DETERMINING NATURAL (BACKGROUND) ARSENIC SOIL CONCENTRATIONS IN YELLOWKNIFE NWT, AND DERIVING SITE-SPECIFIC HUMAN HEALTH-BASED REMEDIATION OBJECTIVES FOR ARSENIC IN THE YELLOWKNIFE AREA

FINAL REPORT

Submitted to:
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EXECUTIVE SUMMARY

The national soil quality guideline derived for arsenic by the Canadian Council of Ministers of Environment (CCME) is based on an assumed background (natural) arsenic soil concentration of 10 ppm, and a target incremental human health risk level of 1 in 1 million, which resulted in a national guideline of 12 ppm. However, CCME recognizes that inorganic elements vary significantly in natural concentration from one site or region to another. Also, CCME recognizes that the frequency, duration and intensity of use of a particular contaminated site or area may depart significantly from the assumptions used to derive the national guideline. Finally, although the CCME national guideline is based on a hypothetical risk level of 1 in 1 million, a *de minimis* risk level of 1 in 100,000 or lower is considered by Health Canada to be "essentially negligible". Following methods prescribed by CCME, to account for these site-specific factors and policy considerations, site-specific human health-based soil quality remediation objectives were derived for soil-borne and sediment-borne inorganic arsenic contamination in the Yellowknife area.

Based on data available from the Geologic Survey of Canada, the Environmental Sciences Group of the Royal Military College of Canada (Kingston, ON), and data provided by Miramar Mining Ltd. (Con Mine), the average natural background concentration of arsenic in and around Yellowknife was determined to be 150 ppm, with a reasonable upper limit of normal concentration (the 90th percentile value of the distribution of available data) of about 300 ppm.

Site-specific human health-based soil quality remediation objectives were derived following CCME procedures for residential and industrial land uses, as well as for non-residential, publicly-accessible areas such as a proposed local public boat launch. Accounting for the observed background arsenic concentrations in soil, considering a 1 in 100,000 *de minimis* cancer risk level, and considering the limitations on land use (i.e., impacts on the frequency, duration and intensity of site use) presented by the local climate, the remediation objectives presented in Table E1 have been proposed.

The remediation objective for residential properties assumes that the yard soil is accessible for exposure for 5 months per year, due to the climate. This objective should also be applied to playgrounds and urban parks within the city limits where children may frequent on a regular and routine basis for daily play. The remediation objective for industrial lands assumes that little or no public access is available, and the primary receptor is a worker on the site. The soil quality objective for a proposed boat launch assumes that a person is present on the site for 2 hours per

day, every day throughout July and August. The proposed sediment quality objective also assumes that a person is wading bare foot each day throughout July and August.

Table E1. Proposed remediation objectives for arsenic in Yellowknife-area soils and sediment.

Medium	----------------Land Use----------------		
	Residential (µg/g)	Industrial (µg/g)	Boat Launch (µg/g)
Soil	160	340	220
Sediment	N/A	N/A	150

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1.0 INTRODUCTION

1.1 General

Under the authorization of the Yellowknife Arsenic Soils Remediation Committee (YASRC), Risklogic Scientific Services Inc. has undertaken to review existing data and information in order to determine the range of natural (background) concentrations of arsenic in soils in and near the NWT community of Yellowknife. Additionally, site-specific human health-based remediation objectives have been derived for residential properties, industrial (mine) properties and any area that may be proposed for development as a public boat launch. The purpose of those objectives is to define concentrations for arsenic in soil that are risk-based, consistent with these different land uses, and that adequately and appropriately account for arsenic levels of natural origin, as described by procedures of the Canadian Council of Ministers of Environment (CCME, 1996a,b).

1.2 The Need to Quantify Background Levels of Arsenic in Yellowknife Soil

Arsenic is a natural element that is ubiquitous in the environment (EC, 1996; EC/HC, 1993). The natural concentrations of arsenic in soils vary widely (Klassen, undated). Although arsenic concentrations in southern Canadian agricultural and urban soils are generally less than or equal to about 10 μg/g (ppm) (EC, 1996), concentrations in soils and tills overlaying bedrock that is naturally high in arsenic have considerably higher natural arsenic concentrations.

As with all natural elements, arsenic is released from geologic formations (bedrock) during the natural weathering processes that lead to the formation of soils. As a result, the concentration of arsenic in undisturbed, non-polluted soil will reflect and correlate with the concentration of arsenic in the bedrock from which it was formed (Klassen, undated). This fact is the basis for mineral prospecting methods in which soil surveys for arsenic, and other elements, are routinely conducted in order to identify areas of high natural element concentration, as a marker for mineral deposits of potential economic significance (see Boyle, 1979, as this relates to gold exploration, for example).

To establish a national human health risk-based soil quality guideline for arsenic in Canada, the CCME (1997) (see also EC, 1996) derived a concentration that presented a hypothetical incremental skin cancer risk (due to soil ingestion) of 1 in 1 million 'above background'. CCME attempts to define the additional concentration above background that, while being above natural levels, still does not exceed a tolerable or acceptable 'incremental' (additional) increase in risk. That guideline was composed of an assumed national background arsenic soil concentration of 10 ppm and an additional 2 ppm, that was thought to be associated with that incremental 1 in 1 million risk, for a total guideline concentration of 12 ppm.

However, CCME recognizes that the natural concentrations of inorganic elements such as arsenic vary widely across Canada. As a result of this wide spatial variability in natural soil concentrations, the CCME (1996b) acknowledges that remediation to a concentration below natural background is neither generally feasible nor justified. Therefore, for arsenic soil contamination in Yellowknife, a site-specific remediation objective should be derived that adheres to the same risk-based principles as espoused by the CCME methodology, but will account for the natural elevation of arsenic in Yellowknife area soils. Those concentrations significantly exceed the 10 ppm concentration assumed as the basis of the generic national risk-based guideline.

The purposes of this report are to: 1) review existing reports and information towards quantifying the natural concentration of arsenic in Yellowknife soils; and 2) employ that background (natural) arsenic soil concentration and, following CCME (1996a,b) and recent revisions to the CCME guideline derivation process, establish local soil quality remediation objectives for arsenic for different land uses within the Yellowknife area.

2.0 NATURAL (BACKGROUND) CONCENTRATIONS OF ARSENIC IN YELLOWKNIFE SOILS

Four separate lines of evidence will be reviewed and discussed that contribute to delineating natural background concentrations of arsenic in the soils of the Yellowknife area. These lines of evidence are:

1) data collected by staff of the Geological Survey of Canada with respect to arsenic concentrations in tills overlying the volcanic Greenstone Belt that underlies Yellowknife, NWT (that geologic formation being the source of gold ore deposits for both the Con and Giant mines);
2) data collected by staff of the Geological Survey of Canada with respect to arsenic concentrations in tills overlying similar geologic formations elsewhere in NWT;
3) regression analysis of data collected by Miramar Mining (Con Mine) respecting the concentrations of arsenic and a variety of other elements in soil samples collected in and around Yellowknife, NWT; and
4) a principal components analysis conducted by the Environmental Sciences Group (ESG) of the Royal Military College, Kingston, on data they collected in 1999 and 2000 respecting the concentrations of arsenic and a variety of other elements in soil samples from in and around Yellowknife, NWT.

2.1 GSC Data on Arsenic in Tills Overlying the Yellowknife Greenstone Belt

Elevated concentrations of arsenic are known to be associated with deposits of gold (Boyle, 1979; Kerswill and Falck, 2001). Therefore, surveys of arsenic concentrations in soils and tills have been used to prospect for gold deposits in the Yellowknife area (Boyle, 1979; Kerswill and Falck, 2001) as well as mineral deposits elsewhere in the NWT (Cameron and Durham, 1974, for example). As a result, data have been collected on natural concentrations of arsenic in and around Yellowknife and other similar areas that can be evaluated to help define the natural or background concentration of arsenic in area soils.

The gold deposits in the Yellowknife area are associated with the so-called "Yellowknife Greenstone Belt" (Henderson, 1985; McDonald et al., 1993) which is part of the Slave Structural Province (Henderson, 1985). A greenstone belt is an elongate or belt-like geological formation that contains metamorphosed volcano-sedimentary deposits; such formations are of economic interest due to the presence of metal deposits (Bates and Jackson, 1980). The gold mineralization within the Yellowknife Greenstone Belt has resulted in the Giant and Con mines being among the most significant gold producers in Canada (Henderson, 1985).

The Yellowknife Greenstone Belt is a deposit of predominantly volcanic origin that borders Yellowknife Bay of Great Slave Lake. It extends from approximately 20 km south of Yellowknife in a more or less northerly direction to approximately 30 km north of Yellowknife (Henderson, 1985), with geologically-related deposits located 80 to 100 km and more beyond (D. Kerr, Geological Survey of Canada, personal communication). The city of Yellowknife is totally underlain by this same Greenstone Belt (Henderson, 1985) and, therefore, the minerals and elements occurring in the undisturbed soils in and around Yellowknife will reflect the mineralization of this underlying geologic formation.

During 1999 and 2000, staff of the GSC collected till (sub-soil) samples overlaying the Yellowknife Greenstone Belt, for analysis of arsenic and other elements (Kerr, 2001). To ensure a lack of influence from atmospheric deposition, and to ensure that the samples clearly reflected the underlying geology, till samples were collected from 10 cm to 60 cm depth below grade. Samples collected at depth are free of potential industrial influence (NRCan, undated).

The data of Kerr (2001) are summarized in Table 2.1. He collected a total of 67 samples of till (soil) that overlaid bedrock of volcanic origin (same as what underlies Yellowknife). The naturally-occurring concentrations of arsenic ranged from 7 ppm to 1,560 ppm, with an arithmetic average of 153 ppm and a median value of 39 ppm. The 90th percentile concentration from the data presented by Kerr (2001) is 320 ppm.

The soil-borne arsenic content is obviously elevated, relative to agricultural soils or the national CCME soil quality guideline, but it is also natural in origin.

2.2 GSC Data on Arsenic in Tills Overlaying Volcanic Geologic Formations Elsewhere in NWT

Geologic formations similar to that underlying Yellowknife are relatively common in the NWT. They give rise to active mines or ore deposits of significant economic potential across the Territory. One such area is located at Agricola Lake, which is located within the same geologic Slave Structural Province (Cameron and Durham, 1974). The geologic formation at Agricola Lake is similar in volcanic origin to the Yellowknife Greenstone Belt and similarly has elevated concentrations of arsenic and other elements in the soils and tills overlaying it.

Data on arsenic levels in till samples collected from the Agricola Lake area are summarized in Table 2.1. As for samples collected by Kerr (2001), Cameron and Durham (1974) collected soil samples below grade, in this case at a depth of 15 to 20 cm. As observed for soils overlaying the Yellowknife Greenstone Belt, arsenic levels in soils around Agricola Lake are elevated relative to what is typically observed for agricultural soils in southern Canada. The arsenic content in soils overlaying the Agricola Lake geologic formation ranged from 2 ppm to 890 ppm with an arithmetic average of 73 ppm and a median value of 25 ppm. Arsenic soil concentrations reported by Cameron and Durham (1974) were slightly lower than those reported for the Yellowknife area. However, the data of Cameron and Durham (1974) were not exclusive to tills overlying greenstone deposits but encompassed some samples from soils overlying closely adjacent deposits of differing geologic composition. Therefore, a lower average arsenic concentration (compared to that from data of Kerr, 2001) was expected. However, the data again clearly demonstrate that arsenic levels in soils overlaying such formations are routinely an order of magnitude or more higher than those of southern agricultural soils.

2.3 Con Mine Data on Arsenic and other Elements in Soils In and Around Yellowknife

In 1987, the Con Mine conducted an extensive soil sampling survey in and around Yellowknife. A total of 1791 samples of surficial soil were collected and analyzed for a variety of elements. Of those, 1685 samples provided reliable (>detection limit) analyses of arsenic content. Those data are summarized in Table 2.1. With the maximum reported concentration ranging up to 58,000 ppm, it is quite apparent that the sampling program included the collection of contaminated material such as tailings and waste rock from the Con Mine property. However, many of the soil samples also represent undisturbed soils containing arsenic of natural origin.

For samples of the natural soil, it can be expected that the ratio of arsenic concentration to the concentration of other elements would be relatively consistent, reflecting the ratio of these elements arising from the underlying bedrock. It can also be expected that the ratio of arsenic concentration to the concentration of other elements will be consistent in mine tailings and mining debris (waste rock, processed ore, etc.), however this latter ratio will be different from that for natural soils. The mining processes from which the tailings and debris arose will have increased or decreased the concentration of the various elements relative to arsenic when compared to natural soil.

As a result, if the concentrations of arsenic in the soil samples are plotted on a graph against the concentrations of the other elements in the same soil samples, you would not expect to observe a single, straight regression line through all points, but rather the data derived from soil samples would define one regression line, while samples derived predominantly from mine tailings and other waste material would define one other (or more) separate regression line, with differing slope and/or intercept.

Figures 2.1 through 2.5 present the regression of concentrations of silver (Ag), gold (Au), copper (Cu), lead (Pb) and zinc (Zn) against that of arsenic from the data collected by the Con Mine. The numerous individual points of each plot have not been displayed so that the line reflecting the overall trend in their relationship is clearly evident. A statistically-objective smoothing technique (LOWESS; see Wilkinson et al., 1992) was employed to draw that trend line so as not to arbitrarily pre-define the statistical relationship.

In Figures 2.1 through 2.5, a second trend line is also presented, one that reflects the relationship between arsenic concentration and that of each of the other elements in those samples that can be assumed to be tailings and/or mining debris (i.e., that data that contains the highest reported concentrations of arsenic). The point at which the LOWESS curve deviates from that second trend line is interpreted to indicate the point at which the samples begin to contain element concentrations of natural origin (i.e., soil). That point of deviation (indicated in the Figures by a vertical line) is interpreted to represent an upper limit for arsenic concentration that is natural in origin.

The arsenic concentrations associated with those points of deviation range from approximately 79 ppm to 794 ppm. Although there would be some overlap between the upper range in natural soils and the lower range of industrially-contaminated samples, the arsenic concentrations associated with these points fall generally within the range of natural arsenic concentrations observed for undisturbed soils overlaying volcanic bedrock in the area (see Kerr, 2001; and Table 2.1).

2.4 Evidence Presented by ESG, Royal Military College, Kingston

Ollson et al. (2001) undertook an analysis of data from samples of Yellowknife soil, mine tailings and sediment, towards differentiating natural from industrially-contaminated samples. As above (for the Con Mine soil survey data), it was assumed that the relative concentrations of the various natural elements detected in the soil, sediment and tailings samples would differ between natural soils and soils impacted by industrial emissions (C. Ollson, ESG, personal communication). However, individual regression analyses of arsenic concentration versus the concentrations of the other natural elements had failed to detect any point of inflection that might define the presence of both naturally-contaminated and industrially-contaminated samples (Ollson et al., 2001). It is likely that the smaller number of samples (n = 217 for ESG samples, versus >1600 samples from the Con Mine survey) provided an insufficient quantity and mix of sample types to differentiate natural and anthropogenic soil contamination via simple regression analysis. Therefore, principal components analysis (PCA) was employed.

PCA is a robust statistical technique for evaluating the degree of association between multiple variables in a group of samples (such as the concentrations of arsenic, gold, etc. in soil samples). PCA permits the simultaneous inclusion of several variables for greater statistical power in differentiating groups or clusters with common characteristics or associations within the samples.

Ollson et al. (2001) evaluated a total of 217 soil, sediment and tailings samples for which analyses had been conducted for 10 natural elements: arsenic, antimony, iron, gold, potassium, sodium, zinc, manganese, copper and nickel. The PCA analysis suggested that natural soil levels of arsenic in the samples analyzed ranged from about 3 ppm to 150 ppm.

Subsequent PCA analysis of only those samples clearly characterized as soil (n = 142) was undertaken by ESG at the request of Risklogic Scientific Services Inc. (ESG, 2001). These later results suggested a natural level of arsenic in the Yellowknife soils samples analyzed ranging from 3 ppm to 218 ppm.

2.5 Conclusions Respecting Natural (Background) Arsenic Levels in Yellowknife Soils

Based on the preceding discussions and analyses, it is apparent that soils in the Yellowknife area contain natural arsenic levels well in excess of the CCME soil quality guideline for arsenic, and in excess of natural levels observed in agricultural soils from southern Canada. Naturally-occurring levels of arsenic can exceed 1,500 ppm in the soils overlaying the Yellowknife Greenstone Belt.

Based on the forgoing, it was concluded that the average concentration derived from the data of Kerr (2001; approximately 150 ppm) was a reasonable measure of the average or typical naturally-occurring level of arsenic in Yellowknife soils, a concentration corroborated by the analyses of Ollson et al. (2001) and ESG (2001). A reasonable upper limit of normal was selected as 300 ppm, this latter statistic being the approximate 90th percentile concentration from the data provided by Kerr (2001).

3.0 PROPOSED HEALTH-BASED REMEDIATION OBJECTIVES FOR RESIDENTIAL, INDUSTRIAL AND RECREATIONAL SITES IN YELLOWKNIFE

Contamination at the Giant and Con Mines is known to be significant, with some soil samples containing up to 87,000 ppm of arsenic (Ollson et al., 2001). Therefore, remediation of the mine sites is likely to be undertaken, and a remediation objective was required to help design remedial strategies and for subsequent confirmation of remedial success.

A remedial objective for residential properties was also desired. Although contamination within the city of Yellowknife does not appear to be generally greater than natural levels typical of soils overlying the Yellowknife Greenstone Belt (see RSSI, 2002), it is possible that some individual residential properties may be identified in the future that have higher than average levels of contamination and, therefore, require remediation. This may be particularly true of any properties where mining debris, such as waste rock or "mine muck", was used to surface a driveway or backfill parts of the property. Also, as reported in RSSI (2002), the land in and around the Con trailer courts, that for all intents and purposes represents residential land use, exceed the average background (natural) arsenic concentration and may require remediation or risk management.

Finally, RSSI was directed to propose a remedial objective for an area being considered for a public boat launch, an area that was known to be contaminated. Such a site will present significantly lower exposures and risks, relative to residential properties, due primarily to the limited frequency, duration and/or intensity of site use. Therefore, contamination on such sites can be greater than that which might be construed as tolerable or acceptable for residential land. However, allowable contamination will be less than what would normally be acceptable for industrial lands, the latter generally having restricted public access.

3.1 CCME Soil Quality Guidelines for Arsenic

The Canadian Council of Ministers of Environment has established a protocol for the derivation of risk-based soil quality guidelines that are protective of human health (CCME, 1996a). For carcinogens such as arsenic, the protocol prescribes that the background soil concentration (for natural elements) should be increased by an amount associated with an 'acceptable' or *de minimis* incremental cancer risk. For purposes of the national guideline, the CCME prescribed a *de minimis* incremental cancer risk of 1 in 1 million, and derived a Canadian national soil quality guideline of 12 ppm (CCME, 1997); background of 10 ppm + 2 ppm (associated with an estimated 1 in 1 million risk) for a total of 12 ppm. However, the CCME and Health Canada acknowledge that such a risk level is a matter of policy rather than science and, in fact, arsenic guidelines were derived for a range of risk levels, from 1 in 10,000 (210 ppm), to 1 in 10 million (10.2 ppm) (HC, 1995a). The CCME allows for individual jurisdictions to apply their own policy on *de minimis* risk while still maintaining consistency and integrity with the CCME process.

The CCME has recently revised its general approach to establishing soil quality guidelines for residential and other land uses. Originally, CCME (1996a) prescribed that the acceptable soil concentration should be derived considering simultaneous exposure via soil ingestion, particulate inhalation and dermal absorption. However, in practice, the CCME established all human health-based soil quality guidelines for non-volatile, non-soluble inorganic and organic substances (including arsenic) solely on the basis of direct soil ingestion (see CCME, 1997, 1999).

While preparing the Canada Wide Standard for Petroleum Hydrocarbons (CCME, 2001), CCME revised its general approach, establishing separate guideline values for each of soil ingestion, inhalation, and dermal absorption. It then selected the lowest value (i.e., for the pathway with the greatest estimated exposure) as the national PHC health-based soil quality guideline. That approach ensured that the pathway with greatest potential for exposure and risk was the basis of the soil quality guideline, while avoiding the compounding of uncertainties and conservatisms that would result if all exposure pathways were combined simultaneously.

This same approach has been adopted herein such that proposed remedial objectives have been determined for each of direct ingestion (of soil, house dust and backyard produce), particulate inhalation, and dermal absorption from soil and house dust. Dermal absorption from sediments while wading was included during determination of a remedial objective for the boat launch area. Dermal absorption from water while swimming was omitted here due to its relatively low contribution to total exposure (see RSSI, 2002) and because water levels of arsenic in the Yellowknife area are not strongly linked to arsenic levels in either soil or sediment (see Jackson et al., 1996, with respect to water and sediment).

3.2 CCME Remediation Objectives

Comparison of local contaminant soil concentrations to the CCME national soil quality guidelines is considered Tier 1 in the contaminated site assessment process. Tier 2 in that process generally involves the derivation of site-specific soil quality remediation objectives (CCME, 1996b). CCME recognizes that inorganic elements may be present at natural concentrations greater than that assumed for the Tier 1 guideline, and/or site-specific factors and conditions may result in reduced exposure to environmental contaminants. As a result, site-specific soil quality objectives can be developed, consistent with the CCME protocol for national guidelines, that achieve an acceptable *de minimis* risk level, but that correct or adjust for site-specific factors.

3.3 Remediation Objectives for Arsenic in Yellowknife soils

As discussed above, Yellowknife soils have a significantly higher background arsenic content than was assumed for purposes of deriving the national CCME soil quality guideline of 12 ppm. Rather than having a background concentration of 10 ppm, Yellowknife soils have an average natural concentration of about 150 ppm, and a reasonable upper limit of normal concentration of 300 ppm.

Other conditions in Yellowknife are different from those assumed for the derivation of the Tier 1 guideline. The national CCME guideline assumed that the soil was accessible for exposure for 365 days per year. Obviously, the climate in Yellowknife prevents year-round soil contact, limiting it to only a 5 month ice-free/snow-free period (EC, 2001).

Although the CCME national soil quality guideline for arsenic of 12 ppm is based on a *de minimis* risk level of 1 in 1 million, the CCME does allow jurisdictions to apply their own policies with respect to acceptable risk levels. Health Canada (1995b) considers that a risk level of 1 in 100,000 or lower can be considered as essentially negligible. Consistent with this federal position, both RSSI and the YASRC consider that a risk level of 1 in 100,000 is *de minimis*. Given that the background incidence of cancer in Canada is approximately 1 in 3, management of environmental contamination to a level more than 30,000 times lower is believed to be reasonably conservative with respect to health protection.

Considering the above-noted site-specific factors and policy issues, remediation objectives were derived for Yellowknife consistent with CCME procedures as discussed above in Section 3.1. Since arsenic is a carcinogenic substance, CCME (1996a) prescribes the derivation of soil quality guidelines (and objectives) on the basis of its carcinogenic potential in an adult receptor. An adult receptor is used due to the fact that chronic (life-long) exposure is assumed to be required for cancer formation as a result of environmental contamination, and the adult age range (20+ years) represents the vast majority of total life expectancy. The remediation objectives presented herein were derived in this same manner.

3.3.1 Residential Soil Quality Objective

Use and occupation of residential properties in Yellowknife will be significantly limited by climate. In particular, potential access to a residential garden, sand box or bare soil is only likely to be possible for 5 months of the year (See RSSI, 2002). During the winter months, contact with indoor dust was considered. The concentration of elements in indoor dust is approximately 30% of that found in outdoor soil (Calabrese and Stanek, 1992).

The equations used to derive pathway-specific (ingestion, inhalation, dermal absorption) soil quality objectives are presented in Table 3.1, while necessary input parameters are presented in Table 3.2 (receptor-specific) and Table 3.3 (substance-specific and site-specific).

Based on those equations and the defined assumptions and receptor characteristics, site-specific soil quality remediation objectives for ingestion, inhalation and dermal absorption were derived (see Table 3.4). The lowest derived residential remedial objective was for direct soil ingestion, with a value of 160 μg/g (rounded to two significant digits). This value is proposed as the remedial objective for residential lands in the Yellowknife area. This concentration recognizes the relatively high natural background levels in the area, and will ensure that exposure will lead to no more than an incremental risk of 1 in 100,000 given the local climate and how it will influence peoples' contact and interaction with the soil.

It should be noted that the proposed objective is still within the range of observed natural concentrations of arsenic in Yellowknife-area soils. However, to be conservative, it should be assumed that contamination in excess of 160 ppm on residential properties is industrial in origin.

This remedial objective should also be applied to urban parks and playgrounds where contamination is found. Parks and playgrounds often substitute for children's main play areas and, as such, may constitute the main source of both ingestion and dermal exposure for younger age groups.

3.3.2 Industrial Soil Quality Objective

Industrial lands are assumed to have little or no public access, and the receptor for exposure is anticipated to be an adult worker on the site. Besides the 5 month period of snow-free conditions, workers will attend an industrial site generally for up to 10 hours per day, 5 days per week (CCME, 1996a).

The equations for deriving ingestion, inhalation and dermal site-specific soil quality remediation objectives for arsenic in industrial soils are presented in Table 3.1.

Based on these equations and necessary assumptions and receptor characteristics (Tables 3.2 and 3.3), site-specific soil quality remediation objectives were derived for direct ingestion, particulate inhalation and dermal contact (see Table 3.4). The remedial objective derived for the dermal pathway, 340 µg/g, is the lowest for the identified exposure pathways and is proposed for application to industrial lands in the Yellowknife area. This concentration recognizes the natural background levels in the area, and will ensure that exposure will lead to no more than an incremental risk of 1 in 100,000 given the local climate and assuming that industrial lands are restricted to public access. For this land use, the upper limit of normal concentration (300 ppm) was employed as the measure of natural background arsenic concentration. This is consistent with methods employed by the Ontario Ministry of Environment, for example, when establishing human health-based soil quality guidelines, and reflects the generally greater overall presence of natural arsenic on the mine sites, which are situated in close proximity to sheers, faults and other geologic structures with elevated and exposed mineralization (the reason the mines are located where they are).

It should be noted that the proposed objective is still within the range of observed natural concentrations of arsenic in Yellowknife-area soils. However, to be conservative, it should be assumed that contamination on industrial properties, in excess of this objective, is industrial in origin.

3.3.3 Boat Launch Area

RSSI was requested to derive soil and sediment remedial objectives for a proposed public boat launch on Giant Mine property. Besides the launching and trailering of boats, the area may also be used for recreational fishing or wading and swimming. It can be conservatively assumed that a dedicated fisher or wader/swimmer might spend an average 2 hours per day, 7 days per week throughout July and August at or near this location.

The equations for deriving site-specific soil and sediment quality remediation objectives for arsenic at a boat launch area are presented in Table 3.1, while necessary assumptions are detailed in Tables 3.2 and 3.3.

Based on those equations and the assumptions, site-specific soil quality remediation objectives considering soil ingestion, particulate inhalation and dermal absorption were determined (see

Table 3.4). From those, the lowest objective, 220 µg/g for the dermal exposure route, is recommended as the remedial objective for any public boat launch area in Yellowknife. This concentration recognizes the natural background levels in the area, and will ensure that exposure should lead to no more than an incremental risk of 1 in 100,000 given the local climate and assuming that no picnicking or camping on the site.

It should be noted that the proposed objective is still within the range of observed natural concentrations of arsenic in Yellowknife-area soils.

For the proposed boat launch area, a sediment quality remediation objective was also derived. Based on assumed dermal exposure for 2 hours per day throughout July and August, a sediment remediation objective of 150 µg/g (rounded to 2 significant digits) was determined. This derivation assumed that the background (natural) concentration in sediment was comparable to that in soil (see Ollson et al., 2001), and was set at 150 ppm.

4.0 CLOSURE

This report has been prepared for the exclusive use of the Yellowknife Arsenic Soils Remediation Committee (YASRC). This report pertains only to inorganic arsenic, and to the exposure pathways specifically referenced herein.

The conclusions respecting natural levels of arsenic in Yellowknife soils, and the proposed remediation objectives, are based on a limited amount of data as well as many unconfirmed assumptions concerning the frequency, duration and intensity of land use in the area. Although the proposed remediation objectives were based on data and assumptions that were considered to be generally representative, valid and/or defensible for the average or typical situation, they may not protect every individual in every possible circumstance. In particular, cancer slope factors are not derived in a manner that can guarantee the absence of health effects or risks in persons with hypersensitivity, allergy or other genetic or environmental predisposition to illness caused by the contaminant of concern. Also, the proposed remediation objectives have been derived solely on the basis of the potential chronic cancer risk and may not prevent phytotoxicity, other ecological effects, physical or chemical damage to building materials, nor prevent aesthetic impacts.

We trust that the enclosed is satisfactory for your present requirements. If you should have any questions or comments, please contact the undersigned.

Respectfully submitted,

RISKLOGIC SCIENTIFIC SERVICES INC.

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Table 2.1 Summary of data evaluated to establish the natural (background) concentration of arsenic in Yellowknife-area soils

Source	Sample size	Arithmetic mean concentration (µg/g)	Median Concentration (µg/g)	Concentration Range (µg/g)	Comments
Kerr (2001)	67	153.3	38.6	7 – 1,560	Samples of till overlaying bedrock of volcanic origin (Yellowknife Greenstone Belt)
Cameron and Durham (1974)	64	73.1	24.5	2 - 890	Samples of till overlaying bedrock at Agricola Lake, that is similar to that of the Yellowknife Greenstone Belt
Con Mine soil survey (1987)	1791	232.1	55.0	1 – 58,000	Concentration set to ½ detection limit (DL = 2 ppm) for 106 samples where As concentration <DL

Table 3.1 Equations Used to Derive Remedial Objectives for the Yellowknife Area

EXPOSURE VIA INADVERTENT INGESTION OF SOIL/DUST

The equation for a remedial objective for intake of arsenic via soil and dust ingestion is:

$$SRO_{HH} = \{(RsD_{Oral} \times BW) \div (ET_4 \times AF_{GIT} \times [(IR_S \times ET_1) + (IR_S \times 0.3 \times ET_2) + (BAF_{S-P} \times IR_{Veg})])\} + BSC$$

Where:

SRO_{HH}	= soil remediation objective for protection of human health (µg/g)
RsD_{Oral}	= risk-specific oral dose of arsenic associated with 1 in 100,000 risk level (µg/kg-d)
BW	= body weight for adult (kg)
AF_{GIT}	= absorption factor from the gastrointestinal tract (unitless)
IR_S	= adult soil ingestion rate (g/d)
ET_1	= exposure term for duration of summer (outdoor) period (months/12 months)
ET_2	= exposure term for duration of winter (indoor) period (months/12 months)
ET_4	= exposure term for days spent working per week (d/7 d; applicable to industrial land use only)
0.3	= relative proportion of outdoor soil contaminants in indoor dust (unitless)
BAF_{s-p}	= bioaccumulation factor for arsenic from soil (dry wt) to plants (fresh wt) (unitless)
IR_{Veg}	= adult backyard vegetable intake (g/d)
BSC	= background soil concentration (µg/g)

INHALATION OF CONTAMINATED SOIL PARTICLES

The equation for a remedial objective for intake of arsenic via inhalation of suspended particulate is

$$SRO_{HH} = \{(RsD_{Inhal} \times BW) \div (TSP \times P_{PM10} \times P_{Dep} \times IR_{Inh} \times ET_1 \times ET_3 \times ET_4 \times AF_{Inh})\} + BSC$$

Where:

SRO_{HH}	=	soil remediation objective for protection of human health (µg/g)
RsD_{Inh}	=	risk-specific inhalation dose of arsenic associated with 1 in 100,000 risk level (µg/kg-d)
BW	=	body weight for adult (kg)
TSP	=	total suspended particulate concentration in air (g/m^3)
P_{PM10}	=	proportion of TSP composed of particles ≤ 10 µm aerodynamic diameter (PM_{10})
P_{Dep}	=	proportion of inhaled PM_{10} deposited to respiratory system (unitless)
IR_{Inh}	=	receptor inhalation rate (m^3/d)
ET_1	=	exposure term for duration of summer period (months/12 months)
ET_3	=	exposure term for daily duration of outdoor inhalation exposure during summer period (h/d)
ET_4	=	exposure term for days spent working per week (d/7 d; applicable to industrial land use only)
AF_{Inh}	=	relative absorption factor for inhalation exposure (unitless)
BSC	=	background (natural) soil concentration (µg/g)

DERMAL CONTACT WITH SOIL/DUST

The equation for a remedial objective for intake of arsenic via dermal contact with soil and dust is:

$$SRO_{HH} = \{(RsD_{Oral} \times BW) \div (ET_4 \times AF_{Derm} \times EF_1 \times \{[ET_1 \times [(SA_H \times SL_H) + (SA_O \times SL_O)]] + [ET_2 \times 0.3 \times [(SA_H \times SL_H) + (SA_O \times SL_O)]]\})\} + BSC$$

Where:

SRO_{HH}	= soil remediation objective for protection of human health (µg/g)
RsD_{Oral}	= risk-specific oral (and dermal) dose of arsenic associated with 1 in 100,000 risk level (µg/kg-d)
BW	= body weight for adult (kg)
AF_{Derm}	= dermal absorption factor (unitless)
EF_1	= exposure frequency (events/d)
ET_1	= exposure term for duration of summer (outdoor) period (months/12 months)
ET_2	= exposure term for duration of winter (indoor) period (months/12 months)
ET_4	= exposure term for days spent working per week (d/7 d; applicable to industrial land use only)
SA_H	= surface area of hands (m^2)
SL_H	= soil loading to hands (g/m^2-event)
SA_O	= surface area of exposed skin surfaces other than hands (m^2)
SL_O	= soil loading to exposed skin surfaces other than hands (g/m^2-event)
0.3	= relative proportion of outdoor soil contaminants in indoor dust (unitless)
BSC	= background soil concentration (µg/g)

DERMAL CONTACT WITH SEDIMENT WHILE WADING (RELEVANT TO BOAT LAUNCH AREA ONLY)

The equation for a sediment remedial objective for dermal exposure during wading is:

$$SedRO_{HH} = \{(RsD_{Oral} \times BW) \div (AF_{Derm} \times EF_1 \times ET_1 \times SA_F \times SedL_F)\} + BSedC$$

Where:	$SedRO_{HH}$	=	Sediment remediation objective to protect human health (µg/g)
	RsDOral	=	risk-specific oral (and dermal) dose of arsenic associated with 1 in 100,000 risk level (µg/kg-d)
	BW	=	body weight (kg)
	SA_F	=	surface area of feet (m^2)
	$SedL_F$	=	sediment loading to feet (g/m^2-event)
	AF_{Derm}	=	Relative absorption (bioavailability factor for dermal exposure (unitless))
	EF_1	=	wading events per day (events/d)
	ET_1	=	exposure term for duration of wading season (months/12 months)
	BSC	=	background sediment arsenic concentration (µg/g)

Table 3.2 Substance-specific and site-specific parameters for derivation of remedial objectives for the Yellowknife area

VARIABLE	Symbol	Units	Residential land use	Industrial land use	Boat launch	Reference
Risk-specific Oral (+dermal) Dose of Arsenic for 1 in 100,000 risk	RsD_{Oral}	µg/kg-d	0.0036	0.0036	0.0036	based on HC, 1996
Risk-specific Inhalation Dose of Arsenic for 1 in 100,000 risk	RsD_{Inh}	µg/kg-d	0.00036	0.00036	0.00036	based on HC, 1996
Absorption (bioavailability) factor for gastrointestinal tract exposure	AF_{GIT}	unitless	1	1	1	See text, Section 3.3.1
Absorption (bioavailability) factor for dermal exposure	AF_{Derm}	unitless	0.02	0.02	0.02	Wester et al., 1993
Absorption (bioavailability) factor for inhalation exposure	AF_{Inh}	unitless	0.9	0.9	0.9	ATSDR, 2000
Bioaccumulation factor for arsenic from soil (dry wt) to plants (fresh wt)	BAF_{S-P}	unitless	0.001			Koch et al., 2001
Air-borne particle (TSP) concentration	TSP	g/m^3	2.5×10^{-4}	2.5×10^{-4}	2.5×10^{-4}	Claiborn et al., 1995
Proportion of air-borne TSP that is ≤ 10 µm aerodynamic diameter (PM_{10})	P_{PM10}	unitless	0.56	0.56	0.56	EC, 1999
Proportion of inhaled PM_{10} that is deposited to respiratory surfaces	P_{Dep}	unitless	0.4	0.4	0.4	ACGIH, 1999
Dermal exposure event frequency per day	EF_1	events/d	1	1	1	Assumed
Exposure term for duration of summer (outdoor) exposure	ET_1	months/months	5/12	5/12	2/12	EC 2001 (Res, Ind) Assumed (Rec)
Exposure term for duration of winter (indoor) exposure	ET_2	months/months	7/12	N/A	N/A	Assumed
Duration of inhalation exposure while out-of-doors during summer	ET_3	hr/hr	1.42/24	10/24	2/24	Richardson, 1997 (Res) CCME, 1996a (Ind) Assumed (Rec)
Exposure term for days per week spent working	ET_4	d/d	N/A	N/A	5/7	CCME, 1996a

Table 3.3 Receptor-specific parameters for derivation of remedial objectives for the Yellowknife area

Receptor Characteristic	Symbol	Units	Adult	Reference
Body Weight	BW	kg	70.7	Richardson, 1997
Air Inhalation Rate	IR_{Inh}	m^3/d	15.8	Allan & Richardson, 1998; Richardson, 1997
Soil Ingestion Rate	IR_S	g/d	0.02	CCME, 1996a
Soil Loading to Hands	SL_H	g/m^2-event	10	Kissel et al., 1996;1998
Soil Loading to Other Surfaces	SL_O	g/m^2-event	1	Kissel et al., 1996; 1998
Surface Area of Hands	SA_H	m^2	0.089	Richardson, 1997
Surface Area of Other Surfaces [1]	SA_O	m^2	0.250	Richardson, 1997
Sediment Loading to Feet	$SedL_F$	g/m^2-event	153.5	Kissel et al., 1996
Surface area of Feet	SA_F	m^2	0.119	Richardson, 1997
Backyard produce intake	IR_{veg}	g/d	23	See RSSI, 2002

Table 3.4 Pathway-specific and land use-specific remediation objectives for arsenic in Yellowknife-area soils. Highlighted cells identify the most conservative (lowest) remediation objectives.

Pathway	Residential (µg/g)	Industrial (µg/g)	Boat Launch (µg/g)
Soil/dust ingestion	157	343	225
Particulate Inhalation	169	338	216
Dermal Absorption – soil/dust	1418	558	2433
Dermal Absorption - sediment	N/A	N/A	[redacted]

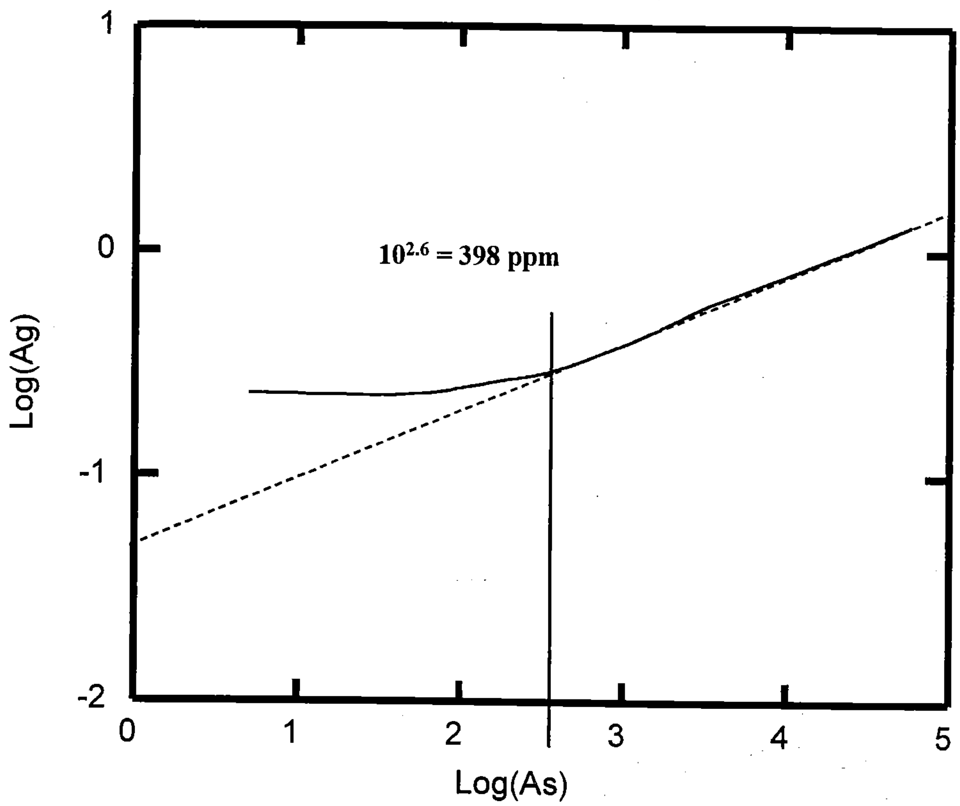

Figure 2.1 Statistical association of silver (Ag) and arsenic (As) soil concentrations from data collected by Miramar Mining (1987). Individual data points omitted so as not to obscure trend line. Curvilinear trend line drawn with LOWESS module of SYSTAT (see Wilkinson et al., 1992), which requires no subjective, *a priori* decision regarding the shape or nature of the data relationship. Linear (dashed) trend line drawn as best fit to upper portion of data. Vertical line indicates point at which data deviate from linear relationship, indicating demarcation between natural (lower values) and industrial (higher values) soil samples.

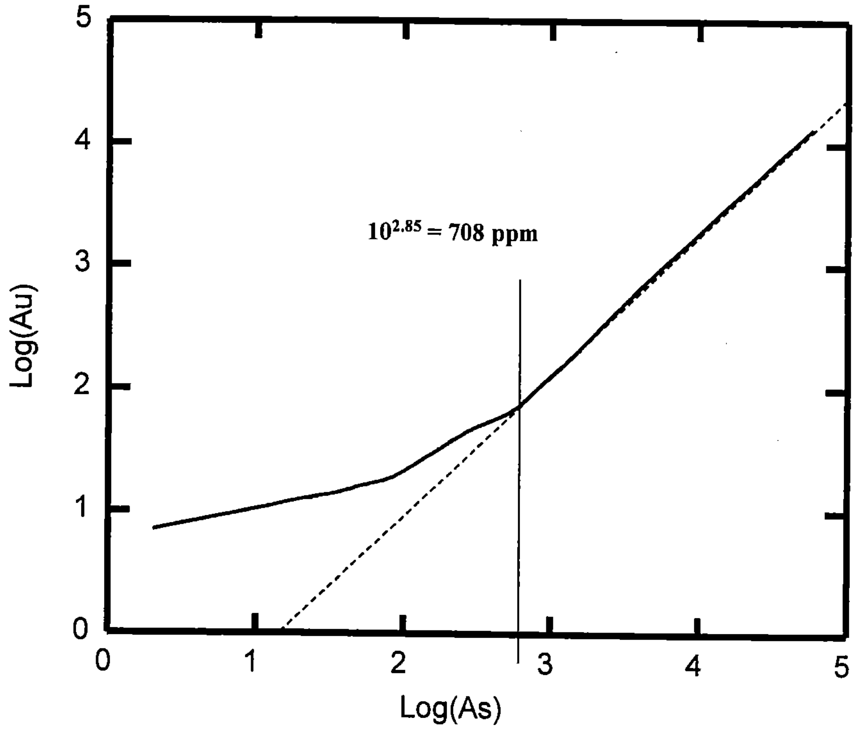

Figure 2.2 Statistical association of gold (Au) and arsenic (As) soil concentrations from data collected by Miramar Mining (1987). Individual data points omitted so as not to obscure trend line. Curvilinear trend line drawn with LOWESS module of SYSTAT (see Wilkinson et al., 1992), which requires no subjective, *a priori* decision regarding the shape or nature of the data relationship. Linear (dashed) trend line drawn as best fit to upper portion of data. Vertical line indicates point at which data deviate from linear relationship, indicating demarcation between natural (lower values) and industrial (higher values) soil samples.

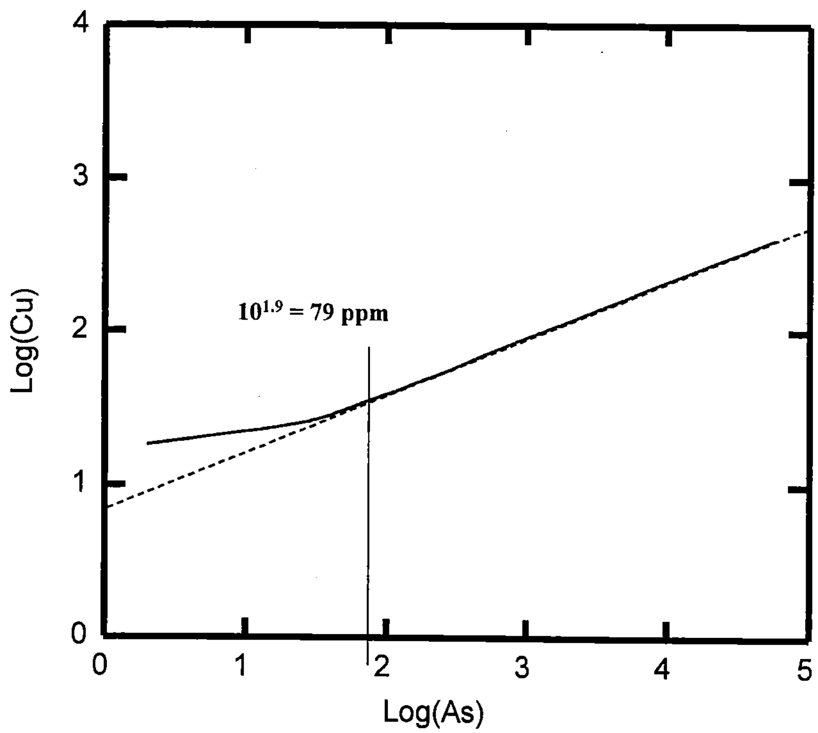

Figure 2.3 Statistical association of copper (Cu) and arsenic (As) soil concentrations from data collected by Miramar Mining (1987). Individual data points omitted so as not to obscure trend line. Curvilinear trend line drawn with LOWESS module of SYSTAT (see Wilkinson et al., 1992), which requires no subjective, *a priori* decision regarding the shape or nature of the data relationship. Linear (dashed) trend line drawn as best fit to upper portion of data. Vertical line indicates point at which data deviate from linear relationship, indicating demarcation between natural (lower values) and industrial (higher values) soil samples.

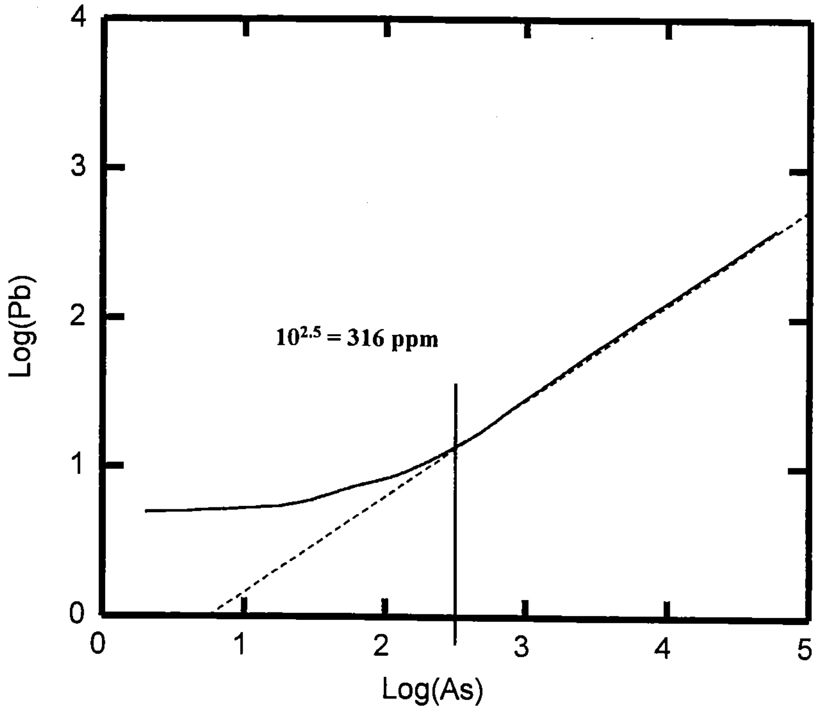

Figure 2.4 Statistical association of lead (Pb) and arsenic (As) soil concentrations from data collected by Miramar Mining (1987). Individual data points omitted so as not to obscure trend line. Curvilinear trend line drawn with LOWESS module of SYSTAT (see Wilkinson et al., 1992), which requires no subjective, *a priori* decision regarding the shape or nature of the data relationship. Linear (dashed) trend line drawn as best fit to upper portion of data. Vertical line indicates point at which data deviate from linear relationship, indicating demarcation between natural (lower values) and industrial (higher values) soil samples.

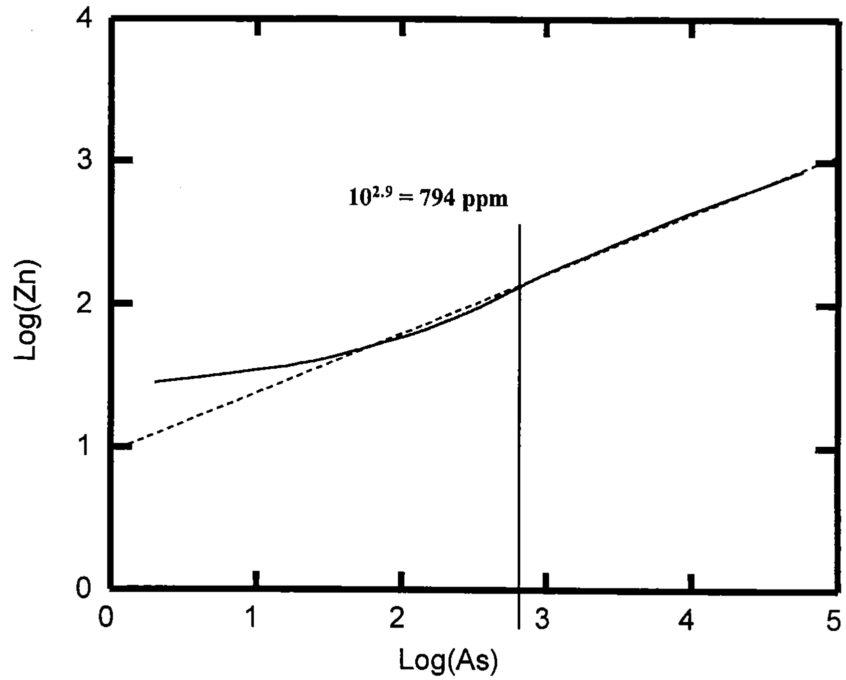

Figure 2.5 Statistical association of zinc (Zn) and arsenic (As) soil concentrations from data collected by Miramar Mining (1987). Individual data points omitted so as not to obscure trend line. Curvilinear trend line drawn with LOWESS module of SYSTAT (see Wilkinson et al., 1992), which requires no subjective, *a priori* decision regarding the shape or nature of the data relationship. Linear (dashed) trend line drawn as best fit to upper portion of data. Vertical line indicates point at which data deviate from linear relationship, indicating demarcation between natural (lower values) and industrial (higher values) soil samples.