8.2 Galkeno 300 Discharge

The Galkeno site is located on the north-east slope of Galena Hill. The main adit is the 300 level (elevation of 1158 m). Flow from the Galkeno 300 adit drains downslope, crosses the Keno City Road (where it may be responsible for ice formation in winter) and enters Christal Creek. Flow was approximately 3 L/sec in 1999 (PWGSC, 2000), but it has recently increased several-fold. It was approximately 8 L/sec in August, 2000, and between 10-15 L/sec in October 2001 (Davé, 2002b). Hatch/Rescan estimate the flow from Galkeno 300 in June 2003 to be approximately 40-50 L/sec and the concentration of zinc was measured to be 123 ppm Zn. It is possible that the concrete bulkhead installed in the Galkeno 900 adit in 1993 is partly responsible for that increased flow by causing the groundwater level to rise within Galena Hill.

High concentrations of zinc and manganese in the Galkeno 300 drainage are partially reduced by natural absorption by soil as the water flows through the substrate of the slope (Davé, 2002b). However, the high concentrations of zinc in the water, sediments and fish of Christal Creek indicates that some metals loading is continuing to occur, although it may be coming from other sources apart from Galkeno 300, including natural, non-mine-related sources.

There must be an upper limit to the soil's capacity to hold metals and eventually that upper limit will migrate down the slope and reach Christal Creek. The end result will be the direct loading of high concentrations of heavy metals into Christal Creek and even higher concentrations of zinc in the system downstream of Christal Creek. The length of time required for the soil storage capacity for heavy metals to be filled is not known, but it could be extended (again by an unknown period of time) by distributing the flow over a wider area of hillside and a greater volume of soil.

Davé (2002b) examined the options available for treating the effluent from Galkeno 300 and concluded that it is not prudent to continue to allow untreated water with high concentrations of heavy metals to enter Christal Creek. However, installing a bulkhead inside the 300 adit is unlikely to stop the flow since installing a bulkhead did not work at the nearby Galkeno 900 adit. Lime treatment of the flow, either at Galkeno 300 or at the Galkeno 900 site where treatment is already occurring, is feasible, but is not a long-term solution because it would require perpetual investment in treatment and monitoring. Long-term passive treatment of water by engineered wetlands may be possible, but problems are anticipated because of the low efficiency of such wetlands in a sub-Arctic environment and because there is not enough flat area near the site to create the large wetlands that would be required (Davé, 2002a, 2000b). The use of natural attenuation is possible, particularly if the flow is distributed over a wider area of hillside, but it should be backed up by a lime treatment system, particularly since the time to the complete filling of the soil's metal storage capacity is unknown. A combination of passive and primary water treatment methods is likely to provide the correct answer for Keno Hill.

The studies by Davé (2002a, 2000b) were preliminary in nature. They eliminated some options, such as the "do nothing" and "wetlands only" options, but they did not provide conclusive answers regarding the relative economic and environmental value of the remaining options, *i.e.*, natural attenuation and a combination of natural attenuation and active chemical treatment. More research has to be done to design and test a system that can provide a reliable, long-term, cost-effective solution to the problem of metal loading from the Galkeno 300 adit.

8.3 Galkeno 900 Discharge

The Galkeno 900 site is at the eastern base of Galena Hill, 200 m west of the north end of Christal Lake and 20 m above the surface of the lake. In 1993, a concrete bulkhead was installed inside the adit, but it failed to stop water flowing from the adit and may actually be responsible for increased flows from the Galkeno 300 adit higher on the slope of the hill. A treatment facility was constructed inside the portal soon after it was known that the bulkhead had failed to stop the flows. Water flowing from the adit is treated with lime and the clear effluent enters a settling pond. The second pond has been decommissioned due to slope stability concerns. The effluent then flows to Christal Lake through a 3 m deep gully. The main problem with this site is the failure of the bulkhead – it means that the treatment facility may have to be run in perpetuity if reliable, cost-effective passive treatment techniques for the mine water cannot be devised.

8.4 Bellekeno Discharge

The Bellekeno site lies on the north-east slope of Sourdough Hill. Water that collects in the Bellekeno mine system is pumped out to the 625 level where it was treated with lime. Treatment has been suspended since 2002. The treated water collects in two ponds where precipitate settles. The flow from the downstream settling pond does not exit via a spillway but apparently exfiltrates through the waste rock walls of the pond and enters Lightning Creek through subsurface channels. The main problem with this site is the same problem at for the Galkeno 900 site – how to treat the water without committing to a lime treatment system in perpetuity.

8.5 Elsa Tailings Dam Stability

The Elsa tailings dams were built on permafrost using inadequate construction methods and have breached at least twice resulting in release of sediment to Flat Creek. The dams were classified as "marginally stable" by UKHM's own geotechnical consultants in 1996 (Yukon Water Board, 1997: Exhibit 1.6).

The Elsa tailings were derived from ore mined at 35 different deposits in the Keno area (PWGSC, 2000). Beginning in 1935, the tailings were discharged from the Elsa mill and allowed to flow down Porcupine Gulch and the hillside around the gulch to form an alluvial fan in a bog in the headwaters of Flat Creek. Beginning in 1962 and continuing to 1979, a series of three dams were built in sequence on the western side of the bog to contain the tailings. The impoundment behind those dams now covers an area of 75 hectares and contains approximately 4.6 million tons of tailings.

The dams were constructed of local gravel and waste rock from underground mines laid on variably frozen peat and silty till. Dam number 1 was breached several times in the 1960's, resulting in the flow of supernatant and tailings into Flat Creek (and possibly into the South McQuesten River). In 1972, Dam number 2 was built to the west of Dam number 1, primarily as a polishing pond for lime-treated water from Dam number 1. Dam number 3 was built further west in 1979. In that same year, a ditch was constructed to divert water from Porcupine Creek around the south-west corner of the tailings to reduce erosion of tailings into Flat Creek (see section 8.2.4 below). In 1996, a toe berm was placed to reinforce Dam number 1. The soils underlying the dams have thawed since construction causing portions of the dams to subside. DIAND conducted the last remedial lift on the tailings dam in 2001. Tailings have begun to re-vegetate naturally in areas where standing water is present, for example downstream of Dam number 3. Approximately 10 hectares or 13% of the surface area of the tailings are now vegetated. Most of the tailings behind Dam number 1 are dry and unvegetated and are easily lifted by strong winds to create dust clouds.

Effluent from the tailings impoundment is treated by addition of lime in spring when zinc levels exceed 0.5 mg/L. Treatment was not occurring at the time that PWGSC (2000) conducted their survey nor during the Hatch/Rescan field visit in June 2003.

The principal environmental problem of the Elsa tailings impoundment is the potential instability of the tailings dams due to the inadequacy of their design and construction. INAC's intervention to the hearings concerning water licence QZ96-001 stressed these problems (Yukon Water Board, 1997: Exhibit 1.7). The actual water licence specified that the Licensee had to submit updated designs for toe berms and spillways for Dams number 1 and 3 and designs for the proposed tailings cells within the impoundment, and complete their construction prior to commercial production (among other requirements). The licence also specified that the Licensee had to submit designs to address dam stability issues, conduct a risk assessment and provide assurance of construction quality standards. None of these requirements were satisfied by UKHM before it went bankrupt.

Therefore, the stability of the tailings dams remain uncertain. There is currently no long-term plan to stop dam subsidence. Future dam failure and release of tailings and supernatant into Flat Creek and the South McQuesten River are possible, although the length of time that may pass before failure occurs has not been estimated.

8.6 Water Level in the Tailings Impoundment

Tailings should be kept submerged in order to prevent contact with air and subsequent generation of acid rock drainage, but a high water level in the impoundment threatens the stability of the tailing dams. The site inspection of June 11, 2003, showed that the water level in the impoundment is probably high considering the lack of suitable spillways. The water in the Elsa tailings dams may have to be lowered to increase the dam's safety margin.

8.7 Porcupine Gulch and the Tailings Diversion Ditch

Tailings from the Elsa mill flowed down Porcupine Gulch into the impoundment basin. Hence, residual tailings are still present in the gulch and metals may be leached from them when Porcupine Creek water flows through the gulch. In 1979, a diversion ditch was built to divert water flow from the gulch around the south-western side of the tailings impoundment and reduce the mobilisation and downstream transport of tailings into Flat Creek. However, the ditch still cuts through part of the tailings.

The diversion ditch has not been upgraded since it was built. It was never a well-engineered structure and has been continuously subject to small-scale failures and slumping as its walls thaw progressively. INAC recommended that the ditch be re-engineered to handle a 1:200 year flood event (Yukon Water Board, 1997: Exhibit 1.7), and that requirement became part of the water licence. However, UKHM never conducted that work because they ran out of money. At present, tailings continued to be periodically mobilised by large spring flows down Porcupine Gulch, resulting in periodic metal loading to Flat Creek.

8.8 Water Treatment Plants

Lime treatment has been used to remove heavy metals from mine water at four sites over the last 10 years: Silver King, Bellekeno, the Elsa tailings impoundment and Galkeno 900. At the present time, only Galkeno 900 has a continually active water treatment facility. The mine water from Silver King is now allowed to flow downslope to Galena Creek in the hope that natural attenuation removes metals. Treatment of water from the Bellkeno site stopped in 2001 when the mine dewatering pumps were shut down. The Bellekeno water treatment ponds leak and there is no measurable discharge.. Supernatant from the Elsa tailings impoundment is apparently treated with lime on an "as needed" basis to maintain acceptable metal levels in the overflow into Flat Creek. Lime treatment is a proven means of reducing metal loading, but it is an active technique that requires constant input of manpower and material. Besides the cost of adding lime to the water and maintaining the settling ponds, is the cost of dredging the metal-rich sludge from the settling ponds and storing it in a safe location. It would be preferable to use a passive treatment, if one is possible in the sub-Arctic environment of the Keno Hill area.

8.9 Sludge Disposal

The metal-rich sludge from the settling pond at Galkeno 900 is currently dumped on the Elsa tailings impoundment. This may be a short-sighted policy because of the danger that metals from the sludge may be re-mobilised back into solution. Consideration should be given to dewatering the sludge and compacting it in a secure landfill.

8.10 Wetlands

The use of wetlands for passive removal of heavy metals from mine water is an attractive idea because it does not require the perpetual input of manpower and materials. A small, experimental engineered wetland was constructed at Galkeno 900 to study the effectiveness of this technique. Davé (2002a) reviewed that facility and the scientific literature on the subject and concluded that a wetland treatment system is probably inappropriate for the sub-Arctic conditions of central Yukon where temperatures are below freezing for 9 months of the year. In addition, the area required for such a treatment system at Keno Hill is estimated to be on the order of 54 hectares, which is excessive considering the minimal flat area that is available. Therefore, Davé (2002a) did not recommend a stand-alone wetland treatment system. The Hatch/Rescan review team agree with Davé's conclusion that wetlands are not an appropriate primary treatment system for sub-Arctic environments.

8.11 Natural Attenuation

Natural attenuation of metals concentration by percolating mine water through subsurface channels is the second most popular passive treatment idea after wetlands. Davé (2002b) studied the effect of natural attenuation on zinc concentrations in mine water from the Galkeno 300 adit. He reported substantial declines in zinc concentration downslope from the adit, and suggested that it may be one of a suite of possible treatment options for that site. He also mentioned that soil has a finite capacity to store metals and that given enough time all of the soil in a natural attenuation area would become charged with metals and the system would cease to effectively treat mine water. He suggested that spreading mine water over a wider area to soak a larger volume of soil may be one way of increasing storage capacity. However, he recommended that the most reliable method would be a combination of natural attenuation and chemical treatment either in sequence or in parallel.

Observations by the Hatch/Rescan review team during the site visit indicated that the primary metal removal mechanism at the Galkeno 300 and Silver King sites is the co-precipitation of metals on the surface of iron and manganese precipitates. Dissolved iron and manganese are very high in the underground water due to the negative redox conditions. As the water is exposed to oxygen in the air upon discharge, iron and manganese precipitates and act as surfaces for the adsorption and co-precipitation of zinc, cadmium, copper, arsenic and other heavy metals. Precipitation of iron and manganese oxide is the primary source of metal removal. For example, a sample of precipitated iron (62%) from the Silver King site that was collected on June 11, 2003, by the Hatch/Rescan review team showed high levels of zinc (4,410 mg/kg), cadmium (74 mg/kg), copper (751 mg/kg) and arsenic (554 mg/kg) (see Appendix C). This natural mechanism needs to be investigated as a potential primary treatment method.

8.12 Waste Dumps and Acid Rock Drainage

One of the few environmental advantages of the Keno Hill area is that its rock appears to be not strongly acid-generating or, rather, there is enough acid-consuming material to balance acid generation. Hence, production of low-pH water is not a major problem in this study area. The single site where it may be a problem is the waste rock dump of the Husky mine site.

The Husky mine site is located east of Silver King and downslope of the Elsa townsite. The main point of interest from the perspective of environmental issues is the waste rock dump located on the north side of the shaft pad area. Water from the mine flows under the toe of the waste rock dump. That area shows clear evidence of production of acid rock drainage. There is significant iron staining and accumulation of precipitates, the nearby vegetation appears stressed, and the pH of water from that area is very low – from 2.6 to 3.6 in 1999 (PWGSC, 2000). Water from this site flows north and downslope into Flat Creek.

8.13 Other Tailings

8.13.1 Christal Lake/Mackeno Tails

The Mackeno mill site is located on the east and north-east shore of Christal Lake. From 1952 to 1954, a mill was used on this site. A total of approximately 40,000 tonnes of tailings were produced and deposited in Christal Creek, Christal Lake and along the eastern shore of Christal Lake. These tailings may be contributing to the metal loading of Christal Lake and Christal Creek.

8.13.2 Flat Creek Tails

Beginning in 1935, the tailings were discharged from the Elsa mill and allowed to flow down Porcupine Gulch and the hillside around the gulch to form an alluvial fan in a bog in the headwaters of Flat Creek. Some of the material continued to move down Flat Creek and into the South McQuesten River. That material may be part of the tailings sludge that is still visible along the bottom of Flat Creek. Some tailings sludge has been reported in the South McQuesten River as far west as the log jam 20 km west of the Elsa impoundment.

9. Health and Safety Issues

9.1 Public Access

The Yukon Occupational Safety Act, (Mine Safety Regulations) requires that closed or discontinued mines be protected against inadvertent access. *“ When a mine has been closed down or work in it has been discontinued, the owner or agent shall cause the entrances to the mine and all other pits and openings, dangerous by reason of their depth or other conditions, to be fenced and to be kept securely fenced….”*

There are a considerable number of safety hazards on the Keno Hills site including easily accessible open shafts and adits. Many of the sites are easily accessible to the public and are not fenced or identified as dangerous. A listing of physical hazards by the CS&I Mines Inspector includes details of 26 Keno Hill sites with safety issues. These include shafts in poor condition, open holes due to collapsed workings, unlocked portal entrances and old open buildings.

Hatch/Rescan visited a few of the dangerous sites on June 11, 2003 and photographs are presented in Appendix B. The Shamrock J skip house is particularly hazardous to the public due to its location adjacent to the popular Signpost Road.

Many of the old buildings are in poor condition and are susceptible to collapse. Due to their wooden construction and advanced age, these buildings are also fire hazards. Power lines are collapsing because of the poor support offered by the permafrost and many cables are lying on the ground. Some public access roads such as the Calumet road were not built to high standards and are not in good condition. Wooden cribbing, used to support the road in many areas, is old and in need of repair.

Of particular note is the roof of the Elsa Mill building. Its central beam is cracked and will probably collapse with the next snow load. The collapse of the building will make recovering the asbestos from the building hazardous and expensive. The roof beam should be immediately propped up with a vertical support until such time as the asbestos can be safely removed from the building.

Public access to many of these dangerous sites by 4WD vehicle is relatively easy in summer as local public roads such as the Calumet road, Keno Signpost road and the Werneke road allow unrestricted travel. There are some gates on access roads leading off the Keno City Highway notably to Elsa and Husky. However, not all the gates were locked and there was very little signage noted during the Hatch/Rescan visit.

In many cases, demolition of old structures and clean up of refuse will be necessary to make the area safe to the public. However, the Silver Trail Tourism Association has identified sites of historical significance that directly affect tourism potential in the area. The association should be consulted regarding their sites of interest prior to clean up.

Public safety is an immediate concern and as a priority all open stopes should be locked, danger signs should be posted at all dangerous sites and fences with gates erected to restrict public where possible. In the longer term, a demolition and clean up plan should be prepared including proper closure of all mine openings and removal of unsafe buildings and equipment.

9.2 Ice Plugs

A documented hazard at the Keno Hill site is the formation of ice barriers in the entrances of abandoned adits containing free flowing water (PWGSC, 2000). These ice plugs have the potential to block the flow of water and build up the pressure of water behind the plug. A sudden release of the plug due to ice melting can release large quantities of water very quickly. The force of the flow may be hazardous to people or buildings nearby and the water is likely to contain toxic quantities of metals that will be hazardous to aquatic life.

The Onek adit is a hazard due to its location near Keno City and due to the high levels of dissolved cadmium and zinc in the discharge. The Onek adit is known to have had at least three ice plug failures (PWGSC, 2000). Heat tape is currently being used to maintain the opening in this adit.

An ice plug monitoring plan and mitigation plan should be developed for all open adits susceptible to ice formation. Proper future closure of the adits with rock should eliminate this hazard.

9.3 Asbestos in Buildings

According to the Asbestos Institute, exposure to airborne asbestos fibres is a proven source of disease and inhalation of all types of asbestos, at sufficient doses, can cause serious health disorders. Only fibres that are inhaled, deposited and retained in the respiratory tract induce negative health effects.

Asbestos was a common component of building insulation materials and is present in many of the UKHM buildings. The PWGSC, 2000 report documents that of the 57 building assessed in Elsa Village, visual inspections found that 21 contained asbestos siding or floor materials. Approximately 1,600 m^2 of asbestos shingles are present on the Elsa Mill walls.

The Asbestos Institute comments that the presence of an asbestos-containing material will not, of itself, pose any hazard to building occupants. No risk occurs unless a significant number of respirable asbestos fibres are released from the material and enter the building air supply. In its guidelines for managing buildings containing asbestos materials, the US Environmental Protection Agency (EPA) states that removal of asbestos is often not a building owner's best course of action to reduce asbestos exposure. In fact, an improper removal can create a dangerous situation where none previously existed. The EPA only requires asbestos removal in order to prevent significant public exposure to airborne asbestos fibres during building demolition or renovation activities.

Friable asbestos, meaning any material which, when dry, can be easily crumbled or powdered by hand pressure is a particular concern. The Canadian Occupational Health and Safety (OHS) regulations require that:

"(1) The employer must ensure that a friable asbestos-containing material in the workplace is controlled by removal, enclosure or encapsulation so as to prevent the release of airborne asbestos fibre.

(2) The employer must not allow any work that would disturb friable asbestos-containing material unless necessary precautions have been taken to protect workers."

The presence of asbestos in many of the old unused UKHM buildings is in itself not likely to be an immediate risk to health. However, a proper risk assessment would have to take place before any work or demolition could commence. The OHS regulations require that:

"(1) The employer must ensure that a risk assessment is conducted by a qualified person on asbestos-containing material identified in the inventory, with due regard for the condition of the material, its friability, accessibility and likelihood of damage, and the potential for fibre release and exposure of workers.

(2) The employer must ensure that a risk assessment has been conducted before any demolition, alteration, or repair of machinery, equipment, or structures where asbestos may be disturbed."

9.4 PCB Contamination

The Canadian Environmental Protection Act (Storage of PCB Material Regulations) requires that every person who owns or manages a property on which more than 100 L (100 kg) of PCB material is located, shall store the PCB material in an approved site. Liquids or solids that contain more than 50 ppm of PCBs are defined as PCB material. Any equipment containing PCB material that is not being used daily or has been shut down for longer than six months has to be stored.

The Keno Hill site has significant quantities of electrical equipment manufactured prior to 1977 when Canadian PCB regulations were introduced. Transformers, capacitors and fluorescent lighting ballast can potentially contain material with PCBs.

The PWGSC,2000 report identifies some sites containing PCBs in concentrations lower than 50 ppm. The EBA report appears to have reasonably accurate identification of the location of the electrical sites, however the documentation and testing for PCBs was not rigorous. Field screen tests were done on some of the transformers at Elsa and some detailed laboratory results were reported noting the presence of PCBs in three of the transformers in Elsa village. All were less than 50 ppm. A drum located in a shed at the No Cash 100 site was determined to have a PCB content of 2.69 ppm. Many transformers were reported to be still in operation and therefore not tested.

The UKHM site has a licensed PCB storage shed near the tailings pond containing a small quantity of transformers and capacitors. The storage area is fenced and locked and the PCB contaminated material is catalogued. The larger transformers are stored in metal containers however there is no labeling as required by regulations. The storage shed is built on a concrete slab, however there is no secondary containment berm as required by regulations.

The Keno Hill site contains many obvious unused transformers and likely has quantities of capacitors and lighting ballasts that may contain PCBs. The Canadian Environmental Protection Act requires that PCB material be stored in an approved site or removed and treated. The fact that a PCB storage area exists indicates that previous owners were aware of the issues and may have already tested unused equipment for PCBs. However, this documentation was not seen. A detailed assessment and inventory of PCBs at Keno Hill will be necessary to determine if PCB storage is an issue. Should PCBs be found at site the material will have to be removed or stored in an approved facility for future destruction.

9.5 Keno City Water Quality

The level 400 adit of the Onek site discharges mine water within the municipal limits of Keno City. Occupied residences are within 100 m of the portal and the groundwater well supplying water to the community is located approximately 300m away. Water flows down a permanent channel for 120 m and then disappears into the ground. In 1996, the concentrations of cadmium and zinc in the Onek mine drainage water were 0.998 and 24.2 mg/L, respectively and are well over acceptable limits.

There is concern that the heavy metals in the Onek effluent may migrate through the ground and into the city water supply. Tests have indicated that the pathway for the water from Onek is not likely to affect the Keno City water supply, however there was no conclusive evidence. The water supply for Keno City should be monitored for heavy metals frequently to prevent public health and safety concerns.

9.6 Hazardous Material Storage

The Keno Hill property has many storage buildings containing potentially hazardous items such as chemicals, oils and lubricants. There are reportedly no explosives or cyanide on site. There are above ground and below ground fuel and oil storage tanks with evidence of spills. The PWGSC, 2000 report contains references to eight solid waste dump areas on the site containing old drums, electrical equipment, batteries, waste oil, scrap metal, rubber tires and wood debris. The major dump north of Elsa is still being used for municipal waste. The PWGSC, 2000 report presents anecdotal evidence that this dump may have been used for hazardous materials.

The Elsa mill building contains quantities of flotation reagents (sodium sulphide, creyslic acid, xanthate and polyphosphates). These chemicals are not stored safely and should be removed immediately.

In the short term general public should be restricted from access to these storage sites. In the longer term, the Keno Hill site requires a detailed closure plan to quantify the extent of the hazardous material and to determine what should be done about it.

9.7 Dust

The Elsa tailings impoundment is an old facility that is partly covered by grasses and water. However, the upper reaches are un-vegetated and are susceptible to wind generated dust. Although local dust concentrations appear to be high, it is unlikely that that this dust will be hazardous to residents of Keno City, approximately 5 km away. The future closure plan for the tailings impoundment should address revegetation to eliminate the dust problem.

10. Assessment of Issues

10.1 Characterisation Matrix

In order to determine the priority for addressing the multiple issues affecting the Keno Hill site, an attempt was made to roughly evaluate the items by three categories; the probability of occurrence, the severity of the impact and the spatial scale of impact. The categories were ranked high, medium or low according to the definitions presented overleaf. This preliminary qualitative assessment was for ranking purposes only. The ranking of the issues and the characterisation matrix summary is presented below.

Table 1 Characterisation Matrix

Issue	Probability of Occurrence	Severity of Impact	Spatial Scale of Impact
Metal Loading of the Aquatic Ecosystem	High	High	High
Galkeno 300 Discharge	High	High	Medium
Galkeno 900 Discharge	Low	Medium	Medium
Silver King Discharge	Medium	Low	Medium
Bellekeno Discharge	Medium	Low	Medium
Tailings Discharge	Low	Medium	Medium
Other Discharges	Medium	Low	Medium
Public Access to Dangerous Sites	High	High	High
PCB Contamination	Medium	High	High
Failure of Tailings Dam	Medium	High	High
Failure of Porcupine Diversion Ditch	Low	High	Medium
Collapse of Elsa Mill building	Medium	Medium	Low
Ice Plugs in Adits	Low	High	Low
Contamination of Keno City Water Supply	Low	High	Low
Asbestos Exposure in Old Buildings	Low	Medium	Medium
Hazardous Material Storage	Medium	Medium	Low
Dust from Elsa Tailings	Medium	Low	Medium
Lime Sludge Disposal	Low	Low	Low
Waste Rock Dump Effluent	Low	Low	Low
MacKeno Tailings	Low	Low	Low
Flat Creek Tailings	Low	Low	Low

Table 2 Definitions of Category Rankings

	High	**Medium**	**Low**
Probability of Occurrence	Likely to happen or is already happening	Has happened before and may happen again	Has not happened before and is unlikely to happen again
Severity of Impact	Will cause injury or death to the public or environment	Will affect the public or environment	May affect the public or environment
Spatial Scale of Impact	Affects entire study area	Affects part of study area (i.e. one catchment)	Affects small part of study area (i.e. a mine site)

The assessment and ranking of the Keno Hill issues indicated that the most important items requiring immediate attention are:

- metal loading of the aquatic system (in particular Galkeno 300)
- public access to dangerous sites
- potential failure of the tailings dam; and
- potential PCB contamination

The other important issues to be addressed in the short to medium term are the formation of ice plugs in adits, the potential for failure of the Porcupine Diversion Ditch, the potential for contamination of the Keno City water supply, the presence of asbestos in old buildings and the generation of dust from Elsa tailings.

10.2 Recommended Action Plan

The suggested action plan to address the Keno Hill issues for both short term and long term horizons is presented in tabular format below.

Issue	Short Term Action Plan	Medium to Long Term Action Plan
Metal Loading of the Aquatic Ecosystem	Maintain current water treatment strategy.	Commence statistical analysis of receiving waters to determine if metal concentrations are increasing or decreasing. There should be a long term monitoring programme to evaluate the status of Valued Environmental Components (VECs) such as grayling, salmon and moose
Galkeno 300 Discharge	The Galkeno 300 discharge is a potentially significant new source of zinc in Christal Creek. Bulkhead pressure at Galkeno 900 should be checked. The quantity and quality of the water all the way down to Christal Creek should be measured. If contaminated water is entering the creek, immediate action is required. The possible treatment options must be evaluated soon and put into place.	An effective long-term water treatment for all the sites at Keno Hill is required. Lime treatment is acceptable in the short term, however it is expensive and requires intensive management. Studies on natural attenuation and other passive systems should be continued.
Galkeno 900 Discharge	Maintain lime water treatment strategy.	As per Galkeno 300
Silver King Discharge	Study current treatment strategy and reinitiate lime treatment if results are unacceptable. Monitor the site to identify extent of contaminated water downstream towards Flat Creek.	Complete a comprehensive evaluation of the success and long term viability of natural attenuation.
Bellekeno Discharge	Study current treatment strategy and reinitiate lime treatment if results are unacceptable. Monitor the site to ensure contaminated water does not enter Lightning Creek.	As per Galkeno 300. Install synthetic liner in ponds.
Tailings Discharge	Maintain surveillance and current water treatment strategy.	As per Galkeno 300

Issue	Short Term Action Plan	Medium to Long Term Action Plan
Other Discharges	Continue monitoring all the sites to ensure that contaminated water is not reporting to receiving waters.	As per Galkeno 300
Public Access to Dangerous Sites	Install gates, padlocks and danger signs on all hazardous sites. Restrict public access to sites where possible.	Demolish old buildings, seal up mine openings and complete clean-up of the site. Complete an evaluation of historic buildings and facilities that may be useful to future mining operations. Most of the old adits are unlikely to be used again due to their poor condition and small size. They should be filled with rock and closed.
PCB Contamination	Carry out a comprehensive audit of the site to test old equipment and soils for the presence of PCBs. Determine if current PCB storage site is compliant.	If there is PCB contaminated material on site it has to be stored correctly or removed and destroyed.
Failure of Tailings Dam	Monitor the subsidence of the dam and complete repairs as necessary. Obtain geotechnical advice as to the stability of the dam.	If the site is to be maintained under care and maintenance, the dam will likely require repairs as specified in the Water License QZ96-001. If the site is to be abandoned then the dam should be closed and rehabilitated.
Ice Plugs in Adits	Monitor the presence of ice and flow of water in all adits. Relieve water pressure when necessary.	Closure of the adits with proper drainage should eliminate the ice plug issue
Failure of Porcupine Diversion Ditch	Monitor the condition of the diversion ditch.	As per the tailings dam, the diversion ditch should be repaired as specified in the Water License QZ96-001or rehabilitated.
Maintain integrity of Elsa Mill building	Install vertical support of cracked roof beam to prevent collapse of building and hazardous recovery of asbestos	Identify hazardous structures and demolish unsafe buildings.
Contamination of Keno City Water Supply	Regularly test the Keno City water supply.	Complete studies to conclusively determine flow path for Onek adit discharge water
Asbestos Exposure in Old Buildings	Leave as is	Complete a risk assessment study prior to demolition of the buildings.

Issue	Short Term Action Plan	Medium to Long Term Action Plan
Hazardous Material Storage	Remove reagents from Elsa mill building to safer storage	Complete closure plan to quantify the extent of hazardous material and develop plan to remove or contain it.
Dust from Elsa Tailings	Leave as is	Complete closure of the tailings dam and re-vegetate tailings area.
Lime Sludge Disposal	Leave as is	Complete study to dispose dewatered sludge in a secure landfill.
Waste Rock Dump Effluent	Leave as is	Remove the relatively small quantity of acid generating waste at Husky or cap it and divert the water.
MacKeno Tailings	Leave as is	Study the role of the tailings in heavy metal loading of Christal Creek.
Flat Creek Tailings	Leave as is	Study the role of the tailings in heavy metal loading of Flat Creek.

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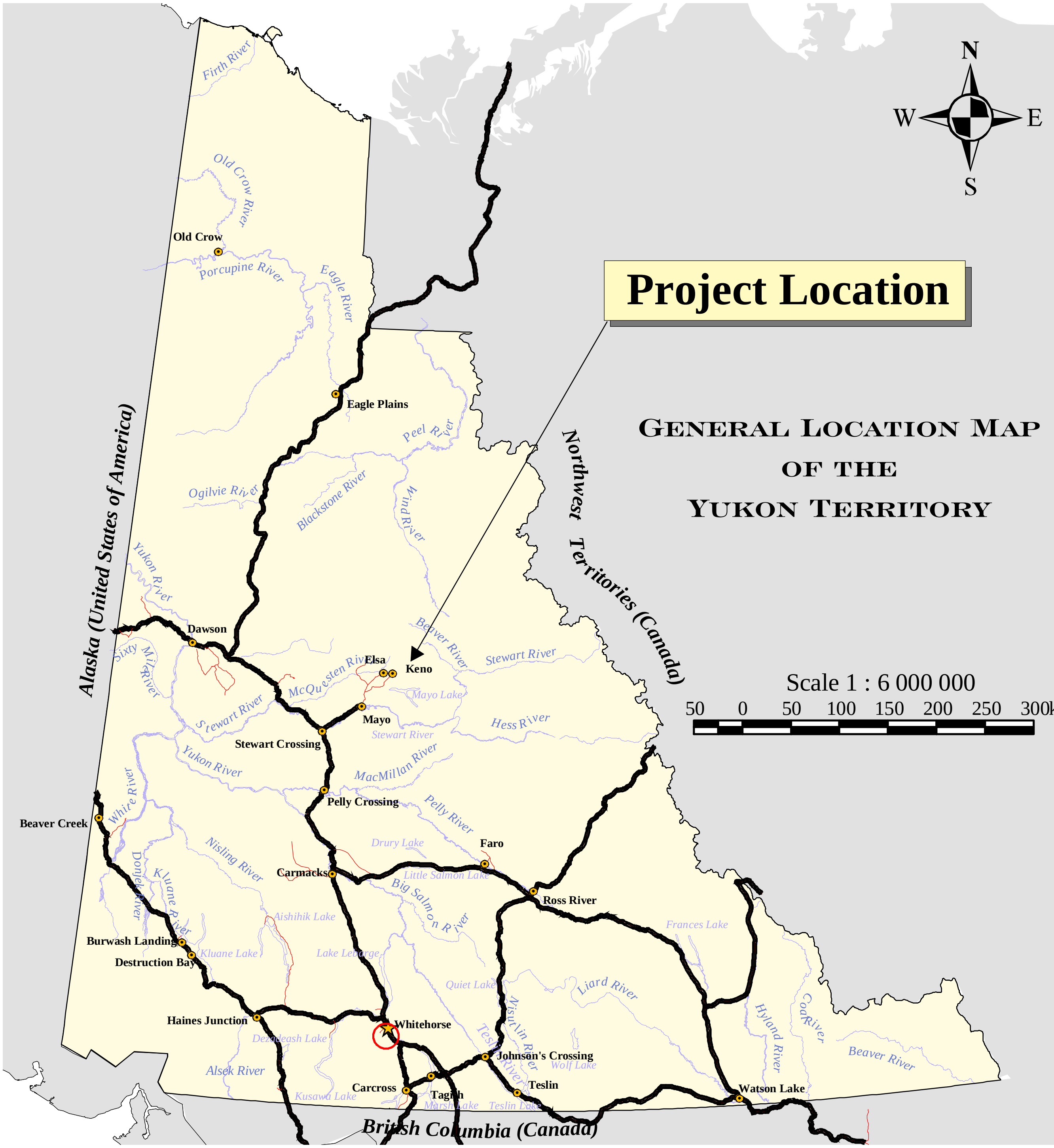
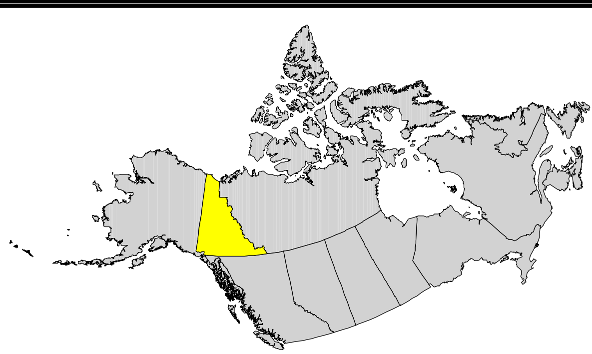
Appendix A

Maps





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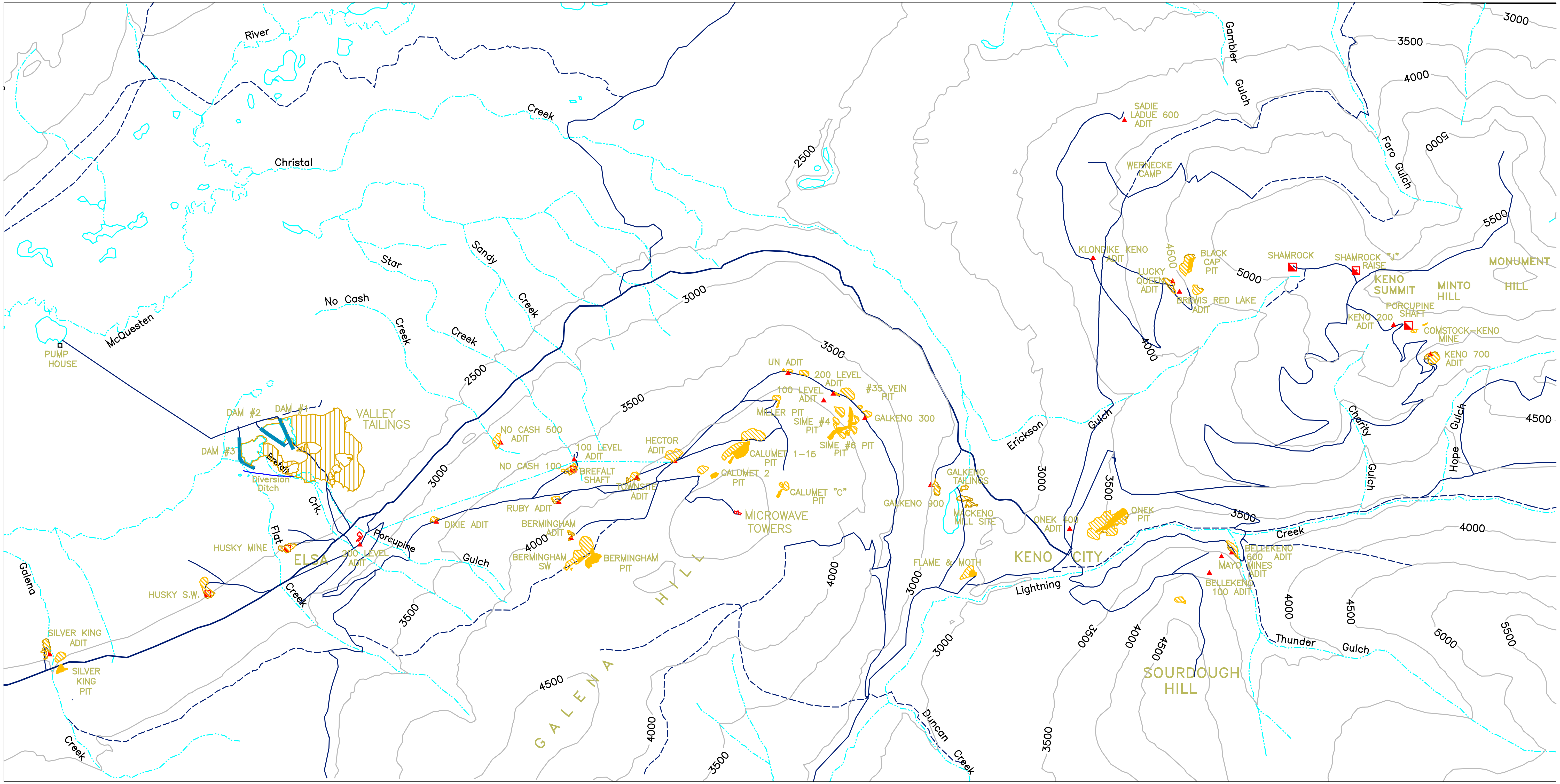
Keno Hill

Drawn By: PI	Figure 1.
Checked By: DDC	Date: June 27, 2003

File: D:\Project\NND-03-01\ArcMap\MXD\Figure1.mxd



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LEGEND

Creek, river, waterbody	Open pit
Territorial Highway (11)	Waste rock dump
Secondary road	Tailings
Trail	
Adit	
Shaft	

0 1000 2000 3000

METRES

Elevation contour interval – 500 feet

UTM GRID NORTH

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KENO HILL Property Location Map

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DRAWN: LCP/GDS | FILE: Keno_Hill_Property.DWG | DATE: 27/06/03

Appendix B

Photographs

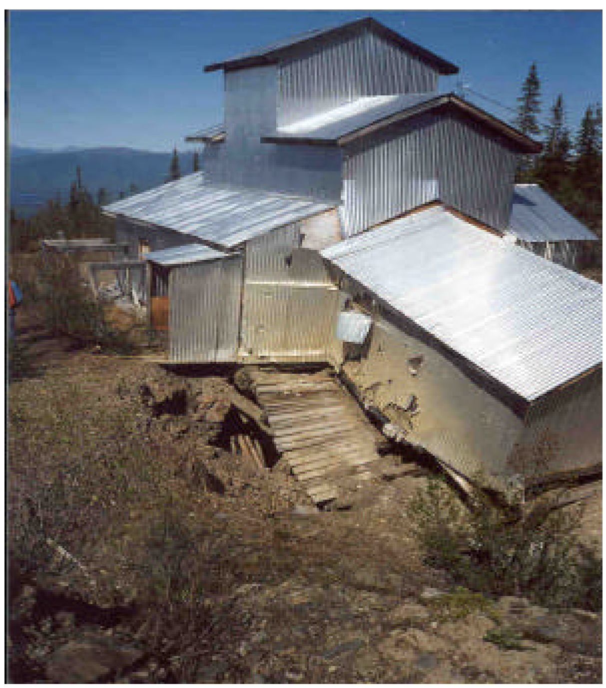
Galkeno 300 mine water flowing down hill

Galkeno 300 water crossing Calumet road

Galkeno 300 weir

Silver King Water Treatment Ponds


Shamrock J Skip


Ruby Skip

Husky Site Transformers

Elsa Garbage Dump

Elsa Tailings Dam viewed from Calumet

Elsa Tailings Dam subsidence

Elsa Tailings Dam #1 lift and toe berm

Elsa tailings dust observed over internal tailings ditch in foreground

Appendix C

Silver King Site Precipitate Analysis

Project	663-1 Solids Analysis
Report to	Rescan Environmental Services
ALS File No.	S9523
Date Received	06/17/2003
Date:	INTERIM

RESULTS OF ANALYSIS

Sample ID	100m LevPort300mDS Port.
Date Sampled	06/11/2003
Time Sampled	
ALS Sample ID	1
Nature	Solid
Physical Tests	
Moisture %	68.8
Total Metals	
Aluminum T-Al	5160
Antimony T-Sb	554
Arsenic T-As	2980
Barium T-Ba	109
Beryllium T-Be	<3
Bismuth T-Bi	<100
Cadmium T-Cd	74
Calcium T-Ca	18000
Chromium T-Cr	13
Cobalt T-Co	12
Copper T-Cu	751
Iron T-Fe	620000
Lead T-Pb	<300
Lithium T-Li	<10
Magnesium T-Mg	<300
Manganese T-Mn	1490
Molybdenum T-Mo	<20
Nickel T-Ni	81
Phosphorus T-P	4130
Potassium T-K	<1000
Selenium T-Se	<300
Silver T-Ag	<10
Strontium T-Sr	91
Thallium T-Tl	<300
Tin T-Sn	<50
Titanium T-Ti	<20
Vanadium T-V	<10
Zinc T-Zn	4410
Organic Parameters	
Total Organic Carbon C	2.53

Footnotes:

Results are expressed as milligrams per dry kilogram except where noted.
< = Less than the detection limit indicated.
Total Organic Carbon results are expressed as percent, dry weight basis.