

**PHASE II ENVIRONMENTAL ASSESSMENT
of the
FORMO MINE SITE**

Prepared for:

Action on Waste Program
Indian and Northern Affairs Canada

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Executive Summary

The Formo exploration site is located at 63° 56' 26" N, 135° 22' 09" W, approximately 7 km east of the village of Elsa, and straddles the road connecting Elsa and Keno Hill. Environmental Services, Public Works and Government Services Canada was retained to conduct an assessment of the Formo abandoned mine site to a) identify specific environmental and human safety risks and aesthetic concerns; b) provide clean-up recommendations; and c) provide a Class "D" cost estimate for recommended remediation or mitigation measures. The Formo mine site was inspected by PWGSC on 13 and 20 August, 1996.

Assessment components included mine openings and workings, buildings and infrastructure, waste disposal areas, waste rock disposal areas, surface water (including receiving waters), and hazardous and non-hazardous materials on the site.

Adits at the middle and lower workings are accessible and present serious safety risks.

Although most waste rock materials at Formo are presently or potentially acid-generating, these probably contribute little in terms of metal loads to Christal Creek. The greatest ARD-related concern at the Formo site is the slumping material in Christal Creek below the lower workings, and a high probability that future slope failures will deliver more mineralized waste rock into Christal Creek. Hydrocarbon-stained soils within the shed are presumed to be a very minor environmental concern.

The principal aesthetic concerns are associated with waste material and the condition of site buildings.

A physical barrier should be placed at the toe of the lower east waste rock dump to prevent further movement of slumping overburden/waste rock material into Christal Creek. The upper portion of that waste rock dump should be graded to a stable angle of repose. A lined diversion ditch should be constructed across the top of the dump to reduce surface and near-surface water flows into potential areas of slope failure.

All buildings should be demolished by burning in situ. Before burning the core shed, asbestos siding shingles should be stripped off and sealed in heavy-gauge plastic bags. After burning the buildings, bury all residues and the bagged asbestos at the south end of the upper workings. Wood wastes located next to the cabin should be consolidated and burned with the cabin.

Empty drums and the 250-gal. diesel tank should be cleaned, cut or crushed, and buried on site. Oily residues should be separated from wash water and recovered with sorbent material; contaminated sorbents can be burned on site. All metal debris should be buried at the south end of the upper workings. Metal wastes in the vicinity of the middle and lower adits should be placed inside the adits; subsequently, both adits should be sealed by blasting.

Site drainage (i.e. seasonal snowmelt) and Christal Creek water quality should be sampled quarterly for a period of five years.

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1. INTRODUCTION AND BACKGROUND

In 1993, assessments of 49 abandoned Yukon mine exploration and development sites were completed under the Arctic Environmental Strategy - Action on Waste program by DIAND Technical Services. These initial assessments provided a general overview of historical activities, described site infrastructure, workings and wastes, summarized existing environmental or safety concerns on each site, and provided general recommendations for remediation or mitigation work.

At the Forno site, the overview assessment (DIAND, 1994) identified safety concerns associated with a) instability of waste rock, b) potential undermining of a waste rock pad supporting a garage and storage shed, and c) possible storage of explosives on site. A low-level environmental risk from hydrocarbon products remaining on site was identified, and a low-priority aesthetic concern was expressed with respect to deterioration of site buildings. No rock, soil or water samples were collected for the initial assessment.

Indian and Northern Affairs Canada has determined that further investigation is warranted. Environmental Services, Public Works and Government Services Canada was retained to conduct an environmental assessment of the abandoned Forno mine site to a) identify specific environmental and human safety risks and aesthetic concerns; b) provide clean-up recommendations; and c) provide a Class "D" cost estimate for recommended remediation or mitigation measures. The Forno mine site was inspected by PWGSC on 13 and 20 August, 1996.

1.1 Location

The Forno exploration site is located at 63° 56' 26" N, 135° 22' 09" W, approximately 7 km east of the village of Elsa. The mine site straddles the road connecting Elsa and Keno Hill (Figures 1 and 2).

1.2 Overview of Site Development

The Forno Group of claims originated with a 25 metre deep inclined shaft the late 1920's, when 35 tonnes silver ore was mined. Between 1952 and 1953, two adits and connecting drifts on two levels were driven 60 and 90 metres below the 1920 shaft. Approximately 1220 metres of drifting and crosscutting, as well as minor raising and shaft sinking, were completed during this period. In 1961, 13.4 tonnes of ore was shipped from the property.

On the main Forno Vein zone (the upper workings) over 6825 m³ of rock has been removed from four trenches to expose the Forno Vein and a number of satellite structures. Three trenches were excavated on the Northern Occurrence, 155 m northeast of Forno. A total of 810 m³ was removed from these trenches. Two smaller trenches totalling 360 m³ were dug peripheral to a greenstone lens about 450 m south of the main Forno workings. 71.7 tonnes of ore were shipped from the site in 1983-84.

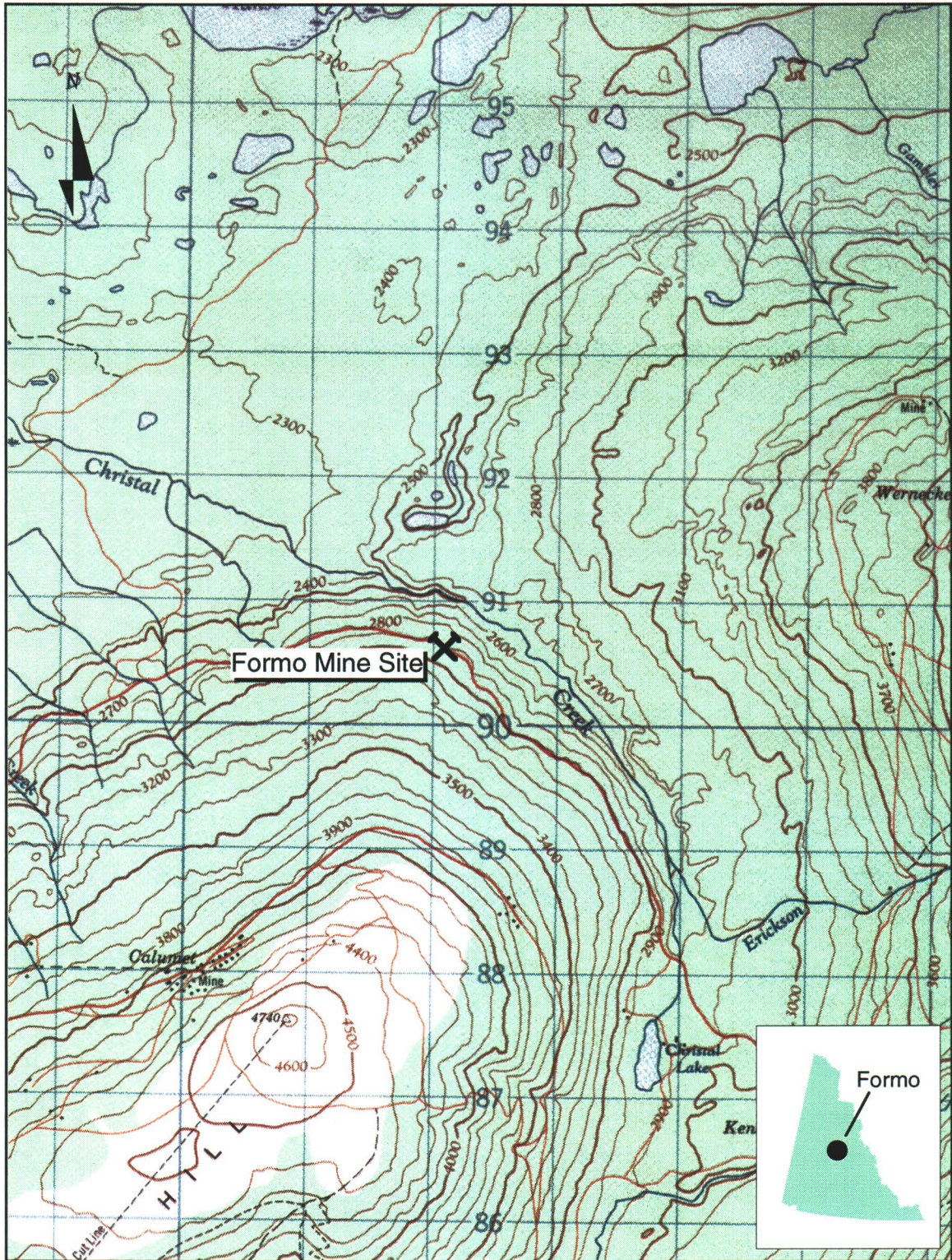
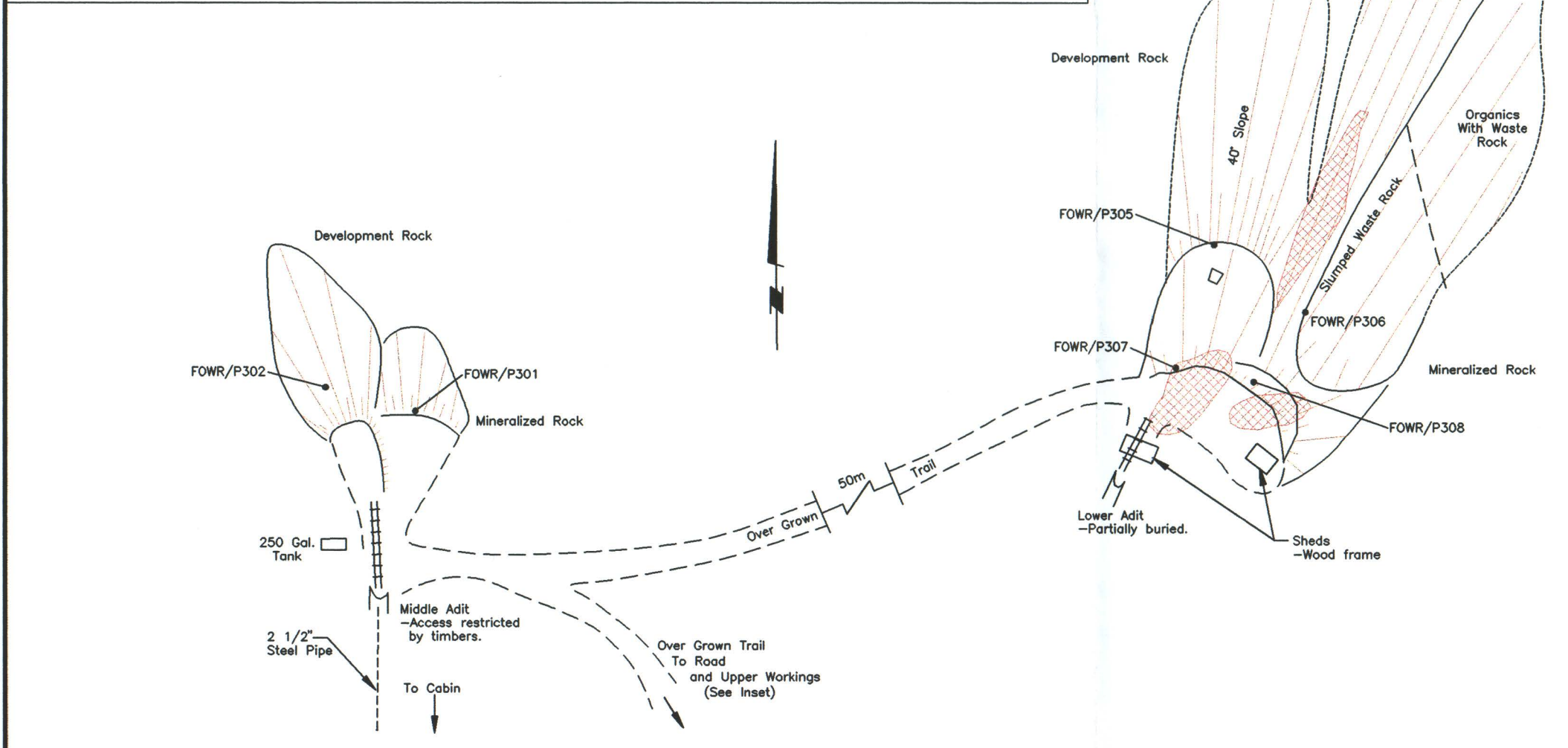
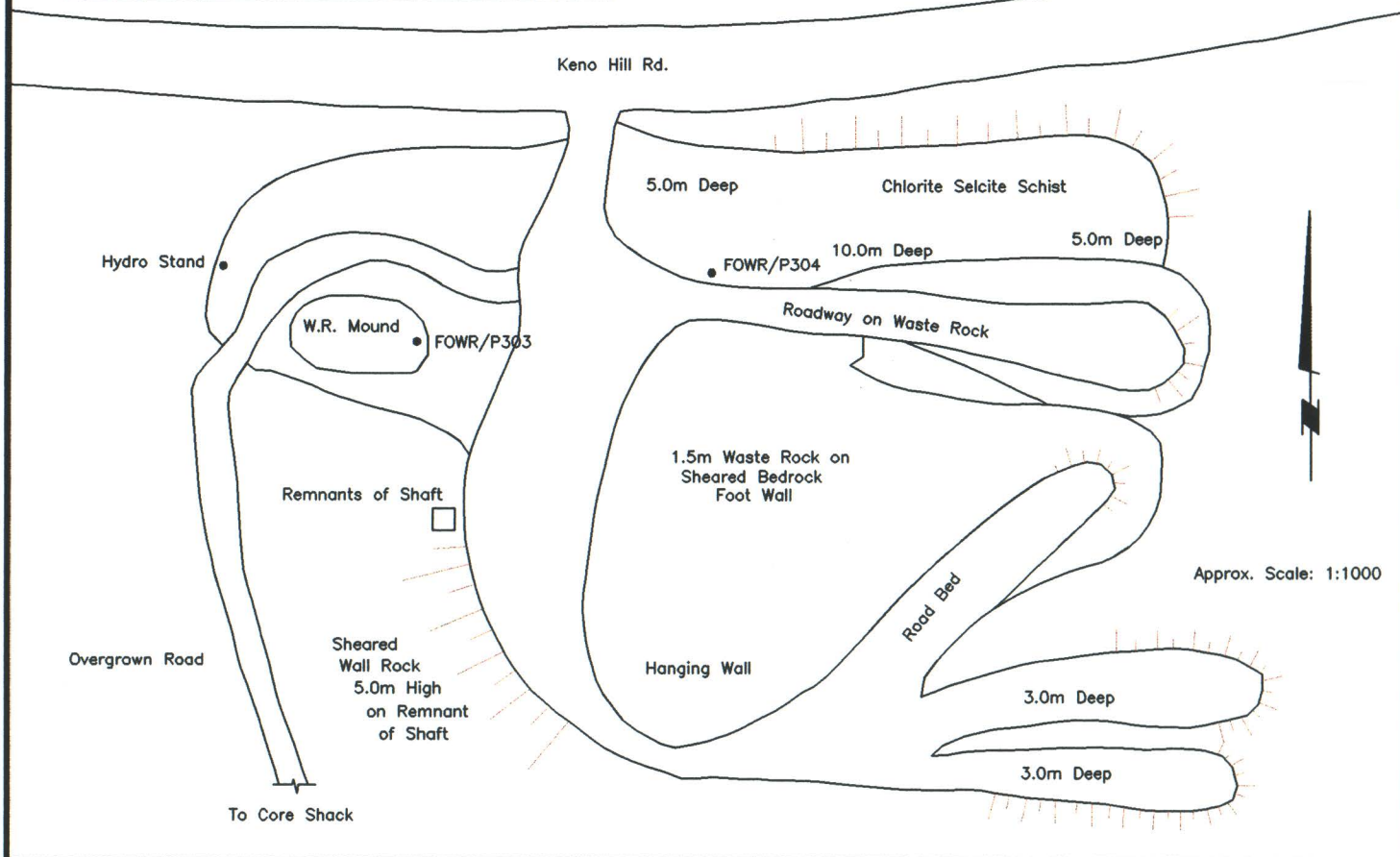


Figure 1: FORMO SITE
 N.T.S. 105 M/14 Map Name: Keno Hill Map Scale: 1:50,000
 Latitude: 63° 56' 26" N Longitude: 135° 22' 09" W

FORMO MINE SITE - UPPER WORKINGS



Legend

- Outcrop Boundry
- Waste Rock
- Outcrop
- Overburden
- Adit
- Road
- Culvert
- Extent Of Waste Rock
- Trestle, with Track
- Track
- Water Quality Sample (site designation)
- Soil Sample (site designation)
- Waste Rock (site designation)
- Barrel Sample (site designation)
- Slope Down
- Carbonate Staining On Surface
- Chlorite-rich Waste Rock
- Sericitic Waste Rock
- Cherty Waste Rock
- Buildings
- Extent of Debris, Timber, Cable, Pipe, etc.
- Fracture Location, Strike and Dip
- Elevation in Meters

Approx. Scale: 1:1000

PLOT: 1=1
CAD FILE: INVEN-96\FORMO\FORMO-1

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Formo Mine Site Development & Geological Information Yukon Territory		project no. no. du projet:	revisions: dwg. no. dessin no.:
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1.3 Site Access

Formo is accessible by 2-wheel drive vehicles via a compacted dirt and gravel road from Mayo and terminating at the village of Keno Hill. The upper workings are accessible from the road; a core shed east of the upper workings can be accessed with a 4-wheel drive vehicle along an overgrown road bed leading from the upper workings area. At present, the middle workings area is accessible only by foot; the lower east workings can be accessed by foot along an overgrown road bed from the vicinity of the cabin.

2. PURPOSE AND SCOPE OF WORK

This assessment was carried out by PWGSC for Indian and Northern Affairs Canada to a) identify potential environmental and human safety risks associated with specific abandoned mine sites and b) to provide recommendations and preliminary cost estimates for remediation or mitigation of those risks. Accordingly, the following assessment activities were completed:

- Visual inspection of mine openings and workings, buildings and infrastructure, and waste disposal areas
- Photo documentation and mapping of relevant site features
- Sampling of waste rock disposal areas, stained soils, surface water (including waste rock seeps and receiving waters) and barrel contents
- Identification and inventory of hazardous and non-hazardous materials on the site
- Identification of environmental pathways and receptors for site contaminants
- Assessment of human safety hazards and potential for accidental or deliberate access to hazardous areas
- Assessment of acid rock drainage potential in waste rock and mine development areas

Upon completion of these activities, preliminary cost estimates were generated to meet the following remediation/mitigation requirements:

- Physical stabilization of waste rock disposal areas
- Chemical stabilization of waste rock disposal areas, taking into account onsite resources and accessibility
- Sealing of all mine openings
- Consolidation and landfill of all non-hazardous, non-combustible solid wastes
- Remediation and/or removal and disposal of contaminated soils as required to meet CCME Commercial/Industrial criteria for soils
- Removal and disposal of hazardous solid wastes
- Draining, cleaning, and disposal of drums, ASTs, or other containers containing

- petroleum products or other liquid hazardous wastes
- Onsite flaring or removal and off-site disposal of petroleum products and other liquid hazardous wastes
- Demolition of buildings and infrastructure to foundation level and burning of combustible non-hazardous materials in approved location

3. SITE ASSESSMENT METHODOLOGY

3.1 Assumptions

At the Forno mine site, the assessment was limited to the area specifically developed or occupied for mine exploration or mining purposes and off-site environmental resources potentially affected by mine exploration or development activities.

3.2 Assessment Criteria

CCME Criteria

The Canadian Council of Ministers of the Environment (CCME) Interim Canadian Environmental Quality Criteria for Contaminated Sites are numerical limits for contaminants in soil and water intended to protect, maintain or improve environmental quality and human health at contaminated sites in general.

CCME criteria include two types of benchmarks for soil and water quality: assessment criteria and remediation criteria. Assessment criteria are approximate background concentrations or approximate analytical detection limits for contaminants in soil and water, and remediation criteria are for specified uses of soil and water. Remediation criteria are for generic use and do not address site-specific conditions. They are considered generally protective of human and environmental health for specified uses of soil and water at contaminated sites. The remediation criteria for soil are classified by three land uses:

- 1) Agricultural,
- 2) Residential/Parkland, and
- 3) Commercial/Industrial.

Remediation criteria for water are classified by four uses of water likely of concern at contaminated sites:

- 1) Freshwater aquatic life,
- 2) Irrigation,
- 3) Livestock watering, and
- 4) Drinking water.

For the Yukon mine assessments, Commercial/Industrial criteria were used to assess soil contaminants and the Freshwater Aquatic Life criteria were used to assess surface water quality.

Mine Reclamation in Northwest Territories and Yukon (INAC, 1992)

This report defines factors which are to be considered in reclamation of abandoned mine sites operating in northern climates. Factors include:

- open pit and underground mines
- waste rock and tailings disposal
- acid generation and leaching, and
- estimating cleanup costs.

3.3 Methods

3.3.1 Background Information

Available background information was consolidated from the Yukon Chamber of Mines mine records, Whitehorse Public Library, Yukon Archives holdings, and records and reports from the Yukon Renewable Resources Library, Yukon Water Board, DIAND Lands Branch, DIAND Water Resources, and DIAND Library. INAC (1994) provided an overview assessment of the Formo mine site to that date. Other published information sources were examined for site or regional information as applicable. On the basis of available information, knowledge gaps regarding existing or potential safety and environmental risks at the site were identified and a site assessment plan was developed.

3.3.2 Site Assessment Components

A site assessment was conducted to identify existing or potential safety and environmental risks on the site. The assessment included the following components:

Waste Rock disposal areas were inspected and sampled by a professional geologist to assess acid rock drainage and metal leachate potential by:

- Identifying variations in rock type, mineralization and alteration
- Mapping and logging waste rock, pit walls and rock faces as appropriate
- Collecting and field testing (paste pH and conductivity) representative samples of mine wastes
- Laboratory testing of selected samples, including whole rock analysis (solids assay) and acid base accounting (ABA). Laboratory leach tests (static or kinetic) were not included in the Phase II assessment.

Mine Openings and Excavations were visually inspected and documented to identify safety concerns and closure requirements.

Non-Hazardous Site Debris was inventoried.

Contaminated Soil Areas were measured and sampled to determine the degree of contamination and estimate soil volumes for remediation.

Hazardous Materials were inventoried and sampled for analyses of contaminant constituents, as necessary.

Barrels and Pails containing petroleum products were sampled and analysed for metals and screened for total halides (indicative of chlorinated organic compound such as PCBs) to determine suitability for on-site incineration of barrel contents. Drums containing substances other than petroleum products were sampled as applicable to identify hazardous constituents.

Buildings and other Structures were inspected for hazardous materials and assessed for stability.

Borrow Sources were identified and assessed for accessibility and approximate quantity and type of granular material as applicable.

Scale site plans were prepared to identify the dimensions and locations of site structures, mine workings and adits, waste rock disposal areas, on-site sampling locations (as applicable), and any other pertinent information.

3.3.3 Sampling Methods and Quality Assurance

Mine Waste Sampling

Test pits were excavated to depths between 0.3 m and 1.0 m. Horizons in the test pit walls were logged, noting colour/weathering, rock composition, primary and secondary mineralization, particle size distribution, paste pH and paste conductivity, and moisture content. Test pits were photographed and the locations marked on the field map.

Approximately 2 kg of rock was collected at each sample site. For test pits showing a homogeneous wall face, a plastic sheet was placed at the bottom of the test pit and the pit wall was cut vertically down with a cleaned shovel. All rock larger than 75 mm in size was discarded. Where test pit walls showed distinct horizons (distinguishable by the sulphide and carbonate contents), each horizon was sampled.

Water Sampling

Samples were collected from surface streams upstream and downstream of mine-related flows, and from representative seeps emanating from waste rock, pit walls, and/or adits. Observations of flow, flora, and fauna habitat, fisheries resources, and field pH and conductivity measurements were recorded. The field observations and a comparison of downstream water quality to the upstream were used to assess impact. Since water sampling was restricted to a single sampling event it does not necessarily reflect seasonal variations.

250 ml water samples were collected by hand, facing upstream, ensuring that the sample was not contaminated by disturbed sediment, debris and other floating materials. Sample bottles were rinsed three times with water from the sample stream prior to collecting the sample. 2 ml of HNO₃ were immediately added to water samples intended for metals analyses. For analyses of non-metallic parameters, water samples were brim-filled to minimise head space, placed in a cooler, and maintained at 4° C until delivery to the laboratory.

Soil Sampling

Soil lithology was recorded from observations of the side walls of the test pit, and soil samples for both field and laboratory testing were collected. Observations were recorded for each soil sample site, including soil particle size, consistency, colour, moisture, discoloration, stratification, odour, and any other observations of significance.

Samples were collected at depth intervals selected on the basis of stratigraphic observations and anticipated or apparent contamination. The lab samples were collected using disposable latex gloves and decontaminated stainless steel sampling utensils. All samples intended for organic analyses were stored in laboratory-cleaned 250 ml glass jars; samples intended for metals analyses were placed in new "Whirl-Pak" bags. All samples were placed in a cooler for shipment to the laboratory.

Barrel and Pail Sampling

Barrels and pails containing hydrocarbons were sampled with 1.2 m clean hollow glass rods ("drum thieves"), capable of extracting up to 25 ml of product. The rods were inserted into the drum or pail, and the uppermost open tip was sealed to maintain the sample within the rod as it was extracted from the drum or pail. The sampled hydrocarbon was then drained into a 40-ml laboratory-cleaned vial. The extractions were repeated until at least 20-30 ml of product was obtained. The vial was then sealed and placed in a container for shipment to the laboratory. Each used drum thief rod was subsequently destroyed to prevent accidental re-use.

Since hydrocarbon samples were collected only for analyses of Total Halides and metals, no cooling or other preservative was required.

Quality Assurance

Quality Assurance (QA) is a set of procedures for ensuring that the results of chemical analyses are (and can be shown to be) accurately representative of field conditions. A complete QA program includes both a field component and a laboratory component.

In addition to the standard sample collection methods outlined above, the field QA measures that were implemented for this assessment study include:

- chain of custody procedures and forms;
- a sample labelling and sample location identification scheme;
- laboratory preparation of all sampling containers;
- laboratory defined sample preservation and shipping procedures; and
- regular maintenance (including re-calibration) and cleaning of field equipment.

Laboratory QA measures included replicate analyses of selected soil and water samples. Replicate analytical results were submitted with each analytical report.

4. ENVIRONMENTAL SETTING

4.1 Mineralization

The commodities of interest at the Formo site on Galena Hill are silver, gold, lead and zinc. The Keno Hill-Galena Hill silver-lead ores occur in erratic shoots and lenses lying in vein faults that cut fine-bedded to massive quartzite, intercalated with greenstone sills and lenses, and various schistose rocks.

The Formo veins are composed of siderite (FeCO_3) with variable, but small, amounts of quartz, sphalerite ($(\text{Zn,Fe})\text{S}$), galena (PbS) and freiberigite (silver-bearing tetrahedrite $(\text{Cu,Fe})_{12}\text{Sb}_4\text{S}_{13}$). The cubiform galena occurs as clots and clusters rarely more than a few centimetres in size. The vein has been affected by post-mineralization fault movement, as well as intense weathering. Siderite (FeCO_3) and galena are commonly weathered to limonite and anglesite. The footwall is greenstone and the hangingwall is graphite schist which is highly brecciated within a few metres of the vein.

4.2 Hydrology

Regional drainage is generally southwest and encompasses the Pelly, Ross, North and South Macmillan, Hess, Stewart and North and South McQuesten river systems.

Local drainage from the upper, middle and lower workings enters Christal Creek, a third-order stream which joins the South McQueston River about 7.5 km west of Formo. The upper, middle and lower workings are approximately 110m, 75m, and 50m in elevation above Christal Creek respectively. No surface water bodies cross the Formo mine site, and no active seep was found at any waste rock pile. Hydrological/water quality records were not available for Christal Creek.

4.3 Climate

Meteorological data are incomplete, but inferences from surrounding locations and data presented by Burns (1973, 1974) suggest the mean annual precipitation to be about 500 mm in the Keno Hill area. The mean annual temperature is estimated to be -6°C.

4.4 Vegetation

The terrain below treeline (1350 to 1500 m above sea level) lies within the B26c forest region (Rowe, 1972). Open black spruce and, occasionally, lodgepole pine form extensive forests. White spruce, occasionally with aspen or lodgepole pine, occurs on warmer and better drained sites. Paper birch is scattered throughout. Alpine fir occurs in the subalpine. An undescribed variety of pine, similar in appearance to Pinus albicaulis, occurs near treeline.

Moss, usually with ericaceous shrubs and willows, forms the most extensive understorey vegetation. Sedge tussocks, sphagnum and small shrubs prevail in poorly drained situations and on north-facing slopes. Shrub birch and willow are extensive in sub-alpine and lower alpine sites. Lichen development is common in dry situations, including tops of hummocks, tussocks and well-drained, rocky alpine sites.

4.5 Fisheries Resources

No fisheries data for Christal Creek were available from Yukon Renewable Resources.

4.6 Site Topography and Soils

The Formo area has been glaciated by ice from the Selwyn Lobe which moved in a westerly to north-westerly direction. The ice level reached about 1500 m above sea level; many higher areas were subjected to alpine glaciation. Lateral moraines, ice contact

channels and kame terrace deposits occur on a number of hills in this area.

Generally, glacial scouring was not intense in this area. Mid and lower slopes are mantled with deep morainal and glaciofluvial material. Large lakes filled a number of valleys during deglaciation. Large deposits of silts occur in the Mayo Lake area, and small glaciolacustrine deposits are present throughout (Vernon and Hughes 1966; Hughes et al. 1969; Bostock 1966; McTaggart 1960).

Forno is situated on a 28° north-facing slope (Photo 1). The upper workings are located at an approximate elevation of 880 m above sea level, the middle workings at about 850 m elevation, and lower east workings at about 820 m elevation. The lower east waste rock disposal area (Photos 7-10) and associated slumped soils extend from the 820 m level to Christal Creek at 775 m. Slumped soil has recently blocked Christal Creek, which has cut through the slumped material to re-establish its original channel.

Area soils typically are peaty silts and sands to a depth of 20-40 cm, underlain by well-mixed, compacted boulders, cobbles, sand and silt to depths varying between 3 and 8 m.

5. SITE DESCRIPTION AND FINDINGS

5.1 Buildings, Infrastructure, and Equipment

A core shed, cabin, and a small storage shed are the only significant buildings at the Forno site. Building features and interior contents are summarized in Table 5.1. The core shed is about 60 m east of the upper workings area, and accessible by an overgrown roadbed. Shed sides are clad with asbestos-coated asphalt shingles. The interior of the shed contains 42 full and partially-full core trays; core samples in some trays have been spilled. A cabin structure is situated approximately 60 m downslope and north of the main Keno Hill road. This structure was once accessible by road, but all roadways are heavily overgrown with alder. The storage shed is located at the lower east workings adit and above the waste rock dump. Each of these buildings were somewhat in disrepair although not in imminent danger of collapse.

Next to the small storage shed are the remnants of an adit enclosure (which also may have served as a small workshop); floor timbers and a timber-and-log retaining wall between the enclosure and adit have rotted and partially collapsed.

5.2 Non-Hazardous Waste Materials

Three non-hazardous material storage/disposal areas were discovered on the Forno property. Locations and inventoried materials are summarized in Table 5.2.

Table 5.1 Formo Building Construction Features and Interior Contents

Structure	Construction Features	Interior Contents	Photo No.
Core shed (Upper workings)	<ul style="list-style-type: none"> - 11 x 6 m in plan and 5 m in height - "2 x 4" wood frame, wood plank siding and roof, dirt floor - asbestos-coated asphalt shingles on building sides; asphalt shingles on roof 	<ul style="list-style-type: none"> - 42 core trays, some core scattered - about 40 m spiral aluminum-sheathed electrical cable; no PCB ballasts - 2 x 20 litre oil pails (empty) 	2,3,4
Cabin (Middle adit area)	<ul style="list-style-type: none"> - 7 x 5.5 m in plan and 8 m in height - "2 x 6" wood frame, plywood interior cladding - wood plank floor and exterior siding - plywood roof with asphalt shingles - 4 x 6 m plank porch with misc wood waste & 2 sheets of steel siding material 	<ul style="list-style-type: none"> - 3 x 1 x 1 m water tank, 1/8-inch steel, at doorway to cabin 	
Outhouse	<ul style="list-style-type: none"> - 4 x 3 m in plan, wood frame, wood plank siding 		
Storage shed and adit enclosure (Lower east workings)	<ul style="list-style-type: none"> - shed is 5 x 4 m in plan and 4 m in height, "2 x 4" wood frame with wood plank floor, exterior siding, and roof - adit enclosure is 5 x 3 m; wood frame, rotted timber floor - rotted and collapsed timber and log retaining wall between shack and adit opening 	<ul style="list-style-type: none"> - small quantity of steel tubing inside shed - no contents inside adit enclosure 	5, 6

Table 5.2 Formo Non-Hazardous Waste Materials

Area	Location	Inventoried Materials	Photo No.
Upper workings	25 m east-northeast of core shed	- 4 x 205 litre drums, empty	
Lower west workings	Middle adit area	- 250 gallon steel diesel tank (empty), connected to cabin by approx. 50 m of 2.5" steel fuel line - 2 steel rails extending 16 m from middle adit	
Lower east workings	East adit	- 2 steel rails extending 7 m from adit opening	
	Foot of east waste rock dump	- 3 x 205 litre drums, 1 x 20 litre pail, empty - ore car - miscellaneous timber & wood waste	

5.3 Hazardous Materials

5.3.1 Stained Soil and Other Solid Hazardous Materials

Minor hydrocarbon stains were noted on the soil floor of the core shed. Two samples (FO-SL-201 and -301) were collected from 15 cm depth near the stairs and north wall respectively. Soil from surface to 15 cm depth was typically sandy silt with gravel, and a mild hydrocarbon odour was noted in both samples. Only trace quantities of naphthalene and pyrene were analysed in FO-SL-201 and -301 respectively; these results suggest hydrocarbons in the soil are aged or comprised of heavier lubricating oils which are beyond the PAH analytical range (and for which no CCME criteria exist). Arsenic, cadmium and zinc above CCME C/I levels were found in FO-SL-301.

Asbestos-coated siding shingles were observed on the core shed, although the asbestos did not appear friable (Photo4).

5.3.2 Petroleum Hydrocarbons and Other Liquid Hazardous Materials

No petroleum hydrocarbons or other liquid hazardous wastes were observed at Formo.

5.4 Surface Water Quality

No ponded water, surface runoff, or seepage from the adits or waste rock piles was observed, even the the site visits occurred during an extended period of heavy rainfall. A groundwater spring was found in a gully below the middle workings, and sample FOWQ/Str-302 was collected from the springwater stream approximately 75 m below the spring and 250 m below the middle workings. Discharge at the sample site was < 1 L/sec.

Three water samples were collected from Christal Creek. Sample FOWQ/Str-002 was collected 100 m upstream of the failed waste rock pile of the lower adit and is representative of the background water quality in Christal Creek. Sample FOWQ/Str-001 was collected 100 m upstream from the drainage area of the middle workings, which would be approximately 50 m below the drainage area of the lower workings. Sample FOWQ/Str-301 was collected 50 to 100 m downstream of the drainage area affected by the middle workings. At that sample site, discharge was visually estimated at 20 L/sec.

Complete analytical results are provided in Appendix B; significant results are summarized in Table 5.3. All the water samples had field pH values between 7 and 7.9 and elevated laboratory conductivity readings (615 to 1020 $\mu\text{S}/\text{cm}$). The upstream water quality in Christal Creek is high in metals, particularly zinc and silver. Zinc and silver concentrations in the samples collected in Christal Creek downstream of the middle and lower workings were double those measured in the upstream sample. There was little difference in the

concentrations of other metals. Zinc and silver concentrations were also elevated above the CCME Freshwater Aquatic Life criteria in the groundwater seep below the middle workings.

Comparison of the upstream and downstream water quality indicates that the Forno workings are linked to elevated zinc (and possibly silver) concentrations in Christal Creek. The major source of the zinc and silver is probably slumped, mineralized waste rock lying within Christal Creek immediately below the lower workings.

Table 5.3 Significant Results - Forno Surface Water Samples

Sample ID	Sample Location	pH	Conductivity (μ mhos/cm)	Metallic parameters
FO-WQ-STR-001	Christal Creek immediately below lower east waste rock dump	8.1 (7.0)	618 (45)	Cd, Ag, Zn >CCME FAL
FO-WQ-STR-002	Christal Creek approx. 100 m upstream from lower east waste rock dump	8.1 (7.7)	633 (440)	Zn >CCME FAL
FO-WQ-STR-301	Christal Creek approx. 100 m downstream from lower east waste rock dump	8.1 (7.0)	615 (220)	Ag, Zn >CCME FAL
FO-WQ-STR-302	Small tributary to Christal Creek approx. 200 m downstream from lower east waste rock dump	7.7 (7.4)	1020 (600)	Ag, Zn >CCME FAL

Note: pH and conductivity readings in brackets are field measurements; unbracketed values are lab measurements. Field conductivity results reported as microsiemens. FAL = Freshwater Aquatic Life.

5.5 Waste Rock Disposal Areas

At the upper workings, over 6900 m³ of rock was removed to expose the main Forno vein in trenches. Waste rock was deposited beside the trenches .

Two adits and connecting drifts of unknown length were driven at elevations about 50 metres and 80 metres below the upper workings. These are shown as the middle and the lower workings on the site map. Waste rock was end-dumped from rail trestles to form two lobes of waste rock below each adit.

Waste rock at the middle workings covers an area of approximately 1000 m². Over 30% of the waste rock is covered with mosses and alders. No evidence of slumping or extension cracks were observed. The slope angle of the pile was 35°, which is similar to natural slope of the underlying hillside. The eastern lobe of the waste rock pile is covered with relatively unmineralized rock compared to the western lobe of the pile.

The area of disturbance at the lower workings is approximately 6000 m². The area covered by waste rock was increased by an additional 55% when the eastern lobe failed, causing overburden mixed with waste rock to flow down the hillside into Christal Creek. Waste rock has slumped to within 20 m of Christal Creek, and massive sulphides are evident in the mixed overburden/waste rock slump material. The slope angle was measured to be 45° along the upper parts of the pile. Extension cracks were observed along the top of both lobes and the head scarp of the failure was still evident at the crest of the eastern lobe. Both lobes of the rock pile are undergoing active creep deformation (possibly related to poor drainage and frost action). The western lobe of the waste rock pile is covered with relatively unmineralized rock as compared to the eastern lobe.

Seven pits were dug and eight samples collected of the predominately schistose waste rock. Samples FOWR/P301 and FOWR/P302 were collected from the rock pile at the middle workings. Pit P301 was dug in unmineralized material and pit P302 in the mineralized material. Samples FOWR/P303 and FOWR/P304 were collected from the overburden and weathered bedrock excavated and spread by bulldozer at the upper workings. Samples FOWR/P305, FOWR/P306, FOWR/P307/1, FOWR/P307/2 and FOWR/P308 were collected from the rock pile at the lower workings. Pit P305 was dug in unmineralized material. Pits P306 and P308 were dug in similar mineralized material, and P307 was dug in an area exhibiting iron carbonate staining on the surface. Sample descriptions and discussion of ABA test results are summarized in Table 5.4.

As described in the *Formo Acid Rock Drainage Assessment Report* prepared by SRK (Appendix A), most of the waste rock at the lower adit is either generating acidic drainage or is potentially acid-generating. The material from the upper workings, the middle workings and the unmineralized rock located at the lower workings are not currently generating acid, however the mineralized material at the lower workings is acidic. Acid Base Accounting results indicate that only the unmineralized lobe at the middle workings is not a potential source of acid.

The material collected from the mineralized rock piles and the upper workings also contained elevated concentrations of cadmium, lead, silver and zinc. Arsenic was elevated in the material from the mineralized lobe of the pile at the middle workings.

5.6 Mine Openings and Excavations

Shallow shafts dug at the upper workings were destroyed during trenching. Two adits were driven at elevations approximately 50 metres and 80 metres below the upper workings at locations. The lower adit is partially blocked by a log retaining wall (Photo 11); however, the logs are loose and rotting, and access to the interior of the adit is possible. Entry to the middle adit has been restricted by a board enclosure, but this adit also is accessible (Photo 12).

Table 5.4 Waste Rock Sample Descriptions and Summarized ABA Test Results - Formo Mine Site

Sample ID	Sample Location and Description	Summary of ABA Test Results
FOWR/P301	Unmineralized rock from east lobe of middle workings. Black/grey coloured graphite schist with 1% quartz carbonate vein material and 1% visible pyrite collected over a thickness of 30cm. Surface is covered with moss and small alders. Field paste pH measured 7.0 and paste conductivity 260µS/cm.	Low potential for acid generation (NP:AP= 6.4).
FOWR/P302	Mineralized rock from west lobe middle workings. Graphite schist with 3% quartz carbonate vein material and 3% visible pyrite collected over a thickness of 40 cm. Field paste pH measured 7.60 and conductivity 180µS/cm.	Potentially acid generating (NP:AP=0.5) with high metal concentrations; 125 ppm As, >100 ppm Cd, >10000 ppm Pb, >200 ppm Ag, >10000 ppm Zn.
FOWR/P303	Chlorite schist waste rock at upper workings, 1% visible pyrite, Field paste pH measured 6.4. Included fragments up to 5cm in diameter.	Potentially acid generating (NP:AP=1.2) with high metal concentrations; >100 ppm Cd, >10000 ppm Pb, 154.6 ppm Ag, >10000 ppm Zn.
FOWR/P304	Chlorite sericite schist typical of waste rock at upper workings. Sample collected over a thickness of 40 cm with fragments up to 5cm in diameter. Contained <1% quartz carbonate vein material. Field paste conductivity measured 210µS/cm.	Potentially acid generating (NP:AP=0.2) with high metal concentrations; 3148 ppm As, >100 ppm Cd, >10000 ppm Pb, >200 ppm Ag, >10000 ppm Zn.
FOWR/P305	Unmineralized rock from west lobe lower workings. Sample collected over a thickness of 40cm; upper 12cm consisted of bands of dark brown iron carbonate altered material and graphite chlorite schist bands over a 20cm band of graphite schist and 13cm of dark red brown coloured sand and silt size material. Includes fragments up to 7cm in diameter.	Potentially acid generating (NP:AP=2.3).
FOWR/P306	Mineralized rock from face of east lobe at lower workings. Chlorite sericite schist, with bands of limonite. Surface is weathered to a black colour and contains 15% pyrite, and 30% quartz carbonate vein material. Samples collected over a thickness of 30cm.	Acid generating (NP:AP=<0.1) with high metal concentrations; >10000 ppm Pb, 103.8 ppm Ag.
FOWR/P307/1	Sample of iron carbonate stained surface material collected over a thickness of 18cm in schist.	Acid generating (NP:AP=<0.1) with high metal concentrations; 55.3 ppm Cd, >10000 ppm Pb, 133.7 ppm Ag, >10000 ppm Zn.
FOWR/P307/2	Collected below FOWR/P307/1 over a thickness of 17cm in brown red coloured schist with grey silt lenses and wood fragments.	Potentially acid generating (NP:AP=<0.1) with high metal concentrations; >100 ppm Cd, 9900 ppm Pb, 151.3 ppm Ag, >10000 ppm Zn.
FOWR/P308	Mineralized rock from top of dump at lower workings similar to P306. Bands of schist including graphite schist, chlorite schist and limonite collected over a thickness of 35cm.	Acid generating (NP:AP=0.75) with high metal concentrations; >10000 ppm Pb, >200 ppm Ag, 3448 ppm Zn.

6. CONCLUSIONS

Existing or potential health and safety hazards or environmental/aesthetic concerns associated with the Formo mine site are summarized in Table 6.1, and are examined more fully in the following sections.

Table 6.1 Summary of Hazards or Concerns at Formo Mine Site

Site Assessment Component	Hazard or Concern
Buildings, Infrastructure, and Equipment	Upper core shed, cabin and outhouse, and storage shed and adit enclosure are in varying states of disrepair and pose minor risk to human safety.
Non-Hazardous Waste Materials	Empty drums and other non-hazardous wastes near the middle workings, cabin, and lower workings are an aesthetic concern
Waste Rock Disposal Areas	Mineralized waste rock at the lower workings is acid-generating. Overburden has slumped into Christal Creek. Waste rock has slumped to within 20 m of Christal Creek; massive sulphides are evident in the mixed overburden/waste rock slump material. Slope angle is 45° near upper edge of the waste rock pile. Extension cracks observed along the top of the pile.
Mine Openings and Excavations	Adits at lower and middle workings are accessible and pose serious safety risk.
Hazardous Materials	Hydrocarbon-stained soil within core shed is a very minor environmental concern.

6.1 Health and Safety

The Formo buildings present a minor safety concern due to their varying states of disrepair.

Adits at the middle and lower workings are accessible and present serious safety risks. Although access to both adits is partially restricted by a log retaining wall (lower adit) and an adit enclosure (middle adit), relatively little effort would be required to remove those barriers.

6.2 Environmental Risks

ABA testing indicates most of the waste rock materials on the Formo site are either acid generating or potentially acid-generating; however, waste rock piles on the hillside appear to contribute relatively little in terms of metal loads to Christal Creek. Precipitation in the area is low and catchment areas above the dumps are small. No seeps were observed emerging from the dumps at the time of the inspection, even though it had been raining heavily. The greatest environmental concern at Formo is the presence of slumped material in Christal Creek below the lower workings, and a high probability that future slope failures will deliver more material into Christal Creek.

With respect to hydrocarbon-contaminated soil in the core shed, there are no signs of off-site transport and no significant environmental features in the vicinity of the stained soil. Therefore, the hydrocarbon-stained soils within the shed are presumed to be a very minor environmental concern.

6.3 Aesthetic Concerns

The principal aesthetic concerns are associated with waste materials inventoried in Tables 5.1 and 5.2, and with the condition of site buildings.

7. RECOMMENDATIONS

Recommended remediation and management actions are compliant with applicable federal or territorial regulations and criteria, rely upon available technology, and intended to be appropriate for local conditions and sensitivities.

Recommendation 1. To prevent further movement of slumped overburden/waste rock material into Christal Creek, gabion baskets, concrete lock blocks, or some other physical barrier should be placed at the toe of the lower east waste rock dump. Stabilize the upper portion of the waste rock dump by grading to a natural angle of repose. Construct a lined diversion ditch across the top of the dump to reduce surface and near-surface water flows into potential areas of slope failure.

Recommendation 2. All buildings should be demolished by burning in situ. Before burning the core shed, asbestos siding shingles should be stripped off and sealed in heavy-gauge plastic bags. After burning the buildings, bury all residues and the bagged asbestos on site. The recommended burial site for the asbestos is the south end of the upper workings.

Recommendation 3. Wood wastes located next to the cabin should be consolidated and burned with the cabin.

Recommendation 4. Empty drums should be consolidated, rinsed, crushed and buried on site. Similarly, the 250-gal. diesel tank should be cleaned, cut or crushed, and buried on site. Oily residues should be separated from wash water and recovered with sorbent material; contaminated sorbents can be burned on site. All other metal debris should be buried on site. The recommended burial site for metal wastes is the south end of the upper workings. Metal wastes in the vicinity of the middle adit (including the 250-gal. tank, steel rails, and steel fuel line should be placed inside the middle adit. Steel rails leading from the lower adit should be placed inside that adit.

Recommendation 5. After metal wastes have been placed inside the middle and lower adits, both adits should be sealed by blasting.

Recommendation 6. Site drainage (i.e. seasonal snowmelt) and Christal Creek water quality should be sampled quarterly for a period of five years.

8. COST ESTIMATES TO IMPLEMENT RECOMMENDATIONS

An estimated breakdown of expected remediation/mitigation costs to an accuracy of 25% is provided under separate cover to this report. The cost estimate includes contractor and project

management costs and contingency.

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Appendix A

Determination of Acid Rock Drainage Potential

**FORMO ACID ROCK DRAINAGE
ASSESSMENT REPORT**

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SITE MAP

P118105

**FORMO
ACID ROCK DRAINAGE
ASSESSMENT REPORT**

1.0 INTRODUCTION

This report has been prepared in conjunction with a *Phase II Environmental Assessment of the Formo Abandoned Mine Site*, prepared by Environmental Services, Public Works and Government Services Canada (PWGSC). As part of the Phase II assessment prepared by PWGSC, Steffen Robertson and Kirsten (SRK) was requested to assess the potential for acid rock drainage associated with the site, which is the subject of this report. The reader is directed to the PWGSC report for a comprehensive environmental assessment of the Formo site.

This report assesses existing, and potential, acid rock drainage (ARD) conditions at the Formo site and provides recommendations for remediation. This site specific report is part of the *Acid Rock Drainage Review Report, Yukon Abandoned Mine Site Assessments*, prepared by Steffen, Robertson and Kirsten (SRK), which includes similar assessments for a number of sites. The reader is directed to that report for details regarding the scope of work, site assessment methodology, ARD remediation options and the evaluation of potential remediation options.

The Formo site is located on Galena Hill in the Keno Hill district, approximately 5 km northwest of the Village of Keno City along Highway 2. The site is accessible by vehicle.

Mine workings observed during the site assessment consist of three areas of development, including: two adits; deep trenches; and waste rock piles. The waste rock present at the Formo site is the result of several generations of exploration and development. Mine development work occurred in the late 1920's, between 1947 and 1953, between 1961 and

1964 and most recently between 1980 and 1984. The ore was shipped off the site for processing (Yukon Minfile 105M 018).

The site is covered by thick vegetation made up predominantly of alder, willow, and black spruce. The surface material is a silt and gravel till overlying bedrock. The trenching at the upper workings has exposed bedrock. The waste rock pile at the lower workings has failed and caused slump material to enter Christal Creek.

2.0 GEOLOGY AND MINERALIZATION

The commodities of interest at the Formo site on Galena Hill are silver, gold, lead and zinc. The Keno Hill-Galena Hill silver-lead ores occur in erratic shoots and lenses lying in vein faults that cut fine-bedded to massive quartzite, intercalated with greenstone sills and lenses, and various schistose rocks (GSC Paper 68-68, p.21).

The Formo veins are composed of siderite (FeCO_3) with variable, but small, amounts of quartz, sphalerite ($(\text{Zn,Fe})\text{S}$), galena (PbS) and freiberigite (silver-bearing tetrahedrite ($(\text{Cu,Fe})_{12}\text{Sb}_4\text{S}_{13}$)). The cubiform galena occurs as clots and clusters rarely more than a few centimetres in size. The vein has been affected by post-mineralization fault movement, as well as intense weathering. Siderite (FeCO_3) and galena are commonly weathered to limonite and anglesite. The footwall is greenstone and the hangingwall is graphite schist which is highly brecciated within a few metres of the vein (Van Angeren, P.D. and White, P.S., 1987).

3.0 WASTE ROCK DISPOSAL AREAS

3.1 Description

There are three areas of mining disturbance on the Formo site: the upper workings, the middle workings and lower workings. The upper workings, located on the south (uphill) side of the highway, are shown in plan view in Drawing 3. The middle and lower workings, located on the north (down-hill) side of the highway, are shown in Drawing 2.

At the upper workings, on the south side of the highway, approximately 6900 m³ of rock was removed to expose the main Formo vein in trenches (Van Angeren, P.D. and White,

P.S., 1987). The rock was pushed with a bulldozer into piles beside the trenches as shown on the site map of the upper workings. Shallow shafts were destroyed during trenching. No ponding water or surface runoff was observed during the site visit (which was during an extended period of heavy rainfall).

Two adits and connecting drifts of unknown length were driven at elevations approximately 50 metres and 80 metres below the upper workings. These are referred to as the middle and the lower workings on the site map, Drawing 2. Two lobes of waste rock were piled below each of the adits. The rock has been end-dumped from rail trestles.

The waste rock at the middle workings covers an area of approximately 1000 m². Over 30% of the waste rock is covered with mosses and alders. No evidence of slumping or extension cracks were observed. The slope angle of the pile was 35°, which is similar to natural slope of the underlying hillside. The eastern lobe of the waste rock pile is covered with relatively unmineralized rock as compared to the western lobe of the pile. No seeps were located above or within 100 metres below the rock pile. Christal Creek is approximately 250 metres below the toe of the rock pile.

The area of disturbance at the lower workings is approximately 6000 m². The area covered by waste rock was increased by an additional 55% when the eastern lobe failed, causing overburden mixed with waste rock to flow down the hillside into Christal Creek. The slope angle was measured to be 45° along the upper parts of the pile. Extension cracks were observed along the top of both lobes and the head scarp of the failure was still evident at the crest of the eastern lobe. Both lobes of the rock pile are undergoing active creep deformation (possibly related to poor drainage and frost action). Due to the fine-grained, schistose nature of the material in the dump and the relatively steep slopes of both the dump faces and the underlying natural ground, further failures are likely to occur in the future. The western lobe of the waste rock pile is covered with relatively unmineralized rock as compared to the eastern lobe.

3.2 Samples

Seven pits were dug and eight samples collected of the predominately schistose waste rock. The sample locations and field paste test results are shown on the site maps, Drawings 2 and 3. The test pit logs are summarized in Table 1.

Samples FOWR/P301 and FOWR/P302 were collected from the rock pile at the middle workings. Pit P301 was dug in unmineralized material and pit P302 in the mineralized material.

Samples FOWR/P303 and FOWR/P304 were collected from the overburden and weathered bedrock excavated and pushed around by a bulldozer at the upper workings.

Samples FOWR/P305, FOWR/P306, FOWR/P307/1, FOWR/P307/2 and FOWR/P308 were collected from the rock pile at the lower workings. Pit P305 was dug in unmineralized material. Pits P306 and P308 were dug in similar mineralized material, and P307 was dug in an area exhibiting iron carbonate staining on the surface.

There was no visible seepage issuing from the adits or waste rock piles. A groundwater spring was observed in the gully below the middle workings. Sample FOWQ/Str-302 was collected from the seep approximately 250 metres below the middle workings. At the sample site (which was within a metre of Christal Creek) the channel was 30 cm wide and 5 cm deep and was flowing at < 1 L/sec. The spring first surfaced approximately 75 metres upslope of the sample site.

Three water samples were collected from Christal Creek. Sample FOWQ/Str-002 was collected 100 metres upstream of the failed waste rock pile of the lower adit and is representative of the background water quality in Christal Creek. Sample FOWQ/Str-001 was collected 100 metres upstream from the drainage area of the middle workings, which would be approximately 50 metres below the drainage area of the lower workings. Sample FOWQ/Str-301 was collected 50 to 100 metres downstream of the drainage area affected by the middle workings. At the downstream sample site the creek was 2 metres wide, 15 cm deep and flowing at 20 L/sec (visual estimate).

3.3 Analytical Results

Results of geochemical analyses of waste rock samples are provided in Table 2 and the analytical results for the water samples are provided in Table 3.

Paste Parameters

The paste pH values for the material from the upper workings, the middle workings and the unmineralized rock located at the lower workings are neutral. The mineralized waste rock samples collected at the lower workings had acidic paste pH values, indicating that the material is currently generating acid.

Acid Base Accounting

Six of nine waste rock samples collected had negative Net Neutralizing Potentials, indicating that they are potentially acid generating. Of the remaining three samples, two had Neutralizing Potential to Acid Potential (NP:AP) ratios below 3, suggesting that they may also be potentially acid generating.

Metals Concentrations

The samples collected from the mineralized rock piles and the upper workings contained elevated concentrations of cadmium, lead, silver and zinc. Arsenic was also elevated in the material from the mineralized lobe of the pile at the middle workings.

Water Quality

All the water samples had field pH values between 7 and 7.9 and elevated laboratory conductivity readings (615 to 1020 $\mu\text{S}/\text{cm}$). The upstream sample obtained from Christal Creek contained concentrations of zinc (0.122 mg/L) that exceed the CCME freshwater aquatic life criteria (0.03 mg/L). The concentration of arsenic in the upstream water sample was equal to the CCME criteria (0.0001 mg/L).

Zinc and silver concentrations in the samples collected in Christal Creek downstream of the middle and lower workings were double those measured in the upstream sample. There was little difference in the concentrations of other metals. Zinc and silver concentrations were also elevated above the CCME freshwater aquatic life criteria in the groundwater seep below the middle workings.

4.0 EXISTING AND POTENTIAL ACID ROCK DRAINAGE CONDITIONS

Based on the limited sampling completed for this study, it appears that most of the waste rock at the lower adit is either generating acidic drainage, or is potentially acid generating. The amount of this material is estimated to be 10,500 tonnes, (assuming a specific gravity of 2.65, a thickness of one metre overall and a swell factor of 15%). An additional 20,000 tonnes of waste rock from the upper and middle workings has the potential to become net acid generating.

The upstream water quality in Christal Creek is high in metals, particularly zinc and silver. Comparison of the upstream and downstream water quality indicates that the workings at the Formo site are causing an increase in zinc and possibly silver concentrations in Christal Creek. It is likely that the major source of the zinc and silver is the failed mineralized waste rock lying withing Christal Creek immediately below the lower workings.

It is interesting to note that, while all of the mineralized waste rock samples contained high concentrations of lead, lead concentrations in water samples collected in Christal Creek, both upstream and downstream of the mine workings, were below CCME criteria for freshwater aquatic life.

Although the sampling and testing indicating that most of the waste rock materials on the Formo site are either acid generating or potentially acid-generating, the rock piles on the hillside probably contribute relatively little metal loads to Christal Creek. Precipitation in the area is low and catchment areas above the dumps small. No seeps were observed emerging from the dumps at the time of the inspection, even though it had been raining heavily at the time. By far the greatest ARD concern associated with the Formo site is the presence of the failed dump material in Christal Creek below the lower workings, and the high probability that similar failures will occur in the future.

5.0 REMEDIATION OPTIONS

Typical reclamation and control options for acid generating mine waste and mine openings include:

- source control which includes limiting further oxidation, for instance, by placing the waste under water thus preventing oxygen entry;
- migration control which limits the mobility of oxidation products, for example, by reducing infiltration to the waste by placing a low permeability cover; and,
- release control by collecting and treating contaminated flows prior to discharge.

As discussed in the previous section, the greatest ARD risk associated with the Formo site is the presence of mineralized material lying in Christal Creek as a result of failure of the waste rock dump at the lower mine workings. There is also a significant risk of similar failures occurring in the future, adding to the amount of material already in the creek. Highest priority should be given to stabilizing the dumps at the lower and middle workings.

If possible, the failed dump material that is lying within Christal Creek should be removed. Access will be extremely difficult, however, and the environmental damage that will result from constructing access roads to the area will have to be weighed against the environmental benefit of removing the material. Another alternative, if necessary, would be to leave the failed material in place, and divert Christal Creek around it.

Physical stabilization of the waste rock dumps is outside of the scope of this study. However, given the fine-grained schistose nature of the waste dump materials and the steep slope of the terrain underlying the dumps, it will probably be difficult to stabilize the dumps in place, and the dump material will probably have to be relocated elsewhere. Options available for relocation include rehandling the material to the upper workings (on the south side of the highway), placing the material in the underground workings, or a combination of both.

Relocating the dump material to the upper workings will adequately address the physical stability concerns. The relocated material should be placed in an area of the upper workings with a minimal catchment area for surface run-on, and placed in as compact a pile as possible to minimize the surface area available for infiltration. This will help control migration of oxidation products. Migration of oxidation products could be reduced further, if required, by placing a cover over the rehandled dump material. Covers

to be considered range from a simple soil cover (such as silt-glacial till) or a composite cover incorporating an geomembrane, depending on the level of control required.

Relocation of some of the dump material into the underground workings may also be possible. Because of bulking, however, it is unlikely that all of the waste rock at the middle and lower workings will fit back in the underground workings. Before placing any material underground, however, the configuration, stability and drainage conditions in the underground workings will have to be determined.

Relocation of a significant portion of the mineralized waste rock to the underground workings would effectively sterilize the underground workings. However, the adit entrances need to be securely sealed for health and safety reasons.

Covering the waste rock or relocating it underground would improve the aesthetic appearance of the site and the perceived environmental risk.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

From the limited sampling and testing completed for this assessment it appears that the majority of the waste rock on surface at the Formo site is either currently generating acid or has the potential to do so. The waste rock also contains high concentrations of several metals, including arsenic, cadmium, lead, silver and zinc, which, if leached into adjacent receiving waters could be detrimental to freshwater aquatic life.

Based on the water samples collected during the inspection, the only noticeable impact on the water quality appeared to be an increase in zinc and possibly silver concentrations originating from the waste rock material lying within Christal Creek. This dump is unstable and is likely to fail again in the future. Failure of additional waste rock into Christal Creek would probably result in an increase in metal loadings.

The impact of the zinc loadings is difficult to assess, however, as the background water quality in Christal Creek at the Formo site is naturally high in zinc. Zinc concentrations in the water sample collected from Christal Creek upstream of the Formo workings

showed zinc concentrations four times greater than CCME guidelines for fresh water aquatic life. The additional zinc loadings from the Formo waste rock may be insignificant relative to upstream (and possibly downstream) sources.

6.2 Recommendations

The waste rock piles at the lower mine workings (and the middle workings, if required) should be stabilized as soon as possible to minimize the risk of additional dump material failing into Christal Creek.

If possible, the waste rock material already lying within Christal Creek should be removed. Access will be extremely difficult, however, and the environmental damage that will result from constructing access roads to the area will have to be weighed against the environmental benefits of removing the material.

While ARD has been identified as a possible concern at the Formo site, the need for additional measures to control ARD is not clear from this limited assessment. A more detailed site assessment is required to evaluate the potential and current impacts of the waste rock on the receiving environment and to develop an effective remediation plan.

It is assumed that additional water quality and hydrology data is available for Christal Creek due to the proximity of United Keno Hill Mine's underground workings and their mill to the Formo site. It is recommended that this information be obtained if possible and compiled.

It is recommended that for 1997 a monitoring program be undertaken to obtain water quality data during spring freshet, middle summer, and late fall conditions. The method detection limits used are to be less than or equal to the CCME freshwater aquatic life criteria. The results can then be used in conjunction with historical water quality and hydrology data to determine appropriate remediation measures and future monitoring requirements.

Detailed plans of the underground workings should be obtained, the stability of the underground openings assessed and the underground drainage patterns determined. This

information is required to assess the feasibility and long-term impact of rehandling waste rock from the surface piles to the underground workings.

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TABLE 1 Formo Waste Rock Sample Descriptions

Sample ID	Sample Description
FOWR/P301	unmineralized rock from east lobe of middle workings. Black/grey coloured graphite schist with 1% quartz carbonate vein material and 1% visible pyrite collected over a thickness of 30cm. Surface is covered with moss and small alders. Field paste pH measured 7.0 and paste conductivity 260 μ S/cm.
FOWR/P302	mineralized rock from west lobe middle workings. Graphite schist with 3% quartz carbonate vein material and 3% visible pyrite collected over a thickness of 40 cm. Field paste pH measured 7.60 and conductivity 180 μ S/cm.
FOWR/P303	Chlorite schist waste rock at upper workings, 1% visible pyrite, Field paste pH measured 6.4. Included fragments up to 5cm in diameter.
FOWR/P304	chlorite sericite schist typical of waste rock at upper workings. Sample collected over a thickness of 40 cm with fragments up to 5cm in diameter. Contained <1% quartz carbonate vein material. Field paste conductivity measured 210 μ S/cm.
FOWR/P305	unmineralized rock from west lobe lower workings. Sample collected over a thickness of 40cm, upper 12cm consisted of bands of dark brown iron carbonate altered material and graphite chlorite schist bands. Over laying a 20cm thick band of graphite schist and 13cm of dark red brown coloured sand and silt size material. Includes fragments up to 7cm in diameter.
FOWR/P306	mineralized rock from face of east lobe at lower workings. Chlorite sericite schist, with bands of limonite. Surface is weathered to a black colour and contains 15% pyrite, and 30% quartz carbonate vein material. Samples collected over a thickness of 30cm.
FOWR/P307/1	Sample of iron carbonate stained surface material collected over a thickness of 18cm in schist.
FOWR/P307/2	Collected below FOWR/P307/1 over a thickness of 17cm in brown red coloured schist with grey silt lenses and timber.
FOWR/P308	mineralized rock from top of dump at lower workings similar to P306. Bands of schist including graphite schist, chlorite schist and limonite collected over a thickness of 35cm.

TABLE 2 Formo Waste Rock ABA and ICP Results

Parameter	Unit	Sample Number FOWR								
		P301	P302	P303	P304	P305	P306	P307/1	P307/2	P308
Field Paste pH		7.00	7.60	6.40	na	na	na	na	na	na
Field Cond	uS/cm	260	180	na	210	na	na	na	na	na
Lab Paste pH		7.82	7.79	7.49	7.36	7.52	3.87	3.12	5.46	4.02
Total Sulfur	%	1.04	8.44	2.25	4.79	1.79	4.18	6.55	4.61	4.02
Sulfate	%	0.24	0.20	0.38	0.54	0.85	2.59	1.74	1.67	2.36
AP		25.00	257.50	58.44	132.81	29.38	49.69	150.31	91.88	51.88
NP		161.00	127.00	68.75	29.00	68.25	-24.78	-14.25	4.28	38.94
NET NP		136.00	-130.50	10.31	-103.81	38.88	-74.47	-164.56	-87.59	-12.94
NP/AP		6.44	0.49	1.18	0.22	2.32	<0.1	<0.1	<0.1	0.75
Aluminum	%	1.02	0.35	0.56	0.73	0.68	0.38	0.47	1.34	0.63
Antimony	ppm	3	155	71	169	6	36	77	85	140
Arsenic	ppm	125	5165	180	3148	253	651	833	582	603
Barium	ppm	34	22	54	38	29	38	23	39	35
Beryllium	ppm	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Bismuth	ppm	<1	<1	<1	<1	<1	<1	<1	<1	<1
Cadmium	ppm	<0.1	>100	>100	>100	<0.1	<0.1	55.3	>100	<0.1
Calcium	%	6.00	4.95	2.50	2.93	3.27	2.64	1.26	1.98	1.97
Chromium	ppm	86	83	76	81	88	90	71	111	79
Cobalt	ppm	11	15	15	17	12	5	10	15	8
Copper	ppm	25	130	150	129	25	29	166	123	107
Gallium	ppm	<1	<1	<1	<1	<1	<1	<1	<1	<1
Iron	%	3.37	7.99	3.79	5.82	3.46	4.55	9.46	6.24	6.35
Lead	ppm	1426	>10000	>10000	>10000	1039	>10000	9900	>10000	>10000
Lithium	ppm	17	4	6	10	11	5	7	23	9
Magnesium	%	1.48	0.68	0.79	1.04	0.96	0.21	0.30	1.24	0.50
Manganese	ppm	2432	2064	3277	3487	1321	122	206	536	310
Molybdenum	ppm	13	20	21	21	16	15	23	22	18
Nickel	ppm	42	42	45	61	38	16	29	54	29
Potassium	%	0.10	0.10	0.11	0.11	0.10	0.12	0.09	0.10	0.11
Potassium	ppm	1080	1090	1510	1180	1330	590	790	630	530
Silver	ppm	12.7	>200	154.6	>200	11.3	103.8	133.7	151.3	>200
Sodium	%	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Strontium	ppm	113	26	42	43	43	11	6	28	19
Thorium	ppm	<1	<1	<1	<1	<1	<1	<1	<1	<1
Tin	ppm	3	6	4	5	2	3	6	6	5
Titanium	%	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Tungsten	ppm	2	19	56	27	3	2	20	51	4
Uranium	ppm	<1	<1	<1	<1	<1	<1	<1	<1	<1
Vanadium	ppm	27.8	3.4	8.2	20.8	9.8	10.3	10.3	38.4	18.8
Zinc	ppm	1435	>10000	>10000	>10000	1144	505	>10000	>10000	3448

AP = Acid Potential in tonnes CaCO₃ equivalent per 100 tonnes of material
 NP = Neutralization Potential in tonnes CaCO₃ equivalent per 1000 tonnes of material
 Net NP = Net Neutralization Potential = tonnes CaCO₃ equivalent per 1000 tonnes of material
 na = no assay / analysis
 < = lower detection limit
 > = upper detection limit

TABLE 3 Formo Water Quality Results

Parameter	Units	Sample Number FOWQ/			
		STR-001	STR-301	STR-302	STR-002
Field Conductivity		45	280	600	440
Field pH		7	7.9	7.38	7.7
Conductivity	umhos/cm	618	615	1020	633
Hardness CaCO3	mg/L	339	336	589	333
Moisture %	%	-	-	-	-
pH		8.08	8.11	7.73	8.06
Acidity (to pH 8.3) CaCO3	mg/L	5	3.6	13.4	3.8
Alkalinity-Total CaCO3	mg/L	136	135	234	138
Chloride Cl	mg/L	-	-	-	-
Sulphate SO4	mg/L	192	168	409	193
Aluminum T-Al	mg/L	0.017	0.008	0.083	0.018
Antimony T-Sb	mg/L	-	-	-	-
Arsenic T-As	mg/L	0.0024	0.0024	0.0014	0.0026
Barium T-Ba	mg/L	0.04	0.04	0.04	0.04
Beryllium T-Be	mg/L	<0.005	<0.005	<0.005	<0.005
Boron T-B	mg/L	<0.1	<0.1	<0.1	<0.1
Cadmium T-Cd	mg/L	0.0019	0.0018	0.0009	0.0011
Calcium T-Ca	mg/L	103	102	145	102
Chromium T-Cr	mg/L	<0.001	<0.001	<0.001	<0.001
Cobalt T-Co	mg/L	<0.02	<0.02	<0.02	<0.02
Copper T-Cu	mg/L	<0.001	<0.001	0.002	<0.001
Iron T-Fe	mg/L	0.11	0.1	0.15	0.11
Lead T-Pb	mg/L	0.001	0.001	0.004	0.002
Lithium T-Li	mg/L	<0.02	<0.02	<0.02	<0.02
Magnesium T-Mg	mg/L	19.5	19.3	54.9	18.9
Manganese T-Mn	mg/L	0.106	0.099	0.006	0.113
Mercury T-Hg	mg/L	<0.00005	<0.00005	<0.00005	<0.00005
Molybdenum T-Mo	mg/L	<0.03	<0.03	<0.03	<0.03
Nickel T-Ni	mg/L	<0.02	<0.02	<0.02	<0.02
Selenium T-Se	mg/L	0.0009	0.001	0.0007	0.0008
Silver T-Ag	mg/L	0.0002	0.0002	0.0002	0.0001
Sodium T-Na	mg/L	<2	<2	2	<2
Tin T-Sn	mg/L	-	-	-	-
Vanadium T-V	mg/L	<0.03	<0.03	<0.03	<0.03
Zinc T-Zn	mg/L	0.237	0.228	0.052	0.122

< = lower detection limit

Steffen Robertson and Kirsten
February, 1997

Appendix B

Site Photographs



Photo 1. Aerial view of Formo mine site from northeast with lower adit, middle adit and upper workings visible.



Photo 2. Wood frame wood clad core shed located southwest of upper workings area.



Photo 3. Interior of core shed; core trays visible at middle left of photo.



Photo 4. Asbestos-coated asphalt shingles on sides of core shed.



Photo 5. Wood frame wood clad workshop at entrance to lower adit looking southwest.



Photo 6. Wood frame wood clad shed at lower adit looking east.



Photo 7. Aerial view of lower east waste rock dump. Christal Creek at lower left corner of photo; slumping area evident as brown-colored lobe.



Photo 8. Downhill view of slumped overburden and waste rock, looking toward Christal Creek.



Photo 9. Close-up view of slumped area, lower east waste rock dump. Dead trees visible near toe of slump indicates effects from past slumping.



Photo 10. Slumped overburden and waste rock, with recent tension cracks at head of unstable lobe.



Photo 11. Remnants of log and timber barrier at entrance of lower adit.



Photo 12. Middle adit enclosure and entrance.

Appendix C

Analytical Results

service

laboratories

ltd.



CHEMICAL ANALYSIS REPORT

Date: September 24, 1996

ASL File No. G4270

Report On: Soil, Water And Product Analysis

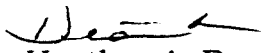
Report To: **Public Works & Gov't Services**
Environmental Services
204-1166 Alberni Street
Vancouver, BC
V6E 3W5

Attention: **Mr. Tim Sackmann**, Manager, Contaminated Sites

Received: August 20, 1996

ASL ANALYTICAL SERVICE LABORATORIES LTD.

per:


Heather A. Ross, B.Sc.
Project Chemist


Frederick Chen, B.Sc.
Supervisor, Trace Metals Lab





RESULTS OF ANALYSIS - Sediment/Soil¹

File No. G4270

FO-SL- 201	FO-SL- 301
96 08 20 11:00	96 08 13 11:00

Physical Tests

Moisture	%	14.3	71.3
Total Metals			
Antimony	T-Sb	33	<20
Arsenic	T-As	37.8	148
Barium	T-Ba	246	127
Beryllium	T-Be	<0.5	<0.5
Cadmium	T-Cd	<2	115
Chromium	T-Cr	21	16
Cobalt	T-Co	15	19
Copper	T-Cu	39	28
Lead	T-Pb	167	115
Mercury	T-Hg	0.043	0.068
Molybdenum	T-Mo	6	<4
Nickel	T-Ni	22	62
Selenium	T-Se	0.6	0.6
Silver	T-Ag	4	<2
Tin	T-Sn	<30	<30
Vanadium	T-V	32	26
Zinc	T-Zn	294	8610

Remarks regarding the analyses appear at the beginning of this report.
 < = Less than the detection limit indicated.
¹Results are expressed as milligrams per dry kilogram except where noted.



RESULTS OF ANALYSIS - Sediment/Soil¹

File No. G4270

	FO-SL- 201	FO-SL- 301
	96 08 20 11:00	96 08 13 11:00
<hr/>		
<u>Polycyclic Aromatic Hydrocarbons</u>		
Acenaphthene	<0.1	<0.05
Acenaphthylene	<0.1	<0.05
Anthracene	<0.1	<0.05
Benzo(a)anthracene	<0.1	<0.05
Benzo(a)pyrene	<0.1	<0.05
Benzo(b)fluoranthene	<0.1	<0.05
Benzo(g,h,i)perylene	<0.1	<0.05
Benzo(k)fluoranthene	<0.1	<0.05
Chrysene	<0.1	<0.05
Dibenz(a,h)anthracene	<0.1	<0.05
Fluoranthene	<0.1	<0.05
Fluorene	<0.1	<0.05
Indeno(1,2,3-c,d)pyrene	<0.1	<0.05
Naphthalene	0.1	<0.05
Phenanthrene	<0.1	<0.05
Pyrene	<0.1	0.05

Remarks regarding the analyses appear at the beginning of this report.

< = Less than the detection limit indicated.

¹Results are expressed as milligrams per dry kilogram except where noted.



RESULTS OF ANALYSIS - Water¹

File No. G4270

		FO-WQ- STR-001	FO-WQ- STR-301	FO-WQ- STR-302
		96 08 13 11:00	96 08 13 11:30	96 08 13 11:30
Physical Tests				
Conductivity (umhos/cm)		618	615	1020
Hardness	CaCO ₃	339	336	589
pH		8.08	8.11	7.73
Dissolved Anions				
Acidity	CaCO ₃	5.0	3.6	13.4
Alkalinity - Total	CaCO ₃	136	135	234
Sulphate	SO ₄	192	168	409
Total Metals				
Aluminum	T-Al	0.017	0.008	0.083
Arsenic	T-As	0.0024	0.0024	0.0014
Barium	T-Ba	0.04	0.04	0.04
Beryllium	T-Be	<0.005	<0.005	<0.005
Boron	T-B	<0.1	<0.1	<0.1
Cadmium	T-Cd	0.0019	0.0018	0.0009
Calcium	T-Ca	103	102	145
Chromium	T-Cr	<0.001	<0.001	<0.001
Cobalt	T-Co	<0.02	<0.02	<0.02
Copper	T-Cu	<0.001	<0.001	0.002
Iron	T-Fe	0.11	0.10	0.15
Lead	T-Pb	0.001	0.001	0.004
Lithium	T-Li	<0.02	<0.02	<0.02
Magnesium	T-Mg	19.5	19.3	54.9
Manganese	T-Mn	0.106	0.098	0.006
Mercury	T-Hg	<0.00005	<0.00005	<0.00005
Molybdenum	T-Mo	<0.03	<0.03	<0.03
Nickel	T-Ni	<0.02	<0.02	<0.02
Selenium	T-Se	0.0009	0.0010	0.0007
Silver	T-Ag	0.0002	0.0002	0.0002
Sodium	T-Na	<2	<2	2
Vanadium	T-V	<0.03	<0.03	<0.03
Zinc	T-Zn	0.236	0.228	0.052

Remarks regarding the analyses appear at the beginning of this report.

< = Less than the detection limit indicated.

¹Results are expressed as milligrams per litre except where noted.



RESULTS OF ANALYSIS - Water¹

File No. G4270

FORM-WQ-
STR-002

96 08 17

Physical Tests

Conductivity (umhos/cm)		633
Hardness	CaCO ₃	333
pH		8.06

Dissolved Anions

Acidity	CaCO ₃	3.8
Alkalinity - Total	CaCO ₃	138
Sulphate SO ₄		193

Total Metals

Aluminum	T-Al	0.018
Arsenic	T-As	0.0026
Barium	T-Ba	0.04
Beryllium	T-Be	<0.005
Boron	T-B	<0.1
Cadmium	T-Cd	0.0011
Calcium	T-Ca	102
Chromium	T-Cr	<0.001
Cobalt	T-Co	<0.02
Copper	T-Cu	<0.001
Iron	T-Fe	0.11
Lead	T-Pb	0.002
Lithium	T-Li	<0.02
Magnesium	T-Mg	18.9
Manganese	T-Mn	0.113
Mercury	T-Hg	<0.00005
Molybdenum	T-Mo	<0.03
Nickel	T-Ni	<0.02
Selenium	T-Se	0.0008
Silver	T-Ag	0.0001
Sodium	T-Na	<2
Vanadium	T-V	<0.03
Zinc	T-Zn	0.122

Remarks regarding the analyses appear at the beginning of this report.

< = Less than the detection limit indicated.

¹Results are expressed as milligrams per litre except where noted.



APPENDIX

**CHAIN OF
CUSTODY
FORMS**

CHAIN OF CUSTODY / ANALYTICAL REQUEST FORM



Specialists in Environmental Chemistry

1988 Triumph Street
 Vancouver, BC
 Canada V5L 1K5
 FAX: (604) 253-6700
 TEL: (604) 253-4188
 TOLL FREE: (800) 665-0243

CLIENT PULISC ENVIRONMENTAL SERVICES
204 / 1116 ALBERTA ST.
VANCOUVER, B.C.
VIC 3M5
 PH/FAX# 623 6388 / 623 6274
 CONTACT TIM SICKMANN
 SAMPLED BY T. SICKMANN A. LAURUM
D. CARROHEAN

PAGE 3 OF 4 5
YUKON A.M.D. PROJECT NO. 92
 ASL CONTACT HEATHER DUNN
 CLIENT PROJECT # _____
 PO # _____
 DATE SUBMITTED _____
 RESULTS REQUIRED BY _____

ANALYSIS REQUESTED

TOTAL METALS
MINERALOGY
GEOPHYSICAL CHEMISTRY

LAB USE	SAMPLE IDENTIFICATION	SAMPLE TYPE	DATE/TIME Y M D	SAMPLED	FIELD PRESERVATION															COMMENTS
23	RU-WQ - STR - 003	WATER	96 03 14	12:30	AM	NITRIC	✓													
	RU-WQ - STR - 003	"	96 03 14	12:30	PM	φ		✓												
24	SG - WQ - STR - 202	"	96 03 17	10:00	AM	NITRIC	✓													
	SG - WQ - STR - 202	"	96 03 17	10:00	PM	φ		✓												
25	MACT - WQ - STR - 001	"	96 03 15	11:00	AM	NITRIC	✓													
	MACT - WQ - STR - 001	"	96 03 15	11:00	PM	φ		✓												
26	MACT - WQ - STR - 002	"	96 03 15	11:15	AM	NITRIC	✓													
	MACT - WQ - STR - 002	"	96 03 15	11:45	AM	φ		✓												
27	MACT - WQ - 003	"	96 03 15	11:30	AM	NITRIC	✓													
	MACT - WQ - 003	"	96 03 15	11:30	PM	φ		✓												
28	MACT - WQ - 004	"	96 03 15	1:00	AM	NITRIC	✓													
	MACT - WQ - 004	"	96 03 15	1:00	PM	φ		✓												
29	MACT - WQ - 005	"	96 03 15	1:16	AM	NITRIC	✓													
	MACT - WQ - 005	"	96 03 15	1:15	AM	φ		✓												

NOTES/COMMENTS

CONDITION RECEIVED
 FROZEN _____
 COLD _____
 AMBIENT _____
 TOTAL PACKAGES _____

RELINQUISHED BY _____
 AFFILIATION _____
 RECEIVED BY _____ Y / M / D
 AFFILIATION _____ AM / PM



METHODOLOGY

File No. G4270

Outlines of the methodologies utilized for the analysis of the samples submitted are as follows:

Extractable Organic Halide (EOX) in Oil

This analysis is carried out using a procedure that is consistent with the requirements of the appropriate regulatory agencies and adapted from U.S. EPA Method 9020 (Publ. # SW-846, 3rd ed., Washington, DC 20460). The procedure involves extracting a subsample with ethyl acetate and analysing the extract with a TOX analyser.

Moisture

This analysis is carried out gravimetrically by drying the sample to constant weight at 103 C.

Conventional Parameters in Sediment/Soil

These analyses are carried out on a leachable basis. The procedure involves mixing with reagent grade water and leaching for several hours. The leachate is centrifuged and analysed in accordance with "Standard Methods for the Examination of Water and Wastewater" 17th ed. published by the American Public Health Association, 1989.

Metals in Sediment/Soil

This analysis is carried out using procedures adapted from "Test Methods for Evaluating Solid Waste" SW-846 Method 3050 or Method 3051, published by the United States Environmental Protection Agency (EPA). The procedures involve a digestion using a 1:1 ratio of nitric acid and hydrochloric acid, along with hotplate or microwave heating. Instrumental analysis is by atomic absorption spectrophotometry (EPA Method 7000) and/or inductively coupled plasma - optical emission spectrophotometry (EPA Method 6010).

Method Limitation: The stated acid digestion will provide excellent results for total recoverable metals; however, it is only partially effective on mineralized or non-environmentally available metals.

Polycyclic Aromatic Hydrocarbons in Sediment/Soil

This analysis is carried out using a procedure adapted by ASL from U.S. EPA Methods 3500, 3630, and 8270 (Publ. #SW-846 3rd ed., Washington, DC 20460). The procedure involves a microwave assisted extraction with



dichloromethane followed by a clean-up using silica gel column chromatography. This clean-up procedure has been found to effectively remove aliphatic and heterocyclic hydrocarbons which could potentially interfere with the analysis. The final extract is analysed by capillary column gas chromatography with mass spectrometric detection.

Conventional Parameters in Water

These analyses are carried out in accordance with procedures described in "Methods for Chemical Analysis of Water and Wastes" (USEPA), "Manual for the Chemical Analysis of Water, Wastewaters, Sediments and Biological Tissues" (BCMOE), and/or "Standard Methods for the Examination of Water and Wastewater" (APHA). Further details are available on request.

Metals in Water

This analysis is carried out in accordance with procedures described in "Standard Methods for the Examination of Water and Wastewater" 19th Edition 1995 published by the American Public Health Association, and with procedures adapted from "Test Methods for Evaluating Solid Waste" SW-846 published by the United States Environmental Protection Agency (EPA). The procedures may involve preliminary sample treatment by acid digestion or filtration (EPA Method 3005), followed by instrumental analysis by atomic absorption spectrophotometry (EPA Method 7000), inductively coupled plasma - optical emission spectrophotometry (EPA Method 6010), and/or inductively coupled plasma - mass spectrometry (EPA Method 6020).

Mercury in Water

This analysis is carried out using procedures adapted from "Standard Methods for the Examination of Water and Wastewater" 19th Edition 1995 published by the American Public Health Association. A cold-oxidation procedure involving bromine monochloride is used, followed by instrumental analysis by cold-vapour atomic absorption spectrophotometry (CVAAS).

End of Report