HEMMERA
ENVIROCHEM

RISK ASSESSMENT

Brooks Brook
Alaska Highway
Yukon

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EXECUTIVE SUMMARY

Overview

Hemmera Envirochem Inc. (Hemmera) was retained by Indian and Northern Affairs Canada (INAC) to undertake a risk assessment at a portion of the former Alaska Highway construction camp located along the Alaska Highway at Mile Post 830. The property is now used as a native meeting ground and recreational area.

The historical land use of the property has ranged from residential to industrial. Due to the historic land use of the property over the years, INAC retained the Environmental Services Group to conduct an environmental investigation of the property in 1997.

In 1998 INAC retained Lorimer and Associates and Hemmera to complete a Phase I Environmental Investigation to further assess the areas of environmental concern identified in the ESG report. During this investigation hydrocarbons were found to be impacting the soil and groundwater at one area of the site known as the "vicinity of Foundation AB." A Detailed Site Investigation was completed in the fall of 2001 to further delineate soil and groundwater hydrocarbon contamination.

The hydrocarbon contamination extends to the vicinity of a brook (Brooks Brook). Due to the close proximity of the brook to the impacted soil and groundwater, INAC requested the possibility of risk managing the contamination in this sensitive area rather than undertaking remedial actions such as excavation.

This risk assessment uses the site data provided by previous investigations and combines the results of an exposure assessment and a toxicity assessment to quantify human health risks. The potential environmental risks are assessed separately on the basis of the defined environmental receptors and existing aquatic and terrestrial toxicity. The results of the risk assessment are summarized by illustration in **Figure I**.

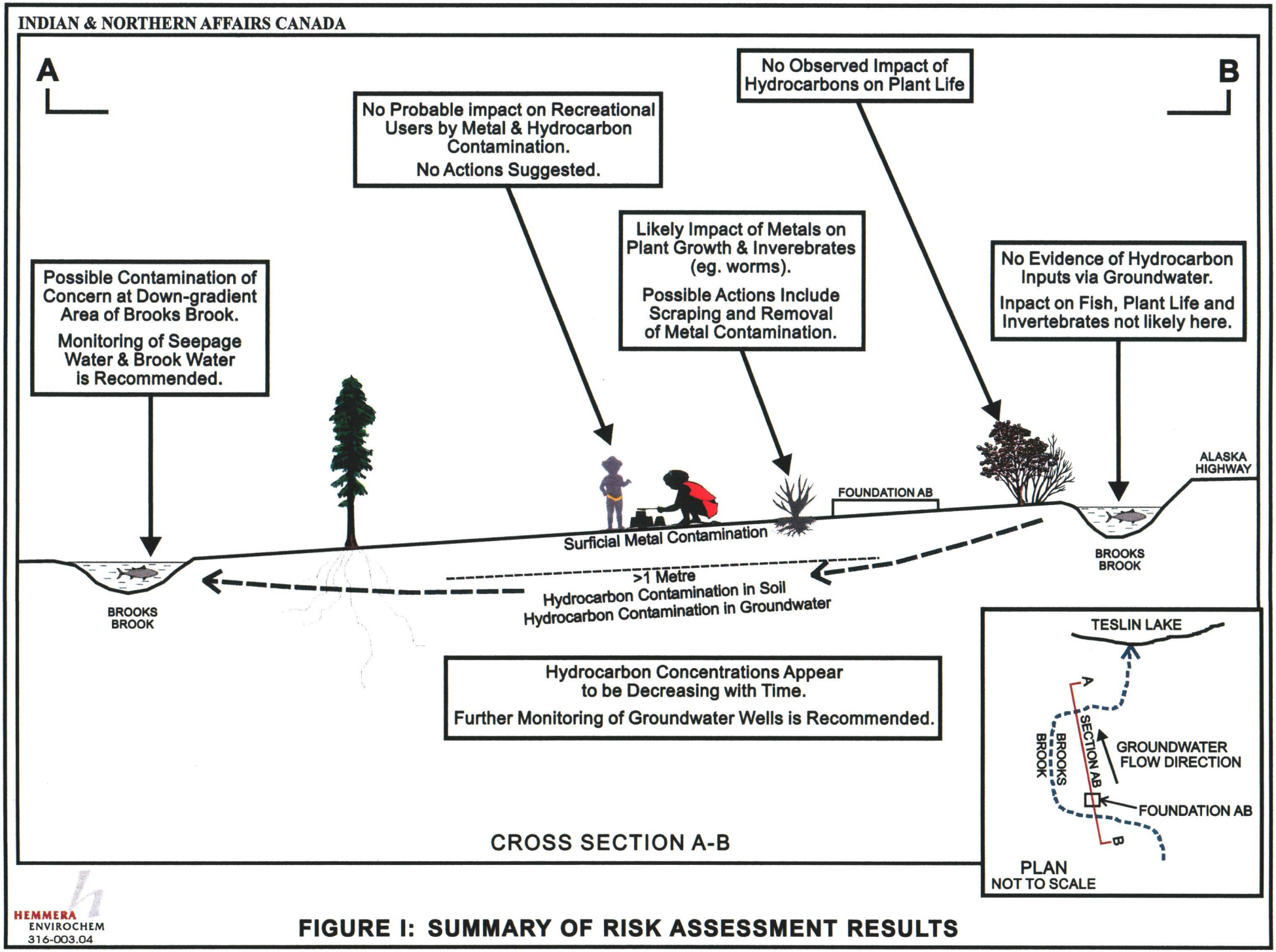

FIGURE I: SUMMARY OF RISK ASSESSMENT RESULTS

Human Health Risk Assessment

The current human health risk assessment was initiated to assess the potential risks to human health in the vicinity of Foundation AB. The risk assessment is based on the current land use of the property as a meeting ground for the Tlingit Band as well as for recreational purposes such as camping and picnics during the summer months.

A review of the previous reports indicate that in addition to hydrocarbons, metals at concentrations in excess of the applicable standards are found in surface soils in the vicinity of Foundation AB. The hydrocarbons are found in soil at a depth ranging from 0.8 meters to 2.5 meters below grade. The groundwater in this area has also been impacted by hydrocarbon contamination.

Contaminants of concern in soil were selected if the 95th percentile concentration of the samples analysed exceeded the applicable Yukon Contaminated Sites Regulation (YCSR) generic or human health protection standards and/or the applicable CCME guidelines, or if the maximum observed concentration is greater than two times any standard or guideline. Groundwater contaminants were not considered for the human health risk assessment, as there are no nearby drinking water wells.

Based on analytical data provided in the previous report, the chemicals selected for the human health risk assessment are summarized in following table:

Chemicals Selected for the Human Health Risk Assessment

Metals	Hydrocarbons
Chromium	Volatile Petroleum Hydrocarbons
Copper	Light Extractable Petroleum Hydrocarbons
Lead	Naphthalene
Zinc	

Once the chemicals were selected, an exposure assessment was conducted. The exposure assessment assesses the pathways that the contaminants could potentially take to come in contact with receptors (humans) on the site.

Three exposure pathways were identified:

1. Dermal
2. Ingestion
3. Inhalation

Dermal exposure, ingestion and inhalation were selected for the surface metals. The possibility of the public being exposed to the soil at depth is unlikely therefore dermal exposure and ingestion were not selected for hydrocarbons. However, inhalation of hydrocarbon vapours was selected as a possible exposure route.

Once the exposure pathways were identified, the quantity of the potential exposure in milligrams per kilogram per day was assessed, i.e. the dose of each chemical for each exposure pathway was calculated. All calculations were very conservative, e.g. it was assumed a member of the public would be present in the area of Foundation AB once every 14 days throughout the year and would confine his/her activities to that area. The estimated doses were then compared to the reference dose (RfD) or tolerable recommended daily intake (TDI) for each chemical of concern. The RfDs and TDIs are based on the toxicity of each of the chemicals. If the estimated dose is greater than the RfD or TDI then there may be potential for human health effects.

None of the estimated doses were found in excess of the RfDs or TDIs for the chemicals of concern. In fact, the calculated estimated doses were well below the RfDs and TDIs. Thus, the current human health risk assessment did not identify any potential risks to human health within the subject area from the metals and hydrocarbon impacted soil and groundwater.

Ecological Risk Assessment

The ecological risk assessment was conducted to assess the potential risks associated with the impacted soil and groundwater to ecological health.

Terrestrial Ecological Risk Assessment

The ecological setting is such that the site-related chemicals of potential concern (COPCs) may contact a wide variety of terrestrial species.

The terrestrial exposure routes and receptors identified in the ecological risk assessment are:

- Root uptake by terrestrial plants of metals and hydrocarbons, and;
- Soil Ingestion and dermal exposure of metals and hydrocarbons by soil invertebrates (e.g. worms).

Ingestion of food with elevated concentrations of the COPCs for small mammals and birds was not considered in the risk assessment due to the small size of the impacted area relative to the large foraging area of small mammals and birds.

Toxicology data for plants and invertebrates were obtained for metals and hydrocarbons in the Subject Area. The chemicals of concern were then selected for the terrestrial ecological risk assessment. These chemicals are listed in the following table.

Summary of Chemicals Selected for the Terrestrial Ecological Risk Assessment

Metals	Hydrocarbons
Chromium	Volatile Petroleum Hydrocarbons (VPH)
Copper	Light Extractable Petroleum Hydrocarbons (LEPH)
Lead	Heavy Extractable Petroleum Hydrocarbons (HEPH)
Zinc	

The toxicity ranges obtained from the literature were then compared to the 95th percentile concentrations observed in the soil. Based on the toxicity assessment of the chemicals of concern, copper and zinc in the surficial soils around the perimeter of Foundation AB appear to have concentrations that pose a potential risk to ecological health. The observed concentrations of copper

and zinc are higher than the recorded LC_{50} concentrations for soil invertebrates and plants. The LC_{50} is the concentration of the chemical that causes mortality in 50 % of a particular species.

Aquatic Ecological Risk Assessment

The aquatic ecological risk assessment looked at the potential impact of groundwater contamination on the quality of the water in Brooks Brook. Fish and aquatic invertebrates in Brooks Brook and Teslin Lake were identified as the primary receptors exposed to groundwater contamination. Aquatic plants were not considered receptors based on field observations, which indicated the absence of algae and macrovascular vegetation in the adjacent brook. In addition, ingestion of food with elevated chemical concentrations by birds and mammals was not considered given the small size of the impacted area relative to a typical feeding area for most birds and mammals that feed on aquatic biota.

The toxicity assessment was conducted for the chemicals in which the 95th percentile of the groundwater samples were in excess of the applicable aquatic life standards and guidelines.

These chemicals in excess of guidelines and standards are listed on the following table:

Metals	**Polycyclic Aromatic Hydrocarbons**	**Petroleum Hydrocarbons**
Iron	Naphthalene	LEPH
Manganese	Phenanthrene	HEPH
	Pyrene	
	Toluene	

The toxicity assessment found concentrations in groundwater of manganese, most polycyclic aromatic hydrocarbons, (PAHs), and HEPH well below the referenced toxicology data which included no-effect levels (NOEL), lowest observed effect levels (LOEL), and acute toxicity levels (LC_{50}'s and EC_{50}'s).

The toxicity assessment indicated a potential risk of LEPH and naphthalene to aquatic health.

A comparison of groundwater quality with toxicology data is obviously very conservative as processes (e.g. biodegradation, adsorption, precipitation, dilution etc.) will decrease the concentration of chemicals in groundwater prior to reaching receiving water such as Brooks Brook. The assessment of groundwater impact on Brooks Brook is complicated in that groundwater in the Subject Area directly adjacent to Brooks Brook flows away from this area of the brook. Field data in this area of the brook showed no evidence of any of the potential chemicals of concern in the brook water. However due to "U" shaped flow direction of Brooks Brook, contaminated water may extend to a down-gradient area of the brook.

The extent of down-gradient groundwater contamination could not be evaluated due to dense trees in the area that prevented the drill rig from advancing additional boreholes and wells. As a result, a groundwater model was used to evaluate the likely concentrations of chemical contaminants at two possible points of discharge to the brook. The predicted LEPH and naphthalene concentrations would be significantly less than reported toxicity concentrations to aquatic biota. As a result, it is predicted there should be no impact on aquatic life in Brooks Brook.

Conclusions and Recommendations

The human health risk assessment did not identify any potential risks to human health within the subject area from the metals and hydrocarbon impacted soil and groundwater.

Based on the soil, groundwater, sediment and surface water sampling, it appears that the brook sediment and the brook water to the east of the Subject Area have not been impacted by the soil and groundwater contamination.

Copper and zinc in the surficial soils around the perimeter of Foundation AB appear to have concentrations that pose a potential risk to ecological health.

Two options are suggested:

i.) Bioassay tests could be conducted on the soils to evaluate whether actual impacts would occur. If no impact is observed then the soils could be left as is.

ii.) Metals impacted soils in the vicinity of the foundation could be excavated and removed from the site without further testing.

The risk assessment suggests there should be no impact on aquatic life in Brooks Brook. However the uncertainty of the aquatic ecological risk assessment is relatively high. Therefore Hemmera recommends that the brook and seepage waters to the west and south be sampled for metals and hydrocarbons at these locations to confirm the quality of the surface water in the down gradient direction of the groundwater plume.

Based on the elevated concentrations of hydrocarbons observed in the groundwater within the Subject Area, annual monitoring and sampling all of the monitoring wells should be conducted as a component of a risk management approach. This approach would monitor the natural attenuations and biodegradation of the concentrations observed in the groundwater. Such attenuations are suggested in a comparison of historical data. Monitoring could cease upon assurance that the groundwater contamination is of a level that there is little or no potential for environmental impact.

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1 OVERVIEW

Hemmera Envirochem Inc. (Hemmera) was retained by Indian and Northern Affairs Canada (INAC) to undertake a risk assessment at the former Alaskan Highway construction camp located along the Alaskan Highway at Mile Post 830. The camp has since been decommissioned and the property is now used as a native meeting ground and recreational area.

In 1997, Environmental Sciences Group (ESG) completed an environmental assessment of the Site. Lorimer and Associates Ltd. and Hemmera (formerly Hemmera Resource Consultants) completed several phases of Environmental Site Assessments of the Site in the summer and fall of 1997 and in 1998, based on the ESG report results.

Hydrocarbons and total organochlorine pesticides (OCP) in exceedance of the Yukon Contaminated Sites Regulations (YCSR) and other applicable standards for OCP were detected in the vicinity of a cook shack located on the western portion of the property. In September 1999, Hemmera supervised the remedial excavation of an area of 3900 m^2 of OCP contaminated soil at the Site. Confirmatory soil samples analyzed by a laboratory indicated that the Site had been remediated to within the remedial criterion of 0.7 parts per million DDT.

Hydrocarbon contamination remained in two areas of the property and a Detailed Site Investigation (DSI) was completed in the fall of 2001 to delineate the hydrocarbon impacted soil and groundwater exceeding the YCSR standard for residential and parkland use and YCSR aquatic life standard, respectively. As one area (Foundation AB) was located near a brook (Brooks Brook), INAC requested the possibility of risk managing the area versus undertaking remedial actions such as excavation. As a result, the DSI also involved collecting information in preparation for completing a risk assessment for the area in the vicinity of Foundation AB.

The current risk assessment was initiated to assess whether human health and ecological exposure to the contaminants could occur in the Foundation AB area ("Subject Area") and if the exposure could

result in any risk. It is the understanding of Hemmera that the site is used occasionally as a meeting ground for the Tlingit Band as well as for recreational purposes such as camping and picnics during the summer months. The risk assessment is based on current land use. If changes to the land use occur, the risk assessment may no longer be applicable and additional procedures may be required for the management of the contaminated soils and groundwater in the Subject Area.

This document constitutes a baseline risk assessment report in accordance with the 1992 "Risk Assessment Guidance" provided by The British Columbia Ministry of Water, Air and Land Protection (MWALP), a 1995 document by Health Canada, and The U.S. Environmental Protection Agency (EPA) Risk Assessment Guidelines. The objectives of the risk assessment are to:

- Provide a consistent process for evaluating and documenting risk at the area in the vicinity of Foundation AB;
- Provide an analysis of baseline risks within current land use: recreation/parkland;
- Provide a basis for determining levels of chemicals that can remain on-site and still be adequately protective of public health and the receiving environment, and
- Provide a basis for comparing potential impacts of various remedial alternatives, if required.

This risk assessment uses the site data provided by previous investigations and combines the results of an exposure assessment and a toxicity assessment to quantify human health risks. The potential environmental risks are assessed separately on the basis of the defined environmental receptors and existing aquatic and terrestrial toxicity information.

2 SITE BACKGROUND

2.1 SITE LOCATION

The Brooks Brook property is located in the Yukon Territory at Mile Post 830 on the Alaska Highway.

Latitude 60° 25' 15"
Longitude 133° 11' 00"

The geographical location in shown in **Figure 1.**

2.2 SITE DESCRIPTION

2.2.1 Definition of Subject Area

The Subject Area that this risk assessment addresses is a small portion of the property noted as "Brooks Brook Property" **(Figure 2, Photo 1)**. At this time the entire Brooks Brook Property is used as a native recreation and meeting area. Structures currently on the Brooks Brook Property include a wooden framed meeting hall and cook shack, along with numerous tent bases and outhouses. Foundations from former buildings on the Brooks Brook Property are still visible **(Figure 2)**.

The Subject Area is defined by the presence of hydrocarbon residue in soil and groundwater at concentrations that exceed YSCR standards. The Subject Area contains a picnic table, bench and garbage can along the west bank of the brook and thus, the Subject Area is occasionally used for recreational purposes. A local resident indicated that the brook is not used for swimming.

The Subject Area is approximately 2000 m^2 and is located at the extreme southeast end of the Brooks Brook property **(Photo 2)**, adjacent to the brook known as Brooks Brook **(Figure 2)**. As shown in **Figure 2**, the brook flows around the border of the Subject Area towards Teslin Lake. The Subject

Area includes the remains of a concrete foundation referred to as Foundation AB, which is approximately 30 m northwest of the brook.

2.2.2 Neighbouring Properties

The Brooks Brook Property is bordered to the west by Teslin Lake and to the east by the Alaska Highway. The land to the east of the Alaska Highway is forested. In addition, the properties to the north and south of the property are currently undeveloped and remain forested (**Figure 2**). Approximately 500m northwest of the subject property is one residence.

2.2.3 Regulatory Permits

A review of the previous investigations for the Brooks Brook Property did not indicate any applicable regulatory permits for past or current activities.

2.2.4 History of the Site

The Brooks Brook Property was originally commissioned in 1942 as a line camp for construction of the Alaska Highway. The camp was also used as a telephone relay station for the U.S. Relay Stations network. The stations were used to relay telephone, teletype and radio messages. The camp also functioned as a base for the truck drivers, pipe-layers and construction workers involved in the construction of the Canol (Canadian Oil) project oil pipeline in the vicinity of the Brooks Brook Property. This project was abandoned in 1945.

In 1946, the camp was transferred to the Canadian Army, with the Royal Canadian Air Force (RCAF) being made responsible for the land communications. The relay line was transferred from the RCAF to Canadian National Telegraphs, which was responsible for the actual operation of the line. The Canadian Army continued to supervise the maintenance and road improvements of the Alaska Highway until 1964. This task then became the responsibility of the Federal Department of Public Works. In 1965 the Brooks Brook Property road maintenance station was moved near the Teslin Airport and the repeater station was shut down. The inhabitants of the Brooks Brook Property gradually moved from the site.

Historically, the property contained between 20 to 30 buildings. These buildings included barracks, married personnel living quarters, a school, a curling rink, at least two powerhouses, fuel storage tanks, at least two fuel dispensing locations, garages, storage sheds, a pumphouse and a relay station building. Sewer lines ran from each building into Brooks Brook. All of the buildings have since been removed. Three landfills were later identified during investigative works in 1997. The landfills were located at the north end of the main property and at the western edge of the property in the woods near Teslin Lake and approximately 2 km south of the main site along the Alaska Highway.

Previous reports speculate that Foundation AB within the Subject Area was the historic location of a gas operated generator.

As part of the Teslin Tlingit Council land claim agreement, the Brooks Brook Property is now under the jurisdiction of the Teslin Tlingit Council.

2.2.5 Physical Characteristics

2.2.5.1 CURRENT SITE TOPOGRAPHY

The general area slopes steeply down from the Alaska Highway towards Teslin Lake (**Photo 3**), which is southwest of the site as shown in **Figure 1**. Water in Brooks Brook generally flows southwest until it drains into Teslin Lake (**Figure 2, Photo 4**). The brook was rerouted from its original location during the construction of the Alaska Highway (**Figure 2**). The banks of Brooks Brook are approximately sloped 1:1 adjacent to the Subject Area and are on the average 1.5 m in height. During the site visit in September 2001 the brook was observed to be approximately 0.25 m deep and was flowing at approximately 1.2 metres per second.

2.2.5.2 SITE GEOLOGICAL CONDITIONS

Figure 3, obtained from the Hemmera Detailed Site Investigation (December, 2001), indicated the soil stratigraphy in the vicinity of Subject Area is characterized by 2 – 3.5 metres of sand and gravel

overlaying silt.

2.2.5.2.1 Hydrogeological Conditions

The studies completed by Hemmera indicate groundwater has been observed at a minimum depth of 1.67 m below grade to a maximum depth of 2.08 m below grade. The average depth to groundwater was 1.85 m below grade (Hemmera, 2001).

The relative groundwater elevations and contours, obtained from the Hemmera DSI, for the September 27, 2001 groundwater monitoring event are included on **Figure 4**. Based on the groundwater elevations, an inferred groundwater flow oriented in the southwest direction, away from Brooks Brook was shown. At the time of the collection of hydrogeological data (during the Hemmera DSI), the elevation of the water in Brooks Brook, east of the Subject Area, was also surveyed. It appeared that the water surface in Brooks Brook was at a slightly higher elevation than the piezometric surface in the wells, which suggested that there may be a net flow from Brooks Brook into the highly permeable sand and gravel horizon.

The estimated hydraulic gradient for the Subject Area on September 27, 2001 was 0.034 , as measured between MW01-07 and MW01-04.

On September 25 and 27, 2001, single well response tests were conducted in monitoring wells H97-15 and H98-23, respectively. Hemmera conducted calculations based on the rising head data to determine the hydraulic conductivity of the saturated soils at the Site. Using Hvorslev's method, an estimated hydraulic conductivity of 9.82×10^{-8} m/s was obtained for monitoring well H97-15, which was completed with a screened section in the silt layer only. A hydraulic conductivity of 1.47×10^{-5} m/s was estimated for monitoring well H98-23, which was completed with a screened section across both the sand layer and the silt layer. It should be noted that conducting a rising head test on a well screened across two different stratigraphic units could affect the conductivity value calculated as the different conductivity properties in each layer contributes to the overall value. Based on the calculated conductivity values, approximate groundwater velocities would range from 0.00072

m/day (H97-15) in the silt layer to 0.087 m/day (H98-23) in the sand layer.

2.2.5.2.2 Site Ecology

A brief inspection of terrestrial vegetation at the subject area was conducted by Hemmera personnel in September 2001. The inspection found approximately 50% of the Subject Area is covered by vegetation with the majority of the vegetation located along both sides of the banks of the brook and in the vicinity of the Foundation AB. No berries or edible plants were observed at the time of the site visit. There were primarily poplar trees in the Subject Area and alder trees were present along the banks of Brooks Brook for the entire length that it crosses the Subject Area (**Photo 5**). Hemmera personnel suspected the alders were placed to maintain slope stability along the brook. A small area of suspect stressed vegetation (i.e. browned leaves, wilted grass) was present east of Foundation AB.

In addition to the Hemmera site inspection, in an Environmental Assessment entitled "*An Environmental Assessment of Brooks Brook, Yukon Territory*", Environmental Sciences Group (ESG) (1997) collected and recorded the terrestrial vegetation on the property. A list of the vegetation observed by ESG is summarized in **Table I**. Approximately 60 different species of terrestrial plants were observed by ESG during their Assessment of the Brooks Brook property.

A detailed inventory of terrestrial plants, soil invertebrate, birds or mammals within the Subject Area has not been conducted. During the site visit in September 2001 no obvious signs of wildlife were visible with the exception of a beaver dam in Brooks Brook located downstream of the site. No mole hills or gopher holes were noted in the area. During the Hemmera DSI, no signs of organic life such as worms, insects or larvae were observed in the soils close to surface. This may have been a result of the time of year in which the site visit occurred. In addition, the soil inspection was limited due to the compactness of the surficial soil. Residents of the area have observed fish (graylings) in Brooks Brook seasonally.

Although a detailed evaluation of terrestrial invertebrates and vertebrates was not completed, the Yukon government currently lists 61 mammal species, 4 amphibian species, and 278 bird species

within the territory. Many of these of these species likely occupy the subject area at certain times of the year. A list of the terrestrial vertebrates has been included in **Appendix A.**

Given the small size of the Subject Area, it is unlikely that the Subject Area itself would provide an adequate terrestrial feeding area for birds and mammals.

2.2.5.2.3 Receiving Environment

The receiving environment for the Subject Area includes Brooks Brook, which borders the Subject Area to the east and south and soil and groundwater in the vicinity of the impacted area. Teslin Lake is also considered part of the receiving environment as Brooks Brook flows into the lake approximately 300 m southeast of the Subject Area.

In addition, humans and all of the terrestrial plants, soil invertebrates, birds and mammals: that utilize the Subject Area are considered receptors within the receiving environment. A conceptual diagram of the receiving environment, and the receptors is included as **Figure 5.**

2.3 PREVIOUS SITE INVESTIGATIONS

Four site investigations and one soil remediation project have been conducted at this site. As the current risk assessment is for the Subject Area in the southeast corner of the Brooks Brook Property, information collected from the previous reports within this area will be reviewed in detail. Analytical results of the previous reports have been compared to the most applicable current guidelines and standards.

2.3.1 Environmental Sciences Group, Royal Military College – An Environmental Assessment, 1997

APPROACH

Environmental Sciences Group (ESG) conducted an assessment of the entire Brooks Brook Property in 1996/1997. The entire study consisted of:

- Cataloguing debris at the site,
- Collection of 108 surficial soil samples for assessment of one or more of the following: Polychlorinated biphenyls (PCBs), Metals, Polycyclic Aromatic Hydrocarbons (PAHs), Total Petroleum Hydrocarbons (TPHs) and Pesticides,
- Collection of one sediment sample from Brooks Brook for the assessment of PCBs and Metals,
- Collection of three surface water samples from Brooks Brook for the assessment of PCBs and Metals concentrations,
- Assessment of 23 plant tissues for concentrations of PCBs and/or Metals,

RESULTS FOR THE SUBJECT AREA– SOILS

Within the Subject Area, ten surficial soil samples were analysed for PCBs and metals, while two samples were analysed for pesticides. The sample locations are indicated on **Figure 6**. All of the PCB and pesticide samples were within the applicable standards and guidelines. Seven of the samples analysed contained concentrations exceeding the CCME RL/PL guidelines and YCSR RL/PL standards for one or more metals. Copper levels in three samples exceeded the CCME guidelines, but only one sample contained concentrations that exceeded the YCSR Toxicity to Soil Invertebrates and Plants guideline. One sample contained a cadmium concentration in exceedance of the CCME RL/PL guideline but within the YCSR RL/PL standards. Zinc concentrations were in exceedance of the CCME RL/PL guideline in five of the soil samples; three of these samples also contained zinc in exceedance of YCSR RL/PL standard. Chromium concentrations were in exceedance of the CCME RL/PL guideline in three of the soil samples and in one of these samples chromium was also in exceendance of the YCSR standard. Lead concentrations were in exceedance of the CCME RL/PL guideline in three of the soil samples and in one of these samples lead was also in exceedance of the YCSR RL/PL standard. No soil samples were submitted for concentrations of hydrocarbons in the Subject Area. A summary of the metals concentrations in soil are summarized in **Table 1** and sample locations and exceedances are indicated on **Figure 6**.

Table 1. Summary of Metals Concentrations in Soil in Subject Area (Environmental Sciences Group, 1997)

Metal	Number of Samples	Concentration Range mg/kg (ppm)	CCME Residential/ Parkland Guidelines (mg/kg)	YCSR 1996 Standards (mg/kg)
Cadmium (Cd)	10	<1.0 – 11.3	10 [1]	35 [0] *(1)*
Copper (Cu)	10	23 – 3000	63 [3]	150 [1] *(2)*
Chromium (Cr)	10	53-263	64 [3]	150 [1] *(4)*
Lead (Pb)	10	<10 –780	140 [3]	500 [1] *(1)*
Zinc (Zn)	10	72-2600	200 [5]	450 [3] *(2)*

[N] Indicates number of samples in exceedance of the guideline or standard

Intake of Contaminated Soil

Toxicity to Soil Invertebrates and Plants

Generic Standards

Groundwater flow to surface water used by aquatic life

RESULTS FOR THE SUBJECT AREA– WATER

There were no surface or groundwater samples collected within the subject area.

RESULTS FOR THE SUBJECT AREA– PLANT TISSUE ANALYSIS

Two plant samples were collected from the Subject Area. PCBs were analysed in one sample. The results indicate concentrations below the method detection limit. Both plant samples were analysed for metals concentrations. Cadmium and zinc had higher concentrations in one of the samples, a *Salix sp.* specimen. This sample was collected in a low area approximately 1 m southeast of the corner of the foundation. Concentrations of cadmium and zinc collected from this specimen were 5.4 µg/g and 241 µg/g respectively where as the concentrations observed in the *Epilobium angustifolium* specimen were <0.5 µg/g and 31 µg/g respectively.

CONCLUSIONS AND RECOMMENDATIONS OF THE ENVIRONMENTAL SCIENCES GROUP FOR THE SUBJECT AREA

- Metals impacted soil will need to be delineated and excavated, and;

- Debris should be collected and disposed in an appropriate landfill.

CONCLUSIONS AND RECOMMENDATIONS OF THE ENVIRONMENTAL SCIENCES GROUP FOR THE ENTIRE BROOKS BROOK PROPERTY

- None of the soil samples contained concentrations of PCBs in excess of the CCME guideline and/or the YCSR guideline;
- Metals concentrations (cadmium, chromium, copper, lead and zinc) were found in excess of the CCME guidelines and/or YCSR standards;
- Concentrations of PAHs did not exceed either the CCME guidelines or the YCSR standards in any of the soils analysed for PAHs;
- Concentrations of petroleum hydrocarbons were elevated in two soil samples, which was attributed to recent rather than historical activities;
- One soil sample was found to contain concentrations of DDT at levels exceeding the Netherlands Soil Guidelines (guideline adopted for this project);
- ESG estimated that no more than 12 m^2 of contaminated soil required remediation at the site, and
- ESG recommended that this soil be excavated and placed in an appropriate landfill.

2.3.2 Lorimer & Associates/Hemmera Resource Consultants – Phase II Assessment, 1997

APPROACH

Lorimer and Associates in association with Hemmera Envirochem (formerly Hemmera Resource Consultants) completed a Phase II assessment of the Brooks Brook Property in 1997. The Phase II was completed to further assess the presence and/or extent of groundwater and soil contamination at the site. The Phase II consisted of:

- A limited Phase I investigation,
- Limited test pitting and soil sampling around potential areas of concern,
- Limited test pitting and soil sampling around those areas identified in the ESG report

as having concentrations of contaminants in excess of either the CMCS or the YCSR guideline in order to confirm the estimated volumes of contaminated soil to be remediated, and

- Installation of monitoring wells upgradient and downgradient of the two identified landfills.

RESULTS FOR THE SUBJECT AREA– SOIL

Boreholes

Seven boreholes were advanced within the Subject Area. The locations of the boreholes and exceedances of the applicable standards and guidelines are indicated on **Figure 7**. Fifteen soil samples were collected and analysed for the following parameters, light extractable petroleum hydrocarbons (LEPH), heavy extractable petroleum hydrocarbons (HEPH), benzene, toluene, ethylbenzene, xylenes (BTEX), and volatile petroleum hydrocarbons (VPH).

For the purpose of this risk assessment the VPH, LEPH and HEPH results have been compared to the 2000 Canada Wide Standards (CWS) for Petroleum Hydrocarbons in soils and the YCSR RL/PL generic standards. The VPH, LEPH, and HEPH were compared to the corresponding 2000 CWS Tier 1 Fraction 1 (F1), Fraction 2 (F2), and Fraction 3 (F3) standards for Residential Eco Soil Contact for coarse-grained surface soils at depths greater than 1.5 meters below grade.

Two of the soil samples submitted for LEPH indicated concentrations in excess of the YCSR RL/PL standard and the F2 CWS. Both of the samples in exceedance of the above referenced standards for hydrocarbons were collected at depths greater than 1.5 meters below grade. All of the soil samples submitted and analyzed for HEPH and BTEX, indicated concentrations within the applicable YCSR standards and CCME guidelines. Of the fifteen soil samples analysed for VPH, only one sample indicated concentrations above the YCSR RL/IL standard while four of the samples exceeded the F1 CSW.

Test Pits

Six testpits were advanced within the Subject Area in the vicinity of Foundation AB. Two samples collected from the test pits were analysed for metals; these samples indicated concentrations of metals within the applicable YCSR standards and/or CCME guidelines. One of the test pit soil samples was submitted for LEPH/HEPH, PAH and VPH analysis. The analysis indicated concentrations within the YCSR RL/PL standards, CCME RL/PL guidelines and the CWS. The test pit and soil sample locations are indicated on **Figure 7**. The Phase II did not indicate the depths at which the samples were collected within each test pit; however the deepest test pit was advanced to 2.2 meters.

Table 2. Summary of Soil Hydrocarbon Concentrations in the Subject Area (Lorimer & Associates and Hemmera Resource Consultants, 1997)

Parameter	Number Sampled	Concentration Range mg/kg (ppm)	2000 CWS Tier 1 Eco Soil Contact for Coarse Grained Surface Soils <1.5 m (mg/kg)	YCSR 1996 Standards (mg/kg)
VPH (F1)	16	<10 – 730	130 [4]	200 [1]
LEPH (F2)	16	<250 – 3400	450[2]	1000 [2]
HEPH (F3)	16	<250- 300	400 [0]	5000 [0]

[N] Indicates number of samples in exceedance of the guideline or standard

RESULTS FOR THE SUBJECT AREA– GROUNDWATER

Four of the seven boreholes advanced in the subject area were completed as monitoring wells. The locations of the monitoring wells and exceedances are indicated on **Figure 8**. Groundwater samples were collected and analysed for one or more of; TEH, PAHs, and BTEX. Three groundwater samples were collected and submitted for analysis of TEH. The concentrations of TEH ranged from 1000 to 5000 µg/L. Currently, there is no YCSR aquatic life (AW) standard or CCME freshwater aquatic life (FAL) guideline for TEH. TEH consists of LEPH and HEPH fractions. Given the BC Environment standard of 500 µg/L LEPH, there is a strong probability that the LEPH fraction of the observed 1000 – 5000 µg/L TEH is in excess of the BC standard. Each of the four monitoring wells were analysed

for concentrations of PAHs. One monitoring well indicated concentrations of naphthalene and phenanthrene in exceedance of the CCME FAL guidelines. A second well also indicated concentrations in excess of the CCME FAL guideline for pyrene. Analysis of BTEX in the groundwater collected from the four monitoring wells indicated no concentrations in excess of the referenced standards and guidelines.

It should be noted that the CCME FAL guideline is intended for the application to ambient waters for protection of aquatic life, and is discussed in this document for comparison purposes only. The YSCR standards consider a 1:10 fold dilution factor from the groundwater well to a possible exposure of aquatic biota in a waterbody.

Table 3. Summary of Hydrocarbon Concentrations in the Groundwater at the Subject Area (Lorimer & Associates and Hemmera Resource Consultants, 1997)

Parameter	Number of Samples	Concentration Range µg/L (ppm)	CCME FAL Guideline* (µg/L)	YCSR 1996 Standards (µg/L)
TEH	3	1000 – 5000	No Guideline	No Standard
Naphthalene	4	<0.3 – 4.6	1.1 [1]	10 [0]
Phenanthrene	4	<0.05 – 0.44	0.4 [1]	3 [0]
Pyrene	4	<0.02 – 0.04	0.025 [1]	0.2 [0]

[N] Indicates number of samples in exceedance of the guideline or standard

** ambient water quality guideline*

CONCLUSIONS AND RECOMMENDATIONS OF THE PHASE II FOR THE SUBJECT AREA

The test pitting and borehole drilling results were successful in determining the vertical extent of hydrocarbon contamination in the Subject Area, however horizontal closure on the hydrocarbon contamination was not obtained. The vertical extent of hydrocarbon contamination in the soil appears to be limited to the sand and gravel layer between 1.5 m and 2 m below grade. Recommendations of the Phase II report were to delineate the horizontal extent of hydrocarbon contamination within the Subject Area.

RECOMMENDATIONS FOR THE ENTIRE BROOKS BROOK PROPERTY

Based on the Lorimer/Hemmera Resource Consultants, Phase II Assessment the recommendations for the entire site included:

- Remediation of the two landfills and annual monitoring of the groundwater wells in the vicinity of the landfills,
- Excavation of the pesticide contaminated soil south of the cook shack,
- Excavation of hydrocarbon contamination in the vicinity of foundation K, and
- Cover areas with localized metals contamination with 0.5 metres of clean backfill.

2.3.3 Hemmera Resource Consultants – Phase III Assessment, 1999

APPROACH

Hemmera conducted a Phase III Assessment in 1998 to further investigate the extent of soil and groundwater contamination in several of the areas identified as areas of concern at the Brooks Brook Property. This assessment focused primarily on the Subject Area as well as the area in the vicinity of the new cook shack. The objectives of the Phase III were to:

- Complete step out boreholes and monitoring wells around existing boreholes and monitoring wells in the vicinity of the Foundation AB (Subject Area),
- Complete hand dug test pits in the vicinity of the new cook shack in order to delineate the extent of OCP and hydrocarbon contamination in this area, and
- Develop remedial options for the contaminated areas at the Brooks Brook Property.

RESULTS FOR THE SUBJECT AREA – SOILS

In August 1998, 10 boreholes were advanced in the Subject Area. The locations of the boreholes and the soil exceedances have been included in **Figure 9**. Fifteen soil samples were submitted for the analysis of LEPH/HEPH, BTEX and VPH. Concentrations of LEPH in four of the soil samples were

in exceedance of the YCSR RL/PL standard and the 2000 F2 CWS. HEPH in two of the samples was in exceedance of the F3 CWS. Analysis for VPH concentrations indicated three soil samples in exceedance of the YCSR RL/PL standard while VPH in four of the samples was in exceedance of the 2000 F1 CWS. All of the soil samples were within the applicable standards and guidelines for BTEX.

The results of the soil sampling program indicated the depth of hydrocarbon contamination ranged from 1.22 to 1.98 meters.

Table 4. Summary of Hydrocarbon Concentrations in Soil (Hemmera Resource Consultants, 1999)

Parameter	Number of Samples	Concentration Range mg/kg (ppm)	2000 CWS Tier 1 Eco Soil Contact <1.5 m Depth (mg/kg)	YCSR 1996 Standards (mg/kg)
VPH (F1)	15	<10 – 730	130 [4] 1.2-1.98 m	200 [3] 1.2-1.98 m
LEPH (F2)	15	<250 – 7400	450 [4] 1.2-1.98 m	1000 [4] 1.2-1.98 m
HEPH (F3)	15	<250- 690	400 [2] 1.2-1.98 m	1000 [0]

[N] Indicates number of samples in exceedance of the guideline or standard

(1.2-1.98 m) Indicates the depth range that the concentrations were observed in exceedance

RESULTS FOR THE SUBJECT AREA – GROUNDWATER

Four of the boreholes the Subject Area were completed as monitoring wells. The monitoring wells advanced in 1998 have the prefix H98 associated with them. All eight of the existing and new monitoring wells in the Subject Area were sampled for concentrations of TEH, PAHs, and BTEX. The location of the monitoring wells and the groundwater exceedances are indicated in **Figure 10**.

Although there are no current standards for TEH, concentrations ranged from < 100 µg/L to 30,000 µg/L in the groundwater samples collected.

Three of the monitoring wells and one duplicate indicated concentrations of naphthalene in exceedance of the CCME FAL guideline; two of these wells were also in exceedance of the YCSR

AW standard. The PAHs fluorene and phenanthrene were in excess of the CCME FAL guidelines in one or more of the monitoring wells sampled.

There were no concentrations of BTEX in exceedance of the above referenced standards in the groundwater samples collected.

Table 5. Summary of Hydrocarbon Concentrations in Groundwater (Hemmera Resource Consultants, 1999)

Parameter	Number of Samples	Concentration Range µg/L (ppb)	CCME FAL Guidelines * (µg/L)	YCSR 1996 Standards (µg/L)
TEH	8	<100 – 30,000	No Guideline	No Standard
Naphthalene	8	<0.3 – 130	1.1 [4]	10 [2]
Fluorene	8	<0.05 – 0.44	3 [1]	120 [0]
Phenanthrene	8	<0.05 – 1	0.4 [3]	3 [0]

[N] Indicates number of samples in exceedance of the guideline or standard

** ambient water quality guidelines*

CONCLUSIONS AND RECOMMENDATIONS FOR THE SUBJECT AREA

The results of the analysis of soil and groundwater samples indicated the presence of hydrocarbon contamination in over a fairly restricted area to the west of Brooks Brook. However, the distribution of monitoring wells in the Subject Area did not allow for closure on the groundwater plume. Hemmera recommended several approaches that INAC could take regarding the impacted soil and groundwater in the Subject Area. The approaches included, excavation, soil vapour extraction, pump and treat, enhanced in-situ chemical oxidation, or risk management. Hemmera indicated that a risk management approach would suggest the need to monitor the surface water quality in Brooks Brook for the presence of elevated concentrations of hydrocarbons. The absence of elevated concentrations would suggest that there would be no need for remediating the hydrocarbons in the soil and groundwater. Hemmera suggested that this approach would be the most cost effective and would require support by an ecological and human health risk assessment.

CONCLUSIONS AND RECOMMENDATIONS FOR THE ENTIRE SITE

Several areas of concern at the Brooks Brook Property were further delineated and volumes of impacted soil were estimated for each of the areas of concern. Based on the volume and extent of the contamination, several remedial options were recommended for each area. A volume approximately 1437 m^3 of soil was estimated to be impacted with OCP (organo chlorine pesticides). Due to the elevated concentrations in the vicinity of the cook shack, excavation of the soils was recommended. For a detailed description of the impacted areas delineated during the Phase III assessment, please refer to the Phase III document.

2.3.4 Hemmera Envirochem – Detailed Site Investigation, 2001

APPROACH

Hemmera Envirochem completed a Detailed Site Investigation (DSI) in the fall of 2001 in the vicinity of Foundation K (northwest of the Subject Area) and Foundation AB (Subject Area). The purpose of the DSI was to confirm that delineation in the area of Foundation K had been completed and to further delineate the hydrocarbon impacted soil and groundwater within the Subject Area. Part of the work program for the DSI included collecting site information required to complete a risk assessment for the Subject Area.

RESULTS OF SOILS ANALYSIS – SUBJECT AREA

A total of eight boreholes were advanced within the subject area. Eleven soil samples were submitted for analysis of EPHs, BTEX and VPH. Six soil samples were also submitted for analysis of PAHs and three soil samples were submitted for analyses of metals.

The results indicated that LEPH concentrations exceeded the F2 CSW in four of the soil samples and in three of these samples LEPH also exceeded YCSR RL/PL standard. HEPH concentrations in four of the soil samples exceeded the F3 CWS and two of these samples also contained HEPH in exceedance of the YCSR RL/PL standard. All of the soil samples submitted for BTEX analysis

indicated concentrations below the laboratory method detection limit. Of the eleven soil samples submitted for VPH analysis two samples were in exceedance of both the YCSR RL/PL standard and the F1 CSW. Naphthalene concentrations exceeded the CCME RL/PL guidelines in two of the soil samples submitted. The metals analysis indicated all three of the samples were within both the YCSR RL/PL and CCME RL/PL guidelines for all regulated metal constituents. A summary of the hydrocarbon concentrations is included in **Table 6** and the borehole locations and soil exceedances are indicated on **Figure 11**.

Table 6. Summary of Hydrocarbon Concentrations in Soil (Hemmera Envirochem, 2001)

Parameter	Number of Samples	Concentration Range mg/kg (ppm)	2000 CWS Tier 1 Eco Soil Contact <1.5 m depth (mg/kg)	YCSR 1996 Standards (mg/kg)
VPH (F1)	11	<100 – 270	130 [2] 0.8-2 m	200 [2] 0.8-2 m
LEPH (F2)	11	<250 - 8000	450 [4] 0.8-2.7 m	1000 [3] 0.8-2.7 m
HEPH (F3)	11	<150 – 1000	400 [4] 0.8-2.7 m	1000 [2] 0.8-2.7 m
Naphthalene	6	<0.05 – 0.8	0.6 [2] 2.3-2.7 m	5 [0]

[N] Indicates number of samples in exceedance of the guideline or standard

RESULTS OF SURFICIAL SOIL SAMPLE ANALYSIS – SUBJECT AREA

Three surficial soil samples were collected from the area of the impacted soil plume and analysed for BTEX, VPH and EPHs. One of the samples was submitted for PAH analysis and one sample was submitted for metals analysis. The analytical results indicate concentrations of BTEX, VPH, EPH and PAHs were less than the analytical detection limits. In the sample submitted for metals analysis, all constituents were within the referenced soil standards and guidelines. The surface sample locations are indicated on **Figure 11**.

RESULTS SOIL VAPOUR SURVEY – SUBJECT AREA

Soil vapour surveys were conducted at three locations within the Subject Area and one background location, as indicated on **Figure 11**. The charcoal tubes from the soil vapour points were submitted for the analysis of BTEX and total hydrocarbons. The results of the soil vapour survey revealed non-detectable concentrations of benzene for all four survey points. Total hydrocarbon concentrations

ranged from 0.341 µg/L to 0.973 µg/L. The highest concentration was found in the background sample.

RESULTS OF GROUNDWATER SAMPLES – SUBJECT AREA

Seven of the eight boreholes advanced during the DSI were completed as monitoring wells. The locations of the monitoring wells and groundwater exceedances are indicated on **Figure 12**. 13 of the 15 new and existing monitoring wells were sampled during the DSI. Thirteen groundwater samples and two duplicate samples were submitted for analysis of BTEX, VPH and EPHw. Eight samples and two duplicates were submitted for analysis of PAHs, while two samples and two duplicates were submitted for metals analysis.

The results of the groundwater samples collected from the Subject Area indicated one sample with a toluene concentration in exceedance of the CCME FAL guideline. Naphthalene concentrations exceeded the YCSR AW standard and the CCME FAL guideline in one of the groundwater samples analysed. Pyrene concentrations exceeded the YCSR AW standard in one of the samples but it was within the CCME FAL guideline. There are no current LEPH/HEPH CCME FAL guidelines or YCSR AW standards for groundwater therefore the analytical results were compared to the BC CSR AW standard. Nine of the groundwater samples were in exceedance of the BC CSR AW standard for LEPH.

Iron concentrations exceeded the YCSR AW standard and the CCME FAL guideline in two of the monitoring wells. One of these wells was also in exceedance of the YCSR AW standard for manganese. The Hemmera DSI attributed the elevated iron and manganese concentrations to naturally occurring background concentrations. **Table 7** summarizes the range of concentrations observed for the parameters in exceedance of the above referenced standards. The locations of the monitoring wells and the exceedances are indicated on **Figure 13**.

Table 7. Summary Groundwater Results (Hemmera Envirochem Inc., 2001)

Parameter	Number of Samples	Concentration Range µg/L (ppb)	CCME FAL 1999 Guidelines * (µg/L)	YCSR AW 1996 Standards (µg/L)	BC CSR 1999 Standards (µg/L)
LEPH	15	<250 – 2500	No Guideline	No Standard	500 [9]
Toluene	10	<0.1 – 24	20 [1]	3000 [0]	3000 [0]
Naphthalene	10	<0.3 - 12	1.1 [1]	10 [1]	10 [1]
Pyrene	10	<0.1 – 0.2	0.025 [1]	0.2 [1]	0.2 [1]
Iron	10	2.46 – 13.1	0.3 [2]	3 [2]	Standard Removed
Manganese	4	0.6 – 1.59	No Guideline	1 [1]	Standard Removed

[N] Indicates number of samples in exceedance of the guideline or standard

* *applicable to ambient water for protection of aquatic life*

RESULTS – SEDIMENT SAMPLES

Sediment samples were collected at three locations along the west bank of Brooks Brook, (up-gradient, adjacent to and down-gradient of the suspect soil contaminant plume. The sediment samples were analysed for BTEX, VPH and EPH. One sample was also analysed for PAHs and two samples were analysed for metals. All of the samples submitted for the analysis of hydrocarbon were below the laboratory method detection limit. The results of the metals analysis indicated concentrations within the YCSR RL/PL standards and the CCME Interim Freshwater Sediment Quality guidelines.

RESULTS – SURFACE WATER SAMPLES

Surface water samples were collected from the west bank of Brooks Brook at locations upstream and downstream on the eastern border the impacted Subject Area. The samples were analysed for BTEX, VPHw, LEPHw, HEPHw, PAH and total metals.

The results indicated that concentrations of BTEX, VPHw, LEPHw, HEPHw and PAHs were less than the analytical detection limits in both samples tested. Total metal concentrations were within the CCME FAL guidelines for all regulated parameters. No differences were noted in the water

quality of brook samples obtained up-gradient and down-gradient of the eastern portion of the Subject Area.

SUMMARY – SUBJECT AREA

Based on the Detailed Site Investigation conducted at Brooks Brook, located in the Yukon, the following conclusions were made:

The assessment of soil contamination in excess of YCSR and/or CCME RL/PL standards/guidelines in the Subject Area has been completed to the extent possible without disturbance to the site area, including removal of trees and vegetation. Hydrocarbon contamination is present northeast, east and southeast of Foundation AB and extends to the west bank of Brooks Brook on the eastern portion of the Subject Area. Contamination was primarily identified in the sand and gravel fill above the silt and was detected at depths ranging from 1.0 m to 2.5 m below grade. **Figures 13 and 14** show the horizontal and vertical extent of impacted soil. A horizontal extent of 400 square meters of impacted soil was estimated for the Subject Area. Sediment samples collected from the brook had non-detectable levels of the pollutants of concern.

Assessment of groundwater contamination in the Foundation AB area has been completed to the extent possible without disturbance and removal of trees and vegetation in order to install additional wells. Dissolved hydrocarbon contamination in excess of applicable YCSR standards and CCME guidelines was detected east and northeast of the Subject Area, between Foundation AB and the brook. **Figure 15** shows the estimated horizontal extent of hydrocarbon impacted groundwater.

SUMMARY – FOUNDATION K

Minor soil contamination in the Foundation K area is identified by testpit TP6. An area of approximately 70 m^2 of soil is estimated to be impacted.

2.4 SUMMARY OF PREVIOUS INVESTIGATIONS FOR THE SUBJECT AREA

2.4.1 Soil

The previous reports have delineated the vertical and horizontal extent of the hydrocarbon impacted soil on the eastern portion of the Subject Area. **Figures 13, 14A,** and **14B** show the extent of impacted soil in this area. The impacted soil ranges from 0.8 m to 2.0 m below grade. The previous reports indicate surficial soils are impacted with metals and are localized around the perimeter of Foundation AB. A summary of the potential contaminants of concern (PCOC) is presented in **Table 8.**

2.4.2 Groundwater

Groundwater appears to be impacted with hydrocarbons to the east of Foundation AB **(Figure 15).** The previous reports indicated the net groundwater flow to be in a west to south west direction. The groundwater in this direction has not been fully delineated due to dense tree growth preventing access of the drill rig. At the request of the client, the trees were not removed to gain access.

Concentrations in excess of the YCSR AW standards and the CCME FAL guidelines for manganese and iron were observed in the groundwater within the Subject Area.

Table 8 summarizes the contaminants found in exceedance of the standards and guidelines during the previous investigations. A statistical summary of the contaminants of concern in soil has been included in **Table I** and a summary of groundwater contaminants has been included in **Table II.** In addition, **Table III** contains a summary of the soil vapour concentrations collected during the Hemmera DSI. The risk assessment will be based on these findings.

Table 8. Potential Contaminants of Concern

Chemical	Soil	Groundwater
Cadmium	✓	
Chromium	✓	
Copper	✓	
Iron		✓
Lead	✓	
Manganese		✓
Zinc	✓	
Naphthalene	✓	✓
Fluorene		✓
Phenanthrene		✓
Pyrene		✓
Toluene		✓
VPH	✓	✓
LEPH	✓	✓
HEPH	✓	✓
TEH		✓

2.5 OTHER REPORTS FOR THE BROOKS BROOK PROPERTY

2.5.1 Hemmera Resource Consultants – OCP Remediation, 2000

APPROACH

Hemmera Resource Consultants completed the supervision of the remediation of the organochlorine pesticide (OCP) contaminated soils at the Brooks Brook Property. Hemmera's objectives were to provide technical supervision to the remediation contractor for such items as delineation of

excavation extent, confirmation sampling, and general contractor's procedures. The scope of work for the project was the remediation of OCP contaminated soil in the vicinity of the new cook shack through excavation and off-site removal.

An area of approximately 3900 m^2 was removed from the Site and transported by truck to an appropriate landfill in West Edmonton, Alberta. During the excavation, confirmation samples were collected on a 5 metre grid over the base of the excavation area and tested in the field using an immuno assay test kit. A total of 351 samples were tested in the field using the immuno assay kit. In order to provide laboratory confirmation of remediation of OCP contaminated soil to concentrations less than 0.7 ppm DDT, 157 samples were analysed at Cantest Laboratories of Vancouver for concentrations of OCPs. The results of the analysis indicated remediation of the OCP contaminated soil at the Brooks Brook site was completed such that concentrations of DDT are less than 0.7 ppm.

3 DESCRIPTION OF RISK ASSESSMENT PROCESS

3.1 GENERAL APPROACH OF A RISK ASSESSMENT

The information summarized in **Section 2** indicates that the Subject Area soil and groundwater contain chemical parameters that are at concentrations in excess of the YCSR, CCME and/or the CWS. INAC requested a risk assessment to determine whether the impacted soil and groundwater can be managed on-site to keep the risks to human health and the ecosystem at a minimum.

A risk assessment is a logical process, whereby all available scientific information is brought together, to produce a description of the nature and magnitude of the potential risk associated with exposure to contamination in a given environmental scenario.

As per the recognized framework procedure, a risk assessment must include:

- *Characterization of the chemicals of concern,*
- *Exposure assessment:* Based on a given scenario for the subject property, including, the definition of receptors, dose in means of exposure i.e. inhalation, ingestion, skin contact, timing, and duration under which the receptors are exposed to the identified chemicals of concern,
- *Toxicity assessment:* An evaluation of the types of toxicity that the chemicals of concern can produce as well as an evaluation of effects of the identified chemicals of concern,
- *Risk characterization:* An estimation of the risk and uncertainty of the risks based on a comparison of the exposure assessment with information on the toxicity of the chemicals of concern.

3.1.1 Description of Development Scenarios

At this time there are no plans to change the current land use. It is the intention of INAC to continue to use the Brooks Brook Property as a native meeting location and occasional camping and

picnicking area. Based on the current land use this risk assessment will assume the following physical features:

- No excavations or movement of soil are planned.
- The area is only used for occasional recreational purposes and the only facilities on site are a picnic table and garbage can located along the west bank of the brook.
- The only permanent structure remaining on the subject site is the foundation for the former gas powered generator.
- Approximately 50% of the area is covered by vegetation and there is no intent to remove the vegetation.
- Poplar and alder trees are present along the banks of the brook and provide a means for stabilization of the banks.

This risk assessment would not be applicable to any other land use scenario.

3.1.2 Scope of Risk Assessment

Section 2 describes the impacted soil and groundwater within the Subject Area. The previous reports indicated that the foundation within the Subject Area is the location of a former gas generator. It is possible that the gas generator was the source of the hydrocarbon contamination; however this is only speculation. The purpose of the risk assessment is to evaluate whether the impacted soils and groundwater actually constitute any potential risk to human health or the ecosystem, and if so, the risk assessment could be used to develop *in situ* risk management procedures.

Subsequent to a review of the previous soil and groundwater studies (summarized in **Section 2**), and based on the continuation of the current land use. The risk assessment will evaluate the following:

1. The potential impact to the public which may use the Subject Area for recreational purposes (**Section 4**), in particular members of the public (children) who may be in direct contact with the surface soils, and who may inhale hydrocarbon vapours from the hydrocarbon impacted

soil and groundwater, and

2. The potential impact of the soil and groundwater on the wildlife, vegetation, and invertebrates (**Section 5**).

4 HUMAN HEALTH RISK ASSESSMENT

The human health risk assessment is for the Subject Area identified in **Figure A**. The approach used for the human health risk assessment follows the BC Environment, Health Canada and U.S. EPA Guidelines.

4.1 POTENTIAL CONTAMINANTS OF CONCERN

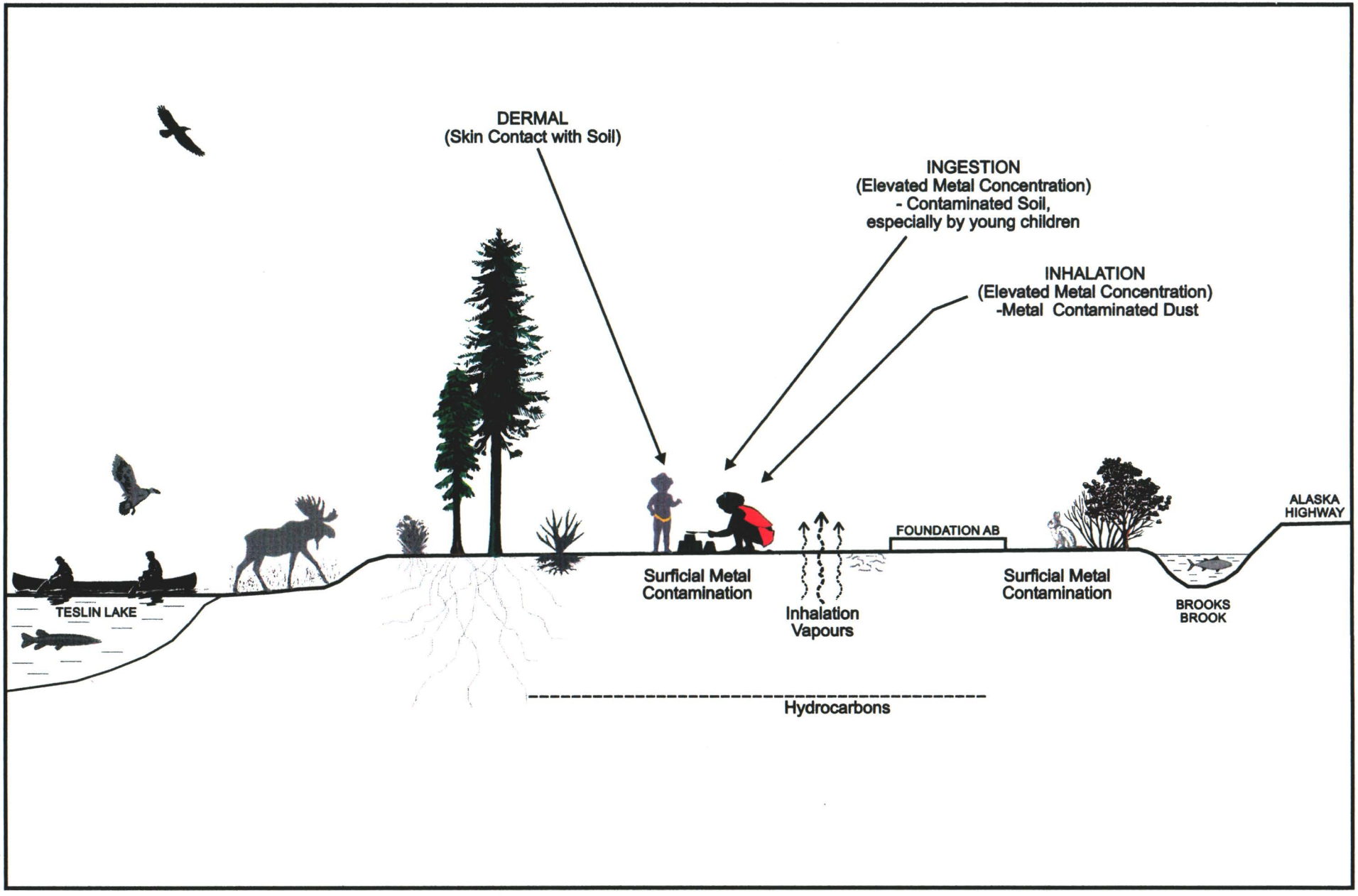
Section 1 indicates that metals at concentrations in excess of the standards are found in surface soils in the vicinity of Foundation AB, and hydrocarbons are found in soil at a depth of 1 meter or more below grade. In addition, hydrocarbons are also found in excess of the applicable guidelines and standards in groundwater at the Subject Area. This section describes the selection process for the contaminants of concern.

4.1.1 Selection of Contaminates of Concern

For the purpose of this risk assessment, contaminants of concern are defined as those for which the concentration representing the 95th percentile (the value in the range of the data set in which 95 percent of the values lie below) of the samples analysed exceeds the applicable YCSR generic or human health protection standards and/or the applicable CCME guidelines, or if the maximum observed concentration is greater than two times the standards. These criteria have been accepted by the BC MWLAP risk assessment group. The soil standards for comparison in the human health risk assessment are those for the protection of human health (intake of contaminated soil). The impact of groundwater on human health is not considered for the Subject Area since there are no nearby drinking water wells.

A statistical summary of the contaminants of concern in soil is presented in **Table IV**. In addition, a summary of total hydrocarbon vapour concentrations is presented in **Table III**.

INDIAN & NORTHERN AFFAIRS CANADA



HEMMERA
ENVIROCHEM
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FIGURE A: HUMAN HEALTH EXPOSURE PATHWAY DIAGRAM

4.1.1.1 CADMIUM

The sample location where cadmium exceeded the applicable human health standards is presented on **Figure 6**.

Of the 15 soil samples analyzed for cadmium, none were in exceedance of the YCSR soil standard to protect groundwater flow to surface water used by aquatic life. One sample was in exceedance of the CCME RL/PL guideline of 10 mg/kg. The concentration range was 0.125 to 11.3 mg/kg, with a 95th percentile of 8.43 mg/kg.

USE OF CADMIUM

A large part of the cadmium produced is used in electroplating metals such as iron and steel in the automotive, aircraft and marine equipment industries. It is used as a protective agent against corrosion. Cadmium is also used in plastics, paints, alloys and in the nuclear industry (Sullivan and Krieger 1992).

BACKGROUND LEVELS

Cadmium is found in the rare mineral elements greenockite and otavite. Both forms are found in zinc- and zinc-lead-rich ores (Sullivan and Krieger, 1992). The cadmium content of normal soils is low except in the vicinity of cadmium-bearing deposits (National Research Council Canada, 1981).

SOURCES OF CONTAMINATION

Cadmium contamination is widely distributed in soil, groundwater and air and has become widespread through mining, refining and smelting operations. Other sources include combustion of fossil fuels, municipal waste incineration and agricultural practices of using phosphate fertilizers (Sullivan and Krieger, 1992).

The source of cadmium at this site is speculated to be associated with pipes containing cadmium or a result of emissions from the generator. ESG found pipes near Foundation AB that were assumed to

be part of the former gas-operated generator system at this location.

CHEMISTRY

Cadmium is a soft-white, blue tinged, lustrous metal, seldom found as a pure mineral. It occurs in nature a divalent cation (Cd2+). The elemental form of cadmium is insoluble in water, whereas the solubility of cadmium salts varies from 0.00013 to 140 g/100ml (Lide, 1992).

HEALTH IMPACT

Cadmium is a very toxic heavy metal. Human exposure to cadmium has been and continues to be a major concern. Cadmium has been associated with hypertension and carcinogenesis. Acute toxicity from cadmium can occur from either ingestion or inhalation. Acute cadmium exposure is typically most toxic to the tissue to which it is initially exposed i.e. the lung (from inhalation) and gastrointesinal tract (ingestion). Typical symptoms of oral intoxication with cadmium include nausea, vomiting, abdominal cramping and pain, diarrhea, increased salivation, tenesmus and choking (Sullivan and Krieger, 1992). Chronic toxic (non-carcinogenic) effects of cadmium are associated with the pulmonary, kidneys, and skeletal system.

SELECTION

Cadmium in excess of the CCME RL/PL guideline was found in only one of ten soil samples. The 95th percentile concentration was less than the guideline. None of the samples were in excess of the YCSR standard for human health protection. As a result, cadmium is not selected as a chemical of concern.

4.1.1.2 CHROMIUM

The sample locations where chromium concentrations exceeded the applicable human health standards are presented on **Figure 6**.

Of the 15 soil samples analyzed for chromium, one was in exceedance of the YCSR standards of 150 mg/kg for the protection of human health. In addition, 3 of the samples were in exceedance of the

generic CCME RL/PL guideline of 64 mg/kg. The concentration range was 19 to 263 mg/kg, with a 95th percentile of 151 mg/kg.

USE OF CHROMIUM

Chromium is used for pigments, metal surface plating, leather tanning, textile production, photoic processes, and catalyst production (Geller, 1992).

BACKGROUND LEVELS

Background chromium concentrations in Canadian soils are reported to range from 20 to 125 mg/kg. In American soils, a range of 1 to 1500 mg/kg has been reported (NRCC, 1976). 96% of samples from Canadian water systems had dissolved chromium concentrations less than 10 μg/L (ppb) and 99% of the samples had concentrations less than 25 μg/L (NRCC, 1976). Chromium concentrations in food stuffs are typically less than 1 mg/kg fresh weight (NRCC, 1976).

SOURCES OF CONTAMINATION

The major sources of chromium emissions into the atmosphere are from ferrochrome production in electric furnaces, refactory proccessing and coal combustion (NRCC, 1976). Soil and water contamination could potentially originate from all processes where chromium or chromium-containing minerals are used.

The source of chromium contamination at the Subject Area is unknown.

CHEMISTRY

Chromium makes up 0.1 to 0.3 ppm of the earth's crust and is primarily associated with ultramafic igneous sedimentary iron ore and phosphorite rock types. Chromium is usually associated with other elements. As well as in metallic form, chromium can exist in oxidation states from +2 to +6, but is most common in the +3 and +6 valences. Chromium III (Cr+3) is the most common form in nature. Chromium VI (Cr+6) rarely occurs in nature and its presence is usually a result of anthropogenic production (Goyer, 1991).

Chromium in biological material is almost always in the trivalent form. Chromium III is also an essential trace nutrient by acting as a cofactor for insulin receptors (Goyer 1991).

HEALTH IMPACTS

The most significant adverse health impacts are caused by chromium VI. Chromium is considered an irritant. Acute dermal exposure may cause hypersensitization and lead to allergic contact dermatitis. Ingested chromium in acute concentrations is likely to cause severe erosive injury in the gastrointestinal tract. Renal failure may result from high concentrations of systemic chromium. Acute inhalation of chromium VI has been linked with lung cancer (Geller, 1992). However chromium VI is unlikely to be present at the site because of its reactivity, the less toxic form of chromium (chromium III) is more likely to be present.

SELECTION

Chromium has been selected for the risk assessment as a chemical of concern based on the soil concentrations whereby the 95th percentile exceeds the YCSR standard for protection of human health and the CCME RL/PL guideline.

4.1.1.3 COPPER

The sample locations where elevated concentrations of copper were observed is presented on **Figure 6**.

Of the 15 soil samples analysed, none contained copper concentrations in exceedance of the YCSR standard of 15,000 mg/kg for intake of contaminated soil. Copper in three of the samples exceeded the CCME RL/PL guideline of 63 mg/kg. The concentrations ranged from 15 mg/kg to 3000 mg/kg with a 95th percentile of 984 mg/kg.

USE OF COPPER

Copper is widely used in the manufacturing of textiles, antifouling paints, electrical conductors, plumbing fixtures and pipes, coins and cooking utensils. Copper compounds are found as an active

ingredient in wood preservatives, pesticides, and fungicides. Copper sulphate may be used as a micronutrient in agricultural fertilizers (CCME 1999).

BACKGROUND LEVELS

The average concentration of copper in Canadian soil is estimated to be 20 mg/kg with a range between 2 and 100 mg/kg (BC MELP, 1992).

SOURCES OF CONTAMINATION

The source of copper at the site is not known, and may be related to the use of copper piping or paints.

CHEMISTRY

Copper is a metal that occurs in four oxidation states (Cu, Cu^{1+}, Cu^{2+} and Cu^{3+}) with Cu^{2+} being most common (CCME, 1997). Copper occurs in a wide range of mineral deposit types as both primary and secondary mineral. Elemental copper metal does occur in nature, but most copper occurs in the form of sulphide minerals.

HEALTH IMPACT

Copper is an essential element required for good health and proper functioning of biological processes (CCME 1999). However over exposure and deficiency can have serious adverse effects. Estimated total daily copper intake for Canadians ranges from about 22 to 74 µg/kg. Copper is required for many enzymatic reactions. However, doses as low as 0.12 mg/kg body weight (bw) per day may induce nausea and vomiting in some individuals. Acute copper poisoning in humans is rare because of the strong emetic properties of the metal. However, the ingestion of gram quantities of inorganic copper salts is usually fatal in humans and there is considerable variability in individual sensitivities (lethal dose ranges from 50 – 500 mg/kg bw per day (CCME, 1997)). Chronic oral exposure resulting in adverse health effects is rare; however young children, particularly those under 12 months of age have a greater risk due to their limited ability to excrete metals (CCME, 1999). Many factors may affect the toxic potential of copper, including chemical form, interaction with

other micro-elements and other components of the diet, health and nutrient status of individuals.

SELECTION

Copper has been selected for the risk assessment as a chemical of concern based on the soil concentrations in exceedance of the CCME RL/PL guidelines. It is noted that the YCSR standard for human health protection is based soley on ingestion, and the risk assessment will enable a more complete evaluation of human health impacts.

4.1.1.4 LEAD

The sample locations where lead exceeded the applicable human health standards are present in **Figure 6**.

Of the 15 soil samples analysed, one contained lead concentrations in exceedance of the YCSR standard for the intake of contaminated soil of 500 mg/kg and three of the samples exceeded the CCME RL/PL guideline of 140 mg/kg. The concentrations ranged from 5 mg/kg to 780 mg/kg with a 95th percentile of 546 mg/kg.

USE OF LEAD

In Canada, the primary use of lead is in the production of acid storage batteries. Other uses include ammunition, radiation shielding, glassware and solders.

BACKGROUND LEVELS

The average lead concentration in the continental crust is approximately 12 mg/kg, and it is estimated Canadian estuarine and coastal sediments contain an average of approximately 20 mg/kg (Garret, 1985). Levels from 24 to 2,000 mg/kg were reported in the Victoria Inner Harbour and 4 to 950 mg/kg were reported in the Brunett River basin (Garret, 1985.)

SOURCE OF CONTAMINATION

Weathering of sulphide ores, mining and smelting, and municipal sewage are sources of lead

contamination. It is estimated that anthropogenic inputs of lead to oceans are approximately 10 fold greater than inputs from weathering. (CCME, 1995). Possible sources include solder for piping and lubricating oil.

The source of lead contamination within the Subject Area is unknown; however it appears to be in a fairly localized area around the perimeter of Foundation AB.

CHEMISTRY

Galena (PbS) is the most common lead mineral (CCME, 1995). The divalent form, Pb(II), is the stable form in most of the environment. The speciation of lead as carbonates and hydroxides is complex and dependent upon factors such as pH, dissolved oxygen, and the presence of co-existing organic and inorganic compounds. Many lead compounds such as lead sulphides and carbonates are insoluble. Free lead ions also readily associate with organic matter, hydrous oxides and clays (CCME, 1995).

HEALTH IMPACTS

Lead can affect most of the body's biological systems, including the blood, kidneys, gastrointestinal tract, nervous system and reproductive system. The potential impacts of lead on human health are of concern and have received considerable attention by regulatory agencies.

SELECTION

Lead has been selected for the risk assessment as a chemical of concern based on the soil concentrations in exceedance of the YCSR intake of contaminated soil standards and the CCME RL/PL guidelines.

4.1.1.5 ZINC

The sample locations where elevated concentrations were observed is presented on **Figure 6**.

Of the 15 soil samples analysed, none contained zinc concentrations in exceedance of the YCSR

standard of 10,000 mg/kg for the protection of human health and five of the samples exceeded the CCME RL/PL guideline of 200 mg/kg. The concentrations ranged from 23 mg/kg to 2600 mg/kg with a 95th percentile of 1284 mg/kg.

USE OF ZINC

Zinc is used for galvanizing products for automobiles and structural components in the construction industry (CCME, 1999). It is also used in the manufacture of brass and bronze for plumbing, heating and cooling system components. In addition, zinc is used in the production of zinc oxides, chemicals and zinc dust. Zinc oxide is important in the manufacturing of tires and other rubber products. Zinc powder is also used in batteries (Environment Canada, 1996).

BACKGROUND LEVELS

Zinc constitutes about 0.02 percent of the earth's crust and is widely distributed (Sullivan and Krieger, 1992). The mean concentration of zinc in soils in Canada is 74 mg/kg (Mckeague and Wolyntz, 1980).

SOURCES OF CONTAMINATION

Sources of anthropogenic zinc in the environment include electroplaters, smelting and ore processors, mine drainage, domestic and industrial sewage, combustion of solid wastes and fossil fuels, road surface runoff, corrosion of zinc alloy and galvanized surfaces, and erosion of agricultural soils (Environment Canada, 1996).

Source of zinc at this site may be associated with fuel use or use of galvanized siding or culverts.

CHEMISTRY

Zinc is divalent and tends to strongly react with organic and inorganic compounds. Zinc forms stable combinations with many organic substances including humic and fulvic acids and a wide range of biochemical compounds (CCME 1999). Metallic zinc is insoluble, while the solubilities of different zinc compounds range from highly soluble to insoluble (Environment Canada, 1996).

HEALTH IMPACT

Zinc is an essential element required for good health and proper functioning of biological processes. It is a known constituent of over 2000 metalloenzymes and other metabolic compounds (CCME 1999). At high concentrations, zinc may be toxic. Acute symptoms of oral zinc poisoning are primarily gastrointestinal. Symptoms include nausea, vomiting, abdominal pain, diarrhea, and hematemesis. Fever is also reported. The primary organs that are impacted by elevated concentrations of zinc include skin, eyes, respiratory, renal, neurologic and hematologic (chronic ingestion). Other than corneal and lens opacities after ocular zinc salt injury and anaemia from zinc-induced copper deficiency, there are no known chronic effects of zinc toxicity (Sullivan and Krieger, 1992).

SELECTION

Elevated concentrations of zinc were observed in the soil samples collected from around the perimeter of Foundation AB. Based on the soil concentrations in exceedance of the CCME RL/PL guidelines and the potential toxicological effects of zinc, this metal has been selected as a chemical of concern for the risk assessment.

4.1.1.6 HYDROCARBONS IN SOIL

The Canada Wide Standards for petroleum hydrocarbons consider petroleum hydrocarbons in four fractions (F1 through F4). The fractions F1 through F3 roughly correlate with territorial parameters VPH, LEPH and HEPH. **Table 9** presents the fractions and examples of some associated sources.

Table 9. Carbon Ranges and Sources of Petroleum Hydrocarbons (CWS, 2000)

Fraction	Carbon Range	Source
VPH F1	C_6-C_{10} C_6-C_{10}	Gasoline/Diesel
LEPH F2	C_{10}-C_{19} C_{10}-C_{16}	Diesel/Motor Oil (Lubricants)
HEPH F3	C_{19}-C_{32} C_{16}-C_{34}	Lubricants/Crude Oil
F4	>C_{34}	Crude Oil/Asphalt

4.1.1.7 VOLATILE PETROLEUM HYDROCARBONS (VPH OR F1)

VPH consists of volatile compounds such as pentane and hexane, which are normally found in fuels such as gasoline. As the compounds are volatile, their concentrations at the Subject Area would be decreasing rapidly from the time that the contamination occurred.

SOIL SUMMARY

Analysis of 44 samples at the site showed concentration ranges of VPH from <100 to 730 mg/kg, versus the Canada Wide Standards (CWS) of 15,000 mg/kg (for ingestion) for VPH (FI) in coarse-grained surface soils. CWS indicates that a standard for dermal contact would be greater than 30,000 mg/kg. There are no structures on the Subject Area, therefore the CWS for inhalation is not applicable. Six VPH samples were in excess of the YCSR generic standard of 200 mg/kg. It is noted that a generic standard is intended to protect human health and the environment, and the scientific basis for the generic standards is weak compared to the CWS and the YCSR matrix standards.

USE OF VPHS

VPHs are components of gasoline, solvents, and to some degree jet fuel and diesel.

BACKGROUND LEVELS

Normally there would not be background levels of VPHs in a natural soil.

SOURCE OF CONTAMINATION

Fuel use at the Subject Area is likely the source of contamination.

CHEMISTRY

VPHs are by their name volatile and evaporation is a major fate, along with biodegradation (EPA, 1978).

HEALTH IMPACTS

Animal studies indicate effects on blood chemistry after exposure to high concentrations of VPHs. Workplace occupational studies indicate inhalation of high concentrations of VPHs may effect the central nervous system (CWS, 2001).

SELECTION

Providing there is a probability of human exposure to VPHs (**Section 4.2.6** of this report), VPHs are selected as a potential chemical of concern. Although the CWS suggests the observed concentrations are much lower than the predicted affect levels, the YCSR is exceeded. The risk assessment, if necessary may have to address the possible risk of the VPH concentrations in excess of the YCSR. It is intended that the vapour monitoring program at the Subject Area would provide a definitive means of evaluating exposure of VPHs to the public.

4.1.1.8 LIGHT EXTRACTABLE PETROLEUM HYDROCARBONS (LEPHS OR F2)

SOIL SUMMARY

LEPHs consist of components with more than 10 carbons and less than 16 carbons. Aliphatics such as decane and substituted PAHs are within the LEPH range.

Analysis of 44 samples at the site showed an LEPH range of 125 to 8,000 mg/kg with a 95th percentile of 5830 mg/kg, versus a CWS of 8000 mg/kg for ingestion of coarse grained soils. The CWS for inhalation is based on exposure of individuals who would live over the contaminated area, and therefore it is not applicable to this site. A total of 9 samples were in excess of the YCSR generic standard of 1000 mg/kg.

USE OF LEPHS

LEPHs are components of fuels such as diesel and jet fuel. LEPHs are also found in lubrication oils.

BACKGROUND LEVELS

Compounds in the LEPH range may include natural and organic compound such as those found in peat moss and trees. These may be reported as part of the LEPH concentrations but are considered an interference.

SOURCE OF CONTAMINATION

The use of fuel at the Subject Area is likely the source of contamination.

CHEMISTRY

LEPHs are normally biodegradable in soil with biodegradation rate dependent upon temperature, oxygen availability, nutrient levels and water levels.

HEALTH IMPACTS

Laboratory Studies have exposed animals to elevated levels of LEPH compounds resulting in effects to the liver and blood chemistry (CWS 2000).

SELECTION

Providing there is a probability of human exposure to LEPHs (**Section 4.2.4** of this report), LEPHs are selected as potential contaminants of concern. Although the observed concentrations are within the 2000 CWS standards for protection of human health, the YCSR is exceeded.

4.1.1.9 HEAVY EXTRACTABLE PETROLEUM HYDROCARBONS (HEPH OR F3)

SOIL SUMMARY

A range of 125 to 4500 mg/kg petroleum hydrocarbons was reported in the Subject Area, versus the CWS of 18,000 mg/kg for soil ingestion and a value in excess of 30,000 mg/kg for dermal contact. The YCSR generic standard for HEPH is 1000 mg/kg for urban parks and residential properties. The 95th percentile is 905 mg/kg.

USE OF HEPHS

HEPHs are found in lubricating oils and fuels such a Bunker oil and crude oil.

BACKGROUND LEVELS

Normally there would be no background levels of HEPH. Extracts from plants may contribute to HEPH levels reported in soil. These would be considered an interference and not part of the HEPH concentration.

SOURCE OF CONTAMINATION

Fuel use in the Subject Area and machinery maintenance may be the sources at the Subject Area.

CHEMISTRY

HEPH will biodegrade in the environment, however at a rate slower than that for LEPH. The components of HEPH would determine the rate of biodegradation as well as oxygen, bacteria, nutrients and water concentrations in the soil.

HEALTH IMPACT

Tests on laboratory animals suggest that frequent exposure to HEPH may affect the functions of the liver and the kidney (CWS 2000).

SELECTION

Based on the concentrations of HEPH below the CWS and given that the 95th percentile of the HEPH concentrations is less than the YCSR, HEPH is not selected as a chemical of concern for the human health risk assessment.

4.1.1.10 NAPHTHALENE

SOIL SUMMARY

The soil sample locations where elevated concentrations were observed is presented on **Figure 13**.

Of the 7 soil samples analysed, none contained naphthalene concentrations in exceedance of the YCSR RL/PL generic standard of 5 mg/kg. Naphthalene in 2 of the samples exceeded the CCME RL/PL guideline of 0.6 mg/kg. The concentrations ranged from 0.025 mg/kg to 0.8 mg/kg with a 95th percentile of 0.77 mg/kg.

USE OF NAPHTHALENE

Naphthalene is used as a moth repellent and is also used in dye manufacturing. It is the most abundant component of coal tar creosote, which is used as a wood preservative, disinfectant and insecticide (CCME, 1999). Naphthalene is also found in gasoline and fuels.

SOURCES OF CONTAMINATION

Anthropogenic sources of naphthalene include emissions from aluminum smelters, steel mills, coal fire generating plants, petroleum refineries, creosote wood preserving facilities, municipal incinerators and leachate from municipal/industrial landfill sites (CCME, 1999). Naphthalene is also released indirectly from creosote-treated telephone poles and railway ties, petroleum spills, waste crank case oil, cigarette smoke, and vehicle exhaust (CCME, 1999). The presence of napthalene in soil at the Subject Area is likely related to historical use of diesel.

CHEMISTRY

Naphthalene has a chemical formula of $C_{10}H_8$, it is a white crystalline solid. It is the simplest structured PAH. The persistence of naphthalene in the soil profile increases with increasing depth, because of the decreased volatilization and microbial transformation processes at depth (CCME, 1999).

HEALTH IMPACT

Naphthalene is known to cause acute red blood cell hemolysis and it is also an irritant to the mucous membranes and the eyes (Sullivan and Krieger, 1992). Clinical intoxication syndrome includes eye irritation, headache, confusion, excitement, diaphoresis, nausea, and vomiting. These symptoms can progress to hemolytic anemia with jaundice and acute failure from myoglobinuria (Sullivan and Krieger, 1992). Naphthalene vapour causes mucous membrane and eye irritation at 5 ppm.

SELECTION

Elevated concentrations of naphthalene were observed in the soil and groundwater samples collected within the Subject Area. Based on the concentrations in exceedance of the YCSR standards and the CCME guidelines and the toxicological effects of naphthalene, this chemical has been selected as a chemical of concern for the human health risk assessment.

4.1.2 Summary of Selected Potential Chemical of Concern within the Subject Area

Based on previous sampling and analysis of soil within the Subject Area, the following table (**Table 10**) summarizes the chemicals selected for evaluation of potential recreational human health risks.

Table 10. Summary of Selected Chemicals for the Human Health Risk Assessment

Selected Chemicals For Risk Assessment	Rational
Chromium	3 soil samples > CCME RL/PL soil guideline 1 soil sample > YCSR soil standard 95th percentile > YCSR and CCME RL/PL soil guideline Sensitive acute and chronic effects
Copper	3 soil samples > CCME RL/PL soil guideline 95th percentile > CCME RL/PL soil guideline Sensitive acute and chronic effects
Lead	1 soil sample > YCSR soil standard 3 soil samples > CCME RL/PL soil guideline 95th percentile > YCSR and CCME RL/PL soil guideline Sensitive acute and chronic effects
Zinc	5 soil samples > CCME RL/PL soil guideline 95th percentile > CCME RL/PL soil guideline Sensitive acute and chronic effects

VPH (F1)	6 of soil samples > YCSR standard 95th percentile > YCSR standard
LEPH (F2)	9 soil samples > YCSR standard 95th percentile > CWS and YCSR standard
Naphthalene	2 soil samples > CCME RL/PL guideline 95th percentile > CCME RL/PL soil standard

4.2 EXPOSURE ASSESSMENT – HUMAN HEALTH

4.2.1 Type of Risk Characterization

The deterministic approach is used for the risk assessment. The deterministic approach provides a conservative risk estimate using statistically defined contaminant concentrations and conservative point estimates for the associated exposure and uptake variables.

4.2.1.1 CHARACTERIZATION OF EXPOSURE SETTING

This human health risk assessment is conducted on the basis of the following exposure settings:

4.2.1.2 RECREATIONAL/PARKLAND LAND

Although the impacted soil and groundwater is not uniformly distributed throughout the Subject Area, a worst case scenario will be assumed for the risk assessment. It will be assumed that persons using the Subject Area in the summer months for recreational purposes would confine their activites to the area with impacted soil and groundwater.

4.2.1.3 IDENTIFICATION OF POTENTIALLY EXPOSED POPULATION

The following human populations are unlikely to be exposed to contamination at the Subject Area:

- Neighbouring residences – The nearest domestic dwelling is approximately 500 m away from the Subject Site.
- Neighbouring workers – The neighbouring properties are undeveloped and will likely remain undeveloped.
- Construction workers – There are no known plans for development or any excavation

activities in the Subject Area.

The receptors selected for evaluation of risk associated with the surficial soil contamination on the Subject Site are limited to the general public, specifically incidental exposure to children whom may be playing in the area of the impacted soil.

4.2.1.4 IDENTIFICATION OF EXPOSURE ROUTES

A generalized exposure pathway flowchart shown in **Figure A** is used to identify human exposure pathways of significance to this study. **Table 11** summarizes the exposure pathways selected for the risk assessment. The following summarizes the evaluation of possible exposure pathways of potential human health impacts in the Subject Area:

4.2.1.4.1 Ingestion:

Surficial Metals – Ingestion of the metals impacted surficial soils by children in the case of improper hygiene prior to eating and ingestion of berries growing in the vicinity of the metals impacted soils.

Hydrocarbons in Soil – There is no logical pathway for ingestion of the hydrocarbon impacted soils which are noted to be at greater than 1 meter below grade.

Hydrocarbons in Groundwater – There are no groundwater wells in the vicinity of the Subject Area; thus there is no logical pathway for ingestion of the hydrocarbon impacted groundwater.

Metals in Groundwater - There are no groundwater wells in the vicinity of the Subject Area; thus there is no logical pathway for ingestion of the groundwater impacted with metals. Additionally the metals of concern in the soil, are not found in groundwater at concentraitons of the Canadian Drinking Water Guidelines.

4.2.1.4.2 Dermal Contact:

Surficial Metals - By children playing in the impacted soil

Hydrocarbons - There is no logical pathway for dermal contact of the hydrocarbon impacted soil and groundwater which are at a depth greater than 1 meter below grade, in the Subject Area.

4.2.1.4.3 Inhalation:

Hydrocarbon Vapours – Inhalation of the hydrocarbon vapours by the general public may occur during the time spent in the Subject Area.

Surficial Metals – Inhalation of particulates of the impacted soils by children during the handling of the soils is not likely as the soil is comprised of primarily sand and gravel, however a conservative approach for the risk assessment will be taken and inhalation of metals will be considered.

Table 11 Summarizes the exposure pathways selected for the human health risk assessment.

Table 11. Selected Exposure Pathways for The Human Health Risk Assessment

Exposure Pathway	Exposure	Rational
Ingestion	Surficial Metals	Improper hygiene and ingestion of berries
Dermal Contact	Surficial Metals	Children playing in soil
Inhalation	Hydrocarbon Vapours Metal Particulates	Air breathed while on site Dust breathed in while on site

4.2.1.5 QUANTIFICATION OF EXPOSURE TO GENERAL PUBLIC

The initial approach of the risk assessment is to undertake the most conservative approach. For example, regular exposures throughout the year are initially assumed. If the calculated risks are found to be in excess of the acceptable risks, then an iterative approach will be undertaken.

4.2.1.5.1 Potential Incidental Ingestion Doses

Incidental ingestion of soil may occur during incidents such as eating lunch without prior washing of hands, in particular in the case of children. In the deterministic approach, a worst-case scenario is assumed whereby children would have minimal hygiene practices. Additionally, children may deliberately ingest soil. This risk assessment assumes an age group less than 5 years, as this age group is most likely to ingest soil. As well this age group represents the most sensitive sector of the population. Health Canada has recommended the use of 50 mg/day as normal soil intake by children between the ages of 0.5 to <5 years old (Health Canada, 1995).

NON-CARCINOGENIC DOSES

Equation 1 provides a means of calculating the potential ingestion of the selected chemical parameters by children between the ages of 0.5 - < 5 years old.

(Equation 1) $$\mathbf{ED_s = \frac{C \times IR \times EF \times BA \times 10^{-6}}{BW}}$$

Where:

$\mathbf{ED_s}$ = Estimated Dose through eating soil.

C = Concentration of the selected chemical contaminants. The deterministic estimate will use the 95th percentile values as follows:

Metal	95th Percentile (mg/kg)
Chromium	151
Copper	984
Lead	546
Zinc	1284

IR = Ingestion Rate: The amount of soil a child between the ages of 0.5 - <5 years old eats per day in mg/day (50 mg/day).

EF = Exposure Factor: Indicates how often the individual has been exposed to the contaminant. Based on discussion with local individuals, the frequency of use of the Subject Area for recreational purposes would be "infrequent". For the purposes of this risk assessment 1 day in 14 days will be assumed, i.e. the child may be exposed to the contaminated soils once every two weeks.

The risk assessment will therefore use a 0.071 exposure factor.

BA = Bioavailability Factor: It will be assumed that a contaminant at the site is in the same form as the chemical used in toxicological tests. This assumption is conservative as the soluble forms of metal salts are used for toxicity testing while a metal in soil may be "bound" within a relatively insoluble form.

BA (Chromium)

Inorganic chromium (III) and cxhromium (VI) are generally poorly absorbed by the gastrointestinal tract (Mertz, 1969). Approximately 0.5% of an oral dose of $CrCl_3$ was absorbed by humans and 2-3% was absorbed by rats. Chromate was absorbed slightly higher, 2.1% of an oral dose by man and 3-6% by rats (National Research Council Canada, 1976).

The risk assessment will use a 0.021 bioavailability factor for chromium.

BA (Copper)

Based on studies with radioactive isotopes of copper, most copper is absorbed from the stomach and duodenum of the gastrointestinal tract. Maximum blood copper levels were observed within 1 to 3 hours following oral administration. About 50% the ingested copper was absorbed (U.S. Environmental Protection Agency, 1980).

The risk assessment will use a 0.5 bioavailability factor for copper.

BA (Lead)

The Royal Society of Canada (1989) reported that the bioavailability of lead from food and water is in the order of 15%. Booth and MacDonald (1982) summarized that only 1-2% of ingested lead is absorbed from the gastrointestinal tract because lead can form insoluble compounds, even within the gut. Clark *et al* (1981), indicated that the portion of lead absorbed from the gastrointestinal tract is much the same whether the lead is present as a soluble or insoluble salt.

The risk assessment will use the higher exstimate of 0.15 bioavailability for lead.

BA (Zinc)

Absorption of zinc occurs throughout the gastrointestinal tract but primarily in the duodenum. Sullivan and Krieger (1992) found oral absorption of zinc in humans to range from 25-90%. About 20-30% of zinc in the diet is absorbed, but this is highly variable (Elinder, 1986). Increased zinc absorption is associated with low body weight, poor zinc status and various prostoglandins (Elinder, 1986).

The risk assessment will use a 0.3 bioavailability factor for zinc.

BW = Body Weight: The average body weight in kilograms (kg) based on a child between the ages of 0.5 - <5 years old. Health Canada recommends using 13 kg as the average weight for this age group (Health Canada, 1995).

Note: The equation includes a conversion factor of 10^{-6}, which is required to convert the concentration of the contaminant in the soil (**C**) from mg/kg to mg/mg of soil. In this way, the units for soil concentration are the same as those for soil ingestion (both in milligrams of soil) (Health Canada, 1995).

Based on the deterministic approach, **Table 12** summarizes the estimated dosages for potential ingestion of the selected metals by children between the ages of 0.5 - < 5 years old.

Table 12. Estimated Dose – Ingestion for Evaluation of Non-Carcinogenic Effects on Children

Chemical	95th Percentile Concentration (mg/kg)	Estimated Dose (mg/kg/day)
Chromium	151	8.66×10^{-7}
Copper	984	1.34×10^{-4}
Lead	546	2.2×10^{-5}
Zinc	1284	1.1×10^{-4}

Example: Chromium

Estimated Dose = $\frac{151 \text{ mg/kg} \times 50 \text{ mg/day} \times 0.071 \text{ day/days} \times 0.021 \times 10^{-6} \text{ kg/mg}}{13 \text{ kg}}$

$= 8.66 \times 10^{-7}$ mg/kg/day

4.2.1.5.2 Dermal Contact

If a child's skin is exposed to the contamination in the soil, then the chemicals may desorb from the soil with subsequent migration through the skin and into the blood stream.

The dosage of metals resulting from dermal contact would be calculated by **Equation 2**:

(Equation 2) $\mathbf{ED_{ss}} = \frac{\mathbf{C \times A \times BA \times EF \times SF \times 10^{-6}}}{\mathbf{BW}}$

Where:

$\mathbf{ED_{ss}}$ = Estimated Dose through skin contact with soil (mg/kg/day).

C = Concentration of the contaminant of concern (mg/kg). The risk assessment will use the 95th percentile concentrations

A = Total soil adhered: The amount of soil that will stick to a person, expressed in milligrams per day (mg/day). Health Canada recommends 3,500 mg/day for a child between the ages of 0.5 – <5 years old (Health Canada, 1995). Based on previous risk assessments conducted by Hemmera, this quantity is very conservative. Other means of calculating the soil adhered would result in a much lower adherence factor than the Health Canada recommendation.

BA = Absorption Factor: The percentage of the contaminant in the soil that is actually free to move out of the soil and through the skin (unitless). For the purposes of the risk assessment the following absorption factors for metals are assumed:

Chromium – Most data for skin uptake of chromium is related to chromium VI solutions, which are used in industry. This form of chromium is not expected in the environment and chromium III is likely at the site. Chromium III concentrations may cause the skin lesions, however at very high concentrations, in the order of 26,000 mg/L. This assessment will assume an adsorption factor of 1.0 for chromium.

Copper – The behaviour of copper during dermal adsorption should not be different than similar divalent cations such as cadmium and lead. An adsorption factor of 0.01 is assumed for copper.

Lead – Laug and Kunze (1948) studied the uptake of lead from the application of aqueous lead acetate and a paste of lead ortho arsenic to the skin of rats. A bandage was used to maintain exposure for 24 hours. It was estimated that no more than 1% of the applied lead was taken up by the rat body. This assessment will assume a factor of 0.01 for lead.

Zinc - The behaviour of zinc during dermal adsorption should not be different than similar divalent cations such as, cadmium and lead. An adsorption factor of 0.01 is assumed for zinc.

EF = Exposure Factor: Indicates how often the individual has been exposed to the contaminant. The risk assessment will assume once in 14 days (0.071).

SF = Solubility factor: For skin absorption to occur, the chemicals of concern must be solubilized from soil, possibly by skin sweat. A conservative solubility factor of 1 (100%) is assumed for the soil-associated chemicals.

BW = Body Weight: The average weight in kilograms of a child between the ages of 0.5 – <5 years old (13 kg).

Based on the deterministic approach, **Table 13** summarizes the calculated dosages of the selected

metals via dermal uptake by children between the ages of 0.5 – <5 years old.

Table 13. Estimated Dose – Dermal Uptake for Evaluation of Non-Carcinogenic Effects of Children Between The Ages of 0.5 – <5 Years Old

Chemical	95th Percentile Concentration (mg/kg)	Estimated Dose (mg/kg/day)
Chromium	151	2.9×10^{-5}
Copper	984	1.88×10^{-4}
Lead	546	1.04×10^{-4}
Zinc	1284	2.45×10^{-4}

Example: Lead

$$\text{Estimated Dose}_{ss} = \frac{546 \text{ mg/kg} \times 3{,}500 \text{ mg/day} \times 0.01 \times 0.071 \text{day/days} \times 1 \times 10^{-6} \text{ kg/mg}}{13 \text{ kg}}$$

$$= 1.04 \times 10^{-4} \text{ mg/kg/day}$$

4.2.1.5.3 Inhalation

INHALATION OF METALS

Metals are found in surface soils near Foundation AB. Given the type of substrate (i.e. sand and gravel), it is unlikely that dust would be generated during recreational use of the Subject Area. Nonetheless, the risk assessment will calculate the potential uptake via inhalation.

The amount of contaminant absorbed into the body through the inhalation of dust can be estimated by the equation:

(Equation 3) $$\mathbf{ED_{dust}} = \frac{\mathbf{C \times CR \times RF \times RR \times DE \times EF \times SF}}{\mathbf{BW}}$$

Where:

$\mathbf{ED_{dust}}$ = Estimated dose via inhalation of dust. The dose is expressed as milligrams of contaminant inhaled per kilogram of body weight per day.

C = Concentration of selected chemical contaminants. The deterministic estimate will use the 95th percentile concentrations as follows:

Chemical	95th Percentile Concentration (mg/kg)
Chromium	151
Copper	984
Lead	546
Zinc	1284

CR = Concentration of respirable dust in air. A dust concentration of 0.6 mg/m^3 as reported by Cowherd et al (1974) at active industrial sites is used for this risk assessment.

RF = Retention Factor (fraction taken up by lungs)

Chromium: For chromium III, a factor of 0.4 based on lead uptake is assumed.

Copper: A factor of 0.4 based on lead uptake is assumed.

Lead: As per the Royal Society of Canada (1989) review, a respiratory uptake factor 0.4 is used for lead.

Zinc: A factor of 0.4 is used for zinc.

RR = Respiration Rate. A point estimate of 5 m^3/day is used to assess the respiration rate of a child at the site (Health Canada, 1995).

DE = Length of exposure per day. An exposure of two hours is assumed.

EF = Exposure Factor. An exposure of once per 14 days is assumed, as per the previous assumptions for ingestion and dermal exposure. The exposure factor used is 0.071.

BW = Body Weight. Health Canada (1995) suggests an assumption of an average weight of a child

between the ages of 0.5 to 5 years old is 13 kg.

SF = Conversion factor – mg/kg to mg/mg (10^{-6})

Based on the deterministic approach, **Table 14** summarizes the estimated dosages via respiratory uptake of metals by children between the ages of 0.5 to <5 years old.

Table 14. Estimated Uptake for Evaluation of Metals Inhalation of Children Between the Ages 0.5 – 5 Years Old

Chemical	95th Percentile	Estimated Dose(dust) (mg/kg/day)
Chromium	151	8.24×10^{-8}
Copper	984	5.3×10^{-7}
Lead	546	2.9×10^{-7}
Zinc	1284	7.0×10^{-7}

Example: Zinc

Estimated Dose $_{(dust)}$ =

$$\frac{1284 \text{ mg/kg} \times 0.6 \text{ mg/m}^3 \times 0.4 \times 5\text{m}^3\text{/day} \times 0.071\text{day/days} \times 2\text{hours/24hours} \times 10^{-6} \text{ mg/kg}}{13 \text{ kg}}$$

$= 7.0 \times 10^{-7}$ mg/kg/day

4.2.1.5.4 Inhalation Hydrocarbons

Inhalation of hydrocarbon vapours by the general public during time spent in the Subject Area is possible. Field studies described in **Section 2.3** of this report were conducted to determine actual soil vapour concentrations. This risk assessment will conservatively assume that a recreational user will be exposed to similar concentrations. In reality, soil vapours would be diluted considerably upon exposure to the atmosphere. The amount of contaminant absorbed into the body through inhalation (ED_v) can be estimated with **Equation 4**:

(Equation 4) $\mathbf{ED_v} = \frac{\mathbf{C \times IR \times RF \times DE \times EF}}{\mathbf{BW}}$

Where:

ED_v = Estimated Dose of vapour via inhalation: The air inhalation dose is expressed as milligrams of the contaminant inhaled per kilogram of body weight per day (mg/kg/day).

C = Concentration of the contaminant of concern, in milligrams per cubic meter of air (mg/m^3).The highest soil vapour concentration will be used (0.973 mg/m^3.)

IR = Inhalation Rate: The amount of air a person breathes in a day, in cubic meters (m^3/day). A point estimate of 5 m^3 / day is used to assess the respiration rate of a child at the site (Health Canada, 1995).

RF = Retention Factor: It is assumed 100% of the hydrocarbons are retained in the lungs.

DE = Length of exposure per day. An exposure of two hours per day is assumed.

EF = Exposure Factor: Indicates how often the individual has been exposed to the contaminant. For the purposes of the risk assessment an exposure of once per 14 days is assumed as per the previous assumption for ingestion and dermal exposure.

BW = Body Weight: The average body weight in kilograms (kg) of a child between the ages of 0.5 and 5 years old is assumed to be 13 kg.

The dose of hydrocarbons via air inhalation is therefore:

$$\mathbf{ED_v} = \frac{0.973\ mg/m^3 \times 5\ m^3/day \times 1.0 \times 1day/14days \times 2hours/24hours}{13\ kg}$$

ED_V = 0.002 mg/kg/day total hydrocarbon inhalation

4.3 TOXICITY ASSESSMENT – HUMAN HEALTH

4.3.1 Selection of Reference Doses (Noncarcinogenic Effects)

The human health toxicity values for the contaminants found in the Subject Area are discussed in the U.S. Environmental Protection Agency's Integrated Risk Information System (IRIS), and the general literature. These values will be compared with the exposures calculated in the previous section.

The Reference Doses (RfD) are summarized in the **Table 15** of **Section 4.3.7** of this report. These represent an estimate of a daily exposure level for the human population that is likely to be without an appreciable risk of chronic effects upon exposure to each specific chemical within a particular time frame. The RfDs for the selected chemical apply to the specific route of exposure. In **Section 4.4**, the RfDs for noncarcinogenic compounds will be compared with the exposure dosages calculated previously. If an exposure dosage exceeds the RfD, then a human health effect may be expected.

4.3.2 Toxicity – Chromium

4.3.2.1 REFERENCE DOSE: RFD

Although the analytical data of the previous studies did not differentiate between chromium III (Cr III) and chromium VI, the risk assessment will use the RfD for chromium III as chromium VI readily reduces to chromium III in the environment. As well, historical use of hexavalent chromium at the site is unlikely. Hexavalent chromium is generally found at sites previously used for chrome-plating, wood preservation and maintenance for locomotives that use chromium VI solutions as engine coolants. Such activities did not occur in the Subject Area.

Ivanovik and Pressman (1975) reported reduced absolute weights in rats livers and spleens at a Cr III dose equivalent to 1,400 mg/kg/day. The dose was administered to the rats five days a week for 90

days. Based on this study and others, the EPA has estimated a "No Observed Adverse Effects Level" (NOAEL) of 1,468 mg/kg/day (EPA, 1998). An uncertainty factor of 100 has been applied to the NOAEL based on expected interhuman and interspecies variability to the toxicity of chromium. In addition, a 10 fold modifying factor has also been applied based on the experimental procedures and assumptions made during the studies. With the uncertainty factor and the modifying factor, the EPA recommends a reference dose of 1.5 mg/kg/day for Cr III.

4.3.2.2 CARCINOGENIC EFFECTS

There is currently data to suggest the potential carcinogenicity of trivalent chromium (chromium III) (IRIS, 1998). Hexavalent chromium (chromium VI) is a known human carcinogen however hexavalent chromium is unlikely to be present at the Subject Area.

4.3.3 Toxicity – Copper

Copper is required in the human diet however the ingestion of gram quantities of inorganic copper salts is usually fatal in humans. There is considerable variability in individual sensitivities (CCME 1999).

4.3.3.1 REFERENCE DOSE RFD

The CCME suggests that the use of NOAEL is inappropriate in the case of copper, as "too many factors may affect the toxic potential of copper i.e. chemical form, potential interaction with other micro elements and other components of the diet, health and nutritional status of individuals" (CCME 1999). The dietary copper requirements that "seem to be adequate and safe" have been adopted by Health Canada for the tolerable daily intake. Health Canada (1995) recommends a tolerable daily intake of 0.05 mg/kg/day – 0.5 mg/kg/day. This range will be used as the RfD for the risk assessment.

4.3.3.2 CARCINOGENIC EFFECTS

Limited data in human and experimental animals indicate that copper does not appear to be teratogenic or carcinogenic (CCME 1999).

4.3.4 *Toxicity – Lead*

Normal daily intakes of lead from food are estimated to be approximately 70 μg for adults (Royal Society of Canada, 1989). Lead is widely used in industry for uses such as car battery manufacture, solders and ammunition.

4.3.4.1 ACUTE TOXICITY

Symptoms of acute poisoning by inorganic lead include a metallic taste in the mouth, vomiting and cramps. The fatal dose of lead to an adult is estimated to be 0.5 grams (Driesbach, 1983).

4.3.4.2 CHRONIC EFFECTS

Considerable attention has been given to the possibility of adverse health effects from continuous exposure to low levels of lead. Chronic effects at such exposures may include headaches, fatigue, irritability pains in the joints and muscles, stomach cramps and constipation. The symptoms are reversible and complete recovery is possible. More severe exposure that results in wrist drop and severe abdominal pains, may require long-term recovery.

The doses at which adverse human health effects occur, as a result of chronic exposure, have not been unequivocally established. Low blood lead levels can affect certain blood enzymes and aspects of children's neurobehavioural development. Blood-lead (Pb-B) levels are the best indicator of dose regardless of the route of exposure, however the relationship between Pb-B and effects (such as neuropsychological effects in children) are controversial (Royal Society of Canada, 1989). It appears that some of the effects occur at blood lead levels so low as to be essentially without a threshold.

4.3.4.3 REFERENCE DOSE (RFD)

As of 1994, the U.S. EPA in IRIS, states that the existing health database is not appropriate to develop an RfD for inorganic lead.

Health Canada (1995) has defined a tolerable daily intake of 0.00375 mg/kg/day for lead. This value will be used as the RfD for the risk assessment.

4.3.4.4 CARCINOGENIC EFFECTS

The available human health evidence is considered to be inadequate to refuse or demonstrate any potential carcinogenicity for humans for lead exposure (IRIS, 1996).

There is sufficient information to show that lead is an animal carcinogen and the U.S. EPA classified lead as: B2 probable human carcinogen. Quantitative estimates of carcinogenic risks from oral exposure are not provided by the U.S. EPA because, "estimates derived by standard procedures would not truly describe the potential risk."

4.3.5 Toxicity – Zinc

4.3.5.1 REFERENCE DOSE RFD

Zinc is an essential element in the human diet. Health Canada (1995) has recommended a Tolerable Daily Intake (TDI) of 0.3 – 1.0 mg/kg/day. This value will be used as the RfD in the human health risk assessment.

4.3.5.2 CARCINOGENIC EFFECTS

The U.S. EPA classified zinc as: D, not classifiable as to human carcinogenicity. The human carcinogenicity data for zinc is considered inadequate by the U.S. EPA, as there are no reports on the possible carcinogenicity of zinc in humans (U.S. EPA, 1991).

4.3.6 Toxicity – Hydrocarbon Vapours

The chromatogram of the hydrocarbons in soil vapour indicate the presence of $C_8 - C_{16}$ compounds hence, the vapour concentrations are in the F2 fraction of the CWS. The CWS (2000) for F2 is based on a TDI of 0.1 mg/kg/day and an RfC of 1.0 mg/m^3.

4.3.7 Summary of Reference Toxicity Values

Table 15 summarizes the chronic RfD values, which will be used to evaluate the hazard quotients

for the chemicals of concern.

Table 15. RfD Values For The Human Health Risk Assessment

Chemical	Chronic RfD (mg/kg/day)	RfD Source
Chromium	1.5	IRIS, 1998
Copper	0.05 – 0.5	Health Canada, 1995
Lead	0.00357	Health Canada, 1995
Zinc	0.3 – 1.0	Health Canada, 1995
Hydrocarbons in air	0.1	CWS, 2000

4.4 RISK CHARACTERIZATION

The final step in the human health risk assessment consisted of the estimation of risks associated with the predicted exposures. Risks associated with non-cancer health effects from exposure to the selected contaminants of concern were estimated using a Hazard Quotient (HQ) approach. The HQ was calculated by dividing the estimated exposure to chemicals, by the corresponding TDI or RfD, according to the following equation:

(Equation 5) **Hazard Quotient =** $\dfrac{\textbf{Exposure Estimate (mg/kg/day)}}{\textbf{Tolerable Daily Intake or Reference Dose (mg/kg/day)}}$

For hydrocarbons where the estimated exposure limit was expressed as a "safe" air concentration, the Hazard Quotient was calculated as follows:

(Equation 6) **Hazard Quotient =** $\dfrac{\textbf{Estimated Air Concentration } (\mu g/m^3)}{\textbf{Reference Concentration } (\mu g/m^3)}$

The worst-case hazard quotients, as calculated by the deterministic assessment, are summarized in **Table 16**. Each of the hazard quotients for each chemical and exposure were added to get a total hazard index. For example, the total dermal, ingestion and inhalation HQ's for copper were summed to determine the total copper hazard index. A total hazard index in excess of 1.0 would imply

potential for adverse health effects. However, due to the large number of conservative factors typically employed in the deterministic approach, HQs that are greater than 1 do not necessarily indicate that adverse health effects will occur. Instead, HQs that are greater than 1 suggest that the results of the risk assessment should be closely examined before concluding on the possibility of health effects.

Table 16. Summary of Worst Case Chronic Hazard Index Estimates for Children Between the Ages of 0.5 to 5 Years Old

Chemicals	Exposure (mg/kg/day)	TDI or RfD (mg/kg/day)	Hazard Quotient Maximum
Copper (Dermal)	1.88×10^{-4}	0.05 – 0.5	3.8×10^{-4}
Copper (Ingestion)	1.34×10^{-4}	0.05	2.7×10^{-3}
Copper (Inhalation)	5.3×10^{-7}	0.05	1.06×10^{-5}
Total Copper Chronic Hazard Index:			3.1×10^{-3}
Chromium (Dermal)	2.9×10^{-5}	1.5	1.9×10^{-5}
Chromium (Ingestion)	8.24×10^{-7}	1.5	5.5×10^{-7}
Chromium (Inhalation)	8.24×10^{-8}	1.5	5.47×10^{-8}
Total Chromium Chronic Hazard Index:			2.0×10^{-5}
Lead (Dermal)	1.04×10^{-4}	0.00357	2.9×10^{-2}
Lead (Ingestion)	2.2×10^{-5}	0.00357	6.2×10^{-3}
Lead (Inhalation)	2.98×10^{-7}	0.00357	8.3×10^{-5}
Total Lead Chronic Hazard Index:			3.5×10^{-2}
Zinc (Dermal)	2.45×10^{-4}	0.3 – 1.0	8.2×10^{-4}
Zinc (Ingestion)	1.1×10^{-4}	0.3	3.7×10^{-4}
Zinc (Inhalation)	7.0×10^{-7}	0.3	2.33×10^{-6}
Total Zinc Chronic Hazard Index:			1.2×10^{-3}

Hydrocarbon (Inhalation)	0.002	0.1	0.02
Total Hydrocarbon Chronic Index:			0.02
CHILDREN BETWEEN THE AGES OF 0.5 TO 5 WORST-CASE TOTAL CHRONIC HAZARD INDEX Regulatory Limit = 1.0			3.9×10^{-2}

4.5 UNCERTAINTY ANALYSIS

The purpose of an uncertainty analysis is to enable the reader to determine the likelihood that a risk estimate might overestimate or underestimate the true risk. It is noted by BC Environment that for a deterministic risk estimate (based on conservative default factors), which result in significantly less than regulatory levels of concern, a qualitative uncertainty analysis would provide very little information value. Nonetheless an uncertainty analysis is provided in this report.

Table 17 presents a summary of the uncertainty analysis.

Table 17. Summary of Uncertainty for The Human Health Risk Assessment

Assumption	Uncertainty	Rational
Contaminant Distribution		
Evaluation of contaminant Distribution (Metals)	Low to Moderate – Possible underestimate of risk	Previous investigations did not adequately delineate extent of contamination
Evaluation of contaminant Distribution (Hydrocarbons)	Low	Soil contamination fully delineated
Exposure Pathway		
Frequency of exposure	Moderate to High – Possible over-estimate of risk	Uncertain how often the site would be used for recreational purposes
Dermal exposure	Moderate to High • Probable overestimate of risk • Assumption of 100% availability of metals in soil	• Area of surficial metals contamination is covered with plants • Health Canada exposure parameter much greater than literature estimates
Inhalation	Moderate overestimate of vapour exposure	Soil vapour concentrations above area of contamination are less than at the background sampling

	• Moderate possible over estimate of dust inhalation	location – no risk assumed based on background data • Dust levels based on levels at construction sites where fine grained soils were located, versus sand/gravel at the Subject Area
Reference Dose		
RFDs	Moderate – possible overestimate for metals High – uncertainty for hydrocarbons	High uncertainty factor for Chromium – 1000 fold safety factor applied from animal studies

4.6 SUMMARY

The human health risk assessment identified seven contaminants of concern based on the concentrations in soil within the subject area and their toxicity to human health.

The next part of the human health risk assessment identified the potential population exposed to the contaminants in the soil. The general public was identified as the exposed population, in particular, young children who may be playing in the area of the impacted soil.

The exposure assessment of the risk assessment identified three exposure pathways in which the contaminants could potentially impact children: dermal, ingestion, and inhalation. The previous investigations identified hydrocarbons in soil at a depth of 0.8 meters or more below grade. Dermal and ingestion exposure to the soil at this depth by humans was not considered in the human health risk assessment. Inhalation of hydrocarbon vapours was considered.

Because there are no groundwater wells in the vicinity of the Subject Area, and no logical pathway for humans to be exposed to the contaminants in groundwater, groundwater was not considered in the human health risk assessment.

Based on the three exposure pathways (dermal, ingestion and inhalation), models were used to

calculate the most conservative exposure levels to which the population would potentially be subjected. Dermal, ingestion, and inhalation calculations were completed for the metals, cadmium, copper, chromium, lead, and zinc. Inhalation calculations were also completed for total hydrocarbons.

The final step in the human health risk assessment consisted of the estimation of hazard quotient associated with the predicted exposure levels. If the hazard quotients were in excess of 1, it would imply the potential for adverse human health effects. None of the potential contaminants of concern identified in the human health risk assessment indicated a hazard quotient greater than one. The total hazard index values ranged from 3.1×10^{-3} for copper to 0.02 for hydrocarbon inhalation.

For the current land use, the current human health risk assessment did not identify any potential risks to human health within the subject area from the metals and hydrocarbons that impacted the quality of the soil and groundwater at the subject area.

5 ECOLOGICAL RISK ASSESSMENT

Based on prior site investigations and the information summarized in **Section 1**, the chemicals which represent a potential risk to the environment within the Subject Area are metals and hydrocarbons. The current and future land use of the Subject Area is parkland. At this time, there are no proposed development plans for the subject site other than maintaining it as a recreational area. The current ecological risk assessment was based on this land use.

BC Environment has developed guidelines for ecological risk assessments (BC Environment 1998). This assessment will include the required information outlined in this guideline and furthermore will be in the format of the BC Environment guidelines document. Modifications to the guidelines are made where appropriate.

5.1 CHEMICALS OF POTENTIAL CONCERN

The YCSR and CCME soil and groundwater standards will be used to select the potential chemicals of ecological concern. In addition, known effect levels of contaminants in water will be summarized to evaluate whether the observed groundwater concentrations have any potential for impacts on plant growth or aquatic biota.

5.1.1 Soil Concentrations in excess of the YCSR, CCME and CWS

The majority of the metal contamination is located around the perimeter of Foundation AB. The extent of the metals contamination in the soil appears to be within a 0.2 to 0.3 meter surface layer.

The hydrocarbon impacted soil is located on the eastern portion of the Subject Area. Contamination was primarily in the sand-gravel fill above the silt layer and was detected at depths ranging from 1.0 to 2.5 meters below grade.

The analytical data for the metals and hydrocarbons in soil that exceed the applicable standards and guidelines for ecological protection are summarized in **Table 18.**

Table 18. Summary of Potential Contaminants of Concern in Soil

Parameters	Samples (n)	Range (mg/kg) Min / Max		YCSR (mg/kg)	Number >YCSR	CCME RL/PL or CWS (mg/kg)	Number >CCME or CWS	95th Percentile (mg/kg)
Chromium	15	19	263	250 (1) 60 (2)	1 3	64	3	151
Copper	15	15	3000	150 (1) 30,000 (2)	1 0	63	3	984
Lead	15	5	780	1000 (1) 40,000 (2)	0 0	300 (3)	2	546
Zinc	15	23	2600	450 (1) 550 (2)	4 3	200	5	1284
Naphthalene	7	0.025	0.8	5	0	0.6	2	0.77
VPH (F1)	44	5	730	200	6	350(4) 230 (5)	6 6	532
LEPH (F2)	44	125	8000	1000	9	1500 (4) 150 (5)	8 9	5830
HEPH (F3)	44	125	4500	1000	2	2500 (4) Na (5)	1	906

(1) YCSR Toxicity to soil invertebrates and plants

(2) YCSR Groundwater flow to surface water used by aquatic life

(3) CCME Environmental Health Guidelines

(4) CWS generic level for PHC coarse grained subsoil (>1.5 m) for protection of groundwater for aquatic life

(5) CWS generic levels for PHC in coarse grained subsoil (>1.5m) for agricultural eco soil contact

Note: The pH values in soils collected during the Hemmera Envirochem DSI (2001) ranged from 6.8 to 7.9.

5.1.2 Impact of Contaminated Soil on Groundwater

Groundwater in the Subject Area appears to be impacted with metals and hydrocarbons. **Table 19** presents a statistical summary of the potential contaminants of concern in groundwater.

Table 19. Statistical Summary of Potential Contaminants of Concern in Groundwater

Parameters	Samples (n)	Range (µg/L) Min / Max		YCSR (µg/L)	Number >YCSR	CCME FAL* (µg/L)	Number >CCME	95th Percentile (µg/L)
Iron	4	11,100	13,100	3	4	300	4	13,100
Manganese	4	600	1,170	1	1	50,000	0	1,167
Naphthalene	24	0.15	130	10	4	1.1	6	16
Phenanthrene	24	0.025	1	3	0	0.4	5	0.69

Pyrene	24	0.01	0.2	0.2	1	0.025	2	0.09
Toluene	24	0.05	24	3,000	0	2	4	2.48
TEH	27	50	30,000	ns	na	ng	na	19,390
LEPH	15	125	2,500	500 [1]	10	ng	na	2080
HEPH	15	125	420	ns	na	ng	na	322

[1] *BC Contaminated Sites generic numerical standard for groundwater*

* *Guideline applicable to receiving waters with aquatic biota*

It was observed that iron and manganese were found at levels in excess of the groundwater standards and guidelines. The iron and manganese observed in the groundwater may be a product of anaerobic conditions in the hydrocarbon impacted soil and groundwater, drawing the iron and manganese out of their naturally occurring states.

Although there are no current applicable petroleum hydrocarbon standards or guidelines, the concentrations appear elevated. The BC CSR guidelines for LEPH have been included strictly for comparison purposes.

5.1.3 Assessment of Sediment Samples

Sediment soil samples were collected at three locations along the west bank of Brooks Brook, upgradient, adjacent to and downgradient of the suspect soil contaminant plume. The samples were analysed for BTEX, VPH and EPH. The results indicated concentrations less than the laboratory method detection limit.

5.1.4 Assessment of Surface Water

Surface water samples were collected from the west bank of Brooks Brook at locations upstream and downstream of the impacted soil and groundwater within the Subject Area. The samples were analysed for BTEX, VPH, LEPH, HEPH, PAHs, and total metals. The results indicated concentrations of BTEX, VPH, LEPH, HEPH and PAHs below the laboratory method detection limits in both the surface water samples. Total metal concentrations were within the CCME FAL guidelines for all regulated parameters. No differences were noted in the water quality of stream samples obtained up-gradient and down-gradient of the Subject Area.

5.1.5 *Summary of Selected Chemicals*

Based on soil, groundwater, sediment and surface water monitoring, it appears that the brook sediment and surface water to the west of the Subject Area have not been impacted by the soil and groundwater contamination within the Subject Area. No samples of the sediment or surface water have been collected from the brook to the south and southwest of the Subject Area.

The selected chemicals for the ecological risk assessment are metals and hydrocarbons in the soil and groundwater.

Table 20 provides a summary of the initial set of chemicals selected chemicals for the ecological risk assessment based on comparison with existing standards and guidelines. The following sections will describe the rational for final selection of the possible chemicals of concern.

Table 20. Chemicals Selected For The Ecological Risk Assessment

Metals	Hydrocarbons
Chromium (soil)	Naphthalene (groundwater)
Copper (soil)	Phenanthrene (groundwater)
Lead (soil)	Pyrene (groundwater)
Iron (groundwater)	Toluene (groundwater)
Manganese (groundwater)	VPH (soil)
Zinc (soil)	LEPH (soil and groundwater)
	HEPH (soil and groundwater)
	TEH (soil and groundwater)

5.1.6 *Receptors of Concern*

The ecological setting of the Subject Area is such that site-related COPC may contact a wide variety of terrestrial and aquatic species. Site visits conducted during the previous investigations have outlined the ecological resources present on the site and the adjacent areas. Two general habitat types were identified:

- Terrestrial
- Aquatic

A regional species list has been included in **Appendix A**. An inventory of site vegetation is also included in **Appendix A**. The vegetation was identified during the ESG assessment of the Brooks Brook Property.

5.1.7 Conceptual Model

The conceptual model of the Subject Area regarding the potential exposure pathways for site receptors is shown on **Figure B.** This model is used as a guideline for the terrestrial risk assessment. The exposure routes presented on **Figure B** include:

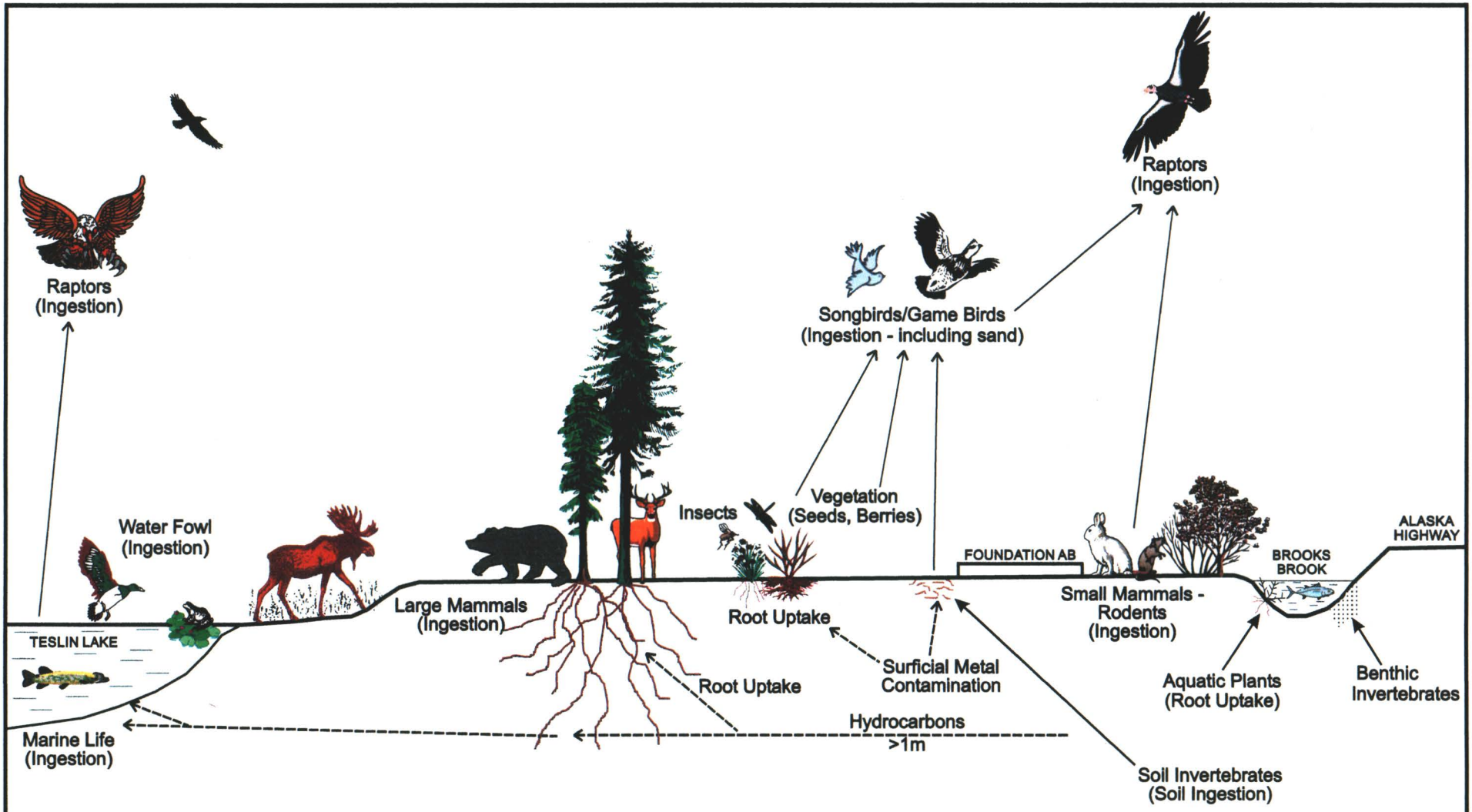
Terrestrial:

- Root uptake by terrestrial plants of COPCs in soil.
- Soil ingestion and dermal exposure of COPCs in soil for soil invertebrates.
- Ingestion of food with elevated concentrations of the COPCs for small mammals and songbirds.

Aquatic:

- For aquatic invertebrates, direct exposure to groundwater-borne COPCs in surface water and porewater.
- For aquatic plants, direct exposure to groundwater-borne COPCs in surface water and porewater.

INDIAN & NORTHERN AFFAIRS CANADA



Note: The carnirvors (eg. bear, fox) and larger birds (eg. Raven, Magpie) will consume vegetation, mammals, marine life, insects, invertebrates, and carrion.

HEMMERA
ENVIROCHEM
316-003.04

FIGURE B: ECOLOGICAL HEALTH EXPOSURE PATHWAY DIAGRAM

- For bottomfish, direct exposure to groundwater-borne COPCs in surface water and porewater and ingestion of food with elevated chemical concentrations.
- For birds, ingestion of food with elevated chemical concentrations.

5.2 TERRESTRIAL ECOLOGICAL RISK ASSESSMENT

5.2.1 Terrestrial Exposure Assessment

5.2.1.1 TERRESTRIAL FIELD OBSERVATIONS

A description of the site ecology is included in **Section 2.2.5.2.2** of this report. The field observations were conducted during the DSI in September of 2001. The DSI concluded that 50 % of the Subject Area was covered by vegetation with the majority of the vegetation occurring along the bank of Brooks Brook (**Photo 2 and Photo 5**) and in the vicinity of Foundation AB. A plant species inventory was conducted during the ESG 1997 field investigation. This report suggests that the trees along the bank of Brooks Brook include lodge pole pine, black cottonwood, white spruce, Alaska willow and trembling aspen. Vegetation observed in the vicinity of Foundation AB is summarized in **Table 21**. A complete list of vegetation observed during the ESG field investigation has been included in **Appendix A.**

Table 21. Vegetation in the Vicinity of Foundation AB

Common Name	Genus Species Name
Fireweed	Epilobium angustifolium
Yarrow	Achillea millefolium
Slender Wheatgrass	Elymus trachycaulus
Common Dandelion	Taraxacum officinale
Prickly Rose	Rosea acicularis
Vetch	Vicia spp.
Bentgrass	Agrostis
Northern Scouring Rush	Equisetum variegatum

Tall Bluebells	Mertensia paniculata
Narrow-leaved Cotton Grass	Eriophorum angustifolium
Horsetail	Equisetum scirpoides
Mushrooms	
Mosses	
Grasses	

A detailed inventory of invertebrates, terrestrial mammals, and birds has not been conducted for the Subject Area. During the Hemmera DSI (2001), a limited inspection of the surface soils for soil invertebrates was conducted. The DSI found no signs of worms, insects or larvae. It is the opinion of the risk assessor that the findings during the field investigation for soil invertebrates is not necessarily representative of the species diversity in the soil at the Subject Area. In addition, the DSI found no signs of terrestrial mammals or birds, with the exception of a beaver dam located downstream from the Brooks Brook property. Given the location of the Subject Area and the species listed for the Yukon Territory it is likely that several species of mammals and birds may be present on the Subject Area at certain times of the year. However, given the small area of the site, it is unlikely that the site by itself could provide an adequate terrestrial foraging area for birds and mammals. A list of the birds and mammals found in the Yukon obtained from the Yukon Government web page has been included in **Appendix A.**

5.2.1.2 EXPOSURE TO TERRESTRIAL BIOTA

Heavy tree growth along the bank of Brooks Brook is evident, (**Photo 5**) while the central portions of the Subject Area contains primarily grasses, shrubs and herbs. The following means of terrestrial community exposure to the potential contaminants may occur:

Root Uptake: The hydrocarbon impacted soil and groundwater are at 1 or meters below grade and the roots of most plants at the site are not likely to extend to this depth. There is no visual evidence of an impact on vegetation in the area. It is suggested that exposure for root uptake of hydrocarbons at this depth is minimal. Root uptake of the surficial metals impacted soil in the vicinity of Foundation AB

may occur.

5.2.1.2.1 Soil Ingestion by Soil Invertebrates

The hydrocarbon impacted soil and groundwater are at 1 or meters below grade. Therefore, the pathway of soil ingestion by invertebrates is probably of minor concern for hydrocarbons at this site. Metals in the vicinity of Foundation AB have the potential for uptake by invertebrates.

5.2.1.2.2 Ingestion of Food With Elevated Concentrations of The COPCs For Small Mammals and Birds

Given that the pathways for hydrocarbon exposure to plants and soil invertebrates at this site are minimal, it is suggested that ingestion of food with elevated concentrations of hydrocarbons by small mammals and songbirds to ingest is not of concern.

Surficial soils impacted with metals may be taken up by plants and invertebrates, and in turn small mammals and songbirds may be exposed to elevated concentrations of metals in the plants in the vicinity of soil impacted with metals. The exposure of small mammals and birds to elevated food concentrations would likely be minimized based on the relatively small area impacted with metals and the relatively large foraging areas of the small mammals and birds likely found at the Subject Area. For example, the home range of a red tailed hawk is in the order of a few hundred hectares to over 1500 hectares, while the range for foxes varies from 50 to 3000 hectares (U.S. EPA, 1993). Ranges of deer mice would be much less, however evidence of such species were not observed at the site.

Although there does not appear to be an exposure pathway for the hydrocarbon impacted soil, the Canada Wide Standards for Petroleum Hydrocarbons in soils specify hydrocarbon standards for coarse and fine-grained soils at depths to 1.5 m and at depths beyond 1.5 meters. As a result the risk assessment will consider potential impacts of the subsurface petroleum hydrocarbons to terrestrial species via each of the exposure pathways. With reference to **Table 20**, **Table 22** provides a

summary of the substances selected for the ecological risk assessment. It is noted that TEH as referenced in **Table 20**, comprises LEPH and HEPH.

Table 22. Summary of Substances Selected for the Terrestrial Ecological Risk Assessment

Metals	Hydrocarbons
Chromium	VPH
Copper	LEPH
Lead	HEPH
Zinc	

5.2.1.3 TOXICITY ASSESSMENT OF METALS IN SOIL– SOIL INVERTEBRATES, PLANTS, MAMMALS AND BIRDS

5.2.1.3.1 Chromium

Receptor – Terrestrial Plants

Breeze (1973) found chromium (III) increased plant mortality at 10 ppm in a solution culture. A review of several studies of plant-chromium toxicity indicate that 1-5 ppm of chromium in an available form in the soil is the toxic threshold for a number of plant species (NRCC, 1981).

Receptor – Soil Invertebrates

Data on toxicity of chromium to terrestrial invertebrates are sparse (Eisler, 1986). Studies conducted in India showed that a concentration of 10 to 15 ppm of chromium VI in irrigation water, when applied to soils for agricultural purposes, was lethal in two species of earthworms in 58 to 60 days (Eisler, 1986; Soni and Abbasi 1981; Abbasi and Soni 1983).

Receptor – Small Mammals and Birds

Rabbits given chromium concentrations of 1.7 mg/kg body weight daily for six weeks had adversely affected blood and serum chemistry and significant morphological changes in the liver (Tandon et al. 1978). Toxic concentrations of chromium in the diet of poultry range from 1,000 to 5000 ppm (Puls, 1988).

5.2.1.3.2 Copper

Receptor – Terrestrial Plants

Effect levels on plants (e.g. growth impairment and seed emergence), resulting from copper exposure were noted to range from 31 mg/kg to 500 mg/kg in various species of terrestrial plants (BC MELP, 1996).

Receptor – Soil Invertebrates

Lowest observed effects concentrations from copper exposure were noted to range from 27 mg/kg to 370 mg/kg in various species of earthworms (BC MELP, 1996). Lethal effect levels (e.g. LC_{50}'s) ranged from 100 to 2760 mg/kg of copper.

Receptor – Small Mammals and Birds

Toxic copper concentrations in the diets of rabbits occur at concentrations greater than 300 ppm (Puls, 1988). Rabbits are reported to be very susceptible to copper toxicity. Concentrations ranging from 300 –600 ppm have been reported to be toxic to geese. Signs of copper toxicity in geese include feather loss, reduced weight gain and egg production, and an increase in the incidence of tibial dischondroplasa (Puls, 1988).

5.2.1.3.3 Lead

Receptor – Terrestrial Plants

Lead inhibits plant growth, reduces photosynthesis, and reduces mitosis and water absorption. Adverse effects have been observed in roadside weeds (Cassia spp.) at lead concentrations of 12 to 312 mg/kg in soil (Krishnayya and Bedi 1986). Non-lethal effect levels were reported at 1200 mg/kg (lead in soil) for species such as pine. The same concentration resulted in an EC_{50} in raddishes.

Receptor – Soil Invertebrates

No observed effect concentrations from lead exposure were noted in the range of 1480 mg/kg, and lethal doses were in the range of 2500 mg/kg in various species of earthworms (BC MELP, 1996).

Receptor – Small Mammals and Birds

Puls (1998), in his review of the literature, noted chronic toxicity levels of 25 mg/kg/day in rabbits. Chronic toxicity signs of lead in rabbits include reduced appetite, reduced weight, lethargy, and reduced immune responses. The chronic toxic dose of lead for ducks is 12 mg Pb/kg body wt/day (Puls, 1988). Lead toxicity signs in water foul include behavioural changes, lethargy, anorexia, anemia, flaccid paralysis and prostration, emaciation, impaction of proventriculus (Puls, 1988).

5.2.1.3.4 Zinc

Receptor – Terrestrial Plants

Uptake of zinc from soils by plants is dependent on soil type; for example, uptake is lower in coarse loamy soils than in fine loamy soils (Chang et al. 1983). In 1996, the British Columbia Ministry of Environment held a CSR review workshop, which outlined the methodology for the CSR standards for soil invertebrates and plants. The workshop provided an overview of the lethal and non-lethal effect levels for several metals to plants as documented in the literature. A wide range of effect levels were noted, ranging from no effect on seed emergence of lettuce at concentrations of 1000 mg/kg zinc to in soil, to 50% effect levels on turnip seed emergence at zinc concentrations of 25 mg/kg in soil.

Receptor - Invertebrates

Among terrestrial invertebrates, adverse effects on earthworm survival were documented to range from 470 to 662 mg/kg of soil. Slugs had reduced food consumption at 300 mg Zn/kg diet and reduced growth at 1,000 mg Zn/kg diet (Chang et al.1983). The BCMELP (1996) indicated zinc toxicity values (LC_{50} concentrations) for invertebrates ranging from 80 mg/kg to 1010 mg/kg.

Receptor – Small Mammals and Birds

Puls (1988) found dietary toxicity levels of zinc to be greater than 1,500 ppm in mink. Concentrations above 1,500 ppm caused toxicity signs such as impaired reproductive performance and reduced hematocrit values. Toxicity occurred in mallards (*Anas platyrhynchos)* when fed 3,000 mg Zn/kg for 30 days (Eisler, 1993); at this concentration many deaths occurred. Other zinc toxicity

signs include leg paralysis, depressed hemoglobin and hematocrit levels, reduced food intake, reduced body weight and egg production, and reduction in pancreas size (Puls, 1988).

Table 23 summarizes the metals chosen for the ecological risk assessment and the associated toxicity concentration ranges for the selected receptors.

Table 23. Metals Toxicity Ranges for the Ecological Receptors

Parameter	95th Percentile mg/kg Soil Concentrations at Subject Area	Reported Toxicity Ranges mg/kg	
		Terrestrial Plants and Invertebrates Soil Concentrations	Small Mammals and Birds Diet Concentrations
Chromium	151	EC_{50} – 250 LC_{20} – 800	1.7 - 5000
Copper	984	27 –2760 EC_{50} – 150 LC_{20} – 250	300-600
Lead	546	12 – 3070 EC_{50} – 1000 LC_{20} – 2000	12-25
Zinc	1284	20 – 1010 LC_{20} – 450 EC_{50} – 600	1500 - 3000

LC_{20} = Lethal Concentration – The concentration at which mortality occurs in 20% of the test subjects

EC_{50} = Effective Concentration – The concentration at which 50% of the test subjects experience some kind of adverse effect, i.e. behaviour, growth, reproduction.

The data suggest that copper and zinc in the soils near Foundation AB are at levels that may impact plant growth and invertebrate survival.

5.2.1.4 TOXICITY ASSESSMENT OF HYDROCARBONS IN SOIL

Literature on toxicity of petroleum hydrocarbons to terrestrial plants and invertebrates is received within the CWS support documentation for the petroleum hydrocarbon criteria. **Table 24** provides an overview of the CWS findings.

Table 24. Summary of Hydrocarbon Toxicity as per the CWS

Hydrocarbon	95th Percentile (mg/kg) Soil Concentrations at Site	Soil Toxicity (mg/kg)		CWS Standard
		Plants	Invertebrates	
Fraction 2 >C_{10} – C_{16} (LEPH equivalent for this study)	2080	• EC_{50} endpoint 1800 mg/kg • Alfalfa shoot 21 day EC_{50} 1, 370 mg/kg (CCME 2000) • Northern wheatgrass 14 day EC_{50} 1,370 mg/kg (CCME 2000)	LC_{50} endpoint 600 mg/kg LC_{50} worm mortality 7 day 1100 mg/kg (CCME 2000) LC_{50} worm mortality 14 day 1100 mg/kg (CCME 2000)	900 mg/kg fine grained soil 450 mg/kg coarse grained soil 2200 mg/kg fine grained soil >1.5 m 1500 mg/kg coarse grained soil > 1.5 m
Fraction 3 >C_{16} – C_{34} (HEPH equivalent for this study)	322	EC_{50} endpoint 2000 mg/kg Alfalfa shoot 26 day EC_{50} 2100 mg/kg	• LC_{50} endpoint 800 mg/kg • LC_{50} worm mortality 57 days 810 mg/kg	800 mg/kg fine grained soil 400 mg/kg coarse grained soil 3500 mg/kg fine grained soil 2500 mg/kg coarse grained soil > 1.5 m
Fresh Diesel			• LC_{50} worms 1000 mg/kg	
Weathered Diesel		EC_{50} endpoint 20,000 mg/kg		

LC_{20} = Lethal Concentration – The concentration at which mortality occurs in 20% of the test subjects

EC_{50} = Effective Concentration – The concentration at which 50% of the test subjects experience some kind of adverse effect, i.e. behaviour, growth, reproduction.

The data show that weathering of a petroleum product such as diesel results in a reduced toxicity of the product in soil. CWS states that the existing database in very limited, and "at face value, the data

suggests that weathered diesel is substantially less toxic to plants than fresh diesel".

5.2.1.5 *Assessment of Potential Risk of COCs to Terrestrial Species*

Table 25 compares the toxicity information provided in **Section 5.2.1.4** with the concentrations of contaminants observed in the site soils. The potential risks to terrestrial species that may be exposed to the contaminants of concern are evaluated.

Table 25. Terrestrial Ecological Risk Characterization

Contaminant of Concern	Concern/Risk	Comparison with toxicity information	Field Observations
Chromium	Minimal – Likely not of concern	95th percentile within EC_{50} and less than most reported chronic and lethal concentrations to plants	Field data inconclusive for vegetation and invertebrates Some areas of contamination have evident vegetation and others do no have vegetation
Copper	Likely of concern	95th percentile concentrations > most reported chronic and lethal concentrations to plants	
Lead	Likely not of concern	95th percentile concentrations within EC_{50} and LC_{20}'s for plants and invertebrates	
Zinc	Likely of concern	Concentrations > than most reported chronic and lethal concentrations to plants and invertebrates	
Hydrocarbons	Probably not of concern	Soils contain LEPH > reported toxicity levels in laboratory studies for plants and invertebrates. However LEPH < reported toxicity levels for weathered diesel Hydrocarbons are at subsurface depths that are not generally accessed by roots and invertebrates	No effect on vegetation noted

5.2.1.6 TERRESTRIAL UNCERTAINTY ANALYSIS

Table 26 summarizes the uncertainty in the assumptions made during the ecological risk assessment.

Table 26. Summary of Uncertainty

Assumption	Uncertainty	Rational
Contaminants Distribution		
Metals	Moderate to High	Insufficient samples submitted for analysis. The dispersion is not well defined.
Hydrocarbons	Low	Sufficient samples submitted for analysis.
Contaminant Concentrations		
Metals and Hydrocarbons in soil, sediment and water	Low	Relative percent difference between samples and duplicates are low. Laboratory results appear reliable.
Hydrocarbon Receptors		
Soil Invertebrates	Moderate	Invertebrate populations to depth of hydrocarbon contamination not well defined.
Terrestrial Plants	Moderate	Root growth to hydrocarbon concentration depth is not known. No effects visibly evident.
Small Mammals and Birds	Low	No logical pathway for exposure to hydrocarbons.
Bioavailability		
Soil Invertebrates	Moderate	No bioassay completed
Terrestrial Plants	High	Limited visual observations and limited bioassay data
Toxicity		
Toxicity Ranges for Metals	Moderate	Toxicity ranges based on species that may not be present on site

5.2.1.7 TERRESTRIAL – RISK CHARACTERIZATION

The primary goal of the deterministic ecological assessment was to determine the impacts, if any, resulting from metals in surface soils around Foundation AB and the presence of hydrocarbons in the subsurface. Based on the toxicity assessment of the metals in **Section 5.2.8.3** and the observed concentrations of copper and zinc, it appears that there is a potential risk to ecological health (**Table 22**) on a localized basis, i.e. to the vegetation and invertebrates.

5.3 AQUATIC ECOLOGICAL RISK ASSESSEMENT

5.3.1 Aquatic Exposure Assessment

5.3.1.1 RECEIVING ENVIRONMENT

Brooks Brook borders the south and east side of the Subject Area. This portion of the brook was re-routed from its historical location during the construction of the Alaska Highway (**Figure 2**). As mentioned in **Section 2.2.5.1** of this report, the banks are sloped 1:1 and on average 1.5 m in height. The bank and stream bottom consist primarily of gravel. The flow is rapid and there was little evidence of settled fine material within the gravel bed. During September 2001, the brook was approximately 0.25 m deep and had an estimated flow-rate of 1.2 m/s. The water was clear, with no evidence of algal growth. No vegetation was present from the top of the bank to the stream bed. Brooks Brook drains to Teslin Lake, which is located approximately 300 meters west of the Subject Area.

Based on the analysis of Brook's Brook water there is no evidence of PCOC presence in the stream. As there is no evidence of a PCOC loading to Teslin Lake, the risk assessment should not consider risk to Teslin Lake.

5.3.1.2 GROUNDWATER

Key to this risk assessment is the possible impact of groundwater contamination on the quality of water in Brooks Brook. As described in **Section 2.2.5.2.1** of this report, two studies of groundwater flow (March 1999 and September 2001) indicated that there may a net flow from Brooks Brook into the highly permeable sand and gravel horizon, and that the net flow of groundwater is southwest, away from Brooks Brook. With reference to **Figure 2** it is observed that Brooks Brook follows a "U" shaped pathway. Although the net flow of groundwater from the area of soil contamination is away from the eastern section of the brook, the flow proceeds in the direction of the brook at a distance which may range from 10 to 100 meters, dependent upon the groundwater flow pattern. Large tree

growths restricted further access of the drill rig to the south of the Subject Area, and further delineation of groundwater flow patterns could not occur without destruction of the trees. Destruction of the trees would have been contrary to the intent of the clients, who wish to maintain the current tree growth on the property. As a result, a risk assessment of groundwater impacts on the quality of Brooks Brook water may be limited in its conclusions, pending additional field information.

5.3.1.3 EXPOSURE TO AQUATIC BIOTA

Within Brooks Brook, the following exposures are evaluated for consideration within the risk assessment:

5.3.1.3.1 Aquatic Invertebrates

Typically, a risk assessment would consider aquatic invertebrates in streams, such as *Daphnia magna* (water flea). Although aquatic invertebrate populations have not been assessed for this area, this risk assessment will consider the possible impact to aquatic invertebrates as a result of direct exposure to groundwater-borne COPCs that may migrate to surface water.

5.3.1.3.2 Aquatic Plants

Given the field observations of the absence of algae and macrovascular vegetation in the brook, aquatic plants are not considered receptors of direct exposure to groundwater-borne COPCs that migrate to surface water.

5.3.1.3.3 Fish

Graylings are noted to inhabit the brook. The risk assessment will first consider direct exposure to groundwater-borne COPCs that migrate to surface water and porewater. Ingestion of food will only be considered if there is evidence of elevated chemical concentrations in the brook water. Given the shallow depth of the brook in September, i.e. 25 cm, and the likelihood of a complete freeze-over, it is unlikely that the stream is a major habitat for resident fish. Fish in Teslin Lake would encounter more long-term exposure if contamination extended to that distance.

5.3.1.3.4 Birds

Ingestion of food with elevated chemical concentrations by birds is not considered a major concern given the small area of the Subject Area, relative to a typical feeding area for most bird species.

5.3.1.4 AQUATIC TOXICITY ASSESSMENT OF COCs

Table 27 summarizes the aquatic contaminants of potential concern in terms of the contaminant toxicity to aquatic invertebrates and fish as selected in the previous section of this report.

Table 27. Summary of Aquatic Contaminants of Potential Concern

COPC	Assessment of COPC
Iron	*Properties*
	Iron occurs naturally, and the level of its presence in water is dependent upon many factors. Mostly present in surface water in ferric state (Fe^{+3}), but occurs in low concentrations in the water column as ferric salts, has a low solubility in aerobic waters. Ferrous iron (Fe^{+2}) persists and is found in high concentrations in reducing waters where sulphide and carbonate anions are absent (i.e. in a landfill). Also occurs as inorganic or organic ferrous and ferric complexes, or as stable colloids (CCREM, 1997). Concentrations in water are influenced by: oxidation-reduction reactions, pH, and other inorganic and organic complexing agents. Ferrous iron predominates at low pH in anoxic environments such as groundwater and ferric iron is most abundant in oxygenated water. Hydroxide complexes form at neutral and alkaline pH. Release of groundwater to surface waters will result in oxidation of ferrous iron to the ferric form. The elevated levels in groundwater at the subject site may be due to natural concentrations and/or due to natural degradation of the hydrocarbon residues in soil. Areas of groundwater seepage to surface waters are generally characterized by a red colour; no such colouration was observed in Brooks Brook.
	Toxicity
	Ferric iron precipitates in high concentration may result in the coating of gills of fish and settled iron precipitates may be detrimental to fish eggs and bottom dwelling fish food organisms. A 72 hr LC_{50} of greater than 500,000 µg/l for the channel fish was recorded by Clemens and Sneed in 1959. 96 hr LC_{50} values for invertebrates (mayflies, stoneflies and caddis flies) are in the order of 320 µg/L iron (NC, 1974).

	Gerhart (1995) found a 42 day EC_{50} of 23,410 µg/L for *Leptophlebia marginata* (mayfly).
	Guidelines
	1000 µg/L iron was deemed adequately protective for freshwater aquatic life (U.S. EPA, 1976). 96 hr LC_{50} values for fish range from 300 to 500,000 µg/L iron. The European Inland Fisheries Advisory Commission recommends that iron should not exceed 1000 µg/L to manage aquatic life. The CCME total iron in the receiving environment is 300 µg/L while the YCSR standard for dissolved iron in groundwater is 3,000 µg/L. The concentrations observed in groundwater from the Subject Area range from 11,100 to 13,100 µg/L.
Manganese	*Properties*
	Manganese occurs naturally and it chemical behaviour is very similar to that of iron. It is frequently found in association with iron. Soluble manganese may be elevated in area of anaerobic decomposition, and the levels observed at the subject site may be due to degradation of hydrocarbon residuals in soil. Adverse effects of manganese on freshwater aquatic organisms have been reported in a number of studies, although the cause-effect evidence is not extensive (Reimer, 1999). A review of the literature on manganese toxicity conducted by Reimer (1999), found aquatic toxicity values of manganese to vary with the water hardness.
	Toxicity
	A 96 h LC_{50} for rainbow trout was found at manganese concentrations of 4.83 mg/L with a pH of 7.53 and a water hardness of 34 mg/L. An IC_{25} (statistically derived concentration at which 25% of organisms are inhibited for the exposure endpoint in the study, i.e. growth, reproduction, hatching success vs. controls) of 5.59 mg/L was found during a 62 day chronic toxicity test on Brown trout. The pH of the water was 7.9 while the hardness was 150 mg/L. Trenel and Kuhn (1982) found a 48 h LC_{50} of 4.7-56.1 mg/L in *Daphnia magna.*
	Guidelines
	Manganese freshwater aquatic life values of 0.1-1 mg/L was recommended by the United States EPA (Reimer, 1999). A review of the EPA guideline for manganese found that the description of the effects of manganese on aquatic life "is inadequate, of little value to aquatic biologists generally out of date, lacks completeness and seldom cites the available literature" (Reimer 1999). The current YCSR standard for groundwater is 1mg/L while there is no current CCME guideline for manganese. Reimer (1999) proposed hardness dependent guidelines for manganese. The concentrations of manganese in groundwater at the Subject Area range from 0.6 – 1.17 mg/L.

Naphthalene	*Properties*
	Naphthalene is found in petroleum products. It is readily biodegraded by soil and aquatic micro-organisms (IEDA, 1974). When exposed to sunlight, photolysis may occur.
	Toxicity
	Fish – Moles (1980) found a 96h LC_{50} of 3220 µg/L in *Oncorhynchus kisutch* (coho salmon). A CCME review reported 96h LC_{50} ranges of 1990 to 7900 µg/L for fathead minnows. Chronic effects to rainbow trout embryo larvae stages were reported at ranges from 8 – 46 µg/L (mean of 11 µg/L) at 4 day exposures. ***Invertebrates*** - A CCME review reposted 48h LC_{50}'s of 2160 to 4663 µg/L for *Daphnia magna.*
	Guidelines
	The CCME FAL guideline for surface water is 1.1 µg/L while the YCSR groundwater standard is 10 µg/L. Concentrations of naphthalene at the Subject Area range from 0.15 – 130 µg/L.
Phenanthrene	*Properties*
	The source of phenanthrene at the Subject Area is likely a petroleum product. Biodegradation is an important fate process along with photolysis when dissolved in water.
	Toxicity
	Fish – In continuous-flow toxicity tests with embryo-larval stages of rainbow trout and largemouth bass (*Micropterous salmoides),* the LC_{50} values for phenanthrene were 40 and 180 µg/L (CWQG, 1996). Call et al. (1986) conducted chronic tests with rainbow trout and embryos exposed to phenanthrene. The LOEC and NOEC for mortality were 8 µg/L and 5 µg/L. The same study found 96h LC_{50} of 375 and 234 µg/L and 96h EC_{50}s (loss of equilibrium) of 50 and 49 µg/L for rainbow trout and sunfish, respectively. ***Invertebrates*** - Call et al. (1986) reported a 48h EC_{50} (immobilization) of 117 µg/L for D. magna. Call et al. (1986) also reported 96h EC_{50} s of 96 µg/L (shortened tentacles and body column for hydroids) (marine species) and 126 µg/L (immobilization) for amphipods (*Gammarus pseudolimnaeus*) exposed to phenanthrene. *Plants* - The CWQG suggests that the effect of polycyclic aromatic hydrocarbons on aquatic plants is variable (CWQG, 1996).
	Guidelines
	The interim water quality guideline for phenanthrene for the protection of freshwater life is 0.4 µg/L. It was derived by multiplying the chronic LOEL of 4 µg/L for rainbow trout (corresponding to the control-adjusted 93% survival of the

	trout) (Black et. al. 1983) by a safety factor of 0.1 (CCME 1991). The YCSR groundwater standard is 3 µg/L for phenathrene. Concentrations at the Subject Area range from 0.025 to 1 µg/L. The CWQG suggests that the effect of polycyclic aromatic hydrocarbons on aquatic plants is variable (CWQG, 1996).
Pyrene	*Properties*
	• Pyrene is found in petroleum products, and natural sources such as forest fires also produce pyrene. • Pyrene would biodegrade in the environment but at a slower rate than naphthalene. Dissolved pyrene can undergo photolysis. Some PAHs, such a pyrene have, been shown to be severely toxic to aquatic organisms when the dissolved PAHs are exposed to sunlight or UV light (BCE, 1993).
	Toxicity
	Fish — Phototoxic effects of pyrene to fish have been demonstrated at concentrations as low as 25.6 µg/L (Oris and Giesy, 1987). In the absence of UV light, acute effects have not been observed at 2000 µg/L in several test species (coho salmon, rainbow trout, chinook salmon, sea lamprey, fathead minnow, northern squawfish). ***Invertebrates*** - A number of tests have been conducted with freshwater species and most of these address phototoxic endpoints (Kagan et al., 1985; Oris and Giesy, 1987; Borovsky et al., 1987; Newsted and Giesy, 1987). Reported LC_{50}s range from 4 to 60 µg/L. The lowest effects concentration from a non-phototoxic endpoint is for freshwater daphnids have also been observed below 100 µg/L in the absence of UV light (Abernethy et al., 1986).
	Guidelines
	The YCSR groundwater standard for pyrene (0.2 µg/L) was derived using the freshwater phototoxic ambient water quality guideline of 0.02 µg/L (BCE, 1999c). The ambient water quality guideline was based on consideration of the relative phototoxic potentials of pyrene and anthracene (i.e., pyrene assumed to be 4.7 times more phototoxic to fathead minnow (*Pimephales promelas*), the phototoxicity of anthracene to fathead minnows (Oris and Giesy, 1987), and by application of a safety factor of 0.01 to the fathead minnow LOEC (12 µg/L) (BCE, 1993). In other words, the pyrene criterion was derived from surrogate chemical toxicity information, rather than from studies conducted specifically with pyrene. Due to a lack of data, no water quality criterion for protection of aquatic life from chronic (non-phototoxic) effects was developed. There is a high degree of uncertainty with the ambient water guideline for pyrene and in turn for the YCSR standard. Based on other PAHs, it is expected that pyrene would have a large difference in relative potency between phototoxic and non-

	phototoxic exposures. The apparent conservatism of the standard, coupled with its assumption of an exposure scenario eliciting phototoxic effects, warranted closer investigation. The BC guideline, upon which the YCSR is based, was developed over seven years ago. Pyrene concentrations in groundwater at the site have ranged from 0.01 to 0.2 µg/L.		
Toluene	*Properties*		
	Petroleum products such as gasoline and solvents contain toluene. Volatilization is a major fate process for toluene. Toluene in water would have a half-life of approximately 5.2 hours (EPA, 1979).		
	Toxicity		
	Fish - Concentrations of toluene causing acute toxicity to fish species ranged from 5,460 µg/L for coho salmon to 1,340,000 µg/L for mosquito fish (CWQG, 1996). The threshold concentration for sublethal effects of toluene on the growth of coho salmon fry was between 0.02 and 5.8 µg/L. ***Invertebrates*** -Chronic toxicity of toluene to aquatic invertebrates may occur at concentrations below 4,300 µg/L.		
	Guidelines		
	The 1996 Canadian Water Quality Guidelines (CWQG) set the guideline for toluene at 300 µg/L. This guideline is based on a review of literature regarding toxicity of toluene to various aquatic organisms. The guideline for the protection of aquatic life was derived using the LC_{50} value of 5,460 µg/L for coho salmon and an application factor of 0.05 (CWQG, 1996). Toluene concentrations in groundwater at this site have ranged from 0.05 to 24 µg/L.		
Hydrocarbons	*Properties*		
	Hydrocarbons degrade in the environment. However the rates of degradation depend upon factors such as temperature, bacteria populations, nutrient levels and the types of hydrocarbons (i.e. light hydrocarbons from products such a diesel degrade faster than heavy hydrocarbons from products such as lubrication oil or Bunker oil). Aging of hydrocarbons in soil has been observed to result in lower toxicity and lower ecological impacts.		
	Toxicity		
	Product	Organism	LC_{50} (µg/L)
	Fuel Oil # 2	Rainbow trout (eggs)	$1.2 \times 10^4 - 2.0 \times 10^4$
	Gasoline	Rainbow trout	$4.0 \times 10^4 - 1.0\text{-x } 10^5$
	Diesel	Daphnia magna	7.2×10^3
	Diesel	Salmo gairderi (Oncorhynchus mykiss)	2.5×10^3

	New crankcase oil	Daphnia magna	3.8×10^2
	Used crankcase oil	Daphnia magna	4.2×10^4
	Guidelines		
	There are no current ambient water quality guidelines for petroleum hydrocarbons. There are no YCSR or CCME groundwater standards or guidelines. The BC CSR groundwater standard for LEPH (F2) is 500 µg/L. TEH levels in groundwater at this site have ranged from 50 to 30,000 µg/L and LEPH concentrations have ranged from 125 to 2,500 µg/L. The TEH concentrations would represent concentrations of product such as diesel, which is likely the source of hydrocarbon contamination at the Subject Area. Until approximately 1998, the BC ministry of Environment required reporting of TEH "as diesel".		

Table 28 summarizes the contaminants of potential concern and the associated toxicity concentrations for the selected receptors.

Table 28. Toxicity Values for the Potential Aquatic Receptors

Parameters	**95th Percentile Concentrations in Groundwater**	**Reported Toxicity Ranges in Surface Waters**	
		Aquatic Invertebrates	Fish
Iron	13.1 mg/L	96 hr LC_{50} of 0.32 mg/L in mayflies and stoneflies	< 1 mg/L to maintain fish populations
Manganese	1.167 mg/L	48 h LC_{50} of 4.7-56.1 mg/L in *Daphnia magna* 48 h EC_{50} of 40 mg/L in *Daphnia magna*	96 h LC_{50} of 4.83 mg/L @ 34 mg/L $CaCo_3$ in rainbow trout 62 day IC_{50} of 5.59 mg/L @ 150 mg/L $CaCo_3$ in Brown Trout
Naphthalene	16 µg/L	24 h EC_{50} 15,000 µg/L in *Daphnia magna*	96 h LC_{50} 3220 µg/L in Coho Salmon Lowest reported chronic effects: 8-46 µg/L
Phenanthrene	0.69 µg/L	96 h EC_{50} of 117 µg/L in *Daphnia magna* (immobilization)	96 h LC_{50} of 375µg/L in rainbow trout 96 h EC_{50} of 49 µg/L Lowest reported effect level (LOEL): 8 µg/L No observed effect level (NOEL): 5 µg/L
Pyrene	0.09 µg/L	In the presence of UV light, LC_{50}'s ranges from	Observed effects of pyrene on fish in the absence of

		4-60 µg/L in *Daphnia magna* In absence of UV light, EC_{50} for *Daphnia magna* has been reported to be less than 100 µg/L	UV from light occur at concentrations in excess of 2000 µg/L. In the presence of UV light toxicity (LT_{50}) occurs in the range of 26 µg/L.
Toluene	2.48 µg/L	EC_{50}'s for *Daphnia magna* range from 7,000 to 310,000 µg/L. Chronic toxicities range from 3,750 µg/L (16 day LC_{50}) for *Daphnia magna* to 173,000 µg/L (6 day EC_{40}	Acute toxicity for fish range from 5460 µg/L (96h LC_{50}) for coho salmon to 1,340,000 µg/L in mosquito fish. Chronic Toxicity ranges from 20 µg/L in rainbow trout to 68,300 µg/L in guppies.
LEPH	2080 µg/L	LC_{50} of 7200 µg/L in *Daphnia magna* (diesel)	LC_{50} of 2,500 µg/L in *Salmo gairderi* (diesel)
HEPH	322 µg/L	LC_{50} of 42,000 µg/L in *Daphnia magna* (used crankcase oil)	LC_{50} of 2,500 µg/L in *Salmo gairderi* (diesel)

5.3.1.5 ASSESSMENT OF POTENTIAL RISK OF COCS TO AQUATIC SPECIES

The assessment of potential risk to aquatic species is dependent upon likely exposure levels. Two iterative conservative scenarios are used in this risk assessment.

Assumption that aquatic life is exposed to chemicals at the 95th percentile concentrations observed in groundwater. It is assumed there are no retarding factors such as biodegradation, adsorption or dilution between a well (where high concentrations were observed) and the receiving water body. Additionally it is assumed, no dilution occurs within the stream. It is noted that the Fisheries Act is applied to discharges to a water body without any consideration for dilution within the water body. It is noted that brook water quality adjacent to the subject area has no detectable concentrations of the PCOC's.

If a comparison of groundwater concentrations with the toxicity values noted in **Tables 27** and **28** show a potential impact, then the iterative approach of assessing potential impacts of groundwater on down-gradient stream water quality will be used. A one dimensional chemical transport in

groundwater modelling will be used to predict possible concentrations at the point of discharge to a down-gradient portion of the brook. It is recognized that the down-gradient groundwater flow is not fully characterized because of site limitations, and conservative assumption will be made for pathways of transport.

5.3.1.5.1 Direct Comparison of Groundwater Quality with Toxicity Information

The first comparison of groundwater concentrations with toxicity information eliminates all chemicals of concern except for naphthalene and LEPH. The following section will provide a further evaluation to groundwater transport.

Table 29 provides an assessment of the aquatic ecological risk based on the prior toxicity information.

Table 29. Aquatic Ecological Risk Characterization

Contaminant of Concern	Concern/Risk	Comparison with toxicity information	Field Observations
Iron	Possibly (could be background)	95th percentile greater than LC_{50} concentrations	No visual indications of red staining along Brooks Brook
Manganese	Not Likely	95th percentile well within EC_{50} and LC_{50} concentrations	
Naphthalene	Possibly	95th percentile well within EC_{50} and LC_{50} concentrations for invertebrates and fish 95th percentile (16 µg/L) greater than lowest range (8 µg/L) of chronic effects to fish but lower than upper range number (46µg/L).	
Phenanthrene	Not Likely	95th percentile concentrations well within EC_{50} and LC_{50}'s for fish and invertebrates 95th percentile (0.69 µg/L) lower than reported No observed effects level (5 µg/L)	
Pyrene	Not Likely	95th percentile concentrations well within EC_{50} and LC_{50}'s for	

		fish and invertebrates, including toxicity values reported in presence of UV light.	
Toluene	Not Likely	95th percentile concentrations well within EC_{50} and LC_{50}'s for fish and invertebrates	
LEPH	Possibly	95th percentile concentrations near the reported LC_{50} concentrations for fish and above 0.05 safety factor typically used by CCME.	Hydrocarbon sheen and odour observed in groundwater samples.
HEPH	Not Likely	95th percentile concentrations well within LC_{50}'s for fish and aquatic invertebrates	

5.3.1.5.2 Comparison of Calculated Down-gradient Groundwater Quality with Toxicity Information

The route of Brooks Brook is such that there are two scenarios by which contaminated groundwater could influence the water quality of Brooks Brook:

A portion of Brooks Brook is directly adjacent to hydrocarbon contamination in the Subject Area. Previous discussion in this report indicates that groundwater at the Subject Area moves away from this portion of Brooks Brook and that Brooks Brook may in part be a source of groundwater in the subject area. Water quality samples showed no impacts of groundwater in this area of Brooks Brook. No further consideration of the impact of the PCOC's for this area of Brooks Brook is necessary. Due to the "U" shaped configuration of Brooks Brook, contaminated groundwater may move towards down-gradient areas of the brook as discussed in **Section 2.3.3** of this report. Within this section it is also noted that down-gradient groundwater flow patterns have not been defined because of limitations of access to down-gradient areas, and points of entry to Brooks Brook of water from the well with the most contaminated groundwater may vary from 20 to more than 100 meters. To estimate the possible concentrations of the two contaminants, LEPH and naphthalene, at down-gradient areas, a one dimensional model is used to simulate transport of the chemicals in a confined groundwater aquifer.

The calculation considers:

- Advection – chemical movement via groundwater flow due to the groundwater gradient
- Dispersion – longitudinal (forward and backward) spreading of the contaminant
- Retardation – adsorption of the chemicals to the soil will cause the chemical velocity to be slower than groundwater velocity. It should be noted the equation makes no allowances for biodegradation.

The equations and the assumptions used for estimating contaminant movement at the Subject Area are provided in **Appendix B.** The results are illustrated in **Figure B** where it is assumed the observed worst-case concentration of 2.5mg/L LEPH represents the initial concentration prior to movement in the groundwater regime. The model predicts that if the plume enters Brooks Brook 20 meters down-gradient of the "worst-case" LEPHs observed in groundwater well MW01-03. The LEPH concentration at the point of entry to Brooks Brook would be no greater than 0.06 mg/L. The 0.06 mg/L concentrations would be observed after 8 months of transport. If the point of entry of the plume was 40 meters from the area of "worst case" groundwater the LEPH concentration would be approximately 0.03 mg/L, and observed after approximately 18 months transport.

The 0.06 mg/L concentration is 40 fold less than the LC_{50} reported for diesel and 700 fold less than the LC_{50} reported for aged diesel.

To calculate guideline concentrations of chemicals on the basis of LC_{50} concentrations, CCME has used a 20-fold application factor (0.05 multiplier) for non-persistent organic compounds (CCME, 1999). The predicted LEPH concentrations at a 20 meter down-gradient distance at the Subject Area, are well within the application (or protection) factors used by CCME if applied to reported LC_{50}'s for diesel and aged diesel, e.g. LC_{50} mg/L x 0.05 = 0.125 mg/L versus the predicted 0.06 mg/L. as a result it is predicted the observed LEPH concentrations in groundwater at the site would no be of concern to Brooks Brook.

A similar decrease would be predicted for naphthalene, where the maximum value of 130 µg/L would decrease to approximately 3 µg/L within a distance of 40 meters. The resulting concentration is less than the lowest reported chronic effect level of 8 µg/L.

Overall the mathematic model predicts there would be no impact on down-gradient portions of Brooks Brook. It is suggested that verification of the model should be pursued by obtaining seepage samples at the shoreline of Brooks Brook.

5.3.1.6 AQUATIC UNCERTAINTY ANALYSIS

Table 30 summarizes the uncertainty in the assumptions made during the aquatic ecological risk assessment.

Table 30. Summary of Uncertainty

Assumption	Uncertainty	Rational
Contaminants Distribution		
Metals	Moderate to High	Insufficient samples submitted for analysis. A real dispersion is not well defined.
Hydrocarbons	High	Hydrocarbon plume not completely delineated due to dense vegetation (trees) to the west of the Subject Area
Contaminant Concentrations		
Metals and Hydrocarbons in groundwater	Low	Relative percent difference between samples and duplicates are low. Laboratory results appear reliable.
Hydrocarbon Receptors		
Aquatic Invertebrates	Moderate to High	Existence of an exposure pathway of contaminants in groundwater to the receptors in Brooks Brook or Teslin Lake not defined/uncertain. (i.e. whether the area of the brook to the west of the subject area is impacted by the plume) Populations are not defined in the brook
Fish Species	Moderate to High	Existence of an exposure pathway of contaminants in groundwater to the receptors in Brooks Brook or Teslin Lake is not certain.
Aquatic Plants	Low	No aquatic plants observed in Brooks Brook

Birds	Low	Area of site smaller than typical feeding area of birds
Toxicity data		
Aquatic Invertebrates	Moderate	Limited bioassay data particularly for LEPH/HEPH.
Fish Species	Moderate	Limited bioassay data particularly for LEPH/HEPH. Toxicity ranges based on species that may not be present in the area of the site.

5.3.1.7 AQUATIC – RISK CHARACTERIZATION

The primary goal of the aquatic ecological risk assessment was to determine the impacts, if any, resulting from metals and hydrocarbons in the groundwater of the Subject Site. Based on the toxicity assessment of the contaminants in **Section 5.2.1.4** it appears that light extractable petroleum hydrocarbons are the only contaminants of potential concern. Iron is not selected on the basis that the elevated concentrations may be representative of background levels. With respect to the observed concentrations of light extractable petroleum hydrocarbons it cannot be stated that there is no potential risk to aquatic health. As summarized in **Section 5.2.1.5**, the uncertainty of this risk is relatively high due to the concentrations of hydrocarbons in the groundwater not being fully delineated and the uncertainty in the groundwater flow patterns. The dense tree growth to the west of the hydrocarbon plume prevented the drill rig from advancing additional boreholes to the west of the hydrocarbon impacted area. Further, Brooks Brook (to the east of the Subject Area) has prevented the advancement of additional boreholes and monitoring wells to the east of the hydrocarbon plume.

A mathematical model suggests that there should be no impacts to Brooks Brook. To verify the model, Hemmera recommends that the brook be sampled at down-gradient locations west and south west of the property to assess the status of the brook and seepage water entering the creek. It is suggested that the brook be surveyed for evidence of red staining due to elevated iron in the groundwater. Those areas should be selected as sampling site. This assessment would enable an evaluation of whether the plume is influencing the brook to the west of the subject area.

Analysis of the groundwater collected from the network of monitoring wells over the last few years has indicated a general decrease in concentrations of hydrocarbons. This positive trend should be

monitored, as biodegradation is key to reducing the risk to aquatic biota. Hemmera recommends that the monitoring wells be sampled in the spring or summer. Groundwater samples should be analysed for hydrocarbons and metals.

Once the additional field observations, groundwater data, and surface water data are obtained, the aquatic risk assessment should be reviewed and updated accordingly.

6 CONCLUSIONS

6.1 HUMAN HEALTH RISK ASSESSMENT

The human health risk assessment identified: chromium, copper, lead, zinc and hydrocarbons as potential contaminants of concern. The exposure assessment found ingestion, dermal, and inhalation as possible pathways of exposure to humans as the Subject Area is used occasionally for recreational purposes. Possible inhalation of hydrocarbon vapours was also considered in the human health risk assessment.

The exposure estimate calculated the estimated daily intake of each of the above mentioned chemicals. The estimated daily intake values were then compared to the reference doses and tolerable daily intake values found in the literature. All of the estimated daily intake values were well within the recommended RfDs and TDIs. Thus, human health risk assessment did not identify any potential risks to human health within the Subject Area from the metals and hydrocarbon impacted soil and groundwater.

6.2 ECOLOGICAL RISK ASSESSMENT

6.2.1 Terrestrial

The terrestrial risk characterization, based on the toxicity assessment of metals, found copper and zinc at concentrations that may be a potential ecological health risk to soil invertebrates and plants on a localized basis. The metals of concern appear to be localized around the perimeter of Foundation AB.

6.2.2 Aquatic

The aquatic risk characterization suggests there is no risk to aquatic biota from groundwater impacted with light extractable petroleum hydrocarbons. However the characterization is based on a mathematical model and the potential risk to aquatic biota from the impacted groundwater should be

re-assessed upon further characterization of the water in Brooks brook south and southwest of the groundwater plume.

7 RECOMMENDATIONS

Based on the human health and ecological risk assessment conducted for the Subject Area at the Brooks Brook Property, Hemmera recommends the following:

1. With regard to the surficial soil around the perimeter of Foundation AB where concentrations of copper and zinc may pose a potential risk to the ecological health of terrestrial plants and soil invertebrates, two options are possible:
    a) The soils could be submitted for bioassay tests to verify whether the predicted impacts reflect reality; or,
    b) The soils could be scraped and removed from the area without any additional studies.

2. An additional field investigation should be conducted. This field investigation would include;
    a) Sampling the brook and seepage waters to the west and south of the Subject Area in order to determine if the hydrocarbon impacted groundwater has migrated to the surface water.
    b) Further visual observations of the ecology of the Subject Area.

3. Once the field investigation has been conducted, the risk assessment would be amended to include the additional information collected.

8 RISK MANAGEMENT

The risk management approach for the impacted groundwater would be annual monitoring and sampling of all of the monitoring wells in the Subject Area. Each of the wells should be sampled for LEPH/HEPH and dissolved metals. Ongoing monitoring of the hydrocarbon concentrations in the groundwater will assess the rate and degree of attenuation over time. Monitoring would cease upon confirmation of lowered concentrations of LEPH and naphthalene to levels of minimal concern. If the levels do not decrease and are shown to impact Brooks Brook, then optional management procedures such as excavation will have to be considered.

The risk management approach for surficial soils contaminated with metals would be removal and placement in a landfill approved by the Yukon Government. There is the option for addition assessment prior to undertaking a remediation program. A cost evaluation should be made of further assessment versus scrapping and disposal.

9 STATEMENT OF LIMITATIONS

This report ("Report") was prepared by Hemmera Envirochem Inc. ("Hemmera") for the sole benefit and exclusive use of Indian and Northern Affairs Canada ("INAC"). The material in it reflects Hemmera's best judgement in light of the information available to them at the time of preparing the Report. Any use which a third party makes of this Report, or any reliance on or decisions made based on it, are the responsibility of such third parties. Hemmera accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions taken based on this Report.

Hemmera has performed the work as described in the Scope of Work and made the findings and conclusions set out in this Report in a manner consistent with the level of care and skill normally exercised by members of the environmental science profession practising under similar conditions at the time the work was performed.

This Report was prepared by Hemmera for INAC and represents a reasonable review of the information available to Hemmera within the established Scope of Work, work schedule and budgetary constraints. It is therefore possible that currently unrecognised contamination or potentially hazardous materials may exist at the site(s) and that the levels of contamination or hazardous materials may vary across the site(s). No warranty, expressed or implied, is given concerning the presence or level of contamination on the site. The conclusions and recommendations contained in this Report are based upon applicable legislation existing at the time the Report was drafted and changes in the legislation may alter the conclusions and/or recommendations. Further, any discussion of regulatory implications is based on the applicable legislation existing at time of drafting the Report.

In preparing this Report, Hemmera has relied in good faith on information provided by others as noted in this Report, and has assumed the information provided by those individuals is both factual and accurate. Hemmera accepts no responsibility for any deficiency, misstatement or inaccuracy in this Report resulting from the information provided by those individuals.

The liability of Hemmera to INAC shall be limited to injury or loss caused by the negligent acts of Hemmera. The total aggregate liability of Hemmera related to this agreement shall not exceed the lesser of the actual damages incurred, or the total fee of Hemmera for services rendered on this project.

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11 REPORT CREDITS

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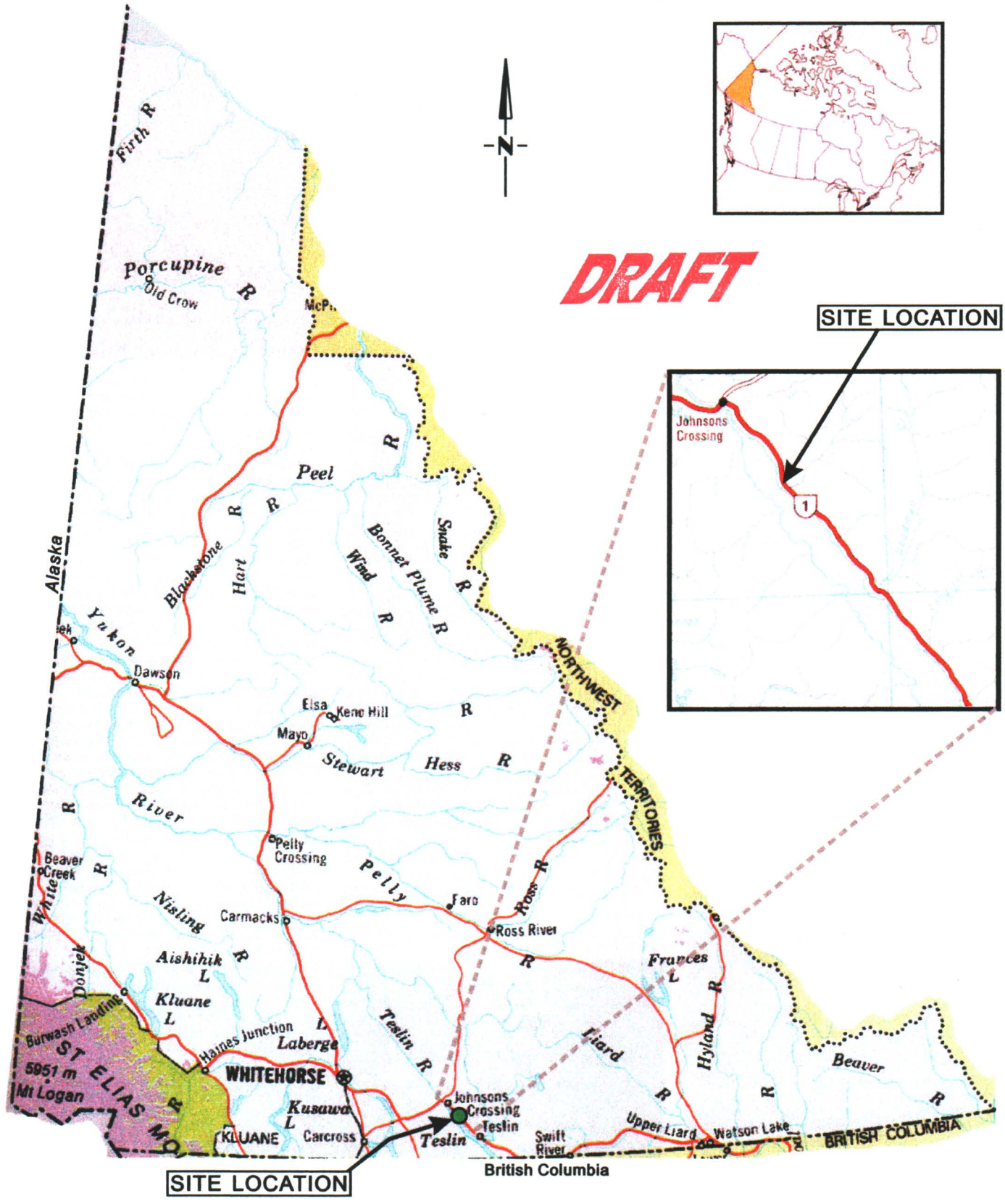
Hemmera Envirochem Inc.

DRAFT DRAFT

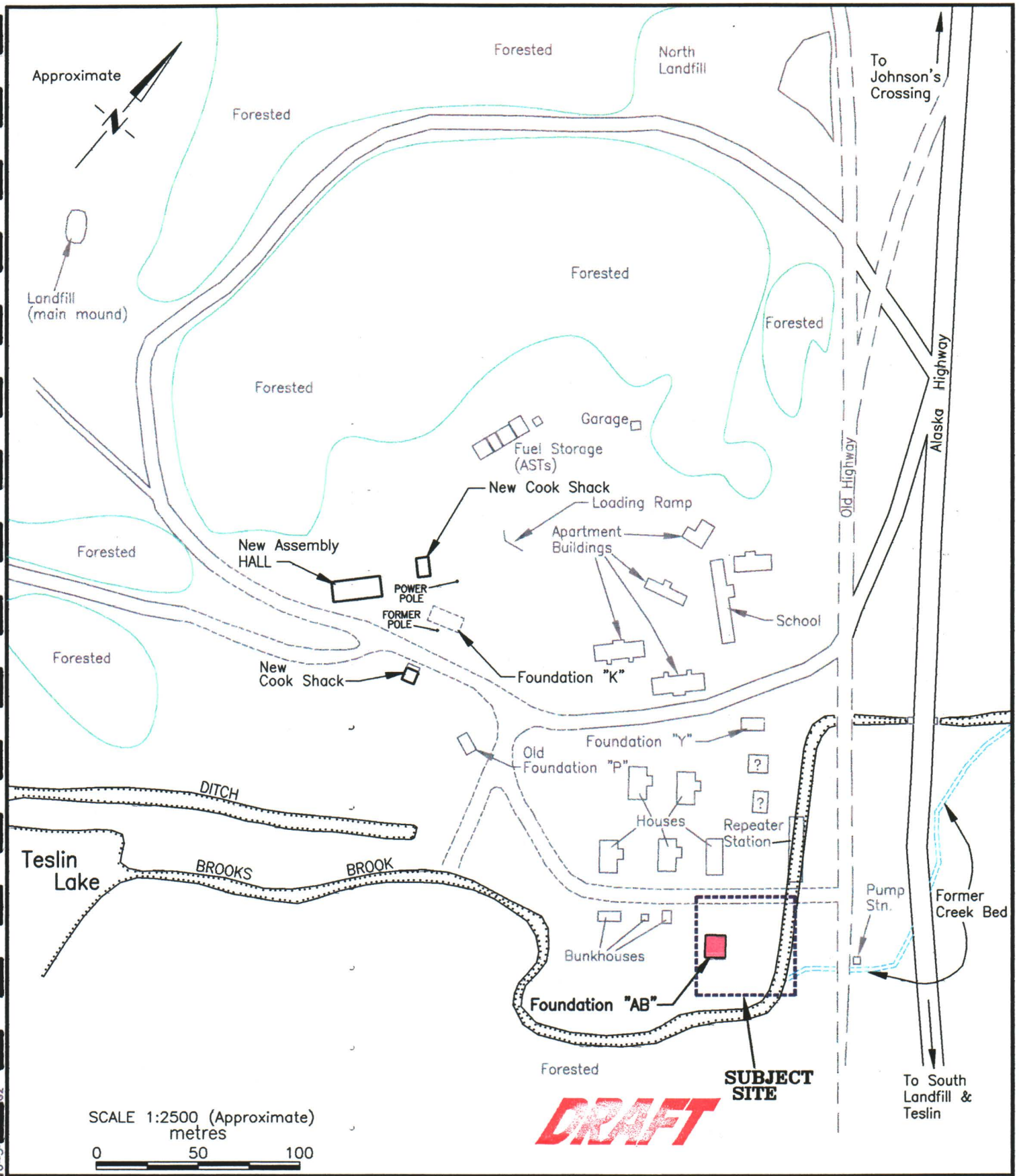
Per: Kelli Bergh B.Sc. Date

DRAFT DRAFT

Per: Dennis Konasewich, PhD.
Project Manager Date



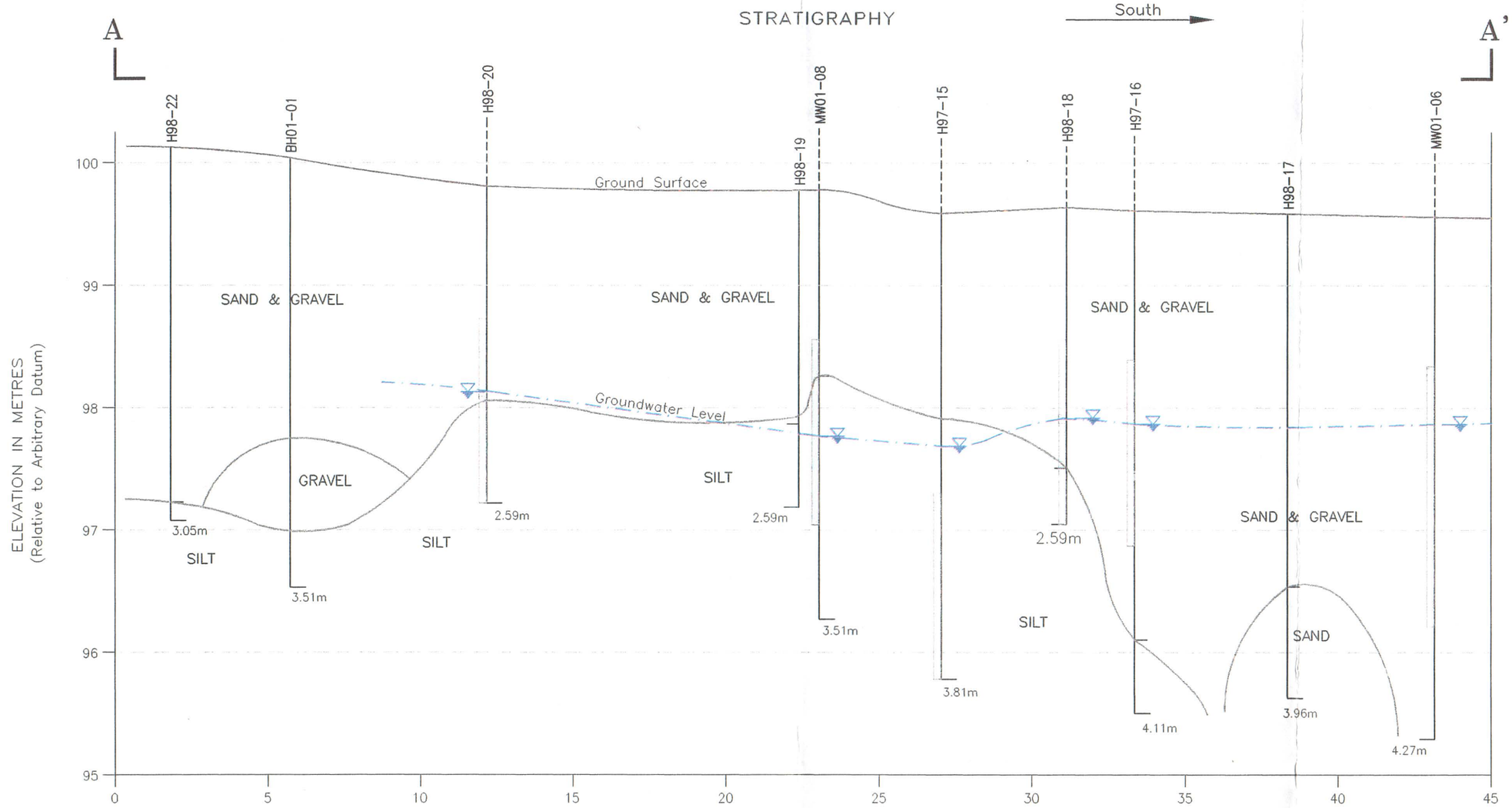
HEMMERA ENVIROCHEM HEMMERA ENVIROCHEM INC. Suite 350, 1190 Hornby Street Vancouver, BC V6Z 2K5	RISK ASSESSMENT Brooks Brook, Yukon Territory		
	LOCATION MAP		
CLIENT: **INDIAN & NORTHERN AFFAIRS CANADA**	PROJECT No. 316-003.04	March 2002	Figure 1



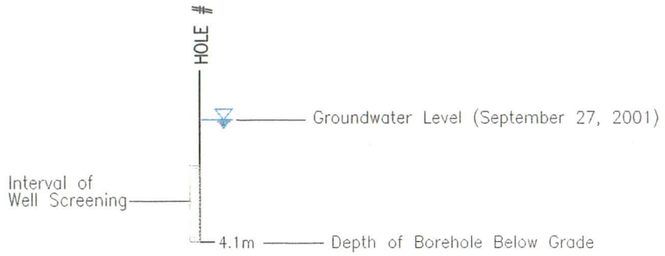
HEMMERA ENVIROCHEM HEMMERA ENVIROCHEM INC. Suite 350, 1190 Hornby Street Vancouver, BC V6Z 2K5	RISK ASSESSMENT BROOKS BROOK , ALASKA HIGHWAY, YT		
	SITE LAYOUT BROOKS BROOK, YT		
CLIENT: INDIAN & NORTHERN AFFAIRS CANADA	File No. 316-003.04	March 2002	FIGURE 2

316\RA-FIG2 6-3-

STRATIGRAPHY



DRAFT



HORIZONTAL SCALE:
1:150 (Approximate)
metres
0 3 6
VERTICAL SCALE EXAGGERATED 4X.

NOTE: See Figure ? for location of section.

HEMMERA ENVIROCHEM

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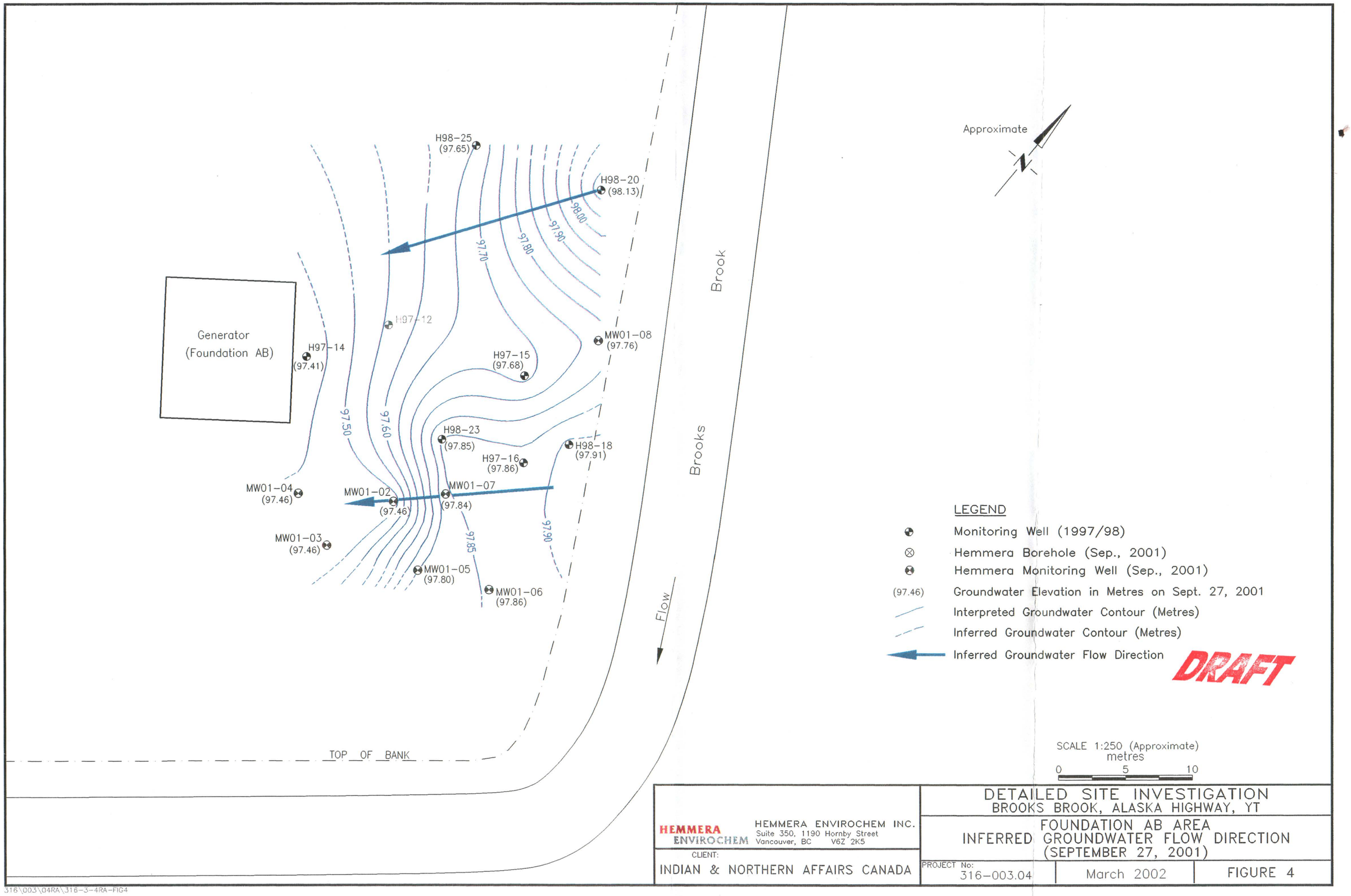
CLIENT:
INDIAN & NORTHERN AFFAIRS CANADA

RISK ASSESSMENT
BROOKS BROOK, ALASKA HIGHWAY, YT

FOUNDATION AB AREA
CROSS SECTION A-A'

PROJECT No: 316-003.04 | March 2002 | FIGURE 3

316\003\04RA-FEB02\316-3-4F.DGN



LEGEND

- Monitoring Well (1997/98)
- Hemmera Borehole (Sep., 2001)
- Hemmera Monitoring Well (Sep., 2001)
- (97.46) Groundwater Elevation in Metres on Sept. 27, 2001
- Interpreted Groundwater Contour (Metres)
- Inferred Groundwater Contour (Metres)
- Inferred Groundwater Flow Direction

DRAFT

SCALE 1:250 (Approximate)
metres
0 5 10

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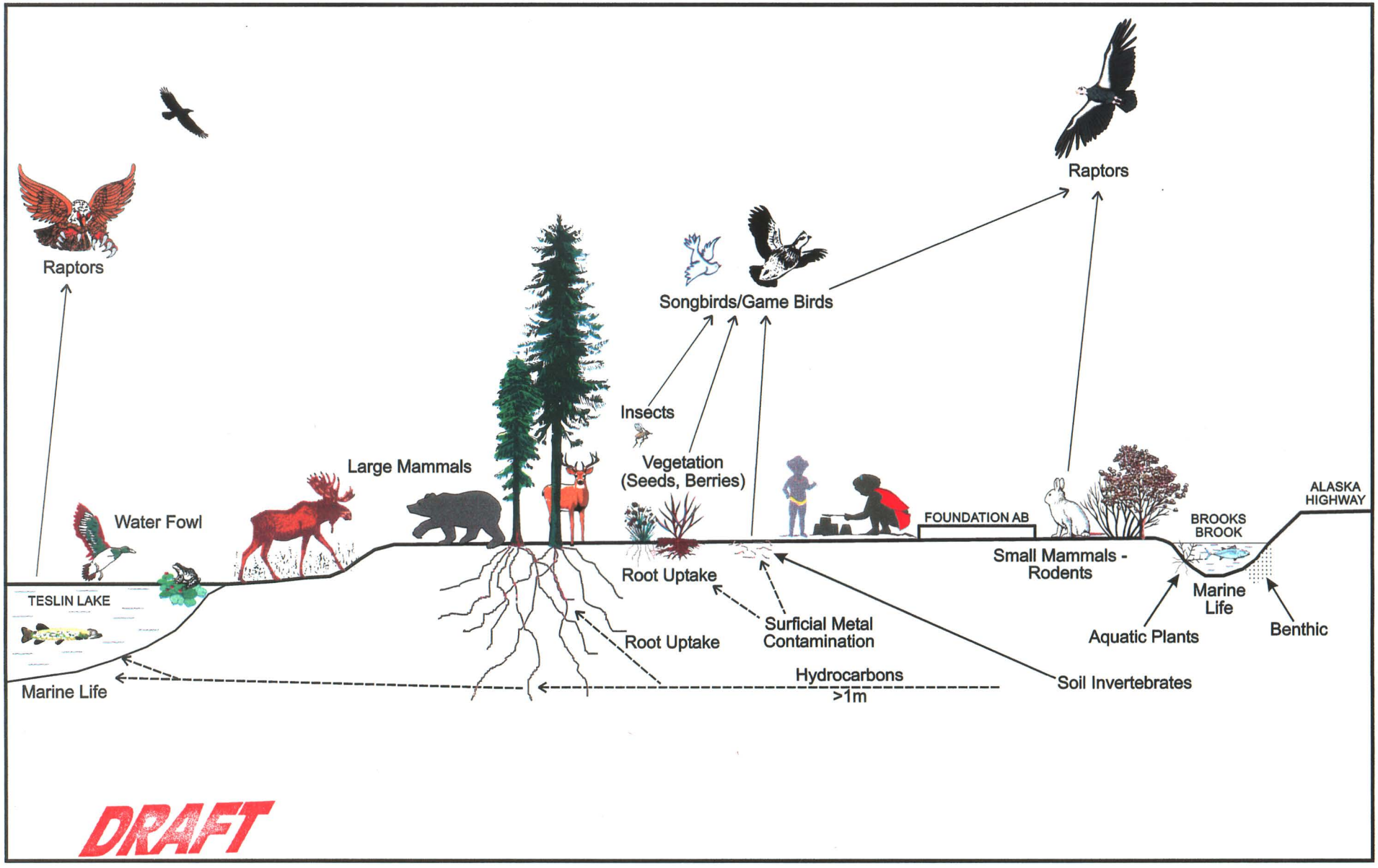
CLIENT:
INDIAN & NORTHERN AFFAIRS CANADA

DETAILED SITE INVESTIGATION
BROOKS BROOK, ALASKA HIGHWAY, YT
FOUNDATION AB AREA
INFERRED GROUNDWATER FLOW DIRECTION
(SEPTEMBER 27, 2001)

PROJECT No: 316-003.04 | March 2002 | FIGURE 4

316\003\04RA\316-3-4RA-FIG4



Note: The carnirvors (eg. bear, fox) and larger birds (eg. Raven, Magpie) will consume vegetation, mammals, marine life, insects, invertebrates, and carrion.

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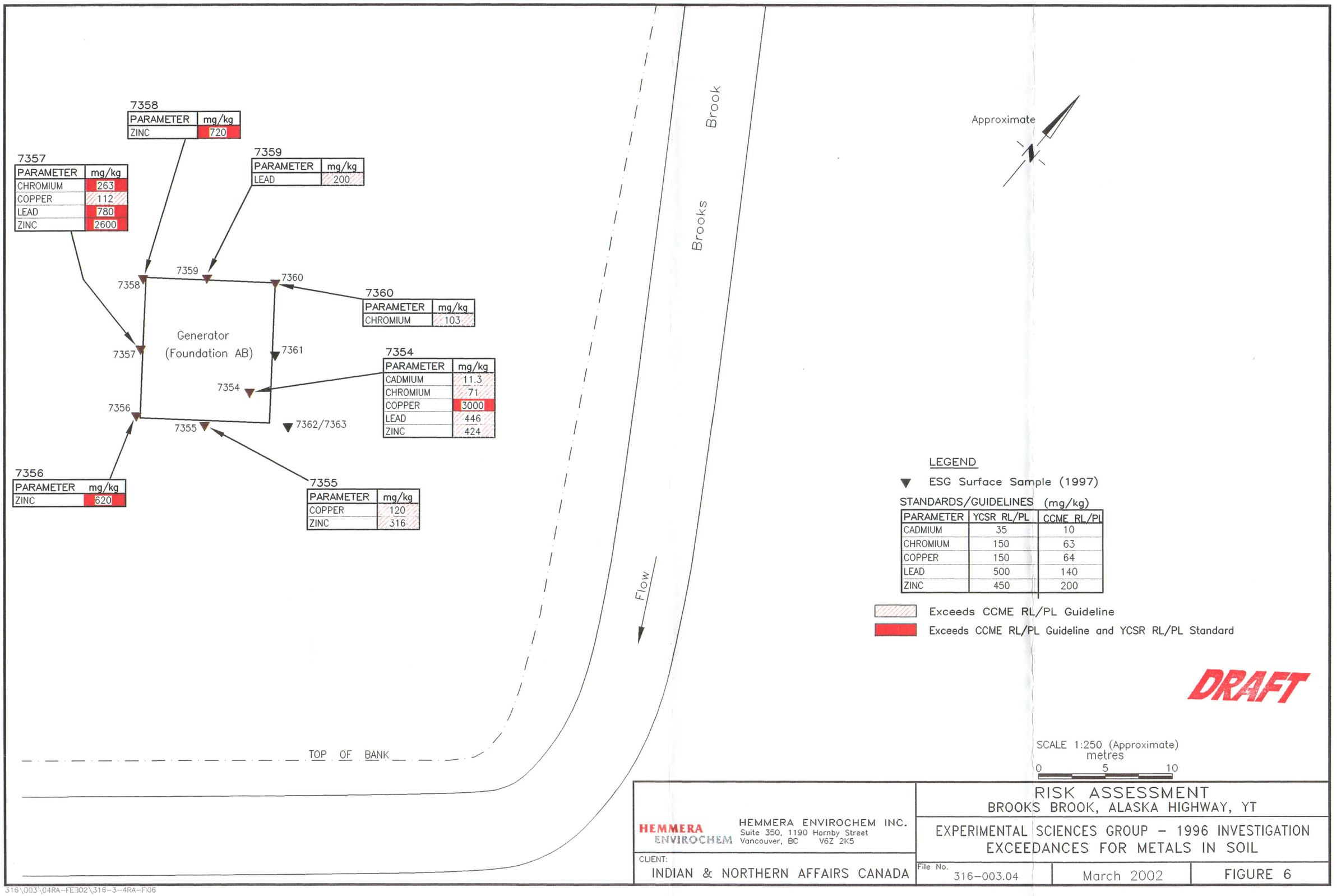
RISK ASSESSMENT
BROOKS BROOK, ALASKA HIGHWAY, YT

CONCEPTUAL DIAGRAM OF RECEIVING ENVIRONMENT & RECEPTORS

PROJECT No.		
316-003.04	March 2002	Figure 5



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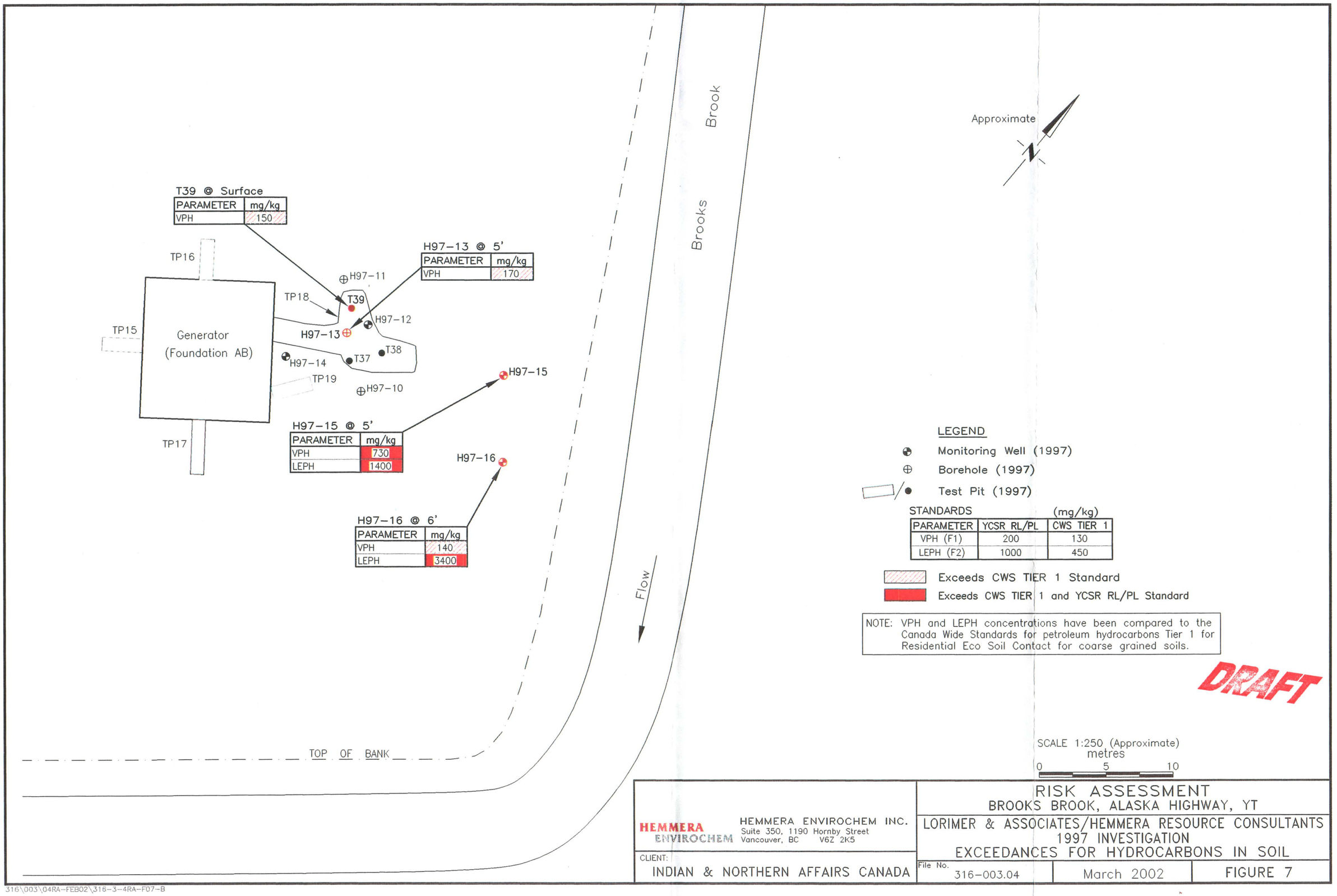
RISK ASSESSMENT
BROOKS BROOK, ALASKA HIGHWAY, YT

EXPERIMENTAL SCIENCES GROUP – 1996 INVESTIGATION
EXCEEDANCES FOR METALS IN SOIL

File No. 316-003.04 | March 2002 | FIGURE 6

316\003\04RA-FE302\316-3-4RA-F06



LEGEND

- Monitoring Well (1997)
- Borehole (1997)
- Test Pit (1997)

STANDARDS (mg/kg)

PARAMETER	YCSR RL/PL	CWS TIER 1
VPH (F1)	200	130
LEPH (F2)	1000	450

Exceeds CWS TIER 1 Standard

Exceeds CWS TIER 1 and YCSR RL/PL Standard

NOTE: VPH and LEPH concentrations have been compared to the Canada Wide Standards for petroleum hydrocarbons Tier 1 for Residential Eco Soil Contact for coarse grained soils.

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SCALE 1:250 (Approximate)
metres
0 5 10

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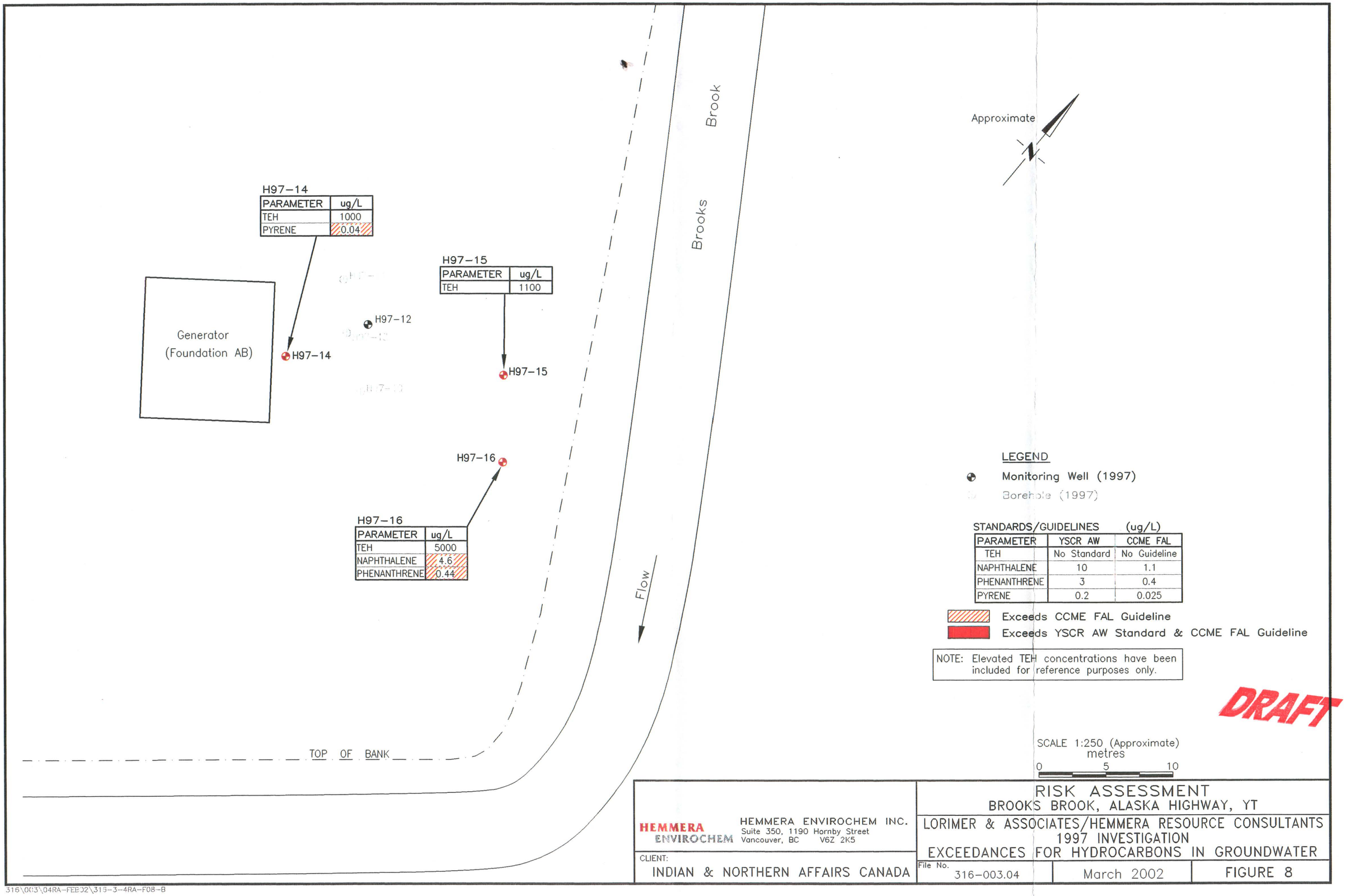
RISK ASSESSMENT
BROOKS BROOK, ALASKA HIGHWAY, YT

LORIMER & ASSOCIATES/HEMMERA RESOURCE CONSULTANTS
1997 INVESTIGATION
EXCEEDANCES FOR HYDROCARBONS IN SOIL

File No. 316-003.04 | March 2002 | FIGURE 7

316\003\04RA-FEB02\316-3-4RA-F07-B



LEGEND

- Monitoring Well (1997)
- Borehole (1997)

STANDARDS/GUIDELINES (ug/L)

PARAMETER	YSCR AW	CCME FAL
TEH	No Standard	No Guideline
NAPHTHALENE	10	1.1
PHENANTHRENE	3	0.4
PYRENE	0.2	0.025

Exceeds CCME FAL Guideline

Exceeds YSCR AW Standard & CCME FAL Guideline

NOTE: Elevated TEH concentrations have been included for reference purposes only.

DRAFT

SCALE 1:250 (Approximate)
metres
0 5 10

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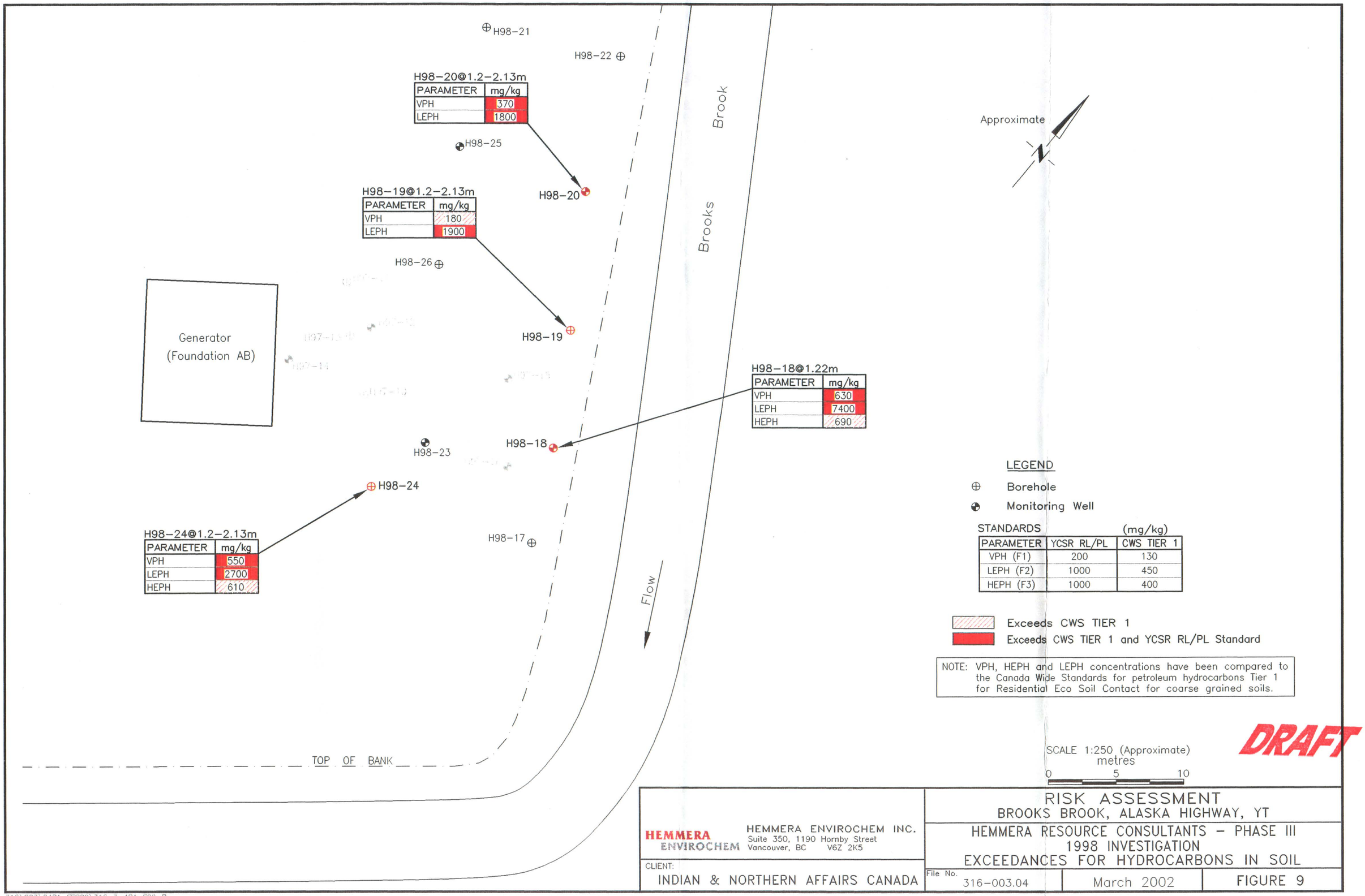
RISK ASSESSMENT
BROOKS BROOK, ALASKA HIGHWAY, YT

LORIMER & ASSOCIATES/HEMMERA RESOURCE CONSULTANTS
1997 INVESTIGATION
EXCEEDANCES FOR HYDROCARBONS IN GROUNDWATER

File No. 316-003.04 | March 2002 | FIGURE 8

316\003\04RA-FEED2\316-3-4RA-F08-B



LEGEND

- ⊕ Borehole
- ◓ Monitoring Well

STANDARDS (mg/kg)

PARAMETER	YCSR RL/PL	CWS TIER 1
VPH (F1)	200	130
LEPH (F2)	1000	450
HEPH (F3)	1000	400

Exceeds CWS TIER 1

Exceeds CWS TIER 1 and YCSR RL/PL Standard

NOTE: VPH, HEPH and LEPH concentrations have been compared to the Canada Wide Standards for petroleum hydrocarbons Tier 1 for Residential Eco Soil Contact for coarse grained soils.

DRAFT

SCALE 1:250 (Approximate)
metres
0 5 10

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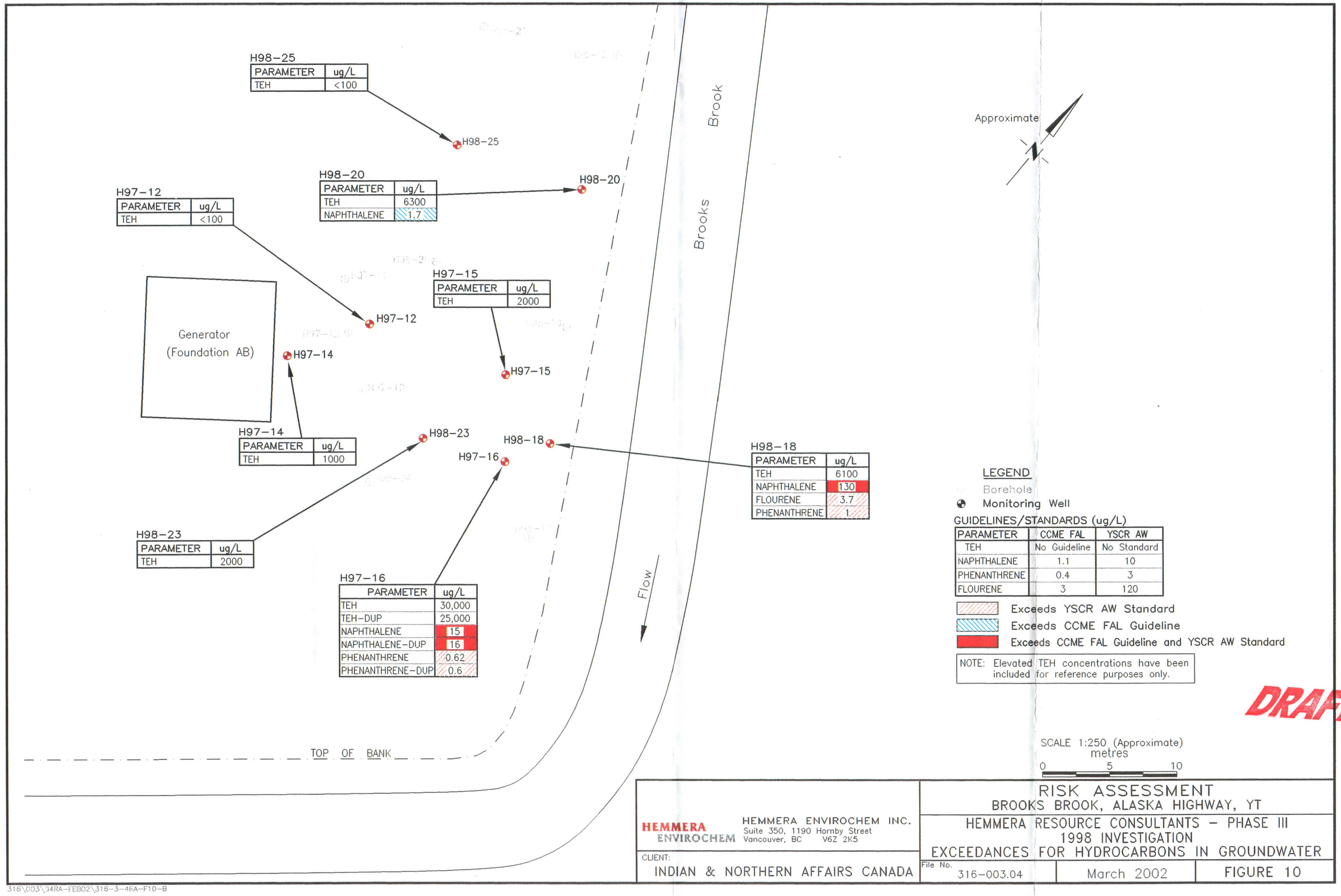
Vancouver, BC V6Z 2K5

CLIENT:
INDIAN & NORTHERN AFFAIRS CANADA

RISK ASSESSMENT
BROOKS BROOK, ALASKA HIGHWAY, YT
HEMMERA RESOURCE CONSULTANTS – PHASE III
1998 INVESTIGATION
EXCEEDANCES FOR HYDROCARBONS IN SOIL

File No. 316-003.04 | March 2002 | FIGURE 9

316\003\04RA-FEB02\316-3-4RA-F09-B



LEGEND

Borehole

Monitoring Well

GUIDELINES/STANDARDS (ug/L)

PARAMETER	CCME FAL	YSCR AW
TEH	No Guideline	No Standard
NAPHTHALENE	1.1	10
PHENANTHRENE	0.4	3
FLOURENE	3	120

Exceeds YSCR AW Standard

Exceeds CCME FAL Guideline

Exceeds CCME FAL Guideline and YSCR AW Standard

NOTE: Elevated TEH concentrations have been included for reference purposes only.

DRAFT

SCALE 1:250 (Approximate)
metres
0 5 10

HEMMERA ENVIROCHEM

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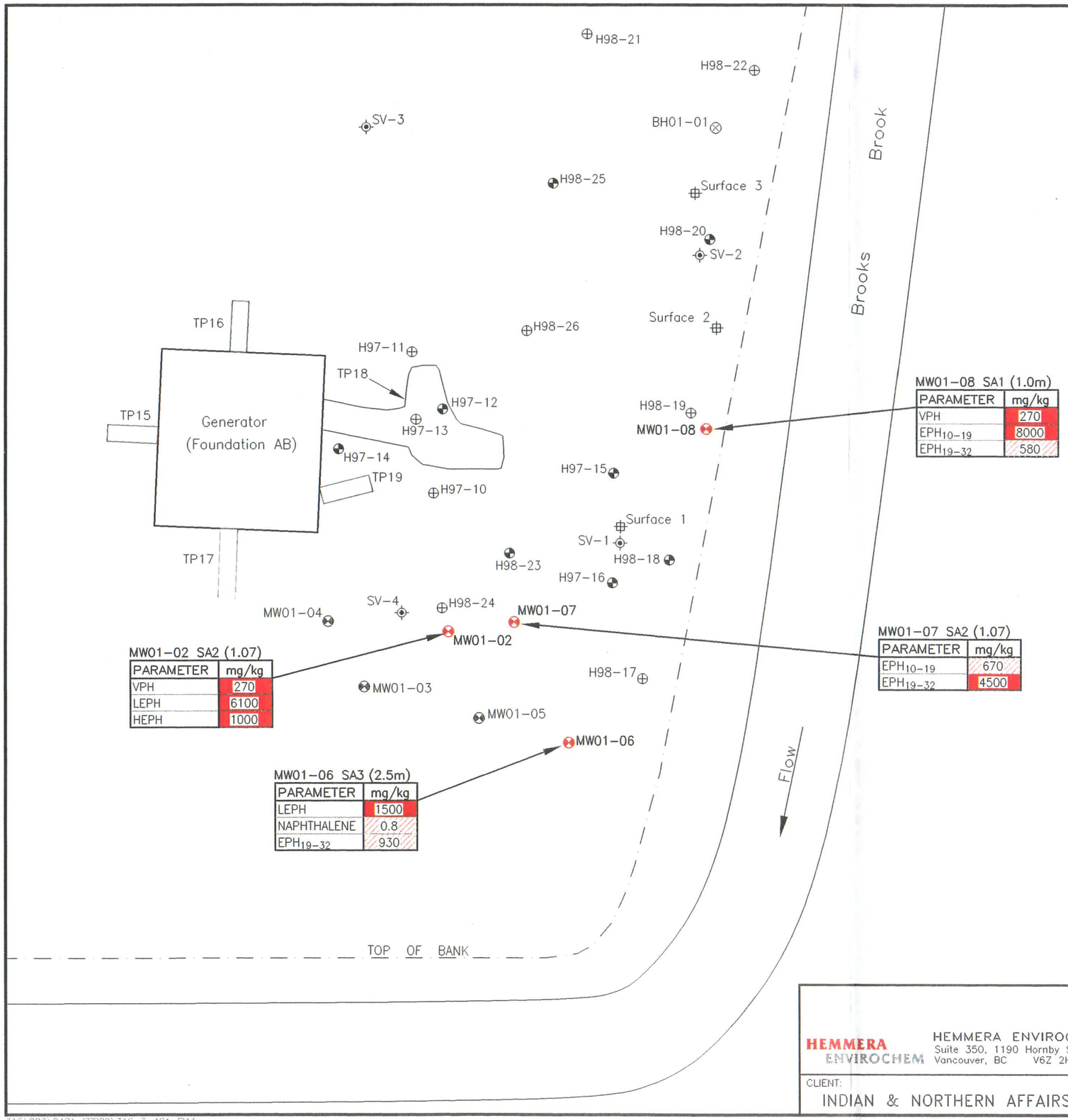
Vancouver, BC V6Z 2K5

CLIENT:
INDIAN & NORTHERN AFFAIRS CANADA

RISK ASSESSMENT
BROOKS BROOK, ALASKA HIGHWAY, YT
HEMMERA RESOURCE CONSULTANTS - PHASE III
1998 INVESTIGATION
EXCEEDANCES FOR HYDROCARBONS IN GROUNDWATER

File No. 316-003.04 | March 2002 | FIGURE 10

316\003\04RA-FEB02\316-3-4RA-F10-B



MW01-08 SA1 (1.0m)

PARAMETER	mg/kg
VPH	270
EPH_{10-19}	8000
EPH_{19-32}	580

MW01-07 SA2 (1.07)

PARAMETER	mg/kg
EPH_{10-19}	670
EPH_{19-32}	4500

MW01-02 SA2 (1.07)

PARAMETER	mg/kg
VPH	270
LEPH	6100
HEPH	1000

MW01-06 SA3 (2.5m)

PARAMETER	mg/kg
LEPH	1500
NAPHTHALENE	0.8
EPH_{19-32}	930

LEGEND

- Monitoring Well (1997/98)
- Borehole (1997/98)
- Hemmera Borehole (Sep., 2001)
- Hemmera Monitoring Well (Sep., 2001)
- Hemmera Vapour Probe (Sep., 2001)
- Hemmera Surface Sample (Sep., 2001)
- (1.2m) Average Depth of Sample

STANDARDS [mg/kg]

PARAMETER	YCSR RL/PL	CWS TIER 1
VPH (F1)	200	130
LEPH (F2)	1000	450
HEPH (F3)	1000	400

VPH Volatile Petroleum Hydrocarbons
LEPH Light Extractable Petroleum Hydrocarbons
HEPH Heavy Extractable Petroleum Hydrocarbons
NOTE: EPH_{10-19} and EPH_{19-32} have been compared to LEPH and HEPH Standards and Canada Wide Standards for F2 and F3.

Exceeds CWS TIER 1 Standard
Exceeds CWS TIER 1 and YCSR RL/PL Standard

NOTE: VPH, HEPH and LEPH concentrations have been compared to the Canada Wide Standards for petroleum hydrocarbons Tier 1 for Residential Eco Soil Contact for coarse grained soils.

SCALE 1:250 (Approximate)
metres
0 5 10

DRAFT

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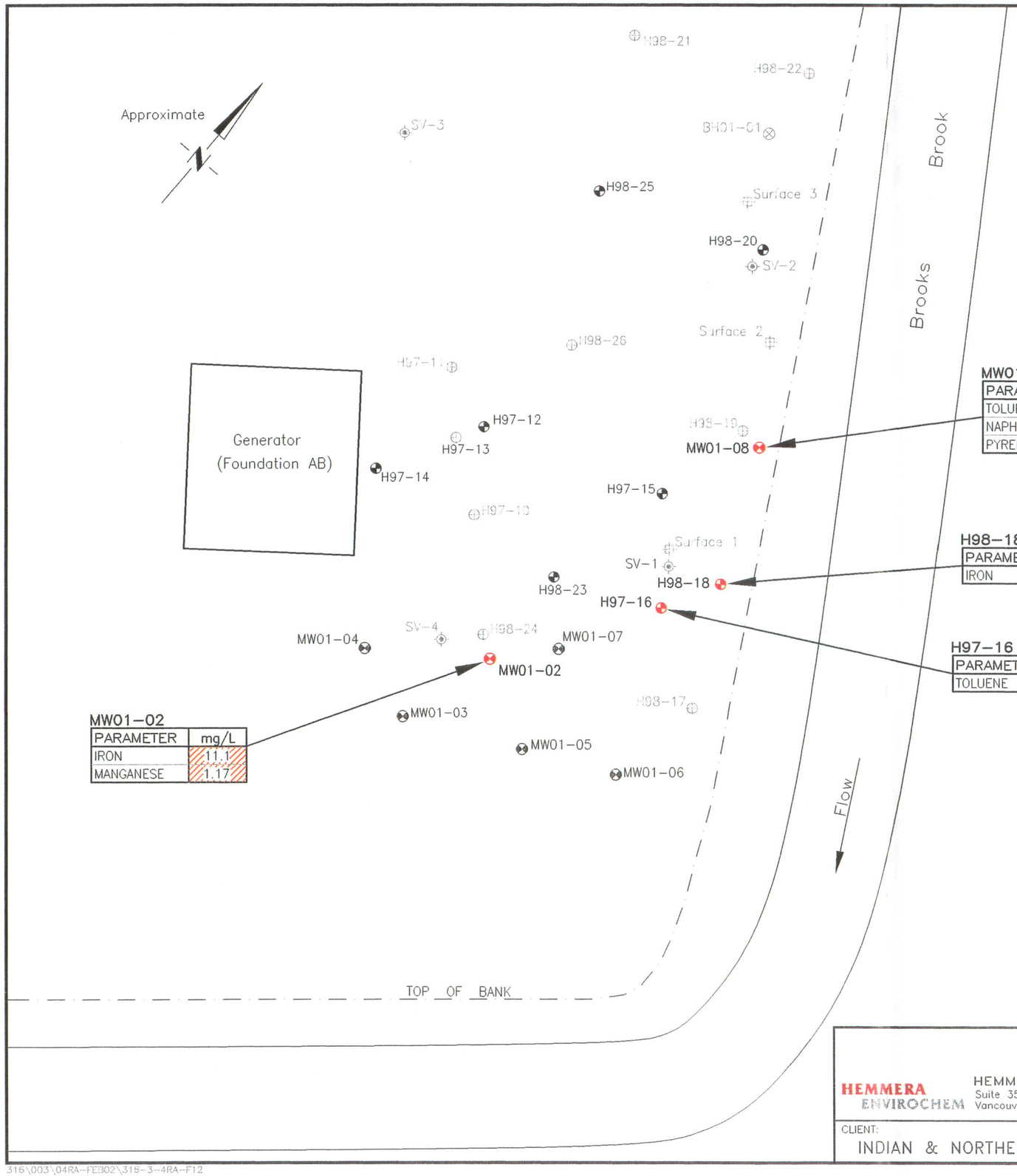
HEMMERA ENVIROCHEM INC.
2001 DETAILED SITE INVESTIGATION
EXCEEDANCES FOR HYDROCARBONS IN SOIL

File No. 316-003.04 | March 2002 | FIGURE 11

316\003\04RA-FEB02\316-3-4RA-FI11



BC CSR $LEPH_W$ AW COMPARISON

WELL ID	LEPH CONCENTRATION (ug/L)
H97-7	1800
H97-15	1500
H98-18	960
H98-20	1100
MW01-02	970
MW01-03	2500
MW01-04	750
MW01-07	610
MW01-08	1900
BC CSR AW Standard	500

LEPH Light Extractable Petroleum Hydrocarbons

LEGEND

- Monitoring Well (1997/98)
- Borehole (1997/98)
- Hemmera Borehole (Sep., 2001)
- Hemmera Monitoring Well (Sep., 2001)
- Hemmera Vapour Probe (Sep., 2001)
- Hemmera Surface Sample (Sep., 2001)

STANDARDS/GUIDELINES (ug/L)

PARAMETER	YCSR AW	CCME FAL
TOLUENE	3000	2
NAPHTHALENE	10	1.1
PYRENE	0.2	0.025
(mg/L)		
IRON	3	3
MANAGANESE	1	ng

Exceeds YCSR Groundwater Aquatic Life Standard

Exceeds CCME Freshwater Aquatic Life Standard (Ambient Waters)

NOTE: See tables for analytical details.

SCALE 1:250 (Approximate)
metres
0 5 10

DRAFT

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Vancouver, BC V6Z 2K5

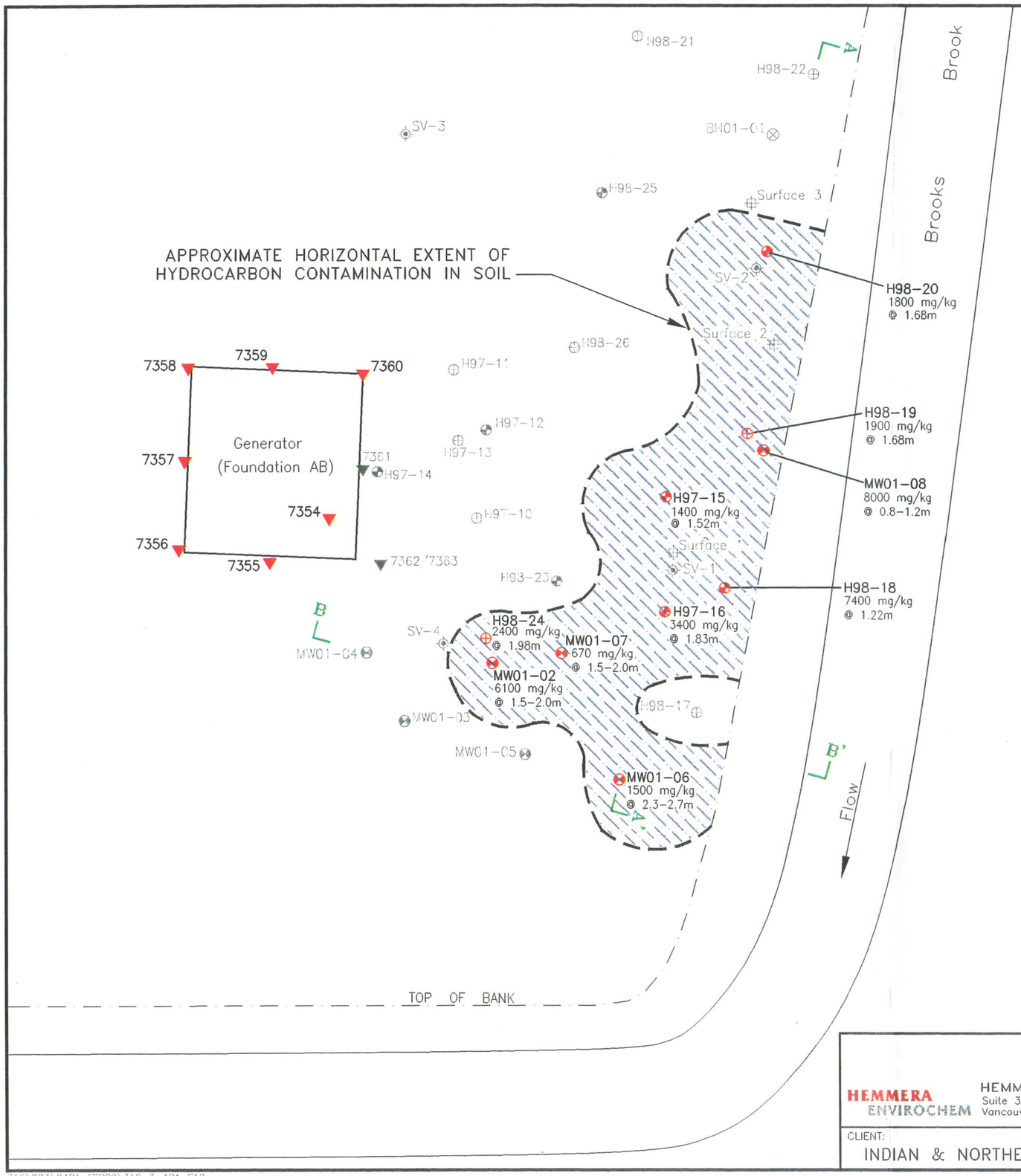
CLIENT:
INDIAN & NORTHERN AFFAIRS CANADA

RISK ASSESSMENT
BROOKS BROOK, ALASKA HIGHWAY, YT

HEMMERA ENVIROCHEM INC. – 2001 DETAILED SITE INVESTIGATION
EXCEEDANCES FOR
METALS & HYDROCARBONS IN GROUNDWATER

File No. 316-003.04 | March 2002 | FIGURE 12

316\003\04RA-FE302\316-3-4RA-F12



Approximate

LEGEND

- Monitoring Well (1997/98)
- Borehole (1997/98)
- Hemmera Borehole (Sep., 2001)
- Hemmera Monitoring Well (Sep., 2001)
- Hemmera Vapour Probe (Sep., 2001)
- Hemmera Surface Sample (Sep., 2001)
- Surface Soil Sample (1966)
- Sample Exceeded Standard and/or Guideline for Light Extractable Petroleum Hydrocarbons in Soil

B B' Location of Cross Section
- See Figure 2 & 14A for Cross Section A–A'
- See Figure 14B for Cross Section B–B'

NOTE: See tables for analytical details.

SCALE 1:250 (Approximate)
metres
0 5 10

DRAFT

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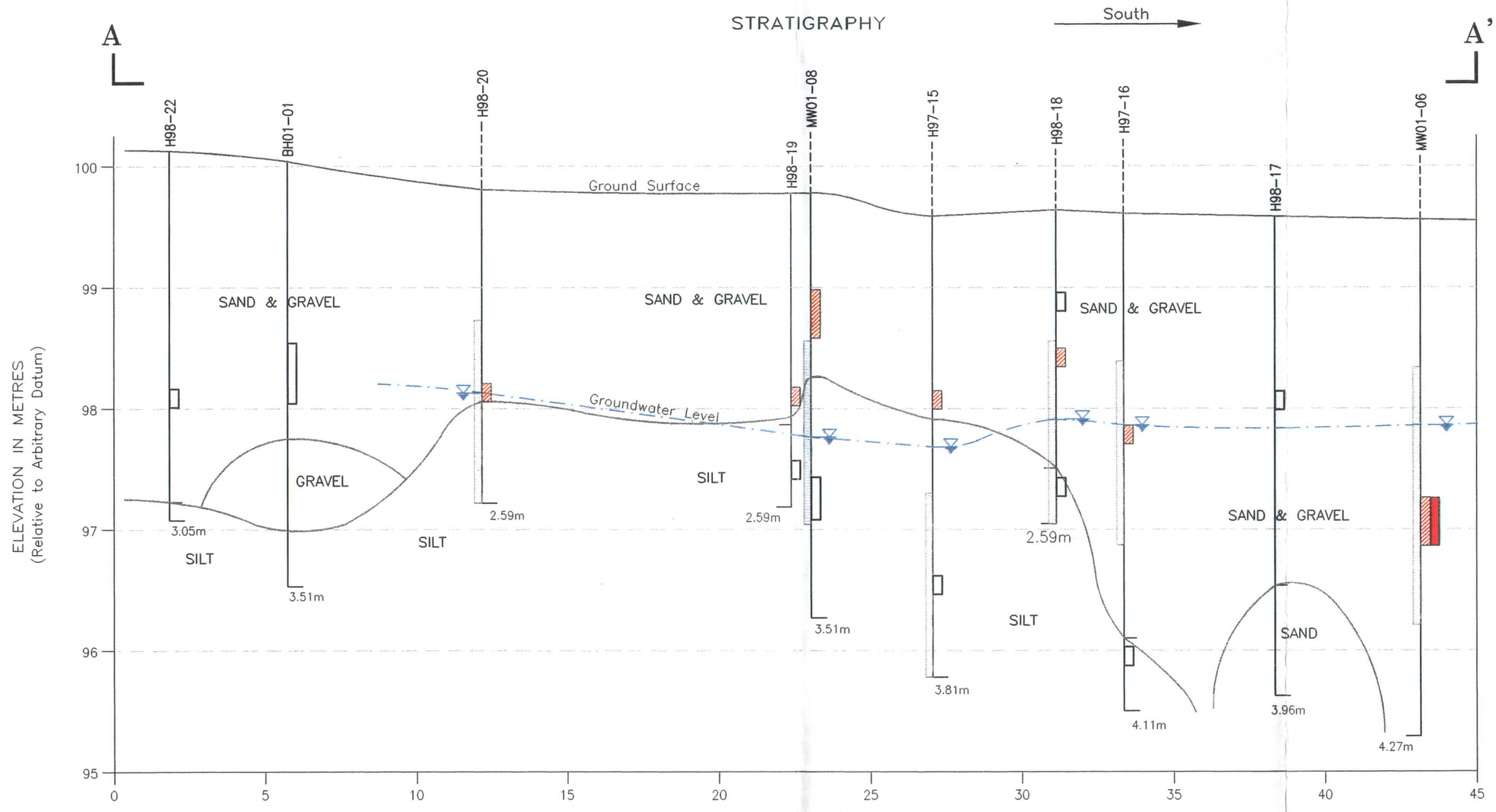
BROOKS BROOK, ALASKA HIGHWAY, YT

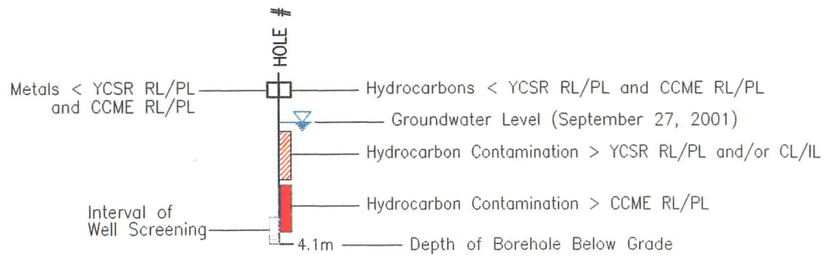
HEMMERA ENVIROCHEM INC.
2001 DETAILED SITE INVESTIGATION
HORIZONTAL EXTENT OF IMPACTED SOIL

File No. 316-003.04 | March 2002 | FIGURE 13

316\003\04RA-FEB02\316-3-4RA-F12

STRATIGRAPHY





NOTE: SEE TABLES FOR DETAILS OF ANALYSIS.

HORIZONTAL SCALE:
1:150 (Approximate)
metres

0 3 6

VERTICAL SCALE EXAGGERATED 4X.

NOTE: See Figure 13 for location of section.

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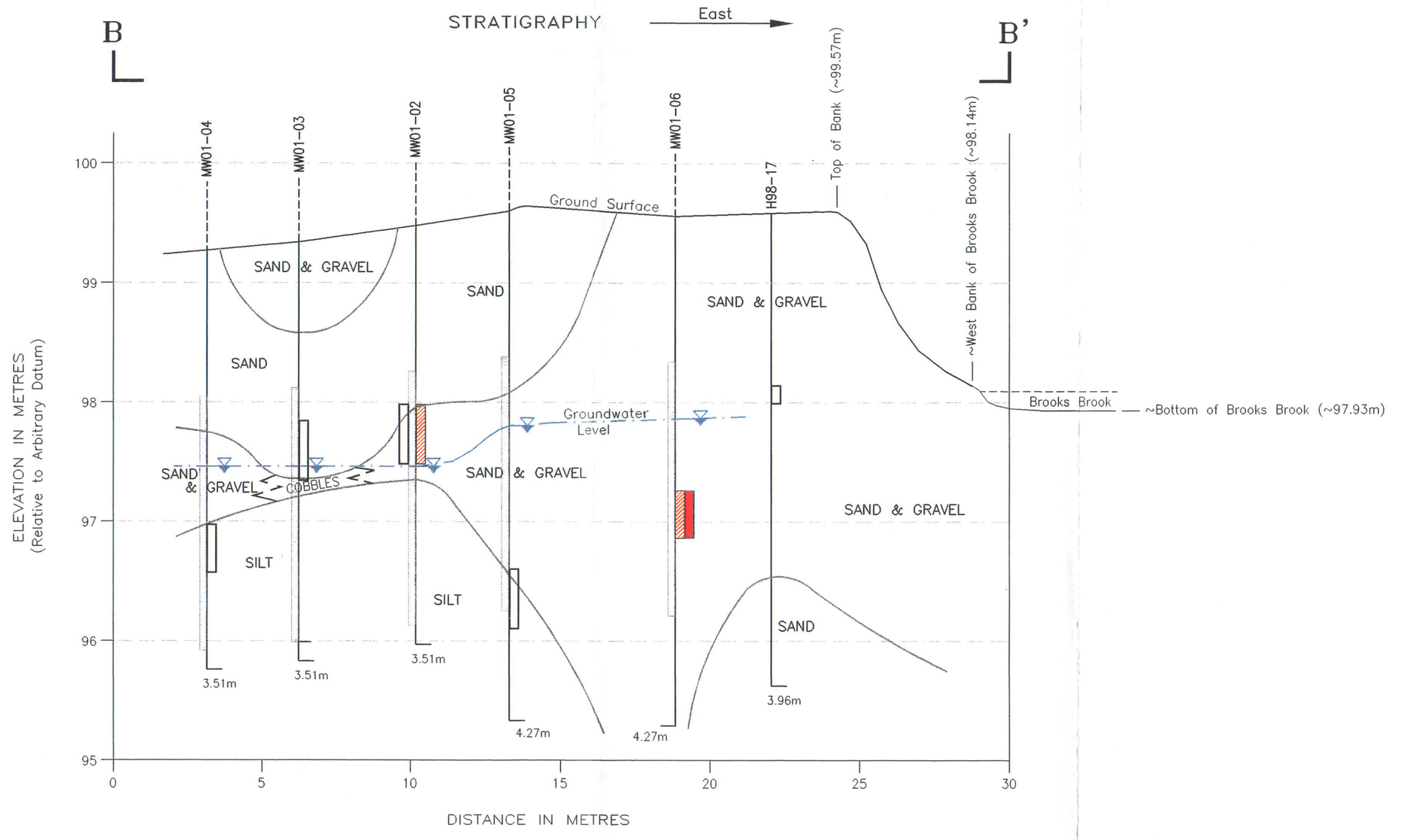
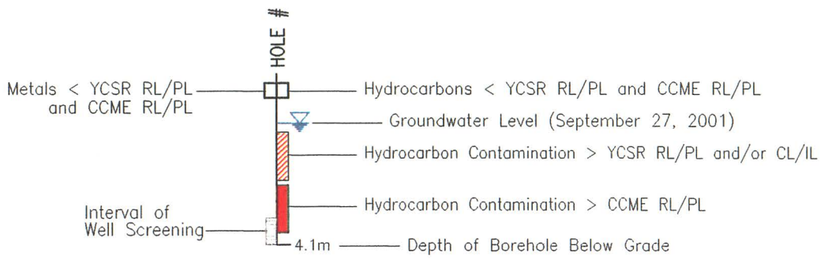
RISK ASSESSMENT
BROOKS BROOK, ALASKA HIGHWAY, YT

EXTENT OF HYDROCARBON IMPACTED SOIL
CROSS SECTION A–A'

PROJECT No: 316–003.04 | March 2002 | FIGURE 14A

316\003\04RAFEB02\316-4RA-FIG14A





NOTE: SEE TABLES FOR DETAILS OF ANALYSIS.

DRAFT

HORIZONTAL SCALE:
1:150 (Approximate)
metres
0 3 6
VERTICAL SCALE EXAGGERATED 4X.

NOTE: See Figure 13 for location of section.

HEMMERA ENVIROCHEM

HEMMERA ENVIROCHEM INC.
Suite 350, 1190 Hornby Street
Vancouver, BC V6Z 2K5

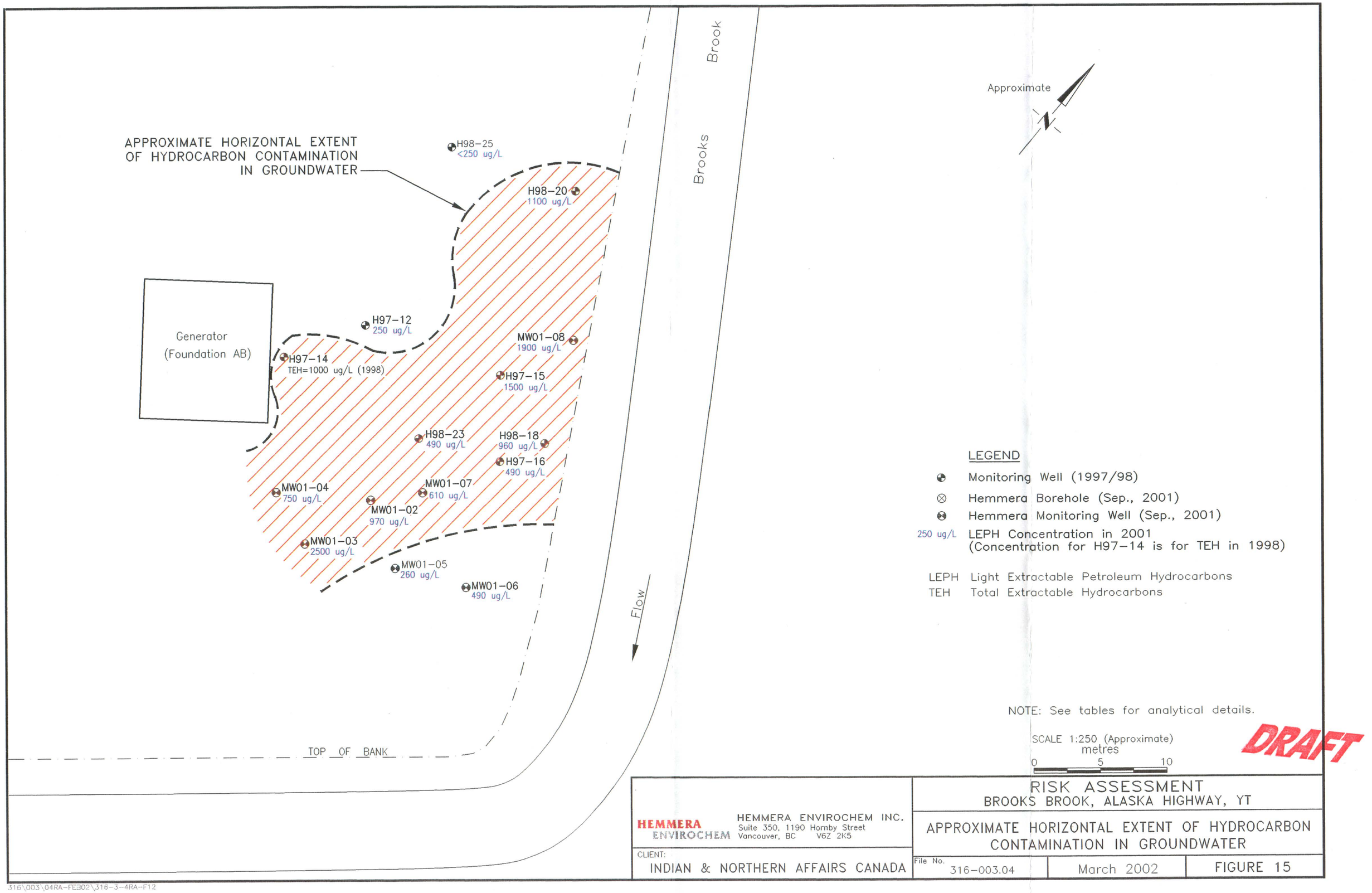
CLIENT:
INDIAN & NORTHERN AFFAIRS CANADA

RISK ASSESSMENT
BROOKS BROOK, ALASKA HIGHWAY, YT

EXTENT OF HYDROCARBON IMPACTED SOIL CROSS SECTION B-B'

PROJECT No: 316-003.04 | March 2002 | FIGURE 14B

316\003\04RAFEB02\316-4RA-FIG14B



HEMMERA ENVIROCHEM HEMMERA ENVIROCHEM INC. Suite 350, 1190 Hornby Street Vancouver, BC V6Z 2K5	RISK ASSESSMENT BROOKS BROOK, ALASKA HIGHWAY, YT	
CLIENT: INDIAN & NORTHERN AFFAIRS CANADA	APPROXIMATE HORIZONTAL EXTENT OF HYDROCARBON CONTAMINATION IN GROUNDWATER	
	File No. 316-003.04	March 2002 / FIGURE 15

316\003\04RA-FEB02\316-3-4RA-F12

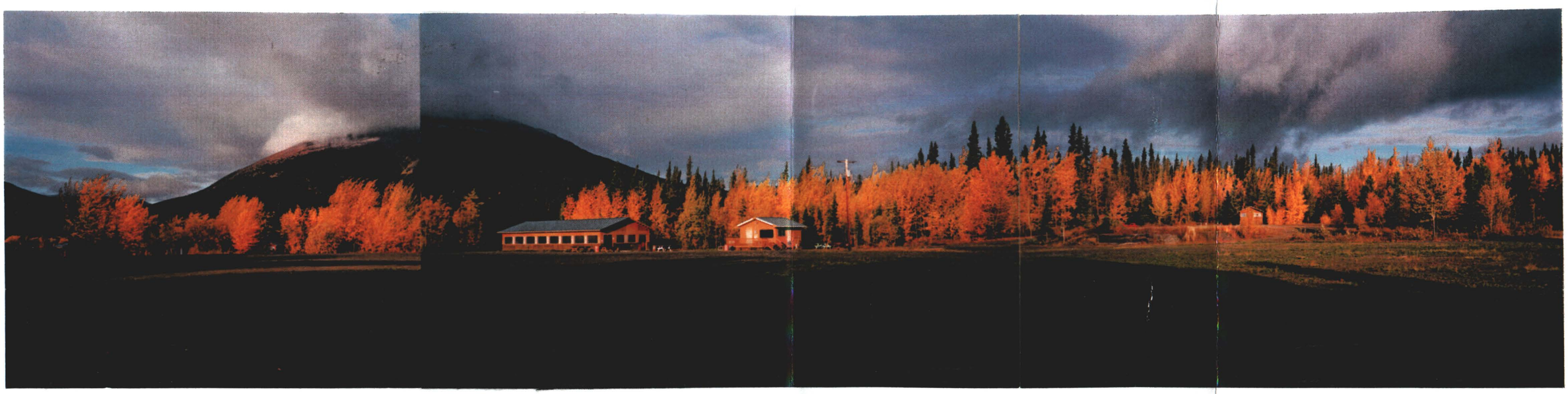


PHOTO 1: View of the Brooks Brook property looking west towards main site area.

File: 316-003.04
CLIENT:
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Site: Brooks Brook, Alaska Highway, YT

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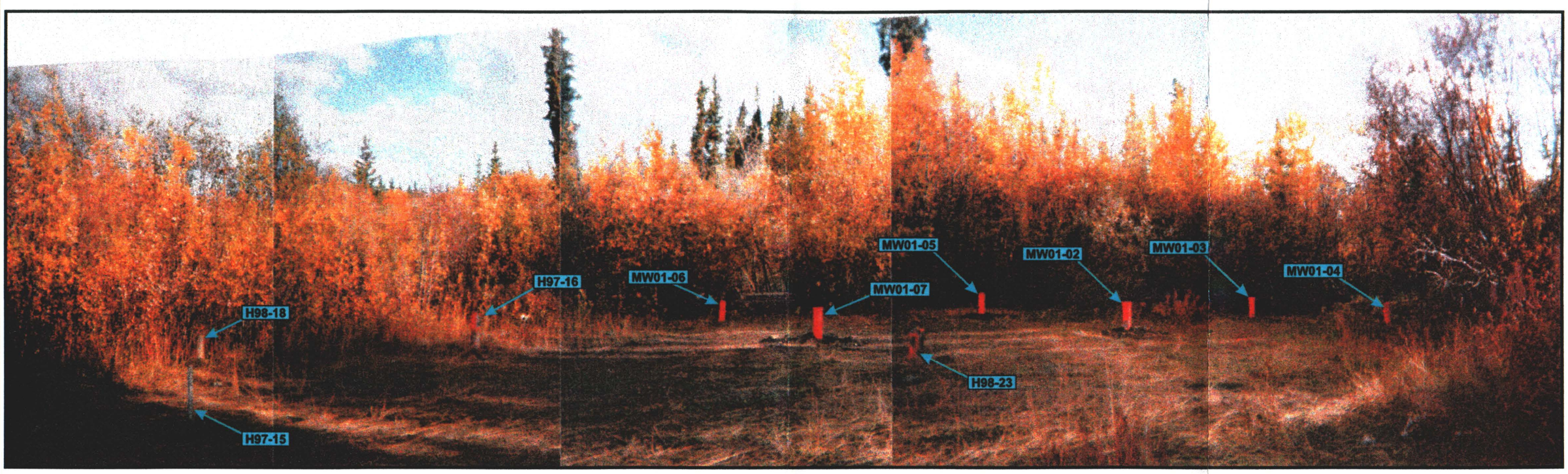

PHOTO 2: View of the subject area looking southeast. Brooks Brook is located just behind the brush located on the perimeter of the clearing.

File: 316-003.04
CLIENT:
INDIAN & NORTHERN AFFAIRS CANADA

Site: Brooks Brook, Alaska Highway, YT

HEMMERA ENVIROCHEM

HEMMERA ENVIROCHEM INC.

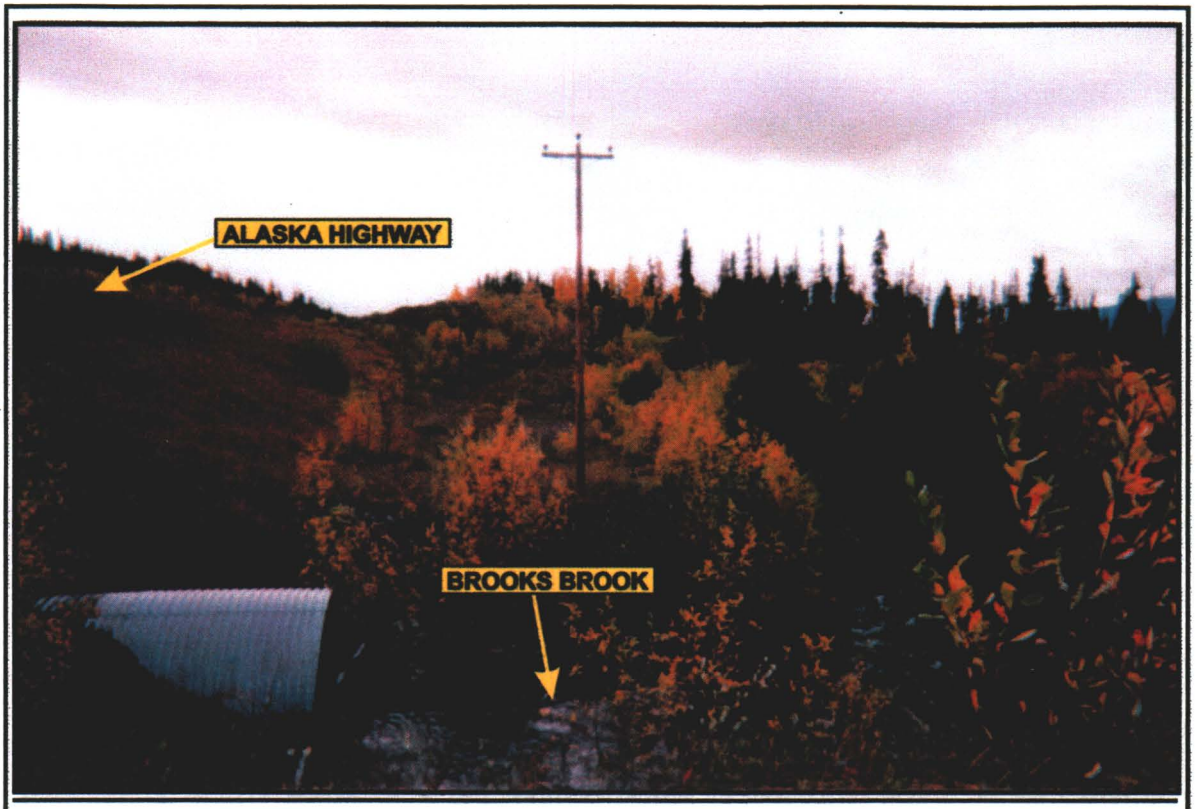

PHOTO 3: View of the topography sloping from the Alaska Highway to Brooks Brook.

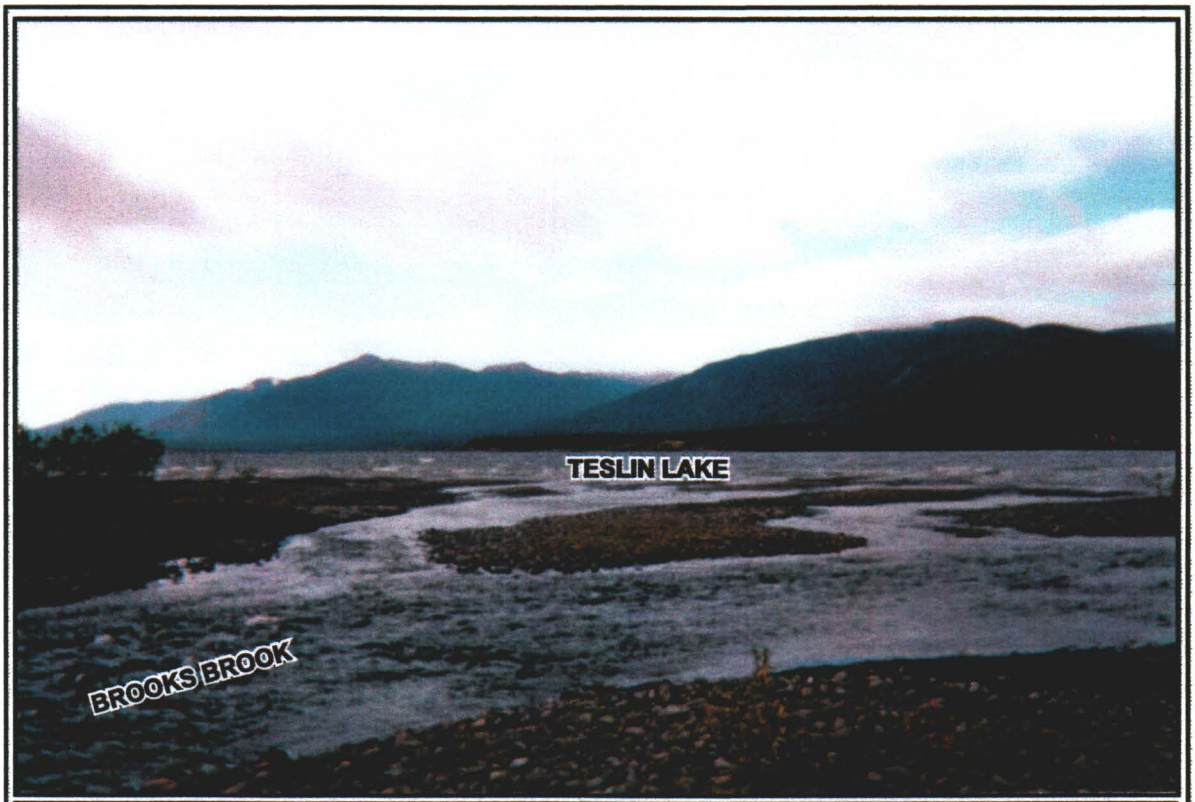

PHOTO 4: View of Brooks Brook flowing into Teslin Lake, approximately 300m west of the subject site.

PHOTO 5: Heavy vegetation along the banks of Brooks Brook.

Table I
Statistical Summary of Chemical Parameters in Excess of the YSCR RL/PL Standards and CCME RL/PL Guidelines for Soil

PARAMETER	YCSR RL/PL	CCME RL/PL	CWS Tier 1	No. of Samples	Range (mg/kg) Min	Range (mg/kg) Max	Mean (mg/kg)	Median (mg/kg)	# > YSCR	# > CCME	# > CWS	95th Percentile mg/kg
PAHs												
Naphthalene	5	0.6	ns	7	0.025	0.8	0.33	0.25	0	2	na	0.77
MAHs												
Volatile Pet. Hydrocarbons (F1)	200	ng	130	44	5	730	100.73	72.36	6	na	10	532
LEPH-uncorrected for PAH's (F2)	1000*	ng	450	44	125	8000	895.34	510.17	9	na	10	5830
HEPH-uncorrected for PAH's (F3)	1000*	ng	400	44	125	4500	307.5	216.25	2	na	6	906
Metals												
Cadmium Cd	8 (pH6.5- 7.0)*† 35 ‡‡	10	ns	15	0.125	11.3	1.59	0.5	0	1	na	8.43
Chromium Cr	60*	64	ns	15	19	263	61.73	49	3	3	na	151
Copper Cu	150‡	63	ns	15	15	3000	234.87	28	1	3	na	984
Lead Pb	500 ‡‡	140	ns	15	5	780	123.6	18	1	3	na	546
Zinc Zn	450‡	200	ns	15	23	2600	358.27	82	3	5	na	1284

Footnotes:

All values in mg/kg (ppm)

YCSR RL/PL - Yukon Contaminated Sites Regulation Residential/Park Land Standards

CCME RL/PL - Canadian Council of Ministers of the Environment Residential/Park Land Guidelines

CWS Teir 1 - Canada Wide Standards for Petroeum Hydrocarbons, Teir 1 for eco soil contact of surface soils

* YCSR - Groundwater Flow to Surface Water used by Aquatic Life

‡ YCSR - Toxicity to Soil Invertebrates and Plants

† YCSR - Standard varies with pH

‡‡ YCSR - Intake of Contaminated Soil

ns = No Standard

ng = No Guideline

Table II

Statistical Summary of Chemical Parameters in Excess of YCSR AW Standards and CCME FAL Guidelines for Groundwater

Parameter	YCSR AW	CCME FAL	No. of Samples	Range (ug/L) Min	Range (ug/L) Max	Mean (ug/L)	Median (ug/L)	# > YSCR	# > CCME	95th Percentile (ug/L)
PAHs										
Naphthalene	10	1.1	24	0.15	130	7.59	0.15	4	6	15.85
Fluorene	120	3	24	0.025	3.7	0.54	0.025	0	1	2.09
Phenanthrene	3	0.4	24	0.025	1	0.17	0.025	0	5	0.69
Pyrene	0.2	0.025	24	0.01	0.2	0.02	0.01	1	2	0.09
MAHs										
Toluene	3000	2	29	0.05	24	1.14	0.05	0	2	2.48
VPHs	ns 1500*	ng	15	50	470	124.67	50	na	na	323
Extractable Hydrocarbons										
TEH	ns	ng	27	50	30,000	4071.40	1000	na	na	19390
LEPH	ns 500*	ng	15	125	2500	923.67	780	na	na	2080
HEPH	ns	ng	15	125	420	155	125	na	na	322
Dissolved Metals										
Dissolved Iron Fe	3	0.3	4	11.1	13.1	12.1	12.1	4	4	13.1
Dissolved Manganese Mn	1	ng	4	0.6	1.17	0.88	0.875	2	2	1.167

Footnoetes:

YCSR RL/PL - Yukon Contaminated Sites Regulation Residential/Park Land Standards

CCME RL/PL - Canadian Council of Ministers of the Environment Residential/Park Land Guidelines

ns = no standard

ng = no guideline

* = British Columbia Contaminated Sites Regulation Aquatic life Standards (AW) provided for comparison purposes only

Table III. Summary of Soil Vapour Survey Conducted During The Hemmera Envirochem Detailed Site Investigation

Brooks Brook Risk Assessment

TABLE D1: SOIL VAPOUR SURVEY DETAILS				
Sample Location	Location	Depth of rod below grade (m)	Length of Screened Section (m)	Air pump operating time (min)
SV#1	Vicinity of H98-18 and H97-16	0.4	0.25	348
SV#2	Vicinity of H98-20	0.45	0.25	321
SV#3 (background)	West of H98-25	0.45	0.25	227
SV#4	Vicinity of MW01-02	0.45	0.25	44

TABLE D2: SOIL VAPOUR RESULTS (ug)					
Sample Location	Benzene	Toluene	Ethylbenzene	Xylenes	Total Hydrocarbons
SV#1	<0.5	2.7	1.7	1.8	24.5
SV#2	<0.5	4.1	<0.5	1.8	33.6
SV#3	<0.5	3.0	<0.5	0.6	45.6
SV#4	<0.5	<0.5	<0.5	<0.5	<5

TABLE D3: TOTAL HYDROCARBON CONCENTRATION CALCULATION				
Sample Location	Time Operated (min)	Flow Rate (l/min)	Total Hydrocarbons (ug)	Concentration (ug/L)
SV#1	348	0.2065	24.5	0.341
SV#2	321	0.2065	33.6	0.507
SV#3 (background)	227	0.2065	45.6	0.973
SV#4	44	0.2065	<5	<0.55

TABLE D4: BTEX CONCENTRATIONS IN SOIL VAPOUR (ug/L or mg/m^3)				
	Benzene	Toluene	Ethylbenzene	Xylenes
SV#1	<0.007	0.038	0.024	0.025
SV#2	<0.008	0.062	<0.008	0.027
SV#3 (background)	<0.01	0.065	<0.01	0.013
SV#4	<0.055	<0.055	<0.055	<0.055
Yukon WCB 8-hour exposure	32	375	435	435

Table IV
Statistical Summary of Chemical Parameters in Excess of YSCR Soil Standards and CCME Soil Guidelines for the Protection of Human Health

PARAMETER	YCSR	CCME RL/PL	CWS Tier 1	No. of Samples	Range (mg/kg) Min	Range (mg/kg) Max	Mean (mg/kg)	Median (mg/kg)	# > YSCR	# > CCME	# > CWS	95th Percentile mg/kg
PAHs												
Naphthalene	5 *(1)*	0.6	ns	7	0.025	0.8	0.33	0.25	0	2	na	0.77
MAHs												
Volatile Pet. Hydrocarbons (F1)	200 *(1)*	ng	15,000 *(4)* > 30,000 *(5)*	44	5	730	100.73	72.36	6	na	0	532
LEPH-uncorrected for PAH's (F2)	1000 *(2)*	ng	8000 *(4)*	44	125	8000	895.34	510.17	9	na	0	5830
HEPH-uncorrected for PAH's (F3)	1000 *(2)*	ng	18,000 *(4)* > 30,000 *(5)*	44	125	4500	307.5	216.25	2	na	0	906
Metals												
Cadmium Cd	35 *(2)*	10	ns	15	0.125	11.3	1.59	0.5	0	1	na	8.43
Chromium Cr	150 *(3)*	64	ns	15	19	263	61.73	49	1	3	na	151
Copper Cu	15,000 *(4)*	63	ns	15	15	3000	234.87	28	0	3	na	984
Lead Pb	500 *(4)*	140	ns	15	5	780	123.6	18	1	3	na	546
Zinc Zn	10,000 *(4)*	200	ns	15	23	2600	358.27	82	0	5	na	1284

Footnotes:

All values in mg/kg (ppm)

YCSR - Yukon Contaminated Sites Regulation Residential/Park Land Standards

CCME RL/PL - Canadian Council of Ministers of the Environment Residential/Park Land Guidelines

CWS Teir 1 - Canada Wide Standards for Petroeum Hydrocarbons, Teir 1 for eco soil contact of surface soils

(1) Residential/Parkland generic standard

(2) Groundwater flow to surface water used by aquatic life

(3) Protection of human health

(4) Intake of contaminated soil

(5) Dermal Contact

ns = No Standard

ng = No Guideline

Table I. Terrestrial Plant Species Identified in the ESG 1997 Report

Common Name	Genus Species Name
High bush cranberry	*Viburnum trilobum*
Sphagnum moss	*Sphagnum spp.*
Labrador tea	*Ledum latifolium*
Leather leaf	*Chamaedaphne calyculata*
Wild rose	-
Lodge pole pine	*Pinus contorta*
Strawberry	*Fragaria sp.*
Perennial herb (Pussytoes)	*Antennaria rosea*
Fireweed	*Epilobium angustifolium*
Milk Vetch	*Astragalus alpinus*
Dandelion	*Taraxacum sp.*
Slender Wheatgrass	*Agropyron trachycailus*
Spike Trisetum	*Trisetum spicatum*
Yarrow	*Achillea millefolium*
Jacob's Ladder	*Polemonium spp.*
Bluegrass	*Poa spp.*
Slender Wheatgrass	*Elymus trachycaulus*
Common Bearberry	*Arctostaphylos uva-ursi*
Black Cottonwood	*Populus balsamifera*
White Spruce	*Picea glauca*
Common Dandelion	*Taraxacum officinale*
Common Horsetail	*Equisetum arvense*
Rosehip	-
Grasses	-
Lingonberry	*Vaccinium vitis-idaea*
Alaska Willow	*Salix alexensis*
Prickly Rose	*Rosa acicularis*
Trembling Aspen	*Populus tremuloides*
Vetch	*Vicia spp.*
Soapberry	*Shepherdia canadensis*
Arctic Lupin	*Lupinus arcticus*
Field Locoweed	*Oxytropis campestris*
Sedges	*Carex sp.*
(grass)	*Agropyrum violaceum*
Lichen	-
Prostrate juniper	*Juniperous communis*
Clover	*Trifolium epilobium anustifolium*
Alaska Plantain	*Plantago*
Bluejoint	*Calamagrotis*
Northern Scouring Rush	*Equisetum variegatum*

Willow	*Salix longistylix*
Tall Bluebells	*Mertensia paniculata*
Narrow-leaved Cotton Grass	*Eriophorum angustifolium*
Mushrooms	-
Hawksbeard	*Crepis spp.*
Sitka Alder	*Alnus crispa*
Twinflower	*Linnea borealis*
Kentucky Bluegrass	*Poa pratensis*
Raspberry	-
Sandwort	*Mohringia* fern
Villous Cinquefoil	*Potentilla*
Knotweed	*Polygonum macrophylum*
Gooseberry	*Ribes lacustre*
Lousewort	Pedicularis Family
Lichen	*Fructicose*
Bastard toad-flax	*Comandra umbellata*
Mushroom	*Glecaulon lividum*
Wintergreen	*Pyrola*
Horsetail	*Equisetum scirpoides*
Horsetail	*Equisetum saipoides*
-	*Astragalus Mckenzie*

61 mammal species.
4 amphibian
278 Bird sp. 27 freshH2O sp.
1000 pl.

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Hoary Marmot
Lemmings
Porcupine
Woodchuck
Beaver
Jumping Mice
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Wood Rat
Deer Mouse
Least Chipmunk
Northern Flying Squirrel
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Others

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FISH SPECIES IN THE YUKON TERRITORY

INCONNU	LAKE (HUMPBACK) WHITEFISH
BROAD WHITEFISH	ROUND WHITEFISH
PYGMY WHITEFISH	LEAST CISCO
ARCTIC CISCO	ARCTIC GRAYLING
LAKE CHUB	BOREAL SMELT
LAKE TROUT	DOLLY VARDEN
BULL TROUT	ARCTIC CHAR
RAINBOW TROUT/STEELHEAD	KOKANEE
SOCKEYE SALMON	COHO SALMON
CHINOOK SALMON	CHUM SALMON
PIKE	BURBOT
LONGNOSE SUCKER	WHITE SUCKER
SLIMY SCULPIN	NINESPINE STICKLEBACK
TROUT PERCH	ARCTIC LAMPREY

INCONNU

Stenodus leucichthys (Guldenstadt). Its name in French means "the unknown fish". also called coney or sheefish. Inconnus are light in exterior colouring with the dor fins dusky at the tip, the tail fin shading to dark at the edge. The lower jaw is long than the upper and usually somewhat hooked. The flesh is white, but rather soft a oily. In the Yukon, inconnus are smaller than the 25-30 pound fish of the MacKen delta area. Although they will take the hook and are excellent fighting fish, most a caught by gillnets of domestic fishermen. They are late summer or fall spawners Inconnu are fairly abundant in the Yukon, Pelly, Stewart and Porcupine River syste

LAKE (HUMPBACK) WHITEFISH

Coregonus clupeaformis (Mitchill). This species is important commercially in th Yukon, where it is found in most of the lakes. In colouring the whitefish is olivace on the upper part of the body, with whitish sides and under portions. The tail fin deeply forked. The lower fins may be dusky. The mouth is subterminal. Adults hav fleshy bump at the shoulders; hence their name. Mature fish average 18 inches in le and weigh about 2.5 pounds. They live on minute molluscs, crustaceans and other s aquatic creatures. Its summer habitat is in the deeper, colder parts of the lakes, fro which it moves into more shallow water at spawning time - late October onward Gillnetting is the chief method of catching them, although they have been known strike angler lures in early spring.

BROAD WHITEFISH

Coregonus nasus (Pallas). Flattened sides and a compressed body have resulted in whitefish species being given the name "broad whitefish". The head is short and t snout blunt. Adults have a large adipose fin and a deeply forked tail fin. During f spawning, the large scales become covered with white conical tubercles, especially the males. Adults have a brown or blackish coloured back and yellowish or silver

belly. Commercially caught broad whitefish are 3-5 pounds in weight although m heavier fish do exist. They are found mostly in rivers, but sometimes in lakes. A evidenced by their blunt snouts, broad whitefish are bottom feeders, feeding mainl molluscs and aquatic insect larvae. In the Yukon, broad whitefish are more import for local consumption than for commercial purposes.

ROUND WHITEFISH

Propopium cylindraceum (Pallas). As their Latin name implies, round whitefish a almost cylindrical in cross-section. They are cigar-shaped with a strongly forked t short head, small mouth devoid of teeth, and a laterally "pinched" snout which proj beyond the lower jaw. Large, easily loosened scales cover their dark brown olive-gr above and silvery below bodies. They average under 16.5 inches in length and 2 pounds in weight. They are widely distributed throughout the Yukon. Round white are shallow water bottom feeders, feeding mainly on caddis fly larvae and pupae snails, and fish eggs. Spawning occurs along lake and stream shorelines in autum "Rounds" are not important as a commercial species as they are seldom caught in mesh gillnets, but are utilised by First Nations who fish for their own needs.

PYGMY WHITEFISH

Prosopium coulteri (Eigenmann & Eigenmann). Their range in the Yukon Territor limited to the Alsek River system and the headquarters of the Yukon River. Squan Lake, east of Whitehorse, has a sizeable population of pygmy whitefish. The pyg whitefish has a cigar-shaped body, round in cross-section, short head, blunt snout small mouth devoid of teeth. Adult fish are dark brown above, silvery below, and fins are clear of any pigment. Little is known about their behaviour except that they carnivorous, feeding on organisms such as aquatic insect larvae, crustaceans and s molluscs. Spawning occurs in autumn or early winter in lakes or streams with the e being scattered over gravel.

LEAST CISCO

Coregonus sardinella (Valenciennes). The least cisco has often been called "lak herring" because of resemblance to the salt water herring. A trout-like body, moder sized head, large eyes and scales, no teeth and a projecting lower jaw identify th species. Adults are gray to olive-green above and silvery below. The non-migrato form seldom exceeds 9 inches in length and has no spots on the fins or back. It occ abundantly in almost all lakes and rivers of the upper Yukon system right up to t headwaters, including Lake Laberge, Atlin, Teslin, Tagish and Bennett Lakes. Le cisco are plankton feeders, but smaller insect larvae form a part of their summer die turn, they are preyed upon by burbot, northern pike, inconnu and lake trout. Least c are autumn spawners.

ARCTIC CISCO

Coregonus autumnalis (Pallas). The Arctic cisco has a trout like body, moderate si head and eyes, and large scales. When its mouth is closed, the upper and lower jaw are equal. Though they may attain a length of 25 inches and a weight of 5.5 pounds, average is much smaller. Anadromous adults are brown to light green on their bac and bright silver below. Spawning males develop rows of flat tubercles on their sid As their name implies, Arctic cisco are found along the Beaufort Sea coast. They common in the lower reaches of the rivers and are particularly abundant in bracki water. They feed mainly on crustaceans and small fish. In spring they ascend rive where they spawn in late summer, after which they migrate back to a marine environment.

ARCTIC GRAYLING

Thymallus arcticus (Pallas). Arctic grayling have a slender body, short head, unusu large eyes, small square shaped mouth, and a greatly enlarged dorsal fin. They m

grow as large as 24 inches long and attain a weight of 5 pounds, but the average Yu grayling would be less than 20 inches long with a weight under 2 pounds. They a vividly coloured fish, especially during the spawning period. The adult grayling ha dark purplish blue back and purplish grey sides with scattered black spots. The lar dorsal fin with its rows of orange or emerald green spots edged with orange give t Arctic grayling male an iridescent peacock coloration. Terrestrial insects form th larger part of their diet, but they also feed on bottom nymphs, snails, small fish a eggs.

LAKE CHUB

Couesius plumbeus (Aggasiz). This Yukon species has a slender body, short flatti head, broad snout and no adipose fin. The mouth is oblique and of moderate size the upper jaw extending backward. There is a distinct barbel near the end of the up jaw. Lake chub are small fish, usually less than 4 inches in length. Adults are blac dark brown or green above, pale silvery below with an indistinct dark mid-lateral b Lake chub frequent lakes and streams (both clear and muddy waters) throughout t territory. They remain close to the bottom regardless of depth and may occur in lar schools. Terrestrial and aquatic insects (both larval and adults forms), zooplankto algae, freshwater shrimp and small fish are eaten by the lake chub. In turn they serv part of the diet of larger fish.

BOREAL SMELT

Osmerus eperlanus (Linnaeus). The smelt family is comprised of small, slender sil fish which tend to occur in schools. The head and eyes of the boreal smelt are of moderate size, but the mouth is large, extends well back and has well developed te in both jaws. They are generally less than 10 inches long though they may grow to inches. Adult fish are light olive green on the back and iridescent silver below. Spawning males develop large tubercles on their scales as well as a slight lateral ri Boreal smelt are anadromous in the Yukon and have been taken from some of th Arctic coastal rivers as well as in the Beaufort Sea. Adult fish feed partially on crustaceans and on small fish, as suggested by their large canine teeth.

LAKE TROUT

Salvelinus namaycush (Walbaum). In exterior colouring, lake trout vary from alm black to greyish or very light green with light coloured, irregular shaped spots. Similarly, there are variations in the colour of the flesh - from deep red to pale ivo These differences are probably determined in part by heredity and in part by environment. Their main food is fish although smaller aquatic organisms are also e Spawning occurs in the fall. Lake trout are sport fish as well as important commercially. Growth is quite slow in most water bodies in the Yukon yet twenty thirty pound fish are not uncommon. Those living in large lakes usually grow to larger size than those in smaller bodies of water. They will take the hook in fly fish with artificial lures, as well as some baits.

DOLLY VARDEN

Salvelinus malma (Walbaum). A trout like body, slightly oblique mouth, forked tail and small scales typify the dolly varden. They are dark blue to olive-green on the b and sides covered with light coloured yellow spots on the dorsal surface and orange pink spots on the sides fading to white or dusky underparts. The spots are usuall smaller in diameter that the pupil of the eye. The non-migratory fish found in th Yukon Territory average 4 to 6 pounds and are smaller than the sea-run form. Ad fish are carnivorous, feeding mainly on other fish, aquatic insect larvae and gastrop They are autumn spawners. Stella Lake (MP 108, Haines Road) contains landlock dollies. They are also reported from the Blackstone River (MP 68, Dempster Hw These fish are easily confused with Bull trout which are now known to be a separ species.

BULL TROUT

Salvelinus confluentus. Bull trout have long been confused with Dolly Varden, although we now know that they are a distinct species. They are very similar in appearance to the Dolly Varden and can only be distinguished by a few subtle differences. The easiest to distinguish physical characteristics are that Bull trout h no black spots on the dorsal fin and the eye is closer to the top of the head than a D Varden. They also occupy different geographic ranges. Fish fitting this descriptio found in the Liard drainage are likely Bull trout, while those found elsewhere in t Yukon are likely Dolly Varden. Beware of confusing these fish with Arctic char well.

ARCTIC CHAR

Salvelinus alpinus (Linnaeus). The Arctic char occurs in two principal forms. On migrates into the sea in the summer to feed, but returns to fresh water to pass th winter. The non-anadromous form remains in fresh water throughout its entire life. Arctic char has an elongate body and in the sea run form is silvery with a deep blu greenish blue on the back and upper sides. The non-anadromous form varies from blue to olive green or brown. Both forms have violet-pink or red spots on the dors surface and the sides which are usually larger in diameter than the pupil of the eye. char approach spawning condition in the autumn, body colours range from bright re deep vermilion. Adults are sexually mature at 18 inches and fish of over 20 poun have been caught in Canada. During the winter, char feed little or not at all, but u large fat reserves stored during the previous summer. Arctic char occur in the north drainages of the Yukon naturally, but are also stocked by the Yukon government some accessible pothole lakes.

RAINBOW TROUT/STEELHEAD

Oncorhynchus mykiss. A typically trout like body, rounded snout, large mouth an black spots on the back, dorsal, adipose and tail fins identify the rainbow trout. T back is bluish green to brown with white or dusky sides and underparts. Usually a l pink to vivid red distinct lateral stripe is visible. In lake populations with good fo sources (generally stocked lakes in the Yukon) rainbows can reach 15 pounds in weight, but native stream fish typically weigh less than 3 pounds. Adult trout fee mainly on crustaceans (freshwater shrimp), aquatic insect larvae (caddis and black f mollusks and the occasional small fish. Their flesh ranges from bright orange to p pink and is very delicious.

The steelhead is a sea-going form of rainbow trout. When in the sea, the body is ma silvery, with a blue back. At spawning time a band of red colour develops along e side of the body. After spawning, many adult steelhead go back to the sea and so although usually not a high proportion, return to fresh water after recuperation to sp a second time. Females survive more often than males. The young fish live for one two full years in freshwater before travelling to the sea as smolts from 4-10" in len This migration takes place in the spring. Steelheads have been reported from Alse Tatshenshini River system in the southwest corner of the territory. They are ofte confused with the native trout which also exist in this watershed. However, steelh are much larger fish, averaging better than 5 pounds.

KOKANEE

Oncorhynchus nerka (Walbaum). Kokanee are landlocked sockeye salmon and ar identical to the anadromous sockeye salmon except for their size. In Kathleen La they seldom exceed two pounds in weight or 20 inches in length. Kokanee are usu bright silver bluish colour and typically trout like in appearance. At spawning tim they take the appearance and coloration of spawning anadromous sockeye. Male become bright red on the back and sides with dirty white underparts. Their head becomes green in colour with a dusky elongated snout, and a light hump forms beh

the head. Spawning females are similarly coloured, but the red is much darker. Dur most of the year, kokanee are in deep water. In early June they are found in shallo water in Kathleen Lake and are eagerly sought after by anglers for their tasty fles

SOCKEYE SALMON

Oncorhynchus nerka (Walbaum). The body of the sockeye is slightly elongated, t head is conical and the teeth are small and weak. They are distinguished from the o salmon by the absence of black spots on the back and tail fins. They average about feet in length and under 5 pounds in weight. When male sockeye reach the Alsek Tatshenshini waters at spawning time, their bodies turn brilliant red with metallic g heads. The upper jaw develops its characteristic hook and a slight hump forms beh the head. The female fish are a dark red with green and yellow blotches. After the hatch, young fry spend two years in freshwater lakes before migrating to the ocea where they spend the next three years. Sockeye are the most highly prized salmo because of the rich red, firm flesh.

COHO SALMON

Oncorhynchus kisutch (Walbaum). Coho have the typical body shape and fins of Pacific salmon. They are distinguished from the other salmon by the fine black spot the back and upper lobe of the tail (above the lateral line), and no black pigment al the base of the teeth in the lower jaw. During spawning, the fish have dark backs a stomachs, with a red stripe on the sides (males are more brilliant). Young coho sal reach the ocean before the end of their first year and return to spawn after a further and some months in the ocean. Coho salmon are found in the Alsek-Tatshenshini R system, e.g. Klukshu River where anglers eagerly seek them out in late September early October. Cohos are also found in the Porcupine River system in the northern of the territory.

CHINOOK SALMON

Oncorhynchus tshawytacha (Walbaum). Other names for this Pacific salmon inclu springs, kings, or tyee when they are more than 30 pounds. The top half of the ba (including the dorsal fin and both lobes of the tail fin) is heavily marked with irreg black spots and gums in the lower jaw are black. At spawning time, their backs a dark, with the sides being pink to dark reddish in colour. The male snout is elonga and strongly hooked. The adult fish average 15-20 pounds, but fish of 65 pounds h been taken in the Yukon River or its tributaries. The young spend their first year freshwater lakes or quiet backwaters of the mainstem Yukon before migrating downstream as smolts. They arrive back as 4-7 year old fish ready to spawn.

CHUM SALMON

Oncorhynchus keta (Walbaum). Chum salmon are often called dog salmon becaus the sharp dog-like teeth of spawning males and because they are often used to feed dogs. They are distinguished by the lack of black spots on the back and fins. Spaw fish have a greenish colour with dusky red mottlings or bars on their sides. The pel and anal fins are white-tipped. Adult fish average under 5 pounds in weight. Chu salmon spawn in the major tributaries of the Yukon River - the White, Stewart, Pe and Teslin Rivers. The Porcupine River and its tributary the Fishing Branch River, contain a sizeable spawning population. They first appear in Dawson about the mid of August and are still running after ice covers the river. The fry migrate immediat upon emerging from the gravel and return in their third or fourth year.

PIKE

Esox lucius (Linnaeus). Northern pike are soft-rayed fish with no adipose fin, and dorsal fin which is positioned well towards the tail. They are quite long in proportio depth and width, and have a flattened snout. Their mouths bristle with sharp, point teeth. They are a dark green colour across the back, mottled down the sides with lig

spots going into a whiteish belly. Adult pike spawn in the spring in shallow, weed flooded areas of rivers, marshes and bays of large lakes. Pike are found throughout year in shallow water due to their ability to tolerate higher water temperatures, lo concentrations of oxygen and higher concentrations of carbon dioxide than man species of freshwater fish. They generally lie motionless and well camouflaged am the shallow water vegetation, waiting to pounce on anything that swims too clos Although they primarily eat fish, they also take any other creatures which are sm enough and within striking distance.

BURBOT

Lota lota (Linnaeus). An eel like, elongate body tapering to a posterior rounded ta flattened short head, large mouth with a single barbel under the chin, and two spine dorsal fins can only describe the burbot. Although the body feels slippery, there a small embedded scales covered with slime. Adults are olive-green to dark brown their back and sides with irregular pale blotches. Burbot may reach 4 feet in length a weight of 75 pounds, but the average Yukon fish is under 10 pounds. They are of called lingcod, ling, maria, or loche. They are voracious feeders, feeding mainly night on fish, though aquatic insects, crustaceans, plankton and fish eggs can make part of their diet. They are easily caught on baited set lines, as they are bottom dwel

LONGNOSE SUCKER

Catastomus catostomus (Forster). Any sucker taken from the Yukon River system probably of this species. Suckers are identified by their ventral mouth and large li The back and sides of adult fish are dark grey to black with white underparts. Ad longnose suckers can attain a length of 25 inches and 3.5 - 4.5 pounds is the avera weight. Spawning occurs in spring soon after the ice goes out, at which time the m have dark bands along their backs and lateral lines which are separated by a wid brilliant red stripe. They also have well-developed calcified tubercles on their hea anal and caudal fins. Suckers live in nearly all types of water, but thrive in war shallow turbid rivers and lakes. They feed upon bottom insects, shells and vegetati sucked up from shallow muddy places.

WHITE SUCKER

Catostomus commersonii (Lacepede). This sucker species is found in some of th southern Yukon streams that drain into the Mackenzie River. Adults are brassy bro to black on their backs and silvery white sides and underparts. There is a dark stri just below the lateral line, but no red stripe is visible in spawning males, as in th longnose sucker. They spawn in late spring or early summer.

SLIMY SCULPIN

Coganatus cogantus (Richardson). Sculpins are grotesque looking, small, botto dwelling fish with broad flat bony heads, and very large pectoral fins. There are t dorsal fins, the anterior fin is spiny and the posterior is soft. One to three spines a found on the preopercle. Sculpins spawn in spring with the egg masses becomin attached under stones and guarded by the males. Sculpins are principally botto feeders with aquatic insects and their larvae, plankton, crustaceans, and small fis making up their diets. In turn they are often eaten by burbot or lake trout.

NINESPINE STICKLEBACK

Pungitius pungitius (Linnaeus). The ninespine stickleback is a small (3 inch) bu aggressive fish that lacks scales, and instead has bony plates along its sides. Seven 12 sharp spines are located ahead of the soft dorsal fin or the pelvic fins and the bo tapers to a very narrow point just before the tail. Adults are olive green to light bro on the back (irregular mottling present) with yellowish white underparts. Breedin males become jet black under the chin and along the belly. The stickleback specie typically found in shallow bays of lakes, slow streams and tundra ponds. Large sch

may be associated with heavy aquatic vegetation. They are carnivorous fish, feedi mainly on insect larvae, small crustaceans, molluscs which they pick up near th bottom. All sticklebacks are territorial fish with the male building a tunnel shape vegetation nest into which the female is lured.

TROUT PERCH

Percopsis omisomaycus (Walbaum). These are small fish, usually less than 4 inch long, with large blunt heads, long snout and large scales. They have a small adipos and large pectoral fins that extend beyond the start of the pelvic fins. Their bodies elongated, tapering posteriorly, and when alive, they are translucent. Two rows o almost ten small dark blotches are found along the top half of the back. They are fo in the Porcupine River and some of its tributaries - the Crow, Bell and Eagle Rive They are found in quiet backwaters feeding mainly on aquatic insects, small crustaceans and molluscs. Very little is known about their spawning behaviour, exc that it occurs mainly at night during spring or early summer.

ARCTIC LAMPREY

Lampetra japonica (Martens). The Arctic lamprey has an eel like body, short head a mouth surrounded by a circular sucking disc. No paired fins are present, instead two dorsal fin folds and one caudal fin fold are almost continuous in adults. Lampr differ from bony fishes in that they do not have scales, bones, jaws, ribs, paired fins gas bladders. In the parasitic form, teeth are sharp and strongly developed, wherea the non-parasitic form, teeth are blunt and weakly developed. Arctic lamprey may g to 2 feet in length and reach 8 ounces in weight. A non-migratory, but parasitic lam population is reported to exist in Tatlmain Lake (drains into Pelly River) where it f on whitefish. Anadromous forms along the Arctic-Yukon coast have invaded some the river systems. After spawning the adults die. The larval stage is called ammoco

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The Yukon is a land of stunning scenery, productive ecosystems and truly remarkable wilderness. This extraordinary natural world is home to diverse communities of birds. This checklist summarizes the occurrence and breeding status of 284 species which have been documented in the Yukon. Breeding has been confirmed for 187 species. Distribution codes indicate species which are typically found in a limited range in the Yukon. Frequency codes indicate species which are rare, casual or accidental. Forty-two species which occur annually in winter are indicated. Species names and taxonomic order follow the A.O.U. checklist (1998) and its supplements.

DISTRIBUTION CODES

N **North Coast**: includes the northern foothills of the British and Richardson Mountains, the Coastal Plain and the Beaufort Sea.

S **South**: south of 63° N (includes Pelly Crossing but not Stewart Crossing).

SE **Southeast**: southern Yukon east of 131° W (Swift River) with an underline (SE) for species restricted to the La Biche River and Beaver River valleys in the extreme southeast.

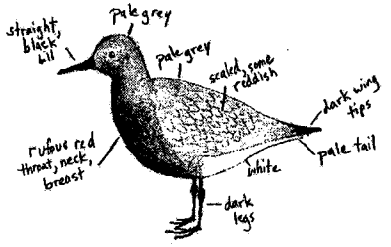
FREQUENCY and BREEDING CODES

r **Rare**: reported annually in very low numbers or extremely localized.
ca **Casual**: at least two records but not seen every year.
ac **Accidental**: recorded only once.
w **Winter:** observed annually in winter (Dec. 1 - Feb. 28).
***** **Confirmed Breeding:** observations of an active nest or dependent, flightless young.

DOCUMENTING BIRD SIGHTINGS

Contribute to our knowledge of the Territory's bird life by sending written or photo documentation of rare, casual, or accidental species or those not on the checklist, and details of breeding observations to:

The Yukon Bird Club
Box 31054, Whitehorse, Yukon, Canada, Y1A 5P7



A joint publication of the Yukon Bird Club, Canadian Wildlife Service (Whitehorse), and Yukon Renewable Resources. March 2001. Compiled by Cameron Eckert, Helmut Grunberg, Greg Kubica, Lee Kubica and Pam Sinclair with data provided by the Birds of the Yukon Database (Canadian Wildlife Service). Illustrations of American Golden-Plover and Red Knot by Pam Sinclair.

✓ SPECIES	A	B	C	D
___Red-throated Loon *				
___Pacific Loon *				
___Common Loon *				
___Yellow-billed Loon				
___Pied-billed Grebe * S r				
___Horned Grebe *				
___Red-necked Grebe *				
___Eared Grebe ac				
___Western Grebe ca				
___Double-crested Cormorant * S r				
___Great Blue Heron S r				
___Black Vulture ac				
___Turkey Vulture ac				
___Bean Goose ac				
___Greater White-fronted Goose *				
___Snow Goose *				
___Canada Goose *				
___Brant *				
___Trumpeter Swan *				
___Tundra Swan *				
___Wood Duck ac				
___Gadwall *				
___Eurasian Wigeon S				
___American Wigeon *				
___Mallard * w				
___Blue-winged Teal *				
___Cinnamon Teal S r				
___Northern Shoveler *				
___Northern Pintail *				
___Green-winged Teal *				
___Canvasback *				
___Redhead *				
___Ring-necked Duck *				
___Greater Scaup *				
___Lesser Scaup *				
___King Eider * N				
___Common Eider * N				
___Harlequin Duck *				
___Surf Scoter *				
___White-winged Scoter *				
___Black Scoter ca				
___Long-tailed Duck *				
___Bufflehead *				
___Common Goldeneye * w				
___Barrow's Goldeneye *				
___Hooded Merganser S r				
___Common Merganser * w				
___Red-breasted Merganser *				
___Ruddy Duck * S				
___Osprey *				
___Bald Eagle * w				

✓ SPECIES	A	B	C	D
___Northern Harrier *				
___Sharp-shinned Hawk *				
___Northern Goshawk * w				
___Broad-winged Hawk ac				
___Swainson's Hawk r				
___Red-tailed Hawk *				
___Rough-legged Hawk *				
___Golden Eagle *				
___American Kestrel *				
___Merlin *				
___Gyrfalcon * w				
___Peregrine Falcon *				
___Ruffed Grouse * w				
___Spruce Grouse * w				
___Willow Ptarmigan * w				
___Rock Ptarmigan * w				
___White-tailed Ptarmigan * w				
___Blue Grouse * w				
___Sharp-tailed Grouse * w				
___Sora * S				
___American Coot * S				
___Sandhill Crane *				
___Common Crane ac				
___Black-bellied Plover				
___American Golden-Plover *				
___Pacific Golden-Plover ca				
___Snowy Plover ac				
___Semipalmated Plover *				
___Killdeer *				
___American Avocet ac				
___Greater Yellowlegs S				
___Lesser Yellowlegs *				
___Wood Sandpiper ac				
___Solitary Sandpiper *				
___Willet ac				
___Wandering Tattler *				
___Spotted Sandpiper *				
___Upland Sandpiper *				
___Whimbrel *				
___Hudsonian Godwit				
___Bar-tailed Godwit ca				
___Marbled Godwit ac				
___Ruddy Turnstone * N				
___Black Turnstone ca				
___Surfbird * r				
___Red Knot ca				
___Sanderling				
___Semipalmated Sandpiper *				
___Western Sandpiper S				
___Little Stint ac				
___Least Sandpiper *				
___White-rumped Sandpiper r				
___Baird's Sandpiper *				

✓ SPECIES	A	B	C	D
___Pectoral Sandpiper *				
___Sharp-tailed Sandpiper S r				
___Dunlin r				
___Stilt Sandpiper *				
___Buff-breasted Sandpiper * N r				
___Short-billed Dowitcher * S				
___Long-billed Dowitcher *				
___Common Snipe *				
___Wilson's Phalarope * S r				
___Red-necked Phalarope *				
___Red Phalarope * N				
___Pomarine Jaeger N				
___Parasitic Jaeger * N				
___Long-tailed Jaeger *				
___Franklin's Gull ca				
___Little Gull ac				
___Bonaparte's Gull *				
___Mew Gull *				
___Ring-billed Gull S r				
___California Gull S r				
___Herring Gull *				
___Thayer's Gull S				
___Iceland Gull ca				
___Lesser Black-backed Gull ac				
___Slaty-backed Gull ca				
___Glaucous-winged Gull S r				
___Glaucous Gull *				
___Sabine's Gull ca				
___Black-legged Kittiwake ac				
___Red-legged Kittiwake ac				
___Ross's Gull ac				
___Ivory Gull ac				
___Caspian Tern S r				
___Arctic Tern *				
___Black Tern * SE r				
___Thick-billed Murre ac				
___Black Guillemot * N r				
___Ancient Murrelet ac				
___Rock Dove * S r w				
___Mourning Dove r				
___Great Horned Owl * w				
___Snowy Owl * N r				
___Northern Hawk Owl * w				
___Great Gray Owl * w				
___Long-eared Owl ac				
___Short-eared Owl *				
___Boreal Owl * w				
___Northern Saw-whet Owl ac				
___Common Nighthawk *				
___Rufous Hummingbird S r				
___Belted Kingfisher *				

✓ SPECIES	A	B	C	D
__Yellow-bellied Sapsucker *				
__Red-breasted Sapsucker ca				
__Downy Woodpecker * S w				
__Hairy Woodpecker * w				
__Three-toed Woodpecker * w				
__Black-backed Woodpecker * S w				
__Northern Flicker *				
__Pileated Woodpecker * SE r				
__Olive-sided Flycatcher *				
__Western Wood-Pewee *				
__Yellow-bellied Flycatcher S r				
__Alder Flycatcher *				
__Least Flycatcher * S				
__Hammond's Flycatcher *				
__Dusky Flycatcher S				
__Eastern Phoebe * SE r				
__Say's Phoebe *				
__Western Kingbird ac				
__Eastern Kingbird SE r				
__Northern Shrike * w				
__Blue-headed Vireo SE				
__Warbling Vireo * S				
__Philadelphia Vireo SE r				
__Red-eyed Vireo SE				
__Gray Jay * w				
__Steller's Jay ca				
__Clark's Nutcracker ca				
__Black-billed Magpie * S w				
__American Crow S r				
__Common Raven * w				
__Horned Lark *				
__Purple Martin ac				
__Tree Swallow *				
__Violet-green Swallow *				
__N. Rough-winged Swallow S r				
__Bank Swallow *				
__Cliff Swallow *				
__Barn Swallow *				
__Black-capped Chickadee * w				
__Mountain Chickadee * S r w				
__Chestnut-backed Chickadee ac				
__Boreal Chickadee * w				
__Gray-headed Chickadee ca				
__Red-breasted Nuthatch * S w				
__Brown Creeper ca				
__Winter Wren SE r				
__Marsh Wren ca				
__American Dipper * w				
__Golden-crowned Kinglet S				

✓ SPECIES	A	B	C	D
__Ruby-crowned Kinglet *				
__Bluethroat N r				
__Northern Wheatear *				
__Mountain Bluebird *				
__Townsend's Solitaire *				
__Gray-cheeked Thrush *				
__Swainson's Thrush *				
__Hermit Thrush *				
__Dusky Thrush ac				
__American Robin * w				
__Varied Thrush *				
__European Starling * S r				
__Yellow Wagtail * N r				
__Red-throated Pipit ca				
__American Pipit *				
__Bohemian Waxwing * w				
__Cedar Waxwing * SE r				
__Tennessee Warbler *				
__Orange-crowned Warbler *				
__Nashville Warbler ac				
__Yellow Warbler *				
__Magnolia Warbler * SE				
__Cape May Warbler SE				
__Yellow-rumped Warbler *				
__Townsend's Warbler *				
__Palm Warbler ca				
__Bay-breasted Warbler * SE				
__Blackpoll Warbler *				
__Black-and-white Warbler * SE r				
__American Redstart * S				
__Ovenbird * SE				
__Northern Waterthrush *				
__Mourning Warbler SE r				
__MacGillivray's Warbler * S r				
__Common Yellowthroat *				
__Wilson's Warbler *				
__Canada Warbler SE r				
__Western Tanager * SE				
__American Tree Sparrow *				
__Chipping Sparrow *				
__Clay-colored Sparrow ca				
__Brewer's Sparrow * S r				
__Lark Sparrow ca				
__Savannah Sparrow *				
__Le Conte's Sparrow SE r				
__Fox Sparrow *				
__Song Sparrow * ca				
__Lincoln's Sparrow *				
__Swamp Sparrow * SE				
__White-throated Sparrow * SE				
__White-crowned Sparrow *				
__Golden-crowned Sparrow *				

✓ SPECIES	A	B	C	D
__Dark-eyed Junco * w				
__Lapland Longspur *				
__Smith's Longspur *				
__Snow Bunting * w				
__Rose-breasted Grosbeak SE				
__Black-headed Grosbeak ac				
__Lazuli Bunting ac				
__Red-winged Blackbird *				
__meadowlark sp. * ca				
__Yellow-headed Blackbird ac				
__Rusty Blackbird *				
__Brewer's Blackbird ca				
__Common Grackle ac				
__Brown-headed Cowbird * S				
__Baltimore Oriole ac				
__Brambling ca				
__Gray-crowned Rosy-Finch * w				
__Pine Grosbeak * w				
__Purple Finch *				
__House Finch ca				
__Red Crossbill * S w				
__White-winged Crossbill * w				
__Common Redpoll * w				
__Hoary Redpoll * w				
__Pine Siskin *				
__American Goldfinch ac				
__Evening Grosbeak SE r w				
__House Sparrow ac				

Notes:

Yukon Bird Club

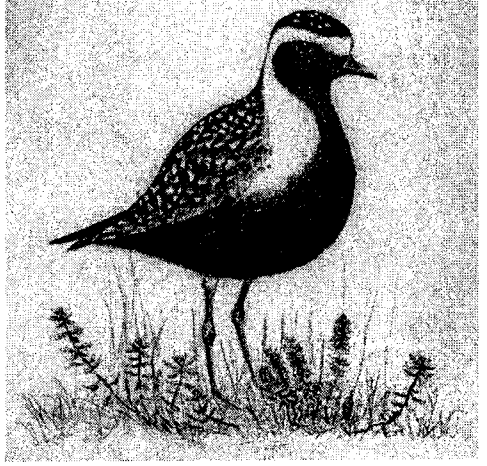
Canadian Wildlife Service / Service Canadien de la faune

Yukon Renewable Resources

Awareness ~ Appreciation ~ Conservation

Checklist of

YUKON BIRDS



OBSERVERS: _____

DATE: _____

LOCATIONS:

A _____

B _____

C _____

D _____

Updated March 2001

Canadian Council of Ministers of the Environment

CANADA-WIDE STANDARDS

for

PETROLEUM HYDROCARBONS (PHCs) IN SOIL

Technical Supplement

January 2001

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Overview of this Technical Supplement

The PHC CWS is a 3-tiered, risk-based remedial standard developed for four generic land uses – agriculture, residential/parkland, commercial and industrial. This technical supplement has been prepared to describe the scientific and socio-economic basis of the standard and guide its appropriate application to PHC contaminated sites in Canada.

The risk-based nature of the PHC CWS means that, for each land use, all values to be protected (life forms or *receptors*, ecosystem properties) are explicitly documented as well as the contaminants considered within PHCs and the pathways by which PHCs can affect these values. This approach provides great flexibility, it allows assessment and management of different variations within a land use and even extension of the standard to other land use categories (e.g., wildlands). The vision, or *exposure scenario*, attached to each land use is the heart of the PHC CWS.

Agricultural lands: where the primary land use is growing crops or tending livestock. This also includes agricultural lands that provide habitat for resident and transitory wildlife and native flora. The portion of a farm that houses people is considered a residential land use.

Residential/Parkland: where the primary activity is residential or recreational activity. The ecologically-based approach assumes parkland is used as a buffer between areas of residency, but this does not include wild lands such as national or provincial parks, other than campground areas.

Commercial: where the primary activity is commercial (e.g., shopping mall) and there is free access to all members of the public, including children. The use may include, for example, commercial day-care centres. It does not include operations where food is grown.

Industrial: where the primary activity involves the production, manufacture or construction of goods. Public access is restricted and children are not permitted continuous access or occupancy.

Section 1 describes the scientific approach, data sources, and specific assumptions made regarding receptors and their interactions with a site under the exposure scenario applicable to each land use. Section 2 describes how the environmental management objectives underpinning the Tier 1 levels can be achieved cost-effectively through the phased acquisition and application of site-specific information in Tiers 2 and 3. Section 3 describes the principal benefits and costs of the PHC CWS as applied at Tier 1. Section 4 provides a summary of the analytical method supporting the PHC CWS.

Section 1: Development of Tier 1 Generic Soil Quality Levels

Approach for PHCs

Tier 1 levels for each land use are derived through a systematic evaluation of all pathways of exposure that apply to the receptors of concern identified under that land use. A detailed account of this process as applied to development of soil quality guidelines is presented in CCME (1996a). Below is a condensed description of the process as applied to development of the Tier 1 PHC CWS. Emphasis is used in areas where changes were made to processes and/or decisions presented in CCME (1996a). A summary of the receptor/pathway combinations considered under each land use in the PHC CWS is presented in Table 1. Each combination is discussed further in the appropriate section of this Technical Supplement. Gaps in the environmental fate and effects literature meant that not all receptor/pathway combinations could be explicitly addressed.

Table 1: Land-uses, key receptors and exposure pathways.

Exposure Pathway	Agriculture	Residential/ Parkland	Commercial	Industrial
Soil Contact	Nutrient cycling Soil invertebrates Crops (plants) Human (child)	Nutrient cycling Invertebrates Plants Human (child)	Nutrient cycling Invertebrates Plants Human (child)	Nutrient cycling Invertebrates Plants Human (adult)
Soil Ingestion	Herbivores Human (child)	(wildlife)* Human (child)	(wildlife)* Human (child)	(wildlife)* Human (adult)
Groundwater/ Surface Water	Aquatic Life/ Livestock Watering Human (child)	Aquatic Life Human (child)	Aquatic Life Human (child)	Aquatic Life Human (adult)
Vapour Inhalation (humans only)	Child, indoor**	Child, indoor	Child, indoor	Adult, indoor
Produce, meat and milk produced on site (humans only)	Child	Child (produce only)		
Off-site migration of Soil/Dust				Human/Eco

* wildlife dermal contact and ingestion data may be particularly important for PHCs (e.g., oiling of feathers, etc., although this should be addressed with an initial assessment of the presence of non-aqueous phase liquids - NAPL), but there are unlikely to be sufficient data to develop guidelines that address this exposure pathway

** a 30m horizontal offset is assumed between the farm residence and the PHC contamination, consistent with oil and gas development practices. Contamination nearer a farm residence triggers a residential assessment.

Tier 1 levels in the CWS are presented as an integration of the above pathway/receptor combinations – only the governing pathway is presented. In application, users will gather information on relevant pathways and will frequently require information on secondary pathways. Tier 1 information on secondary pathways is presented in the technical guidance accompanying this standard (CCME 2000, 2001a).

In addition to the toxic risks addressed by the receptor/pathway analyses, certain other management considerations apply. Chief among these are:

- ignition hazard
- odour and appearance
- effects on buried infrastructure
- formation of non-aqueous phase liquids (NAPL)

Whereas the primary focus in PHC CWS standard development is prevention of toxic effects to the receptors in Table 1, in certain situations these pathways may be of little immediate concern and PHC management is driven by consideration of aesthetic and policy factors.

Human Health Levels

Protocol Summary

Petroleum hydrocarbons are grouped by physico-chemical properties into 4 carbon chain length fractions. Group toxicological and physico-chemical properties are used to estimate concentrations of PHCs in soil that would not lead to an exposure exceeding a hazard index of 1 along the 4 pathways – inhalation of vapours, dermal contact, incidental ingestion of soil and ingestion of cross-contaminated groundwater. The same pathways and same exposure equations are used for all land uses, however, exposure duration and frequency vary between land uses and only an adult's exposure is considered for the industrial land use. Average values for most parameters and characteristics are used which, when combined, gives a protective and practical result. There are insufficient data to evaluate PHC exposure through the food chain. The few data available indicate that plant uptake of PHCs and subsequent exposure at higher trophic levels is not a concern.

Toxicological Basis

Exposure to PHCs leads to a variety of results depending upon the particular compounds or mixtures involved, intensity, frequency and duration of exposure, and exposure pathway. While certain PHCs are confirmed human carcinogens (e.g., benzene, benzo(a)pyrene), these are exceptional and, where present at a site, they are dealt with as separate issues using compound-specific guidelines or risk assessments. Most PHCs are understood to act as threshold toxins, eliciting general narcosis symptoms.

The toxicology of PHCs was extensively reviewed by the US Total Petroleum Hydrocarbons Working Group (US TPHCWG), which was formed by the US Department of Defense in the mid-1990s. The TPHCWG defined 14 aromatic and aliphatic sub-fractions of PHCs based on similar physico-chemical properties. Different oral reference doses (RfDs) and inhalation reference concentrations (RfCs) are presented for each aliphatic or aromatic subfraction in the TPHCWG system. The PHC CWS uses these TPHCWG sub-fractions and further groups them into the four practical fractions -- F1: nC6-C10, F2: >nC10-C16, F3: >nC16-C34, F4: >nC34. Within a TPHCWG sub-fraction the balance between aromatic and aliphatic constituents is assumed to be 20/80 based on an analysis of some representative hydrocarbon products. These analyses were also used to determine appropriate proportions of different carbon ranges within a PHC CWS fraction. Toxicological information for each TPHCWG subfraction is combined with the information on the expected mass of each subfraction to produce a toxicological benchmark for each PHC CWS fraction.

Documented background exposure that Canadians experience is considered in the development of the Tier 1 levels. A review of literature indicated no general information on the occurrence of PHC fractions F2, F3 or F4 in air, water or food. This is likely due to their low volatility and water solubility. Data were available on F1 components indicating that only inhalation exposures are routinely significant. Inclusion of these data reduced the effective RfC for volatile aliphatics by 0.5 to 2% and for volatile aromatics by 20%.

Derivation of Tier 1 Levels

Exposure equations for each pathway are re-arranged to solve for the soil concentration delivering an exposure equivalent to the appropriate allocation of the RfC or RfD (fractions 2, 3 and 4) or "residual" RfC/RfD adjusted for background exposure unrelated to PHC contamination of soil. After all pathways have been assessed the governing value is brought forward for the Tier 1 look-up table.

Soil ingestion and dermal contact values are calculated using the general equation on page 97 of CCME (1996a) and further refined for dermal contact in CCME (2000). These are defined independent of soil texture.

Inhalation exposure Tier 1 levels are based on an implementation of the Johnson and Ettinger (1991) description for intrusion of vapours into an enclosed space (building). Default buildings are, for residential land use, a single family dwelling with basement or slab-on-grade construction and, for commercial and industrial land uses, a slab-on-grade construction. Coarse and fine textured soils, defined as having a median grain size of >75 μm or < 75 μm respectively, are presented as separate cases because vapour transport for the former is dominated by advection as opposed to diffusion for fine soils. Equation 21 of the Johnson and Ettinger paper is used to calculate an attenuation factor for the coarse-textured case and this is coupled to the relevant RfC to back-calculate an acceptable soil concentration. For fine soil, equation 23 of the Johnson and Ettinger paper is used. This is a simplification of equation 21 that assumes vapour intrusion is limited by diffusion within the soil. Critical soil variables include depth to contamination, set to 30 cm to reflect common backfilling practice, and soil organic carbon content, set to 0.5% to reflect average sub-soil conditions in Canada. Both of these are adjustable in Tier 2. Where contamination exists within 30 cm of a building, the proponent must carry out a Tier 2 or 3 assessment. Details regarding transport, building characteristics and exposure are provided in CCME (2000).

Potential human exposure to PHCs from ingestion of water is addressed by defining the downgradient boundary of a PHC contaminated site as the point of compliance for groundwater potability. The simple recharge/leaching and dilution model based on water balance used by both CCME (1996) and Atlantic Partners In RBCA Implementation (1999) is used for the Tier 1 levels. Again, soil textures are separated because of differing transport characteristics. Details regarding site characteristics, hydrological regimes and compliance benchmarks are provided in CCME (2000). Dynamic advective-dispersive models may be used at higher Tiers to address offsite management of PHC-contaminated groundwater.

Ecological Levels

Protocol Summary

Tier 1 levels are derived to protect key ecological receptors that sustain normal activities on the four previously defined land use categories: agricultural, residential/parkland, commercial and industrial. The derivation of Tier I levels for ecological receptors focuses on the effects of PHCs on the biotic component of a terrestrial ecosystem. Specifically, it evaluates the potential for adverse effects to occur from exposures to soil-based PHCs at point-of-contact or by indirect means (e.g., soil to groundwater pathways, food chain transfer).

Toxicological Basis

The derivation of Tier 1 levels for ecological receptors for soil contact is based on toxicological data for vascular plants and soil invertebrates. Toxicological data from recent research generated by the PHC CWS and from an in-depth review of the literature to date was collected and screened. Data includes ecotoxicological effects through exposure to F1 (approximated by response to motor gasoline or Mogas), F2 (crude oil derived), F3 (crude oil derived), whole products (e.g., crude oil, diesel, fuel oil, jet fuel), and surrogates (e.g., naphthalene).

Endpoints examined included chronic and sub-chronic responses (e.g., root elongation, shoot growth, reproduction) as well as acute and lethal responses (e.g., invertebrate survival, seed germination) in both field and artificial soils. Plant and invertebrate responses were analyzed separately.

Derivation of Tier 1 Levels

The approach adopted for the derivation of Tier 1 levels of PHC in soils for the protection of ecological receptors is based on a 'weight of evidence' method as outlined in the CCME 1996 Protocol with some modifications. This approach facilitates the incorporation of disparate types of high quality information on the risks of PHCs to ecological receptors by calculating a percentile of the effects data set to estimate a concentration in soil expected to cause no adverse biological effects.

The following discussion outlines the derivation procedures adopted for soil contact (invertebrates, plants) and ground/surface water protection (aquatic life, livestock watering). Limited information was available to evaluate the soil ingestion (livestock, wildlife) pathway and is therefore not discussed in any detail in the technical supplement.

Soil contact exposure values have been derived for specific PHC fractions based on ecotoxicological data for vascular plants and invertebrates and on a modified Effects Concentration Low (ECL) method as outlined in theCCME 1996 Protocol. Motor gasoline (Mogas) gas toxicity data were used as a reasonable approximation of the ecotoxicity of the PHC CWS F1 fraction since Mogas is a very common, light-end distallate which is predominantly F1 hydrocarbons when fresh. Fractions 2 and 3 data were generated for the PHC CWS and are based on the toxicity of the fraction 2 and 3 of Federated crude oil. Results from specific studies to determine the ecotoxicity through soil contact of fraction 4 to soil organisms are not yet available. All values presented for F4 are based on toxicological response to a whole Federated crude oil and professional

judgment. Experiences with management of heavy PHC over a broad range of soil types was used to support the professional judgment recommendations (CCME 2000).

Different percentiles of the distribution of EC_{50} ranked soil contact data were used to estimate an acceptable soil concentration of PHCs in relation to land use. For agricultural and residential uses where expectations for ecological function are high, the 25th percentile of the ranked EC_{50} data for both plants and invertebrates was chosen. For commercial and industrial land uses where there is less dependence on ecological functions for sustaining land use, the 50th percentile of the ranked EC_{50} data for plants only was chosen.

Recent scientific literature indicates that toxicity of PHCs in soils is strongly affected by texture. This toxicity reduction in fine textured soils (e.g., clays, clay loams) is related to many factors that act to reduce bioavailability. Because primary ecotoxicological data were derived using fresh product in coarse textured soils, they represent essentially worst case conditions. In Tables 2 through 5 below, professional judgment has been applied to these data to incorporate knowledge from field studies and laboratory experiments demonstrating reduced PHC toxicity in fine-textured soils.

Concentrations of PHCs in soil that would not be expected to pose a threat to ecological receptors via ground water exposure pathways were estimated by modeling transport from soil through groundwater to a default discharge point 10 m downgradient from the PHC contaminated site. The lateral distance may be varied in Tier 2 up to a maximum of 500 m. The receptors considered were aquatic life in nearby streams, rivers and lakes where PHC contaminated groundwater may be an issue, and livestock (cattle) ingesting drinking water from a surface source located near groundwater receiving inputs from PHC contaminated soils.

Integration of Ecological and Human Health Levels

Tabular Tier 1 levels in the PHC CWS present the lower of the values generated for human health and ecological protection such that both are protected when Tier 1 levels are applied. Detailed results for all potential receptor/pathway combinations are presented for fine and coarse textured soils in Tables 2 and 3 below. Tier 2 and 3 approaches are expected to focus on the governing condition for a particular fraction.

Information is also presented in Tables 4 and 5 on generic levels applicable to subsoils,defined as earthy materials below 1.5 m depth. Generic subsoil levels for PHCs are judged to be protective of human health and environment so long as subsoil remains at depth. In addition, allowance has been made for certain exposures that could occur as a consequence of excavation. It is recognized, however, that jurisdictions have discretion in the application of generic subsoil PHC levels with regard to any relevant conditions for on-going management.

Table 2

Tier 1 levels (mg/kg soil) for PHCs for fine-grained surface soils.

Land Use	Exposure Pathways	F1 (C6-C10)	F2 (>C10-C16)	F3 (>C16-C34)	F4 (>C34)
Agricultural	Soil Ingestion	15,000	8000	18,000	25,000
	Dermal Contact	RES	RES	RES	RES
	Vapour Inhalation (indoor, 30 m offset)	2100	11,400	NA	NA
	Protection of Potable GW[1]	180	250	NA	NA
	Protection of GW for Aquatic Life[2]	TBD	TBD	NA	NA
	Protection of GW for Livestock Watering[3]	TBD	TBD	NA	NA
	Nutrient Cycling	TBD	TBD	TBD	TBD
	Eco Soil Contact[4]	260	900	800	5600
	Eco Soil Ingestion	TBD	TBD	TBD	TBD
	Produce, Meat and Milk	NC	NC	NC	NC
Residential	Soil Ingestion	15,000	8000	18,000	25,000
	Dermal Contact	RES	RES	RES	RES
	Vapour Inhalation (indoor)	940	5200	NA	NA
	Protection of Potable GW[1]	180	250	NA	NA
	Protection of GW for Aquatic Life[2]	TBD	TBD	NA	NA
	Nutrient Cycling	TBD	TBD	TBD	TBD
	Eco Soil Contact[4]	260	900	800	5600
	Produce	NC	NC	NC	NC
Commercial	Soil Ingestion	RES	29,000	RES	RES
	Dermal Contact	RES	RES	RES	RES
	Vapour Inhalation (indoor)	4600	25,000	NA	NA
	Protection of Potable GW[1]	180	250	NA	NA
	Protection of GW for Aquatic Life[2]	TBD	TBD	NA	NA
	Nutrient Cycling	TBD	TBD	TBD	TBD
	Eco Soil Contact[4]	660	1500	2500	6600
Industrial	Soil Ingestion	RES	RES	NA	NA
	Dermal Contact	RES	RES	RES	NA
	Vapour Inhalation (indoor)	4600	25,000	NA	NA
	Protection of Potable GW[1]	180	250	NA	NA
	Protection of GW for Aquatic Life[2]	TBD	TBD	NA	NA
	Nutrient Cycling	TBD	TBD	TBD	TBD
	Eco Soil Contact[4]	660	1500	2500	6600
	Offsite Migration	NA	NA	12,000	RES

NA = Not applicable. Calculated value exceeds 1,000,000 mg/kg or pathway excluded.
RES = Residual PHC formation. Calculated value exceeds 30,000 mg/kg and solubility limit for PHC fraction.
NC = Not calculated. Insufficient data to allow derivation.
TBD = To be determined
1 = Assumes site is underlain by groundwater of potable quality in sufficient yield (K of 10^{-4} cm/sec or greater).
2 = Assumes surface water body at 10 m from site.
3 = Generally applicable for this land use as related to use of dugouts and wells for supply of livestock water.
4 = Tier 1 values based primarily on laboratory bioassay response to fractions derived from fresh Federated Crude Oil and adjusted for textural factors.

Table 3
Tier 1 levels (mg/kg soil) for PHCs for coarse-grained surface soils.

Land Use	Exposure Pathways	F1 (C6-C10)	F2 (>C10-C16)	F3 (>C16-C34)	F4 (>C34)
Agricultural	Soil Ingestion	15,000	8000	18,000	25,000
	Dermal Contact	RES	RES	RES	RES
	Vapour Inhalation (indoor, 30 m offset)	200	1100	NA	NA
	Protection of Potable GW	860	1200	NA	NA
	Protection of GW for Aquatic Life[1]	230	150	NA	NA
	Protection of GW for Livestock Watering[2]	9000	4000	NA	NA
	Nutrient Cycling	TBD	TBD	TBD	TBD
	Eco Soil Contact[3]	130	450	400	2800
	Eco Soil Ingestion	TBD	TBD	TBD	TBD
	Produce, Meat and Milk	NC	NC	NC	NC
Residential	Soil Ingestion	15,000	8000	18,000	25,000
	Dermal Contact	RES	RES	RES	RES
	Vapour Inhalation (indoor, basement)	50	240	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	30	150	NA	NA
	Protection of Potable GW	860	1200	NA	NA
	Protection of GW for Aquatic Life[1]	230	150	NA	NA
	Nutrient Cycling	TBD	TBD	TBD	TBD
	Eco Soil Contact[3]	130	450	400	2800
	Produce	NC	NC	NC	NC
Commercial	Soil Ingestion	RES	29,000	RES	RES
	Dermal Contact	RES	RES	RES	RES
	Vapour Inhalation (indoor)	310	1700	NA	NA
	Protection of Potable GW	860	1200	NA	NA
	Protection of GW for Aquatic Life[1]	230	150	NA	NA
	Nutrient Cycling	TBD	TBD	TBD	TBD
	Eco Soil Contact[3]	330	760	1700	3300
Industrial	Soil Ingestion	RES	RES	NA	NA
	Dermal Contact	RES	RES	RES	NA
	Vapour Inhalation (indoor)	310	1700	NA	NA
	Protection of Potable GW	860	1200	NA	NA
	Protection of GW for Aquatic Life[1]	230	150	NA	NA
	Nutrient Cycling	TBD	TBD	TBD	TBD
	Eco Soil Contact[3]	330	760	1700	3300
	Offsite Migration	NA	NA	RES	RES

NA = Not applicable
RES = Residual PHC formation. Calculated value exceeds 30,000 mg/kg and solubility limit for PHC fraction.
NC = Not calculated. Insufficient data to allow derivation.
TBD = To be determined
1 = Assumes surface water body at 10 m from site.
2 = Includes use of dugouts and wells for supply of livestock water.
3 = Tier 1 values based mainly on laboratory bioassay response to fractions derived from fresh Federated Crude Oil.

Table 4
Generic levels for PHCs in fine-grained subsoil (> 1.5 m depth).

Land Use	Exposure Pathways	F1 (C6-C10)	F2 (>C10-C16)	F3 (>C16-C34)	F4 (>C34)
Agricultural	Soil Ingestion	RES	RES	RES	RES
	Dermal Contact	RES	RES	RES	RES
	Vapour Inhalation (indoor, 30 m offset)	2100	11,400	NA	NA
	Protection of Potable GW[1]	180	250	NA	NA
	Protection of GW for Aquatic Life[2]	TBD	TBD	NA	NA
	Protection of GW for Livestock Watering[3]	TBD	TBD	NA	NA
	Nutrient Cycling	NA	NA	NA	NA
	Eco Soil Contact[4]	750	2200	3500	10,000
	Eco Soil Ingestion	TBD	TBD	TBD	TBD
	Produce, Meat and Milk	NA	NA	NA	NA
Residential	Soil Ingestion	RES	RES	RES	RES
	Dermal Contact	RES	RES	RES	RES
	Vapour Inhalation (indoor: basement, slab)	(940, 990)	(5200, 5500)	NA	NA
	Protection of Potable GW[1]	180	250	NA	NA
	Protection of GW for Aquatic Life[2]	TBD	TBD	NA	NA
	Nutrient Cycling	NA	NA	NA	NA
	Eco Soil Contact[4]	750	2200	3500	10,000
	Produce	NA	NA	NA	NA
Commercial	Soil Ingestion	RES	RES	RES	RES
	Dermal Contact	NA	RES	NA	NA
	Vapour Inhalation (indoor)	4800	26,000	NA	NA
	Protection of Potable GW[1]	180	250	NA	NA
	Protection of GW for Aquatic Life[2]	TBD	TBD	NA	NA
	Nutrient Cycling	NA	NA	NA	NA
	Eco Soil Contact[4]	1000	3000	5000	10,000
Industrial	Soil Ingestion	NA	NA	NA	NA
	Dermal Contact	NA	NA	NA	NA
	Vapour Inhalation (Indoor)	4800	26,000	NA	NA
	Protection of Potable GW[1]	180	250	NA	NA
	Protection of GW for Aquatic Life[2]	TBD	TBD	NA	NA
	Nutrient Cycling	NA	NA	NA	NA
	Eco Soil Contact[4]	1000	3000	5000	10,000
	Offsite Migration	NA	NA	NA	NA

NA = Not applicable
RES = Residual PHC formation. Calculated value exceeds 30,000 mg/kg and solubility limit for PHC fraction.
NC = Not calculated. Insufficient data to allow derivation.
TBD = To be determined
1 = Assumes site is underlain by groundwater of potable quality in sufficient yield (K of 10^{-4} cm/sec or greater).
2 = Assumes surface water body at 10 m from site.
3 = Generally applicable for this land use as related to use of dugouts and wells for supply of livestock water.
4 = Tier 1 values based primarily on laboratory bioassay response to fractions derived from fresh Federated Crude Oil and adjusted for texture, depth factors and other physical hazard considerations.

Table 5

Generic levels for PHC in coarse-grained subsoil (> 1.5 m depth).

Land Use	Exposure Pathways	F1 (C6-C10)	F2 (>C10-C16)	F3 (>C16-C34)	F4 (>C34)
Agricultural	Soil Ingestion	RES	RES	RES	RES
	Dermal Contact	RES	RES	RES	RES
	Vapour Inhalation (indoor, 30 m offset)	200	1100	NA	NA
	Protection of Potable GW	860	1200	NA	NA
	Protection of GW for Aquatic Life[1]	230	150	NA	NA
	Protection of GW for Livestock Watering[2]	9000	4000	NA	NA
	Nutrient Cycling	NA	NA	NA	NA
	Eco Soil Contact[3]	350	1500	2500	10,000
	Produce, Meat and Milk	NA	NA	NA	NA
Residential	Soil Ingestion	RES	RES	RES	RES
	Dermal Contact	RES	RES	RES	RES
	Vapour Inhalation (indoor, basement)	50	240	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	40	190	NA	NA
	Protection of Potable GW	860	1200	NA	NA
	Protection of GW for Aquatic Life[1]	230	150	NA	NA
	Nutrient Cycling	NA	NA	NA	NA
	Eco Soil Contact[3]	350	1500	2500	10,000
	Produce	NA	NA	NA	NA
Commercial	Soil Ingestion	RES	RES	RES	RES
	Dermal Contact	NA	RES	NA	NA
	Vapour Inhalation (indoor)	340	1800	NA	NA
	Protection of Potable GW	860	1200	NA	NA
	Protection of GW for Aquatic Life[1]	230	150	NA	NA
	Nutrient Cycling	NA	NA	NA	NA
	Eco Soil Contact[3]	700	2000	3500	10,000
Industrial	Soil Ingestion	NA	NA	NA	NA
	Dermal Contact	NA	NA	NA	NA
	Vapour Inhalation (indoor)	340	1800	NA	NA
	Protection of Potable GW	860	1200	NA	NA
	Protection of GW for Aquatic Life[1]	230	150	NA	NA
	Nutrient Cycling	NA	NA	NA	NA
	Eco Soil Contact[3]	700	2000	3500	10,000
	Offsite Migration	NA	NA	NA	NA

NA = Not applicable
RES = Residual PHC formation. Calculated value exceeds 30,000 mg/kg and solubility limit for PHC fraction.
NC = Not calculated. Insufficient data to allow derivation.
TBD = To be determined
1 = Assumes surface water body at 10 m from site.
2 = Includes use of dugouts and wells for supply of livestock water.
3 = Tier 1 values based primarily on laboratory bioassay response to fractions derived from fresh Federated Crude Oil and adjusted for depth factors and other physical hazard considerations.

Section 2: Tiered Framework for Assessment and Management of PHCs at Contaminated Sites.

The framework is based on a synthesis of the ASTM (1995) and CCME (1996a) frameworks for the assessment and management of contaminated sites, and incorporates at successive tiers: (1) the application of generic (national) Tier 1 levels that are protective of human health and the environment, (2) site-specific adjustments to the Tier 1 levels to calculate Tier 2 levels that accommodate unique site characteristics, and (3) Tier 3 levels that are developed from a site-specific ecological or human health risk assessment, when assumptions inherent in the Tier 1 values are not appropriate for a site. The level of protection afforded, and the associated underlying guiding principles, are preserved throughout this tiered process. The tiered approach essentially represents increasing levels of precision in a site assessment through consideration of more specific site characteristics. Equally important to application of the PHC CWS is the recommendation of an approach for the analysis of PHC contamination in soil that is consistent with, and supports application of the ambient soil quality levels.

Though the intent of the CWS is to promote a consistent, high level of protection for human health and the environment as a result of site remediation, in both Tiers 2 and 3, decisions may be taken in calculating a site-specific level that are so specific to a site (e.g. distance to a building), that even minor changes to the specified land use (i.e., a re-located, expanded or additional home on a residentially zoned site) may alter the protection afforded by the recommended ambient soil quality level. Only for stable characteristics of a site (such as depth to groundwater) that will not change with changes to land use, or when the Tier 1 levels are used, should the recommended ambient soil quality level be considered as protective for that site *unconditionally*. Otherwise, *conditions* may be attached to site management (e.g., monitoring, limits to site use, use of groundwater). In situations where engineered or institutional controls are used to manage risks to acceptable levels, closure may also be conditional (i.e., monitoring may be required).

Site Characterization

The goal of site characterization is to adequately describe site conditions in order to address assessment and management options.

The minimum data requirements for a PHC CWS assessment include:

- site description (location, size, etc.)
- land use - historical, existing, intended, and potential land uses at the site and surrounding the site, including presence/absence of critical wildlife habitat
- proximity of the site to surface water and drinking water supplies (presence and nature of any nearby aquatic or marine habitat)
- depth to groundwater (measured or inferred from records)
- human receptors
- ecological receptors
- primary exposure pathways

- stratigraphy and properties of surficial materials (especially soil texture)
- depth to contamination and distances to points of exposure/compliance
- built environment – presence and types of buildings, utility corridors and conduits
- contamination characterization and delineation (including presence or suspected presence of NAPL) as needed for comparison with Tier 1 PHC ambient soil quality levels and soil quality guidelines for other contaminants of concern. Guidance on analytical methods appropriate for the application of the PHC standard is provided in CCME (2001b).

Tier 1 Assessment and Management

Information collected as described above is evaluated to decide whether the site broadly fits any of the four land use categories. If it does not adequately match any of the land uses nor any hybrid thereof, it should be addressed at Tier 3.

Assuming the site is suitable for generic assessment, concentrations of the relevant PHC fractions are determined and compared to the appropriate look-up Tier 1 levels to identify any exceedances. It is critical that the core site characterization data have been collected or the site investigator may enter the lookup tables in a way that leads to management error. For example, Tier 1 levels are available for coarse and fine textured materials. In the absence of soil texture information, it is possible to under-manage contamination by applying Tier 1 values for fine textured sites to a coarse textured site, or over-manage contamination by applying Tier 1 values for coarse textured sites to a fine textured site. In this instance, it is to the proponent's advantage to have textural information because, in its absence, the regulator may insist on the use of the more sensitive default (i.e., Tier 1 values for coarse textured sites).

If no exceedances are found in Tier 1 assessment, investigation ceases and the site can be declared compliant with the PHC CWS. Conversely, if exceedances are found two options exist. First, the site may be remediated to eliminate exceedances. Alternatively, additional site information may be collected to refine the estimate of exposure and risk in a Tier 2 assessment. This may lead to a conclusion that less aggressive management – including, possibly, "no further action" -- is required on the site. Which option is selected will depend on a number of factors including the concentrations and extent of PHC contamination, limiting pathways applicable, availability and cost of technology, and needs for liability reduction.

In general, it is the proponent's responsibility to identify and respond to any site or receptor factors that could unduly accentuate exposure or risk beyond that envisioned in the Tier 1 exposure scenario.

Tier 2 Assessment and Management

Reasonably conservative assumptions are made in Tier 1 regarding site, receptor and contaminant factors to ensure that remediation to these levels will meet environmental management objectives. At individual sites, it is often advantageous to replace default assumptions with actual data concerning certain influential parameters. Tier 2 assessment describes such procedures. In addition, there are opportunities to reduce reliance on

models by replacing model predictions by point-of-exposure or near-point-of-exposure measurements.

Technical options at Tier 2 are not unlimited. Approved procedures meet several criteria:

1. Based on factors influencing exposure that can be measured and verified.
    - Assessments must not be encumbered by technical information regarding factors that have little influence on management outcome
    - Alterations to parameters and assumptions must be made using data that can be relatively easily measured and confirmed as necessary
2. Supports clear land and water use decision making
    - It must be clear what any adjustments mean in terms of the future management of the site
    - The objective is retention or recovery of the maximum range of land and water use options – where options are constrained, this must be made clear to stakeholders
3. Maintains clarity and simplicity in the assessment
    - Stakeholders, including regulators, require that Tier 2 assessments can be reviewed and approved without heavy resource investments. For non-regulatory stakeholders this means faster turnaround on reviews and more efficient land transactions

Taken together, these criteria mean that Tier 2 procedures applicable to *human health protection* will focus on relatively stable aspects of the site and contaminants and how these influence exposure along "secondary pathways" where transport of PHC is involved (primarily inhalation exposures and ingestion of contaminated groundwater). *Characteristics of receptors such as body weight, breathing rate, time spent on site etc. are not candidates for Tier 2 modification because they can be neither predicted nor controlled in a generic way.*

Application of the above criteria to ecological protection indicate that secondary exposure pathways (e.g., transport of PHC to an adjacent surface water body) can be addressed as well as factors that influence the bioavailability of PHC to soil dwelling organisms. *As is the case in human health protection, modifications to exposure scenarios that require changes to the behaviour, distribution or abundance of ecological receptors are not supported in Tier 2. Such proposals generally result in land use limitations and on-going risk management responsibilities. Where necessary, these are best accommodated at Tier 3.*

The following section describes the major data sources relevant to Tier 2 and outlines their application in practical site remediation work. Note that no continuous adjustment procedures are available for pathway/receptor combinations where professional judgement has been used to incorporate qualitative or semi-quantitative factors or information. For example, no calibration adjustments are available for direct contact by ecological receptors. The alternative here is the replication of the bioassay suite used in developing the Tier 1 standards with site soils and relevant representatives of the organismal groups.

DATA-BASED TECHNICAL PROCEDURES

The following procedures may be applied without creation of conditions on land and water use. Details of these procedures are provided in CCME (2001a).

a) Off-site movement of dust (Industrial Land Use only)
Tier 1 levels for surface soils at industrial sites are supported by an erosion/deposition check to protect any adjacent, sensitive lands. If no such surrounding land exists, the check may be removed.

b) Fraction of organic carbon in soils
The fraction of organic C in soil is determined by chemical analysis and this result is inserted in the partitioning model used by the vapour and solute transport models.

c) Depth to contamination from building foundation
This distance is important in determining soil concentrations of F1 and F2 that will be protective against intrusion of vapours into enclosed spaces. The information is gathered through depth sampling and analysis in routine site assessments.

d) Hydraulic conductivity and gradient
These parameters influence lateral movement of PHC in groundwater. The default parameters in the mixing/dilution model can be replaced by measures or estimates from the site.

e) Hydrological recharge
This parameter affects degree of dilution of leachate in groundwater and has been calculated to be protective in the general Canadian environment. Low precipitation, high evapotranspiration regions will have more favourable dilutions. The recharge rate may be calculated based on local data on precipitation, evapotranspiration and runoff.

f) Horizontal distance from contamination source to downgradient property line
This distance is specified as a default in the groundwater model and may be replaced by site data.

g) Exposure point observations on soil air and groundwater
In Tier 1, potential indoor exposure is based on modeled attenuation of vapours from a proximal soil source area. If information is available on actual vapour concentrations in the envelope surrounding the building, a simpler dilution relationship can be used to calculate potential indoor exposure. Such measurements must be supported by evidence that the vapour concentrations measured will not increase in future. Similarly, screening calculations using a simple dilution model are performed in Tier 1 to estimate groundwater-protective soil concentrations. Observations on groundwater at the site are a better form of information provided that there is evidence that concentrations measured will not increase with time.

h) Actual proportion of TPHCWG sub-fractions by mass as per site specific analytical results (%)
The 80/20 assumption for aliphatics/aromatics can be replaced by specific information. Also, the balance among C chain-length sub-fractions can be altered.

i) Depth to groundwater and source dimensions – aquatic life and livestock watering pathways
The model describing PHC movement from soil to groundwater to a point of exposure for aquatic life or livestock watering includes the depth separation between a contaminated soil source and groundwater. The default assumption is that contaminated soil extends to an unconfined aquifer. Distance separation and dimensions of the source can be modified by site-specific measurements.

Other procedures may be acceptable at Tier 2 depending on jurisdiction. Additional candidate procedures may be constrained in application by any combination of:

- Too technically complex to be considered at Tier 2 (appropriate for Tier 3)
- Adjustment alters risk management objectives and requires off-site risk management
- Adjustment mechanism not yet fully proven or demonstrated

Some procedures that may be supported at Tier 2 but are potentially affected by the above practical constraints include:

a) Volatiles in soil gas via application of Raoult's Law
Information on PHC concentrations in all fractions present may be used to estimate more realistic partitioning of volatile PHC among soil solids, soil moisture, soil air and PHC residuals. The analytical characterization must be conducted in the zone of maximum contamination. Recalculated vapour phase concentrations are inserted into the vapour transport model.

b) Contaminated soil volume in relation to vapour intrusion pathway
Complete delineation of all source areas allows calculation of the total contaminant mass. This mass is depleted by redistribution of PHC along transport pathways. A screening level estimate of vapour phase exposure resulting from complete redistribution to an enclosed space has been described by Atlantic PIRI.

c) Point of compliance for groundwater protection outside property boundary
Dynamic advective-dispersive groundwater transport models and monitoring are used to support management of a PHC plume originating on one site and extending to another. The downgradient property owner must agree to forego relevant uses of the groundwater while this condition persists.

In general, site-specific information is useful in creating "headroom" for a PHC proponent when it bears on the governing pathway. Site specific data on non-limiting pathways can promote understanding but does not alter the management outcome.

Tier 2 management may or may not carry on-going risk management considerations that place responsibilities on parties for monitoring, care and control and may require engineered and/or institutional controls. Whether such measures are necessary depends on a number of factors as discussed below.

Tier 3: Site-specific Risk Assessment

In some cases, an Ecological Risk Assessment (ERA) and/or human health risk assessment (HHRA) may be warranted. Risk assessment is an important process for

evaluating and predicting the existing and potential impact of toxic substances and other perturbations on the ecosystem and its components (i.e., species, populations, communities), including human health.

When compared to applying environmental quality guidelines, risk assessment is a more complex and involved method for establishing site-specific remediation objectives. Different descriptions of contaminant fate, behaviour and exposure may be involved. All models must be calibrated and validated for the particular site. Site-specific risk assessment may be appropriate when, for example, guidelines-based objectives (i.e., Tier 1 and 2 levels that have been modified to account for site-specific factors) are not relevant for the specified uses of the site, where guidelines-based objectives do not seem appropriate given the site-specific conditions, where significant or sensitive receptors of concern have been identified, or where there is significant public concern.

Several risk assessment frameworks have been developed in Canada (CCME 1996b; BC MELP 1993; Atlantic PIRI 1999) that are relevant for the assessment and management of petroleum contaminated sites. These frameworks share several common elements, including problem formulation/receptor characterization, exposure and hazard/toxicity assessment, and risk characterization.

The Canadian framework for ecological risk assessment (CCME 1996b) provides a consistent basis for approaching this potentially complex process. The framework provides guidance on deciding when an ERA should be conducted through a series of questions and triggers. Further, it describes key steps and considerations in planning and implementing an ERA, from defining initial goals and objectives and choosing appropriate measurement and assessment endpoints, to reporting the results of an ERA.

The vast majority of site-specific risk assessments are conducted as a consequence of technical or socio-economic barriers to complete remediation. This means that the risk management proposed usually involves exposure management through engineered controls, institutional controls or both. Such controls are necessary when contaminated site stakeholders (owners, operators, adjacent landowners) must alter their actions or refuse to undertake certain future actions in order to prevent exposure (e.g., installation and maintenance of vapour barriers, non-use of groundwater).

Confirmation testing

Once a Tier 1, Tier 2 or Tier 3 approach has been selected and soil PHC contamination levels have been agreed to, analytical information must be supplied to show that these concentrations have been achieved.

Section 3: Socio-economic Analysis

The *Socio-economic Analysis of Canada-wide Standards for Petroleum Hydrocarbons in Soil* was undertaken with the understanding that Tier 1 standards will be implemented and that they will be protective of human and environmental health. The socio-economic analysis is a cost analysis for implementing the standards that assumes all PHC contaminated sites, irrespective of scale and severity of contamination are remediated to Tier 1 levels. In practice, larger and more severely contaminated sites are addressed at Tiers 2 and 3.

The socio-economic analysis was undertaken concurrently with other scientific work done for the PHC Development Committee (DC) and made direct use of the DC's work on human health and ecotoxicity in its consideration of socio-economic impacts. The DC developed recommendations for standards based on that concurrent work and understandings achieved in the socio-economic analysis. Because of this timing the DC provided a set of "seed values" for four categories of land use (agricultural, residential, commercial and industrial), two soil textures (coarse and fine) and conditions that did and did not include protection of groundwater. These were "ball park" estimates of standards that would likely be protective of human and environmental health based on preliminary analyses. Costs of remediating volumes of soil to meet the seed values were estimated assuming common, effective technologies. The socio-economic analysis addressed the matter of how costs and benefits would vary with different levels of protection by considering values that were five times the seed value (i.e. less stringent) and one-fifth the seed value (more stringent). The Development Committee was very clear that the seed values did not have regulatory significance and should not be construed as the most likely set of standards to be recommended to environment Ministers.

The socio-economic analysis considered 11 scenarios of soil contamination to cover most situations pertaining to the upstream, downstream and post-consumer sectors. It examined typical volumes of contamination associated with each scenario. It estimated the costs to remediate those volumes assuming common, effective technologies. The clean up volumes for each scenario were based on the most appropriate combination of land use, soil texture and likely need for groundwater protection for that scenario.

The socio-economic analysis also addressed the potential benefits of implementing a CWS. It did not attempt to economically value health benefits, although it did estimate monetary values for some categories such as reduced agricultural damage and improved land values. Other ecological impacts, such as potential reduction in ability to grow non-agricultural plants or effects on soil fauna that had been scientifically assessed by the DC or Ecological Technical Advisory Group, could not be monetized.

Basic Findings

The analysis confirmed that there is an appreciable difference between costs of remediation to the seed values and to standards more stringent and less stringent than the seed values. The range of costs would be in the order of several billion to a few tens of billions of dollars. Estimated costs to remediate all sites to each of the three levels of protection, for different hypothetical remediation schedules are presented below. The first schedule (clean up all PHC contaminated sites immediately) is unrealistic but sets the context for the other schedules.

	less stringent	seed value	more stringent
All at the present time ($billion)	7.8	15.6	22.8
10% of sites/yr. for 10 yr. ($b)	6.0	12.1	17.6
10%/yr for 5 yr., rest deferred ($b)	4.9	9.7	14.2

Incremental costs of moving from the less stringent case to the seed values and from the seed values to the more stringent case are also shown.

	From less stringent to seed value	From seed value to more stringent
All at present time ($billion)	7.8	7.2
10% of sites/yr. for 10 yr. ($b)	6.1	5.5
10%/yr for 5 yr., rest deferred ($b)	4.8	4.5

The costs were discounted by a public discount rate (5%). The rate at which remediation activity takes place has a large influence on costs.

It was possible to estimate monetary values for some categories of benefits. These included benefits in the areas of: agricultural damage that could be avoided (crop value), increased property value resulting from remediation, blight avoided for some residential sites (effects of PHC contamination on values of adjacent residential sites), and option value of green-field sites (societal preference to clean up a contaminated site rather than developing a previously undeveloped site).

The estimated monetizable benefits are:

	less stringent	seed value	more stringent
All at present time ($billion)	3.4	5.7	9.5
10% of sites/yr. for 10 yr. ($b)	2.7	4.5	7.4
10%/yr for 5 yr., rest deferred ($b)	2.2	3.6	6.0

These monteized benefits do not include health benefits or benefits of ecological protection.

The ratio of monetizable benefits to monetizable costs was approximately 40%, although there was some variation (from 0.37:1 to 0.45:1) depending on the rate of remediation and the stringency of the standard.

It is possible to present monetized costs and benefits according to geographic distribution within Canada.

	% costs	% monetized benefits
West (BC, AB, SK)	70	27
East	23	69
North	5	4

This geographic breakdown does not include human health benefits, which, if included, would be distributed by region in approximately the same proportion as total population.

For most scenarios of contamination that were examined, remediation to any of the three values (seed, less stringent and more stringent) was assumed to be protective of human health. In some instances, however, the margin of safety (based on the work done in the human health component of DC's work) associated with the less stringent values might be considered small. These margins of safety are conservative, and therefore highly likely to be protective of human health, even if small.

These analyses were conducted assuming the Tier 1 values apply to the full depth of contamination. The PHC CWS now includes generic levels for subsoils, which are less stringent than for surface soils. Depending on land use, soil texture, PHC fraction, and depth, the final Tier 1 values recommended by Development Committee vary more or less from the seed values. Generally, Tier 1 levels for surface soils tend to fall between the seed values and the more stringent case, whereas subsoil levels tend to fall between the seed values and the less stringent case.

It is very important to note that the socio-economic analysis addresses only implementation of Tier 1 levels. Tiers 2 and 3 are normally used for many of the more complex PHC release sites because use of site-specific information at those Tiers can contribute to more informed decision making. Often, application of the site-specific information can result in remediation costs that are reduced from those expected if Tier 1 standards were applied. While the reduction in costs of implementing remediation to Tier 2 or Tier 3 is not quantified at this time (principally because the proportion of sites going to the three levels will depend on stakeholder input and regulatory acceptance), it could be appreciable.

Section 4: Analysis of Petroleum Hydrocarbons in Soils, CCME Tier 1 Method

An analytical method was developed in conjunction with the Canada-Wide Standard (CWS) for petroleum hydrocarbons in soil (PHCs) for two reasons. The methods currently in use quantify different fractions of PHCs normally found in soil and secondly, an analytical method must be used in a consistent manner to give consistent results. An interlaboratory study conducted at the beginning of the CWS process confirmed this with results varying by factors of 40.

To develop the method an Analytical Methods Technical Advisory Group (AMTAG) was struck consisting of representatives of provincial and federal governments, the petroleum industry and the private laboratory industry. After considerable effort a consensus was reached on a draft method which was pilot tested and then subjected to an interlaboratory study during the summer of 1999. Based on comments from participants in the study and the PHC CWS Development Committee, the method was finalized (CCME 2001b).

The method is a mixture of performance based elements and prescribed procedures. Effort has been expended to ensure that, if applied properly, the method provides results useful for application of the CWS to PHC contaminated sites. Substitution of alternative methods for use in applying the CWS should only occur if a comprehensive statistical comparison has been conducted. No sampling protocol was developed but reference is made to existing CCME, US EPA and ASTM resources.

The method covers hydrocarbon ranges for nC6 to above nC50 as well as percentage moisture. The analytical fractions were chosen to meet the requirements of the CWS. These are nC6 to nC10 (F1), >nC10 to nC16 (F2), >nC16 to nC34 (F3) and >nC34 to nC50(F4). nC50 is probably the highest molecular weight hydrocarbon that can be routinely chromatographed on normal laboratory equipment. In addition a Gravimetric Heavy Hydrocarbon sub method was developed to account for the fraction occurring above nC50. It is recommended that this result be used if it is greater than the nC34 to nC50 fraction.

It was recognized during the interlaboratory study that laboratories performed better if they had had experience with the method. Thus the continuation of ongoing interlaboratory studies is recommended. Initially these would improve user laboratories' knowledge and handling of this complex method. They would help characterize method performance characteristics such as method detection limit, which is presently being assessed in a single laboratory validation study. After the CWS is incorporated into regulations or guidelines, then these studies would become a means of assessing laboratory performance.

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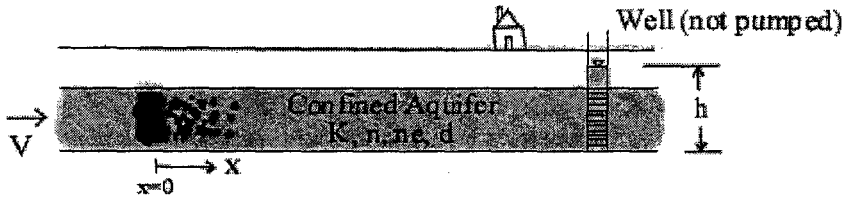
Groundwater Contaminant Transport Calculation: Step Injection

Chemical injected during a finite time period. Compute concentration as a function of time and distance or back-calculate injected concentration. Advection, dispersion, and retardation.

To: LMNO Engineering home page Trouble printing?
Compute gradient from well head measurements
3-D Slug injection with advection and dispersion Unit Conversions Registration



Register to enable "Calculate" button.

Not registered user	Concentration, C (mg/l):	Will be computed
Click to Calculate	Time, t (day), to compute C:	1000.0
	Distance, x (m), to compute C:	30.0
☑ Check box to include retardation	Injected Concentration, Co (mg/l):	10000.0
Solve for C	Duration of Injection, T (day):	100.0
Sandy Soil (sets K, n, ne, d)	Dispersivity, a (m):	10.0
Trichloroethylene (TCE) (sets Koc)	Diffusion Coeff, D* (m²/s):	1.0E-9
	Hydraulic Cond, K (cm/s):	0.0010
Select Units:	Hydraulic Grad, -dh/dx (m/m):	0.0070
Concentrations in mg/l or ppm	Total Porosity, n (%):	35.0
Times in days	Effective Porosity, ne (%):	25.0
Distance in m	Soil Bulk Density, d (g/cm³):	1.6
Dispersivity in m	Soil Organic Carbon, foc (%):	0.1
Diff. and Disp. Coeff. in m²/s	Org. Carbon Coeff, Koc (cm³/g):	100.0
Hydraulic Conductivity in cm/s	Distribution Coeff, Kd (cm³/g):	Will be computed
Hydraulic Gradient in m/m (ft/ft)	Retardation Coeff, Rf:	Will be computed
Soil Bulk Density in g/cm³	Pore Water Velocity, Vw (m/s):	Will be computed
Koc and Kd in cm³/g	Chemical Velocity, Vc (m/s):	Will be computed
Velocities in m/s	Dispersion Coeff, D (m²/s):	Will be computed
http://www.LMNOeng.com	Peclet Number, Pe=Vc(x/D):	Will be computed
© 2000 LMNO Engineering,	Plume leading edge, Vc*t (m):	Will be computed
Research, and Software, Ltd.	Plume trailing edge, Vc*(t-T) (m):	Will be computed

Topics on this page: Introduction Equations Applications Variable Definitions Property Data Error Messages References

Introduction

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This calculation simulates one-dimensional (x-direction) transport of a chemical in a confined

groundwater aquifer. It is also valid for transport in an unconfined aquifer if the head gradient (dh/dx) is nearly constant. There are two common boundary conditions for chemical transport: One is a step (i.e. continuous) injection of chemical - the chemical is added at $x=0$ from time $t=0$ to $t=T$. The other common boundary condition is a pulse input where a mass of chemical is added instantaneously at $x=0$. This web page uses the first boundary condition though a pulse input can be simulated by using a short injection time T. The calculation solves for concentration at whatever time and distance is desired by the user.

The calculation includes advection, dispersion, and retardation. Advection is chemical movement via groundwater flow due to the groundwater hydraulic (i.e. head) gradient. Dispersion is the longitudinal (forward and backward) spreading of the contaminant. If there were no dispersion, all of the contaminant would travel at the mean chemical velocity. With dispersion, some chemical travels faster and some slower than the mean velocity; the chemical "spreads out." Retardation causes the mean chemical velocity to be slower than the groundwater velocity. If your chemical exhibits no dispersion, set both the dispersivity (a) and diffusion coefficient (D^*) to zero. If the chemical is not retarded, then uncheck the retardation check box or use the chemical drop-down menu to select "User enters K_{oc}" and set $K_{oc}=0.0$.

Equations

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Governing Equation and Boundary Conditions

The governing equation for one-dimensional chemical transport in groundwater with advection, dispersion, and retardation is (Van Genuchten and Alves, 1982):

$$R_f \frac{\partial C}{\partial t} = D \frac{\partial^2 C}{\partial x^2} - V_w \frac{\partial C}{\partial x}$$

Boundary and Initial Conditions:

$$C(x, t=0)=0 \qquad \frac{\partial C}{\partial x}(x=\infty, t)=0$$

$$C(x=0,\ 0<t\le T)=C_o \qquad C(x=0,\ t>T)=0$$

Solution

The solution to the governing equation and boundary conditions shown above is (Van Genuchten and Alves, 1982):

$$C(x,t)=\frac{C_o}{2}A(x,t) \quad \text{for } 0<t\le T$$

$$C(x,t)=\frac{C_o}{2}[A(x,t)-A(x,t-T)] \quad \text{for } t>T$$

where:

$$A(x,t)=\operatorname{erfc}\left(\frac{x-V_c t}{2\sqrt{Dt}}\right)+\exp\left(\frac{V_c x}{D}\right)\operatorname{erfc}\left(\frac{x+V_c t}{2\sqrt{Dt}}\right)$$

$$A(x,t-T)=\operatorname{erfc}\left(\frac{x-V_c (t-T)}{2\sqrt{D(t-T)}}\right)+\exp\left(\frac{V_c x}{D}\right)\operatorname{erfc}\left(\frac{x+V_c (t-T)}{2\sqrt{D(t-T)}}\right)$$

$$V_c=\frac{V_x}{R_f} \qquad V_x=-\frac{K}{n_e}\frac{dh}{dx} \qquad R_f=1+\frac{d\ K_d}{n}$$

D^*

$$K_d = K_{oc} f_{oc} \qquad D = a V_c + \frac{\nu}{n_e}$$

erfc( ) is called the "complementary error function." Our calculation uses the most accurate numerical representation of erfc( ) given in Abramowitz and Stegun (1972, eqn 7.1.26).

Applications

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The following graphs were developed to demonstrate effects of dispersion for trichloroethylene (TCE) in a sandy aquifer as predicted by the calculation. The following data were used:

C_o = 10,000 mg/l, d = 1.6 g/cm^3, dh/dx = -0.007 m/m, D^* = 0, f_{oc} = 0.1%,

K = 0.001 cm/s, K_{oc} = 100 cm^3/g, n = 35%, n_e = 25%. Click for variable definitions

Therefore, K_d = 0.1 cm^3/g, R_f = 1.46, V_w = 2.8x10^{-7} m/s, and V_c = 1.92x10^{-7} m/s.

Two injection durations were used: *T=1,000,000 days* in Figure 1 and *T=100 days* in Figure 2. For Figure 1, *T* was selected large enough to simulate an infinite duration injection. In both figures, the concentration front occurs at $x = V_c t = 16.6$ m when $a=0$. In Figure 2, the trailing edge of the concentration front occurs at $x = V_c(t-T) = 14.9$ m when $a=0$. a is dispersivity.

Figure 1. TCE concentration profile at 1000 days for an injection of duration 1,000,000 days

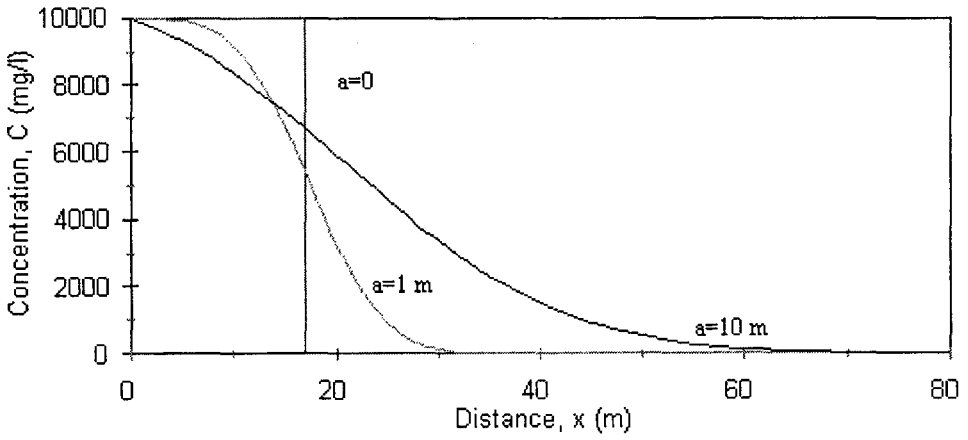
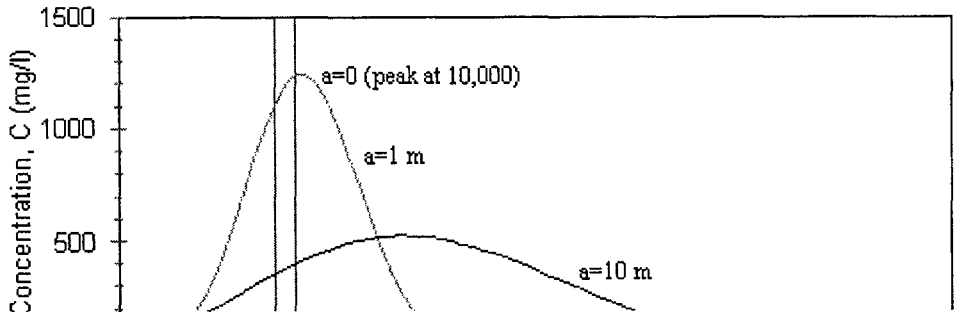
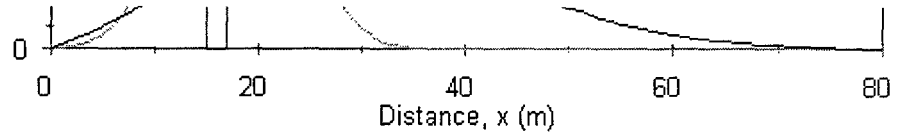


Figure 2. TCE concentration profile at 1000 days for an injection of duration 100 days.





Variable Definitions

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The variables used on this web page are:

a = dispersivity [L]. Varies from 0.1 to 100 m. Field and laboratory tests have indicated that *a* varies with the scale of the test. Large scale tests have higher *a* than small lab column tests. An approximate value for *a* is 0.1 times the scale of your system (Fetter, 1993). If you are simulating contaminant transport in a 1 m long laboratory column, then *a*~0.1 m. However, if you are simulating transport in a large aquifer greater than 1 km in extent, then use *a*~100 m.

C = Chemical concentration [M/L^3].

C_o = Injected concentration at $x=0$ [M/L^3].

d = Dry bulk density of the aquifer [M/L^3].

dh/dx = Hydraulic (or head) gradient [L/L]. Since *dh/dx* is negative, we ask you to enter *-dh/dx* so that you can enter a positive number for convenience. You determine *dh/dx* from two head measurements using the equation, $dh/dx = (h_2-h_1)/(x_2-x_1)$.

D = Dispersion coefficient [L^2/T]. The equation $D=a\ V_c + D^*/n_e$ is adapted from Ingebritsen and Sanford (1998).

D* = Molecular diffusion coefficient [L^2/T]. Varies somewhat for different chemicals but a typical value to use is 1.0×10^{-9} m^2/s (Fetter, 1993).

f_{oc} = Organic carbon fraction in soil [%]. (Mass organic carbon per mass soil) x 100%.

K = Hydraulic conductivity of aquifer [L/T].

K_d = Distribution coefficient [L^3/M]. Represents chemical partitioning between groundwater and soil.

K_{oc} = Organic carbon partition coefficient [L^3/M]. Represents chemical partitioning between organic carbon and water in soil. Good discussion in Lyman et al. (1982).

n = Total porosity of soil [%]. (Void volume/total volume) x 100%.

n_e = Effective porosity [%]. Porosity through which flow can occur. A thin film of water bound to soil particles by capillary forces does not move through the aquifer. n_e is always <= *n*.

Pe = Peclet number. $Pe=(V_c\ x)\ /\ D$. It is a commonly used dimensionless parameter indicating the relative impact of inertial effects to dispersive effects.

R_f = Retardation factor. $R_f=1$ if there is no retardation which implies that $V_c=V_x$. $R_f=1$ would occur for a conservative tracer; that is, a tracer that does not sorb to the aquifer soil.

t = Time [T]. Time at which *C* is to be computed.

T = Duration of injection [T]. C_o is injected from $t=0$ to $t=T$.

V_c = Mean chemical velocity [L/T].

V_w = Pore water velocity [L/T]. Also known as groundwater velocity.

x = Distance [L]. Distance at which to compute *C*.

Property Data

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The following are tables of hydraulic conductivity, total porosity, effective porosity, bulk density, and organic carbon partition coefficient. Parameter values have been compiled from a variety of sources such as Coduto (1994), Fetter (1993), Freeze and Cherry (1979), Hillel (1982), and Sanders (1998). The values used in the calculation above are typical numbers within the ranges given below.

Table of Soil Properties

Soil Type	Hydraulic Conductivity K (cm/s)	Total Porosity n (%)	Effective Porosity n_e (%)	Bulk Density d (g/cm^3)
Clayey	10^{-9} - 10^{-6}	40-60	0-5	1.2-1.8
Silty	10^{-7} - 10^{-3}	35-50	3-20	1.1-1.8
Sandy	10^{-5} - 10^{-1}	20-50	10-35	1.3-1.9
Gravelly	10^{-1} - 10^{2}	25-40	12-30	1.6-2.1

Table of Organic Carbon Partition Coefficient, K_{oc}

Chemical	K_{oc} (cm^3/g)	Chemical	K_{oc} (cm^3/g)
Benzene	20-400	Pyrene	2000-200,000
Ethyl Benzene	90-1500	Tetrachloroethylene	100-3000
Dichloroethane	10-250	Trichloroethylene	20-500
Naphthalene	100-2500		

Error Messages given by calculation

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"Certain inputs must be > 0." No computations. C_o, C, d, $-dh/dx$, K, n, n_e, and T must all be > 0 if entered.

"Certain inputs must be >= 0." No computations. a, D^*, f_{oc}, K_{oc}, t, and x must all be $>= 0$ if entered.

"n, n_e, and f_{oc} must be <= 100%." No computations. Total porosity, effective porosity, and soil organic carbon cannot exceed 100%.

"n_e must be <= n." No computations. Effective porosity cannot exceed total porosity.

"C_o cannot be determined" or ***"C_o=infinity."*** C_o not computed. Certain input combinations result in computing erfc(infinity), and erfc(infinity)=0.0. Therefore, the equation $C_o=C/0.0$ results, in which C_o cannot be evaluated or is evaluated as infinity.

References

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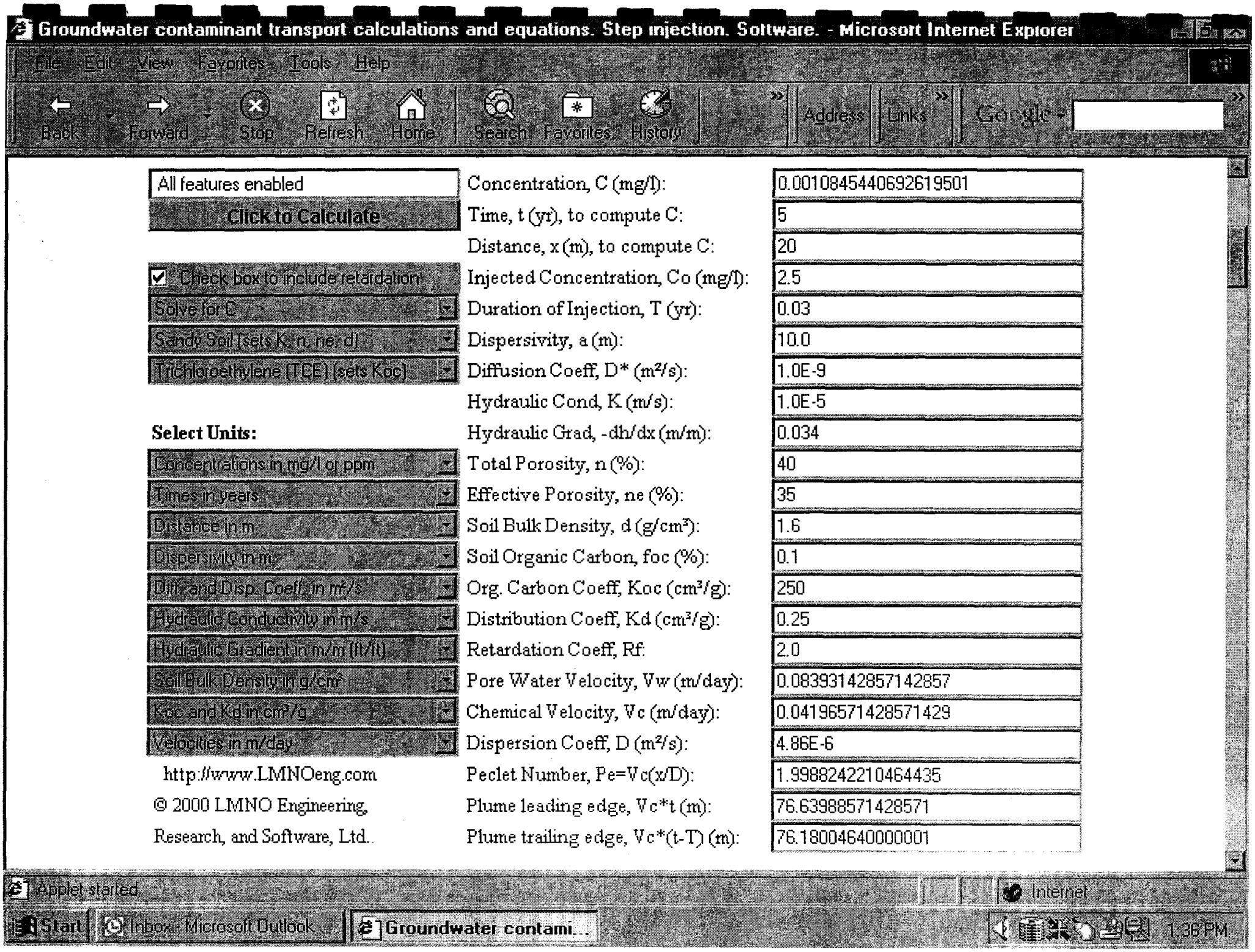
Groundwater contaminant transport calculations and equations. Step injection. Software. - Microsoft Internet Explorer
File Edit View Favorites Tools Help
Back Forward Stop Refresh Home Search Favorites History
Address Links Google
All features enabled
Click to Calculate
Check box to include retardation
Solve for C
Sandy Soil [sets K, n, ne, d]
Trichloroethylene [TCE] [sets Koc]
Select Units:
Concentrations in mg/l or ppm
Times in years
Distance in m
Dispersivity in m
Diff and Disp. Coeff. in m²/s
Hydraulic Conductivity in m/s
Hydraulic Gradient in m/m [ft/ft]
Soil Bulk Density in g/cm³
Koc and Kd in cm³/g
Velocities in m/day
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Research, and Software, Ltd.
Concentration, C (mg/l): 0.0010845440692619501
Time, t (yr), to compute C: 5
Distance, x (m), to compute C: 20
Injected Concentration, Co (mg/l): 2.5
Duration of Injection, T (yr): 0.03
Dispersivity, a (m): 10.0
Diffusion Coeff, D* (m²/s): 1.0E-9
Hydraulic Cond, K (m/s): 1.0E-5
Hydraulic Grad, -dh/dx (m/m): 0.034
Total Porosity, n (%): 40
Effective Porosity, ne (%): 35
Soil Bulk Density, d (g/cm³): 1.6
Soil Organic Carbon, foc (%): 0.1
Org. Carbon Coeff, Koc (cm³/g): 250
Distribution Coeff, Kd (cm³/g): 0.25
Retardation Coeff, Rf: 2.0
Pore Water Velocity, Vw (m/day): 0.08393142857142857
Chemical Velocity, Vc (m/day): 0.04196571428571429
Dispersion Coeff, D (m²/s): 4.86E-6
Peclet Number, Pe=Vc(x/D): 1.9988242210464435
Plume leading edge, Vc*t (m): 76.63988571428571
Plume trailing edge, Vc*(t-T) (m): 76.18004640000001
Applet started.
Internet
Start
Inbox - Microsoft Outlook
Groundwater contami...
1:38 PM

Groundwater contaminant transport calculations and equations. Step injection. Software. - Microsoft Internet Explorer

All features enabled

Click to Calculate

☑ Check box to include retardation

Solve for C

Sandy Soil (sets K, n, ne, d)

Naphthalene (sets Koc)

Select Units:

Concentrations in mg/l or ppm

Times in years

Distance in m

Dispersivity in m

Diffusion Coeff in m²/s

Hydraulic Conductivity in m/s

Hydraulic Gradient in m/m (V/t)

Soil Bulk Density in g/cm³

Koc and Kd in cm³/g

Velocities in m/s

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Concentration, C (mg/l):	0.0010529987576527245
Time, t (yr), to compute C:	.5
Distance, x (m), to compute C:	20
Injected Concentration, Co (mg/l):	.130
Duration of Injection, T (yr):	0.03
Dispersivity, a (m):	10.0
Diffusion Coeff, D* (m²/s):	1.0E-9
Hydraulic Cond, K (m/s):	1.0E-5
Hydraulic Grad, -dh/dx (m/m):	0.034
Total Porosity, n (%):	40
Effective Porosity, ne (%):	35
Soil Bulk Density, d (g/cm³):	1.6
Soil Organic Carbon, foc (%):	0.1
Org. Carbon Coeff, Koc (cm³/g):	831.7637711026708
Distribution Coeff, Kd (cm³/g):	0.8317637711026709
Retardation Coeff, Rf:	4.3270550844106825
Pore Water Velocity, Vw (m/s):	9.714285714285715E-7
Chemical Velocity, Vc (m/s):	2.2450108733960661E-7
Dispersion Coeff, D (m²/s):	2.247868016253209E-6
Peclet Number, Pe=Vc(x/D):	1.9974579087059523
Plume leading edge, Vc*t (m):	3.5423577569141846
Plume trailing edge, Vc*(t-T) (m):	3.3298162914993337

Applet started

Internet

Start | Groundwater contami... | Inbox - Microsoft Outlook | Microsoft Photo Editor | 4:05 PM