

THE UNIVERSITY OF CALGARY

Flare Pit Waste in Western Canada: A Characterization Mechanism to Enhance Flare Pit
Sludge Remediation Efficiency

by

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Abstract

Flare pit sludge is present throughout the oil and gas production areas of Canada. The sites represent varying degrees of liability due to the presence of metals, salts and hydrocarbons. Efforts are underway to remediate flare pit sites, in response to regulatory changes.

To recommend efficient remediation methods for flare pit sludge, thorough sludge characterization must first take place. A database of physical, chemical and historical characteristics of 436 flare pit sites mostly in Alberta was prepared. Chemical parameters in the database were compared to existing remediation criteria. The sites were categorized according to their concentrations of each chemical parameter. The categories were compared to historical site details.

Six significant site categories were determined based on remediation considerations. 27.3% of the flare pits will not require remediation, 30.4% of the flare pits had one primary contamination type while 42.3% of the flare pits had multiple contamination types that require remediation.

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List of Acronyms

AB Tier 1	Alberta Tier 1 Criteria for Assessment and Remediation
AEP	Alberta Environmental Protection
AEUB	Alberta Energy and Utilities Board
AUGFWM	Alberta User Guide for Waste Managers
BTEX	Benzene, Toluene, Ethylbenzene and Xylene
CAPP	Canadian Association of Petroleum Producers
EC	Electrical Conductivity
LD ₂₅	Lethal dose for 25% population mortality
LD ₅₀	Lethal dose for 50% population mortality
SAR	Sodium Adsorption Ratio
TPH	Total Petroleum Hydrocarbons
WCR	Waste Control Regulation

1.0 Introduction

1.1 Flare Pits

Flare pits have been a commonly used method for managing the storage and disposal of oilfield wastes and handling process upsets. Flare pits often began as a reserve pit for drilling fluids and cuttings, and then were transformed to assist during produced fluid testing and full production. As the name implies, the primary purpose of the flare pit is to store and effectively burn the hydrocarbons directed to them from an oilfield operation. The actual uses of some pits reflect the environmental practices of the time, and as a result pits contain a variety of hydrocarbons, produced water, process chemicals and site waste. The sludge created by these practices has tremendous variability in characteristics and poses a hazard to workers, wildlife, groundwater and surrounding vegetation.

Flare pits are usually excavations at a site that are rarely lined. A low pressure line, known as the flare line, connects the operations at the site with the flare pit. Process upsets or blowdown operations at the site will cause excess gas and fluid to enter the flare line. Equipment between the main operations and the flare line can include a knock-out tank and a separator, to store the liquid and solid materials entering the flare line and reduce the amount of liquid and solid material directed to the flare pit. At the end of some flare lines, where they enter the flare pit, is a burner tip to provide thermal destruction of the material exiting the flare line. Hydrocarbons and produced water have the opportunity to enter the pit when the burner tip is not operating or the line is not equipped with any type of burning device. Direct addition of material to flare pits also occurs when the pit is used for storage of bulk production fluids including crude oil and produced water. Process chemicals, spill material and other site wastes have also been directed into flare pits as a means of disposal. Since they are not covered, precipitation can accumulate in flare pits, which adds to the volume of liquid in the pit.

Flare pits were often chosen as a means to manage process upsets in heavily forested areas where a vertical flare stack poses a threat for surrounding trees. The existence of a pit also provides a means for storage of wanted or unwanted materials generated during a process upset or directed into the pit during normal operations. The cost associated with the construction and operation of a flare pit was also considered to be lower than a flare stack, without considering site remediation costs, which was a contributing reason for using flare pits at some locations.

1.2 Environmental Issues Regarding Flare Pits

Regulatory bodies for the upstream oil and gas industry have recently introduced legislation to stop the use of flare pits, and promote remediation of existing flare pits. Flare pits, and the sludge contained in them, represent a liability to the operating company. They symbolize a cost for clean-up that can range from minimal to major, depending on the type and extent of contamination. Their presence also symbolizes waste management practices that are unacceptable according to current standards set by regulatory bodies, the general public and industry (Marr-Laing and Severson-Baker, 1999).

The pit contents can impact the surrounding soil, groundwater, wildlife and vegetation in the area. The permeability of the soil will directly affect the migration of contaminants to the groundwater. Since the contaminants are often contained in material that is a liquid or semi-liquid form, contamination is also able to migrate outward, impacting the soil surrounding the flare pit and negatively impacting site vegetation. Even though security measures such as fences and signs are installed around some flare pits, the pits can still be accessed by wildlife and can represent a hazard to workers at the site.

The possibilities for impacting environment, wildlife and human health and safety have contributed to the establishment of regulations regarding flare pit use and remediation.

Flare pit site remediation has often relied on technologies used for the management of other upstream oilfield wastes. Options such as backfilling the pit with clean material or excavation followed by land treatment are two common methods that have been used for site remediation. Guidelines are in place to manage the level of contamination in the existing or new sludge locations, but a simple dilution and possible transfer of contaminants, increasing the contaminant levels in non-affected areas of land is becoming a larger land management issue. As a result, land treatment has received increasing scrutiny by regulatory agencies, and its use as a sludge management and treatment technique is expected to be less frequent in the future due to increased restrictions on how the practice is carried out. This requires alternative treatment methods for contaminated soils and sludges originating from upstream operations.

1.3 Research Goals

There is a drive for the timely remediation of flare pit sites by both regulatory bodies and upstream oil and gas companies. Brief working guidelines have been compiled that discuss the regulatory process for pit reclamation, which also delve into material management options such as land treatment and backfilling, both of which are fading as popular sludge management techniques due to increased regulatory pressure to minimize contamination of non-affected areas. The investment of time and capital that will be directed to flare pit remediation by numerous oil and gas companies should benefit from the process of continuous improvement like so many other oil and gas industry practices, to increase the efficiency of site assessment and remediation.

This research is the first step in a multi-step project reviewing flare pit remediation. The objective of this project is to develop a statistically significant database of flare pits to identify the key types of flare pits present in Western Canada that are similar in contamination profiles. The resulting flare pit categories can be correlated with

remediation strategies. The contents in this paper describe the construction of a database of 436 flare pit sites in Western Canada, but predominantly in Alberta. Only the significant parameters collected were used to form a working database. The sludge characteristics are compared to existing provincial and federal soil and waste criteria, to determine specific flare pit waste categories based on similarity in contaminants and concentrations. The provincial and federal soil criteria are compared to research in the area of specific element and compound toxicity, to understand the degree of conservatism used when establishing the generic soil guidelines. The contributing factors to each site classification are also explored, to determine if certain production activities, geographic locations and production fluid characteristics play a role in determining the category of a site. Relationships between historical, descriptive data and concentrations of various contaminants were reviewed using statistical tools, to understand how site contamination profiles relate to site activities. Finally, the significance of the database was reviewed using a spatial statistical assessment technique, so conclusions could be made about the ability of the database to represent all flare pit sites in Alberta.

2.0 Background

2.1 *Previous Work on Oilfield Sludge and Solids Characterization and Remediation*

Many research projects in the area of flare pits and other contaminated solids from oilfield operations in Western Canada have been carried out since the problems associated with oilfield waste management were identified (Peake et. al., 1985). Many projects have built on each other, and often involve material classification followed by evaluation of treatment technologies. Major projects that are described in this section have focused on oilfield production facility waste sludge, produced solids from the heavy oil corridor, natural gas processing facility sludges and drilling wastes.

2.1.1 Oilfield Waste Characteristics

In addition to the detailed studies on specific waste types presented in the following sections, a study was completed in 1989 for the Canadian Association of Petroleum Producers (CAPP) titled "Petroleum Industry Waste Management Strategy" by Wotherspoon and David Bromley (DBEL) (1989). The goal of the study was to characterize all major waste types associated with production and processing of oil and natural gas, and determine current and future disposal options. The study described flare pit sludge as the sludge that accumulates in pits used for the disposal of hydrocarbon, containing waste materials that makes recycling unsuitable. The study determined that flare pit sludge was handled using a combination of on-site recycling, open pit burning, licensed oilfield waste reclaimers, road application and other waste disposal companies. At the time of the study, the three preferred management practices for flare pit sludge were industrial landfill, solidification and incineration (Wotherspoon and DBEL, 1989). These preferred contaminated soil and sludge management alternatives indicate that the mobility of sludge contaminants is a concern.

Proper landfill design and management would permit landfill disposal of flare pit sludge and limit the mobility of metals, organics and salts contained in the sludge. Solidification

of the sludge, using materials such as lime or cement, may limit the mobility of all or some of the contaminants, but the resulting solidified material will still require disposal or placement in an area as fill or construction material. Incineration of flare pit sludge primarily addresses the organic content in the sludge, and the resulting material will still have the metal and salt contamination that was in the original flare pit sludge. As with the solidified material, the incinerated material will require disposal or placement in an area as fill or construction material. If a similar study were carried out now that considered full lifecycle management of the material and the current regulatory climate, there might be a change in the preferred treatment and disposal methods.

2.1.2 Oilfield Waste - Sludge Characterization

A study on oilfield waste by DBEL (1991a) focused on waste characterization. The purpose of the study was to develop a database of physical and chemical characteristics of six different waste sludges produced in upstream oil production operations, in order to assist in the evaluation of treatment technology options (DBEL, 1991a). One of the six waste sludges was flare pit sludge, which was defined as sludges and solids that accumulate at the bottom of flare pits, found at batteries, fieldgates and wellsites not tied into flowlines. The other five waste types in the study were process pond sludge, flare knockout drum sludge, treater bottom sludge, tank bottom sludge and spill material. Three samples of each waste type were analyzed for a set of parameters chosen to help assess the potential for treatment using various technologies and methods, as well as indicating if the waste was hazardous (DBEL, 1991a). A total of 37 parameters were assessed that included biological oxygen demand, total organic carbon, phosphorus, nitrogen, % solids, % water, oil and grease, Btu content, sulfur, specific gravity, pH, electrical conductivity (EC), particle size, free liquids, flash point, flammability, soluble cations and anions, and leachable metals. For the three samples of flare pit sludge analyzed, the results showed that there was variability in almost all parameters analyzed. The samples analyzed were most likely non-hazardous based on the results of

flammability testing and leachable metals, but further interpretation of the % oil data might change the classification. The biological oxygen demand results were interpreted as indicating that the sludge was not very biodegradable. Mean and standard deviation calculations were done for each parameter analyzed in each waste type, but the report states that the sample size of three makes the statistical significance of the conclusions regarding typical concentrations of contaminants highly questionable (DBEL, 1991a).

The recommendations from this study indicated that the results cannot be applied to other samples of the same waste type, and the hazardous nature of each new waste sample must be determined on a case by case basis. This is most likely due to the statistical insignificance of the number of samples collected for the report. The report recommends that a more detailed organic analysis focusing on environmentally hazardous substances such as aromatics be carried out for samples, so that sludges may be accurately classified as hazardous or non-hazardous (DBEL, 1991a).

The lack of statistical significance of the data was discussed in the report, as only three samples of each waste type were reviewed. Basic ideas on site activity are known about each sample, but the diversity in geographic location, production liquid characteristics and operating company are not known, which may contribute to a lack of randomness in the data set consisting of only three samples.

2.1.3 Oilfield Waste Treatment - General

B.H. Asano Associates (B.H. Asano, 1991) conducted a comprehensive study on treatment technologies for oilfield waste. The work considered related studies, including the work done by DBEL (1991a) on waste characterization discussed in Section 2.1.2, and the work done by Monenco (1990) in evaluating technologies for treating produced solids from heavy oil operations. Two operating scenarios were considered when evaluating the group of treatment technologies: local, small-scale operations and regional,

large-scale operations (B.H Asano, 1991). Four technologies were listed for further investigation for small-scale operations and five technologies were listed for further investigation for large-scale operations. The technologies recommended for the small-scale local operating scenarios were the ASTCO–STS process (hot water extraction), the RTR/Gulf process (aqueous extraction/leaching), the Aqua Guard Thermal Oxidizer (thermal process) and the B.E.S.T. process (solvent extraction). The technologies recommended for the large-scale regional operating scenarios were the B.E.S.T. process (solvent extraction), the RTR/Gulf process (aqueous extraction/leaching), the BP Oil Solvent Extraction process (solvent extraction), ASTCO – STS process (hot water extraction), and the Taciuk Processor (thermal process).

All of the recommended treatment techniques are ex-situ and require a significant amount of soil movement. Even though two operating scenarios were reviewed, the processes still require careful thought as to where they are implemented to capitalize on waste volumes, required process inputs and material disposal or re-use options. The adoption of the recommended technologies has not been widespread based on a current evaluation of solids treatment companies, with several small-scale and fewer full-scale operations in existence. This indicates that either the technologies are inappropriate for treatment of a larger category of oilfield waste types, or there is a reluctance to invest in such technologies by producers or oilfield service companies.

2.1.4 Oilfield Waste Treatment - Land Treatment

Land treatment of oilfield wastes was the focus of an eight-year study, carried out from 1982 to 1989 by Peake et. al. (1985). A laboratory program followed by a field program at four land treatment facilities located in Brooks, Drayton Valley, Lloydminster and Grande Prairie was carried out to determine the feasibility of land treating oily sludges as an alternative to landfilling and road oiling (Peake et. al., 1985). Specifically, the study focused on determining the decomposition rate of sludge in soil, factors influencing the

decomposition rate and negative environmental effects of the process including impacts on soil, surface water, groundwater and plant health (Peake et. al., 1985, Danielson et. al., 1990).

The laboratory and field studies determined initially that optimal degradation rates were associated with sludge applied to a land treatment area with 10% oil, but with the understanding that higher concentrations of asphaltenes will have slower degradation rates than sludge having high concentrations of aliphatics (Peake et. al., 1985). Oil degradation rates were highest during the first year of sludge application, and decreased during subsequent years after additional sludge applications. Migration of oil into lower soil zones, groundwater or surface water was not detected, but inorganic constituents associated with oilfield sludge such as chloride and nitrate were found in groundwater at land treatment sites. Limiting factors preventing the long term use of a site as a land treatment operation were identified as increased soil salinity as determined by EC and sodium adsorption ratio (SAR) values, and high lead and zinc concentrations in the soil from disposal of used engine oil in oilfield sludge (Peake et. al., 1985).

Further findings in the second half of the study determined that crop growth was related to one or more chemical parameters that could include oil concentration, salt concentration and EC (Danielson et. al., 1987). Different crops were chosen for each land treatment facility based on the local environmental conditions, and the success of each crop was monitored. It was determined that at soil oil concentrations less than 3.5%, crop growth was excellent while at soil oil concentrations greater than 5%, crop growth was very poor (Danielson et. al., 1987). Soil salinity impacted plant growth, and the most successful growth was achieved at maximum chloride concentrations of 22 meq/L and EC of 2.9 dS/m. While crop growth was related to concentrations of oil and salt, it was not directly correlated with the amount of sludge applied to a plot (Danielson et. al., 1987).

Near the end of the study, only the land treatment facility in Lloydminster was used for testing and analysis. The goal of this stage of the program was to rehabilitate the site for agricultural use by stopping further addition of oily wastes for a period of four years, and applying standard agricultural practices to the plot for the last year. This included tillage to break up clay and increase permeability into the soil, fertilizer addition to increase nitrogen concentrations and enhance microbial degradation of oil, and manure treatment to increase organic matter and alter soil properties. As in past years at the site, a barley crop was planted, and both crop growth and plant health were evaluated along with surface and groundwater quality. The results of the study determined that the barley growth was better than past years, most likely a result of the agricultural practices applied at the site. Salt and oil concentrations in the soil decreased compared to previous years to the point that they were no longer at concentrations toxic to plants. Surface water concentrations of salts decreased over time after wastes were not applied to the site (Danielson et. al., 1989).

The study concluded that oil degradation occurred primarily through microbial decomposition, but initially volatilization of lighter fractions also takes place (Danielson et. al., 1990). Asphaltene concentration in the soil is expected to remain constant even though the addition of nitrogen fertilizers can assist in increasing total oil degradation rates. Analysis of plants grown on the land treatment facilities for trace organics determined that there was no plant uptake of organics and that plant consumption should not pose health threats. Finally, the study emphasized that plant growth was inhibited at soil oil levels at or greater than 5%, while below 3.5% plant growth was not affected (Danielson et. al., 1990).

This study determined that land treatment of oilfield wastes from a variety of locations in Alberta can be successfully used as a remediation technique, and the land used for

treatment can be managed to ensure that it can be used in the future for agricultural purposes. The study made fundamental statements about the amount of oil and salt that could be present in the soil to achieve adequate plant growth. The recommended maximum oil content in the soil decreased from 10% to less than 5% as the study started looking at degradation rates over multiple years, and plant toxicity issues.

Part of the success of the study at the Lloydminster land treatment facility is most likely attributable to the fact that wastes were not applied to the site for the latter four years of the program. This may indicate that a designated area of land for land treatment can only accept a certain volume of waste for a certain period of time, after which the entire site must undergo typical agricultural treatment to ensure long term fertility. This is not necessarily the practice at commercial land treatment facilities, which often have set up multiple cells, one of which is available each year for waste application, while the others are treated using traditional agricultural practices (Waddell, 1994). Every year the designated waste application area changes. The ability to provide a four-year rest from waste application to one cell may be difficult to achieve due to the space required to make the total land treatment operation viable.

2.1.5 Oilfield Waste Treatment - Thermal

In 1994, CAPP commissioned a study to evaluate technologies to remove or immobilize contaminants in soils and sludges. The study looked at available and operational technologies, all of which were thermal treatment units (Acres International Limited, 1994a and 1994b). The study actually tested and compared the performance of four directly or indirectly fired thermal units at treating contaminated soil having elevated levels of salinity and hydrocarbons. The study was able to demonstrate the relative effectiveness and costs associated with each technology, by reviewing contaminant levels before and after treatment and operational information compiled during treatment to assess costs associated with the treatment.

2.1.6 Oilfield Waste Treatment – Working Guidelines

Guidelines for site decommissioning and reclamation were prepared by CAPP in 1992 (DBEL, 1992) for small crude oil and natural gas sites, and in 1996 for pits and ponds (DBEL, 1996). Both guides provide an overview of the regulatory agencies that must be contacted in Western Canada prior to, during and after completing a remediation project. They also provide suggestions on treatment and disposal of contaminated soil and sludges. Collectively, the options presented in the two guides include: backfilling, land treatment, oilfield reclaiming facility, landfill, road application, solidification, hazardous waste treatment facility and treatment by other means. The guides also include a description of the steps required in using one of the treatment or disposal methods listed, such as documentation, material analysis, and risk assessments for using a technology not on the list. Even though the most recent guidelines were written in 1996, they are out of date in terms of suggesting treatment and disposal options that meet the approval of regulatory bodies from an environmental perspective. The 1996 guidelines were supposed to be used only for the 1996 season as regulatory issues were expected to change around that time period (DBEL, 1996).

2.1.7 Flare Pit Waste - Characterization

The Upstream Chemically Affected Sites Technical Group (UCASTG) produced the most recent characterization work that focused primarily on flare pits (Green, 1997). The purpose of the study was to develop a database to evaluate the environmental concerns that exist at well sites (Green, 1997). The database is comprised of 338 sites, 75% of which are flare pits while 25% are other samples from well sites. The data collected includes general description data on the site location, site activity and soil type, and chemical composition data that includes the salinity, metal and hydrocarbon parameters in Alberta Tier 1 Criteria for Assessment and Remediation (AB Tier 1).

The study determined that 70% of the sites exceeded the AB Tier 1 hydrocarbon level of 1000 ppm, while 48% of the sites exceed the AB Tier 1 level for EC of 2 dS/m and 44% of the sites exceed the AB Tier 1 level for SAR of 4. Only a small portion of the samples exceeded the metal concentrations in AB Tier 1, and high concentrations were most common with mercury at 23% of sites. The data collected on metals was not as complete as the other parameters and was scant for the non-flare pit sites. The location of the sites in terms of the white and green land use zones of Alberta, the primary divider of agricultural land and forest land, respectively, did not show any relationship with site contamination. The study also determined that the frequency distributions for hydrocarbon and salinity parameters, all of which had large sample sizes in the database, tended to be normal distributions (Green, 1997).

Green (1997) recommended that the database should be expanded to include more parameters and more sites, to improve the statistical power of analysis derived from the database. Green (1997) also recommended that the environmental implications of processes and operations at such sites be studied to determine their relationship to the site characteristics.

The study did not look further into the characteristics of the sites that exceeded one or more of the Tier 1 parameters to identify the contributing factors for such site conditions. Green (1997) was unable to make conclusions about the human health impacts associated with the pits since the database did not include compositional information on hydrocarbons, which would provide insight into specific sites having very toxic hydrocarbons present.

2.1.8 Flare Pit Waste - Bioremediation

Bioremediation of flare pit waste using a bioreactor was the focus of a study commissioned by CAPP (CAPP, 1997). Researchers used a full scale bioreactor to treat

various oilfield wastes including flare pit sludge, using microbial oxidation to remove hydrocarbon contaminants and leaching to reduce salinity (CAPP, 1997). Laboratory studies were used to determine optimal conditions for contaminant reduction, which were then applied on a large scale basis in the bioreactor. The factors determined in the laboratory to be critical to the success of bioremediation included an optimum temperature range of 32-37 °C, soil water content ranging from 15 to 30%, EC less than 7 dS/m and sufficient nitrogen at the initial stages of treatment (CAPP, 1997).

As part of the study, flare pit material was fully characterized, and then the effect of aggregation, cultivation, inoculation and cell depth was tested to determine impact on degradation rates. Material was aggregated to enhance water movement through the soil and increase nutrient retention, which was achieved by adding lime and drying the soil. Carbon dioxide was then injected into the material to reduce the pH, to compensate for the effects of lime. The inoculation process used soil that had already been bioremediated and mixed it into the soil sample, which was shown, on a bench scale basis, to enhance hydrocarbon degradation rates. Water and surfactant were used to leach out salts from the material, including the areas exhibiting water repellency. Following leaching, nitrogen and phosphate fertilizer were added to ensure the nutrient balance in the soil would promote effective remediation. During treatment, temperature, water content, cultivation and aeration were all controlled to ensure optimal levels or to test the effect of different treatment frequencies (CAPP, 1997).

The full scale bioreactor study determined that an average of 17.2% of the original hydrocarbon content was reduced over 75 days, primarily by oxidation but with some losses through volatilization and transformation to organic matter.

Although the study identified variables required for successful remediation of one flare pit sludge sample, the ability to apply the results of the study to other flare pit samples is

not known since only one sample was tested. There was no characterization work done to speculate on the type of results that might be achieved in samples with different soil types or different contaminant profiles. Follow-up work is necessary to identify the range of contaminated soil that could be successfully treated in a bioreactor and the approximate time required for adequate treatment.

2.1.9 Heavy Oil Corridor Solids Treatment - General

Work similar to the studies on oilfield solids and sludges has been done with a specific focus on handling the oily solids from the heavy oil corridor of Alberta. Past management practices of “slop” and “sludge” accumulated in tanks and equipment included burial on-site in a bell-hole, spreading on the lease, and spreading on the lease road (Nygren, 1986). Sludges that were more solid in nature than liquid were also used to build up containment dykes and provide part of the road base material used for municipal and county roads. Fluid wastes considered slop were blended with sludge and disposed of as above, or used as a dust suppressant on unpaved roads. The practice of road application of waste provides the opportunity for toxic contaminants to be transferred from the production site to a public site.

The need for waste management alternatives prompted focused research into techniques that can handle the unique characteristics of waste from the heavy oil corridor. A focused study in this area was undertaken by Monenco Consultants for CAPP (Monenco, 1990). The purpose of the study was to first gather information on produced solids including chemical characteristics, physical characteristics, quantity of solids produced and geographic distribution. The solids data was then used to screen various treatment technologies and recommend specific technologies for field assessment. The report defined produced oily solids as a by-product of heavy oil production that excludes spill and reclamation material. Typical characteristics of the produced solids include high viscosity bitumen at levels of 15-20%, a saline water phase containing chlorides as high

as 60,000 mg/L, and a solid phase containing mostly coarse sand with some clay size particles.

Analytical data on four samples of produced solids was gathered to review parameters such as % oil, water, solids, ash and metal content in the sample, distinct properties of the oil phase including aromatic molecules and olefin content, major cations and anions, oil and grease and pH in the water phase, and mineral composition of the solid phase. Information on physical properties such as particle size of solids, and hydrocarbon analysis focusing on gravity, viscosity, pour point and flash point was gathered (Monenco, 1990).

A group of 34 treatment technologies was then reviewed taking into consideration the characteristics of the produced solids. The technologies were classified into 6 categories: thermal, fixation, hot water extraction, solvent extraction, chemical processes and “other” processes that included centrifugation and filtration. The report concluded that the three technologies that appeared to be the most promising were ASTCO-STS hot water extraction, fluid bed combustion and hydraulic fracturing. The report mentioned that the road application practice that was taking place at the time was also a very good option for produced solids disposal (Monenco, 1990).

Even though produced solids from heavy oil production come from a well-defined geographic area that is only in parts of Alberta and Saskatchewan, the use of four samples is statistically insignificant and may not provide sufficient background information to evaluate treatment technologies.

2.1.10 Natural Gas Plant Sludge - Characterization

An assessment and treatment study of sludges produced during natural gas processing was carried out from 1989 to 1992. The first phase of the study was completed by DBEL,

and reviewed the physical and chemical characteristics of 16 waste sludge categories, one of which was flare pit sludge (DBEL, 1991b). Three samples of the flare pit sludge were analyzed for the same 37 parameters in the 1991 DBEL study on oilfield production sludge characterization, described in Section 2.1.2. The analytical results of the three flare pit sludge samples showed that there was variability in almost all parameters analyzed, and the sludge showed a tendency to be slightly basic. The samples analyzed were classified as potentially hazardous based on the results of flammability testing and leachable metals showing non-hazardous concentrations. Further analysis of oil content for aromatics may change the designation of some flare pit sludge to hazardous. Mean and standard deviation calculations were done for each parameter analyzed in each waste type, but the report notes that the sample size of three makes the statistical significance of the results highly questionable (DBEL, 1991b).

The study concluded that the results cannot be applied to other samples of the same general waste type, and the hazardous nature of each new waste sample must be determined on a case by case basis. This is most likely due to the statistical insignificance of the number of samples collected for the analysis. The study recognized the need for a more detailed organic analysis so that samples may be accurately classified as hazardous or non-hazardous (DBEL, 1991b).

2.1.11 Natural Gas Plant Sludge Treatment - General

B.H Asano Associates and Stanley Industrial Consultants conducted a study to characterize sludges from natural gas processing operations to provide a basis for evaluating treatment technologies (B.H. Asano and Stanley, 1992). Sixty technologies were grouped into seven generic technology classifications: solvent extraction, aqueous extraction/leaching, thermal-destructive, thermal-nondestructive, stabilization/

solidification, biological and other. Two application scenarios were considered: a small, local operation and a large, regional operation (B.H. Asano and Stanley, 1992).

The top five technologies for the small, local operating scenario were the B.E.S.T. process (solvent extraction), Waste-Tech thermal distillation (thermal, non-destructive), Waste-Tech soil wash (water/surfactant leaching process), Centech (water leaching process), and the ASTCO-STS solids treatment system (hot water leaching process) (B.H. Asano and Stanley, 1992). The top six technologies for the large, regional operating scenario were the B.E.S.T. process (solvent extraction), Waste-Tech thermal distillation (thermal, non-destructive), BP Oil Solvent Extraction (solvent extraction), the ASTCO-STS solids treatment system (hot water leaching process), Waste-Tech soil wash (water/surfactant leaching process), and the AOSTRA-Taciuk Processor (thermal desorption and destruction) (B.H. Asano and Stanley, 1992). This study did look at treatment options that were considered biological such as land treatment, composting and anaerobic treatment, but determined that they were not competitive with the 11 processes chosen to provide the necessary treatment in an acceptable period of time at a competitive cost.

2.1.12 Natural Gas Plant Sludge - Mercury Contamination

Metal contamination associated with natural gas operations has been the focus of several studies. Wotherspoon and DBEL (1989) identified soil contaminated with high levels of mercury from manometers as a specific waste issue. The preferred management of this waste was landfill disposal or hazardous waste disposal facility. Sources of the mercury are thought to be the manometers with elemental mercury that were used throughout the natural gas industry for measuring pressure and flow rates (Kohut and Dudas, 1996). Mercury releases are associated with equipment breakage, equipment maintenance and process upsets at gas plants and metering facilities, leading to mercury concentration inside buildings, which were often directed to the soil outside process buildings (Deyell,

1996). Mercury levels in soils were studied at one gas plant, and concentrations were determined to range from 0.3 to 200 ppm at the site, with background concentrations under 0.1 ppm (Kohut and Dudas, 1996). The highest concentrations of mercury were found near doorways of process buildings, with lower concentrations related to distance from the building (Kohut and Dudas, 1996).

The identification of this issue is important in understanding the contributing factors to high concentrations of some contaminants at some sites. While other relationships between a specific contaminant and a specific process will not necessarily be as evident, it is likely that such relationships exist.

2.1.13 Drilling Mud Waste - Land Treatment

Stroscher et. al. (1978) studied drilling mud waste treatment and disposal by land treatment. A total of seven drilling sump fluids from seven diverse locations in Alberta were reviewed for chemical parameters. The sump fluids were categorized as KCl-water-polymer mud, flocculated water-gel mud and dispersed water-gel mud. The characteristics reviewed for all seven muds were very different from the other studies discussed in this section, and included a review of polymer content, oxygenated compounds, sulfur compounds, hydrocarbons and salts. It was determined that the KCl based drilling muds were potentially the most damaging to soils and plants due to high concentrations of organics and salts compared to the other two mud categories. Field studies determined that the amount of damage to plants was dependent on contact between the mud and plants during initial application, and plant uptake of toxic components following application. The amount of salt found in plants grown on areas treated with drilling mud was variable, but was in the toxic range for those muds having high salt content. Toxic organic components found in the soils and plants on land treatment areas included hydrocarbons in the diesel oil range. In a subsequent study, Stroscher et. al. (1980) found that soil penetration of salts and organics was related

primarily to the soil characteristics rather than the salt and organic components in the mud. The movement of salts and organics in loosely compacted, dry soil was observed to be four times greater than the movement through more compacted, wet soils. Penetration depths were measured, and over a one year period the salts had reached a maximum depth of 60 cm while the organics had reached a maximum depth of 65 cm. Lateral movement of both contaminants was less than two meters during the course of the study (Stroscher et. al., 1980).

While the conclusions made in this second study are similar to those made in the studies on oilfield waste and natural gas plant wastes, the statistical significance of this study is greater due to the slightly larger number of samples taken and the geographical diversity represented in the samples. By reviewing three commonly used drilling mud types and determining which type was most toxic to plants and soils, information on land treatment and possible negative plant and soil impacts is available to those selecting drilling muds for various applications. This work provided information for producers to assist them in managing their environmental liability by understanding that various degrees of toxicity are associated with different mud types. It also made important statements on the effect soil type has on contaminant migration, which again provides information to producers on issues that may impact environmental liability associated with a land treatment site.

Drilling mud treatment through separation of liquid and solid phases for separate treatment and disposal has been the subject of other related work (Wojtanowicz et. al., 1986). The application of technologies such as two and three phase centrifuges and belt presses to drilling mud has met with some success in concentrating the solid portion of drilling mud and treating the recovered water, salt and hydrocarbon portion using conventional oil treatment techniques.

2.1.14 Summary

Previous research has focused on addressing the needs of different segments of the industry, based on operational differences related to the type of hydrocarbons produced. Many of the studies evaluated a large group of technologies with the aim of identifying the best technologies for treatment of a specific type of contaminated sludge. However most of the studies were based on statistically insignificant characterization data. A smaller number of studies only looked at determining how a specific technology or set of technologies treated a certain waste, to evaluate the performance of the technology. Only one study has attempted to review the characteristics of many sludges to determine commonalities and differences between the contaminants in flare pit sludge, compared to one provincial soil criterion.

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In many cases, it was noted that the results of a research project could not be applied to the waste type in a broader sense, as the differences in characteristics of the same waste type encountered in Western Canada might influence the results of treatment. This is partially speculative, as thorough research was unavailable to prove that there are significant differences in characteristics among a single category of contaminated sludge.

2.2 *Regulatory Background – Flare Pit Use and Remediation*

The environmental management of the upstream oil and gas industry has been an important focus of regulatory bodies at local, provincial and federal levels. This project focuses on Alberta legislation due to the location of the majority of flare pits in the database. Recent Federal initiatives that review soil quality are also incorporated, due to the Canada-Wide Accord on Environmental Harmonization that will focus on standards development for substances, where ambient and discharge limits are set for the entire country.

The Alberta Energy and Utilities Board (AEUB), the regulatory body for upstream oil and gas industry, originally set out guidelines for the siting of flare pits in the Oil and Gas Conservation Act. Recently, the AEUB has taken steps to eliminate the use of flare pits at upstream oil and gas facilities. The AEUB issued informational letter IL 94-6 in March 1994, which stated that “as of 31 December 1996, oil and gas operators will no longer be permitted to place or store produced liquids into earthen pits or structures. Produced fluids are considered to include crude bitumen, liquid hydrocarbons, process chemicals, and water produced from oil wells, gas wells, and associated batteries and other similar facilities regulated by the ERCB.” (AEUB, 1994a). As a follow up, informational letter IL 96-4 was issued to prohibit flaring to earthen pits at all new facilities constructed after July 1, 1996 (AEUB, 1996a). IL 96-4 also discussed existing facilities, and allowed flaring to earthen pits to continue, provided that the appropriate operational controls were in place to essentially eliminate the possibility of fluid entering the pit (AEUB, 1996a). Existing facilities operating in southwestern Alberta in the shallow gas fields are exempt from the regulation. They use pits that theoretically comply with the storage and containment requirements described in AEUB G-55 for storing blow down fluids that are considered benign in comparison with typical production fluids (AEUB, 1995).

In 1994, the AEUB also issued IL 94-15, an informational letter for the “Assessment and Remediation of Earthen Pits, Land Treatment on Lease” (AEUB, 1994b). It specified the requirements a producer must follow to land treat flare pit sludge. The process was specific for a one-time spread of waste, as a site receiving multiple applications of sludge, a dedicated land treatment facility, requires more rigorous permitting. The stated remediation objectives included the applicable provincial and federal soil quality guidelines described in Section 2.3.

The issuing of this informational letter did not promote an increase in the use of land treatment, as land treatment was already established as a common way of handling

contaminated solids at upstream facilities in 1994. IL 94-15 was prepared to provide guidance to companies addressing IL 94-6. It addressed all aspects of land treatment of flare pit material to ensure that the activity was being performed in a consistent manner by all organizations. Other remediation and disposal methods were not mentioned in this letter, as many remediation and treatment technologies were in developmental stages at the time of writing of the Informational Letter, while disposal options in Alberta included Class 2 industrial landfills and the hazardous waste treatment facility at Swann Hills. The use of methods other than land treatment to remediate flare pit sites was not discouraged, which promoted research into many waste treatment technologies (Acres International Limited, 1994a and 1994b).

In 1996, G-58, the "Oilfield Waste Management Requirements for the Upstream Petroleum Industry", was released (AEUB, 1996b). It includes a discussion on one time, on-site land treatment of flare pit wastes by producers. Prior to spreading, a producer must analyze the flare pit waste and receiving soil to ensure that the resulting mixture will not exceed the allowable levels of metals and pH stipulated in AB Tier 1, a hydrocarbon concentration of 2%, an EC level of 4 dS/m and a SAR value of 6. The time required for hydrocarbon biodegradation must also be estimated through analytical testing such as hydrocarbon fractionation or treatability. The entire process must be documented so records are available, but it does not require the producer to make application to the AEUB nor submit any of the analytical documentation.

The clean up of flare pit sites is a joint effort of the AEUB and Alberta Environmental Protection (AEP). IL 98-2, titled "Memorandum of Understanding Between AEP and EUB on Suspension and Reclamation of Upstream Oil and Gas Facilities", was issued to fully describe the role of both organizations in the reclamation process (AEUB, 1998). The role of the AEUB is to enforce their requirements of eliminating the construction of new flare pits, eliminate the use of existing flare pits and promote the remediation of flare

pit sites. The AEUB is responsible for ensuring that wastes are stored in accordance with G-55, the storage requirements, and that ex-situ treatment of flare pit waste or off-site disposal meets the requirements of G-58, the waste management requirements (AEUB 1998, AEUB, 1996b, AEUB, 1995). Remediation activities and standards for soil and groundwater remediation at flare pits are regulated by AEP, including risk based approaches to clean-up. Reclamation certificates for flare pit sites are issued by AEP upon completion of an acceptable clean-up program. AEP's role with respect to flare pit sludge is based on the enforcement of appropriate soil remediation criteria that are described in the next section. Soil criteria and methods used for site reclamation are reviewed by AEP to ensure land areas are restored to equivalent land capability to enhance future use options (AEP, 1992).

2.3 *Regulatory Background – Soil Quality and Waste Criteria*

Generic site remediation criteria have been established provincially and federally. AEP developed AB Tier 1, a set of soil quality guidelines based on conservative risk assumptions (Brown and Davies, 1994). The AB Tier 1 parameter values were issued in 1994, and include parameters such as pH, EC, sodium adsorption ratio, metals, monocyclic aromatic hydrocarbons, chlorinated hydrocarbons and total extractable hydrocarbons (AEP, 1994a). The AB Tier 1 values apply to the entire province, and land use is not considered. The AB Tier 1 values are used as the de-facto flare pit site clean-up criteria unless an application is made to apply Tier 2 criteria. Tier 2 criteria are determined by the operator of the flare pit on a site specific basis, and are presented to AEP for approval. The criteria are determined using a risk assessment to demonstrate that the proposed criteria provide sufficient protection for the proposed future land use of the site (DBEL, 1992).

The Canadian Council of Ministers of the Environment (CCME) has issued generic remediation guidelines. The guidelines were presented in interim format in 1991, CCME

Interim Criteria (IC), and finalized format in 1997, CCME Soil Quality Guidelines (SQG). The guidelines include generic values for the maximum allowable concentrations of specific elements and compounds according to land use. The four land use categories are agricultural, residential/parkland, commercial and industrial. The agricultural guidelines are typically the most stringent. A comparison of the CCME SQG and CCME IC with AB Tier 1 indicates that many of the AB Tier 1 values are similar to the agricultural values in the CCME documents. This may imply that agricultural land use was considered by AEP to apply to the entire province. The CCME IC issued in 1991 are thorough in their consideration of soil quality parameters, and include all sections described in AB Tier 1 except total hydrocarbons (CCME, 1991). The CCME SQG issued in 1997 are a fraction of the 1991 list, and only consider some metals, five aromatic hydrocarbons, two polycyclic aromatic hydrocarbons, three chlorinated hydrocarbons and ethylene glycol (CCME, 1997). However, this more recent set of criteria contains extensive supporting documentation that explains the type of research used to formulate the soil criteria.

The degree of site contamination may make the achievement of AB Tier 1 or CCME SQG a remote possibility. In addition to regulating site reclamation, AEP also stipulates the maximum concentration of contaminants permissible in Alberta landfills. The provincial documents that describe these levels are the Waste Control Regulation (WCR) and the Alberta User Guide for Waste Managers (AUGFWM). The documents apply to the many Class 2 and one Class 1 landfill in Alberta. The WCR defines hazardous waste in terms of general properties (pH, flash point, PCB content and toxicity), and content of specific elements and compounds listed in the AUGFWM (AEP, 1993a, AEP 1995). These regulatory levels of elements and compounds only apply to material once it has been determined to be hazardous according to the WCR (Fernandes, 1998).

Regulatory levels for a myriad of substances covered in the AUGFWM use units of mg/L (AEP, 1995). The recommended test used to determine the concentration of a parameter in a sample is the Toxicity Characteristics Leachate Procedure, or TCLP (AEP, 1995). The TCLP is a United States Environmental Protection Agency (USEPA) analytical procedure, and involves the extraction of a solid sample with an amount of extraction fluid equal to 20 times the weight of the solid phase (USEPA, 1992). In practice, some Alberta landfills will initially review waste characterization numbers that are presented in mg/kg, and simply divide the number by 20 to estimate the concentration in mg/L (Anderson, 1998). Further analysis of the waste using the TCLP is required if the waste does not meet the regulatory limit after the calculation is done.

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3.0 Methodology

3.1 *Fundamental Database Considerations*

Development of a database and a strategy to use this as a tool for efficient site remediation is the central theme of this research. Remediation can include many specific activities such as land treatment, composting, biopiles, gypsum treatment, thermal treatment, solvent extraction, water leaching and landfill, the choice depending on the types of contamination at the site. The contamination types and concentrations at a site will dictate the issues that must be considered when planning a remediation scheme. For example, hydrocarbon concentration information is important, but understanding if there are high levels of carbon molecules under C-10 chain length is critical to ascertaining the toxicity of the hydrocarbons to soil organisms, while understanding if high concentrations of molecules greater than C-30 are present may indicate that bioremediation efforts will be met with a slow response (Cookson, 1995). Multiple contamination types are also important to identify, since in many cases they have to be addressed separately (Cookson, 1995). For example, high salinity values may need to be lowered prior to remediating hydrocarbon contamination and fixing metals (CAPP, 1997). Multiple step remediation plans need to consider more variables and often take more time and money to complete, due to the inability of having over-lapping steps and the need for additional chemicals, equipment, analysis and operator time. These considerations are applied when assessing the flare pits in the database. Categories reflect the degree of simplicity or difficulty associated with the contaminants and their concentrations.

3.2 *Database Construction*

The database is comprised of 616 flare pit sludge sample entries, representing 436 flare pit sites. All of the sites are located in Western Canada, with 418 of the sites located in Alberta, 14 of the sites located in Saskatchewan and 4 of the sites located in British Columbia. At some sites only one sample of sludge was taken while multiple samples of different areas of the flare pit were obtained at other sites. Data on flare pits was

requested from major oil and gas producers in Calgary. Arrangements were made with those producers willing to share their analytical information to collect available details on flare pit sites. All of the data from all samples from each site was entered into the database. The number of sites entered into the database was 166, some of which had multiple samples. 264 sites were from the database developed by Green (1997), all of which had a single sample. Only the sites in this database designated as flare pits were used for this purpose. Three of the samples were three sites from the report prepared for CAPP by DBEL titled "Physical and Chemical Characteristics of Oilfield Production Facility Waste Sludges and Solids" (1991a). The last three samples were three sites from the report prepared for CAPP by DBEL titled "Physical and Chemical Characteristics of Natural Gas Processing Plant Waste Sludges and Solids" (1991b). Only the sites designated as flare pits in the DBEL studies were incorporated into the database. Data on groundwater quality was available for only six of the sites, and was therefore not included.

The random nature of the sites and samples used to construct the database is an important consideration. All flare pit data described in previous research efforts by Green (1997) and DBEL (1991a and 1991b) was included in the database. The only alteration made to the data was simple unit conversion of % oil data to parts per million for Green's data, and calculation of SAR values for the DBEL data. The other samples used to construct the database were chosen based on the willingness of specific producers to share their site assessment data. Therefore, they cannot be considered random since only a small number of producers provided data for the database. In addition, each producer had different reasons for collecting the data on specific flare pits located at company properties. At some companies the data was collected in a specific area due to a forthcoming land sale. In other cases, one business unit in a defined geographic area collected data on all of their flare pits. In some situations, the sites analyzed by a company were chosen because they were perceived to represent a very high liability, and therefore should be the first priority

for remediation. There is thus the potential for significant bias in the overall database. From this study, it may appear that the flare pit population is more contaminated than is actually the case. This situation only applies to some of the companies providing the data, and for less than half of the samples in the database. However, the results of the analysis on contamination types and extent may inaccurately reflect a too high percentage of medium and highly contaminated sites.

Bias inherent with individual samples or sets of samples in the database may be a result of sampling and analysis. At all of the sites, the concept of taking a random soil sample must be questioned. The manner in which a sample was taken is not specified in the database. The techniques used could include a composite sample of the entire site, multiple samples at various depths and locations, a sample of an area determined to have high contaminant levels based on a visual assessment, a pre-determined sampling plan for random sample procurement, or a combination of these techniques. The manner in which samples were preserved and stored prior to delivery to a lab can influence the concentration of light hydrocarbons including benzene. A variety of laboratories were used to analyze the soil samples in the database, so technician error or bias may play a role in a sub-set of the samples. The standard analytical methods used are consistent in most cases, except when determining hydrocarbon levels. Hydrocarbon levels are a critical parameter in the assessment of sites for remediation.

Hydrocarbons can be measured in a variety of ways using various techniques to yield results. The issue of hydrocarbon testing in soils and the relationship between concentration and toxicity was the focus of a document prepared by AEP (1993b). Essentially, comparisons between the various test methods cannot be made, but the knowledge of a hydrocarbon concentration will help determine reductions in concentrations as remediation techniques are applied on a site specific basis. In this database, hydrocarbon data is amalgamated as described below, which was used solely as

a screening tool against the AB Tier 1 hydrocarbon criteria. Comparisons between sites related to toxicity are difficult to make on the basis of hydrocarbon concentration, since the concentration of specific toxic hydrocarbon components is not known except for those sites having information on benzene, toluene, ethylbenzene and xylene (BTEX) levels.

The data was divided into general description data such as location, soil type and pit use, and chemical composition data such as the concentrations of metals, hydrocarbons, sterilants and salinity parameters in the soil samples. Values for hydrocarbons were consolidated into data expressed as ppm. All hydrocarbon values and total extractable hydrocarbon values in percentages were converted to parts per million and considered as total hydrocarbons. For sites having extractable hydrocarbon range values, the sum of the values was entered as the total hydrocarbon number. The total number of original parameters in the database was 208. A review of the significance of responses determined that, by applying a minimum of 15% responding for all 616 samples, only 46 of the original parameters should be used to construct the working database. Appendix 1 provides a list of all parameters in the original chemical composition database and the percentage of the database having data for that parameter.

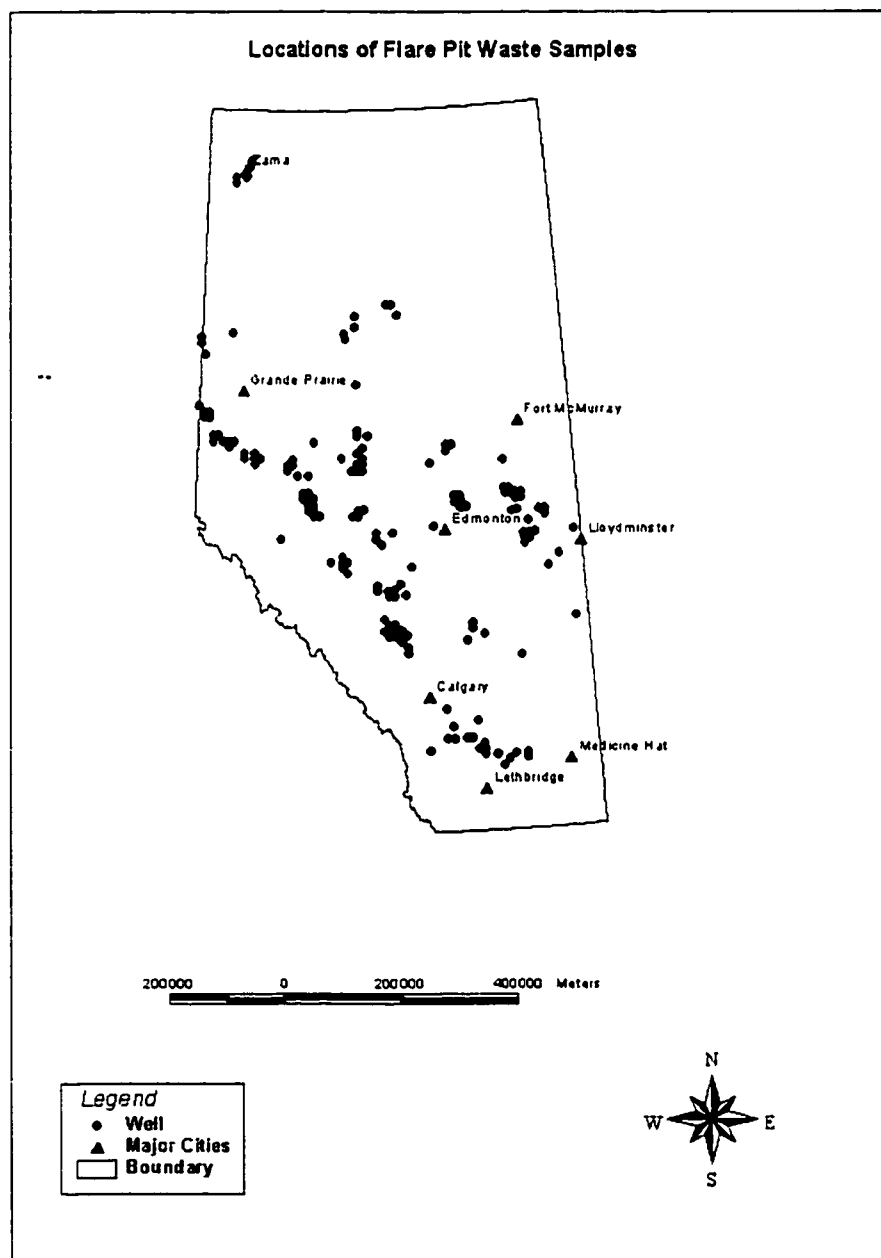
Borehole identification, pit area, pit depth, pit volume and sampling date were omitted from the working database of 46 parameters. While these parameters met the 15% significance level, the information provided would not be of benefit when assessing other flare pits, since the information is site specific. The data on oil percentage and extractable hydrocarbons was also removed, as it is reflected in the total hydrocarbons value. The remaining 39 significant parameters used to construct the working database are listed in Table 1. The working database entries are shown in Appendix 2, while the locations of the 552 database samples from Alberta are shown in Figure 1.

Table 1
Significant Data Used for Site Classification of the Working Database

Initial Data Gathered	Number of Responses	% Responding
Activity	599	97.24
Arsenic (ug/g)	118	19.16
Barium (ug/g)	198	32.14
Benzene (ug/g)	114	18.51
Cadmium (ug/g)	195	31.66
Chromium (ug/g)	189	30.68
Cobalt (ug/g)	116	18.83
Construction Date	141	22.89
Copper (ug/g)	197	31.98
EC (mS/cm)	537	87.18
Ethylbenzene (ug/g)	109	17.69
Produced Hydrocarbon	481	78.08
Hydrocarbons (ug/g and % as ug/g)	485	78.73
Latitude	601	97.56
Lead (ug/g)	191	31.01
Location	608	98.70
Longitude	601	97.56
Mercury (ug/g)	178	28.90
Molybdenum (ug/g)	116	18.83
Nickel (ug/g)	192	31.17
Observations	118	19.16
pH	426	69.16
Pit Contents	212	34.42
Site Management Completed?	220	35.71
Management Technique Suggested	338	54.87
SAR	348	56.49
Saturation %	170	27.60
Soil Type	340	55.19
Soluble Calcium (mg/L)	105	17.05
Soluble Chloride (mg/L)	220	35.71
Soluble Magnesium (mg/L)	105	17.05
Soluble Potassium (mg/L)	95	15.42
Soluble Sodium (mg/L)	105	17.05
Soluble Sulphate (mg/L)	101	16.40
Toluene (ug/g)	96	15.58
Vanadium (ug/g)	155	25.16
"White Zone" or "Green Zone"	552	89.61
Xylene (ug/g)	111	18.02
Zinc (ug/g)	200	32.47

Figure 1

Flare Pit Database Sample Locations



4.0 Analysis of the Database

4.1 Toxicity of Database Elements and Compounds

Sites in the database are categorized as having “no concern”, a “medium concern” or a “serious concern” based on consideration of the level of each contaminant. In order for the database to be useful in assessing all flare pits in Canada, a site identified as having “no concern” must take into consideration the already established general soil quality guidelines for the country or the province. The most recently published soil guidelines are the CCME SQG which include generic numbers for the maximum allowable concentrations of specific elements and compounds according to land use, with the lowest concentrations allowed in lands considered agricultural. Alberta land is divided into two zones based on land use and characteristics. The “white zone” of the province is the settled southern, central and Peace River area, characterized by high population density and significant agricultural use (Alberta Agricultural, Food and Rural Development, 1997). The “green zone” of the province is comprised of the less populated, forested areas in northern Alberta and the mountain and foothills regions, characterized by timber production and minimal agricultural use (Alberta Agricultural, Food and Rural Development, 1997). Oil and gas production activities are carried out in both the “white zone” and “green zone”.

The CCME SQG do not provide data on all of the significant parameters in the database. Since most of the sites in the database are in Alberta, AB Tier 1 values are used to define the “no concern” level for all other parameters, as they were specifically developed for the province and are more current than CCME IC. The AB Tier 1 criteria do not consider land use, but as stated earlier, the numbers in AB Tier 1 and CCME SQG for agricultural land use indicates that for those parameters that are common in both guidelines, the maximum allowable amount is very similar in almost all cases. Between the CCME SQG and AB Tier 1, all parameters in the working database are considered except sodium, magnesium, calcium, chlorides, sulfate, potassium and saturation %. Sodium, magnesium

and calcium are indirectly considered in SAR values. Chloride, sulfate, potassium and the SAR cations indirectly contribute to EC and therefore are indirectly considered in the guidelines. Saturation percentage is not considered in either soil guideline.

The definition of a “serious concern” site is established for this database as any site exceeding the maximum allowable levels of contaminants permitted in hazardous waste destined for landfill disposal in Alberta. The provincial documents that describe these levels are the WCR (AEP, 1993a) and the AUGFWM (AEP, 1995). By applying the element or compound limit stated in the documents, sites can be identified which may have difficulty in meeting the hazardous landfill requirements. The use of these numbers is for reference only, as the procedure in determining if a waste can go to a hazardous waste landfill begins with an assessment of specific waste characteristics to determine if it is hazardous, followed by chemical characterization. For example, a waste might first be tested for pH, flash point, polychlorinated biphenyl concentration and dioxin to identify if it is hazardous. Following the identification of a hazardous waste, the material would then be tested for other elements and compounds to identify if it could be accepted at a hazardous waste landfill.

If a flare pit contained an element or compound in a concentration that exceeds the hazardous waste guidelines for landfills, it indicates that there is an extremely “serious concern” at that site.

The entries in the database that correspond to numbers from the AUGFWM are taken from Table 2, Section 14 (2)(c) and Section 14 (2)(f) of that document, which is shown in Appendix 3. The data in Table 2 of the AUGFWM are presented in units of mg/kg. Conversions from mg/L to mg/kg are made by using a multiplication factor of 20, as described in Section 2.3 of this document.

Flare pits having chemical characteristics that fall between the limits for CCME SQG and AB Tier 1 and the Class 1 landfill limits are considered “medium concern” sites. The sludge from these sites may be disposed of in a Class 1 landfill as waste, but other disposal options and treatment methods may be applied successfully. The primary function of the database is to identify the waste types found in the “medium” and “serious concern” categories and determine their significance. Over the long term, the database should provide insight into how each flare pit category might be most efficiently remediated.

Sections 4.2 to 4.23 describe the numerical criteria applied to each site in order to determine if the site is of “no concern”, “medium concern” or “serious concern”. Metal species is not taken into consideration for any element. For each parameter, a discussion is provided on the applicable numerical criteria for “no concern”, “medium concern” and “serious concern” sites.

The comments on the level of concern associated with the flare pits in the database are based on existing provincial and federal guidelines. Prior research into parameter toxicity was used in the construction of these guidelines, and relevant information from the CCME SQG and other element and compound research relating to human and environmental health is highlighted in the “research” section under each heading. Information provided in this section was chosen to best represent the toxicity of a certain parameter to various important receptors. Soil health indicators such as nitrification, respiration, soil organism populations, plant health, plant growth, and earthworm survival present some idea of how a soil area can cope with different concentrations of a contaminant and why contaminant levels are restricted. The same health indicators can provide some insight into the soil quality guidelines that define a healthy soil area.

Human health toxicity information is also a very important consideration for sites, as the relative risk of certain elements and compounds to human health versus environmental health is sometimes significantly greater. Therefore, understanding if one of the database parameters is a known or suspected human carcinogen or contributes to severe health problems provides the basis for applying a highly conservative allowable limit, based on human health risk assessment. A comparison of the research presented in the CCME SQG and other relevant research with the existing numerical guideline for that parameter provides some indication of the degree of conservatism used when designing soil quality guidelines.

4.2 Arsenic

4.2.1 Regulatory

Maximum arsenic values in soil for specific land uses are provided in both provincial and federal guidelines. According to CCME SQG, arsenic values for all land uses may not exceed 12 mg/kg (CCME, 1997). According to AB Tier 1, arsenic values may not exceed 10 mg/kg (AEP, 1994a). In AUGFWM, arsenic values may not exceed 500 mg/kg according to Section 14 (2)(f) describing solid waste (AEP, 1995).

4.2.2 Research

A review of soils in Alberta for arsenic content determined that the average background concentration is 4.9 mg/kg based on 78 different soil samples (Dudas and Pawluk, 1980). At 10 mg/kg, decreased yield was noticed in plant species such as green beans, spinach and cabbage, all of which are commonly consumed (Woolson, 1973). Studies on earthworms had shown the lethal dose for 50% mortality in the population (LD_{50}) for the earthworm *Eisenia fetida* was 100 mg/kg of soil, while at 83 mg/g there was no observed effect (Environment Canada, 1995). A long term study reviewing the effect of arsenic on corn growth determined that concentrations of 165 mg/kg reduced potential plant growth by 36% in a variety of soil types (Woolson et. al., 1971). A short, 10-day study with three

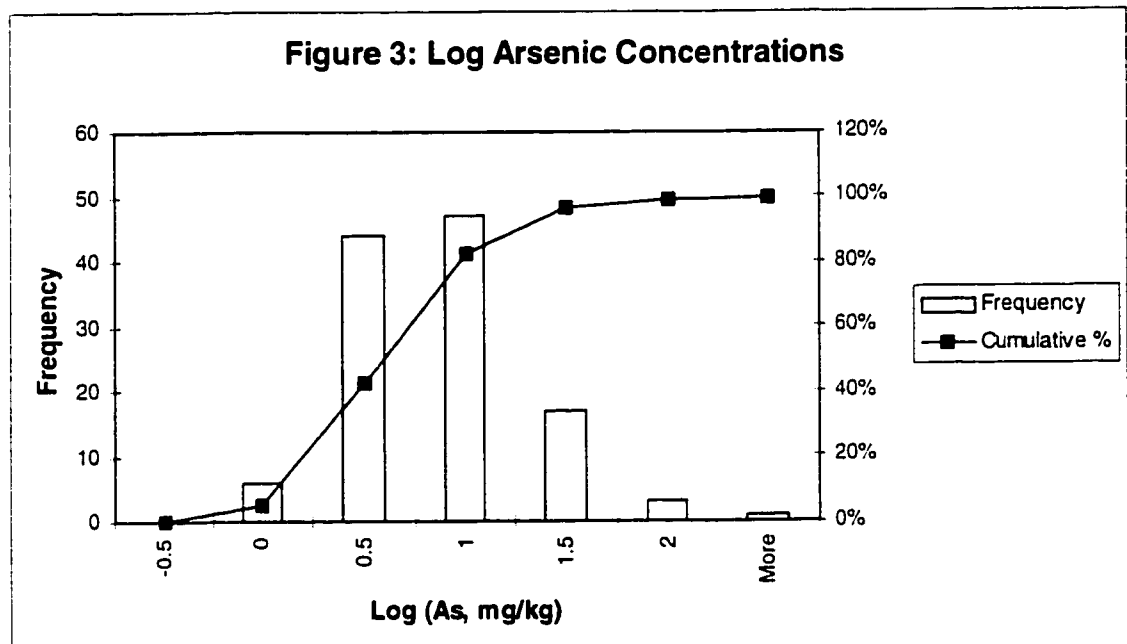
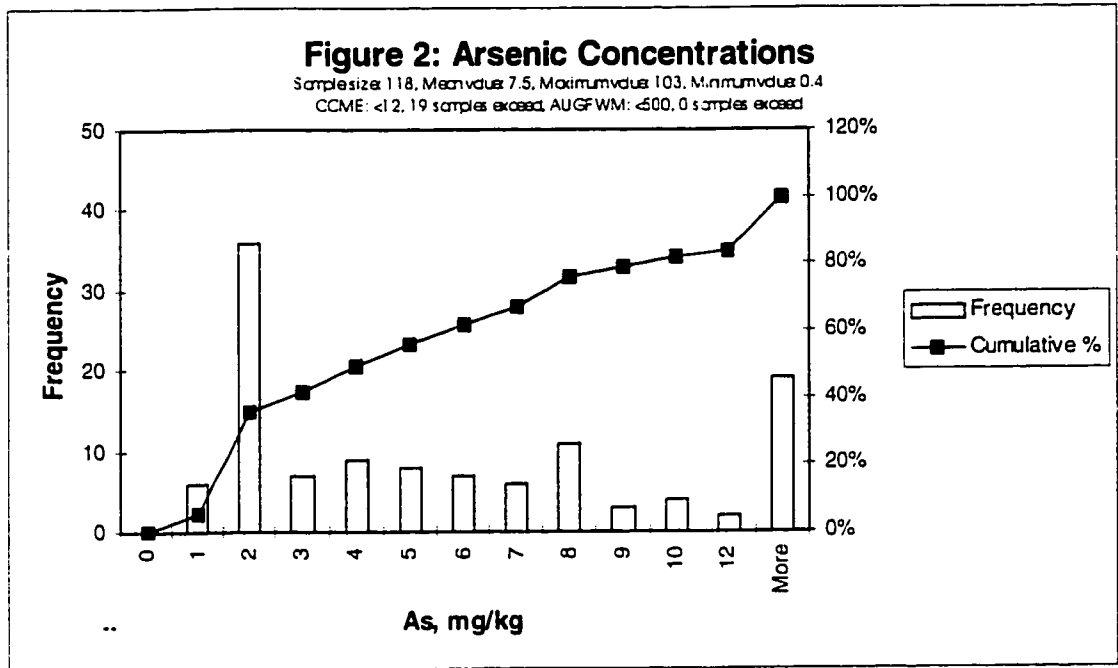
soil types determined that at soil concentrations of 375 mg/kg, nitrification was inhibited by an average of 83.3% (Liang and Tabatabai, 1978).

Inorganic arsenic compounds are considered carcinogenic to humans, so allowable levels in soils are kept to a minimum based on human health risk (CCME, 1997).

4.2.3 Discussion and Application to the Database

Based on the most recent federal soil quality guidelines, a maximum concentration of 12 mg/kg was applied to a site with “no concern”. This value does not seem overly conservative based on the toxicity testing results at arsenic levels of 4.9 and 10 mg/kg, and that it is greater than two times the background concentration of arsenic in Alberta soils. Sites with concentrations greater than 500 mg/kg were considered a “serious concern” based on inability for disposal in a Class 1 hazardous waste landfill. Arsenic data is available for 118 samples, or 19% of the database, with concentrations ranging from 0.4 mg/kg to 103 mg/kg and a mean of 7.5 mg/kg. Using the proposed maximum allowable values, 99 of the samples will fall into the “no concern” category, 19 of the samples will fall into the “medium concern” category, while none of the samples will fall into the “serious concern” category.

Figure 2 is a relative and cumulative frequency distribution of the arsenic data for the entire database. The data does not appear to follow a normal distribution, but the log transformed data shown in Figure 3 do appear to follow a normal distribution.



4.3 Barium

4.3.1 Regulatory

Barium is not considered in the CCME SQG. According to AB Tier 1, barium values may not exceed 600 mg/kg (AEP, 1994a). In AUGFWM, barium values may not exceed 2000 mg/kg according to Table 2, Class 9.3 substances (AEP, 1995).

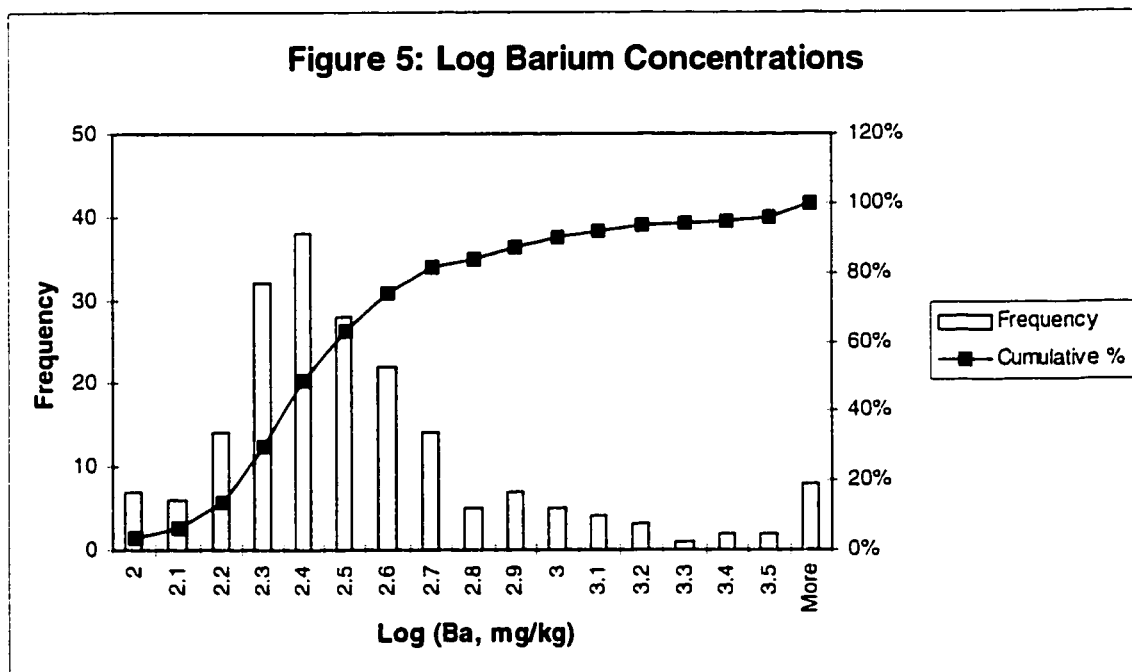
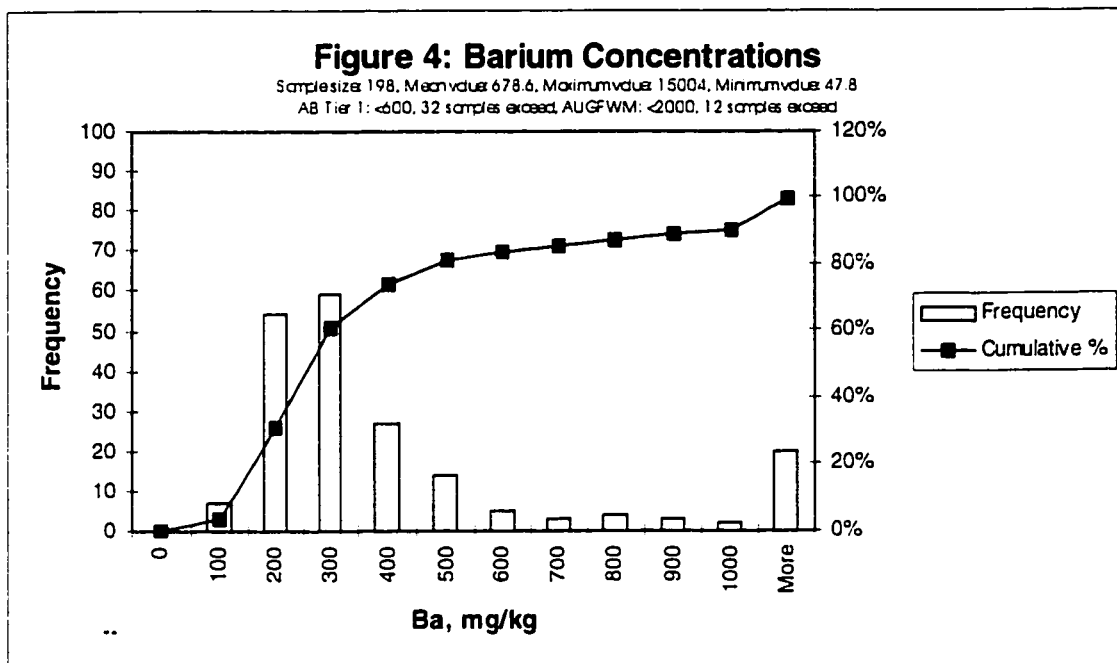
4.3.2 Research

Significant barium levels are commonly found in drilling wastes as barium sulfate. American Petroleum Institute (API) guidance for exploration and production metals of concern indicate a maximum concentration of barium in a mixture of waste and soil should be 180, 000 mg/kg based on its low toxicity to humans, plants and animals (API, 1995).

4.3.3 Discussion and Application to the Database

Based on the most recent provincial soil quality guidelines, a maximum concentration of 600 mg/kg was applied to a site with “no concern”. The degree of conservatism associated with this value appears to be high based on comments made regarding barium toxicity by API. Sites with concentrations greater than 2000 mg/kg were considered a “serious concern” based on inability for disposal in a Class 1 hazardous waste landfill. Barium data is available for 198 samples, or 32% of the database, with concentrations ranging from 47.8 to 15004 mg/kg and a mean of 678.6 mg/kg. Using the proposed maximum allowable values, 166 of the samples will fall into the “no concern” category, 20 of the samples will fall into the “medium concern” category, while twelve of the samples will fall into the “serious concern” category.

Figure 4 is a relative and cumulative frequency distribution of the barium data for the entire database. The data does not appear to follow a normal distribution, but the log transformed data shown in Figure 5 do appear to follow a normal distribution.



4.4 Cadmium

4.4.1 Regulatory

Maximum cadmium values in soil for specific land uses are provided in both provincial and federal guidelines. According to CCME SQG, cadmium values for agricultural, residential/parkland, commercial and industrial land use may not exceed 1.4, 10, 27 and 27 mg/kg, respectively (CCME, 1997). According to AB Tier 1, cadmium values may not exceed 1.0 mg/kg (AEP, 1994a). In AUGFWM, cadmium values may not exceed 100 mg/kg according to Section 14 (2) (f) (AEP, 1995).

4.4.2 Research

A review of soils in Alberta for cadmium content determined that the average background concentration is 0.291 mg/kg based on 78 different soil samples (Dudas and Pawluk, 1980). More recent efforts by AEP to better define ambient soil quality in Alberta determined that average cadmium concentrations are about 0.3 mg/kg, but the data compiled was predominantly below the detection limit of analytical method used, which was 0.5 mg/kg (Lutwick, 1996). A 21% reduction in wheat yield was noticed at concentrations of 2.5 mg/kg (Haghiri, 1973). Cadmium sensitive crops such as spinach and lettuce showed yield reduction at 4 mg/kg, while other crops such as tomatoes, cabbage and rice could tolerate a minimum of 170 mg/kg (Bingham, et. al., 1975). One study reviewing the effect of cadmium on respiration determined that effects were noticed at 56.2 mg/kg in five different soil types (Lighthart et. al., 1983) while a second study reviewing respiration as it relates to soil type noticed inhibition at 1000 mg/kg for sandy and silty soils, while clay soil effects were not noticed until 8000 mg/kg (Doelman and Haanstra, 1984). Studies on *E. fetida* had shown the LD₅₀ to range from 253-1843 mg/kg of soil (Neuhauser et. al., 1985, van Gestel et al., 1991).

Cadmium is a known human carcinogen through inhalation exposure. However, the primary intake route for humans is via food ingestion (Hill, 1996).

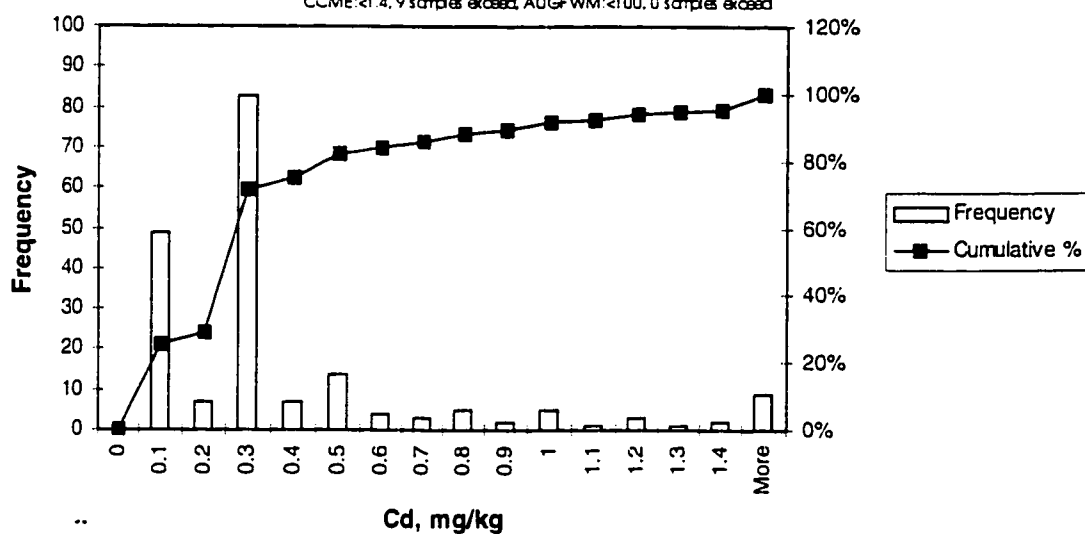
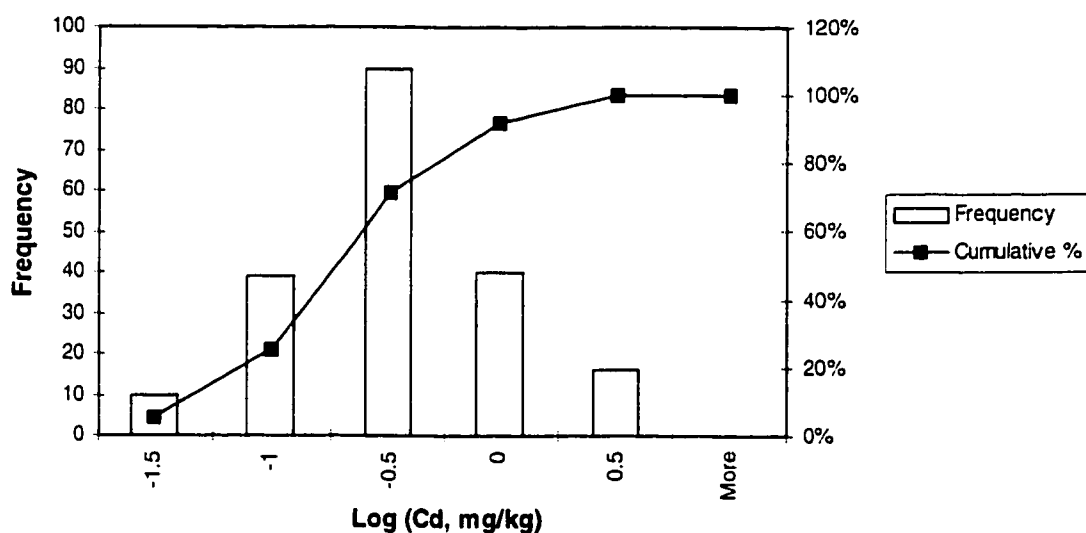
4.4.3 Discussion and Application to the Database

Based on the most recent federal soil quality guidelines, a maximum concentration of 1.4 mg/kg was applied to a site with “no concern”. This value does not seem overly conservative considering its carcinogenic effects. At 1.4 mg/kg the allowable concentration is almost five times the background concentration in Alberta soils, and the negative effect on wheat at 2.5 mg/kg ensures that this major crop is protected. Sites with concentrations greater than 100 mg/kg were considered a “serious concern” based on inability for disposal in a Class 1 hazardous waste landfill. Cadmium data is available for 195 samples, or 32% of the database, with concentrations ranging from 0.025 to 3.1 mg/kg and a mean of 0.4 mg/kg. Using the proposed maximum allowable values, 186 of the samples will fall into the “no concern” category, 9 of the samples will fall into the “medium concern” category, while none of the samples will fall into the “serious concern” category.

Figure 6 is a relative and cumulative frequency distribution of the cadmium data for the entire database. The data does not appear to follow a normal distribution, but the log transformed data shown in Figure 7 do appear to follow a normal distribution.

Figure 6: Cadmium Concentrations

Sample size: 195, Mean value: 0.42, Maximum value: 3.1, Minimum value: 0.025
 CCME: <1.4, 9 samples exceed, AUGFWM: <100, 0 samples exceed

**Figure 7: Log Cadmium Concentrations**

4.5 *Total Chromium*

4.5.1 Regulatory

Maximum chromium values in soil for specific land uses are provided in both provincial and federal guidelines. According to CCME SQG, total chromium values for agricultural, residential/parkland, commercial and industrial land use may not exceed 64, 64, 87 and 87 mg/kg, respectively (CCME, 1997). According to AB Tier 1, total chromium values may not exceed 100 mg/kg (AEP, 1994a). In AUGFWM, hexavalent chromium values may not exceed 500 mg/kg according to Table 2, Class 9.3 substances (AEP, 1995).

4.5.2 Research

The research on chromium typically considers either the trivalent or hexavalent species. As mentioned earlier, insufficient data is available in the database to discuss hexavalent chromium, the more toxic form of this element. The results of modeling the environmental fate of chromium have shown that the majority of chromium will be in a trivalent, rather than hexavalent state, which forms the basis for the regulatory values (Lutwick, 1996). Therefore, a review of work that considers either total chromium or trivalent chromium is appropriate.

Efforts by AEP to better define ambient soil quality in Alberta determined that average total chromium concentrations are 20 mg/kg, and that values greater than 39 mg/kg are most likely from external sources (Lutwick, 1996). Soil microbe effects at chromium (III) levels ranging from 25 to 100 mg/kg include changes in species abundance, decreased respiration, decreased nitrogen transformation and decreased enzyme activities (Government of Canada, 1994). Decreased respiration was observed at concentrations of 100 mg/kg chromium (III) (Bartlett and James, 1988). Decreased yields in the growth of grass, lettuce and radish was observed at 200 mg/kg (Government of Canada, 1994). At 400 mg/kg microbial nitrogen transformations were inhibited while bacterial populations were inhibited at 556 mg/kg chromium (III) (Bartlett and James, 1988). Population

decreases in soil bacteria and soil fungi were observed at 100 mg/kg chromium (III). However decreases in just the bacterial population were noticed at concentrations as low as 10 mg/kg (Wong and Trevors, 1988). Studies on *E. fetida* had shown the LD₅₀ to range from 671 to 1400 mg/kg of soil (CCME, 1997).

While trivalent chromium is an essential element for humans, its toxicity in large quantities has been reviewed and classified as “unclassifiable with respect to carcinogenicity in humans” (Government of Canada, 1994). Hexavalent chromium is classified as “carcinogenic to humans”, based on exposure via inhalation (Government of Canada, 1994).

4.5.3 Discussion and Application to the Database

Based on the most recent federal soil quality guidelines, a maximum concentration of 64 mg/kg was applied to a site with “no concern”. This value does not seem overly conservative, since it is three times the background concentration of chromium (III) in Alberta soils. Sites with concentrations greater than 500 mg/kg were considered a “serious concern” based on inability for disposal in a Class 1 hazardous waste landfill. This value is based on the amount of hexavalent chromium, so using this concentration to gauge total chromium concentrations is conservative. Total chromium data is available for 189 samples, or 31% of the database, with concentrations ranging from 5 to 1050 mg/kg and a mean of 40.4 mg/kg. Using the proposed values, 173 of the samples will fall into the “no concern” category, 7 of the samples will fall into the “medium concern” category, while 9 of the samples will fall into the “serious concern” category.

Figure 8 is a relative and cumulative frequency distribution of the total chromium data for the entire database. The data does not appear to follow a normal distribution, but the log transformed data shown in Figure 9 do appear to follow a normal distribution.

Figure 9: Log Total Chromium Concentrations

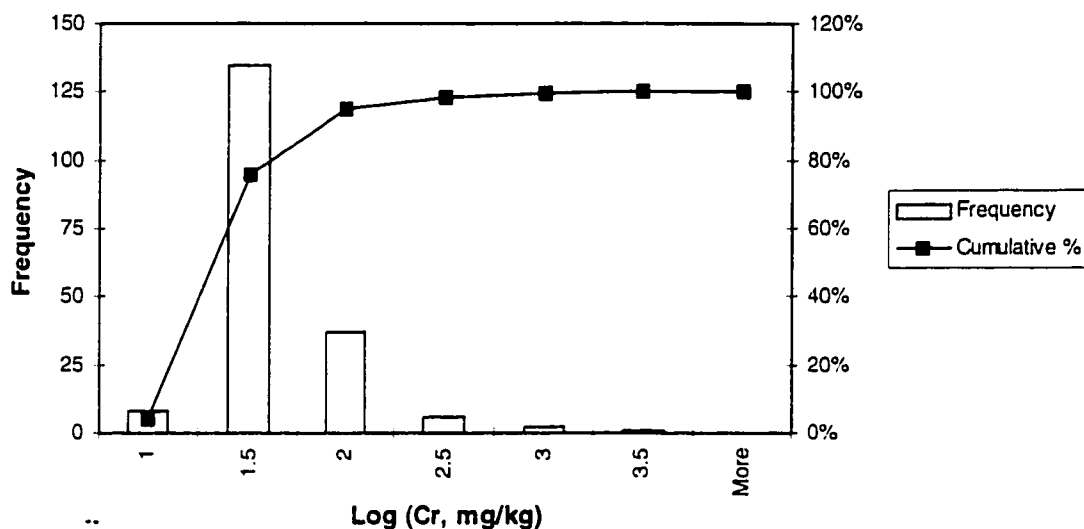
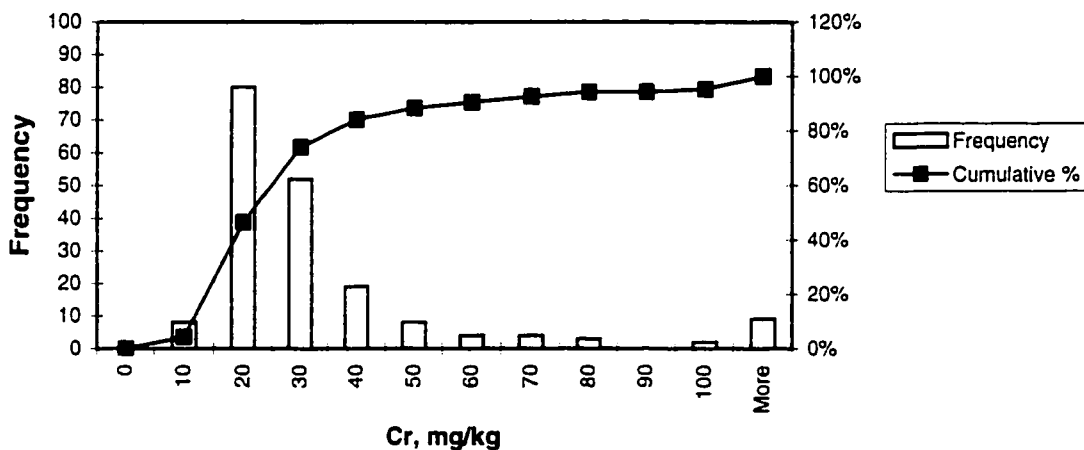


Figure 8: Total Chromium Concentrations

Sample size: 189, Mean value: 40.4, Maximum value: 1050, Minimum value: 5
CCME:<64, 16 samples exceed, AUGFWM:<100, 1 sample exceeds



4.6 Cobalt

4.6.1 Regulatory

Cobalt is not considered in the CCME SQG. According to AB Tier 1, cobalt values may not exceed 20 mg/kg (AEP, 1994a). In AUGFWM, cobalt values may not exceed 2000 mg/kg according to Table 2, Class 9.3 substances (AEP, 1995).

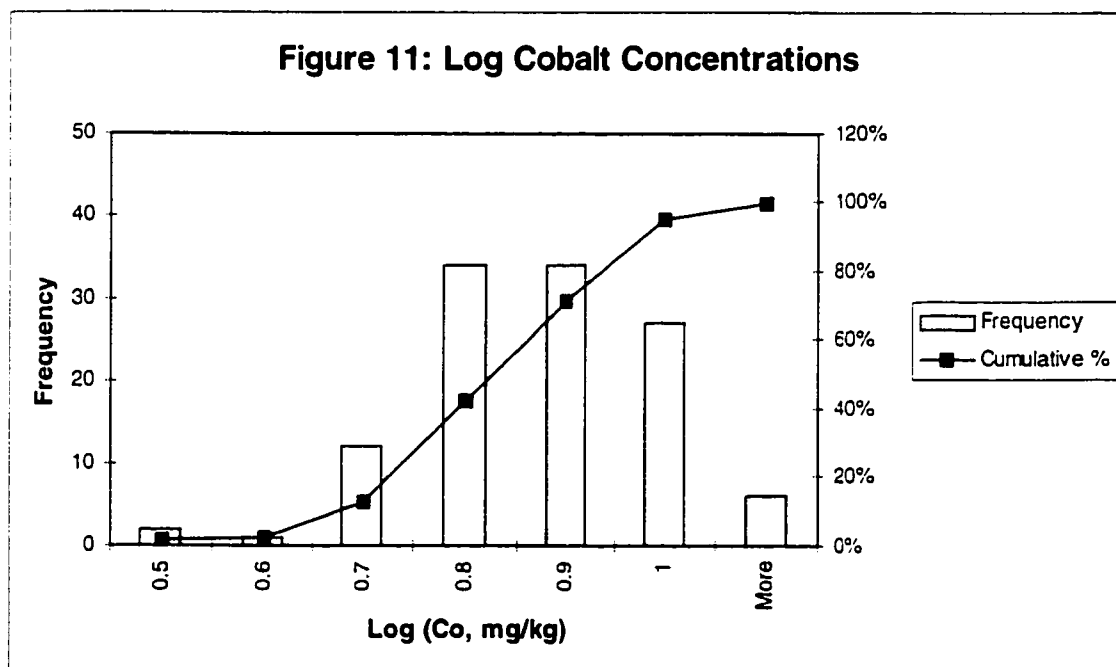
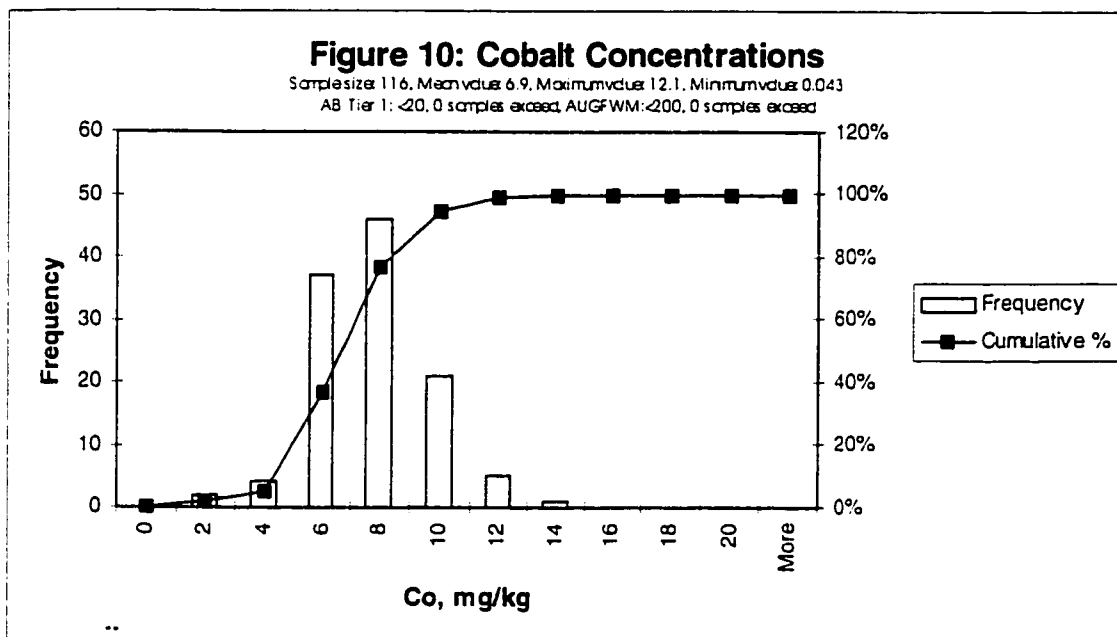
4.6.2 Research

A review of soils in Alberta for cobalt determined that the average background concentration is 9.85 mg/kg, based on 78 different soil horizon samples (Dudas and Pawluk, 1980). Cobalt soil concentrations are often related to soil type, with concentrations in sandy soils up to ten times less than in clay soils (Black, 1965).

4.6.3 Discussion and Application to the Database

Based on the most recent provincial soil quality guidelines, a maximum concentration of 20 mg/kg was applied to a site with “no concern”. This value is two times the background concentration of cobalt in Alberta, indicating that the value may be quite conservative compared to the other metals in the database, and the difference between the regulatory limit and background concentrations. Sites with concentrations greater than 200 mg/kg were considered a “serious concern” based on inability for disposal in a Class 1 hazardous waste landfill. Cobalt data is available for 116 samples, or 19% of the database, with concentrations ranging from 0.043 to 12.1 mg/kg and an average of 6.9 mg/kg. Using the proposed values, all 116 samples will fall into the “no concern” category.

Figure 10 is a relative and cumulative frequency distribution of the cobalt data for the entire database. The data appear to follow a normal distribution, but a log transformation results in a similar distribution as seen in Figure 11.



4.7 Copper

4.7.1 Regulatory

Maximum copper values in soil for specific land uses are provided in both provincial and federal guidelines. According to CCME SQG, copper values for agricultural, residential/parkland, commercial and industrial land use may not exceed 63, 63, 100 and 100 mg/kg, respectively (CCME, 1997). According to AB Tier 1, copper values may not exceed 80 mg/kg (AEP, 1994a). In AUGFWM, copper values may not exceed 2000 mg/kg according to Table 2, Class 9.3 substances (AEP, 1995).

4.7.2 Research

The average concentration of copper in Alberta soils is 24.67 mg/kg, based on a study of 78 horizon samples (Dudas and Pawluk, 1980). More recent efforts by AEP to better define ambient soil quality in Alberta determined that average copper concentrations are 18 mg/kg, and that values greater than 29 mg/kg are most likely from external sources (Lutwick, 1996). Approximately 10 ppm of a plant's dry weight is copper, so at soil levels below 1 ppm, copper deficiency can occur, while high copper concentrations can also cause toxic effects in plants (Black, 1965). Earthworm data has been collected that related copper concentration in soil to cocoon production. A decline in cocoon production was noticed at 28 mg/kg for *Aporrectodea caliginosa* and *Aporrectodea chlorotica* while concentrations had to be increased to 80 mg/kg to observe an effect for *Lumbricus rubellus* (Ma, 1988). At 50 mg/kg, plant injury was noted in a birch tree species while no effect was observed in two pine and one spruce tree species (Patterson and Olson, 1982). One respiration study showed a decrease at 100 mg/kg in an acid sandy soil (Cornfield, 1977), while other studies determined that soil type plays a major role in the amount of copper that can be tolerated with increased tolerance typically seen in clay soils (Doelman and Haanstra, 1984, Lighthart et. al., 1983). Another study that looked at the effect on a soil at increasing copper concentrations determined that at 300 mg/kg, the fungal community structure is altered, at 750 mg/kg, there are decreases in

microbial biomass and adenosine triphosphate (ATP), at 1000 mg/kg, there is a decrease in the number of tolerant microorganisms and in fungal biomass, and at 2600 mg/kg, the number of colony forming units (CFU) fungi decrease (Tyler, et. al., 1989).

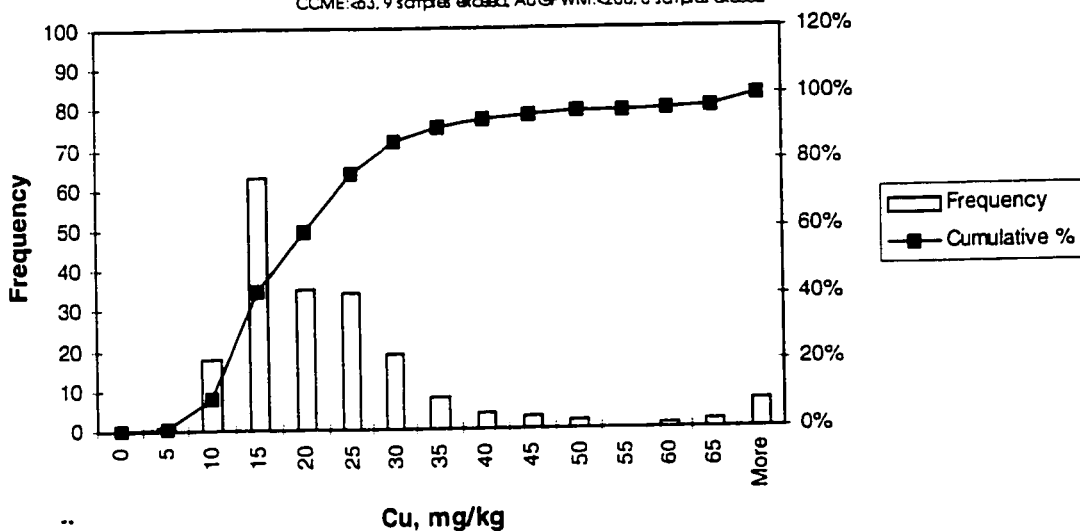
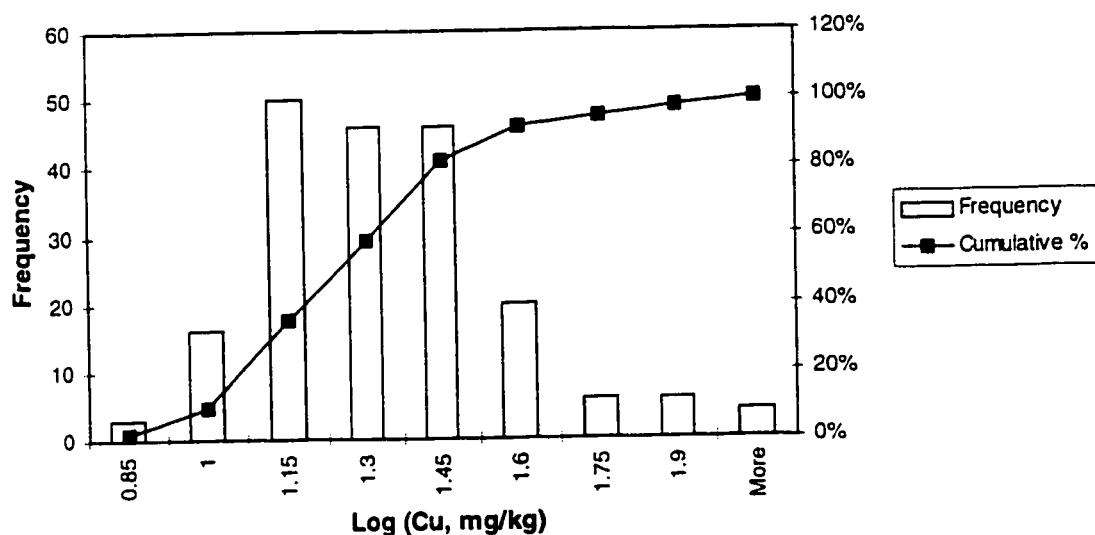
4.7.3 Discussion and Application to the Database

Based on the most recent federal soil quality guidelines, a maximum concentration of 63 mg/kg was applied to a site with “no concern”. This value does not appear to be overly conservative, as it is about three times the background concentration in Alberta soils, and minor problems have been noted at lower concentrations with specific plant and animal species. Sites with concentrations greater than 200 mg/kg were considered a “serious concern” based on inability for disposal in a Class 1 hazardous waste landfill. Copper data is available for 197 samples, or 32% of the database, with concentrations ranging from 4.7 to 503 mg/kg and an average of 26.2 mg/kg. Using the proposed values, 188 of the samples will fall into the “no concern” category, 9 of the samples will fall into the “medium concern” category, while none of the samples will fall into the “serious concern” category.

Figure 12 is a relative and cumulative frequency distribution of the copper data for the entire database. The data does not appear to follow a normal distribution, but the log transformed data shown in Figure 13 do appear to follow a normal distribution.

Figure 12: Copper Concentrations

Sample size: 197, Mean value: 26.2, Maximum value: 503, Minimum value: 4.7
 CCME: <63, 9 samples exceed, AUGFWM: <200, 0 samples exceed

**Figure 13: Log Copper Concentrations**

4.8 *Lead*

4.8.1 Regulatory

Maximum lead values in soil for specific land uses are provided in both provincial and federal guidelines. According to CCME SQG, lead values for agricultural, residential/parkland, commercial and industrial land use may not exceed 70, 140, 260, and 400 mg/kg, respectively (CCME, 1997). Soil quality guidelines specifically for the protection of human health are calculated to be 140 mg/kg, based on a soil ingestion scenario (CCME, 1997). According to AB Tier 1, lead values may not exceed 50 mg/kg (AEP, 1994a). According to the "Remediation Guidelines for Petroleum Storage Tanks", fine grained and coarse grained soil concentrations of lead must be lower than 50 mg/kg, 200 and 600 for high, medium and low risk sites (AEP, 1994b). In AUGFWM, lead values may not exceed 500 mg/kg according to Section 14 (2) (f) (AEP, 1995).

4.8.2 Research

A review of soils in Alberta has shown an average lead concentration of 17.2 mg/kg based on 78 horizon samples (Dudas and Pawluk, 1980). More recent efforts by AEP to better define ambient soil quality in Alberta determined that average lead concentrations are 9 mg/kg, and that values greater than 119 mg/kg are most likely from external sources (Lutwick, 1996). Plant yield reductions were observed at soil lead contents of 50 mg/kg for onions and 500 mg/kg for the root biomass of oats and wheat (Khan and Frankland, 1984). Decreases in soil respiration were noticed at lead levels ranging from 375 to 8000 mg/kg depending on the soil type, with sand soils being affected at lower concentrations and peat and clay soils being affected at higher concentrations (Doelman and Haanstra, 1984, Doelman and Haanstra, 1979). At 1000 mg/kg, the effect of lead on nitrogen mineralization and nitrification is greater with a greater pH based on a study range of 6 to 7.7 (Bhuiya, and Cornfield, 1974). A study that reviewed the effect of increasing lead levels in soil determined that at 940 mg/kg there was a decrease in the number of CFU bacteria and at 3564 mg/kg there was a decrease in the number of CFU fungi and CFU

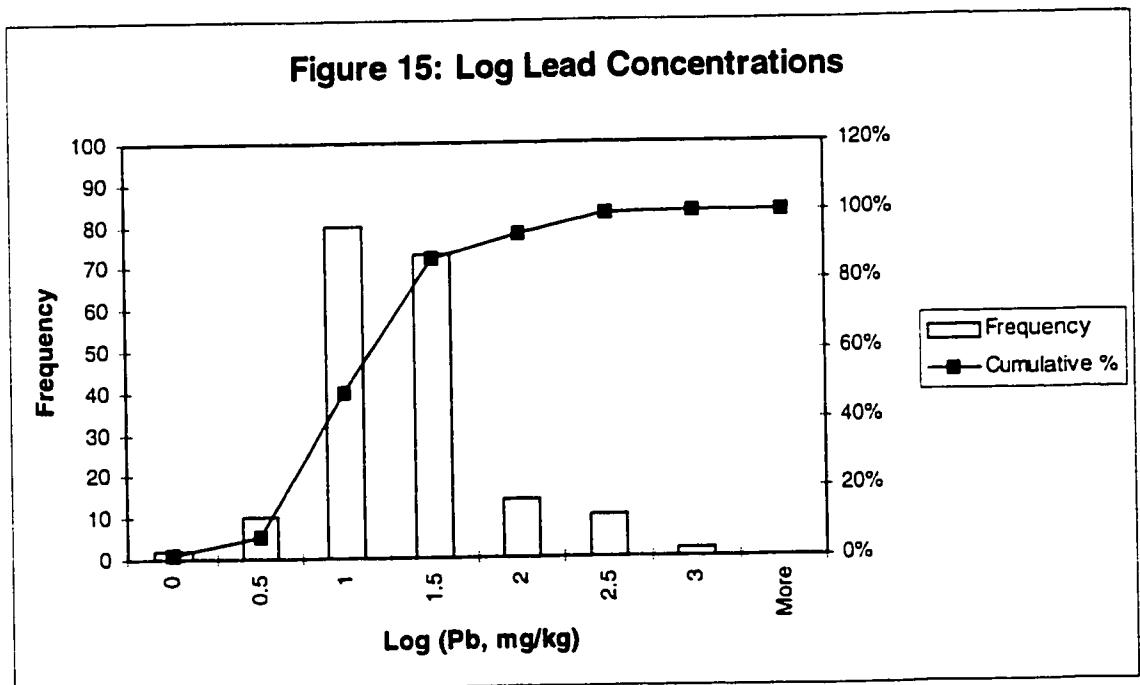
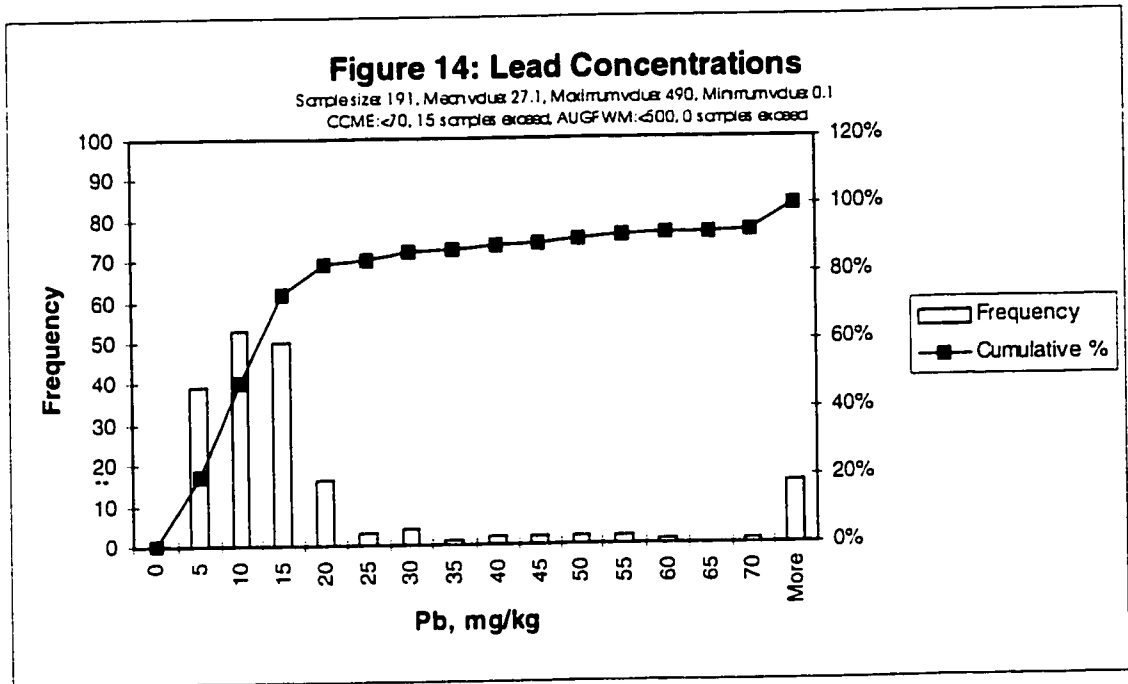
actinomycetes (Tyler et. al., 1989). Studies on *E. fetida* had shown the LD₅₀ to be 2500 mg/kg of soil, while at 1480 mg/g there was no observed effect (Environment Canada, 1995). Cocoon production in the same species was unaffected at 1810 mg/kg and was reduced by 50% at 1940 mg/kg (Spurgeon et. al., 1994).

Lead accumulates in the skeleton, and primarily affects the central nervous system causing mental impairment in humans (Hill, 1996). For humans, the primary route of lead exposure and intake is through food which accounts for 76.6% of total intake, with the exception of children under 2 years, where the intake through soil and food are almost equivalent, at 47.9 and 48.5%, respectively (Hill, 1996).

4.8.3 Discussion and Application to the Database

Based on the most recent federal soil quality guidelines, a maximum concentration of 70 mg/kg was applied to a site with “no concern”. This value does not appear to be overly conservative, as it is about seven times the background concentration in Alberta. The effect of lead on human health may be a contributing factor to this value versus a higher one considering the results of plant studies, as lead is a cumulative general poison that can affect the central nervous system (CCME, 1997). The lead concentrations in the “Remediation Guidelines for Petroleum Storage Tanks” (AEP, 1994b) are for a more specific site operation, often in areas that would not be zoned agricultural. Therefore, petroleum storage tank criteria are inappropriate to apply to flare pit sludge. Sites with concentrations greater than 500 mg/kg were considered a “serious concern” based on inability for disposal in a Class 1 hazardous waste landfill. Lead data is available for 191 samples, or 31.3% of the database, with concentrations ranging from 0.1 to 490 mg/kg and an average of 27.1 mg/kg. Using the proposed values, 176 of the samples will fall into the “no concern” category, 15 of the samples will fall into the “medium concern” category, while none of the samples will fall into the “serious concern” category.

Figure 14 is a relative and cumulative frequency distribution of the lead data for the entire database. The data does not appear to follow a normal distribution but the log transformed data shown in Figure 15 do appear to follow a normal distribution.



4.9 Mercury

4.9.1 Regulatory

Maximum mercury values in soil for specific land uses are provided in both provincial and federal guidelines. According to CCME SQG, mercury values for agricultural, residential/parkland, commercial and industrial land use may not exceed 6.6, 6.6, 24 and 30 mg/kg, respectively (CCME, 1997). According to AB Tier 1, mercury values may not exceed 0.2 mg/kg (AEP, 1994a). In AUGFWM, mercury values may not exceed 20 mg/kg according to Section 14 (2) (f) (AEP, 1995).

4.9.2 Research

Efforts by AEP to better define ambient soil quality in Alberta determined that average mercury concentrations are 0.04 mg/kg, and that values greater than 0.12 mg/kg are most likely from external sources (Lutwick, 1996). Decreases in soil respiration were noted at concentrations of 10 and 100 mg/kg (Cornfield, 1977). In a six hour study on respiration, 40 mg/kg was shown to cause decreases, while over a four week period 100 mg/kg were required to produce the same negative effects indicating the acute and chronic toxicity of mercury (Landa and Fang, 1978). Studies on *E. fetida* had shown the LD₅₀ to range from 60 to 700 mg/kg based on soil type (Environment Canada, 1995, Sheppard et al., 1993, Fisher and Koszorus, 1992). Mercury added to soil at 100 mg/kg showed no measurable impact on microbe numbers (van Faassen, 1973). At mercury levels of 1002.9 mg/kg in soil, nitrogen mineralization was inhibited and caused accumulation of ammonium-N in some soils (Liang and Tabatabai, 1977). Nitrification at this concentration was inhibited on average of 96.3% based on studies of three soil types over ten days (Liang and Tabatabai, 1978).

Mercury in an organic form primarily affects the nervous system in humans, and in an inorganic form, impairs renal function (Hill, 1996). Human exposure and intake of

mercury from soil is only 0.02% of total intake, while the primary source of exposure and intake is from food at 80.7%, followed by air at 19.2% (Hill, 1996).

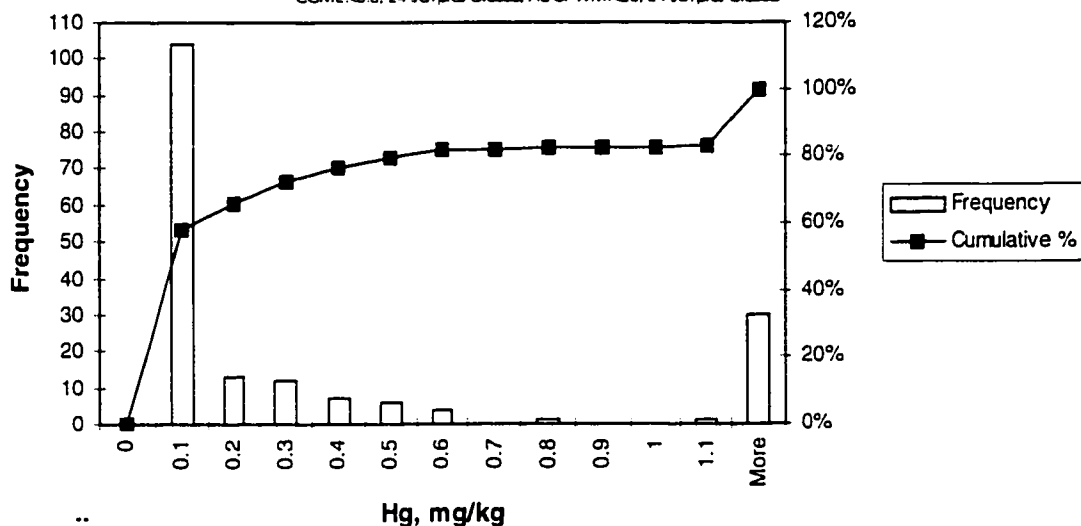
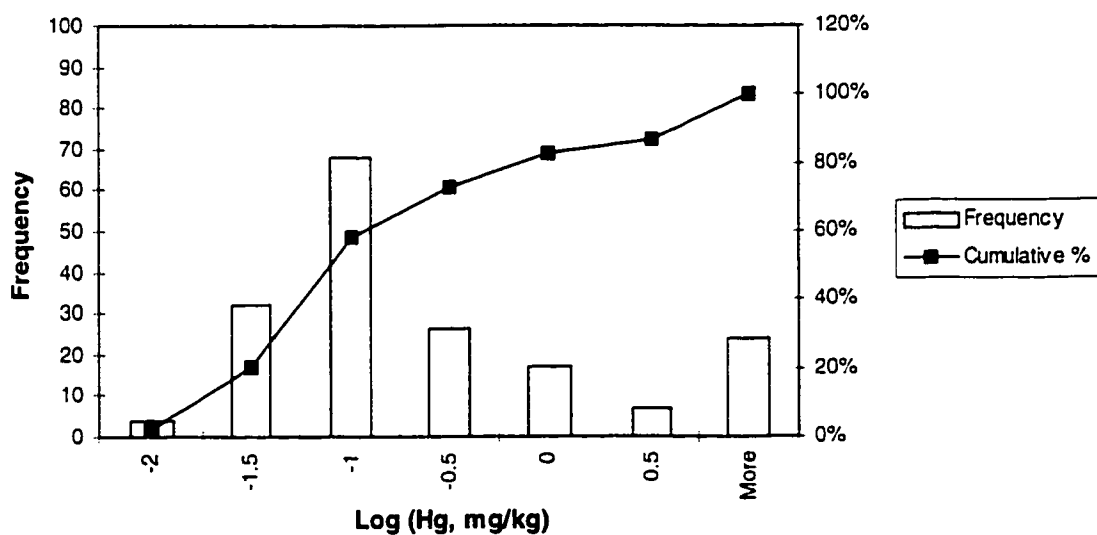
4.9.3 Discussion and Application to the Database

Based on the most recent federal soil quality guidelines, a maximum concentration of 6.6 mg/kg was applied to a site with “no concern”. This value does not appear to be very conservative, as it is 165 times greater than background soil mercury concentrations. The basis for the value is the effect of mercury on human health from an ingestion exposure route (CCME, 1997). Sites with concentrations greater than 20 mg/kg were considered a “serious concern” based on inability for disposal in a Class 1 hazardous waste landfill. This value is lower than the maximum allowable concentration of mercury in an industrial site according to the CCME SQG, indicating that either the landfill requirements are very conservative or the allowable concentration of 30 ppm in an industrial site, which is based on environmental health, is inappropriate. Mercury data is available for 178 samples, or 29% of the database, with concentrations ranging from 0.01 to 245 mg/kg and an average of 8.2 mg/kg. Using the proposed values, 154 of the samples will fall into the “no concern” category, none of the samples will fall into the “medium concern” category, while 24 of the samples will fall into the “serious concern” category.

Figure 16 is a relative and cumulative frequency distribution of the mercury data for the entire database. The data does not appear to follow a normal distribution, but the log transformed data shown in Figure 17 do appear to follow a normal distribution.

Figure 16: Mercury Concentrations

Sample size: 178, Mean value: 8.2, Maximum value: 245, Minimum value: 0.01
 CCME: <6.6, 24 samples exceed, AUGFWM: <20, 24 samples exceed

**Figure 17: Log Mercury Concentrations**

4.10 Molybdenum

4.10.1 Regulatory

Molybdenum is not considered in the CCME SQG. According to AB Tier 1, molybdenum values may not exceed 4 mg/kg (AEP, 1994a). Molybdenum is not covered in the AUGFWM.

4.10.2 Research

Liang and Tabatabai (1978) found that at 479.7 mg/kg of molybdenum in soil, nitrification was inhibited by 53.7% over a ten-day study period. Historical data for North America indicates that molybdenum concentrations greater than 4 mg/kg are rare in agricultural settings (Black, 1965).

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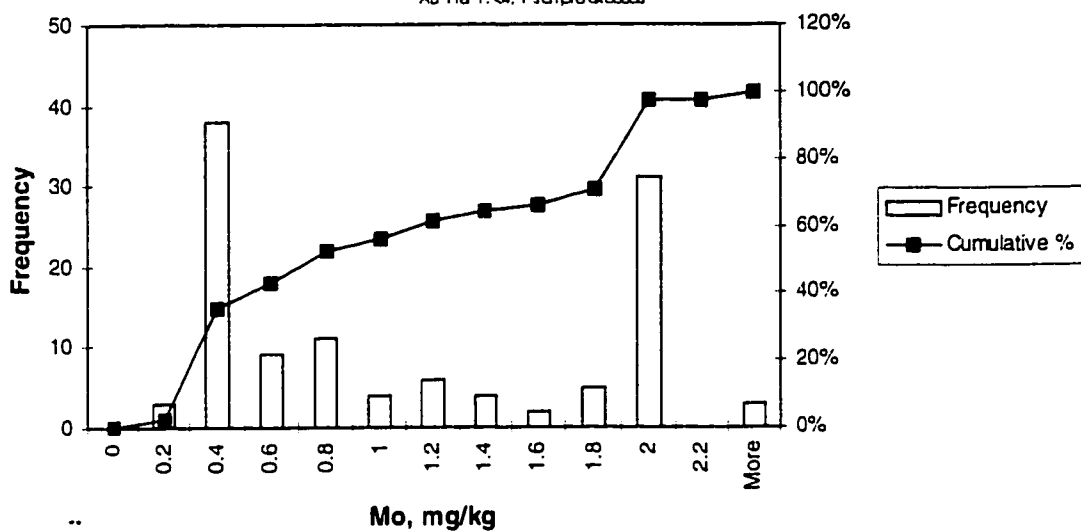
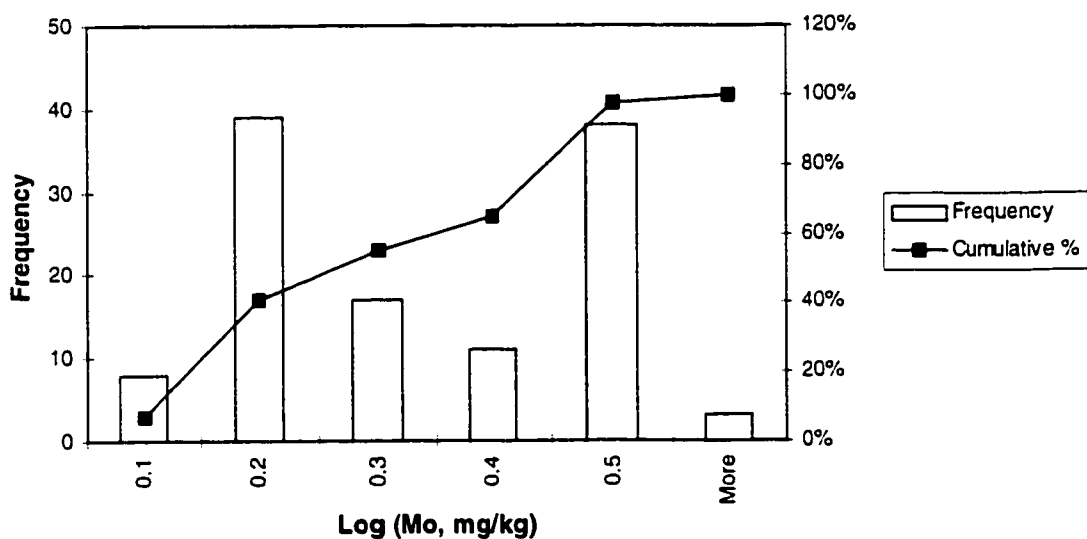
4.10.3 Discussion and Application to the Database

Based on the most recent provincial soil quality guidelines, a maximum concentration of 4 mg/kg was applied to a site with “no concern”. The degree of conservatism associated with this value is difficult to determine, but appears to identify sites greater than typical agricultural background concentrations. No criterion is applied for “serious concern” sites. Molybdenum data is available for 116 samples, or 19% of the database, with concentrations ranging from 0.05 to 4.2 mg/kg and an average of 1.1 mg/kg. Using the proposed values, 115 of the samples will fall into the “no concern” category, 1 of the samples will fall into the “medium concern” category, while none of the samples will fall into the “serious concern” category.

Figure 18 is a relative and cumulative frequency distribution of the molybdenum data for the entire database. The data does not appear to follow a normal distribution, and the log transformed data shown in Figure 19 also do not appear to follow a normal distribution.

Figure 18: Molybdenum Concentrations

Sample size: 116, Mean value: 1.1, Maximum value: 4.2, Minimum value: 0.05
 AB Tier 1: <4, 1 sample exceeds

**Figure 19: Log Molybdenum Concentrations**

4.11 Nickel

4.11.1 Regulatory

Maximum nickel values in soil for specific land uses are provided in provincial guidelines. According to AB Tier 1, nickel values may not exceed 40 mg/kg (AEP, 1994a). In AUGFWM, nickel values may not exceed 500 mg/kg according to Section 14 (2) (f) (AEP, 1995).

4.11.2 Research

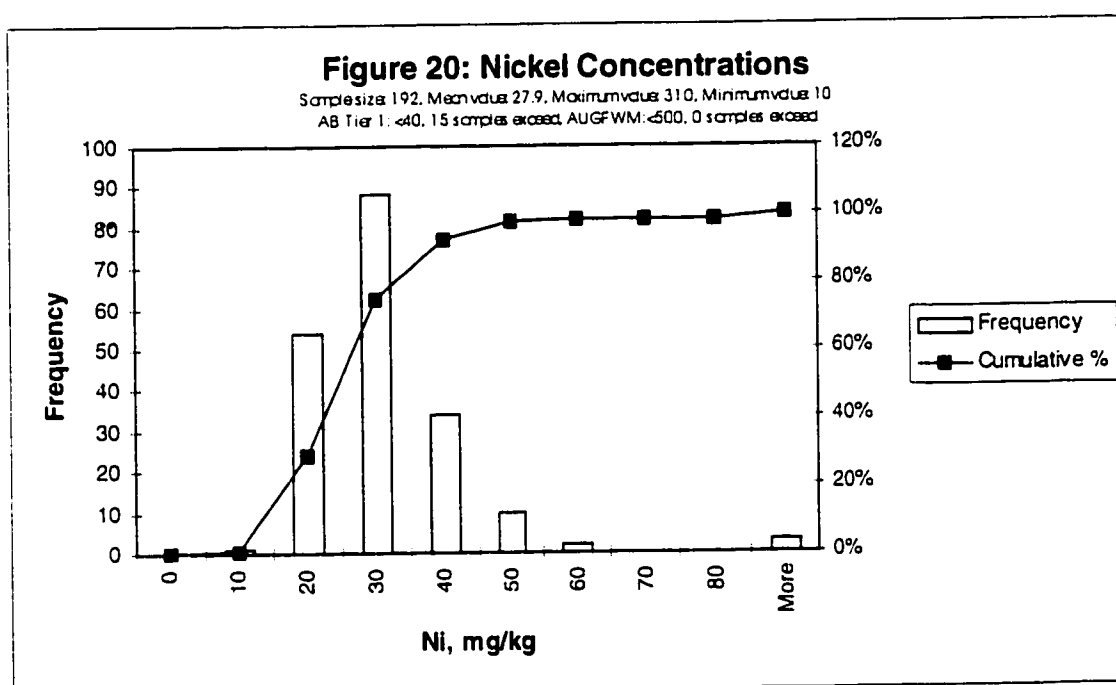
Efforts by AEP to better define ambient soil quality in Alberta determined that average nickel concentrations are 18 mg/kg, and that values greater than 31 mg/kg are most likely from external sources (Lutwick, 1996). Decreased growth of corn and rye was observed at 15 mg/kg, but more negative effects on the same crops were not noticed at 30 mg/kg (Cunningham et. al., 1975). Respiration was inhibited at levels of 150 mg/kg in sandy and clay soils (Doelman and Haanstra, 1984). At 250 mg/kg, there was a decrease in the number of filamentous fungi species and certain microorganism species (Babich and Stotzky, 1982). Nitrogen mineralization was reduced at soil nickel concentrations of 500 mg/kg (deCatanzaro and Hutchinson, 1985).

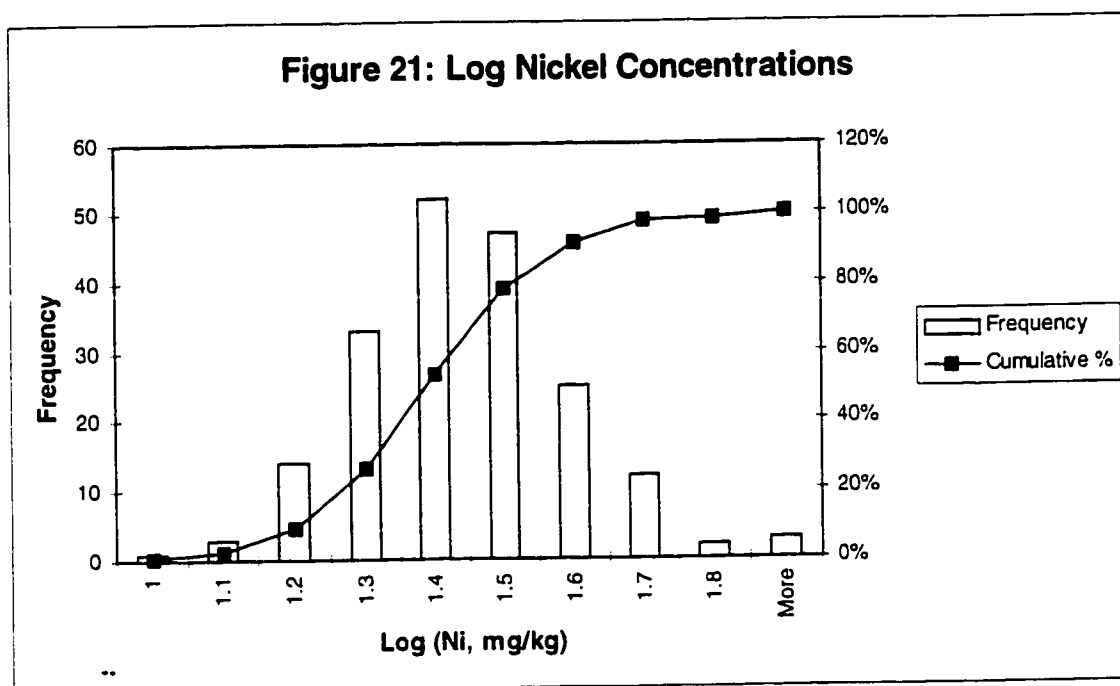
4.11.3 Discussion and Application to the Database

Based on the most recent provincial soil quality guidelines, a maximum concentration of 40 mg/kg was applied to a site with “no concern”. This value is two times the background concentration of nickel in Alberta soils, indicating that the value may be quite conservative compared to the other metals in the database and their regulatory limits. There is a small difference between the regulatory limit and background concentrations of nickel. Sites with concentrations greater than 500 mg/kg were considered a “serious concern” based on inability for disposal in a Class 1 hazardous waste landfill. Nickel data is available for 192 samples, or 31% of the database, with concentrations ranging from 10 to 310 mg/kg and an average of 27.9 mg/kg. Using the proposed values, 177 of the

samples will fall into the “no concern” category, 15 of the samples will fall into the “medium concern” category, while none of the samples will fall into the “serious concern” category.

Figure 20 is a relative and cumulative frequency distribution of the nickel data for the entire database. The data do appear to follow a normal distribution, but the log transformed data shown in Figure 21 do appear to follow a normal distribution.





4.12 Vanadium

4.12.1 Regulatory

Maximum vanadium values in soil for specific land uses are provided in both provincial and federal guidelines. According to CCME SQG, vanadium values for all four land uses may not exceed 130 mg/kg (CCME, 1997). According to AB Tier 1, vanadium values may not exceed 100 mg/kg (AEP, 1994a). In AUGFWM, vanadium values may not exceed 2000 mg/kg according to Table 2, Class 9.3 substances (AEP, 1995).

4.12.2 Research

At 80 mg/kg in sandy soil, biomass reduction was noticed in cabbage while no change in biomass was noted at 100 mg/kg in a loamy-sand soil (Kaplan et al., 1990). Respiration was reduced by 12% in a soil at pH 7.8, vanadium concentration of 255 mg/kg, while at pH 5.8 nitrification was reduced by 62% (Liang and Tabatabai, 1978). Studies on *E. fetida* had shown the LD₅₀ to be 370 mg/kg of soil, while at 210 mg/g there was no

observed effect (Environment Canada, 1995). Seedling emergence begins to be affected in radish and lettuce at vanadium concentrations of 410 and 127 mg/kg, respectively (Environment Canada, 1995).

4.12.3 Discussion and Application to the Database

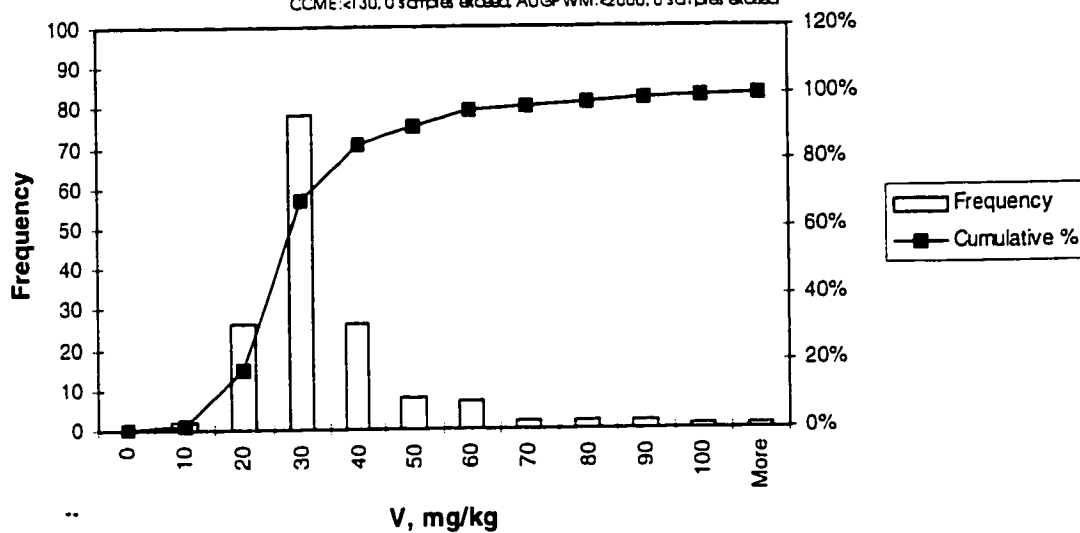
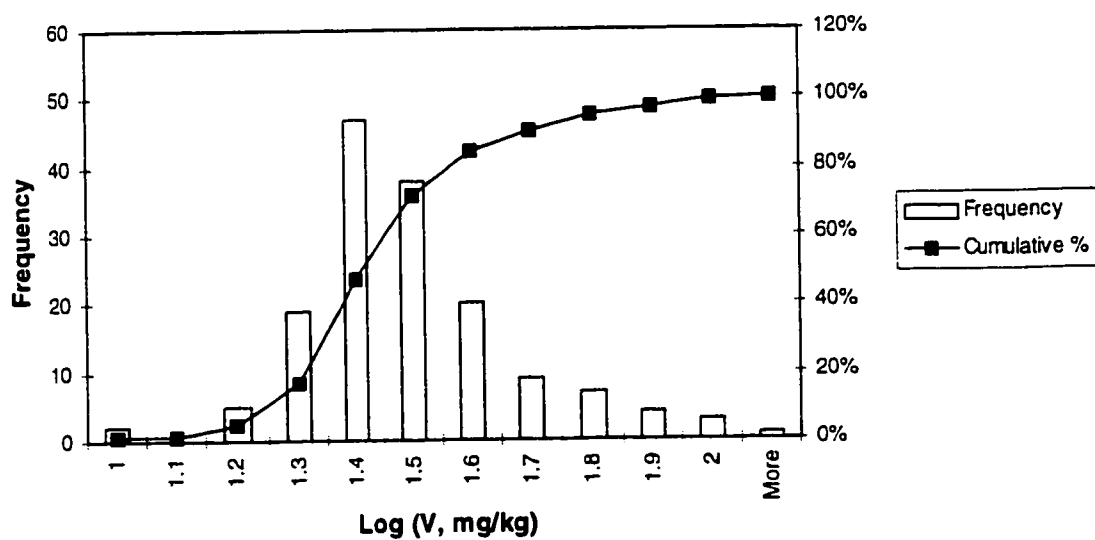
Based on the most recent federal soil quality guidelines, a maximum concentration of 130 mg/kg was applied to a site with “no concern”. This value appears to be consistent with the results of studies completed at concentrations close to 130 mg/kg which showed minor effects on biomass and seedling emergence. Other studies did not show inhibitory effects on soil or plant health until concentrations greater than 130 mg/kg. Sites with concentrations greater than 2000 mg/kg were considered a “serious concern” based on inability for disposal in a Class 1 hazardous waste landfill. Vanadium data is available for 155 samples, or 25% of the database, with concentrations ranging from 3.8 to 120 mg/kg and an average of 30.1 mg/kg. Using the proposed values, all 155 of the samples will fall into the “no concern” category.

Figure 22 is a relative and cumulative frequency distribution of the nickel data for the entire database. The data do appear to follow a normal distribution, but the log transformed data shown in Figure 23 appear to better follow a normal distribution.

Figure 22: Vanadium Concentrations

Sample size: 155, Mean value: 30.1, Maximum value: 120, Minimum value: 3.8

CCME: <130, 0 samples exceed, AUGFWM: <2000, 0 samples exceed

**Figure 23: Log Vanadium Concentrations**

4.13 Zinc

4.13.1 Regulatory

Maximum zinc values in soil for specific land uses are provided in both provincial and federal guidelines. According to CCME SQG, zinc values for agricultural, residential/parkland, commercial and industrial land use may not exceed 200, 200, 380 and 380 mg/kg, respectively (CCME, 1997). According to AB Tier 1, zinc values may not exceed 120 mg/kg (AEP, 1994a). In AUGFWM, zinc values may not exceed 10000 mg/kg according to Table 2, Class 9.3 substances (AEP, 1995).

4.13.2 Research

A review of zinc levels in soils of Alberta showed that the average background concentration is 72.8 mg/kg, based on 78 different soil horizon samples (Dudas and Pawluk, 1980). Efforts by AEP to better define ambient soil quality in Alberta determined that average zinc concentrations are 70 mg/kg, and that values greater than 129 mg/kg are most likely from external sources (Lutwick, 1996). Studies on *E. fetida* had shown the LD₅₀ of zinc to be 80 mg/kg of soil (Sheppard et al., 1993). Respiration studies have shown negative effects at both 10 and 100 mg/kg, and the effect is both long term and increasingly negative over time (Cornfield, 1977). Another respiration study noted significant impacts at 150 mg/kg in sandy peat soils, 400 mg/kg in sandy soils, and 1000 mg/kg in clay soils (Doelman and Haanstra, 1984). Reductions in corn and rye crop yields were noted at soil zinc concentrations of 600 mg/kg (Cunningham, et. al., 1975). A study looking at the effect on soil of increasing zinc concentrations determined that at 300 mg/kg the fungal community structure is altered, at 866 mg/kg the number of CFU fungi is decreased, at 1000 mg/kg there is a decrease in the microbial biomass and amount of ATP, and at 1500 mg/kg there is a decrease in the number of tolerant organisms and fungal biomass (Tyler et. al., 1989). Zinc's adverse effect on nitrogen mineralization and nitrification increases as pH increases. (Bhuiya and Cornfield, 1974).

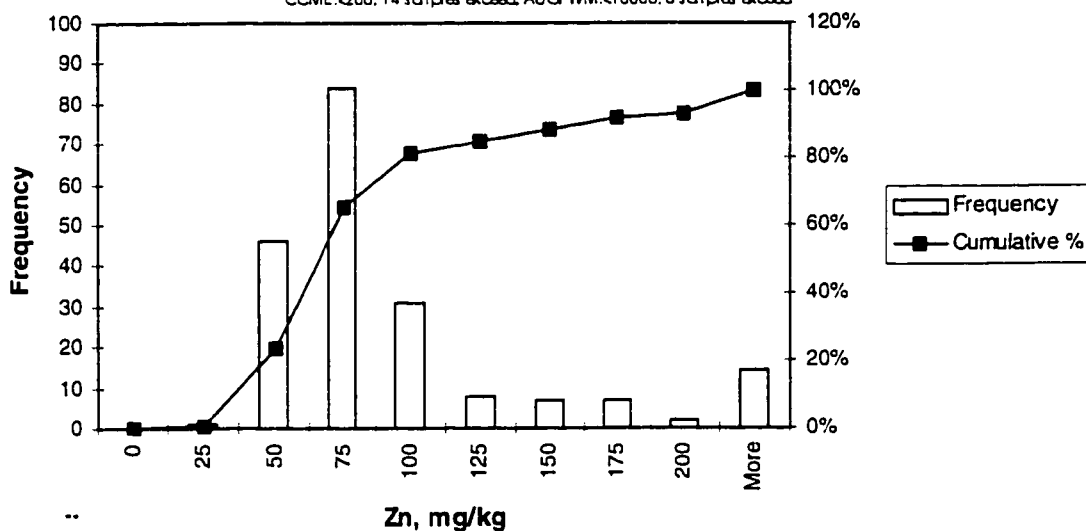
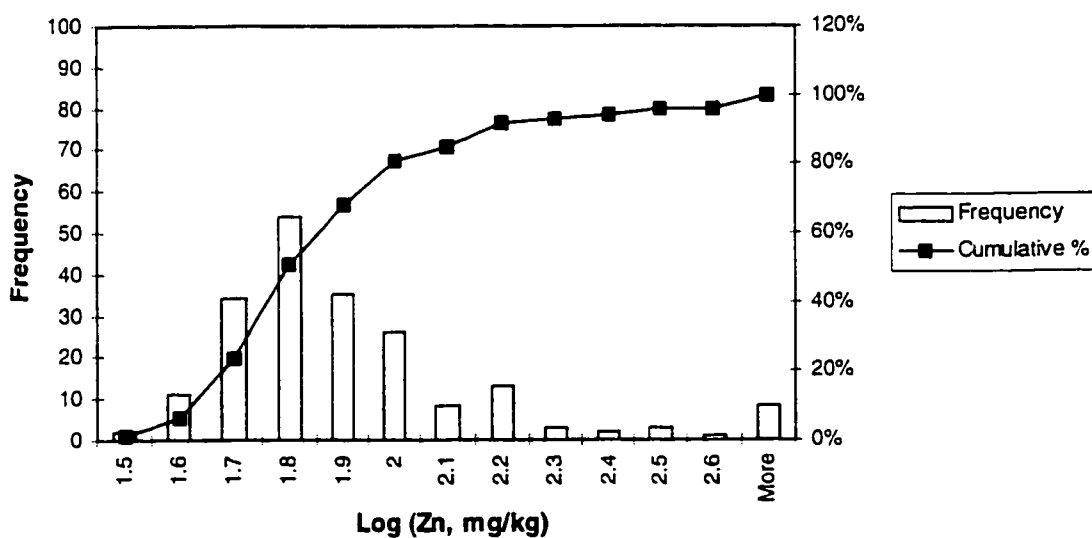
4.13.3 Discussion and Application to the Database

Based on the most recent federal soil quality guidelines, a maximum concentration of 200 mg/kg was applied to a site with “no concern”. This value does not appear to be overly conservative, as even though it is less than three times background, negative effects on plant and soil health have been determined at concentrations lower than 200 mg/kg. Sites with concentrations greater than 10000 mg/kg were considered a “serious concern” based on inability for disposal in a Class I hazardous waste landfill. Zinc data is available for 200 samples, or 32% of the database, with concentrations ranging from 24.2 to 1400 mg/kg and an average of 105.7 mg/kg. Using the proposed values, 186 of the samples will fall into the “no concern” category, 14 of the samples will fall into the “medium concern” category, while none of the samples will fall into the “serious concern” category.

Figure 24 is a relative and cumulative frequency distribution of the zinc data for the entire database. The data does not appear to follow a normal distribution, but the log transformed data shown in Figure 25 do appear to follow a normal distribution.

Figure 24: Zinc Concentrations

Samplesize: 200, Mean value: 105.7, Maximum value: 1400, Minimum value: 24.2
 CCME: <200, 14 samples exceed, AUGFWM: <10000, 0 samples exceed

**Figure 25: Log Zinc Concentrations**

4.14 Benzene

4.14.1 Regulatory

Maximum benzene values in soil for specific land uses are provided in both provincial and federal guidelines. According to CCME SQG, benzene values for agricultural, residential/parkland, commercial and industrial land use may not exceed 0.05, 0.5, 5 and 5 mg/kg, respectively (CCME, 1997). According to AB Tier 1, benzene values may not exceed 0.05 mg/kg (AEP, 1994a). In AUGFWM, benzene values may not exceed 1000 mg/kg according to Section 14 (2) (c) covering non-halogenated organic compounds, however the combined concentration of benzene, ethylbenzene, toluene and xylene (BTEX) may also not exceed 1000 mg/kg (AEP, 1995).

4.14.2 Research

Seedling emergence tests using radish and lettuce showed that adverse effects of 25% reduction were first noticed at 24 and 40 mg/kg, respectively (Environment Canada, 1995). Studies on *E. fetida* had shown the lethal dose for 25% mortality in the population (LD₂₅) to be 161 mg/kg of soil (Environment Canada, 1995).

Benzene is a known human carcinogen, specifically causing acute myelogenous leukemia (International Agency for Research on Cancer, 1982).

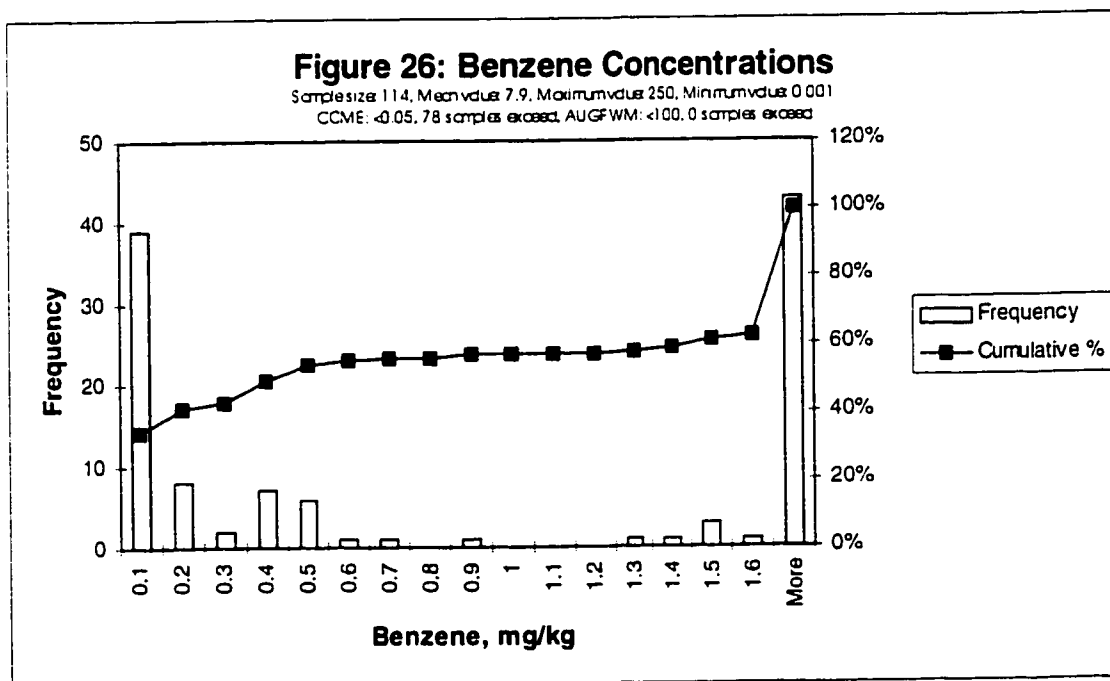
4.14.3 Discussion and Application to the Database

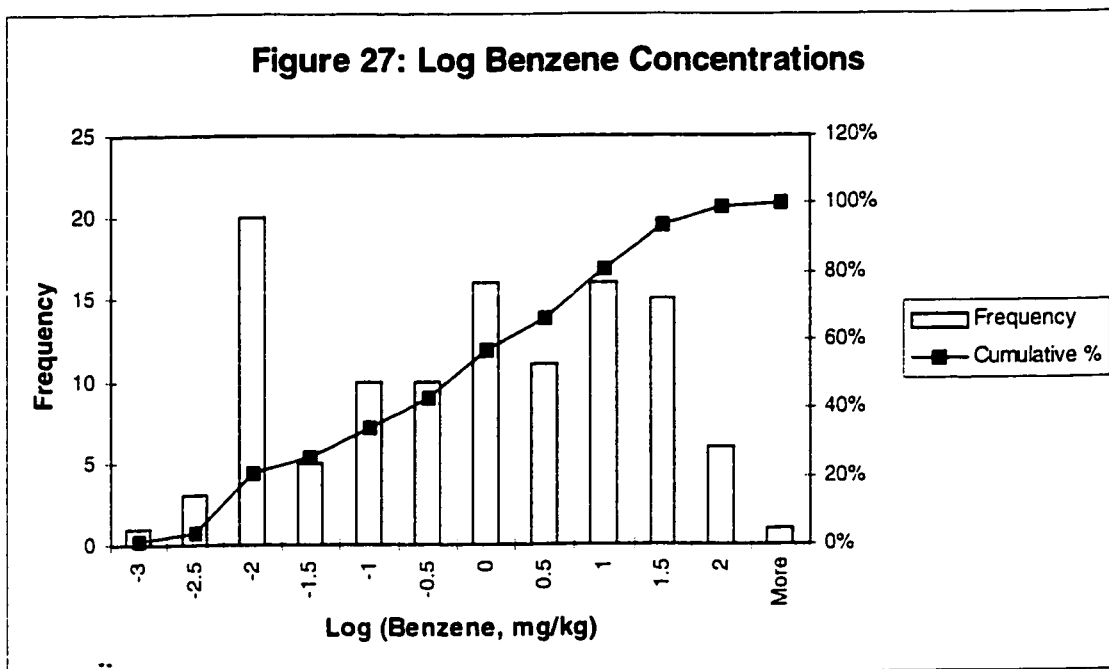
Based on the most recent federal soil quality guidelines, a maximum concentration of 0.05 mg/kg was applied to a site with “no concern”. This value appears to be conservative based on prior toxicity testing relating to plant and soil health. The very negative effect of benzene on human health is presumably the basis for the establishment of such a low value. Sites with concentrations greater than 1000 mg/kg or a combined BTEX concentration of 1000 mg/kg were considered a “serious concern” based on inability for disposal in a Class 1 hazardous waste landfill. Benzene data is available for

114 samples, or 19% of the database, with concentrations ranging from 0.001 to 250 mg/kg and an average of 7.9 mg/kg. Using the proposed values, 36 of the samples will fall into the “no concern” category, 78 of the samples will fall into the “medium concern” category, while none of the samples will fall into the “serious concern” category. After evaluating benzene concentrations and the concentration of the other three BTEX compounds in samples, four additional “medium concern” samples were classified as “serious concern” based on total combined BTEX concentrations.

Figure 26 is a relative and cumulative frequency distribution of the benzene data for the entire database. The data does not appear to follow a normal distribution, but the log transformed data shown in Figure 27 do appear to follow a normal distribution.

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4.15 Toluene

4.15.1 Regulatory

Maximum toluene values in soil for specific land uses are provided in both provincial and federal guidelines. According to CCME SQG, toluene values for agricultural, residential/parkland, commercial and industrial land use may not exceed 0.1, 0.8, 0.8 and 0.8 mg/kg, respectively (CCME, 1997). According to AB Tier 1, toluene values may not exceed 1.0 mg/kg (AEP, 1994a). In AUGFWM, toluene values may not exceed 1000 mg/kg according to Section 14 (2) (c), however the combined concentration of BTEX may also not exceed 1000 mg/kg (AEP, 1995).

4.15.2 Research

Seedling emergence tests using radish and lettuce determined that adverse effects of 25% reduction were noticed at 7 and 9 mg/kg, respectively (Environment Canada, 1995). Plant chlorosis and growth inhibition was induced at toluene levels of 1000 mg/kg in soil

(Slooff and Blokzijl, 1988). Studies on *E. fetida* had shown the LD₂₅ to be 44 mg/kg of soil (Environment Canada, 1995).

Toluene has been classified as not carcinogenic to humans (Government of Canada, 1992).

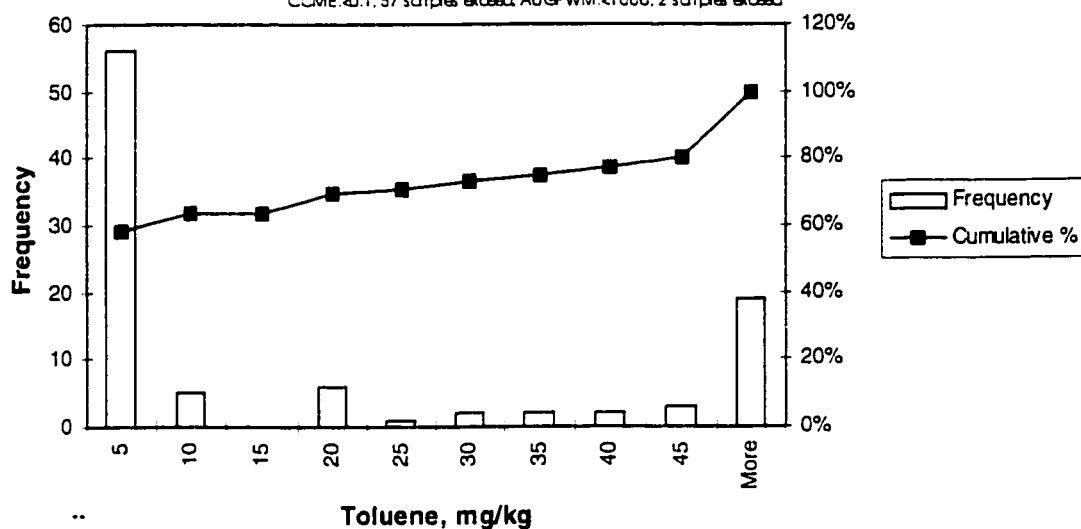
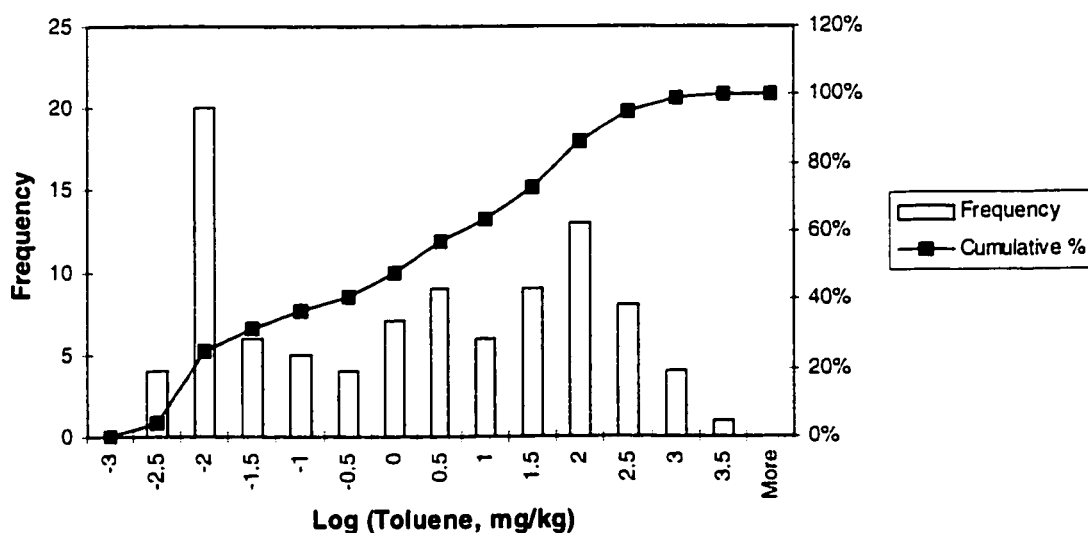
4.15.3 Discussion and Application to the Database

Based on the most recent federal soil quality guidelines, a maximum concentration of 0.1 mg/kg was applied to a site with “no concern”. This value appears to be conservative based on prior toxicity testing relating to plant and soil health. The effect of toluene and its degradation product (ie. benzene) on human health is presumably the basis for the establishment of such a low value. Sites with concentrations greater than 1000 mg/kg or a combined BTEX concentration of 1000 mg/kg were considered a “serious concern” based on inability for disposal in a Class 1 hazardous waste landfill. Toluene data is available for 96 samples, or 16% of the database, with concentrations ranging from 0.002 to 1800 mg/kg and an average of 64.3 mg/kg. Using the proposed values, 35 of the samples will fall into the “no concern” category, 55 of the samples will fall into the “medium concern” category, while 2 of the samples will fall into the “serious concern” category. After evaluating toluene concentrations and the concentration of the other three BTEX compounds in samples, four additional “medium concern” samples were classified as “serious concern” based on total combined BTEX concentrations.

Figure 28 is a relative and cumulative frequency distribution of the toluene data for the entire database. The data does not appear to follow a normal distribution, but the log transformed data shown in Figure 29 do appear to follow a normal distribution.

Figure 28: Toluene Concentrations

Samplesize: 96, Meanvalue: 64.3, Maximumvalue: 1800, Minimumvalue: 0.002
 CCME: <0.1, 57 samples exceed, AUGFWM: <1000, 2 samples exceed

**Figure 29: Log Toluene Concentrations**

4.16 Ethylbenzene

4.16.1 Regulatory

Maximum ethylbenzene values in soil for specific land uses are provided in both provincial and federal guidelines. According to CCME SQG, ethylbenzene values for agricultural, residential/parkland, commercial and industrial land use may not exceed 0.1, 1.2, 20 and 20 mg/kg, respectively (CCME, 1997). According to AB Tier 1, ethylbenzene values may not exceed 0.5 mg/kg (AEP, 1994a). In AUGFWM, ethylbenzene values may not exceed 1000 mg/kg according to Section 14 (2) (c), however the combined concentration BTEX may also not exceed 1000 mg/kg (AEP, 1995).

4.16.2 Research

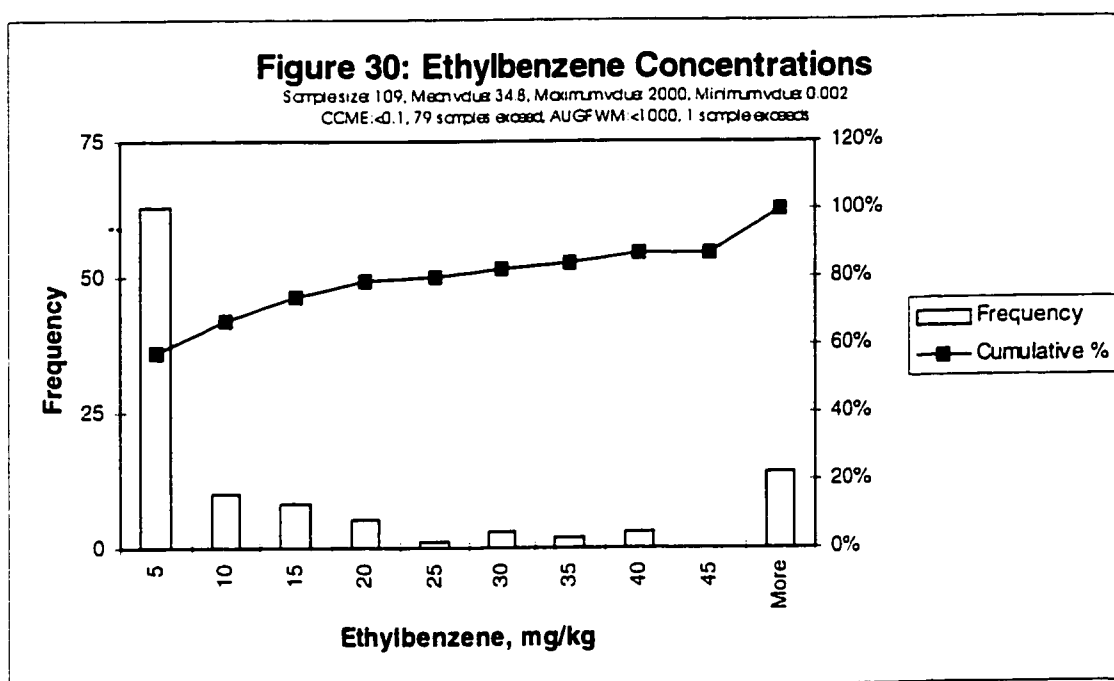
Seedling emergence tests using radish and lettuce determined that adverse effects of 25% reduction were noticed at 12 and 6 mg/kg, respectively (Environment Canada, 1995). Studies on *E. fetida* had shown the LD₂₅ to be 113 mg/kg of soil (Environment Canada, 1995).

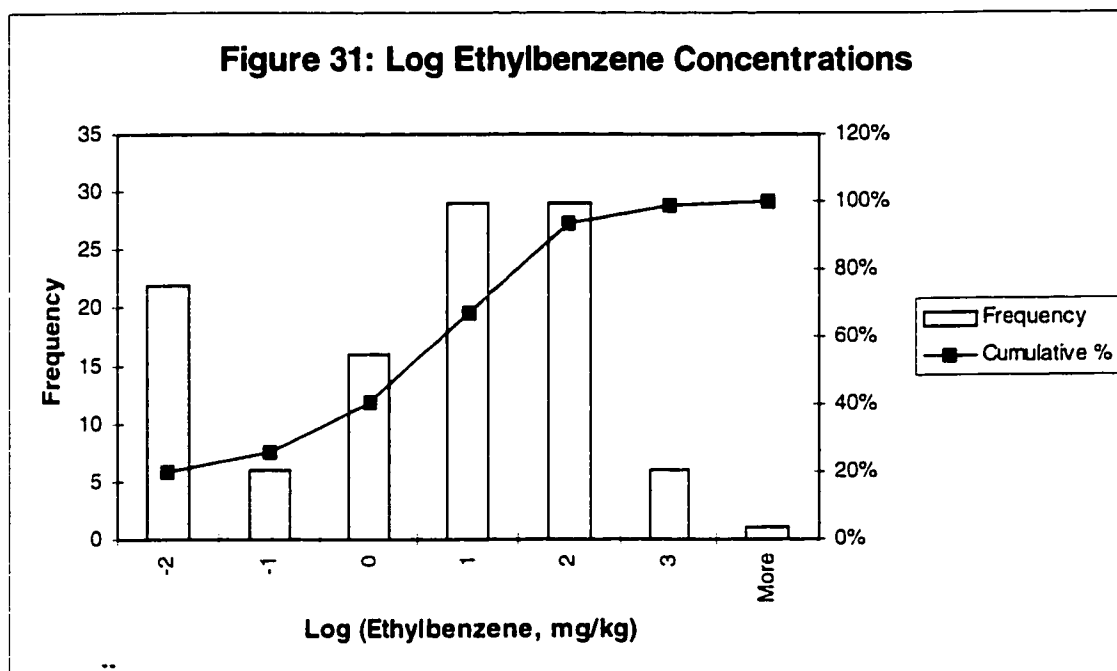
4.16.3 Discussion and Application to the Database

Based on the most recent federal soil quality guidelines, a maximum concentration of 0.1 mg/kg was applied to a site with “no concern”. This value appears to be conservative based on prior toxicity testing relating to plant and soil health. The effect of ethylbenzene and its degradation product (benzene) on human health is presumably the basis for the establishment of such a low value. Sites with concentrations greater than 1000 mg/kg or a combined BTEX concentration of 1000 mg/kg were considered a “serious concern” based on inability for disposal in a Class 1 hazardous waste landfill. Ethylbenzene data is available for 109 samples, or 18% of the database, with concentrations ranging from 0.002 to 2000 mg/kg and an average of 34.8 mg/kg. Using the proposed values, 30 of the samples will fall into the “no concern” category, 78 of the samples will fall into the “medium concern” category, while one of the samples will fall into the “serious concern”

category. After evaluating ethylbenzene concentrations and the concentration of the other three BTEX compounds in samples, six additional “medium concern” samples were classified as “serious concern” based on total combined BTEX concentrations.

Figure 30 is a relative and cumulative frequency distribution of the ethylbenzene data for the entire database. The data does not appear to follow a normal distribution, but the log transformed data shown in Figure 31 do appear to follow a normal distribution.





4.17 Xylene

4.17.1 Regulatory

Maximum xylene values in soil for specific land uses are provided in both provincial and federal guidelines. According to CCME SQG, xylene values for agricultural, residential/parkland, commercial and industrial land use may not exceed 0.1, 1, 17 and 20 mg/kg, respectively (CCME, 1997). According to AB Tier 1, xylene values may not exceed 1.0 mg/kg (AEP, 1994a). In AUGFWM, xylene values may not exceed 1000 mg/kg according to Section 14 (2) (c), however the combined concentration BTEX may also not exceed 1000 mg/kg (AEP, 1995).

4.17.2 Research

Seedling emergence tests using radish and lettuce determined that adverse effects of 25% reduction were noticed at 32 and 5 mg/kg, respectively (Environment Canada, 1995). Studies on *E. fetida* had shown the LD₂₅ to be 56 mg/kg of soil (Environment Canada,

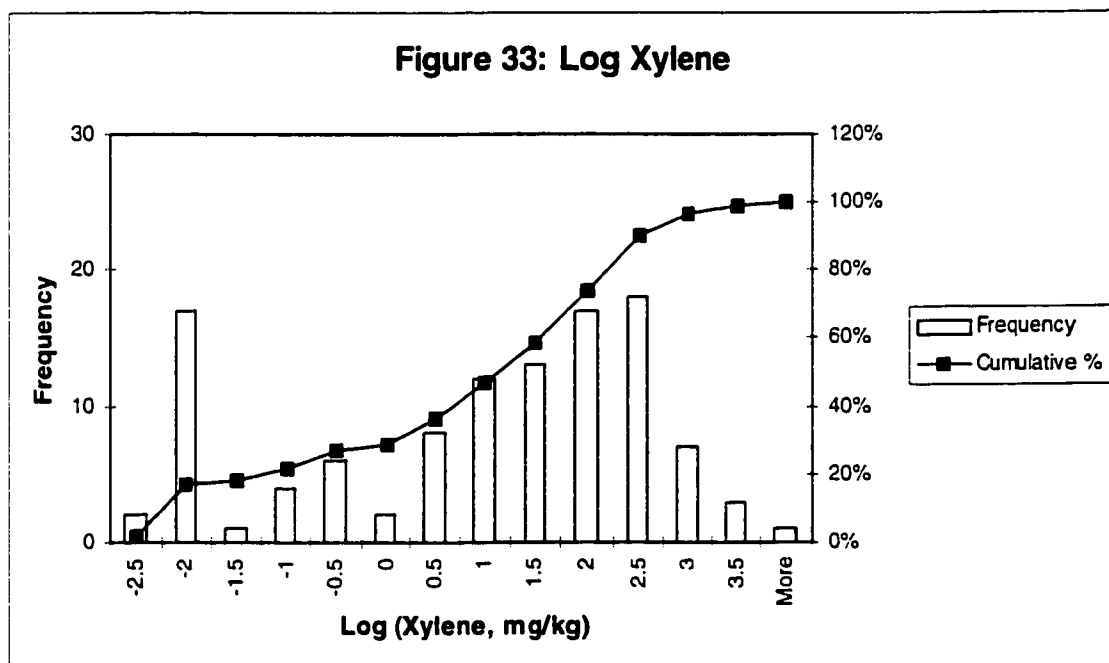
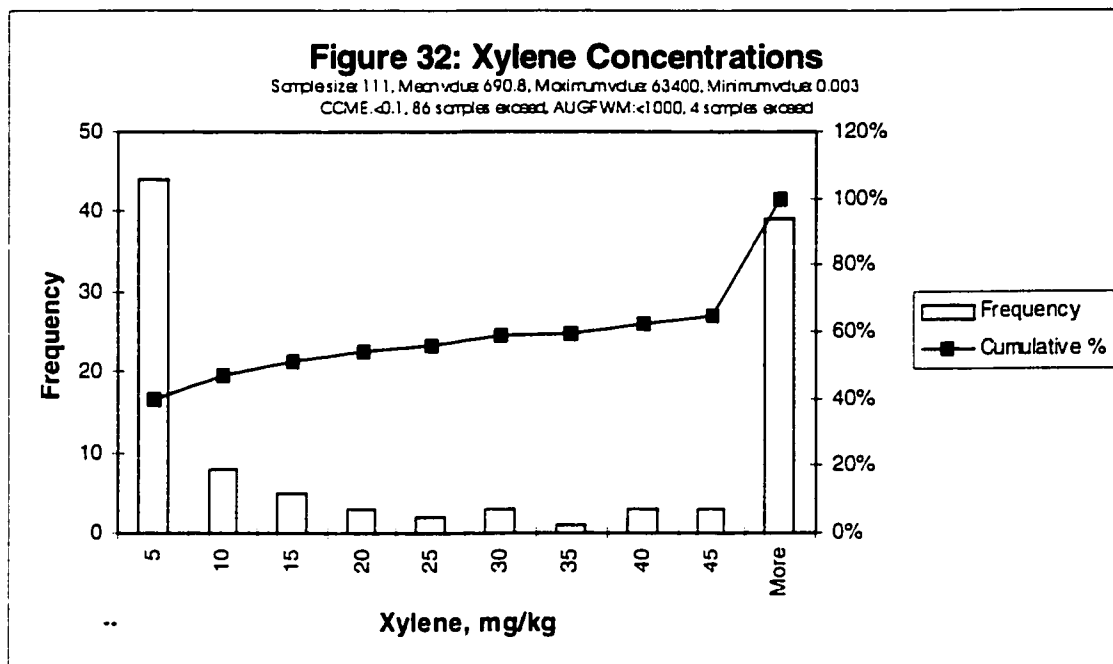
1995). At 100 mg/kg in soil, p-xylene was not found to be toxic to soil microorganisms (Anderson et al., 1991).

Xylene has been classified as not carcinogenic to humans (Government of Canada, 1993).

4.17.3 Discussion and Application to the Database

Based on the most recent federal soil quality guidelines, a maximum concentration of 0.1 mg/kg was applied to a site with “no concern”. This value appears to be conservative based on prior toxicity testing relating to plant and soil health. The effect of the three forms of xylene and their degradation product (benzene) on human health is presumably the basis for the establishment of such a low value. Sites with concentrations greater than 1000 mg/kg or a combined BTEX concentration of 1000 mg/kg were considered a “serious concern” based on inability for disposal in a Class 1 hazardous waste landfill. Xylene data is available for 111 samples, or 18% of the database, with concentrations ranging from 0.003 to 63400 mg/kg and an average of 690.8 mg/kg. Using the proposed values, 25 of the samples will fall into the “no concern” category, 82 of the samples will fall into the “medium concern” category, while four of the samples will fall into the “serious concern” category. After evaluating xylene concentrations and the concentration of the other three BTEX compounds in samples, three additional “medium concern” samples were classified as “serious concern” based on total combined BTEX concentrations.

Figure 32 is a relative and cumulative frequency distribution of the xylene data for the entire database. The data does not appear to follow a normal distribution, but the log transformed data shown in Figure 33 do appear to follow a normal distribution.



4.18 Hydrocarbons

4.18.1 Regulatory

Maximum hydrocarbon values in soil for specific land uses are provided in provincial guidelines. According to AB Tier 1, total hydrocarbon values may not exceed 1000 mg/kg (AEP, 1994a). Maximum total petroleum hydrocarbon (TPH) concentrations in the Remediation Guidelines for Petroleum Storage Tanks are 1000, 2000 and 5000 mg/kg in coarse soils for high, medium and low risk sites, respectively (AEP, 1994b.) In fine soils, the maximum allowable TPH concentrations are 2000, 4000 and 5000 mg/kg for high, medium and low risk sites, respectively (AEP, 1994b). In the Code of Practice for the Land Treatment and Disposal of Soil Containing Hydrocarbons (AEP, 1997) treatment objectives for land treatment facilities are available, which range from 40 to 2000 mg/kg based on final use of the treated soil and the soil grain size. Hydrocarbons are not covered in AUGFWM. However, the AEUB and AEP are in the process of establishing guidelines for landfilling oilfield wastes in a Memorandum of Understanding between the two regulatory bodies (AEUB, 1999). This document proposes to restrict the concentration of TPH permitted in oilfield wastes designated for landfill disposal based on the class and design of the landfill. Class 1 and Class 2 landfills with engineered liners and leachate collection systems can accept any level of TPH in oilfield wastes. However, Class 2 landfills with an engineered liner but no leachate collection can accept oilfield waste with TPH concentration up to 30,000 mg/kg (AEUB, 1999). Class 2 landfills with a natural clay liner can accept oilfield waste with TPH concentrations up to 20,000 mg/kg, and Class 3 landfills can accept oilfield waste with TPH concentrations up to 1000 mg/kg (AEUB, 1999).

4.18.2 Research

Research completed by Danielson et. al. (1990) showed good plant growth in land treatment facility soils containing a maximum of 3% hydrocarbons, satisfactory plant growth in soils with 3-5% hydrocarbons, while very poor plant growth was noticed at

levels above 5%. Xu and Johnson (1995) studied the growth of barley and field pea in four soils with hydrocarbon concentrations at 0, 5, 25 and 55 ppm by weight, where the 5 and 25 ppm hydrocarbon soils represented remediated soils. They showed that plant growth decreased as soil hydrocarbon concentration increased. Li, Storey and Johnson (1996) assessed the growth of barley on soils containing 0, 2 and 4% hydrocarbon. The results showed that germination was acceptable in all three soils, but plant growth as measured by shoot growth rate was 30% lower in the soils containing hydrocarbons, and plant yield was 60% lower in the soils containing hydrocarbons. Xu et. al. (1994) showed that nitrogen losses from the NO_3^- nitrogen source were highest in the soil containing the highest concentration of hydrocarbons, and lowest in the non-contaminated soil, while nitrogen losses from the NH_4 nitrogen source were highest for the soils with 0 and 2.5% hydrocarbon, lowest for the soil with 0.5% hydrocarbon and between the two losses for the most highly contaminated soil.

4.18.3 Discussion and Application to the Database

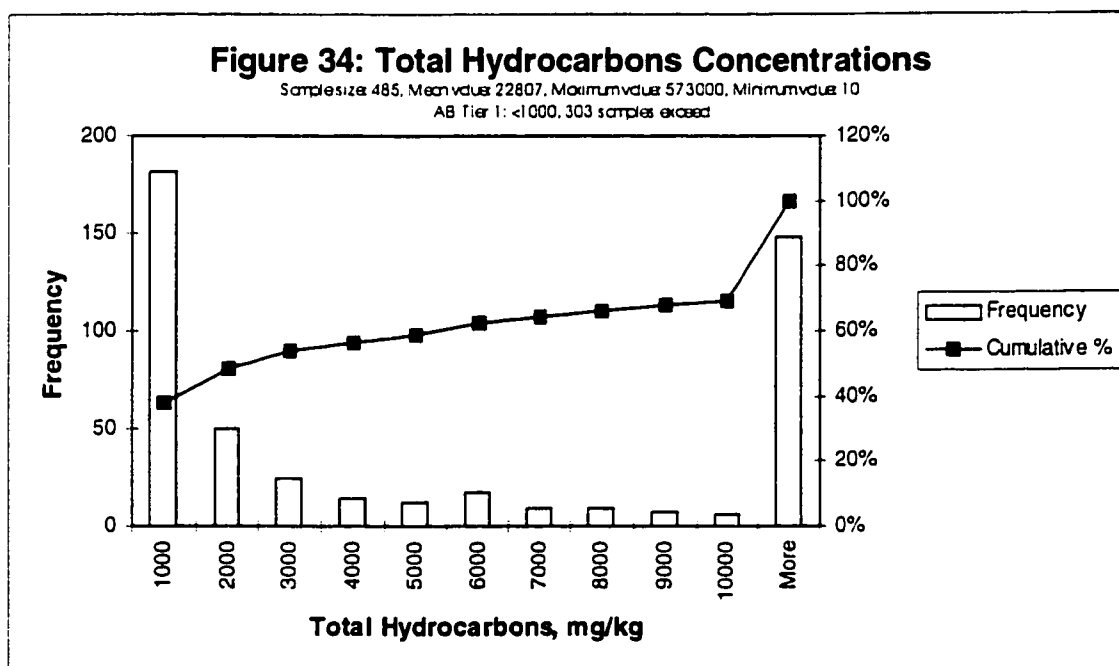
Based on the most recent provincial soil quality guidelines, a maximum concentration of 1000 mg/kg total hydrocarbons was applied to a site with “no concern”. No criterion is applied for “serious concern” sites since hydrocarbons as a general category are not considered in AUGFWM. The hydrocarbon concentrations in the “Remediation Guidelines for Petroleum Storage Tanks” are for a more specific site operation and therefore inappropriate to apply to flare pit sludge.

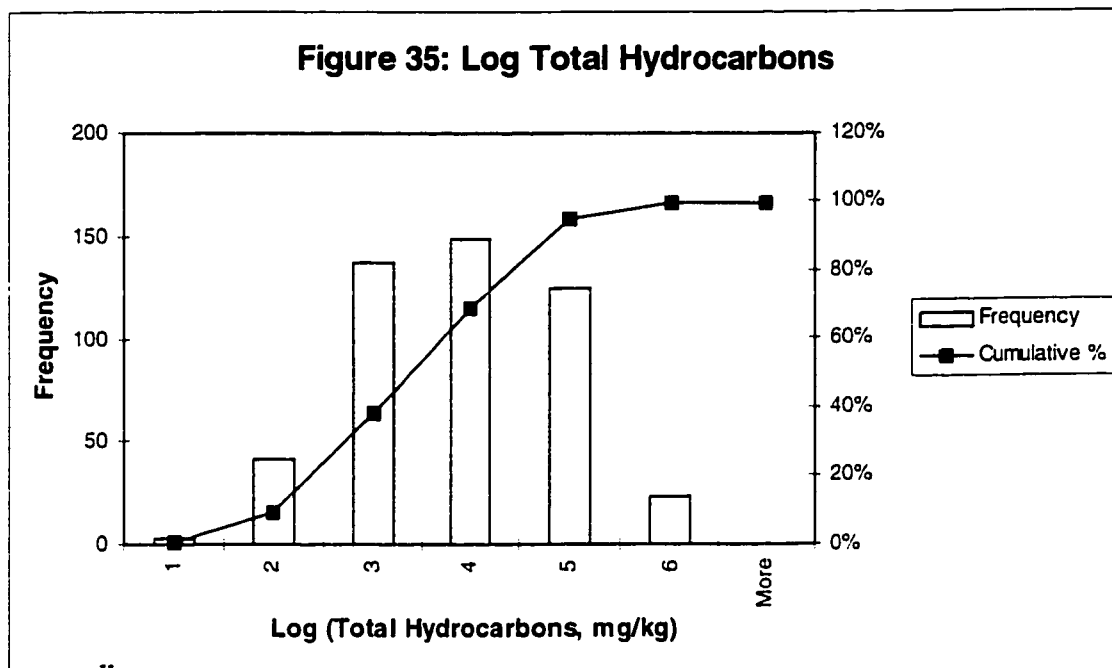
The Tier 1 criterion of 1000 mg/kg is for mineral oil and grease. The analysis of hydrocarbons in soils includes analysis of oil and grease, mineral oil and grease, total extractable hydrocarbons, TPH and total hydrocarbons. None of these gross parameters share a consistent relationship to biological hazard, but they can provide a tool to screen sites and assess remediation (AEP, 1993b). Previous research on hydrocarbon toxicity

indicates that the regulated value of 1000 mg/kg or 0.1% is very conservative, especially since other components of this value such as the BTEX details, are also considered.

Total hydrocarbon data is available for 485 samples, or 79% of the database, with concentrations ranging from 10 to 573000 mg/kg and an average of 22807. Using the proposed values, 182 of the samples will fall into the “no concern” category, 303 of the samples will fall into the “medium concern” category, while none of the samples will fall into the “serious concern” category since there is no value available.

Figure 34 is a relative and cumulative frequency distribution of the total hydrocarbon data for the entire database. The data does not appear to follow a normal distribution, but the log transformed data shown in Figure 35 do appear to follow a normal distribution.





4.19 pH

4.19.1 Regulatory

CCME IC required all soil pH levels to fall between 6 and 8, regardless of land use designation (CCME, 1991). According to AB Tier 1, pH values may not exceed 8.5 or be less than 6 (AEP, 1994a). According to the WCR, Schedule 1, a waste is hazardous if it has a pH value less than 2.0 or greater than 12.5 (AEP, 1993a).

4.19.2 Research

As stated in research sections for individual parameters, pH changes can effect the toxicity of certain metals on certain receptors. It is also well known that metal mobility typically increases with decreasing pH due to the increased solubility of metals, so metal migration and groundwater contamination are more likely to happen at a lower pH (AEP, 1992). A pH range of 5.5 to 7.0 promotes the best availability of plant nutrients when considering major plant nutrients and the populations of soil organisms, but soil should

ultimately be maintained with the range of 4 to 10 (Brady and Weil, 1996, Cookson, 1995).

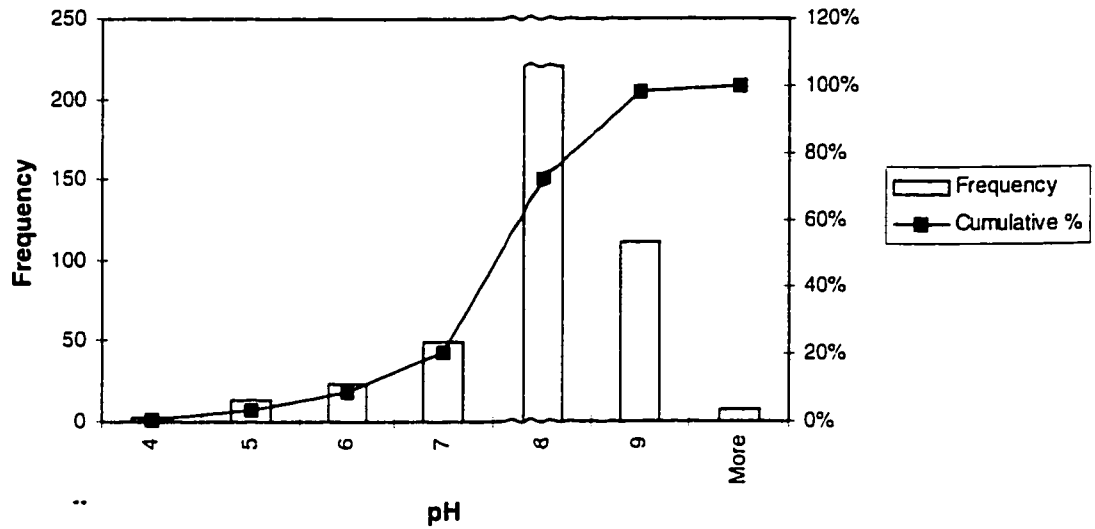
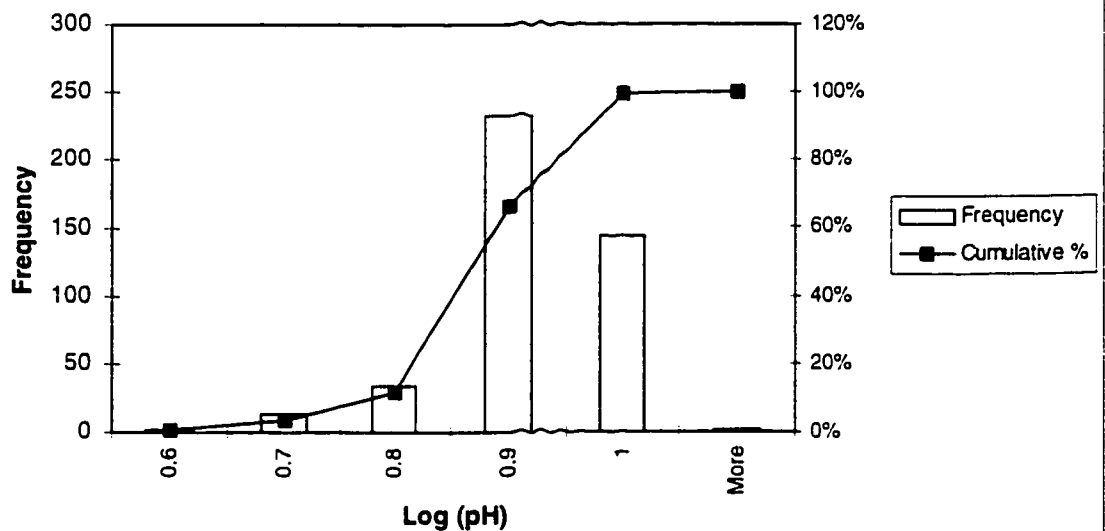
4.19.3 Discussion and Application to the Database

Based on the most recent provincial soil quality guidelines, a pH range of 6 to 8.5 was applied to a site with “no concern”. Sites with a pH greater than 12 or less than 2 were considered a “serious concern” based on inability for disposal in a Class 1 hazardous waste landfill. Data on pH is available for 426 samples, or 69% of the database, with values ranging from 3.2 to 11 and an average of 7.5. Using the proposed values, 342 of the samples will fall into the “no concern” category, 84 of the samples will fall into the “medium concern” category, while none of the samples will fall into the “serious concern” category.

Figure 36 is a relative and cumulative frequency distribution of the pH data for the entire database. The data do appear to follow a normal distribution, and the log transformed data shown in Figure 37 result in a similar distribution.

Figure 36: pH Levels

Sample size: 426, Mean value: 7.5, Maximum value: 11, Minimum value: 3.2
 AB Tier 1: 6-8.5, 37 samples are lower than range, 47 samples are over range, AUGFWM: >2, <12, 0 samples do not meet criteria

**Figure 37: Log pH Levels**

4.20 *Electrical Conductivity*

4.20.1 Regulatory

CCME IC requires soil EC levels to be a maximum of 2 dS/m for agricultural, residential and parkland land use, and a maximum of 4 dS/m for commercial and industrial land use (CCME, 1991). According to AB Tier 1, EC values may not exceed 2 mS/cm (AEP, 1994a). EC is not covered in AUGFWM. AEP, in recommendations for flare pit site assessment, classify soils as saline if their EC is greater than 4 mS/cm (AEP, 1992).

4.20.2 Research

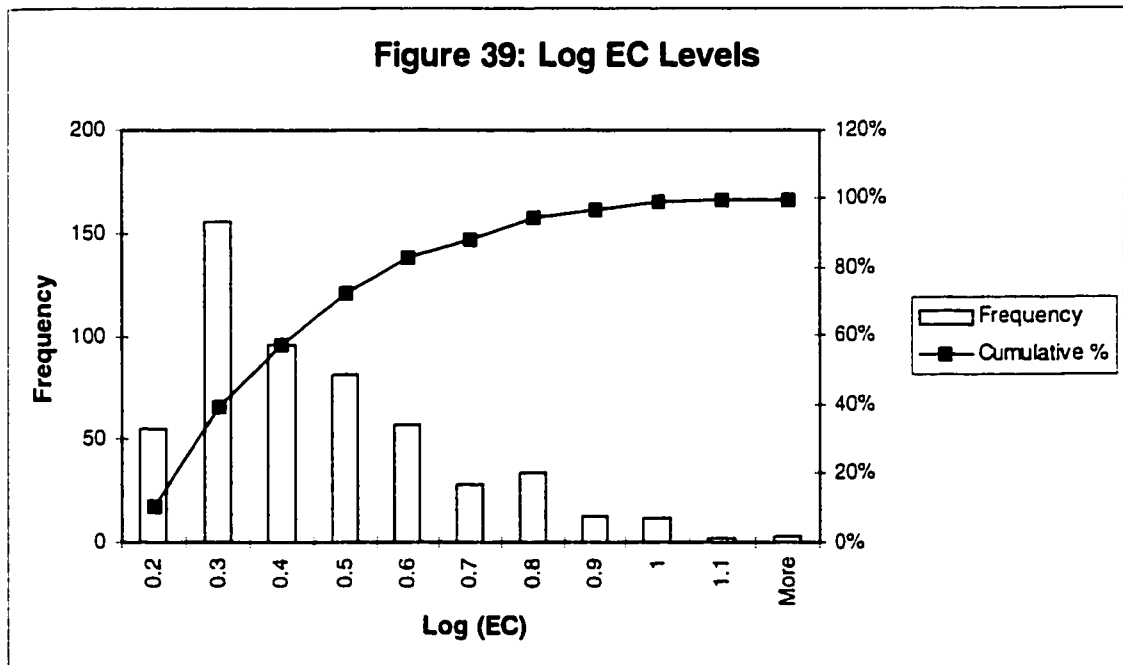
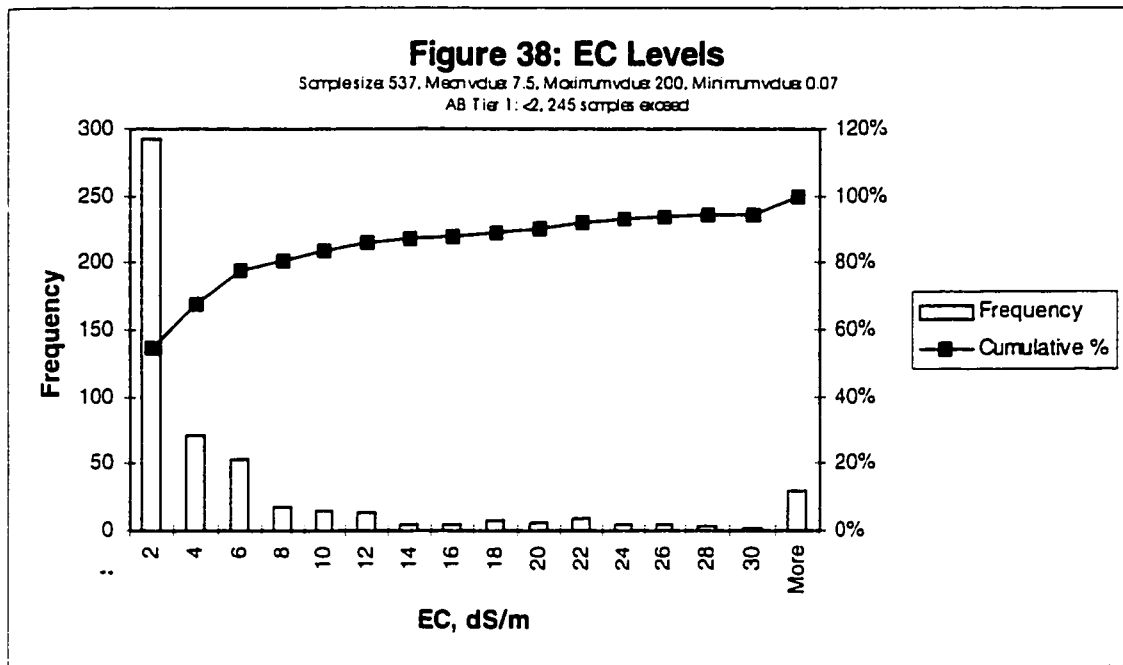
Soil EC is related to plant growth. Normal soils tend to have a maximum EC of 4 dS/m while the limit of survival for most plants is in soil with a maximum EC of 16 dS/m (Brady and Weil, 1996). However plant growth inhibition at EC levels greater than 2.9 mS/cm was identified at land treatment facilities (Danielson et. al., 1987). Only plants known to be salt tolerant can grow at EC levels greater than 32 dS/m (Brady and Weil, 1996). Soil chloride content, which contributes to a higher EC value, also can increase the toxicity of a site by increasing the mobility of specific metals (Sposito, 1989).

4.20.3 Discussion and Application to the Database

Based on the most recent provincial soil quality guidelines, a maximum concentration of 2 mS/cm was applied to a site with “no concern”. No criterion is applied for “serious concern” sites. EC data is available for 537 samples, or 87% of the database, with concentrations ranging from 0.07 to 200 dS/m and an average of 7.5 dS/m. Using the proposed values, 292 of the samples will fall into the “no concern” category, 245 of the samples will fall into the “medium concern” category, while none of the samples will fall into the “serious concern” category since there is no value available.

Figure 38 is a relative and cumulative frequency distribution of the EC data for the entire database. The data does not appear to follow a normal distribution, but the log

transformed data shown in Figure 39 do appear to follow a normal distribution.



4.21 SAR

4.21.1 Regulatory

CCME IC required soil SAR levels to be a maximum of 5 for agricultural, residential and parkland land use, and a maximum of 12 for commercial and industrial land use (CCME, 1991). In AB Tier 1, SAR values may not exceed 6 (AEP, 1994a). SAR is not covered in AUGFWM.

4.21.2 Research

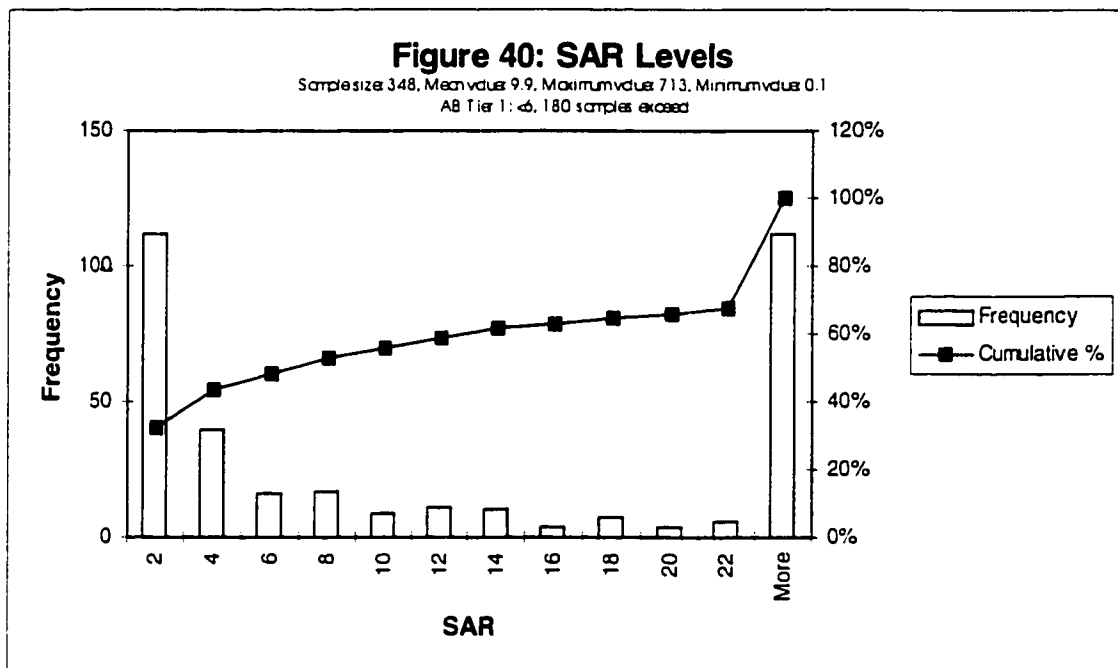
Normal soils tend to have a maximum SAR of 13 while the limit of survival for most plants is in soil with a SAR of 40 (Brady and Weil, 1996). Soil SAR is related to plant growth and it is a calculated value that considers the concentration of calcium, magnesium and sodium in a sample. SAR estimates the dissolved salt concentration in soils which changes the osmotic pressure of the soil solution, impacting plant growth in areas with high salt concentrations (Black, 1965). Water content in soils varies inversely with salt content, and ranges from a lower point where plants wilt permanently, to an upper point which is roughly two times the water content at the lower point (Black, 1965). The range and upper and lower points vary with soil type, due to the differences in water holding capacities of soils. Since clay soils can hold as much as five times as much water as a sandy soil, at equal salt concentrations the sandy soil will have a soil solution with a salt concentration five times greater than the clay soil (Black, 1965).

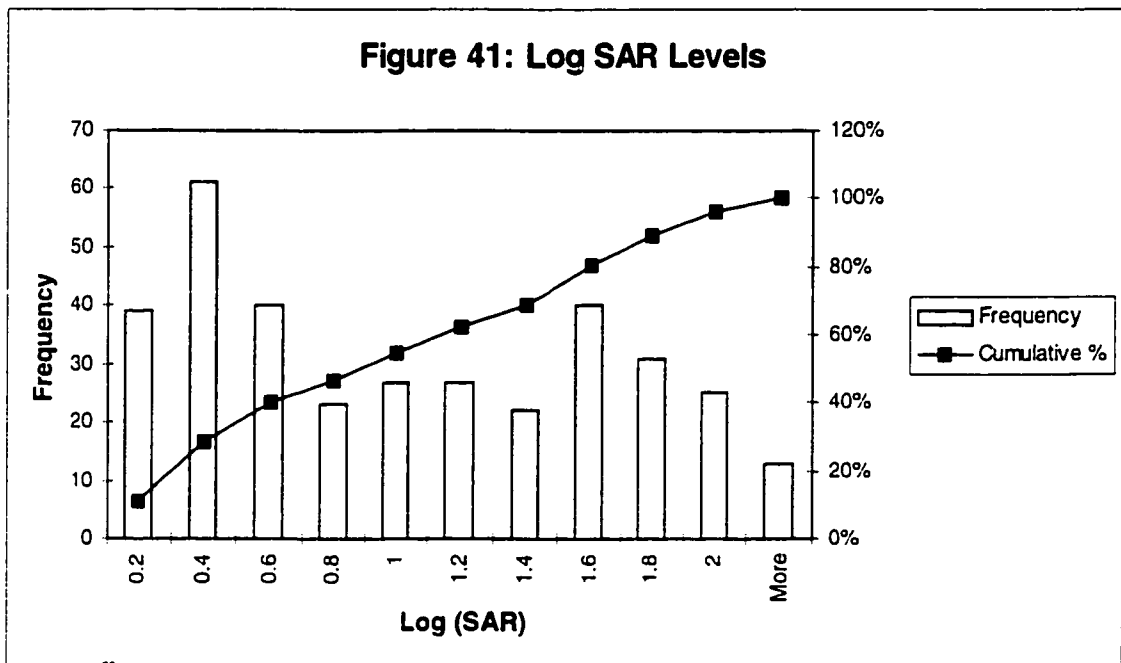
4.21.3 Discussion and Application to the Database

Based on the most recent provincial soil quality guidelines, a maximum level of 6 was applied to a site with “no concern”. No criterion is applied for “serious concern” sites. SAR data is available for 348 samples, or 56 % of the database, with concentrations ranging from 0.1 to 713 and an average of 9.88. Using the proposed values, 168 of the samples will fall into the “no concern” category, 180 of the samples will fall into the

“medium concern” category, while none of the samples will fall into the “serious concern” category.

Figure 40 is a relative and cumulative frequency distribution of the SAR data for the entire database. The data does not appear to follow a normal distribution, but the log transformed data shown in Figure 41 do appear to follow a normal distribution.





4.22 Chlorides

There are no provincial or federal regulations for chloride levels. Therefore, chloride values are not directly considered in assessing the sites in the database.

The issue of chloride contamination in oilfield wastes has recently been addressed in a "Memorandum of Understanding Between AEP and EUB on Deposition of Oilfield Waste into Landfills" (AEUB, 1999). It is proposed to correlate the amount of chlorides that can be present in oilfield waste designated for landfill disposal with landfill design. More robust designs such as those with leachate collection and those having engineered clay or synthetic liners may accept oilfield waste materials containing large concentrations of chlorides, while those constructed with natural clay liners may only accept waste with chloride concentrations less than 3000 mg/kg (AEUB, 1999). Proposed chloride levels would be unrestricted at some Class 2 landfills and all Class 1 landfills, but limited to 5000 mg/kg at Class 2 landfills with an engineered liner but no

leak detection, 3000 mg/kg at Class 2 landfills with a natural clay liner and no leak detection, and 100 mg/kg at Class 3 landfills.

4.23 Calcium, Magnesium, Sodium and Saturation %

There are no provincial or federal regulations for calcium, magnesium and sodium levels and saturation percentage. Therefore, calcium, magnesium, sodium and saturation values are not directly considered in assessing the sites in the database.

4.24 Data Transformations

Appendix 4 provides additional tests for normality that were carried out on the log transformed data sets for chemical variables. QQ plots comparing the log transformed data with the normal curve are provided in Figures A4-1 to A4-20 for metals, hydrocarbons and salinity parameters. Each plot shows the relationship between the log transformed concentration data and the normal cumulative distribution based on a normally distributed data set. Normally distributed data sets will exhibit a straight line relationship, while data sets not normally distributed will not exhibit a linear relationship.

4.25 Site Classification Boundaries

Table 2 summarizes the regulatory values presented in sections 4.2 to 4.23 describing the “no concern”, “medium concern” and “serious concern” concentrations or concentration ranges for each variable. The table identifies the origins of each value, such as a provincial or federal soil or waste criteria. The table also demonstrates the characteristics that define a site as being of “no concern”, “medium concern” and “serious concern” from a regulatory perspective.

Table 2

Numerical Criteria For “No Concern”, “Medium Concern” and “Serious Concern” Sites

Parameter	No Concern Range	Medium Concern Range	Serious Concern Range
Arsenic	0-12 (1)	12-500	>500 (3)
Barium	0-600 (2)	600-2000	>2000 (3)
Cadmium	0-1.4 (1)	1.4-100	>100 (3)
Total Chromium	0-64 (1)	64-100	>500 (3)
Cobalt	0-20 (2)	20-2000	>2000 (3)
Copper	0-63 (1)	63-2000	>2000 (3)
Lead	0-70 (1)	70-500	>500 (3)
Mercury	0-6.6 (1)	6.6-20	>20 (3)
Molybdenum	0-4 (2)	>4	NA
Nickel	0-40 (2)	40-500	>500 (3)
Vanadium	0-130 (1)	130-2000	>2000 (3)
Zinc	0-200 (1)	200-10000	>10000 (3)
Benzene	0-0.05 (1)	0.05-1000	>1000 (3)
Ethylbenzene	0-0.1 (1)	0.1-1000	>1000 (3)
Toluene	0-0.1 (1)	0.1-1000	>1000 (3)
Xylene	0-0.1 (1)	0.1-1000	>1000 (3)
Total HC	0-1000 (2)	>1000	NA
pH	6-8.5 (2)	2-6, 8.5-12.5	>12.5, <2 (3)
EC	0-2 (2)	>2	NA
SAR	0-6 (2)	>6	NA
Chlorides	NA	NA	NA
Sulphate	NA	NA	NA
Sodium	NA	NA	NA
Calcium	NA	NA	NA
Magnesium	NA	NA	NA
Saturation	NA	NA	NA

- all units are in mg/kg except pH which is in pH units, EC which is in dS/m and SAR which does not have units
 - NA = no number exists for this parameter at this level of concern
 - if values existed for chlorides, sulphates, sodium, calcium and magnesium, they would be in units of mg/L
 - if values existed for saturation, they would be in units of %
- (1) the number is from the CCME Soil Quality Guidelines for Agricultural Sites
 (2) the number is from Alberta Tier 1 Criteria for Assessment and Remediation
 (3) the number is from the Alberta Waste Control Regulation

4.26 Site Categories

The values in Table 2 were used to assess each sample individually. Sites were categorized as having no, medium and serious concerns in terms of metal content, salinity/pH, and hydrocarbon content. These three broad classifications were chosen as a basis for site characterization, due to the similarity in treatment techniques that would be applied to a site having contamination that would fall under one of the three classifications. For example, the use of a leaching system might be considered in a situation where salinity was an issue, but would not likely address a site having high concentrations of metals. Multiple treatment steps were considered based on the understanding that for many biological, mechanical and thermal treatment techniques, only one contaminant classification is addressed (Cookson, 1995, Acres International Limited, 1994a and 1994b, Wojtanowicz et. al., 1986). The use of a combination of techniques in a specific order may be required to fully address the range of contaminants present in flare pit sludge.

A total of 9 site categories are used to describe all 616 samples in the database, while 6 categories are used to describe 94% of the database. Table 3 provides a description of each site category along with the number of sites in the category. Sub category designations of “B”, “pH”, “B and pH” and “c” are also used to denote the number of samples in that category having concerns related to elevated BTEX, elevated or low pH, elevated BTEX and elevated or low pH, and significant clay content, respectively. The subcategory designations were applied to sites to identify specific issues associated with the site that would be related to remediation efforts. For example, a high salinity or high hydrocarbon issue can be addressed at the same time as pH, but extra consideration is needed to alter the pH while also handling the contaminants. Similarly, understanding if BTEX is an issue above and beyond a high hydrocarbons issue may alter the methods used to degrade hydrocarbons. Clay soil, in all circumstances, should be noted as the feasibility of some remediation techniques may change since it is more difficult to handle

clay compared to other soil types. For example, thermal treatment of clay soil is more difficult than soil with a high sand content, as large clay masses need to be broken up to expose contaminated surface areas to high temperatures.

Table 3

Distribution of Each Pit Category in the Working Database

Category	Description	#	% of Database	# In Sub Category B	# In Sub Category pH	# In Sub Category B and pH	# in Sub Category c
A	No Elevated Parameters	168	27.27	0	0	0	51
B	Elevated Hydrocarbon Levels	101	16.40	24	0	0	36
C	Elevated Salinity Levels	80	12.99	0	16	0	28
D	Elevated Metals Levels	6	0.97	0	0	0	3
E	Elevated Metals and Hydrocarbons Levels	17	2.76	9	0	0	6
F	Elevated Hydrocarbons and Salinity Levels	158	25.65	25	25	18	66
G	Elevated Salinity and Metals Levels	11	1.79	0	5	0	4
H	Elevated Hydrocarbons, Salinity and Metals Levels	32	5.19	8	8	3	11
I	Serious Elevation of One or More Parameters	43	6.98	11	9	0	38
	Total	616	100.00	77	63	21	243

4.27 Site Details

There was a significant amount of background data collected on each site. This data was reviewed first to determine the commonalties between the sites in the database, and then to determine the significance of various background activities on the classification of a

site. Each background activity that was present in the working database is described below and summarized in Table 4.

It is hypothesized that there are specific cause and effect relationships associated with flare pit contamination. This is based on general knowledge of past operating practices and research into specific areas of contamination. As seen in Figures 3 to 41, the “effect data” is very thorough in comparison to the “cause data”. The causes of the site contamination investigated in this section are the non-subjective descriptive data. The true causes of the contamination are most likely a combination of the descriptive data discussed herein and other descriptive data that may or may not be present in Appendix 1. Historic operational practices or events at the site such as spills of hydrocarbons and brine, open pit burning, temporary storage of hydrocarbons in open, non-lined pits, tank cleaning followed by on-site burial of tank bottoms, and waste disposal using on-site pits will all contribute to various types of contamination. However, details on these activities are not contained in the working database. The underlying reasons for different site contamination can be speculated based on indications provided by site description information, but conclusive statements are difficult to make due to a lack of objective, historical details on the sites.

Selected details from the relative and cumulative frequency distributions information presented in Figures 2 to 41 were extracted for further review, and arranged according to specific site activity. The purpose of this exercise was to identify if the three main areas of contamination: hydrocarbons, salts and metals, had different distributions based on site details. Specifically, hydrocarbon produced, site activity, site age and soil type were reviewed to determine how they might contribute to hydrocarbon concentration, BTEX concentration, salinity levels and metals concentrations at a site. In response to some of the studies on natural gas facilities, mercury concentrations were also reviewed in relation to hydrocarbon produced, to determine trends in concentrations.

Table 4
Summary of Category Details

Site Category	A	B	C	D	E	F	G	H	I
Description	no concern	HC	Sal	Met	Met and HC	Sal and HC	Met and Sal	HC, Met and SAL	Serious HC or Met
Total # of Samples	168	101	80	6	17	158	11	32	43
% of Samples	27.27%	16.40%	12.99%	0.97%	2.76%	25.65%	1.79%	5.19%	6.98%
Oil	49	23	19	1	4	29	2	7	4
Gas	72	51	30	3	7	72	3	14	34
Gas to Oil ratio	1.47	2.22	1.58	3.00	1.75	2.48	1.50	2.00	8.5
Oil and Gas	28	8	7	0	0	8	1	3	2
Not reporting	19	19	24	2	6	49	5	8	3
% of category with oil	29.17%	22.77%	23.75%	16.67%	23.53%	18.35%	18.18%	21.88%	9.30%
% of category with gas	42.86%	50.50%	37.50%	50.00%	41.18%	45.57%	27.27%	43.75%	79.07%
% of category with oil and gas	16.67%	7.92%	8.75%	0.00%	0.00%	5.06%	9.09%	9.38%	4.65%
% not reporting	11.31%	18.81%	30.00%	33.33%	35.29%	31.01%	45.45%	25.00%	6.98%
Pre 1975	34	6	10	0	4	19	0	4	6
Post 1975	3	11	7	2	2	20	1	2	10
Not reporting	131	84	63	4	11	119	10	26	27
% of category pre 1975	20.24%	5.94%	12.50%	0.00%	23.53%	12.03%	0.00%	12.50%	13.95%
% of category post 1975	1.79%	10.89%	8.75%	33.33%	11.76%	12.66%	9.09%	6.25%	23.26%
% not reporting	77.98%	83.17%	78.75%	66.67%	64.71%	75.32%	90.91%	81.25%	62.79%
well to battery ratio	0.97	1.84	0.66	1.00	2.20	1.24	1.00	3.67	3.11
Wells	63	57	27	3	11	73	5	22	28
Satellites	38	2	3	0	0	1	1	1	0
Batteries	65	31	41	3	5	59	5	6	9
Gas plant/production sites	0	6	9	0	1	12	0	3	5
Other	1	0	0	0	0	2	0	0	1
Not reporting	1	5	0	0	0	11	0	0	0

Table 4 (Continued)

Site Category	A	B	C	D	E	F	G	H	I
Landfill suggested	0	0	3	0	0	2	0	0	1
Landfill completed	0	0	0	0	0	0	0	0	0
Landfill and land treat suggested	0	2	0	0	0	5	0	2	0
Landfill and land treat suggested	0	0	0	0	0	0	0	0	0
Land treat suggested	49	22	9	1	4	40	2	7	18
Land treat completed	17	5	1	0	0	6	0	3	1
Leaching system suggested	0	0	6	0	1	5	1	0	1
Leaching system completed	0	0	0	0	0	0	0	0	0
Thermal treatment suggested	0	0	3	0	1	5	1	0	2
Thermal treatment completed	0	0	0	0	0	0	0	0	0
# samples having clay present	51	36	28	3	6	66	4	11	38
# samples having clay absent	60	4	14	1	2	12	1	1	4
# samples with sub cat C	51	36	28	3	6	66	4	11	38
% of category with sub cat C	30.36	35.64	35.00	50.00	35.29	41.77	36.36	34.38	88.37

Some simplification of the chemical parameters was done prior to completing the analysis, to reduce the number of variables while retaining all of the information. For salinity details, only EC is shown, as it represents all of the ions causing salinity in the working database. Hydrocarbon data was limited to total hydrocarbons and total BTEX. Total BTEX was calculated by adding BTEX concentrations for the four BTEX compounds. The concentrations were first converted to numerical values so anything

reported as less than a value was considered to be that value. Figure 42 is a cumulative frequency distribution of the total BTEX data for the entire database. A log transformation was applied to the data in a manner consistent with the individual BTEX compounds, and Figure 43 shows the cumulative frequency distribution of the log transformed data.

Figure 42: Total BTEX Concentrations

Sample size: 125, Mean value: 70.6, Maximum value: 65401, Minimum value: 0.003

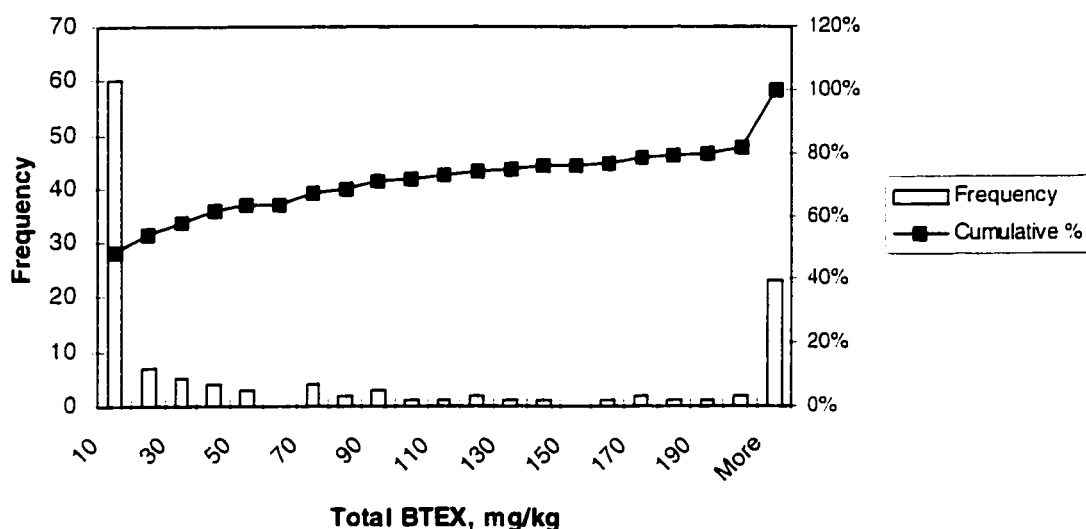
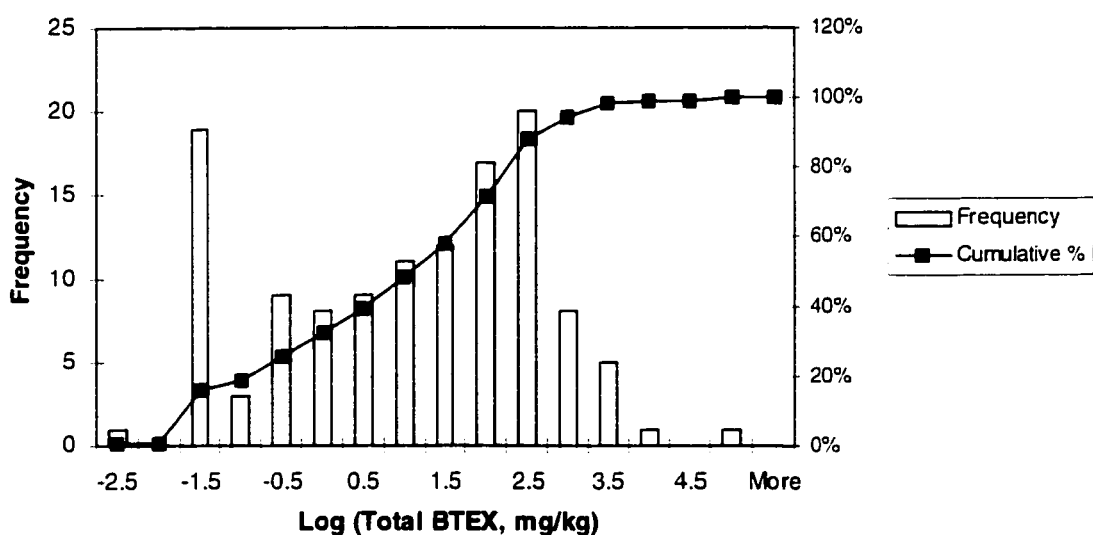


Figure 43: Log Total BTEX Concentrations



An equivalency factor was applied to each of the metals, so a total metals value could be calculated and used to reflect the toxicity associated with the twelve metals in the database. All metals concentrations were first converted to numerical values, so anything reported as less than a value was considered to be that value. Then an equivalency factor was calculated using the allowable zinc level in the CCME SQG as a standard. Zinc was chosen for this purpose, as it is the largest concentration of a metal allowed in agricultural soils based on the CCME SQG. The allowable level of zinc in agricultural soils is 200 mg/kg (CCME, 1997). To determine the equivalency factor for another metal, 200 mg/kg was divided by the allowable limit for that metal according to CCME SGQ or AB Tier 1. For example, the allowable limit for arsenic is 12 mg/kg, so the equivalency factor for arsenic is 16.67. This value was then multiplied by all of the arsenic concentrations reported, to determine the zinc equivalent arsenic levels. This was carried out for all of the metals in the working database, and was followed by calculating the sum of all of the equivalent values to represent a total metals value. In this manner, a metal such as arsenic which has a higher general toxicity associated with it compared to zinc, will contribute to a larger total equivalent metals value for a site if it is present in appreciable quantities.

The working database in Appendix 2 contains the equivalency factors for all metals. Figure 44 is a cumulative frequency distribution of the Total Equivalent Metals data for the entire database. A log transformation was applied to the data in a manner consistent with the individual metals, and Figure 45 shows the cumulative frequency distribution of the log transformed data.

Figure 44: Total Equivalent Metals Concentrations

Sample size: 238, Mean value: 1011.8, Maximum value: 8119, Minimum value: 7.3

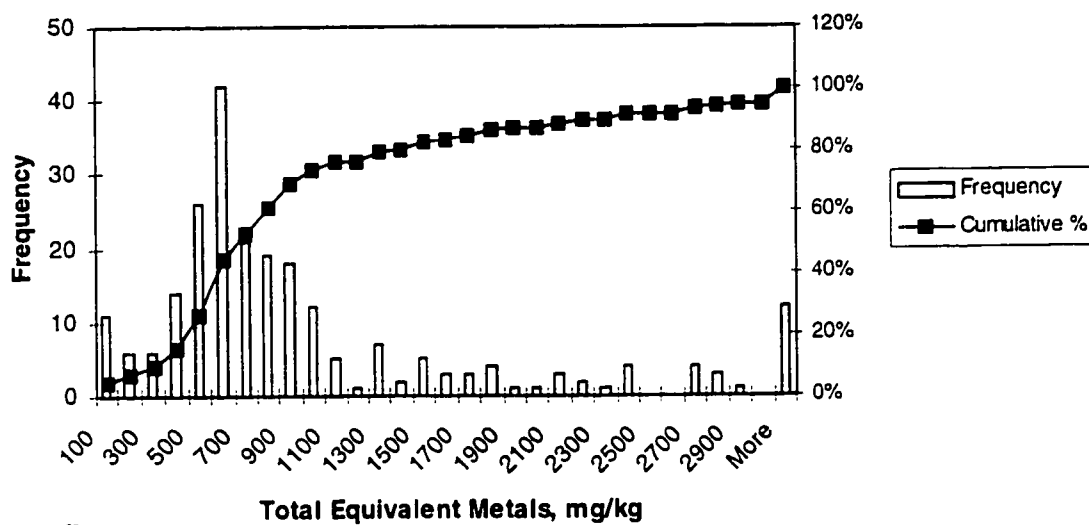
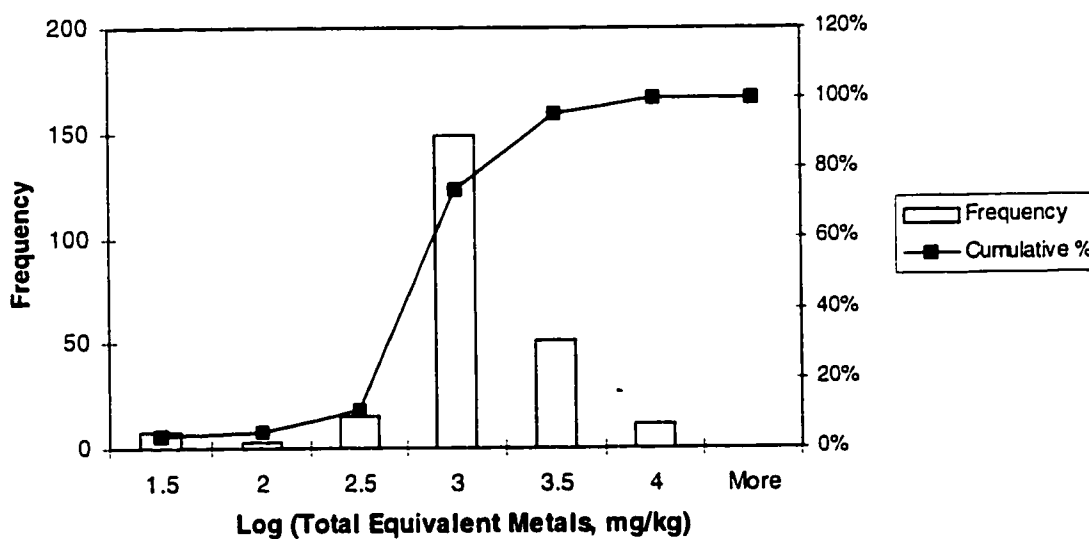


Figure 45: Log Total Equivalent Metals



Hypothesis testing was then carried out on some of the data sets, to identify if the hypothesized relationship would be demonstrated by the data in the database. The data generation steps include transforming the data using a log transformation to achieve a normal distribution, F-tests to identify sample set variance, and t-tests to identify significant differences in sample values. The testing methods are presented in the following sections. For those descriptive variables considered subjective, details on the variable information contained in the database are described, but no hypothesis testing was carried out.

4.27.1 Produced Hydrocarbon

The three possible responses in the “produced hydrocarbon” section are oil, gas and oil and gas. Natural gas and natural gas liquids are mostly comprised of hydrocarbon chain lengths that are below seven carbon atoms (C7). In some cases, these hydrocarbon types are very easy to degrade, and it might be anticipated that such sites would have a low total hydrocarbon concentration. However, the toxicity of the carbon fractions present also requires evaluation, as high levels of toxic compounds may inhibit degradation of the hydrocarbons.

Sites associated with oil production should be expected to have high concentrations of longer chain and cyclic hydrocarbons, the heavier of which are more difficult to degrade. Spills or careless management of oil at such leases may lead to high concentrations of hydrocarbons in lease soils. The nature of the oil will also play a role, as the production location and associated formation pre-determines the types and concentrations of each carbon fraction.

As seen in Table 4, “produced hydrocarbon” data is available for 481 samples, or 78% of the database. Oil was produced at 138 of the sample sites or 29%, gas was produced at

286 of the sample sites or 59%, while both oil and gas were produced at 55 of the sample sites or 12%. Information on flare pits sites in Alberta, grouped by produced hydrocarbon type is found in Appendix 5. Figure A5-1 provides a graph of the Alberta locations of gas producing sites and oil producing sites in the database.

Five hypotheses are suggested for testing based on type of “produced hydrocarbon”. First, it is hypothesized that sites producing oil will have a higher concentration of total hydrocarbons compared to sites producing gas, since the presence of heavier hydrocarbons in oil production should lead to slower degradation rates. This would also be consistent with the findings in the two DBEL studies (DBEL, 1991a and 1991b) that reviewed flare pits at oil batteries and gas batteries. Second, using the same argument, it is hypothesized that sites producing gas will have a higher concentration of total BTEX compared to sites producing oil. This hypothesis may not hold true due to the volatility of some of the BTEX compounds. Third, it is hypothesized that EC levels are higher at sites producing gas versus sites producing oil, as a result of past operating practices at gas sites, where production volumes were often directed to pits on a regular basis. Therefore, produced water in the formation would be introduced to a pit at regular intervals. Fourth, it is hypothesized that mercury concentrations are greater at sites producing gas compared to sites producing oil, since the presence of mercury manometers at gas sites for volume measurements is of historical significance. Finally, it is hypothesized that total equivalent metals concentrations are greater at sites producing gas compared to sites producing oil, since Table 4 identifies that all categories having elevated metals levels had more samples from sites producing gas. In all cases, a one-tailed t-test was used to test the hypothesis.

Table A5-1 shows the differences between the data set for sites producing oil and the data set for sites producing gas. It provides details on the average, standard deviation and coefficient of variation values for hydrocarbon, total BTEX, EC, mercury and total equivalent metals concentrations using non-transformed and log transformed data. Even

though it is hypothesized that metals concentrations will be greater at sites producing gas, a comparison of sample set averages in Table A5-1 indicates that this hypothesis is not supported by a larger concentration of total metals at gas sites versus oil sites.

Table A5-2 was prepared to determine the form of t-test required for the data set. The t-test assumes that there is independence between observations, both data sets have equal variances and that the data sets are normally distributed (McBean and Rovers, 1998). Independence between observations is a result of the data gathering procedure and the testing described in Section 4.33. Normal distribution in sample sets is addressed by reviewing the relative and cumulative frequency distributions. The assumption of equal variances is tested using the F-test, which compares the variance ratio to a critical F value from a statistical table (F Critical). The F ratio is calculated according to the following equation:

$$F \text{ ratio} = \frac{\text{greater estimate of the variance of the population}}{\text{lesser estimate of the variance of the population}} \quad [1]$$

Table A5-2 provides data on the F-ratio and “F Critical” for the hydrocarbon, total BTEX, EC and mercury concentration data grouped by hydrocarbon type produced. The table identifies the mean, variance, number of observations and degrees of freedom for both sets of data. Even though information on produced hydrocarbon is available for 479 samples in the database, the availability of correlating chemical concentration data is significantly less. The table identifies the F ratio value, the F critical value and the result of comparing the two for the combined data sets, which must be considered in the t-test.

Table A5-3 provides detail on the t-test calculations done for the produced hydrocarbon data. The t Statistic can be calculated using Equation 2 or Equation 3, depending on the results of the F test. If the F ratio is less than “F Critical” the samples do not have

statistically different variances, and Equation 2 is used to calculate the t Statistic since it assumes equal variances.

$$t^* = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{n_1 + n_2}{n_1 n_2} \left(\frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2} \right)}} \quad [2]$$

The terms used in Equation 4 are defined as follows: \bar{x} is the mean of the sample set, n is the number of observations in the sample set, S^2 is the sample set variance and t^* is the t test Statistic. If the sample sets do have statistically different variances, the t statistic must be calculated in a manner that allows for unequal variances. Equation 3 is used when the F-test demonstrates that the variances are unequal.

$$t^* = \frac{|\bar{x}_1 - \bar{x}_2|}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}} \quad [3]$$

The terms used in Equation 3 are the same as those defined in Equation 2. For each sample set, the table identifies the mean, variance, number of observations, hypothesized mean difference and degrees of freedom. For each contamination type, or two sample sets, the table identifies the pooled variance (if the sample sets have equal variances), t Statistic and the “t Critical” value for a one-tail and two tail test. Since it was hypothesized that one sample set is significantly larger than a second sample set, a one tail test is appropriate, while a two tail test would identify if the sample sets are significantly different (McBean and Rovers, 1998). Values calculated for the t Statistic that exceed “t Critical” indicate that the hypothesis of one sample set being greater than the other is accepted based on the data.

Equations 2 and 3 are available in Microsoft Excel's data analysis tool pack (Microsoft, 1997), allowing for quick calculation of F ratios and t Statistics.

4.27.2 Activity

The activity at the site was noted, as it relates to the possible volume of hydrocarbon and other contaminants at the site and to amount of attendance at a site. For example, it is expected that hydrocarbon volumes at a site should increase in the order, well, satellite, battery, production site/gas plant. Increasing in the same order is availability of process chemicals and other possible contaminants of a non-hydrocarbon nature. Also increasing in the same order is a notion of site security and restricted site access, since the continuous presence of operators is anticipated only at processing facilities or very large batteries.

According to Table 4, site activity data is available for 599 samples, or 97% of the database. Site activity descriptions were "simplified" to reduce the variation in entries for the 599 samples. Of the 599 samples, 289 samples or 48% were from well sites, 224 samples or 37% were from batteries, 46 samples or 7.7% were from satellites and 40 samples or 6.7% were from gas plants and other processing facilities. Appendix 6 provides information on the flare pits in this database, grouped by the activity at the site. Figure A6-1 provides a graph of the Alberta locations of battery sites and well sites in the database.

Over 85% of the site activity data is associated with wells or batteries. Therefore, three hypotheses are suggested for testing based on type of site activity using information from only the well sites or battery sites. It is hypothesized that sites designated as wells will have higher concentrations of hydrocarbons, EC, total BTEX and total equivalent metals compared to sites designated as batteries. These three hypothesized relationships are suggested based on the amount of attendance at battery sites, which exceeds the

attendance at well sites. Lower attendance combined with more remote locations provides a greater potential for dumping of oilfield waste materials in pits as a means of storage or disposal and longer time required to respond to a process upset.

Table A6-1 shows the differences between the data set for battery sites and the data set for well sites. A comparison of the sample averages in Table A6-1 indicates that metals concentrations are greater at well sites, but EC and total BTEX are greater at battery sites. As done for data on produced hydrocarbon type, Table A6-2 shows F ratios and Table A6-3 shows t-test calculations done for the site activity data.

4.27.3 Age

The age of the pit is considered important information since the date of pit construction reflects the environmental practices of the time. It might be anticipated that older pits would be more likely to have very high levels of contamination. It might also be expected that very old sites that did have hydrocarbon contamination at one point might have much lower concentrations during recent sampling events, since there has been time for unassisted bioremediation.

According to Table 4, site age information is available for 141 samples, or 23% of the database. For this analysis, site age was broken down into two categories: built before and including 1975, which represented 83 samples or 59%, and built after 1975, which represented 58 samples or 41%. Details on flare pit samples in the database grouped by site age are provided in Appendix 7. Figure A7-1 provides a graph of the Alberta locations of sites built before (and including) 1975 and built after 1975.

Three hypotheses are suggested for testing based on site age as it is expected to relate to evolving environmental practices. First, it is hypothesized that sites built after 1975 will have a higher concentration of total BTEX compared to sites built before 1975. This is

suggested based on the volatility of the BTEX compounds. This analysis does not account for older sites that may have had spills or other hydrocarbon releases shortly before site sampling. Second, it is hypothesized that EC will be greater at sites built after 1975. Salinity components are relatively mobile, so historical releases of salinity to the ground at older sites should have moved through the area over time with the assistance of surface water and groundwater. Again, this analysis does not account for older sites that may have had produced water releases shortly before site sampling. The third hypothesis is that total equivalent metals concentrations are greater at sites built up to and including 1975. This is suggested based on the evolution of environmental practices and the enforcement of proper waste disposal. It is more likely that process chemicals and other wastes containing metals would have been disposed of in flare pits in earlier years, while more recent efforts to monitor waste movements have increased the awareness of appropriate disposal techniques (AEUB, 1996b).

Table A7-1 shows the differences between the data sets based on site age. Comparing sample averages in Table A7-1 indicate that BTEX and EC concentrations are greater at sites built after 1975, while metals concentrations are greater at sites built before and including 1975. As done for data on produced hydrocarbon type, Table A7-2 shows F ratios and Table A7-3 shows t-test calculations done for the site age data.

4.27.4 Soil Type

Soil type is an important site detail, since it should impact both the extent of site contamination and the ability to remediate a site. For example, contaminants can migrate across a site with sandy soil much more readily than a site with clay soil. During site remediation, it is much easier to bioremediate sandy soil versus a clay soil, since bioremediation methods require oxygen addition, liquid soil amendments or thermal treatment.

According to Table 4, soil information is available for 340 samples, or 55% of the database. For this analysis, soil type was broken down into two categories: sites with clay as the primary or secondary soil type, representing 243 samples or 71%, and sites with little or no clay content, representing 99 samples or 29%. Additional information on flare pit samples in the database grouped by clay content are provided in Appendix 8. Figure A8-1 provides a graph of the Alberta locations of sites having clay content and sites not having clay present in soils.

Three hypotheses are suggested for testing based on clay content as it is expected to relate to contaminant migration. It is hypothesized that hydrocarbons, EC and total equivalent metals concentrations will be higher at sites having clay present. These three hypothesized relationships are suggested based on the ability of clay to retard movement of contaminants.

Table A8-1 shows the differences between the data sets based on soil type. Comparing sample averages in Table A8-1 indicate that hydrocarbons, EC and total metals are greater at sites having clay content. As done for data on produced hydrocarbon type, Table A8-2 shows F ratios and Table A8-3 shows t-test calculations done for the soil type data.

4.27.5 Pit Contents

The pit contents may be related to the resulting pit category since they may indicate the type and volume of contaminants found in the pit. The five possible pit contents in the database were emulsion, emulsion and brine, brine, water and oily water. The presence of brine in the pit may indicate an elevated salinity, while the presence of emulsion or oily water may indicate a high concentration of hydrocarbons.

According to Table 4, pit contents are available for 212 samples, or 34% of the database. Of the 212 samples, 52 had emulsion, 21 had both emulsion and brine, 9 had brine, 116 water, and 14 had oily water. The data on pit contents was not analyzed in detail, as the presence of certain contents may be a reflection of recent operational practices, a one-time operational practice, or recent precipitation in the case of water. Therefore, the application of a pit content observation to the site is inappropriate without knowledge of site activities over the entire life of the site and an analysis of the fluid in the pit at the time of sampling.

4.27.6 Pit Observations

Observations made regarding the pit may indicate the type of activity directly related to the pit. The three observations made regarding the pits in the database were; oil stained soil, poor vegetation growth, and both oil stained soil and poor vegetation growth. The oil stained soil may indicate high concentrations of hydrocarbons or previous incidences of spills, while poor crop growth may indicate high concentrations of toxic contaminants or herbicide application. Details on herbicide use were in the original database (see Appendix 1) but the quantity of data was not significant and therefore not used in the working database.

According to Table 4, details on pit observations are available for 118 samples, or 19% of the database. Of these, 82 had oil stained soil, 25 had a combination of oil stained soil and poor vegetation growth, while 11 had poor vegetation growth. Similar to the data on pit contents, data on pit observations was not analyzed in detail. A diverse group of people evaluated different sites for different companies, provided their opinion of the pit and applied varying degrees of conservatism to their evaluation. The observation may reflect the pit condition in relation to the surrounding area or the pit condition compared to other pits. As with pit contents, pit observations may relate to recent activities such as an oil spill or sterilant application, or be indicative of site practices for the entire life of

the site. The application of a pit observation to the site is inappropriate, since the contributing factors to the observation are not known.

4.27.7 Management Technique Suggested

In many cases the data on each flare pit was prepared to assess the contamination level at a site and to determine how the site should be remediated. Suggestions on the best method for site management are based on past practices of the producing company and the technical expertise of the group performing the site assessment. Since the earliest sampling date in the database is 1993, there is no significant difference in the technologies and disposal options available to the people analyzing the site.

According to Table 4, recommendations for site management are available for 338 samples, or 55% of the database. Recommendations are; 70 to be backfilled, 21 to be treated using composting or biopiles, 36 to be left alone, 6 samples to be landfilled, 151 to be land treated, 2 to be air sparged, 14 to be leached, 12 to be thermally treated, 9 to be divided into hotspots for landfilling and the remainder for land treatment, and 16 to be divided into material suitable for landfilling and material suitable for thermal treatment. Data on recommended management technique was not analyzed in detail. The suggestions for site management may indicate the company's philosophy regarding site remediation or the evaluator's knowledge of the types of remediation techniques available and applicable. For example, some companies may only be interested in using backfilling or land treatment due to the perceived low cost. Some consultants may be more aware than others of the types of remediation techniques available and how they handle different categories of contamination. Therefore, the evaluation of site management suggestions using the contaminant concentration data is inappropriate since the underlying reasons for the suggestion are not known.

4.27.8 Site Management Completed

A comparison of the methods of site management suggested in Section 4.27.7 with work actually completed provides an indication of the willingness to use unique and unproven technologies for contamination management. It also provides an idea if certain site categories are remediated more commonly than others.

As evident from Table 4, 220 samples, or 41% of the database have been remediated or addressed in some manner. Of these, 41 were backfilled, 36 were left alone, 2 were treated using a combination of landfill for highly contaminated areas and land treatment of the remainder, and 34 were land treated. Furthermore, 107 samples had been remediated, but there was no entry in the “management technique suggested” section, so the method used is not known. Data on remediation completed was not analyzed in detail. Consideration of the issues presented in 4.27.7 and lack of full details on the remediation work make it difficult to evaluate the sites remediated or otherwise addressed. Confirmatory sampling for the sites that have been remediated is not included in the database. It is difficult to comment on the success of the remediation technique without knowledge of how the remediation was carried out and the resulting contaminant levels at the flare pit site and/or the new surface treatment site. Therefore, the evaluation of remediation completion using the contaminant concentration data is inappropriate since there is no follow-up information for the remediated sites.

4.27.9 Location According to Public Land Use Zone

As discussed in Section 4.1, Alberta lands are divided into two land zones based on similarity in land characteristics and land use. The locations of 552 samples in the database from Alberta were compared to the Public Lands, General Classification map for Alberta (Alberta Agriculture, Food and Rural Development, 1995) to determine how the database was distributed between the “white zone” and “green zone” and differences between site category distribution in the two land use zones. The remaining 64 samples

in the database were either located outside of Alberta or location information was not available, so they were not included in the analysis. The information on land use zone is provided in Table 5. The table provides details on the number of samples in the database in each land use zone, and a breakdown of the number of samples in each category located in each land use zone. A calculation was also done to determine the percentage of the samples in the zone represented by each category, and the difference in percentage between green zone and white zone.

4.27.10 Summary

Table 4 provides a summary of each site category in relation to the topics listed from 4.27.1 to 4.27.9. It includes a description of hydrocarbon, construction date, site activity, site description, remediation suggested, remediation completed, soil type and land use zone for each site category.

Table 5**Distribution of Samples in the “White Zone” and “Green Zone”**

	Green Zone	White Zone	Green - White
Total number of samples	223	329	
Category A samples	42	84	
% of Zone that is category A	18.83	25.53	-6.70
Category B samples	42	56	
% of Zone that is category B	18.83	17.02	1.81
Category C samples	32	43	
% of Zone that is category C	14.35	13.07	1.28
Category D samples	1	5	
% of Zone that is category D	0.45	1.52	-1.07
Category E samples	4	13	
% of Zone that is category E	1.79	3.95	-2.16
Category F samples	55	91	
% of Zone that is category F	24.66	27.66	-3.00
Category G samples	2	8	
% of Zone that is category G	0.90	2.43	-1.53
Category H samples	10	21	
% of Zone that is category H	4.48	6.38	-1.90
Category I samples	35	8	
% of Zone that is category I	15.70	2.43	13.26

4.28 Significance Testing of the Database

In order to make conclusions about the information contained in the database, it is important to establish the ability of this database to represent the total population of flare pits in Western Canada. This section explores the analysis used to review the ability of the database to represent the population, and the techniques used to compare the significance of the nine categories with the database.

The database represents 436 flare pit sites, and a total of 616 samples from those sites. It is estimated that there are up to 30,800 flare pits and drilling sumps in Alberta (Pryce, 1998). Details on the calculation of the flare pit and drilling sump population in Alberta are provided in Appendix 9. This is a major concern that the magnitude of the problem is not clearly understood and it should be the responsibility of both industry groups and regulatory agencies to better quantify the presence of flare pits. Based on the only available estimate, the database represents 1.4% of the total number of estimated flare pit sites in Alberta. While this percentage appears low, a visual geographical review of the sites, seen in Figure 1, demonstrates that the sites in the database cover a significant portion of the province. The techniques used to test the significance of the total database and smaller components of the database are described below.

4.28.1 Total Database

Several spatial distribution analyses were chosen as a means of determining the significance of the total database. The various analyses were carried out to identify if the flare pit database could be considered representative of the population of the flare pits in Alberta.

A database prepared by the AEUB was chosen to represent the entire flare pit population in Alberta. The database was chosen as it contains location information for 14,033 oil and gas battery sites in Alberta, most of which operate with a flare stack (AEUB, 1996c).

The sheer magnitude of the database and the presence of the battery locations throughout the oil and gas producing areas of Alberta was considered to be representative of oil and gas production in Alberta, which is thought to be representative of flare pit locations.

The first spatial technique used provides an opportunity to visually assess a data set or sets to determine areas of similarity. The latitude and longitude coordinates for the 14,033 sites in the AEUB battery database were plotted in a graph, provided as Figure 46. The provincial boundaries for Alberta are 60° , -110° in the Northeast corner, 60° , -120° in the Northwest corner, 49° , -110° in the Southeast corner and 49° , -114° in the Southwest corner. Since the AEUB battery database only considers Alberta, only the Alberta sites in the flare pit database were considered. All 552 sample locations from Alberta were plotted in a graph provided as Figure 47. Figure 48 was made by extracting the 297 battery and satellite samples in Alberta from the 552 samples in the province, and plotting their latitude and longitude coordinates. The combination of the locations from the AEUB battery database and the total flare pit database in Alberta are plotted in Figure 49. The combination of the locations from the AEUB battery database and the battery and satellite sites in Alberta from the flare pit data base in Alberta are plotted in Figure 50.

To test if the total flare pit database was a random sample of the AEUB battery database locations, or the proposed Western Canadian flare pit sample population, a visual assessment of Figures 46-50 was completed. Similarity in distribution shape and areas of high and low density were the primary areas evaluated for the figures.

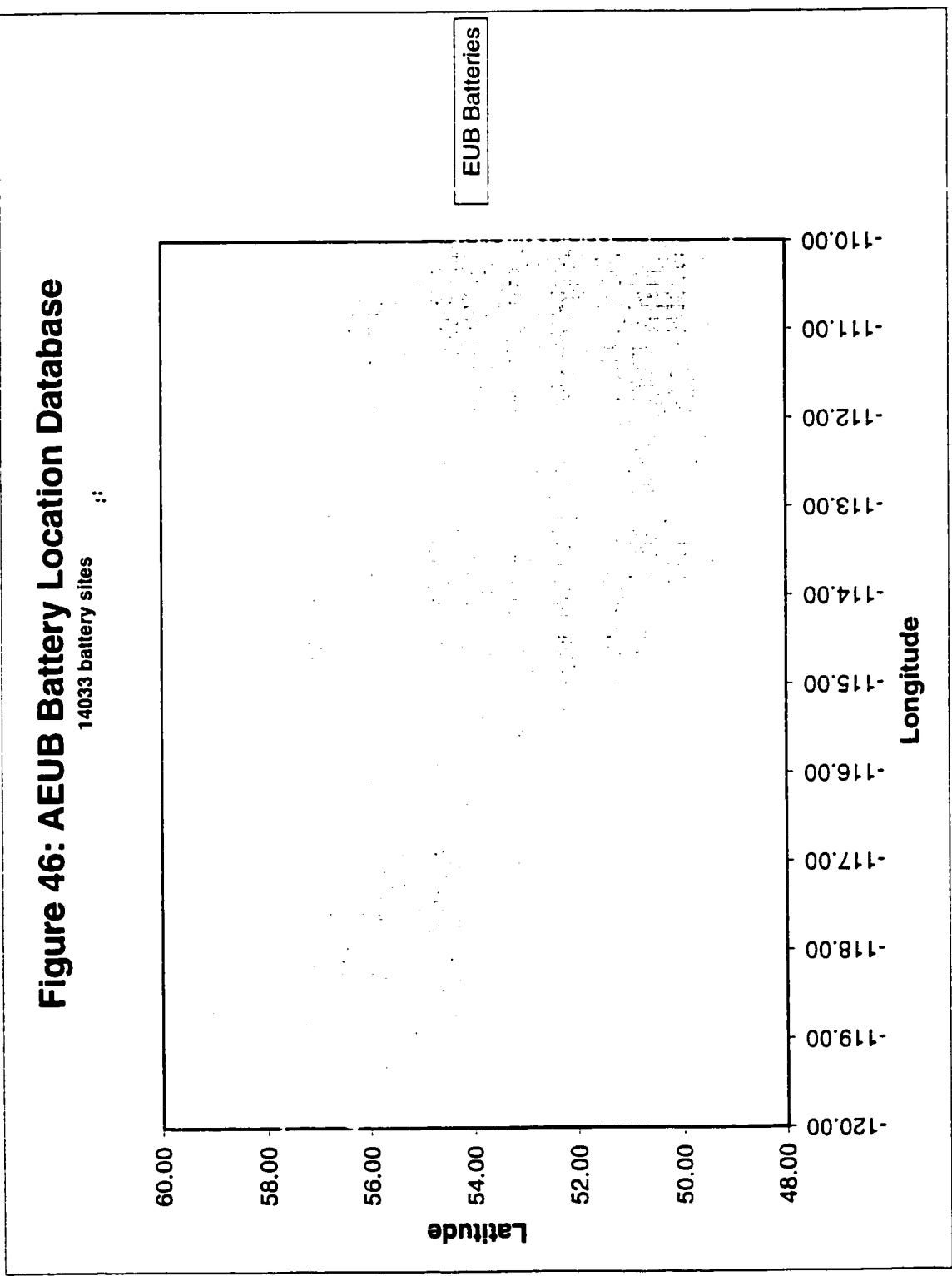
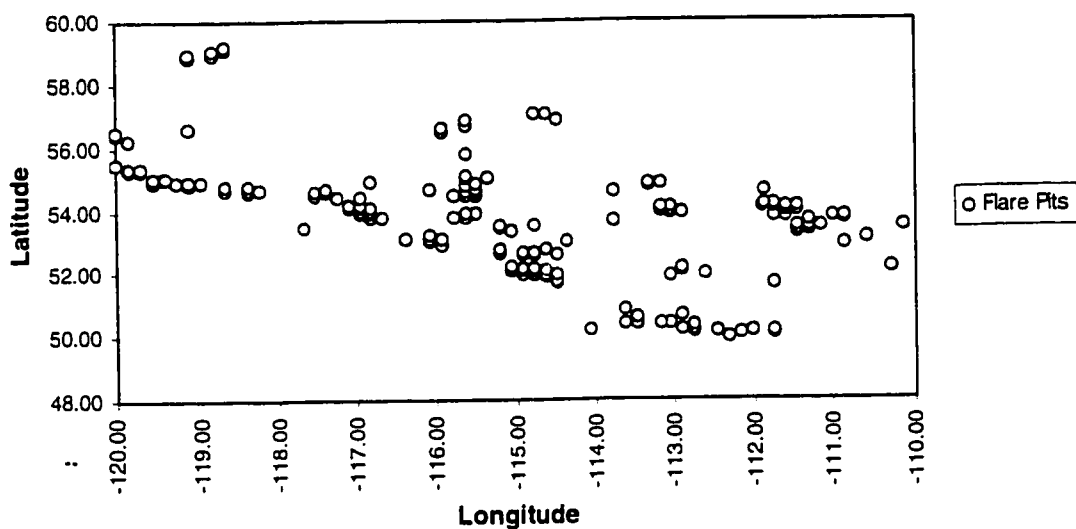


Figure 47: Flare Pits from Database

552 flare pit samples

**Figure 48: Flare Pits at Battery Sites**

225 flare pit samples from batteries

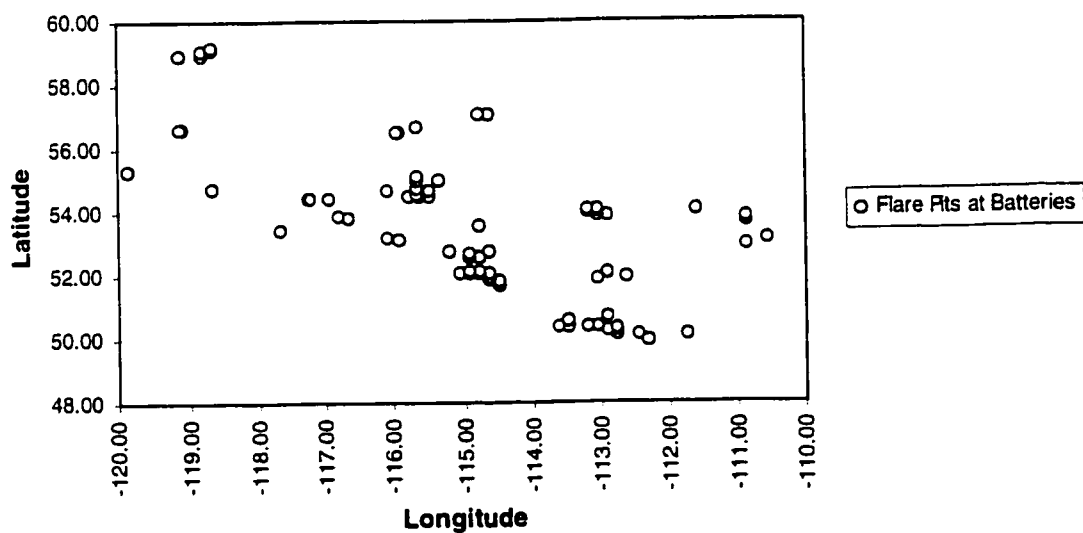


Figure 49: Flare Pit Database and Battery Sites in Alberta

552 flare pit samples, 14033 battery sites

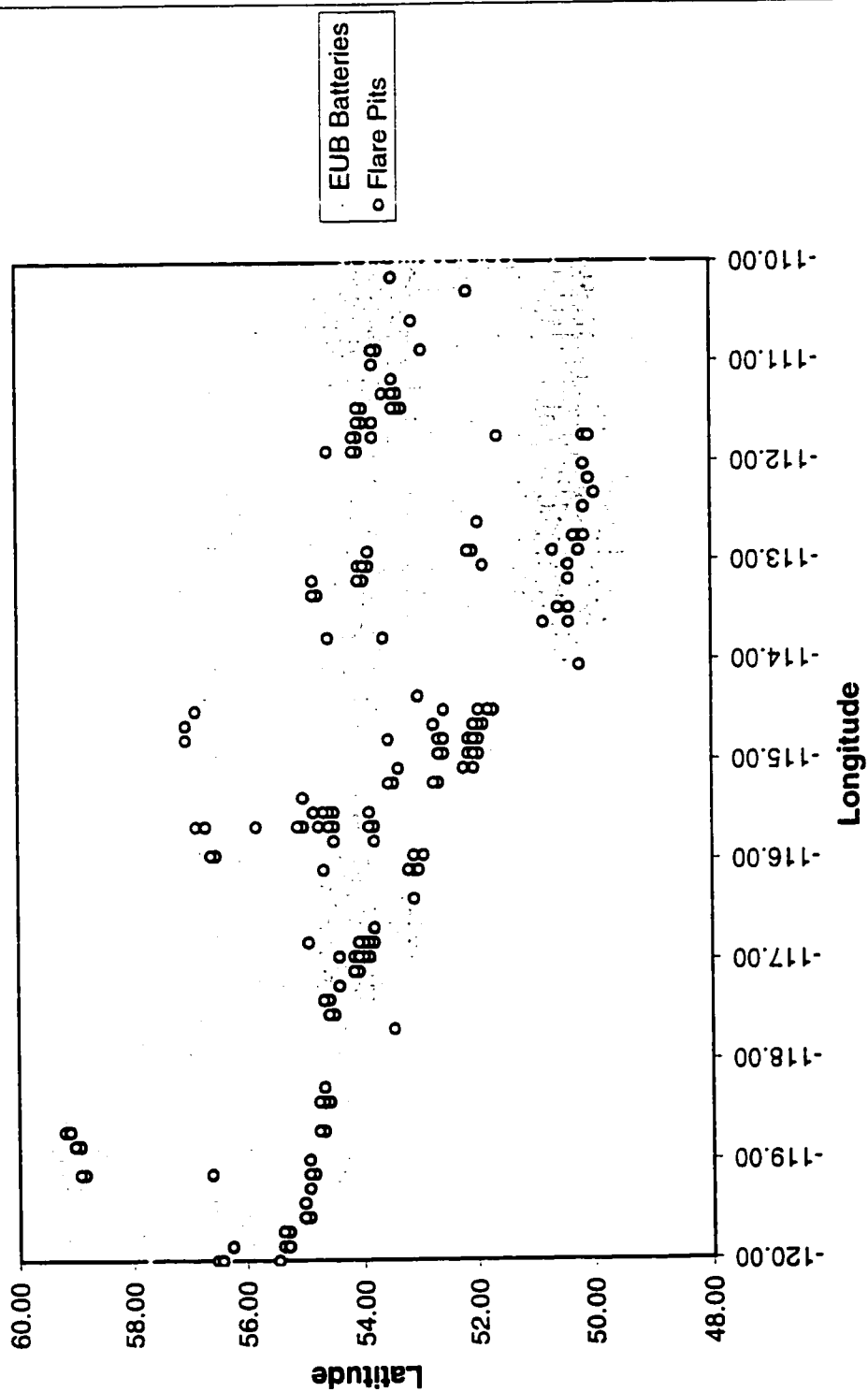
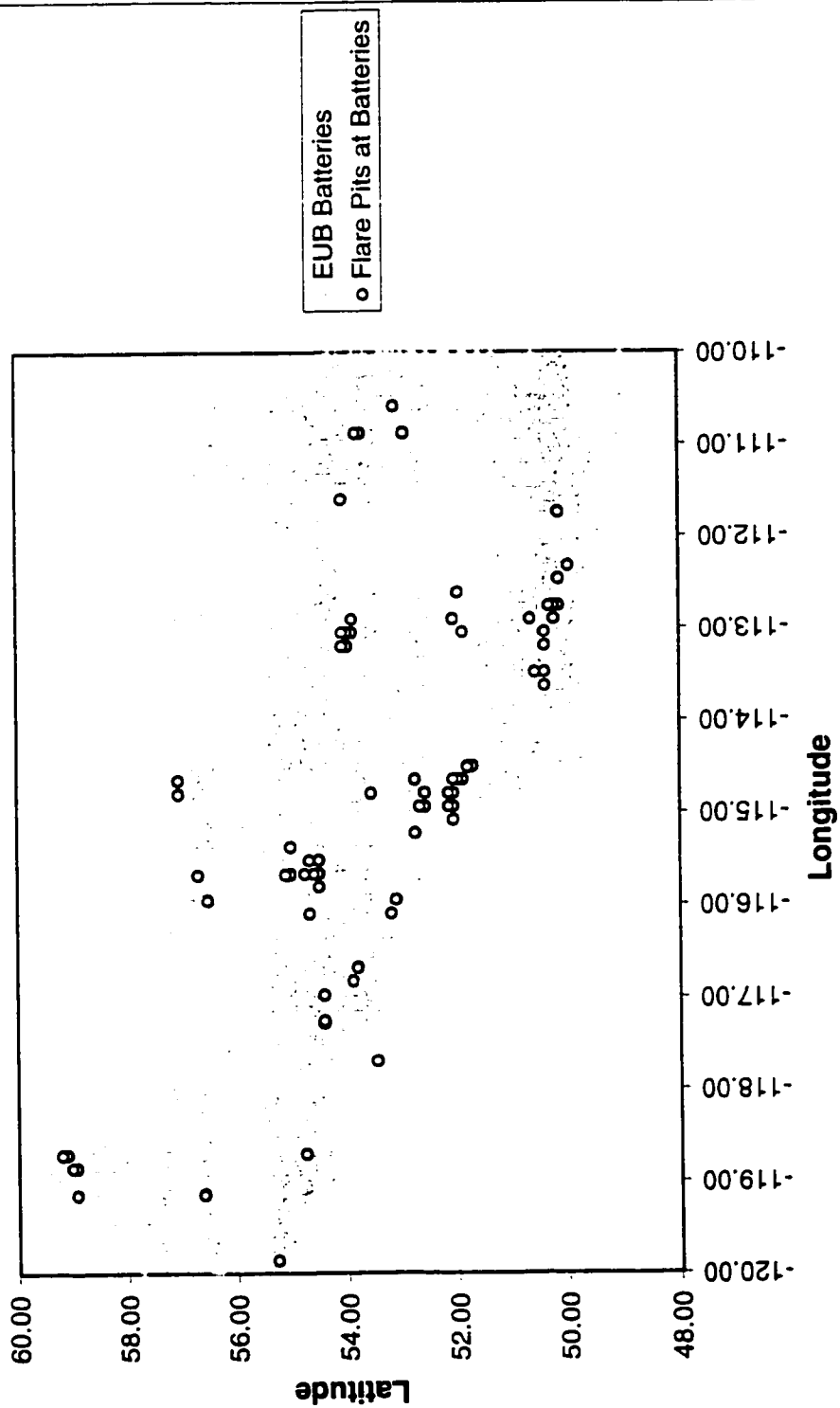


Figure 50: Flare Pit Database Battery Sites and Battery

Sites in Alberta ::

225 flare pit samples from batteries, 14033 battery sites



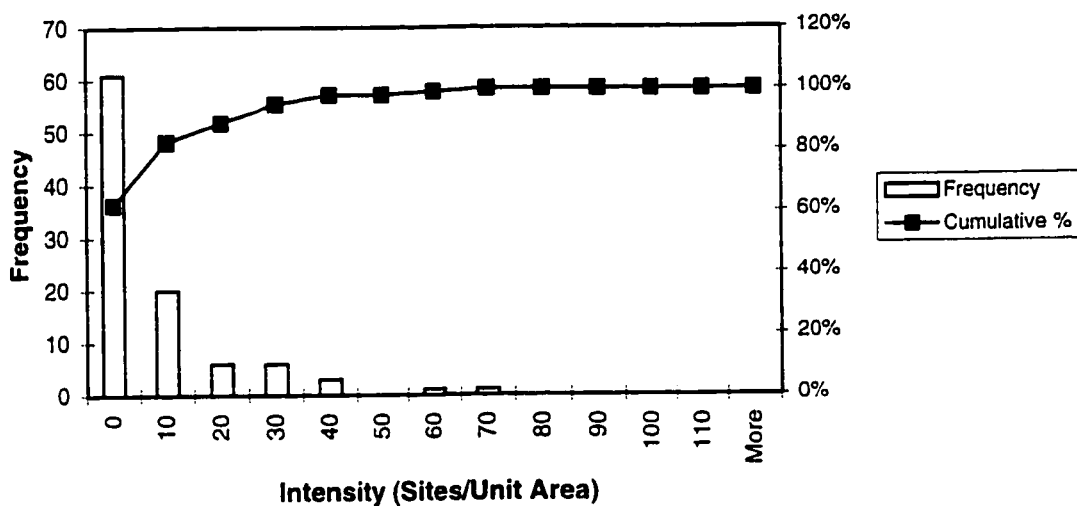
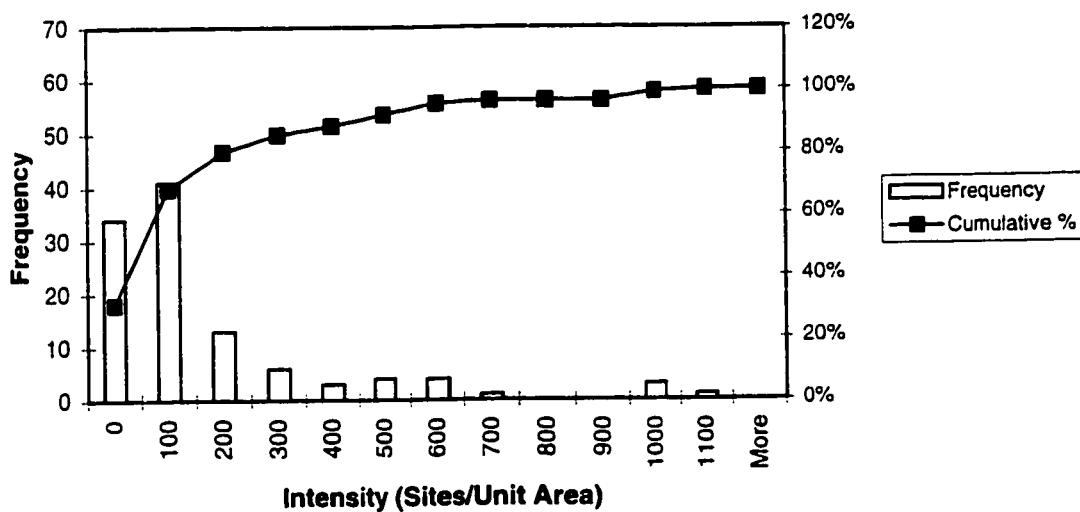
The second spatial technique used was a quadrant analysis to identify spatial patterns. The province was divided into 98 quadrants based on latitude and longitude coordinates. Latitude ranged from 49° to 60° , and longitude ranged from -110° to -120° . The intensity of each database was assessed for each quadrant, where the intensity is considered as the total count of sites divided by the total quadrant area (Diggle, 1983). The number of flare pit samples and AEUB battery sites were determined for each quadrant of area equal to 1. Table 6 provides the intensity data for the flare pit sites, and Table 7 provides the intensity data for the AEUB battery sites. The relative and cumulative frequency distributions for each data set were then plotted, where the x-axis scale is a factor of ten greater for the AEUB battery sites versus the flare pit sites. Figures 51 and 52 show the relative and cumulative frequency distribution for the flare pit sites and the AEUB battery sites, respectively. These figures were compared to identify similarities in the distribution of locations for the two data sets. Differences in distributions would indicate differences between the two data sets.

Table 6**Intensity Data for the Flare Pit Database, Alberta Sites**

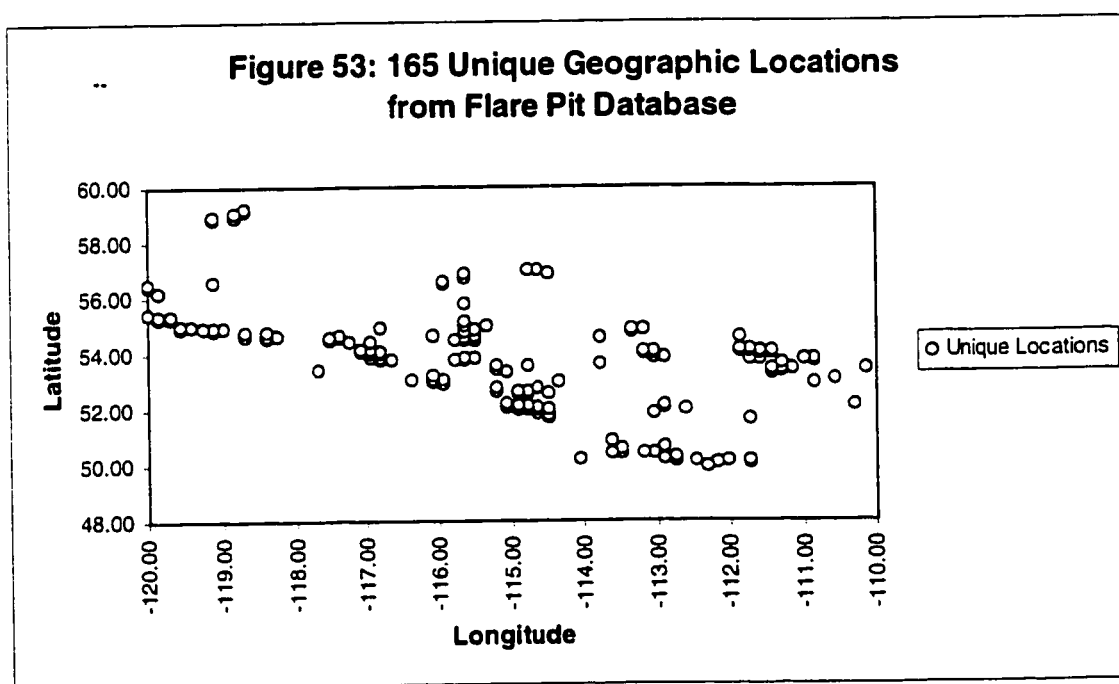
Longitude	119-120	118-119	117-118	116-117	115-116	114-115	113-114	112-113	111-112	110-111
Latitude										
59-60	0	7	0	0	0	0	0	0	0	0
58-59	3	3	0	0	0	0	0	0	0	0
57-58	0	0	0	0	0	8	0	0	0	0
56-57	27	0	0	0	8	10	0	0	0	0
55-56	26	0	0	0	12	0	0	0	0	0
54-55	7	21	36	11	40	0	12	0	31	0
53-54	0	0	4	23	18	2	17	2	63	18
52-53	B.C.	0	0	0	10	25	0	8	0	4
51-52	B.C.	B.C.	0	0	0	52	1	2	2	0
50-51	B.C.	B.C.	B.C.	B.C.	0	1	9	24	3	0
49-50	B.C.	B.C.	B.C.	B.C.	B.C.	0	0	2	0	0

Table 7**Intensity Data for the AEUB Battery Location Database**

Longitude	19-20	18-19	17-18	16-17	15-16	14-15	13-14	12-13	11-12	10-11
Latitude										
59-60	17	70	0	1	0	0	0	0	0	0
58-59	68	17	9	0	0	0	0	0	0	0
57-58	24	35	8	2	3	32	3	3	1	0
56-57	162	41	10	33	290	70	91	9	11	8
55-56	499	152	68	86	101	82	28	36	25	28
54-55	58	104	167	167	152	50	53	59	55	347
53-54	0	0	21	193	555	514	238	152	122	983
52-53	B.C.	0	0	14	157	979	545	238	351	1052
51-52	B.C.	B.C.	0	0	10	435	192	401	286	211
50-51	B.C.	B.C.	B.C.	B.C.	0	25	700	564	977	471
49-50	B.C.	B.C.	B.C.	B.C.	B.C.	2	13	384	207	122

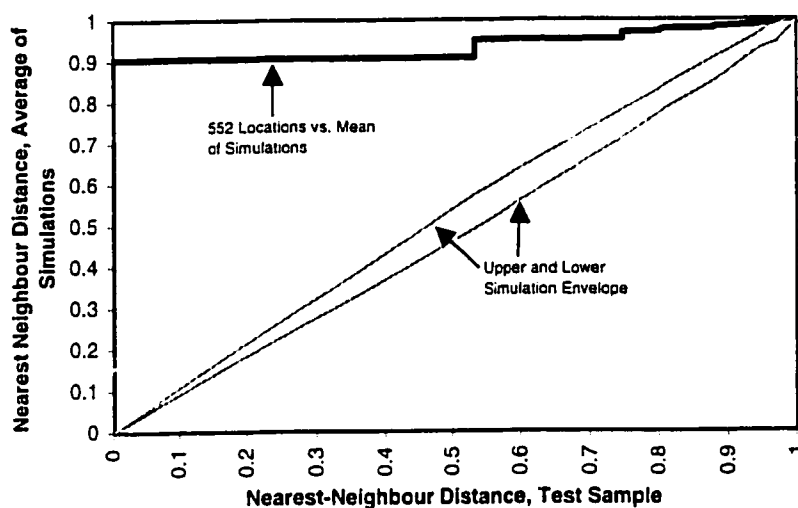
Figure 51: Flare Pit Sites per Alberta Quadrant**Figure 52: AEUB Battery Sites per Alberta Quadrant**

The third spatial technique used to analyze the data focuses on identifying clustering and lack of random behavior. The database is comprised of many sites in close proximity to each other, since producers often operate in a designated field area. In addition, multiple samples of some sites are incorporated into the database. These two factors result in a large amount of sample points in a small location. Figure 53 demonstrates this clustering aspect of the database, where it represents the 165 distinct geographical locations considering all 552 samples in Alberta.

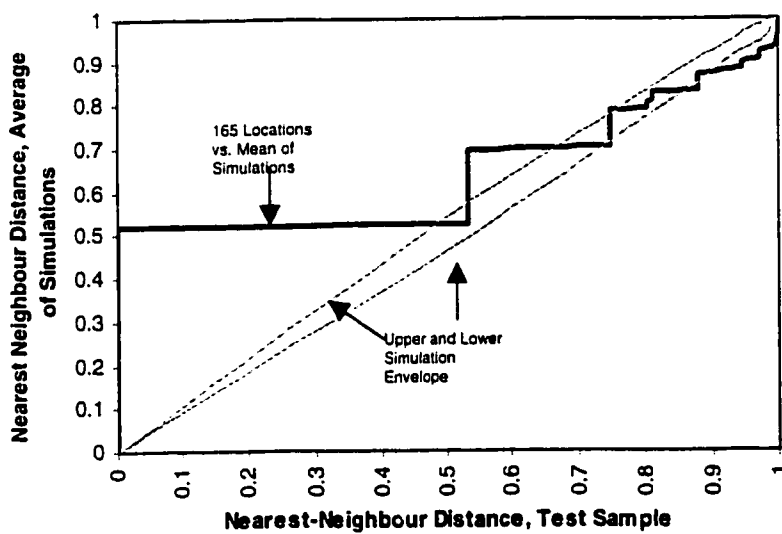


Two tests were carried out on both the 552 and 165 flare pit locations to identify if all locations and just the unique locations could be considered representative of the total population as represented by the AEUB battery location database. The first test reviewed nearest neighbour distances for the locations, which considers each data point in the data set and the distance from this event to the nearest other event. This concept is described in Diggle (1983) using a Poisson process that assumes equal distribution of sites in a given geographical area. It is modified for this application to consider the unique distribution exhibited by the AEUB battery location database (Statistical Consulting and Research Group, 1999). The nearest neighbour distances, which usually include consideration of reciprocal nearest neighbour pairs, were calculated for the 552 sample locations using S plus, a spatial statistics program (Kaluzny, 1996). 30 data sets of sample size 552 were randomly selected from the 14,033 samples in the AEUB battery location database using the random number generation tool in S plus. In all 30 cases, the nearest neighbour distances for each data set were calculated. Details are plotted in Figure 54, which compare nearest neighbour distances from the 552 sample locations with the sample mean of the 30 simulations. Figure 54 also shows the upper and lower boundary of the simulation envelope from the 30 samples randomly selected from the AEUB battery database. The same techniques were used to identify the nearest neighbour distances for the 165 unique locations in the database. The data is shown in Figure 55. A normally distributed data set would fall between the upper and lower boundary of the simulation envelope. A clustered data set would have a greater slope than the upper boundary of the simulation envelope, as there would be a greater number of small nearest neighbour distances in a clustered data set.

**Figure 54: Nearest Neighbour Distances,
552 Sample Locations**

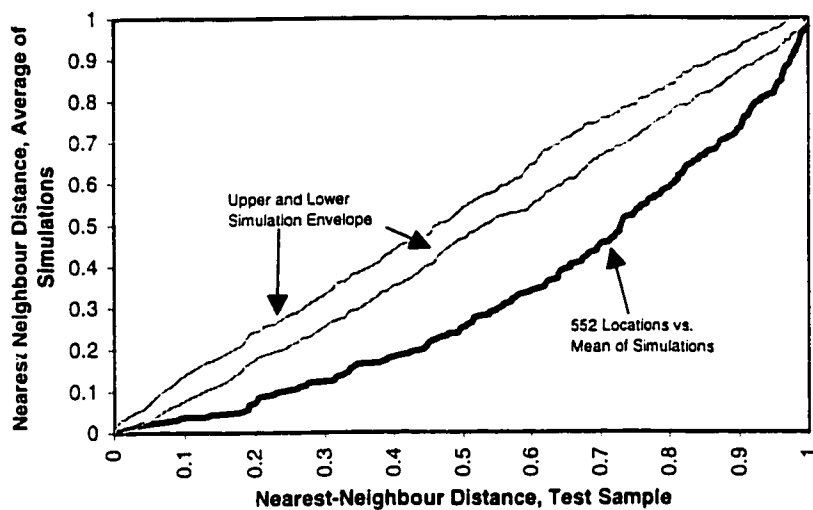


**Figure 55: Nearest Neighbour Distances,
165 Unique Locations**

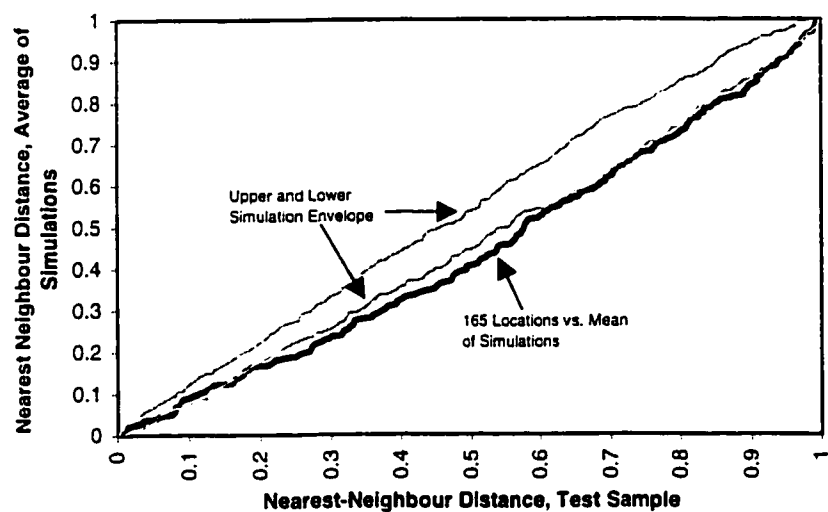


The second test completed to identify if the 552 sample locations were representative of the total population determined the point to nearest neighbour distances, which considers the distance from a randomly selected point from a rectangular grid of points in the unit square to the nearest event. Diggle (1983) also describes this technique using a Poisson process, and it was modified for this application (Statistical Consulting and Research Group, 1999). The point to nearest neighbour distances were calculated for the 552 sample locations using S plus. Again, 30 new data sets of sample size 552 were randomly selected from the 14,033 samples in the AEUB battery location database. For all 30 data sets, the random point to nearest neighbour distances for the 552 random points was determined in each data set. The resulting graph for the point to nearest neighbour distances is shown in Figure 56, and it is similar to the graph for nearest neighbour distances. The 552 sample locations are plotted against the sample mean of the 30 simulations. The upper and lower boundary of the simulation envelope from the 30 samples randomly selected from the AEUB battery database is also shown. A normally distributed data set would fall between the upper and lower boundary of the simulation envelope. A clustered data set would have a lesser slope than the lower boundary of the simulation envelope, as there would be a large number of clusters and significant space between the clusters, causing large distances between random points and clusters.

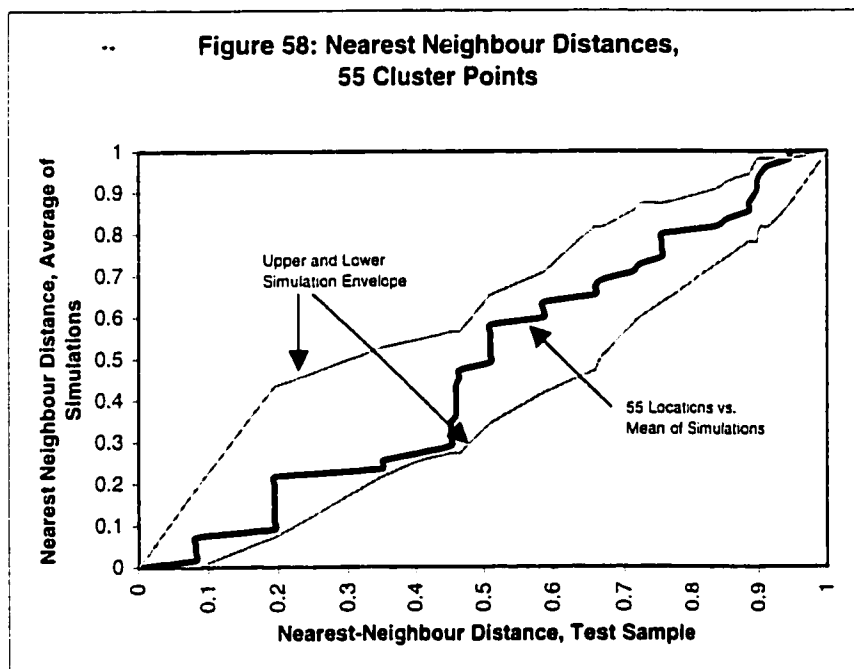
**Figure 56: Point to Nearest Neighbour Distances,
552 Sample Locations**

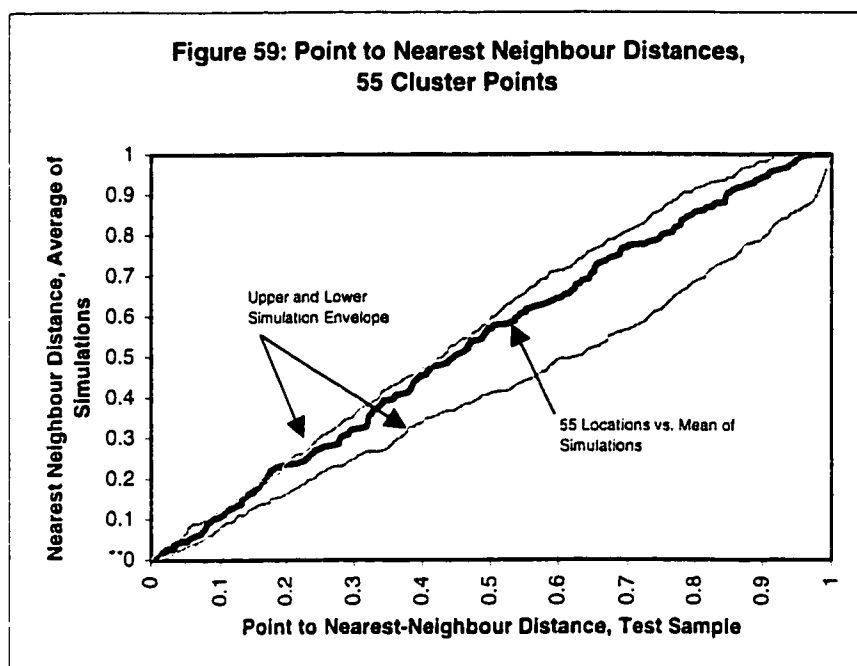


**Figure 57: Point to Nearest Neighbour Distances,
165 Unique Locations**



The results of the nearest neighbour and point to nearest neighbour tests (this will be discussed in Section 5) warranted further analysis of the data set, but only considering cluster centers. The 165 unique locations were assigned to 55 clusters using the “Partition Around Medoids” algorithm (Kaluzny, 1996), where 55 clusters of average sample size 3, grouped together due to close proximity, were chosen to reduce the amount of clustering in the database seen in Figure 47. The nearest neighbour and point to nearest neighbour tests were done on these 55 clusters, where 30 randomly selected data sets of 55 points from the AEUB battery database were chosen for each analysis. The results of the testing are plotted in Figure 58 for the nearest neighbour test, and Figure 59 for the point to nearest neighbour test.





4.28.2 Individual Site Categories

The nine site categories were reviewed in relation to the total flare pit database for their ability to represent the entire database, and their randomness. A combination of graphs of location coordinates and maps were produced for each site category and are found in Appendix 10.

Category A samples are represented in Figures A10-1 to A10-3. Figure A10-1 is a graph of Category A Alberta location coordinates. Figure A10-2 overlays the location coordinates from Figure A10-1 on the location coordinates for Alberta sites in the total flare pit database. Figure A10-3 shows the location of Category A sites on a map of Alberta.

Similar sets of figures were prepared for Categories B to I. These are presented in Figures A10-4 to A10-27. Four additional figures were prepared for Category I samples that focus on specific contamination types. Figures A10-28 and A10-29 show the locations of Category IB and ID locations, respectively. Figures A10-30 and A10-31 overlays the location coordinates from Figures A10-28 and A10-29, respectively on the Alberta locations for the entire flare pit database.

The maps for each category were compared to Figure 1, the map of Alberta with the entire flare pit database. The graphs for each category were compared to Figure 47. In both cases, the distribution of sites within a single category was assessed to identify if the sites could be considered representative of the entire flare pit database.

5.0 Results and Discussion

5.1 Database Chemical Parameters

There are 20 chemical parameters in Table 2 that have numerical criteria to describe maximum allowable regulatory limits for remediation and disposal. Figures 2 to 41 provide details on their concentrations. The following three sections discuss these figures as they relate to metals, hydrocarbons and salinity parameters.

5.1.1 Metals

Figures 2 to 25 demonstrate the range of concentrations present for the 12 metals in the database. Metal concentrations were available for approximately 100 of the 616 samples in the database. The comparison of the regulatory guidelines with background concentrations of metals and toxicity information indicates, that in most cases, there is a range between the background levels and the regulated levels, where regulated levels are a minimum of two times the background level. Exceptions were noted with barium, cobalt and nickel, where regulatory levels seemed to be conservative. In all three cases, the regulatory level was from AB Tier 1 which is not published with supporting documentation, and only limited studies on the toxicity of the three metals were provided in Section 4. Therefore, it is only speculated that the limits for these three metals as stipulated in AB Tier 1 are overly conservative.

Vanadium and cobalt were the only metals where all samples tested did not exceed the criteria for AB Tier 1 or CCME SQG. Seven of the twelve metals, arsenic, cadmium, copper, lead, molybdenum, nickel and zinc, had some samples tested that exceeded the AB Tier 1 or CCME SQG maximum allowable concentrations. None of these seven metals had concentrations in any samples that exceed the AUGFWM maximum concentrations for hazardous waste disposal. Two metals, barium and chromium, had samples with concentrations that exceeded the AB Tier 1 or CCME SQG maximum allowable concentrations. In addition, 12 of the barium samples and one of the chromium

samples also exceeded the AUGFWM maximum concentrations for hazardous waste. Mercury was the only metal present in samples with concentrations that exceeded the AB Tier 1 or CCME SQG maximum allowable concentrations, but in all cases also exceeded the AUGFWM maximum concentrations for hazardous waste.

From this data, it appears that metal concentrations can be expected to exceed the regulatory criteria for ten of the twelve metals reviewed. An exceedance is least likely to be associated with vanadium and cobalt. Such sites would be classified as “no concern” as metal concentrations are not greater than CCME SQG or AB Tier 1. Exceedances that classify a site as “medium concern” since they are greater than CCME SQG or AB Tier 1 are most likely to be associated with arsenic, cadmium, copper, lead, molybdenum, nickel and zinc. All of these metals can be present in crude oil and are often associated with the oilfield chemicals used as part of operations. Exceedances that classify a site as “serious concern” since they are greater than the AUGFWM are most likely to be associated with barium, chromium and mercury. Barium is present in formations and is brought to surface during production. It is also a component of many drilling muds, which were traditionally disposed of at the drilling site by placement into a pit or spreading on lease. Chromium is typically found in oilfield chemicals used as part of general site operations. Mercury, as discussed earlier, is expected to be present at many sites due to the use of manometers.

These results are similar to Green’s (1997) findings where the largest number of samples exceeding a metal concentration was associated with mercury. Mercury was found in 24 samples of this flare pit database at concentrations exceeding both the CCME SQG and the AUGFWM. However the largest number of exceedances was associated with barium. 32 samples exceeded the AB Tier 1 maximum concentration, and 12 of these samples also exceeded the AUGFWM maximum concentration in hazardous waste. Large exceedances of the AB Tier 1 or CCME SQG concentrations were also associated with

arsenic in 19 samples, chromium in 16 samples, nickel in 15 samples, lead in 15 samples and zinc in 14 samples.

For all twelve metals, the initial figure showing the relative and cumulative frequency distributions for concentrations in samples from the database (Figures 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24) indicates that they are not normally distributed. The second figure shown for each metal (Figures 3, 5, 7, 9, 11, 13, 15, 17, 19, 21, 23, 25) provides the relative and cumulative frequency distributions for the concentrations after a log transformation. In all cases, the log transformed data show a normal distribution. The QQ plots for the metals, shown in Figures A4-1 to A4-12 indicate that the log normal transformation is appropriate for the data sets to achieve a normal distribution. Exceptions are noted with cadmium, mercury and molybdenum, where the line describing the relationship between the transformed data set values and the normal distribution quantiles shows erratic behavior.

It is not expected that the chemical parameters would have a normal distribution, as the components of a normal distribution do not necessarily apply to environmental data. In a normal distribution, the data is symmetrical about the mean and the tails extend to infinity in both a negative and positive direction (McBean and Rovers, 1998). The smallest number expected in the database for a given chemical parameter is not detectable, or below method detection limit. Even in these cases, it is not possible to have negative values for the chemical parameters monitored in the database, so achieving a normally distributed data set is also not likely. The lognormal distribution is more likely to be adequate in describing the chemical parameters in the database since it does not accept values less than zero but still preserves an infinite upper limit (McBean and Rovers, 1998).

5.1.2 Hydrocarbons

Figures 26 to 35 demonstrate the range of concentrations present for the five hydrocarbon parameters in the database. The low regulatory limits on BTEX are attributed to potential and confirmed human health impacts, so some degree of conservatism is expected when setting permissible values in soils. The hydrocarbon regulatory guideline in AB Tier 1 is conservative in consideration of research completed in the area of total hydrocarbon toxicity. In the three soil and waste guidelines used in this research, hydrocarbons are only considered in AB Tier 1 which is published without supporting documentation. Extensive research on ecological toxicity of total hydrocarbons has been completed in relation to upstream production wastes, which is supportive of higher levels of hydrocarbons in soils.

BTEX concentrations were evaluated for approximately 100 of the 616 samples in the database, while total hydrocarbons were tested using a variety of analytical techniques on almost 500 samples, or 79% of the database. Benzene, toluene, ethylbenzene, xylene and total hydrocarbons were all present in samples at concentrations that exceed the AB Tier 1 or CCME SQG concentrations. Toluene, ethylbenzene and xylene were all present in samples at concentrations that exceed the AUGFWM maximum concentration in hazardous waste.

Of those samples tested for BTEX compounds, greater than 50% of the samples had concentrations that exceeded the CCME SQG. The percentage of samples analyzed that did not meet the CCME SQG ranges from 59 to 77% for the four compounds, with an average of 70%. For these same samples, the percentage analyzed that exceeded the AUGFWM maximum concentration for hazardous waste ranged from 0 to 3.6% for the four compounds. In both cases, the percentage ranges are not extensive, indicating some similarity amongst the samples.

Total hydrocarbons were tested in 485 samples in the database. Of these, 303 samples or 62%, exceeded the AB Tier 1 criteria for total hydrocarbons. These findings are consistent with Green (1997), where more than half of the samples reviewed exceeded the AB Tier 1 total hydrocarbon criteria.

From this data, it appears that BTEX and hydrocarbon concentrations can be expected to exceed the regulatory criteria in more than half of the samples tested. This is not unexpected since the primary components in crude oil and natural gas are hydrocarbons including the BTEX molecules, and their presence in flare pits is expected. Green (1997) indicated that about 60% of all flare pits will not meet the AB Tier 1 maximum allowable concentration for hydrocarbons, which is consistent with the findings in this database. The low number of samples analyzed for BTEX would merit further sampling and analysis to identify if the 70% exceedance of CCME SQG trend shown in this database is applicable to the total population of flare pits.

Figures 26, 28, 30, 32, 34, showing the relative and cumulative frequency distributions for concentrations of hydrocarbons in samples from the database, indicate that they are not normally distributed. Figures 27, 29, 31, 33 and 35 provides the relative and cumulative frequency distributions for the concentrations after a log transformation. In all cases, the log transformed data show a normal distribution or a distribution that tends toward normal. The QQ plots in Figures A4-13 to A4-17 indicate that the BTEX values all show the same departure from a normally distributed data set.

5.1.3 Salinity and pH

Figures 36 to 41 demonstrate the range of levels present for pH and the two salinity parameters (EC and SAR) in the database. Consistent with the hydrocarbon data, these three parameters were evaluated in a large percentage of the samples in the database. EC was the most commonly tested chemical parameter in the entire database, with data

available for 537 samples. SAR and pH data was available for 348 and 426 samples, respectively. EC, SAR and pH were all present in samples at levels that exceed the AB Tier 1 criteria. None of these three parameters were considered in the CCME SQG. The pH levels tested in the samples were all within the range required by the AUGFWM for non-hazardous waste.

Of those samples tested for pH, 20% did not fall within the range stipulated by AB Tier 1. 9% of these samples were lower, while 11% were greater. Of those samples tested for EC and SAR, 46% and 52%, respectively, were greater than the maximum allowable level in AB Tier 1. These findings are consistent with Green's (1997), where just under half of the samples reviewed exceeded the AB Tier 1 criteria for salinity.

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Since a large number of samples in the database were analyzed for salinity and pH, it is likely that about 50% of flare pit samples will not meet the AB Tier 1 requirements for salinity as determined by EC and SAR, and that about 20% of the samples analyzed will not meet the AB Tier 1 criteria for pH. For the 20% of samples that are not expected to meet the pH range in AB Tier 1, it is equally likely that levels will be lower or higher than the range permitted.

Both Figure 36 and Figure 37, showing the pH data in non-transformed and log-transformed formats, are similar. Both figures tend toward a normal distribution, which is expected since pH is unlike all other chemical parameters in the database as the range 0-14 is a log scale. Figures A4-18 and A4-19 show that the log transformation does not change the distribution of the data.

Figure 38 for EC and Figure 40 for SAR indicate that the data is not normally distributed. The log transformed data sets in Figure 39 for EC and 41 for SAR indicate a normal

distribution. Figures A4-20 and A4-21 that the log transformed data set for both parameters does not follow a strong normal distribution.

5.2 *Significance of the Database*

The database takes into consideration the diversity of environmental conditions throughout the province by representing such a large geographical area. Site details discussed in Section 4.27 also demonstrate the variability in the database. Sites producing oil and gas at wells, satellites, batteries and gas plants are all represented in the database. The database is the largest database available describing flare pit characteristics to date, and it incorporates the information from previous studies on this topic.

It is critical to determine if the database can be considered representative of flare pits in Alberta. The map in Figure 1 shows very obvious clustering in certain areas. This would be expected as oil and gas reservoirs are not distributed evenly throughout the province. Therefore, the likelihood of production activities happening in one location is not equal to the chances of production activities being carried out in another geographic location. Figure 47 confirms that there is definite clustering of site locations in some areas. As seen in Figure 46, this is the case with all oil and gas activities in the province, as evidenced by the obvious clustering of sites throughout the graph. It would be expected to have clustering shown in Figure 47, as the database is representative of seven producers who operate in defined geographic regions. In many cases, multiple samples were taken at site locations, increasing the density of information available for specific areas.

Figure 49 combines the data from Figures 46 and 47. Figure 49 clearly demonstrates that the areas where clustering is identified is present for both data sets. The distribution pattern of locations is also very similar for both data sets. Figure 1, which is another way of presenting the information in Figure 47, shows that the sample locations follow a

specific pattern. There is a strong band of samples in a diagonal direction from Lethbridge to Grande Prairie that runs parallel with the mountains, a cluster of samples in the central Alberta area, extending north, east and west of Edmonton, another cluster of samples in the north central region and a few samples in the far north west corner of the province.

The AEUB battery database only represents battery sites. It could be assumed that wells are indirectly represented, since wells in an area are typically tied into a central battery. The AEUB database might be considered to contain location information that is representative of the central area of a production field. Since site activity information is available for the flare pit database, the locations identified as batteries were extracted to use for comparison purposes. The 225 samples taken from battery sites in the flare pit database are plotted in Figure 48. The figure shows clustering similar to Figure 57, but it is less prominent since less than half of the locations from the database are from batteries. Figure 50 combines the data from Figure 46 and Figure 48. Figure 50 also demonstrates that the areas where clustering is identified is present for both data sets, but some of the major areas of clustering from the AEUB database are sparsely represented in the battery sites from the flare pit database. The distribution pattern of locations is again very similar for both data sets.

The results of the quadrant intensity analysis provide further evidence that the flare pit database is representative of the population. The relative and cumulative frequency distribution in Figure 51 and 52 show tremendous similarity in distribution. The cumulative percentage for both databases indicates that quadrant intensities are concentrated in the lower ranges and are sparsely represented in the upper ranges. Figure 51 showing the intensity information for the flare pit database has the largest number of quadrants in the lowest intensity range, and shows that no quadrants exceed an intensity of 80. Figure 52 showing the intensity information for the AEUB battery database has

almost equivalent quadrants in the lowest and second lowest intensity range, with slightly more in the 100-200 range. Unlike the flare pit database, Figure 52 has 3 quadrants with an intensity greater than 900 and one quadrant with an intensity greater than 1000. The longer right tail in Figure 52 is the primary difference between the two figures.

Figure 53, which shows the 165 unique geographical locations in the flare pit database continues to demonstrate clustering, which would indicate that the locations are not representative of the population. The nearest neighbour and point to nearest neighbour tests were completed to review clustering. A data set that is considered representative of the population, and therefore does not exhibit clustering, will have its nearest neighbour distances compared to the average simulation nearest neighbour distances fall within the upper and lower boundary of the simulation envelope. A data set showing clustering will exceed the upper boundary of the simulation envelope as there will be a large number of small nearest neighbour distances in a highly clustered sample. Figure 54 shows that the 552 sample locations are clustered and therefore cannot be considered to be representative of the population. Figure 56 is similar to Figure 54, as it also shows that the 165 unique geographical locations in the flare pit database are not representative of the population. Contrariwise, Figure 58 identifies that the cluster centers of the flare pit database are considered a random sample from the population, and can be considered to be representative of the flare pit population.

Point to nearest neighbour distances for a sample set compared to the mean simulation values will fall within the upper and lower boundary of the simulation envelope. A data set showing clustering will fall below the lower boundary of the simulation envelope, as there will be a large number of clusters, significant space in between clusters and a higher probability of a random point falling between two clusters. Similar to Figures 54 and 56, Figures 55 and 57 identify that the sample sets of population size 552 and 165 are clustered. As in Figure 58, Figure 59 identifies that the cluster centers are considered a

random sample of the population based on point to nearest neighbour distances, and these 55 points can be considered representative of the population.

5.3 *Significance of Each Site Category*

As shown in Table 3, a total of nine site categories (Category A to Category I) can be used to describe the entire database, while six of the categories (Category A, B, C, F, H, I) can be used to describe 96% of the database. Section 5.3.1 to 5.3.9 discuss all nine site categories in detail.

5.3.1 Category A Sites; Sites With No Concern

Just over 27% of the database, or 168 samples, met the requirements for site Category A making it the largest category in the database. This would imply that about 27% of all flare pit sites in Alberta will meet the soil requirements for CCME SQG for agricultural sites and AB Tier 1, and therefore would not require remediation. 51 samples, or 30.4% of Category A, had soils with clay content, which may indicate that the clay assisted in preventing contamination migration. 27% Category A may be a low estimate of the total flare pit population, based on the discussion in Section 3 that described how some of the data was gathered. If the underlying reason for the majority of site analysis was to review the sites perceived to contain the most contamination, then the distribution of samples may be skewed toward the more contaminated site categories. The primary reasons provided for site analysis discussed in Section 3 indicate that less than half of the database sites were analyzed due to the belief that they were the most highly contaminated sites owned by a producer. 27% Category A may also be a high estimate, due to a lack of analytical details on so many samples in the database. If complete analytical details were available for each sample in the working database, especially in the areas of metals and BTEX concentrations, there may be even fewer samples meeting the Category A criteria.

Category A site locations in Alberta, as seen in Figures A10-1 to A10-3, cover a large section of the oil and gas producing regions of the province. This type of location distribution is expected with this many samples. There is no reason why certain areas would be less likely to achieve Category A status, since local background conditions do not provide major interference. Exceptions to this were not noted in site analysis reports.

Figure A10-1 is similar in distribution to the entire flare pit database, which is supported by Figure A10-2. Category A samples are located in all major clusters, but are lacking the concentration in cluster areas that is evident when reviewing the entire database. Figure A10-3 is mostly consistent with the patterns shown in Figure 1. It has sample clusters in all main areas of the province as described in Section 5.2.2, but has lower population density.

5.3.2 Category B Sites

Just over 16 %, or 101 samples, met the CCME SQG for agricultural sites and AB Tier 1 for all parameters except hydrocarbons and/or BTEX, making them site Category B. 24 of the Category B sites, or 23.8% of Category B, exceeded one or more of the BTEX levels. 10 of these 24 sites only exceeded one or more of the BTEX levels, while the other 15 sites had a combination of high BTEX levels and high hydrocarbon levels. 36 samples, or 35.6% of Category B, had soils with clay content. Hydrocarbons were analyzed using various methods, but data was available for a large percentage of samples in the database. However, BTEX information barely made the 15% cut-off when forming the working database.

Figures A10-4 to A10-6 show the location of Category B sites in Alberta, which cover a large section of the oil and gas producing regions of the province. Figure A10-4 is similar in distribution to the entire flare pit database, which is supported by Figure A10-5. Category B samples are located in all major clusters as shown in Figure A10-6, but are

lacking the concentration in cluster areas that is evident when reviewing the entire database.

5.3.3 Category C Sites

Just under 13%, or 80 samples, met the CCME SQG for agricultural sites and AB Tier 1 for all parameters except pH and/or EC and/or SAR, making them a Category C site. 16 of the Category C sites, or 20% of Category C, do not meet the pH criteria in Alberta Tier 1. 8 of these 16 sites only have a problem with pH, while the other 8 sites had a combination of pH and salinity problems. 28 samples, or 35% of Category C, had soils with clay content. Data on pH, EC and SAR was available for a large percentage of samples in the database.

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Category C site locations in Alberta are located throughout the oil and gas producing regions of the province, as seen in Figures A10-7 to A10-9. Certain areas might be less likely to achieve Category C status since some portions of the province have naturally high salinity conditions. This is reflected when comparing Figure A10-9 and Figure 1, as very few Category C sites are concentrated in the Lethbridge and Grande Prairie regions, which are often associated with highly saline soils (Agriculture Canada, 1988).

Figure A10-7 is similar in distribution to the entire flare pit database, which is supported by Figure A10-8. Figure A10-9 shows that Category C samples are located in all major clusters, but are lacking the concentration in cluster areas that is evident when reviewing the entire database.

5.3.4 Category D Sites

Almost 1%, or 6 samples met the CCME SQG for agricultural sites and AB Tier 1 for all parameters except metals, making them site Category D. 3 samples, or 50% of Category D, had soils with clay content. Even though this category is insignificant in comparison

with other sample categories, it remains in the database until more statistical evidence can determine if the category is relevant to flare pit sites

Category D site locations in Alberta, as seen in Figures A10-10 to A10-12, cover a very small portion of the province. Figures A10-10 and A10-11 show that there is some clustering in major oil and gas producing areas. Category D samples shown in Figure A10-12 exhibit the diagonal distribution parallel to the mountains that is consistent with the entire database.

5.3.5 Category E Sites

Almost 3%, or 17 samples met the AB Tier 1 salinity parameters only, making them site Category E. 6 samples, or 35.3% of Category E, had soils with clay content. This category is considered insignificant in comparison with other sample categories, but it remains in the database until more statistical evidence can determine if it is relevant to flare pit sites

Similar to Category D, Category E site locations as seen in Figures A10-13 to A10-15, cover a relatively small portion of Alberta. Figures A10-13 and A10-14 show that there is some clustering in major oil and gas producing areas. Figure A10-15 shows that the few Category E samples do exhibit the distribution characteristics that are evident in Figure 1.

5.3.6 Category F Sites

The second largest site category represents just over 25%, or 158 samples, that do not meet the CCME SQG for agricultural sites and AB Tier 1 for a combination of one or more of the salinity and the hydrocarbon parameters, making them a Category F site. 8 of the Category F sites have pH as their only salinity problem, while 17 of the Category F sites have pH and another salinity parameter exceed the levels. 21 of the Category F sites have elevated BTEX levels along with elevated hydrocarbons, while 4 sites have elevated

BTEX as the only hydrocarbon problem. 18 of the F sites have a combination of specific BTEX elevations and pH problems. 65 samples, or 41.1% of Category F, had soils with clay content.

Category F site locations in Alberta cover a large section of the oil and gas producing regions of the province. Figure A10-16 is similar in distribution to the entire flare pit database, which is supported by Figure A10-17. Figure A10-18 is mostly consistent with the patterns shown in Figure 1 but exhibits lower population densities.

5.3.7 Category G Sites

Almost 2%, or 11 samples, met the CCME SQG for agricultural sites and AB Tier 1 hydrocarbon parameters only, making them site Category G. 4 samples, or 36.4% of Category G, had soils with clay content. Even though this category is insignificant in comparison with other sample categories, it remains in the database until more statistical evidence can determine if the category is relevant to flare pit sites.

Category G site locations in Alberta, as seen in Figures A10-19 to A10-21, cover a relatively small portion of the province. Only minor clustering in the oil and gas producing areas is shown in Figures A10-19 and A10-20. Figure A10-21 shows that the samples do exhibit the distribution characteristics of the total database, but have a primary cluster in the oil and gas producing region around Edmonton.

5.3.8 Category H Sites

Slightly more than 5%, or 32 samples, do not meet the CCME SQG for agricultural sites and AB Tier 1 criteria for a combination of one or more of the salinity and the hydrocarbon and the metal parameters, making them a Category H site. 8 of the Category H sites have pH as one of their salinity problems, while 8 of the Category H sites has BTEX as one of their hydrocarbon problems. 3 of the Category H sites have a

combination of specific BTEX elevations and pH problems. 11 samples, or 34.4% of Category H, had soils with clay content. This category borders on insignificant but remains in the database until more statistical evidence can determine if Category H is relevant to flare pit sites.

Category H site locations shown in Figures A10-22 and A10-23 tend to cluster in many sections of the oil and gas producing regions of the province. Figure A10-24 shows that the locations of Category H samples exhibit clusters in the primary areas where the total flare pit database tends to cluster.

5.3.9 Category I Sites

Just under 7%, or 43 samples, do not meet the WCR limits for metals and/or BTEX. 6 of the sites have BTEX as their primary problem (Category I, B), 36 of the sites have metals as their primary problem (Category I, D), while the remaining 1 site has a combination of metals and hydrocarbon issues (Category I, E). Of the 36 sites having high metals, 9 of them meet the WCR pH requirements, but do not meet the requirements in AB Tier 1 for pH. 38 samples, or 88.4% of Category I, had soils with clay content.

Figures A10-25 and A10-26 show that there is clustering of Category I samples in the oil and gas producing areas of the province. The samples on the map of Alberta in Figure A10-27 lack clustering in the Edmonton, Zama and north central Alberta areas. Figure A10-28 shows that the 6 sites designated as I,B cluster in one region of the oil and gas producing areas of the province, which is confirmed in Figure A10-30. Sites highly contaminated with BTEX would not be expected to follow a certain geographical distribution, since the opportunity for hydrocarbon introduction to soil is equivalent in all geographic areas. Figures A10-29 and A10-31 shows that the 36 sites designated as I,D cluster in several regions of the oil and gas producing areas of the province. Many of the Category I,D samples had high levels of mercury, and such sites might be expected to

follow a specific distribution, since natural gas is more prominent in certain regions of the province (Oilweek, 1998).

5.4 *Significance of Site Details and Site Category*

5.4.1 Produced Hydrocarbon

Table 4 shows that the produced hydrocarbon data is evenly distributed for most sites, with a ratio of gas to oil ranging from 1.47 to 3. The exception is Category I sites, where there are significantly more samples at sites producing gas than at sites producing oil and this ratio is 8.5. From this database, there appears to be a relationship between gas producing sites and highly contaminated sites. This may be attributed to the differences in producing gas versus oil or the differences in hydrocarbon chain length typically present at a gas versus oil production site.

The results of hypothesis testing identified that two of the four expected relationships were actually exhibited by the data. Table A5-1 does not support the findings in Table 4 that would indicate that total equivalent metals are greater at sites producing gas compared to sites producing oil. Table A5-2 identified that the sample sets for total hydrocarbons, EC, total equivalent metals and mercury had unequal variances, while the sample set for total BTEX had an equal variance. In Table A5-3, the t-test results identified that the concentration of total hydrocarbons at sites producing oil was significantly greater than at sites producing gas. This was expected based on the composition of crude oil compared to natural gas, where larger chain hydrocarbons are expected to be present in crude oil which are more difficult to degrade. Table A5-3 also shows that the concentration of mercury was significantly greater at sites producing gas compared to sites producing oil. This relationship was expected based on the use of mercury manometers for gas measurement. Concentrations of total BTEX, EC and total equivalent metals were not significantly different at sites producing gas compared to sites

producing oil based on t-test results. While sample set averages supported the first two hypotheses, the t-tests did not determine that such differences were significant.

By applying these results to the entire flare pit population in Western Canada, it should be expected that the magnitude of total hydrocarbon and mercury contamination would be related to produced hydrocarbon.

5.4.2 Activity

Site activity data is consistent for most site categories, with a ratio of well sites to battery sites ranging from 0.7 to 3.7 in Table 4. The categories having a higher ratio of well sites to battery sites are H and I, both of which have high to extremely high amounts of multiple contaminants. There appears to be a relationship between well sites and highly contaminated sites which may be attributed to the higher likelihood of well sites being unattended, and therefore susceptible to longer periods of process upsets or site trespassing.

Two of the four expected relationships were actually exhibited by the data when analyzed using t-tests. Table A6-1 supported only the initial hypotheses that total equivalent metals are greater at well sites. The sample set for total hydrocarbons had an unequal variance, while sample sets for total BTEX, EC and total equivalent metals had equal variances as shown in Table A6-2. The t-test results in Table A6-3 identified that the concentration of total hydrocarbons and total BTEX at well sites was significantly greater than at battery sites. This was expected since attendance is expected to be less at wells versus batteries. Operators at batteries are also more likely to be able to quickly address spills or process upsets to minimize hydrocarbon release and address site clean-up quickly. Well site upsets may be more difficult to travel to for containment and site clean-up, allowing for more hydrocarbon to be released to the environment. Table A6-3 also identified that the concentration of EC and total equivalent metals was not

significantly different at well sites compared to battery sites. While sample set average for total equivalent metals supported this hypothesis, the t-test did not determine that such differences were significant.

It should be expected, based on these results, that the magnitude of total hydrocarbon and total BTEX contamination would be related to site activity in the total population of flare pits in Western Canada.

5.4.3 Age

There does not appear to be any relationship between site age and site category shown in Table 4. Many of the categories have more sites in the earlier years, but this may reflect the response to recent regulatory initiatives to stop the use of flare pits, better environmental practices in more recent years and sufficient time for bioremediation of highly contaminated sites from older operations.

Hypothesis testing identified that one of the three expected relationships were actually exhibited by the data. Table A7-1 sample set averages support the initial hypotheses that total BTEX and EC levels are greater at sites built after 1975. Table A7-2 identified that the sample sets for total BTEX and EC had equal variances, while the sample set for total equivalent metals had an unequal variance. The t-test results in Table A7-3 show that the EC levels were significantly greater at sites built after 1975 than at sites built before and including 1975. This was expected since salinity components are mobile, and after years of precipitation salinity levels may have had the opportunity to move out of the flare pit. Total BTEX and total equivalent metals were shown to not be significantly different at sites built after 1975 compared to sites built up to and including 1975 based on t-test results.

Since the relationship between EC level and construction date was determined to be significant, it would be expected that this relationship would apply to the entire flare pit population in Western Canada.

5.4.4 Soil Type

There is some relationship with clay content and contamination type shown in Table 4, as Category I followed by Category D and Category F samples had the highest percentage of clay content in their samples. Category I and F samples have multiple contamination types present, indicating that it might be more difficult to remediate these sites due to soil handling. Any benefits of the clay content are not seen in the data, but sampling of groundwater around the site may indicate that the high level of contaminants only impacted the soil quality. For the soil type data available, Category F and I sites had a significantly larger number of sites containing clay soil versus sites not containing clay, compared to other site categories. The highest number of samples having non-clay soils was Category A.

Only one of the three expected relationships was actually exhibited by the data after hypothesis testing. Table A8-1 supports the initial hypotheses that total hydrocarbons, EC and total equivalent metals are greater at sites containing some clay content compared to sites having little or no clay content. Table A8-2 identified that the sample set for total hydrocarbon has an equal variance, while the sample sets for EC and total equivalent metals had unequal variances. In Table A8-3, the t-test results identified that the EC levels were significantly greater at sites containing clay soils. This was expected since salinity parameters are mobile, but clay provides better retention of chemicals compared to sandy soils. Table A8-3 also identified that the concentration of total hydrocarbons and total equivalent metals was not significantly different at sites containing clay soils compared to sites having little or no clay content.

It should be expected that EC levels in all flare pits will be related to both site age and clay content in soils.

5.4.5 Pit Contents

Data on pit contents is concentrated in Categories A, B, C, and F. The data does not point to any relationships between the presence of brine and Category C sites, or the presence of emulsion and Category B sites. More information on pit contents is required to determine if it has any impact on the type and concentration of contaminants found in the flare pit sludge. The information would also have to be better qualified so subjectivity could be eliminated from this descriptive parameter. For example, samples of pit contents should be taken and analyzed for oil and salinity content so the material can be properly characterized.

5.4.6 Pit Observations

Pit observation data is not available for any of the D and E sites. The observation of oil stained soil did not appear to have an impact on site category, since 31 of the Category A sites and 13 of the Category C sites had oil stained soil and both categories do not have an issue with hydrocarbon levels. Collectively, Categories B, F, H and I have 38 sites with oil stained soil and all of these sites do have an issue with high hydrocarbon levels. The other two observations of poor vegetation growth and poor vegetation growth combined with oil stained soil are distributed almost equally across the 6 categories. Ideally, more information on pit observations including these and other observations may produce some relationships between the observed phenomena and pit category.

5.4.7 Management Technique Suggested

A variety of management techniques including remediation were suggested for treatment of different sites, based on the company's or consultants opinion on the best way to handle the site contaminants. The most commonly recommended remediation method

was land treatment, where it was considered appropriate for a total of 152 sites covering Categories A through I. Suggestions for land treatment were most common for Category A, F, and B sites, which collectively represent 111 samples, indicating that there is some confidence in the ability of land treatment to handle both hydrocarbon and salt levels in sludge. Land treatment was recommended for 17 Category I sites, which had very high levels of metals and/or hydrocarbons. The second most commonly recommended method of management was backfill, where it was considered appropriate for a total of 70 sites covering Categories A through I. Suggestions for backfill were most common for Category A, B, F and I, which collectively represent 52 samples, indicating that there is some confidence that simply filling in the pit with clean soil will suffice for contamination management. The third most commonly recommended remediation technique was to leave the pit alone. This suggestion was made for a total of 36 sites, 30 of which are Categories A and B, 6 of which are Categories C, D, E and I.

Air sparging was recommended for two sites, both of which were Category B. Biopiles or composting was suggested for 21 sites, which represented Categories A, B, C, F, G, H, and I. Incineration or landfill was recommended for 16 sites which included Categories C, F, G, H and I. Landfill was suggested for 6 sites including site Categories C, F and I. A combination of landfill and land treat was recommended for 9 sites including site Categories B, F and H. Leaching was recommended for 14 sites, which include site Categories C, E, F, G and I. Thermal treatment was suggested for 12 sites including site Categories C, E, F, G and I.

Underlying reasons for these suggestions are not known, so the “management technique suggested” parameter is considered to be subjective and further analysis of the information is inappropriate.

5.4.8 Site Management Completed

Even though there were many suggestions for management or remediation of the various sites, only four methods have been used on the samples in the database, based on the flare pit assessment reports from producers. Backfill was recommended for 70 samples and it was completed for 39 samples. The activity was carried out for almost all categories. This is a very simple way of handling site remediation, which might explain why it was carried out in so many situations. However, some of the pit categories were those with very high levels of multiple types of contamination, which might make the suggested remediation method of backfill inappropriate. Land treatment was recommended for 152 samples and was completed for 33 samples. The activity was carried out for almost all site categories but was more prevalent for sites having only one type of contamination or sites not having metal contamination. For the 36 samples where it was recommended to leave the site alone, it was continued to be used most likely with modifications to the flare line and associated infrastructure rather than the flare pit material. Landfill disposal of flare pit sludge was not carried out even though it was suggested alone or in combination with other treatment and disposal options. None of the other biological treatments were carried out on the samples, nor were technologies such as leaching, thermal treatment or air sparging used. This may be due to inexperience or lack of conclusive, positive results from other trials.

The information in this section is considered incomplete since it is likely that other sites in the database have been addressed in addition to the 108 samples that were managed without mention of the technique used. Therefore, the data on the total number of sites remediated or otherwise addresses will continually evolve, along with data on the technique used.

5.4.9 Location According to Public Land Use Zone

Table 5 provides details on the number of samples of each category located in each land use zone. The table also provides information on the percentage of each zone that is represented by each category. A comparison of the percentage details shows that the difference in percentage of each category is very low in most cases, with three percent or less difference between two numbers for each site category. The two exceptions to this observation are Category A and I samples which differ by 6.7 and 13.3%, respectively between the “white zone” and “green zone”. There are significantly more Category A sites in the “white zone” compared to the “green zone”, while there are significantly more Category I sites in the “green zone” compared to the “white zone”.

A review of the Category I sites for specific types of contamination revealed that there were significant differences between the two land use categories. Of the eight “white zone” Category I samples, five had metal contamination while three had BTEX contamination. Barium was the primary metal contaminant, present at elevated levels in four of the five sites, while mercury was elevated in the fifth sample. Both oil and gas were produced at the samples having high metal contamination, while only gas was produced at the white zone samples having high BTEX levels. Of the 35 “green zone” Category I samples, one had contamination from both BTEX and metals, three samples had elevated BTEX, while 31 samples had elevated metals. Of the 31 “green zone” samples having elevated metals, seven had elevated barium, one had elevated chromium, while 23 had elevated mercury. All of the samples contaminated with mercury were gas producing. 30 out of 35 green zone Category I samples had gas as the primary hydrocarbon, while the five oil producing samples were all contaminated with barium.

This comparison between “white zone” and “green zone” site contamination indicates that mercury contaminated soils at natural gas facilities may be an issue in the “green zone”. For both land uses, three of the total number of Category I samples had only

elevated BTEX levels, while a greater number of samples had elevated metals. A review of the distribution of produced hydrocarbon data for the two land uses indicates that 39% of the “green zone” samples were gas producing, while 58% of the “white zone” sites were gas producing.

The contributing reasons for this distribution cannot be directly determined from the database since very limited information is known about past practices at a site. It might be speculated that the higher number of samples meeting provincial and federal land use criteria in the “white zone” is a reflection of the population density in the “white zone” areas, and the public pressure placed on companies to maintain sites in compliance with environmental regulations. Similarly, the higher number of samples exceeding the AUGFWM criteria for hazardous waste located in the “green zone” may be a reflection of the lower population density in the area, and the more remote nature of the “green zone”, leading to less public and regulatory scrutiny of site operations.

5.5 Site Characterization Details Not Provided

This section describes four parameters, considered to be most important in terms of a complete site description that, if available for many of the sites in the database would provide a more in-depth overview of past operational practices and current management opportunities and constraints. While the working database is comprised of parameters considered significant based on the data set, some parameters available in the original database and listed in Appendix 1 would provide important additional details on a site related to historical operations and current site condition. There are parameters not listed in Appendix 1 but considered important for site management based on operational experiences and recent research into soil toxicity and remediation.

5.5.1 Detailed Hydrocarbon Analysis

As seen in Appendix 1, the use of analytical methods to quantify the presence of individual hydrocarbons and specific hydrocarbon chain length was limited to very few samples in the data set. This information is important in assessing the toxicity of the hydrocarbons present at a site, and provides much more insight into site characteristics compared to a total hydrocarbon value. The working database attempts to provide some insight into hydrocarbon contamination by providing data for total soil hydrocarbons and the BTEX molecules. The review of flare pits by Green (1997) considered only the hydrocarbon concentrations, but it was recommended that data on characterization of the hydrocarbons present be reviewed to assess human health impacts of flare pit sites.

Knowledge of the different hydrocarbon chain lengths present can provide more insight into site toxicity, as various impacts on soil health and remediation potential are related to the presence of hydrocarbons having short, medium and long chain lengths. For example, it is known that multi-ringed hydrocarbon structures are much more difficult to degrade than hydrocarbons having smaller, less complex structures (AEP, 1992). Understanding the relative amount of these types of hydrocarbons compared to the overall soil hydrocarbon content will influence the remediation plan, including time allotted for treatment and environmental controls required to enhance remediation efficiency.

The issue of assessing total hydrocarbons at a site has been discussed in earlier sections. The analytical method to determine the concentration of individual carbon fractions having up to 60 carbon atoms (C-60) provides the opportunity to obtain a total hydrocarbon value, the components of which can be explored to determine concentrations of light ends, heavy ends, and specific toxic fractions. It is recommended to standardize the manner in which hydrocarbons are being analyzed, and to use methods that provide additional data on the composition of the total hydrocarbon number. Several research

groups are presently looking at this issue. The primary focus of these research groups is on the toxicity of specific hydrocarbon fractions to determine risk-based remediation end points (PTAC, 1998).

Specific compound concentration is also important information since it can determine very specific human and environmental health risks. The BTEX data contained in this database is a start in this area, but the addition of information on specific polyaromatic hydrocarbons (PAH) known to be toxic to humans would be an asset in site assessment and management (Lou and Abboud, 1994). For example, the three PAHs included in the CCME SQG are Benzo (a) pyrene, naphthalene and phenol. They are included because they can severely impact both human and environmental health (CCME, 1997).

5.5.2 Sterilant Use

The use of sterilants such as aldrin and dieldrin at the flare pit sites was not well documented in the information gathered for the database (Appendix 1). Total pesticides and metabolites are limited in AB Tier 1 to a concentration of 0.1 ppm (AEP, 1994a). This is attributed to their toxicity to many different organisms besides the target organisms, their ability to be passed through and biomagnified in the food chain, and in some cases their resistance to biological metabolism due to their very large, multi-ring structures and often the presence of toxic chlorinated compounds (Brady and Weil, 1996). The knowledge that soil sterilants were used in the past may provide insight into areas of poor plant growth that don't visually appear to be highly contaminated. This type of investigation is recommended in cases where there is the possibility of priority pollutant sterilant use in the past, due to their toxicity to human and environmental health (AEP, 1992). Understanding sterilant application information such as type used, dates applied, locations applied and amount applied improves the knowledge about the site and can be considered during remediation efforts.

It was recommended in Green (1997) to include collection of sterilant data due to the potential for sterilants to have negative impacts on some remediation efforts.

5.5.3 Water Repellency

Soils have the potential to develop water repellent characteristics after being subjected to a hydrocarbon spill (Yeung, 1990). The same behavior also appears in soils that have been burned or amended with large amounts of peat (Yeung, 1990). For sites that were subjected to hydrocarbon spills, they often appeared to be recovering when studied over the short term, but over several years or decades the water repellent characteristics developed (Roy and McGill, 1995). Water repellent soils reduce or eliminate plant growth success, as precipitation does not penetrate soils or it is not retained by these soils (Li, Storey and Johnson, 1996). This phenomena has been observed in Alberta where such soils have a water repellent top layer that visually does not appear to contain hydrocarbons, and lower soil horizons that do contain measurable amounts of residual oil (Roy and McGill, 1995). The molarity ethanol droplet (MED) test was devised to measure the water repellency of soils (Yeung, 1990). Including this information during flare pit site characterization was recommended by Green (1997) and carried out in the CAPP bioreactor project (CAPP, 1997), as it can indicate if specific soil management and treatment techniques should be used to correct for this behavior (Roy and McGill, 1995). Research into reducing hydrophobicity in soils is currently being carried out, and is the focus of a PTAC research project (PTAC, 1998).

5.5.4 Presence of Naturally Occurring Radioactive Material (NORM)

The presence of NORM in oilfield wastes is an issue that has recently played an important role in site management. NORM is present in some formations and soluble NORM components such as radium and radium daughters are mobilized in the liquid phases of production fluid and brought to surface during production (Smith, 1992). The radionuclides either stay in solution due to their water solubility, or precipitate out into

the sludge and scale found inside vessels, piping and in flare pits (Western Canadian NORM Committee, 1995). This is a widespread issue that is known to affect oil and gas production sites in many countries (Western Canadian NORM Committee, 1995). Identifying the presence of NORM in a flare pit increases the number of remediation issues that must be managed when addressing a site. While the protection of worker health and safety must always be a consideration when planning site remediation, the introduction of a radiation hazard will require that activities are planned and carried out in accordance with the exposure limits set by provincial, federal and world-wide radiation protection organizations (Canadian NORM Working Group, 1998). General public and worker exposure to radiation is controlled based on risk assessment data related to increased incidences of cancer (Canadian NORM Working Group, 1998).

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The very long half lives and decay rates associated with some of the components of NORM may require that flare pit sites determined to contain NORM are managed in a manner similar to other oilfield wastes containing NORM, and treated as waste. This may imply that disposal techniques such as subsurface injection, encapsulation and landfilling rather than on-site bioremediation, land treatment or thermal treatment must be used due to the presence of low level radiation and the long term risk of exposure (Veil et. al., 1998). The AEUB is presently reviewing NORM disposal options with the goal of establishing guidelines for NORM management and disposal from upstream oil and gas sites. A radioactivity parameter should be incorporated in flare pit sludge assessment in areas known to contain NORM, so the amount of Radium 226, in Bq/g can be quantified and compared to concentration limits.

6.0 Conclusions and Recommendations for Future Work

The analysis and results of the flare pit database identified the following conclusions:

- The database in its entirety exhibits clustering and therefore is not considered a random sample of AEUB battery location database, chosen to represent the flare pit population. The cluster centers of the flare pit database were identified to be a random sample of the population. This knowledge forms the basis for all other conclusions as they consider the information in the database.
- The comparison of federal and provincial soil remediation guidelines for agricultural sites with research on individual parameter toxicity identified that most values are not overly conservative. Questionably conservative values were associated with barium, cobalt, nickel and total hydrocarbons, all of which originate from AB Tier 1.
- The concentration of chemical variables in the database exhibited specific behaviour:
 - Samples with metal concentrations exceeding soil remediation criteria were most often associated with arsenic, barium and mercury. Analytical data on metals was lacking for many samples in the database.
 - Greater than 60% of those samples analyzed for hydrocarbons exceeded the provincial soil remediation guidelines while a minimum of 59% of samples analyzed for BTEX compounds exceeded the federal soil remediation guidelines. Hydrocarbon analytical information was available for the majority of samples in the database but BTEX values were lacking for many samples.
 - Sample values for EC and SAR values exceeded the provincial soil remediation guidelines in 46% and 52%, respectively. Details on both EC and SAR were available for the majority of the samples in the database.
 - Samples having a pH value falling outside of the provincial soil remediation range occurred in 20% of samples. Data on pH was available for the majority of samples in the database.

- The data set for each chemical variable in the database exhibited a log-normal distribution, which was confirmed by tests for normality on the transformed data set.
- The database identified nine different flare pit categories:
 - Category A, no remediation required, represented 27% of the database.
 - 30 % of the database had elevated concentrations of only one contamination type, with 16% Category B, 13% category C and 1% Category D.
 - 35 % of the database had elevated concentrations of multiple contamination types, with 3% Category E, 25% Category F, 2% Category G and 5% Category H.
 - Category I, severely elevated metals and/or BTEX, represented 7% of the database.
- The location distribution pattern of larger site categories was similar to the total flare pit database, while smaller categories had too little data to identify significant trends.
- Hypothesis testing identified that 6 of the proposed 15 relationships were identified to be significant in the database:
 - Hydrocarbon concentrations were greater at sites producing oil compared to sites producing gas.
 - Mercury concentrations were greater at sites producing gas compared to sites producing oil.
 - Both hydrocarbons and BTEX were greater at well sites compared to battery sites.
 - Electrical conductivity values were greater at newer sites compared to older sites and at sites with greater clay content compared to sites not having clay soils.

- Land use in Alberta as defined by “white zone” and “green zone” areas showed an even distribution of all sites categories with two exceptions:
 - There were significantly more Category A sites located in the “white zone” compared to the “green zone”.
 - There were significantly more Category I sites located in the “green zone” compared to the “white zone”.

Future work in the area of flare pit characterization should aim to improve site characterization by targeting specific analytical and historical information. As a minimum, site characterization should include information on EC, SAR, TEH and four metals often associated with oilfield operations: lead, zinc, barium and mercury. Details on hydrocarbon chain lengths present, water repellant nature of the soils, evidence of sterilant use, and detection of NORM should be added to site information. Historical information on spills, open pit burning and other operational practices that cause specific contamination should also be included.

Site remediation details that show the effectiveness of remediation methods at sites should be included to identify where a remediation technique was successfully applied to specific contamination types. Category specific remediation data should be provided so the effectiveness of specific remediation techniques can be demonstrated for each flare pit category. Understanding the capability of different remediation techniques in reducing the contaminants in the various pit categories will provide a valuable management tool to those responsible for site remediation, as remediation methods chosen will be based on successful application to similar sludges.

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Appendix 1**Total Data Collected for the Initial Database**

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Appendix 1

Total Data Collected for the Initial Database

Initial Data Gathered	Number of Responses	% Responding
Location	608	98.70
Latitude	601	97.56
Longitude	601	97.56
Description	599	97.24
Borehole ID	595	96.59
White or Green Zone?	552	89.61
EC (mS/cm)	537	87.18
Hydrocarbons (ug/g and % as ug/g)	485	78.73
Hydrocarbon Type	481	78.08
pH	426	69.16
Pit Area	415	67.37
Pit Depth (m)	394	63.96
SAR	348	56.49
Soil Type	340	55.19
Remediation Suggested	338	54.87
Sampling Date	330	53.57
Hydrocarbons (ug/g)	299	48.54
Volume	277	44.97
Soluble Chloride (mg/L)	220	35.71
Remediation Completed?	220	35.71
Pit Contents	212	34.42
Zinc (ug/g)	200	32.47
Barium (ug/g)	198	32.14
Copper (ug/g)	197	31.98
Cadmium (ug/g)	195	31.66
Nickel (ug/g)	192	31.17
Lead (ug/g)	191	31.01
Chromium (ug/g)	189	30.68
Mercury (ug/g)	178	28.90
Saturation %	170	27.60
Vanadium (ug/g)	155	25.16
% oil	143	23.21
Construction Date	141	22.89
Arsenic (ug/g)	118	19.16
Observations	118	19.16

Molybdenum (ug/g)	116	18.83
Cobalt (ug/g)	116	18.83
Benzene (ug/g)	114	18.51
Xylene (ug/g)	111	18.02
Ethylbenzene (ug/g)	109	17.69
Soluble Calcium (mg/L)	105	17.05
Soluble Magnesium (Mg/L)	105	17.05
Soluble Sodium (mg/L)	105	17.05
Soluble Sulphate (mg/L)	101	16.40
Toluene (ug/g)	96	15.58
Soluble Potassium (mg/L)	95	15.42
Selenium (ug/g)	74	12.01
Thallium (ug/g)	66	10.71
Manganese (ug/g)	65	10.55
Strontium (ug/g)	63	10.23
Beryllium (ug/g)	60	9.74
Calcium (ug/g)	59	9.58
Magnesium (ug/g)	59	9.58
Potassium (ug/g)	59	9.58
Sodium (ug/g)	59	9.58
Extractable hydrocarbons (ppm)	56	9.09
Chloride (mg/kg)	53	8.60
Sulphate (mg/kg)	53	8.60
Sweet or Sour	51	8.28
Production Water	43	6.98
Boron, water soluble (ug/g)	41	6.66
headspace reading (ppm)	41	6.66
Extractables (C10-C30)	38	6.17
Crop growth	36	5.84
fluorene (ug/g)	30	4.87
phenanthrene (ug/g)	30	4.87
Sulphur (mg/kg)	30	4.87
EOX (ug/g)	29	4.71
benzo b&j fluoranthene (ug/g)	28	4.55
fluoranthene (ug/g)	28	4.55
naphthalene (ug/g)	28	4.55
benzo a anthracene (ug/g)	27	4.38
benzo a pyrene (ug/g)	27	4.38
chrysene (ug/g)	27	4.38
Extractables (C30+)	27	4.38

pyrene (ug/g)	27	4.38
3 methylcholanthrene (ug/g)	26	4.22
7, 12 dibenz a anthracene (ug/g)	26	4.22
acenaphthene (ug/g)	26	4.22
acenaphthylene (ug/g)	26	4.22
anthracene (ug/g)	26	4.22
benzo c phenanthrene (ug/g)	26	4.22
benzo g h l perylene (ug/g)	26	4.22
benzo k fluoranthene (ug/g)	26	4.22
dibenzo a h anthracene (ug/g)	26	4.22
dibenzo a h pyrene (ug/g)	26	4.22
dibenzo a j pyrene (ug/g)	26	4.22
dibenzo a l pyrene (ug/g)	26	4.22
ethanol (ug/mL)	26	4.22
Extractables (<C10)	26	4.22
i butanol (ug/mL)	26	4.22
i propanol (ug/mL)	26	4.22
indeno 1 2 3 cd pyrene (ug/g)	26	4.22
methanol (ug/mL)	26	4.22
acetone (ug/mL)	25	4.06
m cresol (ug/mL)	25	4.06
n butanol (ug/mL)	25	4.06
n propanol (ug/mL)	25	4.06
nitrobenzene (ug/mL)	25	4.06
o cresol (ug/mL)	25	4.06
p cresol (ug/mL)	25	4.06
Fluoride (ug/g)	21	3.41
Atrazine	19	3.08
Bromacil	19	3.08
HNu-Nanby (ppm)	14	2.27
Spills	14	2.27
Diuron	13	2.11
Debuthiuron	12	1.95
Linuron	12	1.95
Phosphorus (ug/g)	12	1.95
Tebuthiuron (mg/kg)	11	1.79
Arsenic (mg/L)	10	1.62
Barium (mg/L)	10	1.62
Boron (mg/L)	10	1.62
Cadmium (mg/L)	10	1.62

Chromium (mg/L)	10	1.62
Lead (mg/L)	10	1.62
Mercury (mg/L)	10	1.62
Selenium (mg/L)	10	1.62
Flash Point (C)	9	1.46
OVA (ppm)	9	1.46
Cyanide, water soluble (ug/g)	7	1.14
Total purgeables (1-12) (ug/g)	7	1.14
Aluminum (ug/g)	6	0.97
Bicarbonate (mg/L)	6	0.97
Biological Oxygen Demand	6	0.97
BTU Content (BTU/lb)	6	0.97
flammability	6	0.97
Free Liquid (%)	6	0.97
Iron (ug/g)	6	0.97
nitrate as N(mg/L)	6	0.97
nitrate/nitrite as N (mg/L)	6	0.97
particle size (%)	6	0.97
Silver (ug/g)	6	0.97
Sulfide (mg/L)	6	0.97
Titanium (ug/g)	6	0.97
Total Kjeldahl Nitrogen (ppm)	6	0.97
Total Organic Carbon (wt %)	6	0.97
Tungsten (ug/g)	6	0.97
Water (%)	6	0.97
Antimony (mg/L)	4	0.65
Beryllium (mg/L)	4	0.65
C10 (mg/kg)	4	0.65
C11 (mg/kg)	4	0.65
C12 (mg/kg)	4	0.65
C13 (mg/kg)	4	0.65
C14 (mg/kg)	4	0.65
C15 (mg/kg)	4	0.65
C16 (mg/kg)	4	0.65
C17 (mg/kg)	4	0.65
C18 (mg/kg)	4	0.65
C19 (mg/kg)	4	0.65
C20 (mg/kg)	4	0.65
C21 (mg/kg)	4	0.65
C22 (mg/kg)	4	0.65

C23 (mg/kg)	4	0.65
C24 (mg/kg)	4	0.65
C25 (mg/kg)	4	0.65
C26 (mg/kg)	4	0.65
C27 (mg/kg)	4	0.65
C28 (mg/kg)	4	0.65
C29 (mg/kg)	4	0.65
C30+ (mg/kg)	4	0.65
Chromium 6 (ug/g)	4	0.65
Cobalt (mg/L)	4	0.65
Copper (mg/L)	4	0.65
Iron (mg/L)	4	0.65
Nickel (mg/L)	4	0.65
Silver (mg/L)	4	0.65
Simazine	4	0.65
Thallium (mg/L)	4	0.65
Uranium (mg/L)	4	0.65
Vanadium (mg/L)	4	0.65
Zinc (mg/L)	4	0.65
Zirconium (mg/L)	4	0.65
1 1 1 trichloroethane (ug/g)	3	0.49
1 1 2 trichloroethane (ug/g)	3	0.49
2 butanone (ug/g)	3	0.49
2 nitropropane (ug/g)	3	0.49
4 methyl 2 pentanone (ug/g)	3	0.49
acetone (ug/g)	3	0.49
C8 (mg/kg)	3	0.49
C9 (mg/kg)	3	0.49
carbon disulphide (ug/g)	3	0.49
carbon tetrachloride (ug/g)	3	0.49
chlorobenzene (ug/g)	3	0.49
cresols (ug/g)	3	0.49
cyclohexanone (ug/g)	3	0.49
Diuron/Linron	3	0.49
ethyl acetate (ug/g)	3	0.49
ethyl ether (ug/g)	3	0.49
isobutanol (ug/g)	3	0.49
Methanol (ug/g)	3	0.49
methylene chloride (ug/g)	3	0.49
n butanol (ug/g)	3	0.49

nitrobenzene (ug/g)	3	0.49
pyridine (ug/g)	3	0.49
tetrachloroethene (ug/g)	3	0.49
Total Glycols (ug/g)	3	0.49
trichloroethene (ug/g)	3	0.49
Benzene (mg/l)	2	0.32
Ethylbenzene (mg/l)	2	0.32
Halogens (ug/g)	2	0.32
Ion Balance	2	0.32
Toluene (mg/l)	2	0.32
Xylene (mg/l)	2	0.32
Bromide, water soluble (ug/g)	1	0.16
Cyanazine (mg/kg)	1	0.16

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Appendix 2

Working Database

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[illegible]

1861	1872-84	1885-99	1900-14	1915-29	1930-39	1940-49	1950-59	1960-69	1970-79	1980-89	1990-99	2000-09	2010-19	2020-29	2030-39	2040-49	2050-59	2060-69	2070-79	2080-89	2090-99	2100-09	2110-19	2120-29	2130-39	2140-49	2150-59	2160-69	2170-79	2180-89	2190-99	2200-09	2210-19	2220-29	2230-39	2240-49	2250-59	2260-69	2270-79	2280-89	2290-99	2300-09	2310-19	2320-29	2330-39	2340-49	2350-59	2360-69	2370-79	2380-89	2390-99	2400-09	2410-19	2420-29	2430-39	2440-49	2450-59	2460-69	2470-79	2480-89	2490-99	2500-09	2510-19	2520-29	2530-39	2540-49	2550-59	2560-69	2570-79	2580-89	2590-99	2600-09	2610-19	2620-29	2630-39	2640-49	2650-59	2660-69	2670-79	2680-89	2690-99	2700-09	2710-19	2720-29	2730-39	2740-49	2750-59	2760-69	2770-79	2780-89	2790-99	2800-09	2810-19	2820-29	2830-39	2840-49	2850-59	2860-69	2870-79	2880-89	2890-99	2900-09	2910-19	2920-29	2930-39	2940-49	2950-59	2960-69	2970-79	2980-89	2990-99	3000-09	3010-19	3020-29	3030-39	3040-49	3050-59	3060-69	3070-79	3080-89	3090-99	3100-09	3110-19	3120-29	3130-39	3140-49	3150-59	3160-69	3170-79	3180-89	3190-99	3200-09	3210-19	3220-29	3230-39	3240-49	3250-59	3260-69	3270-79	3280-89	3290-99	3300-09	3310-19	3320-29	3330-39	3340-49	3350-59	3360-69	3370-79	3380-89	3390-99	3400-09	3410-19	3420-29	3430-39	3440-49	3450-59	3460-69	3470-79	3480-89	3490-99	3500-09	3510-19	3520-29	3530-39	3540-49	3550-59	3560-69	3570-79	3580-89	3590-99	3600-09	3610-19	3620-29	3630-39	3640-49	3650-59	3660-69	3670-79	3680-89	3690-99	3700-09	3710-19	3720-29	3730-39	3740-49	3750-59	3760-69	3770-79	3780-89	3790-99	3800-09	3810-19	3820-29	3830-39	3840-49	3850-59	3860-69	3870-79	3880-89	3890-99	3900-09	3910-19	3920-29	3930-39	3940-49	3950-59	3960-69	3970-79	3980-89	3990-99	4000-09	4010-19	4020-29	4030-39	4040-49	4050-59	4060-69	4070-79	4080-89	4090-99	4100-09	4110-19	4120-29	4130-39	4140-49	4150-59	4160-69	4170-79	4180-89	4190-99	4200-09	4210-19	4220-29	4230-39	4240-49	4250-59	4260-69	4270-79	4280-89	4290-99	4300-09	4310-19	4320-29	4330-39	4340-49	4350-59	4360-69	4370-79	4380-89	4390-99	4400-09	4410-19	4420-29	4430-39	4440-49	4450-59	4460-69	4470-79	4480-89	4490-99	4500-09	4510-19	4520-29	4530-39	4540-49	4550-59	4560-69	4570-79	4580-89	4590-99	4600-09	4610-19	4620-29	4630-39	4640-49	4650-59	4660-69	4670-79	4680-89	4690-99	4700-09	4710-19	4720-29	4730-39	4740-49	4750-59	4760-69	4770-79	4780-89	4790-99	4800-09	4810-19	4820-29	4830-39	4840-49	4850-59	4860-69	4870-79	4880-89	4890-99	4900-09	4910-19	4920-29	4930-39	4940-49	4950-59	4960-69	4970-79	4980-89	4990-99	5000-09	5010-19	5020-29	5030-39	5040-49	5050-59	5060-69	5070-79	5080-89	5090-99	5100-09	5110-19	5120-29	5130-39	5140-49	5150-59	5160-69	5170-79	5180-89	5190-99	5200-09	5210-19	5220-29	5230-39	5240-49	5250-59	5260-69	5270-79	5280-89	5290-99	5300-09	5310-19	5320-29	5330-39	5340-49	5350-59	5360-69	5370-79	5380-89	5390-99	5400-09	5410-19	5420-29	5430-39	5440-49	5450-59	5460-69	5470-79	5480-89	5490-99	5500-09	5510-19	5520-29	5530-39	5540-49	5550-59	5560-69	5570-79	5580-89	5590-99	5600-09	5610-19	5620-29	5630-39	5640-49	5650-59	5660-69	5670-79	5680-89	5690-99	5700-09	5710-19	5720-29	5730-39	5740-49	5750-59	5760-69	5770-79	5780-89	5790-99	5800-09	5810-19	5820-29	5830-39	5840-49	5850-59	5860-69	5870-79	5880-89	5890-99	5900-09	5910-19	5920-29	5930-39	5940-49	5950-59	5960-69	5970-79	5980-89	5990-99	6000-09	6010-19	6020-29	6030-39	6040-49	6050-59	6060-69	6070-79	6080-89	6090-99	6100-09	6110-19	6120-29	6130-39	6140-49	6150-59	6160-69	6170-79	6180-89	6190-99	6200-09	6210-19	6220-29	6230-39	6240-49	6250-59	6260-69	6270-79	6280-89	6290-99	6300-09	6310-19	6320-29	6330-39	6340-49	6350-59	6360-69	6370-79	6380-89	6390-99	6400-09	6410-19	6420-29	6430-39	6440-49	6450-59	6460-69	6470-79	6480-89	6490-99	6500-09	6510-19	6520-29	6530-39	6540-49	6550-59	6560-69	6570-79	6580-89	6590-99	6600-09	6610-19	6620-29	6630-39	6640-49	6650-59	6660-69	6670-79	6680-89	6690-99	6700-09	6710-19	6720-29	6730-39	6740-49	6750-59	6760-69	6770-79	6780-89	6790-99	6800-09	6810-19	6820-29	6830-39	6840-49	6850-59	6860-69	6870-79	6880-89	6890-99	6900-09	6910-19	6920-29	6930-39	6940-49	6950-59	6960-69	6970-79	6980-89	6990-99	7000-09	7010-19	7020-29	7030-39	7040-49	7050-59	7060-69	7070-79	7080-89	7090-99	7100-09	7110-19	7120-29	7130-39	7140-49	7150-59	7160-69	7170-79	7180-89	7190-99	7200-09	7210-19	7220-29	7230-39	7240-49	7250-59	7260-69	7270-79	7280-89	7290-99	7300-09	7310-19	7320-29	7330-39	7340-49	7350-59	7360-69	7370-79	7380-89	7390-99	7400-09	7410-19	7420-29	7430-39	7440-49	7450-59	7460-69	7470-79	7480-89	7490-99	7500-09	7510-19	7520-29	7530-39	7540-49	7550-59	7560-69	7570-79	7580-89	7590-99	7600-09	7610-19	7620-29	7630-39	7640-49	7650-59	7660-69	7670-79	7680-89	7690-99	7700-09	7710-19	7720-29	7730-39	7740-49	7750-59	7760-69	7770-79	7780-89	7790-99	7800-09	7810-19	7820-29	7830-39	7840-49	7850-59	7860-69	7870-79	7880-89	7890-99	7900-09	7910-19	7920-29	7930-39	7940-49	7950-59	7960-69	7970-79	7980-89	7990-99	8000-09	8010-19	8020-29	8030-39	8040-49	8050-59	8060-69	8070-79	8080-89	8090-99	8100-09	8110-19	8120-29	8130-39	8140-49	8150-59	8160-69	8170-79	8180-89	8190-99	8200-09	8210-19	8220-29	8230-39	8240-49	8250-59	8260-69	8270-79	8280-89	8290-99	8300-09	8310-19	8320-29	8330-39	8340-49	8350-59	8360-69	8370-79	8380-89	8390-99	8400-09	8410-19	8420-29	8430-39	8440-49	8450-59	8460-69	8470-79	8480-89	8490-99	8500-09	8510-19	8520-29	8530-39	8540-49	8550-59	8560-69	8570-79	8580-89	8590-99	8600-09	8610-19	8620-29	8630-39	8640-49	8650-59	8660-69	8670-79	8680-89	8690-99	8700-09	8710-19	8720-29	8730-39	8740-49	8750-59	8760-69	8770-79	8780-89	8790-99	8800-09	8810-19	8820-29	8830-39	8840-49	8850-59	8860-69	8870-79	8880-89	8890-99	8900-09	8910-19	8920-29	8930-39	8940-49	8950-59	8960-69	8970-79	8980-89	8990-99	9000-09	9010-19	9020-29	9030-39	9040-49	9050-59	9060-69	9070-79	9080-89	9090-99	9100-09	9110-19	9120-29	9130-39	9140-49	9150-59	9160-69	9170-79	9180-89	9190-99	9200-09	9210-19	9220-29	9230-39	9240-49	9250-59	9260-69	9270-79	9280-89	9290-99	9300-09	9310-19	9320-29	9330-39	9340-49	9350-59	9360-69	9370-79	9380-89	9390-99	9400-09	9410-19	9420-29	9430-39	9440-49	9450-59	9460-69	9470-79	9480-89	9490-99	9500-09	9510-19	9520-29	9530-39	9540-49	9550-59	9560-69	9570-79	9580-89	9590-99	9600-09	9610-19	9620-29	9630-39	9640-49	9650-59	9660-69	9670-79	9680-89	9690-99	9700-09	9710-19	9720-29	9730-39	9740-49	9750-59	9760-69	9770-79	9780-89	9790-99	9800-09	9810-19	9820-29	9830-39	9840-49	9850-59	9860-69	9870-79	9880-89	9890-99	9900-09	9910-19	9920-29	9930-39	9940-49	9950-59	9960-69	9970-79	9980-89	9990-99	10000-09	10010-19	10020-29	10030-39	10040-49	10050-59	10060-69	10070-79	10080-89	10090-99	10100-09	10110-19	10120-29	10130-39	10140-49	10150-59	10160-69	10170-79	10180-89	10190-99	10200-09	10210-19	10220-29	10230-39	10240-49	10250-59	10260-69	10270-79	10280-89	10290-99	10300-09	10310-19	10320-29	10330-39	10340-49	10350-59	10360-69	10370-79	10380-89	10390-99	10400-09	10410-19	10420-29	10430-39	10440-49	10450-59	10460-69	10470-79	10480-89	10490-99	10500-09	10510-19	10520-29	10530-39	10540-49	10550-59	10560-69	10570-79	10580-89	10590-99	10600-09	10610-19	10620-29	10630-39	10640-49	10650-59	10660-69	10670-79	10680-89	10690-99	10700-09	10710-19	10720-29	10730-39	10740-49	10750-59	10760-69	10770-79	10780-89	10790-99	10800-09	10810-19	10820-29	10830-39	10840-49	10850-59	10860-69	10870-79	10880-89	10890-99	10900-09	10910-19	10920-29	10930-39	10940-49	10950-59	10960-69	10970-79	10980-89	10990-99	11000-09	11010-19	11020-29	11030-39	11040-49	11050-59	11060-69	11070-79	11080-89	11090-99	11100-09	11110-19	11120-29	11130-39	11140-49	11150-59	11160-69	11170-79	11180-89	11190-99	11200-09	11210-19	11220-29	11230-39	11240-49	11250-59	11260-69	11270-79	11280-89	11290-99	11300-09	11310-19	11320-29	11330-39	11340-49	11350-59	11360-69	11370-79	11380-89	11390-99	11400-09	11410-19	11420-29	11430-39	11440-49	11450-59	11460-69	11470-79	11480-89	11490-99	11500-09	11510-19	11520-29	11530-39	11540-49	11550-59	11560-69	11570-79	11580-89	11590-99	11600-09	11610-19	11620-29	11630-39	11640-49	11650-59	11660-69	11670-79	11680-89	11690-99	11700-09	11710-19	11720-29	11730-39	11740-49	11750-59	11760-69	11770-79	11780-89	11790-99	11800-09	11810-19	11820-29	11830-39	11840-49	11850-59	11860-69	11870-79	11880-89	11890-99	11900-09	11910-19	11920-29	11930-39	11940-49	11950-59	11960-69	11970-79	11980-89	11990-99	12000-09	12010-19	12020-29
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Appendix 3**Selected Details from the Alberta User Guide for Waste Managers**

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Appendix 3

Selected Details from the Alberta User Guide for Waste Managers

Characteristics of Hazardous Waste:

Liquid or Solid hazardous waste containing one or more of the following in a total combined concentration exceeding 1000 mg/kg: (Section 14 (2)(c))

acetone	iosbutanol
benzene	methanol
n-butyl alcohol	methyl ethyl ketone
carbon disulfide	nitrobenzene
cresols and cresylic acid	2-nitropropane
Cyclohexanone	pyridine
Ethyl acetate	toluene
Ethyl benzene	xylene
Ethyl ether	

Solid hazardous waste producing an extract which contains one or more of the following substances exceeding the concentration shown: (Section 14 (2)(f))

arsenic	500 milligrams per kilogram
beryllium	100 milligrams per kilogram
cadmium	100 milligrams per kilogram
chromium hexavalent	500 milligrams per kilogram
lead	500 milligrams per kilogram
mercury	20 milligrams per kilogram
nickel	500 milligrams per kilogram
selenium	200 milligrams per kilogram
silver	100 milligrams per kilogram
thallium	200 milligrams per kilogram
uranium	100 milligrams per kilogram

Solid hazardous waste producing an extract which contains one or more of the following substances exceeding the concentration shown: (Table 2)

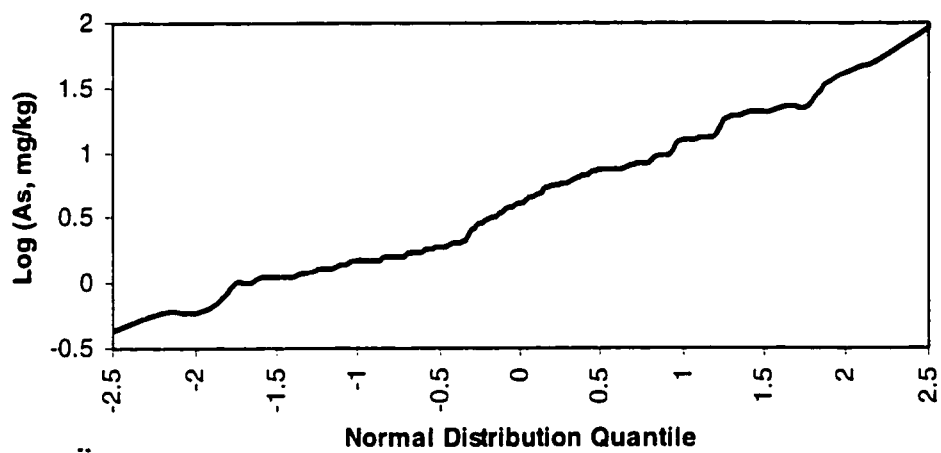
Aldrin + Dieldrin	0.07	milligrams per liter
Ammonia	100.0	milligrams per liter
Antimony	500.0	milligrams per liter
Arsenic	5.0	milligrams per liter
Atrazine	6.0	milligrams per liter
Barium	100.0	milligrams per liter
Benzene	0.5	milligrams per liter
Beryllium	5.0	milligrams per liter
Boron	500.0	milligrams per liter
Cadmium	1.0	milligrams per liter
Chromium	5.0	milligrams per liter
Cobalt	100.0	milligrams per liter
Copper	100.0	milligrams per liter
Cyanazine	1.0	milligrams per liter
2, 4 D	10.0	milligrams per liter
DDT \pm metabolites	3.0	milligrams per liter
Diuron	15.0	milligrams per liter
Endrin	0.02	milligrams per liter
Ethylbenzene	0.5	milligrams per liter
Iron	1000.0	milligrams per liter
Lead	5.0	milligrams per liter
Mercury	0.2	milligrams per liter
Naphthalene	0.5	milligrams per liter
Nickel	5.0	milligrams per liter
Nitrate and Nitrite	1000.0	milligrams per liter
Pentachlorophenol	100.0	milligrams per liter
Phenol	100.0	milligrams per liter
Selenium	1.0	milligrams per liter
Silver	5.0	milligrams per liter
Simazine	1.0	milligrams per liter
Thallium	5.0	milligrams per liter
Toluene	0.5	milligrams per liter
Trihalomethanes	35.0	milligrams per liter
Uranium	2.0	milligrams per liter
Vanadium	100.0	milligrams per liter
Xylene	0.5	milligrams per liter
Zinc	500.0	milligrams per liter

Appendix 4**QQ Plots to Test for Normality in Log-Transformed Chemical Parameters**

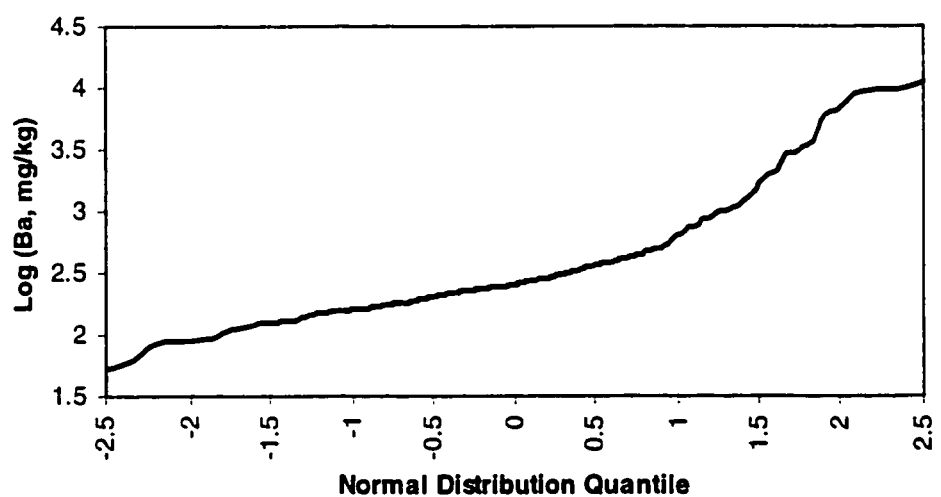
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Figure A4-1: QQ Plot for Arsenic

Log Transformation

**Figure A4-2: QQ Plot for Barium**

Log Transformation



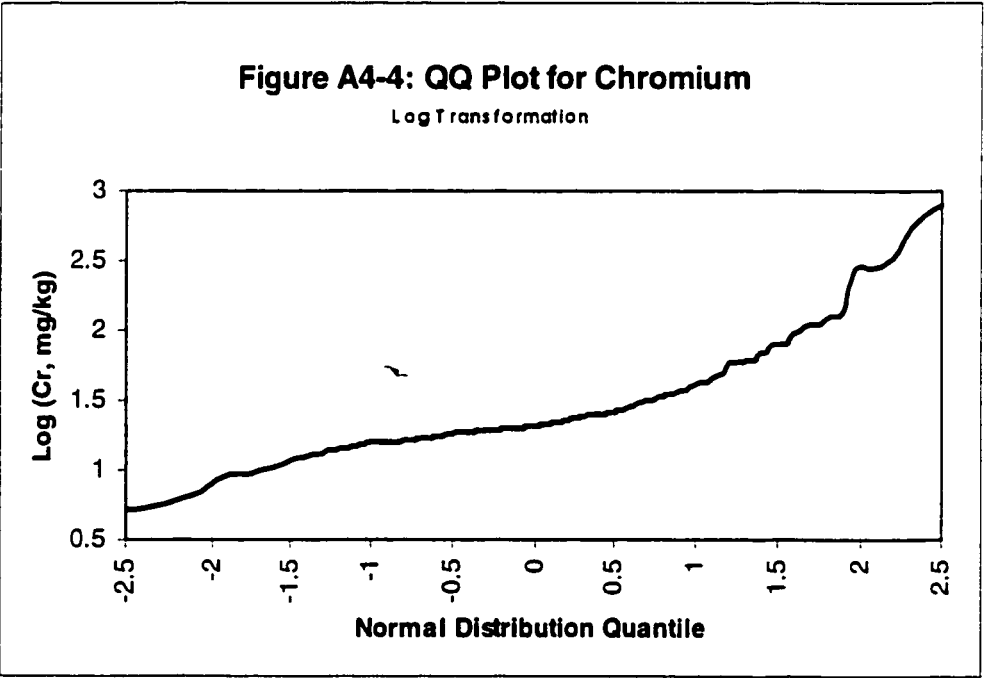
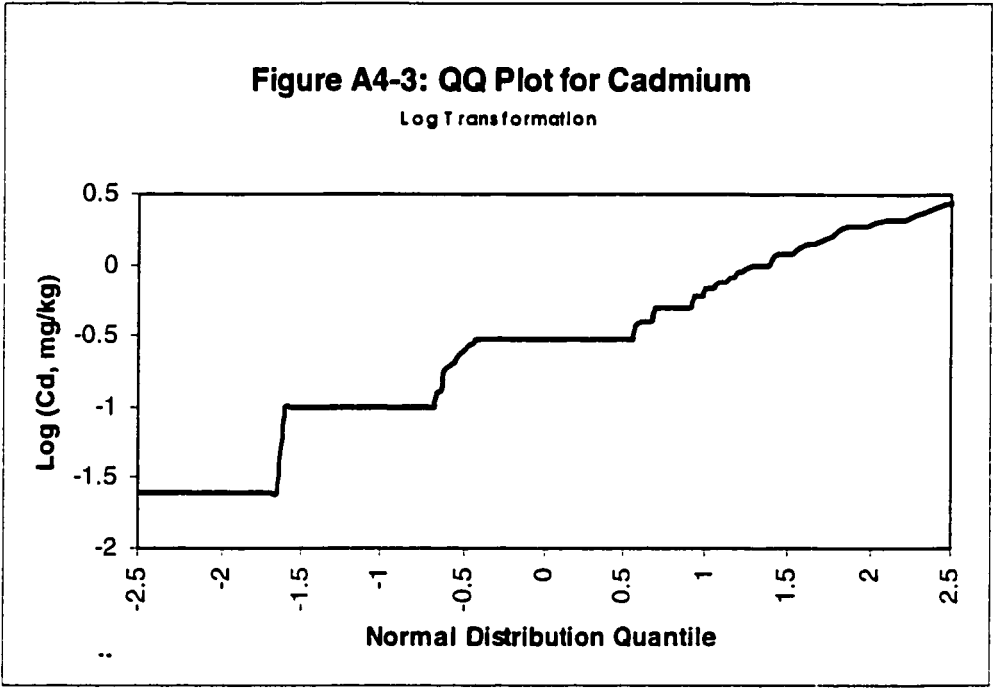
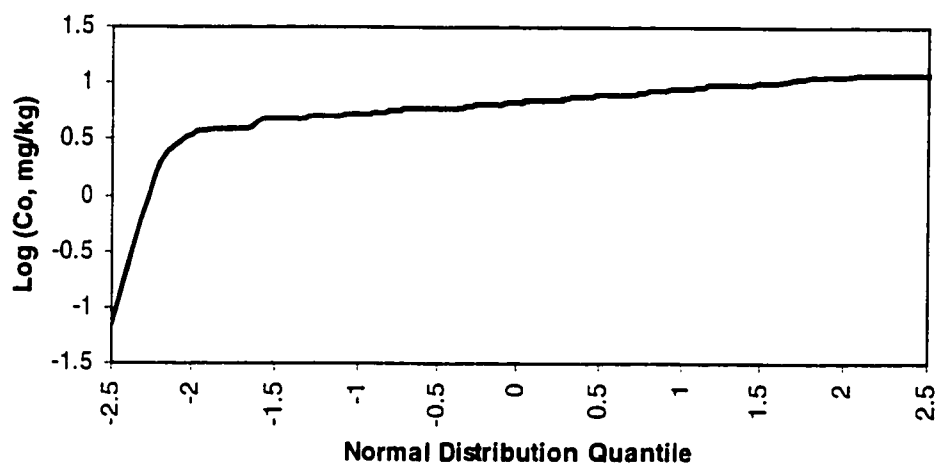


Figure A4-5: QQ Plot for Cobalt

Log Transformation

**Figure A4-6: QQ Plot for Copper**

Log Transformation

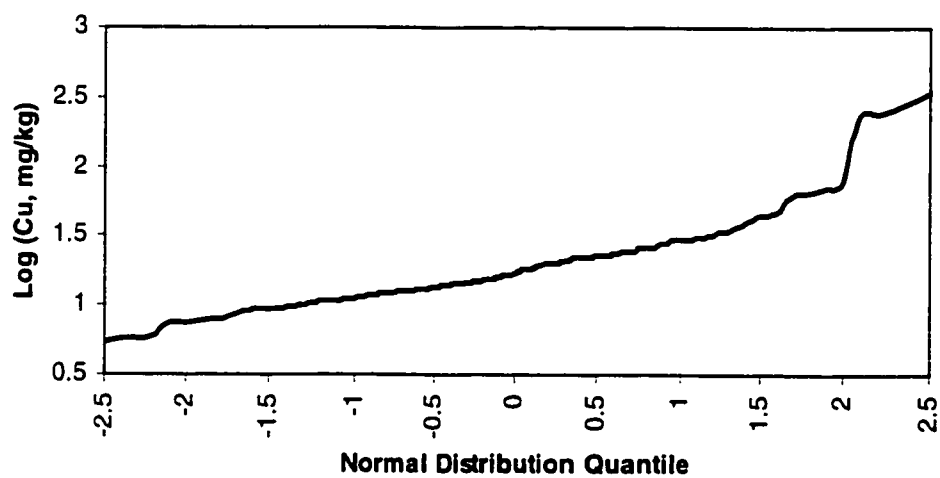
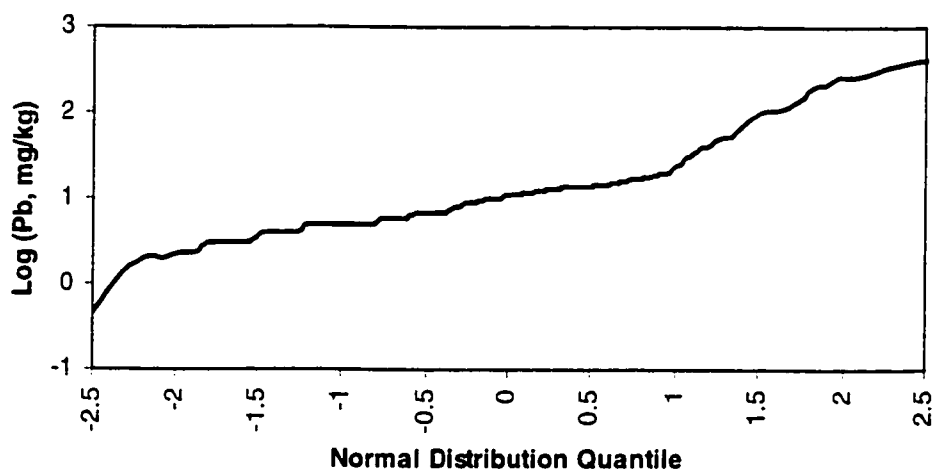


Figure A4-7: QQ Plot for Lead

Log Transformation

**Figure A4-8: QQ Plot for Mercury**

Log Transformation

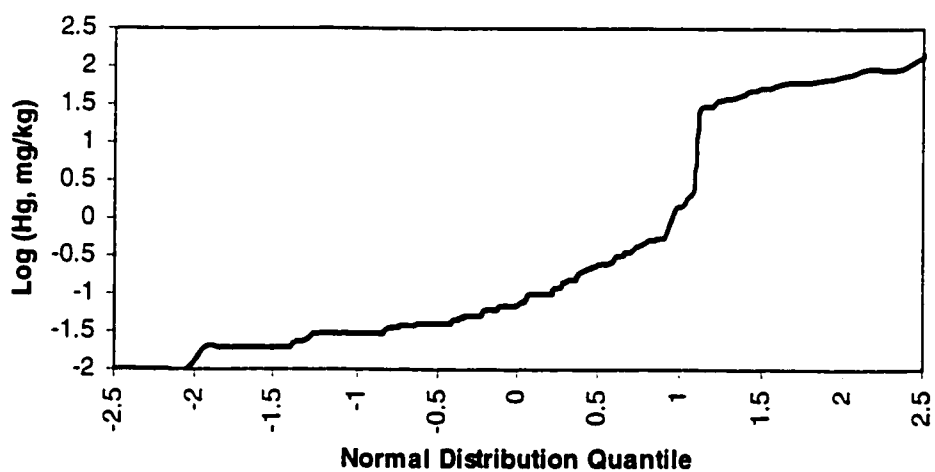
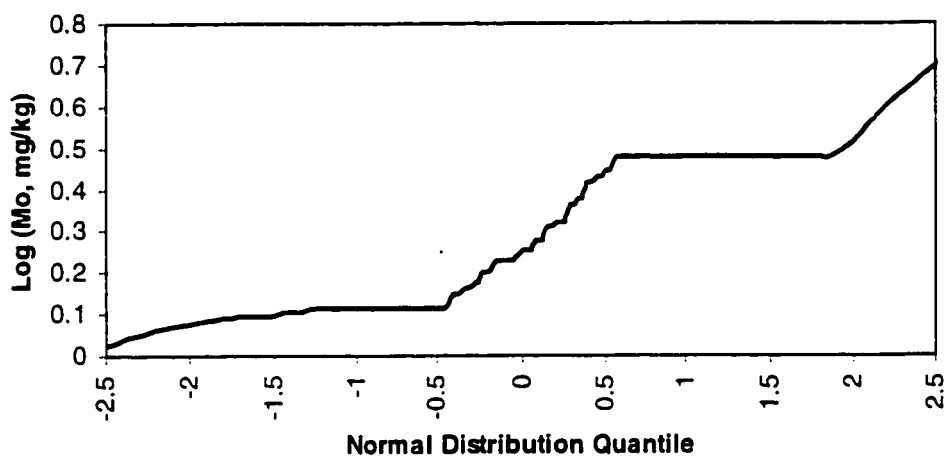


Figure A4-9: QQ Plot for Molybdenum

Log Transformation

**Figure A4-10: QQ Plot for Nickel**

Log Transformation

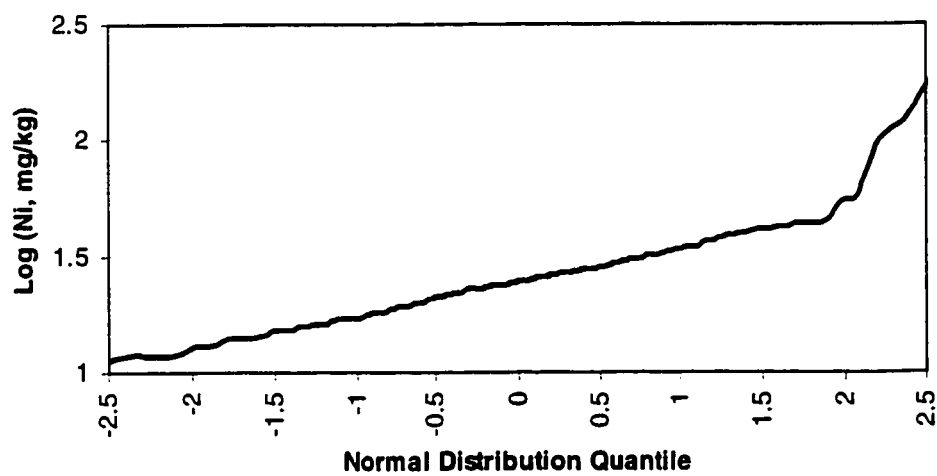
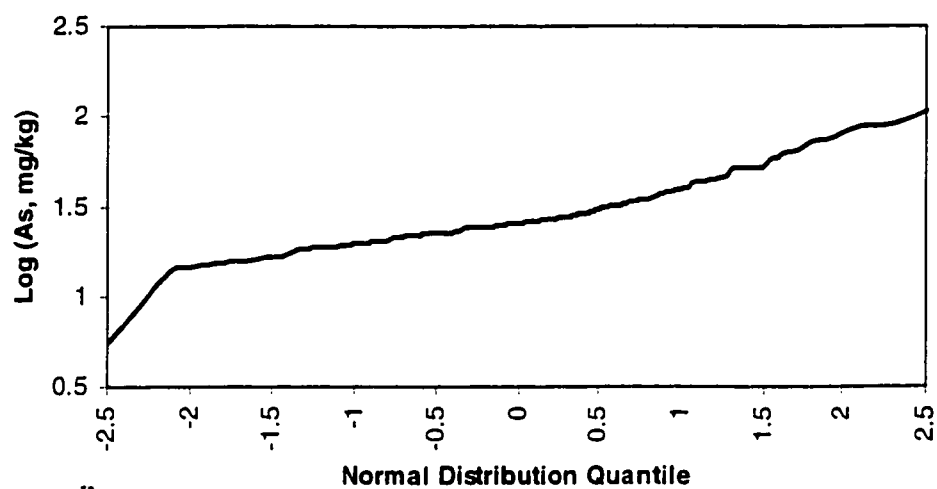


Figure A4-11: QQ Plot for Vanadium

Log Transformation

**Figure A4-12: QQ Plot for Zinc**

Log Transformation

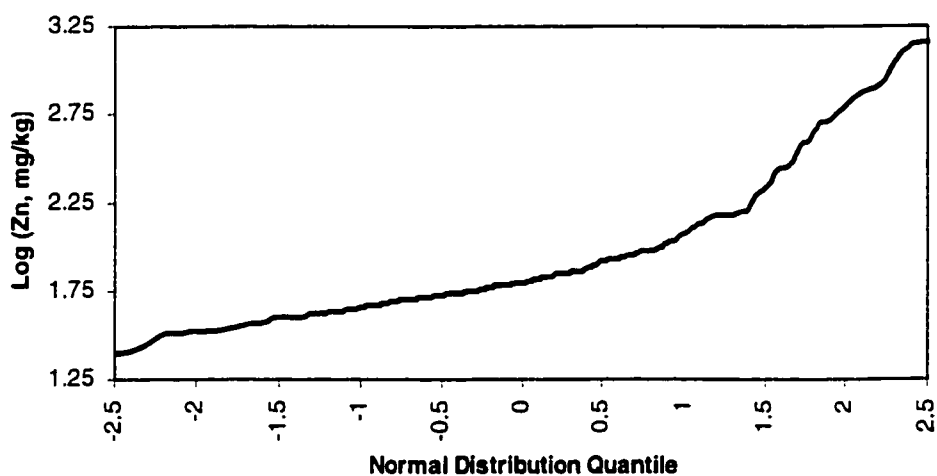


Figure A4-13: QQ Plot for Benzene

Log Transformation

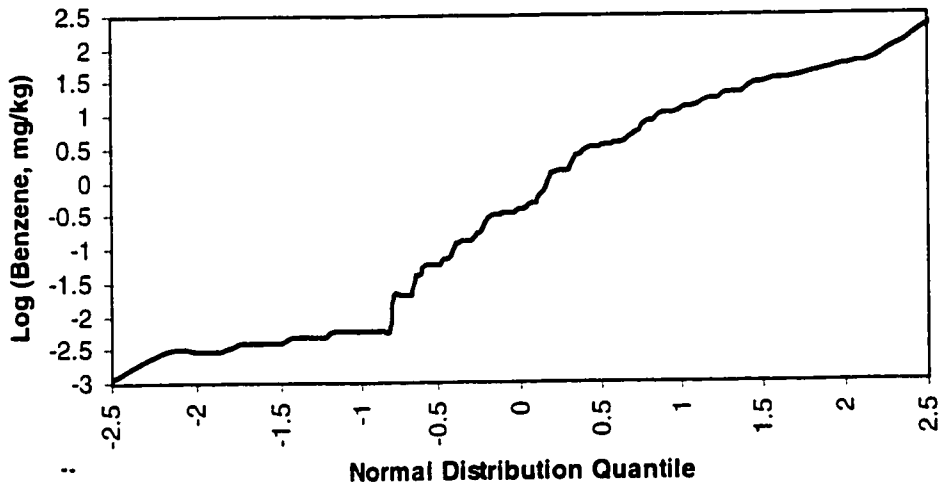


Figure A4-14: QQ Plot for Toluene

Log Transformation

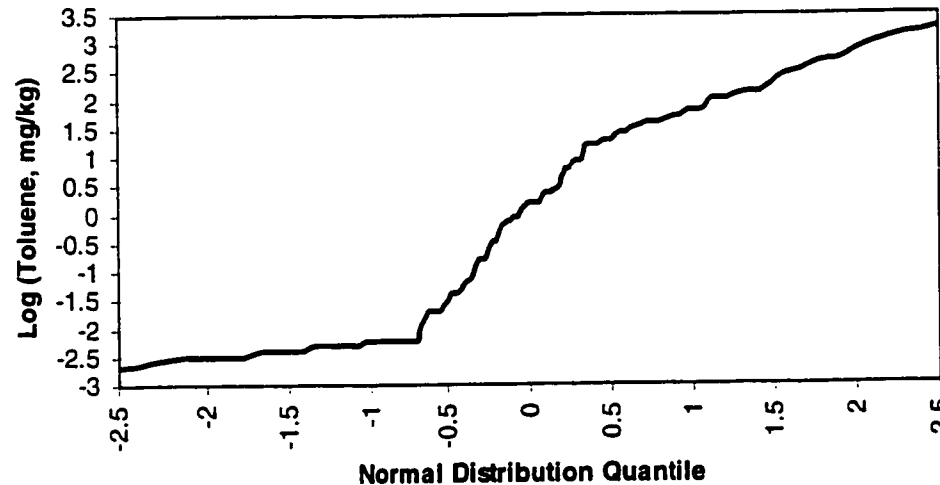
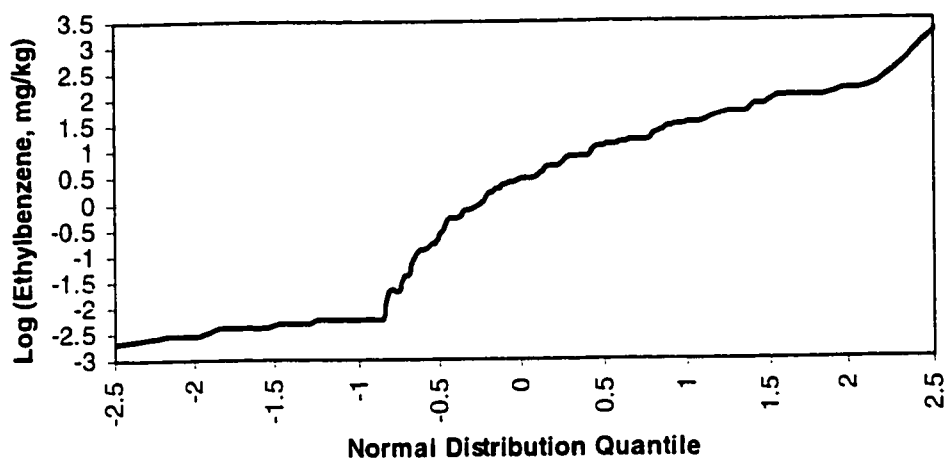


Figure A4-15: QQ Plot for Ethylbenzene

Log Transformation

**Figure A4-16: QQ Plot for Xylene**

Log Transformation

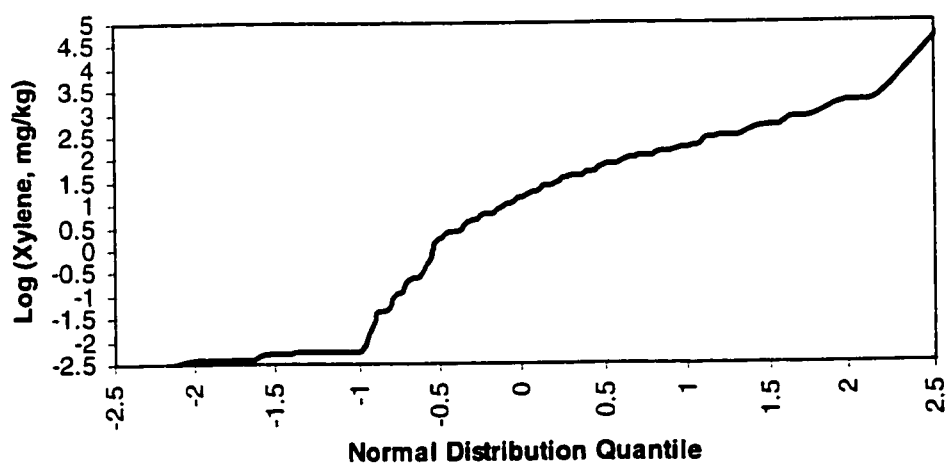


Figure A4-17: QQ Plot for Hydrocarbons

Log T transformation

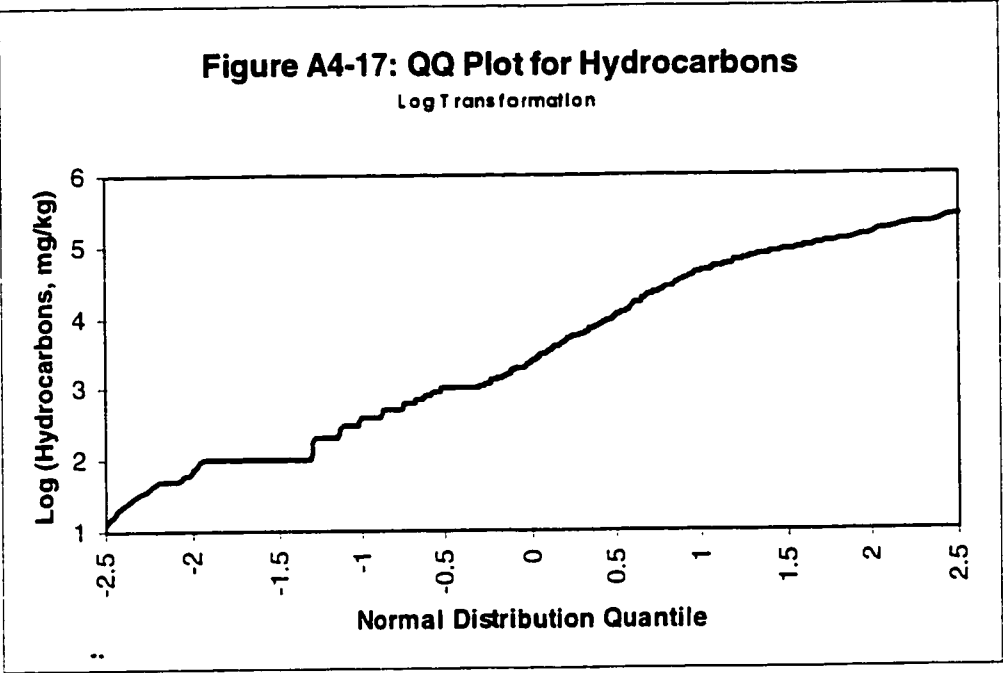


Figure A4-18: QQ Plot for pH

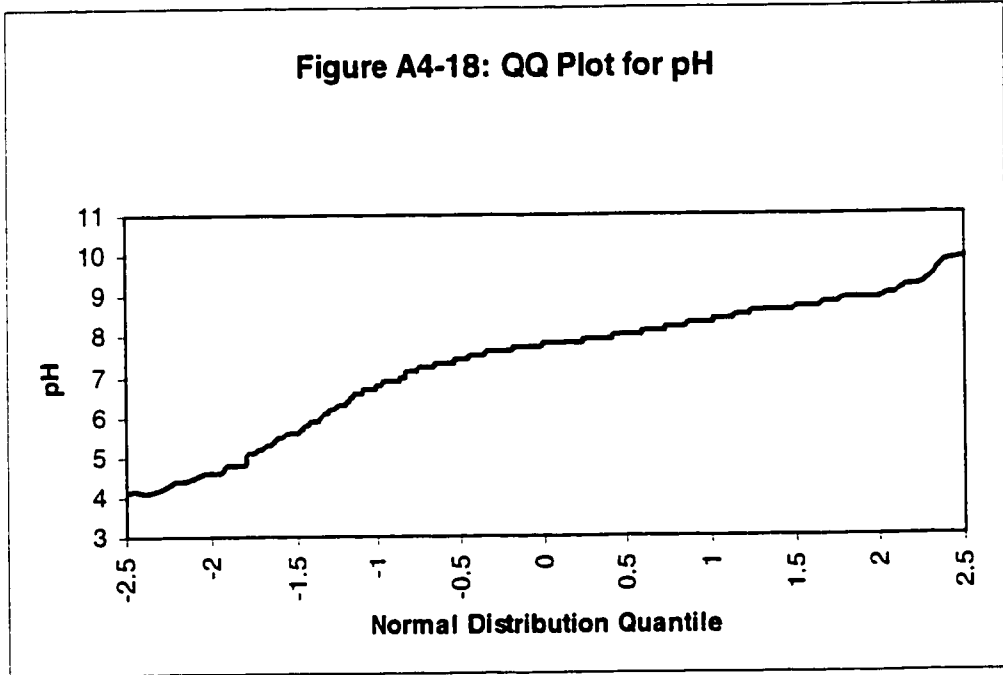
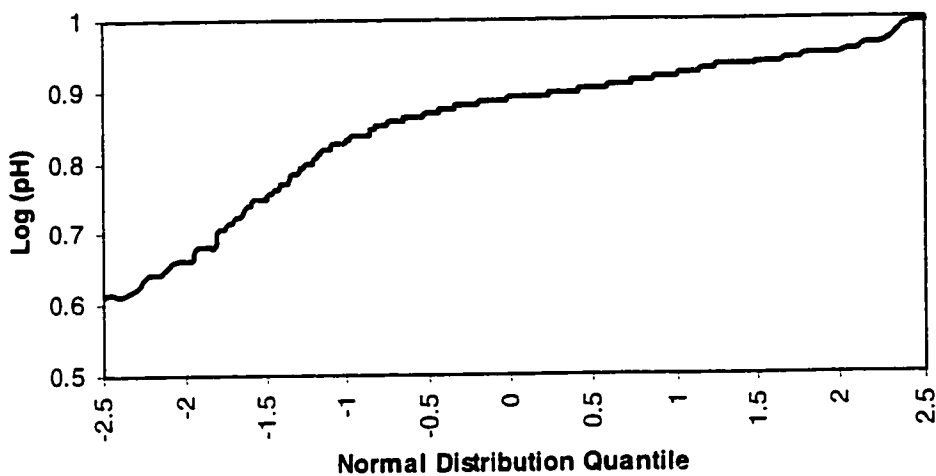
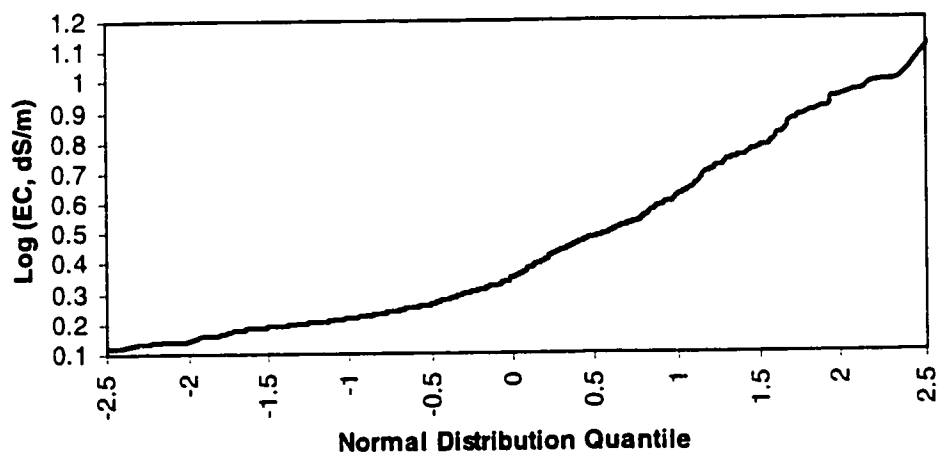


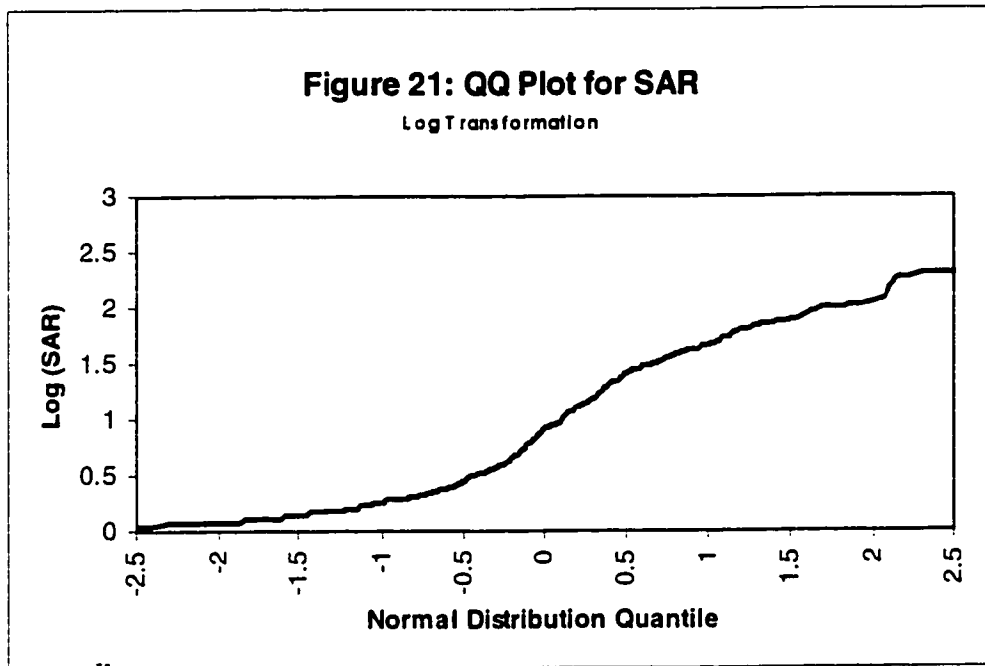
Figure A4-19: QQ Plot for pH

Log Transformation

**Figure 20: QQ Plot for EC**

Log Transformation





Appendix 5**Flare Pit Sites in Alberta, Grouped by Hydrocarbon Produced**

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**Figure A5-1: Flare Pit Sites in Alberta,
Grouped by Hydrocarbon Produced**

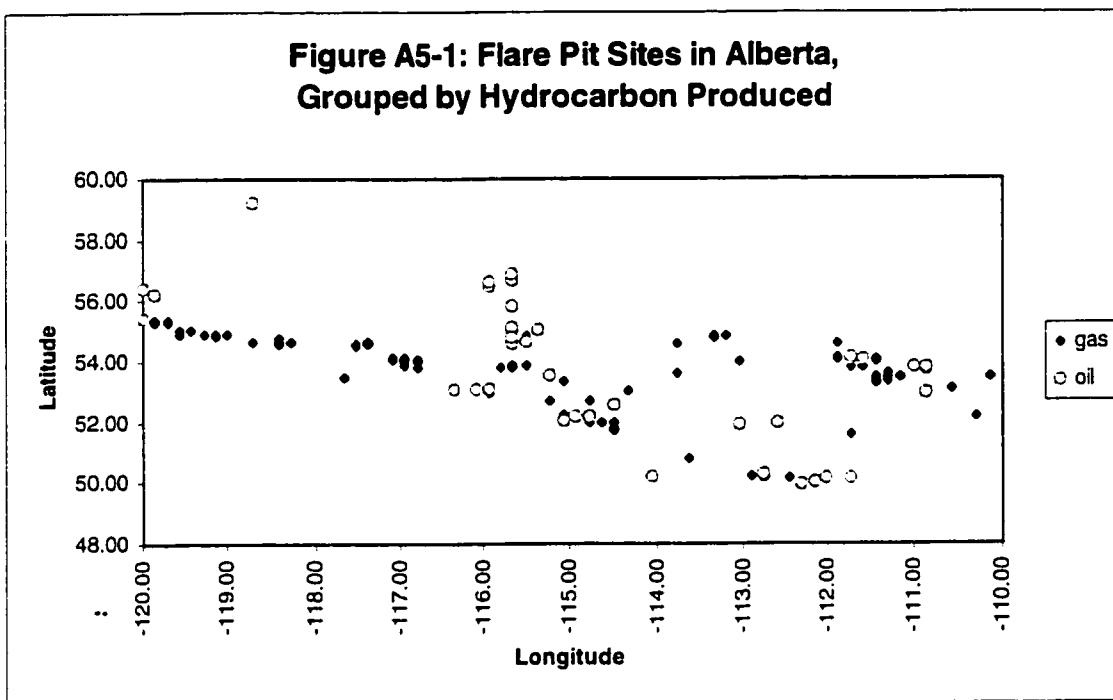


Table A5-1

Details on Samples Grouped by Produced Hydrocarbon

	Samples from Sites Producing Gas			
	<i>Sample Size</i>	<i>Average</i>	<i>Standard Deviation</i>	<i>Coefficient of Variation</i>
Hydrocarbons	245	18211.212	43275.441	2.376
Log		3.366	0.953	0.283
BTEX	72	1142.101	7707.589	6.749
Log		0.556	1.793	3.225
EC	251	6.905	16.416	2.377
Log		1.888	1.832	0.971
Mercury	110	12.895	31.744	2.462
Log		-0.501	1.246	-2.490
Metals	131	1097.100	1066.419	0.972
Log		2.874	0.427	0.149
..	Samples from Sites Producing Oil			
	<i>Sample Size</i>	<i>Average</i>	<i>Standard Deviation</i>	<i>Coefficient of Variation</i>
Hydrocarbons	102	34839.157	84520.905	2.426
Log		3.576	1.063	0.297
BTEX	8	76.188	100.724	1.322
Log		0.804	1.730	2.152
EC	128	4.272	4.946	1.158
Log		0.191	0.573	3.005
Mercury	27	0.130	0.161	1.238
Log		-1.134	0.453	-0.399
Metals	36	1207.618	1458.734	1.208
Log		2.873	0.451	0.157

Table A5-2**Two Sample F-Test for Variance on Samples Grouped by Produced Hydrocarbon**

	Log Total Hydrocarbons	
	<i>Gas Samples</i>	<i>Oil Samples</i>
Mean	3.37	3.58
Variance	0.91	1.13
Observations	245	102
df	244	101
F	0.80	
F Critical one-tail	0.77	
Results	F ratio > F critical, unequal variances	
	Log Total BTEX	
	<i>Gas Samples</i>	<i>Oil Samples</i>
Mean	1.13	1.25
Variance	1.43	1.01
Observations	72	8
df	71	7
F	1.42	
F Critical one-tail	3.29	
Results	F ratio < F critical, equal variances	
	Log EC	
	<i>Gas Samples</i>	<i>Oil Samples</i>
Mean	0.55	0.49
Variance	0.22	0.15
Observations	251	128
df	250	127
F	1.49	
F Critical one-tail	1.30	
Results	F ratio > F critical, unequal variances	

	Log Total Equivalent Metals	
	<i>Gas Samples</i>	<i>Oil Samples</i>
Mean	2.87	2.87
Variance	0.18	0.20
Observations	131	36
df	130	35
F	0.90	
F Critical one-tail	0.66	
Results	F ratio> F critical, unequal variances	
	Log Mercury	
	<i>Gas Samples</i>	<i>Oil Samples</i>
Mean	-0.50	-1.13
Variance	1.55	0.20
Observations	110	27
df	109	26
F ..	7.58	
F Critical one-tail	1.75	
Results	F ratio> F critical, unequal variances	

Table A5-3**Two Sample T-Test on Samples Grouped by Produced Hydrocarbon**

	Log Total Hydrocarbons	
	<i>Gas Samples</i>	<i>Oil Samples</i>
Mean	3.37	3.58
Variance	0.91	1.13
Observations	245	102
Hypothesized Mean Difference	0	
Df	172	
t Stat	-1.731927	
t Critical one-tail	1.653762	
t Critical two-tail	1.973854	
Results	t Stat > t Critical, significant difference	
	Log Total BTEX	
	<i>Gas Samples</i>	<i>Oil Samples</i>
Mean	1.126144986	1.254556945
Variance	1.434984001	1.009398486
Observations	72	8
Pooled Variance	1.396790429	
Hypothesized Mean Difference	0	
df	78	
t Stat	-0.291545334	
t Critical one-tail	1.664625415	
t Critical two-tail	1.990847522	
Results	t Stat < t Critical, insignificant difference	
	Log EC	
	<i>Gas Samples</i>	<i>Oil Samples</i>
Mean	0.55	0.49
Variance	0.22	0.15
Observations	251	128
Hypothesized Mean Difference	0	
df	304	
t Stat	1.27	
t Critical one-tail	1.65	
t Critical two-tail	1.97	
Results	t Stat < t Critical, insignificant difference	

	Log Total Equivalent Metals	
	<i>Gas Samples</i>	<i>Oil Samples</i>
Mean	2.87	2.87
Variance	0.18	0.20
Observations	131	36
Hypothesized Mean Difference	0	
df	54	
t Stat	0.01	
t Critical one-tail	1.67	
t Critical two-tail	2.00	
Results	t Stat < t Critical, insignificant difference	
	Log Mercury	
	<i>Gas Samples</i>	<i>Oil Samples</i>
Mean	-0.50	-1.13
Variance	1.55	0.20
Observations	110	27
Hypothesized Mean Difference	0	
df	117	
t Stat	4.30	
t Critical one-tail	1.66	
t Critical two-tail	1.98	
Results	t Stat > t Critical, significant difference	

Appendix 6**Flare Pit Sites in Alberta, Grouped by Site Activity**

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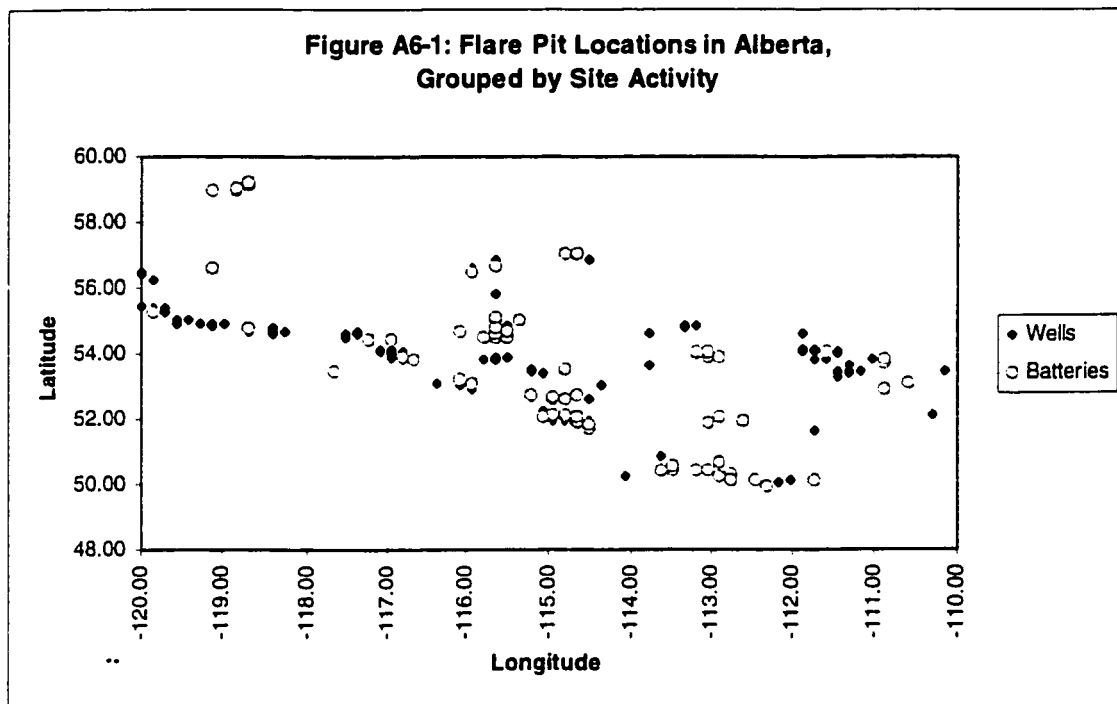


Table A6-1**Details on Samples Grouped by Site Activity**

	Samples from Sites Classified as Batteries			
	<i>Sample Size</i>	<i>Average</i>	<i>Standard Deviation</i>	<i>Coefficient of Variation</i>
Hydrocarbons	174	21911.914	54290.138	2.478
<i>Log</i>		3.369	1.039	0.308
BTEX	67	1032.138	7984.069	7.735
<i>Log</i>		0.223	1.659	7.440
EC	199	7.422	18.380	2.477
<i>Log</i>		0.584	0.444	0.779
Metals	80	909.230	1079.980	1.188
<i>Log</i>		2.776	0.431	0.155
	Samples from Sites Classified as Wells			
	<i>Sample Size</i>	<i>Average</i>	<i>Standard Deviation</i>	<i>Coefficient of Variation</i>
Hydrocarbons	251	20237.063	43925.657	2.171
<i>Log</i>		3.548	0.862	0.243
BTEX	35	360.080	840.717	2.335
<i>Log</i>		1.447	1.365	0.943
EC	256	6.799	15.828	2.328
<i>Log</i>		0.563	0.461	0.819
Metals	133	1126.309	1069.862	0.950
<i>Log</i>		2.871	0.479	0.167

Table A6-2**Two Sample F-Test for Variance on Samples Grouped by Site Activity**

	Log Total Hydrocarbons	
	<i>Batteries</i>	<i>Wells</i>
Mean	3.37	3.55
Variance	1.08	0.74
Observations	174	251
df	173	250
F Ratio	1.45	
F Critical	1.26	
Results	F ratio > F critical, unequal variances	
	Log Total BTEX	
	<i>Batteries</i>	<i>Wells</i>
Mean	0.89	1.63
Variance	1.08	1.08
Observations	67	35
df	66	34
F Ratio	1.00	
F Critical	1.68	
Results	F ratio < F critical, equal variances	
	Log EC	
	<i>Wells</i>	<i>Batteries</i>
Mean	0.56	0.58
Variance	0.21	0.21
Observations	256	199
df	255	198
F Ratio	1.03	
F Critical	1.25	
Results	F ratio < F critical, equal variances	
	Log Total Equivalent Metals	
	<i>Wells</i>	<i>Batteries</i>
Mean	2.87	2.78
Variance	0.23	0.19
Observations	133	80
df	132	79
F Ratio	1.23	
F Critical	1.41	
Results	F ratio < F critical, equal variances	

Table A6-3**Two Sample T-Test on Samples Grouped by Site Activity**

	Log Total Hydrocarbons	
	<i>Wells</i>	<i>Batteries</i>
Mean	3.55	3.37
Variance	0.74	1.08
Observations	251	174
Hypothesized Mean Difference	0	
df	326	
t Stat	1.87	
t Critical one-tail	1.65	
t Critical two-tail	1.97	
Results, one-tail	t Stat > t Critical, significant difference	
	Log Total BTEX	
	<i>Wells</i>	<i>Batteries</i>
Mean	1.63	0.89
Variance	1.08	1.08
Observations	35	67
Pooled Variance	1.08	
Hypothesized Mean Difference	0	
df	100	
t Stat	3.44	
t Critical one-tail	1.66	
t Critical two-tail	1.98	
Results, one-tail	t Stat > t Critical, significant difference	
	Log EC	
	<i>Wells</i>	<i>Batteries</i>
Mean	0.56	0.58
Variance	0.21	0.21
Observations	256	199
Pooled Variance	0.21	
Hypothesized Mean Difference	0	
df	453	
t Stat	-0.48	
t Critical one-tail	1.65	
t Critical two-tail	1.97	
Results, one-tail	t Stat < t Critical, insignificant difference	

	Log Total Equivalent Metals	
	<i>Wells</i>	<i>Batteries</i>
Mean	2.87	2.78
Variance	0.23	0.19
Observations	133	80
Pooled Variance	0.21	
Hypothesized Mean Difference	0	
df	211	
t Stat	1.45	
t Critical one-tail	1.65	
t Critical two-tail	1.97	
Results, one-tail	t Stat < t Critical, insignificant difference	

Appendix 7**Flare Pit Sites in Alberta, Grouped by Site Age**

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Table A7-1**Details on Samples Grouped by Site Age**

Sites Built Up to and Including 1975				
	<i>Sample Size</i>	<i>Average</i>	<i>Standard Deviation</i>	<i>Coefficient of Variation</i>
BTEX	23	194.043	292.278	1.506
Log		1.648	1.019	0.619
EC	66	8.503	27.380	3.220
Log		0.256	0.674	2.631
Metals	19	1525.274	2056.666	1.348
Log		2.770	0.614	0.222
Sites Built After 1975				
	<i>Sample Size</i>	<i>Average</i>	<i>Standard Deviation</i>	<i>Coefficient of Variation</i>
BTEX	38	1933.018	10585.342	5.476
Log		1.102	1.498	1.359
EC	31	10.54645	15.30483552	1.451
Log		0.706967	0.533156576	0.754
Metals	25	897.986	832.2443411	0.927
Log		2.684	0.635	0.237

Table A7-2**Two Sample F-Test for Variance on Samples Grouped by Site Age**

	Log Total BTEX	
	<i>Before 1975</i>	<i>After 1975</i>
Mean	1.65	1.10
Variance	1.04	2.24
Observations	23	38
df	22	37
F	0.46	
F Critical one-tail	0.51	
Results	F ratio < F Critical, equal variances	
	Log Electrical Conductivity	
	<i>Before 1975</i>	<i>After 1975</i>
Mean	0.26	0.71
Variance	0.45	0.28
Observations	66	31
df	65	30
F	1.60	
F Critical one-tail	1.73	
Results	F ratio < F Critical, equal variances	
	Log Total Equivalent Metals	
	<i>Before 1975</i>	<i>After 1975</i>
Mean	2.77	2.68
Variance	0.38	0.40
Observations	18	25
df	17	24
F	0.94	
F Critical one-tail	0.46	
Results	F ratio > F Critical, unequal variances	

Table A7-3**Two Sample T-Test on Samples Grouped by Site Age**

	Log Total BTEX	
	<i>Before 1975</i>	<i>After 1975</i>
Mean	1.65	1.10
Variance	1.04	2.24
Observations	23	38
Pooled Variance	1.79	
Hypothesized Mean Difference	0	
df	59	
t Stat	1.54	
t Critical one-tail	1.67	
t Critical two-tail	2.00	
Results	t stat < t Critical, insignificant difference	
	Log Electrical Conductivity	
	<i>Before 1975</i>	<i>After 1975</i>
Mean	0.26	0.71
Variance	0.45	0.28
Observations	66	31
Pooled Variance	0.40	
Hypothesized Mean Difference	0	
df	95	
t Stat	-3.27	
t Critical one-tail	1.66	
t Critical two-tail	1.99	
Results	t stat > t Critical, significant difference	
	Log Total Equivalent Metals	
	<i>Before 1975</i>	<i>After 1975</i>
Mean	2.77	2.68
Variance	0.38	0.40
Observations	18	25
Pooled Variance	Not required, unequal variances	
Hypothesized Mean Difference	0	
Df	38	
t Stat	0.45	
t Critical one-tail	1.69	
t Critical two-tail	2.02	
Results	t stat < t Critical, insignificant difference	

Appendix 8**Flare Pit Sites in Alberta, Grouped by Clay Content**

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**Figure A8-1: Flare Pit Sites in Alberta,
Grouped by Soil Type**

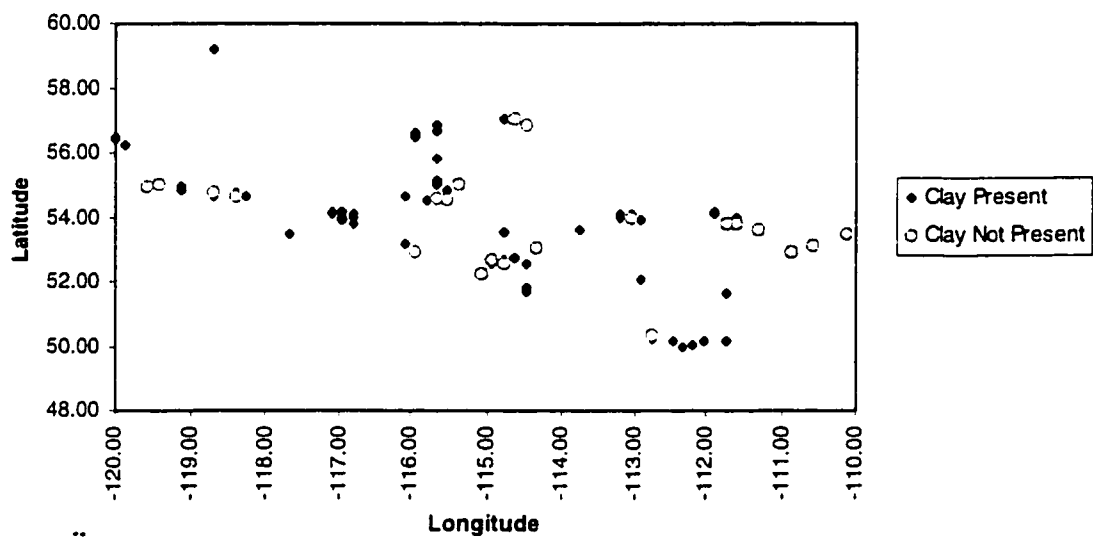


Table A8-1**Details on Samples Grouped by Soil Type**

	Samples from Soils Containing Some Clay Content			
	<i>Sample Size</i>	<i>Average</i>	<i>Standard Deviation</i>	<i>Coefficient of Variation</i>
Hydrocarbons	202	19955.371	37058.852	1.857
Log		3.389	1.017	0.300
EC	188	9.327	21.717	2.328
Log		0.386	0.694	1.798
Metals	116	1173.995	1261.693	1.075
Log		2.838	0.527	0.186
	Samples from Soils Containing Limited Clay Content			
	<i>Sample Size</i>	<i>Average</i>	<i>Standard Deviation</i>	<i>Coefficient of Variation</i>
Hydrocarbons	44	18945.000	51973.637	2.743
Log		3.183	1.126	0.354
EC	85	4.286	8.112	1.893
Log		0.082	0.664	8.073
Metals	19	788.702	1032.900	1.310
Log		2.699	0.478	0.177

Table A8-2**Two Sample F-Test for Variance on Samples Grouped by Soil Type**

	Log Total Hydrocarbons	
	<i>Clay Not Present</i>	<i>Clay Present</i>
Mean	3.18	3.39
Variance	1.27	1.03
Observations	44	202
df	43	201
F	1.23	
F Critical one-tail	1.44	
Results	F ratio < F Critical, equal variances	
	Log Electrical Conductivity	
	<i>Clay Not Present</i>	<i>Clay Present</i>
Mean	0.08	0.39
Variance	0.44	0.48
Observations	85	188
df	84	187
F	0.91	
F Critical one-tail	0.73	
Results	F ratio > F Critical, unequal variances	
	Log Total Equivalent Metals	
	<i>Clay Not Present</i>	<i>Clay Present</i>
Mean	2.70	2.84
Variance	0.23	0.28
Observations	18	116
df	17	115
F	0.82	
F Critical one-tail	0.50	
Results	F ratio > F Critical, unequal variances	

Table A8-3**Two Sample T-Test on Samples Grouped by Soil Type**

	Log Total Hydrocarbons	
	<i>Clay Not Present</i>	<i>Clay Present</i>
Mean	3.18	3.39
Variance	1.27	1.03
Observations	44	202
Pooled Variance	1.08	
Hypothesized Mean Difference	0	
df	244	
t Stat	-1.19	
t Critical one-tail	1.65	
t Critical two-tail	1.97	
Results	t stat < t Critical, insignificant difference	
..	Log Electrical Conductivity	
	<i>Clay Not Present</i>	<i>Clay Present</i>
Mean	0.08	0.39
Variance	0.44	0.48
Observations	85	188
Hypothesized Mean Difference	0	
df	169	
t Stat	-3.45	
t Critical one-tail	1.65	
t Critical two-tail	1.97	
Results	t stat > t Critical, significant difference	
	Log Total Equivalent Metals	
	<i>Clay Not Present</i>	<i>Clay Present</i>
Mean	2.70	2.84
Variance	0.23	0.28
Observations	18	116
Hypothesized Mean Difference	0	
df	24	
t Stat	-1.13	
t Critical one-tail	1.71	
t Critical two-tail	2.06	
Results	t stat < t Critical, insignificant difference	

Appendix 9
CAPP Flare Pit Population Estimates

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Appendix 9**CAPP Flare Pit Population Estimates, August 1998**

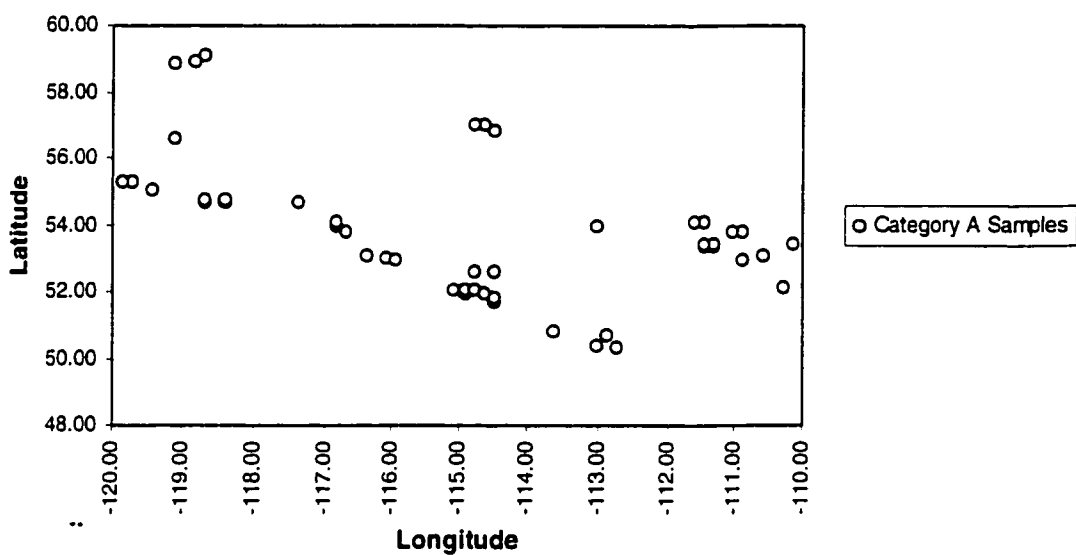
Site Type	Total in Alberta	% With a Pit or Sump	# With a Pit or Sump
Well, Active	70000	25	17500
Well, Inactive	40000	25	10000
Gas Plant	700	75	525
Small Recovery or re-injection site	100	75	75
Compressor Stations	1500	50	750
Multi Well Batteries	3000	65	1950
Total			30800

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Appendix 10

Individual Category Locations

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Figure A10-1: 126 Category A Sample Locations in Alberta**Figure A10-2: 126 Category A Sample Locations in Alberta
and Entire Flare Pit Database, Alberta Locations**

126 Category A Samples, 552 Flare Pit Samples

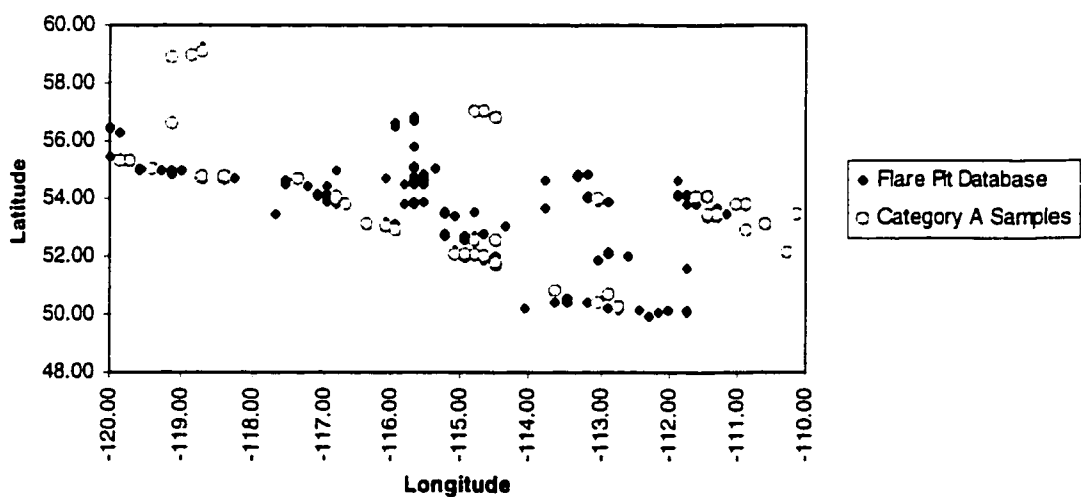


Figure A10-3
Category A Sample Locations

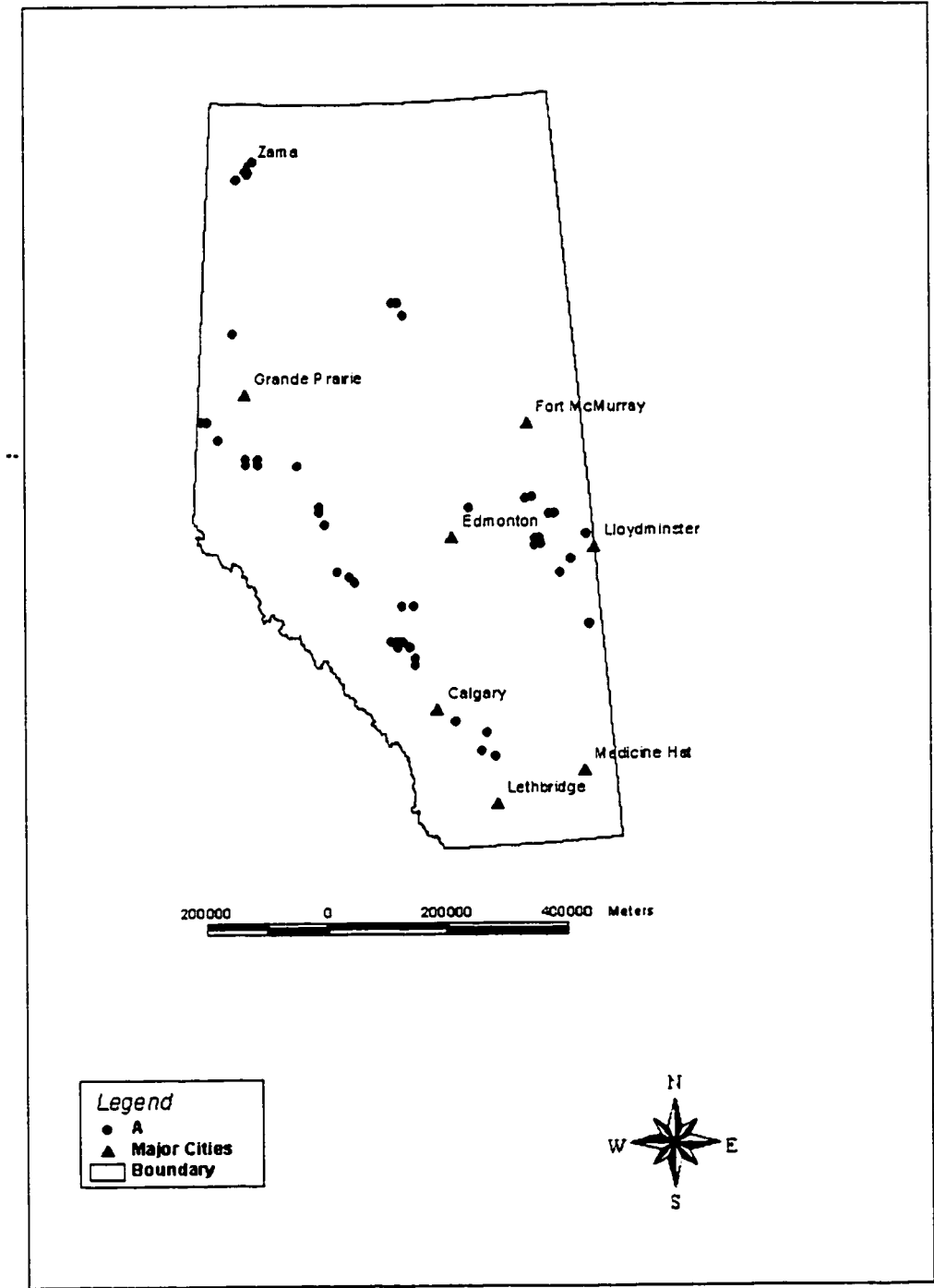
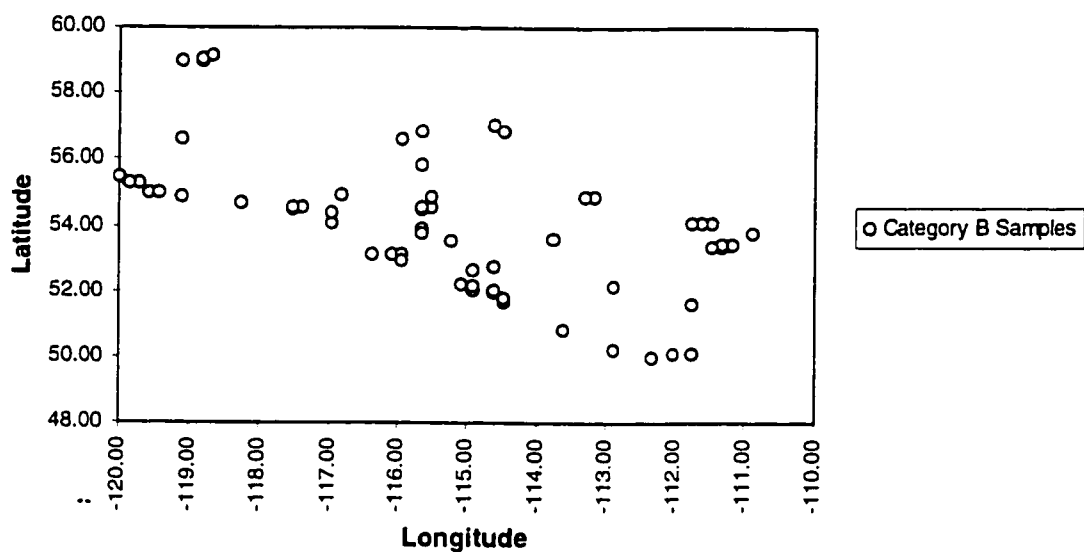


Figure A10-4: 98 Category B Sample Locations in Alberta**Figure A10-5: 98 Category B Sample Locations in Alberta
and Entire Flare Pit Database, Alberta Locations**

98 Category B Samples, 552 Flare Pit Samples

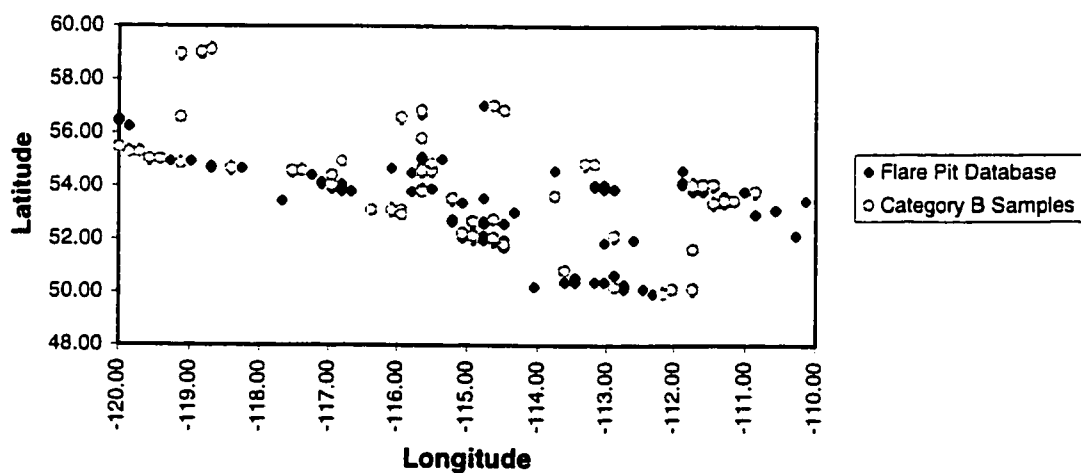


Figure A10-6
Category B Sample Locations

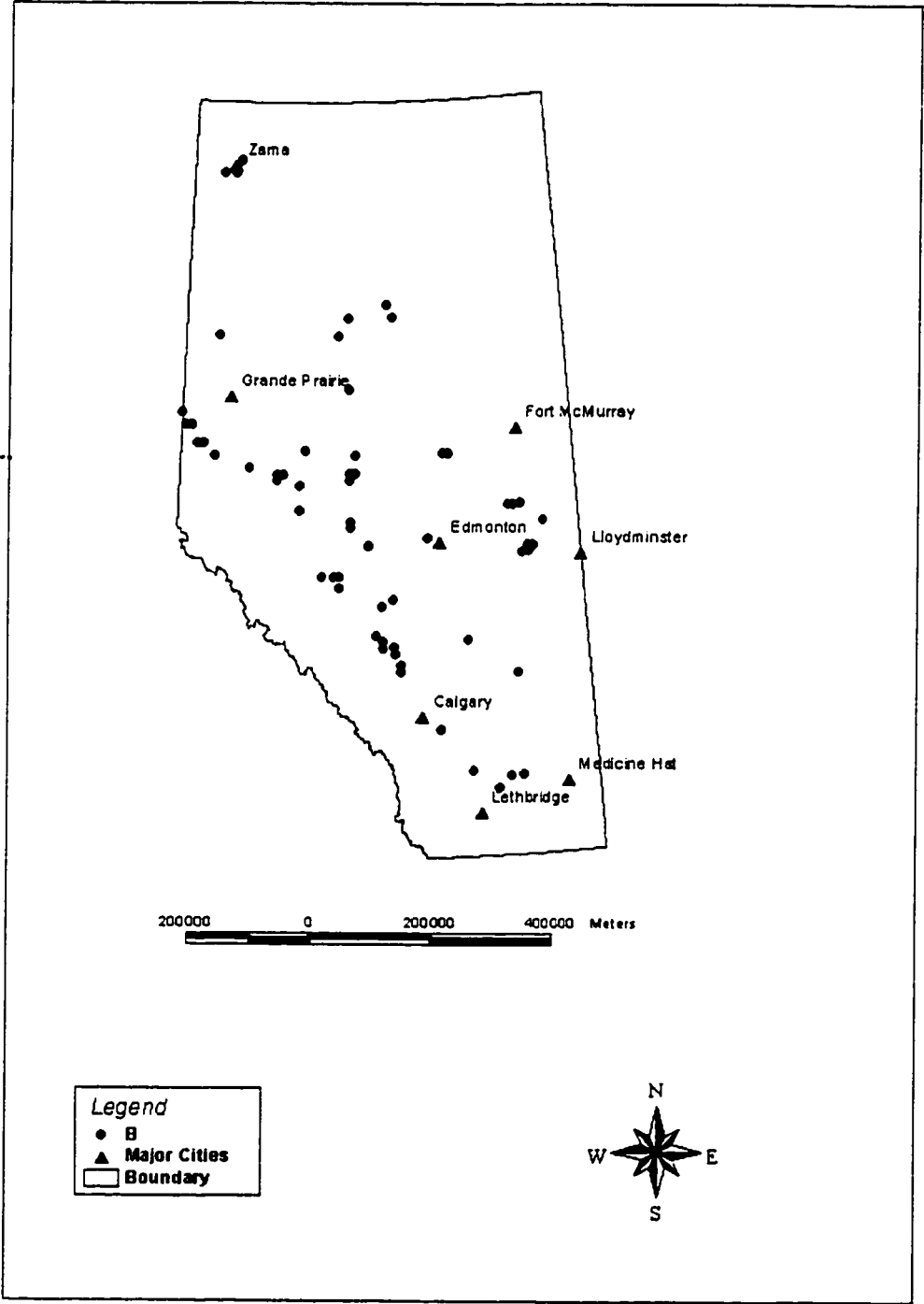
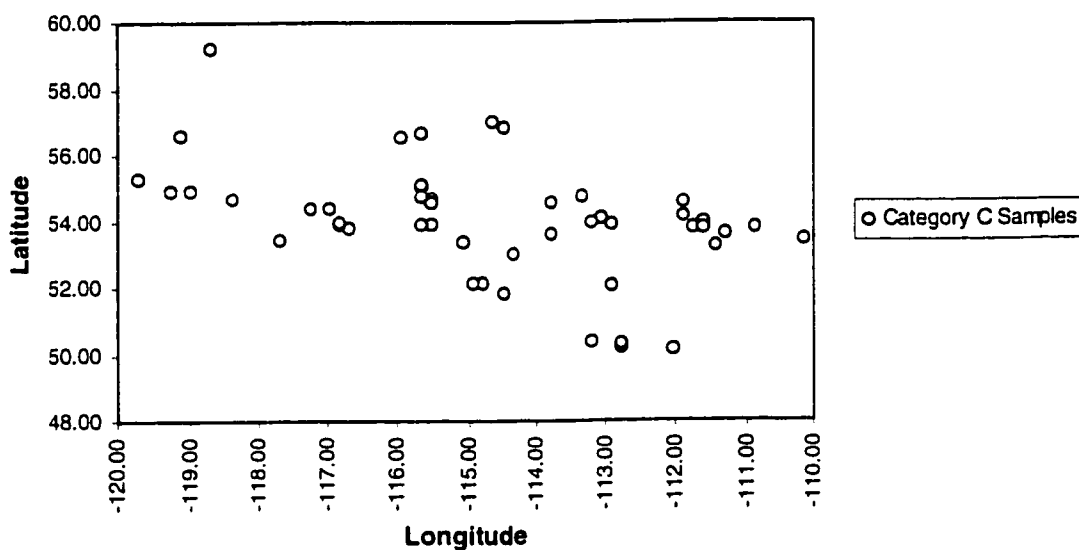


Figure A10-7: 75 Category C Sample Locations in Alberta**Figure A10-8: 75 Category C Sample Locations in Alberta
and Entire Flare Pit Database, Alberta Locations**

75 Category C Samples, 552 Flare Pit Samples

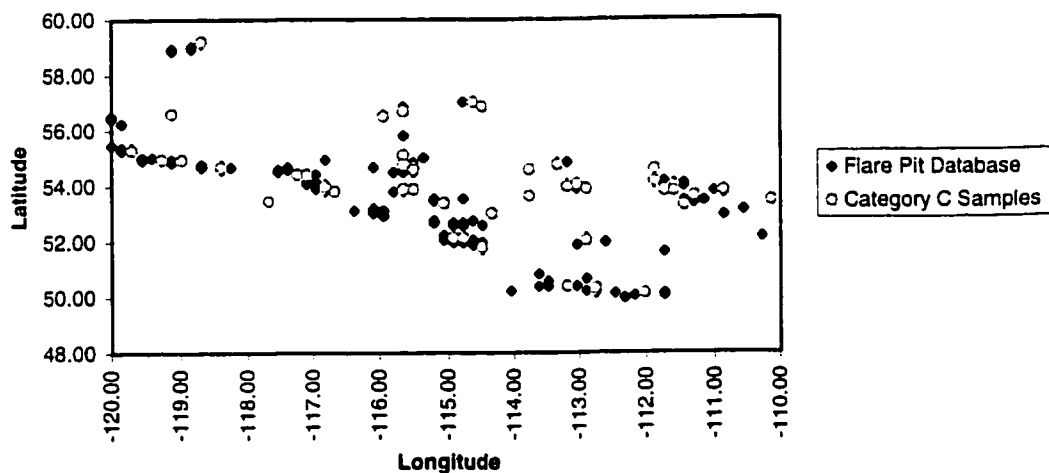


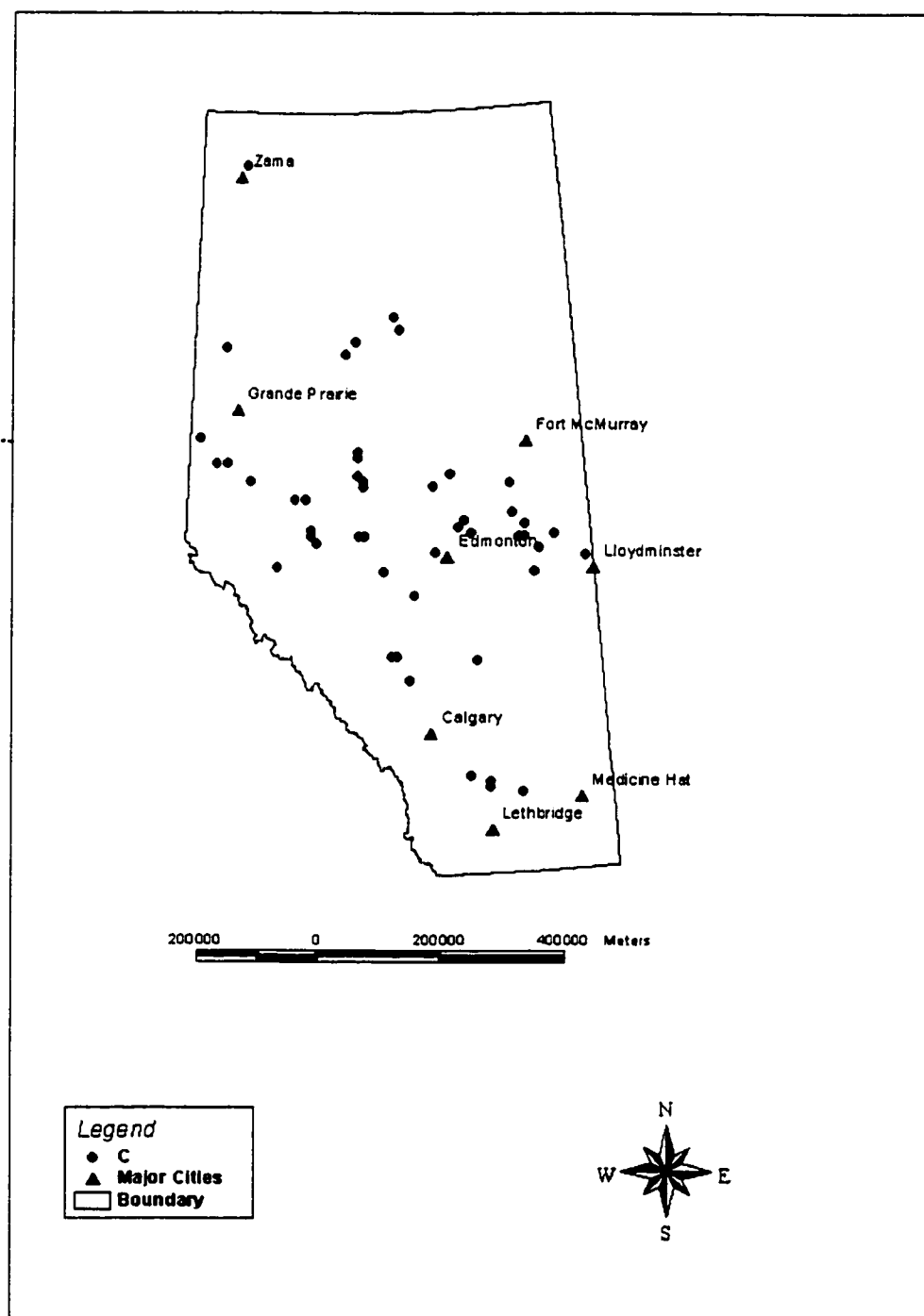
Figure A10-9**Category C Sample Locations**

Figure A10-10: 6 Category D Sample Locations in Alberta

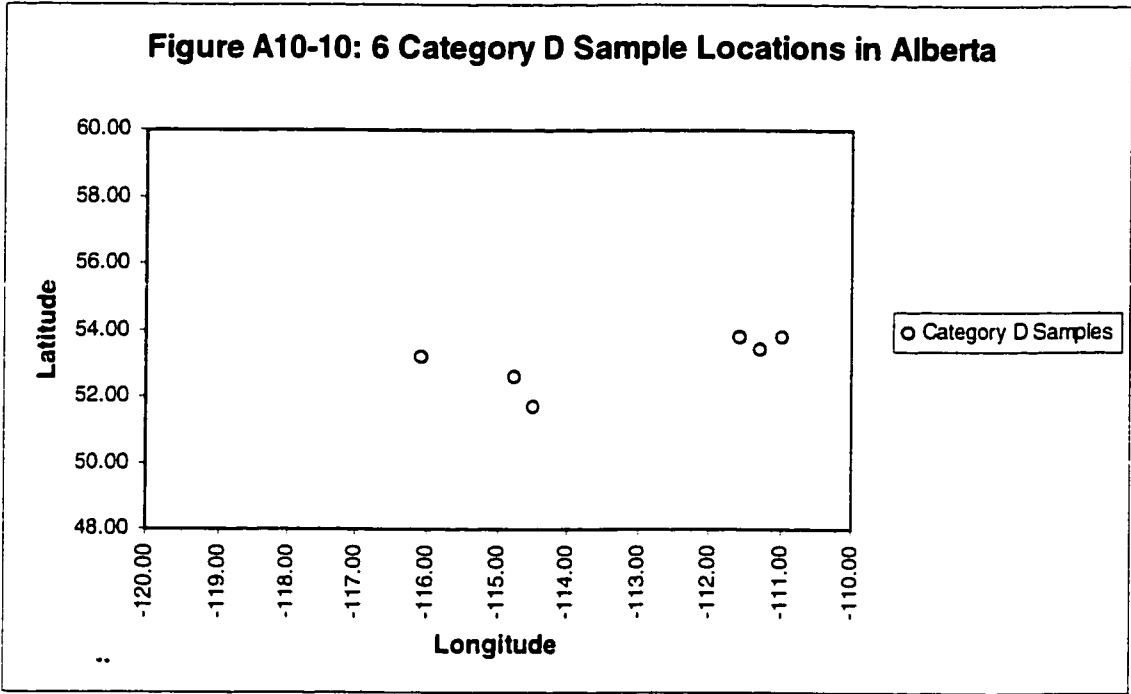


Figure A10-11: 6 Category D Sample Locations in Alberta and Entire Flare Pit Database, Alberta Locations

6 Category D Samples, 552 Flare Pit Samples

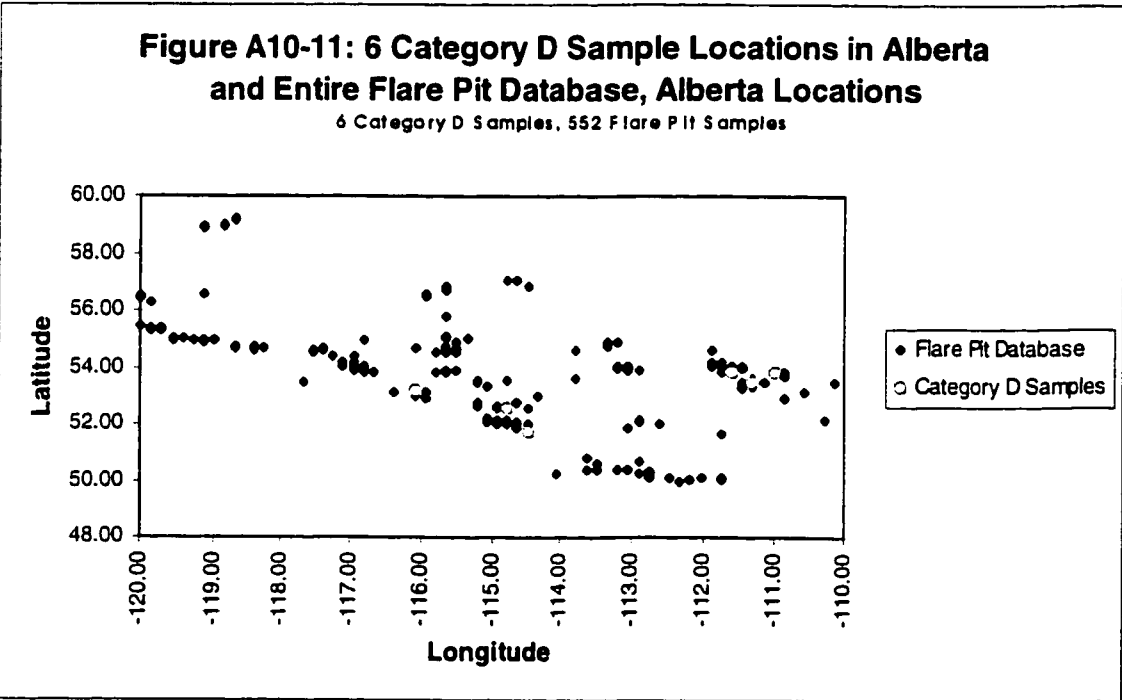


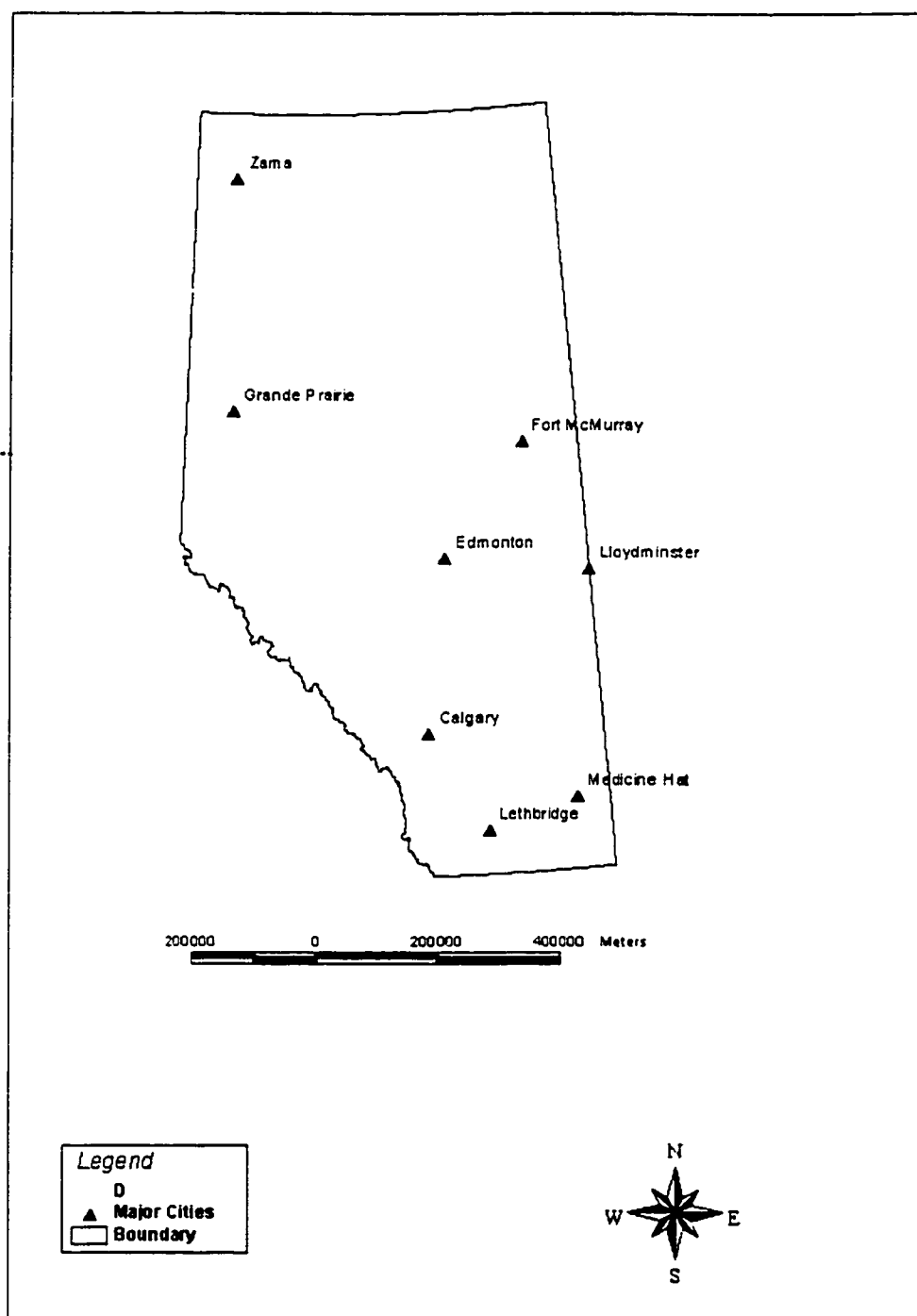
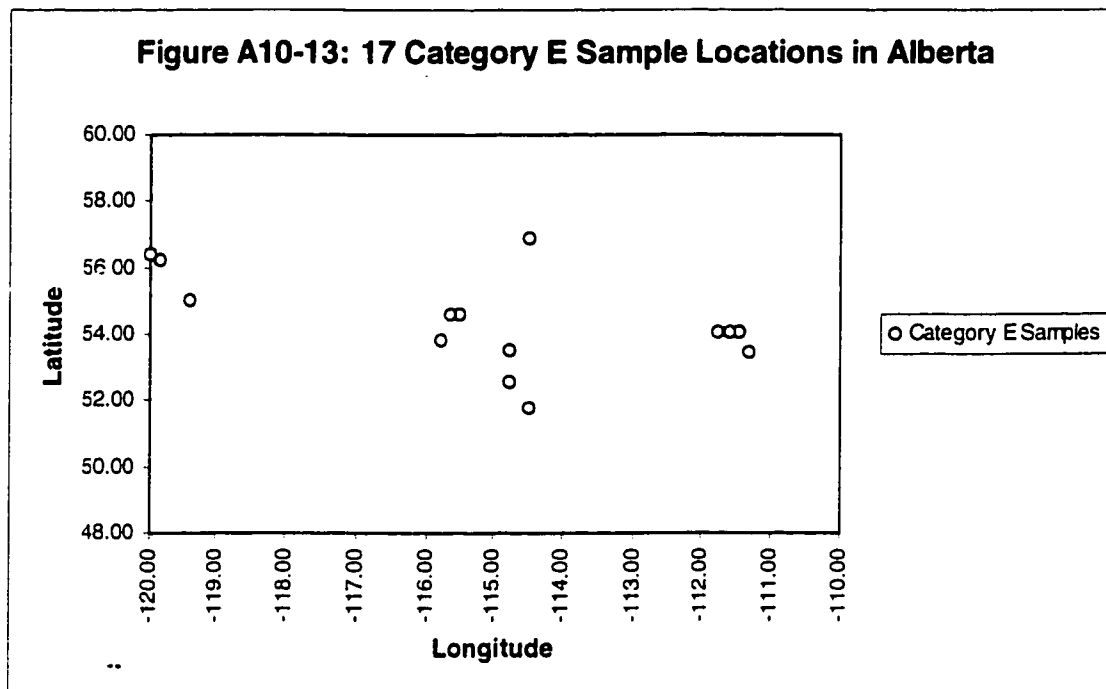
Figure A10-12**Category D Sample Locations**

Figure A10-13: 17 Category E Sample Locations in Alberta**Figure A10-14: 17 Category E Sample Locations in Alberta and Entire Flare Pit Database, Alberta Locations**

17 Category E Samples, 552 Flare Pit Samples

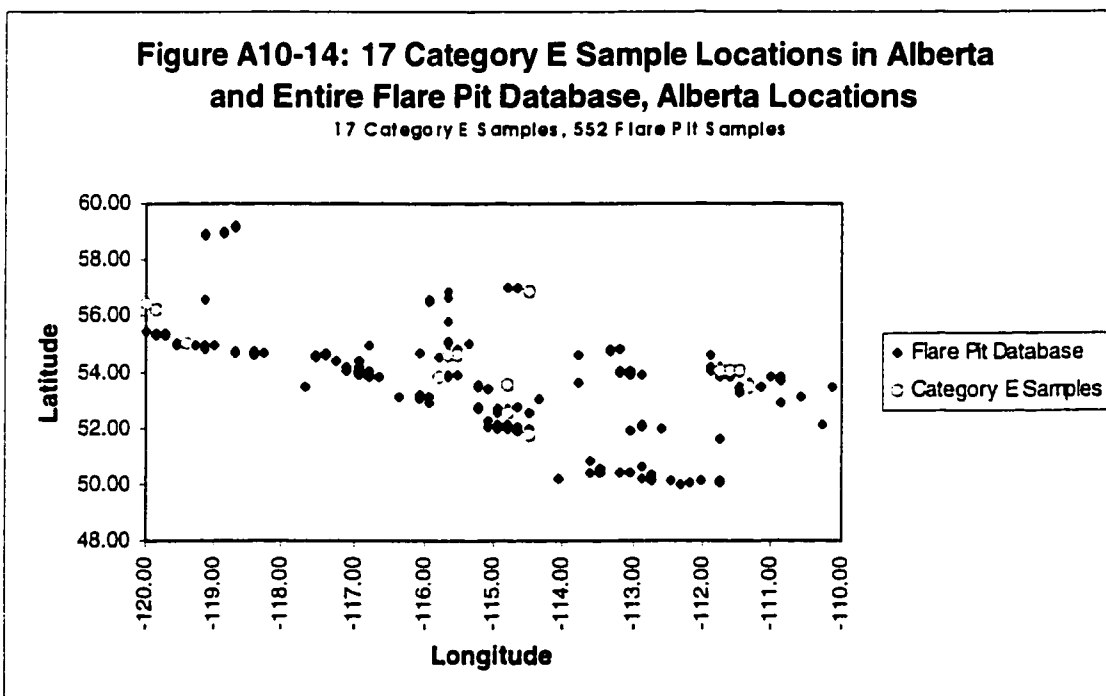


Figure A10-15
Category E Sample Locations

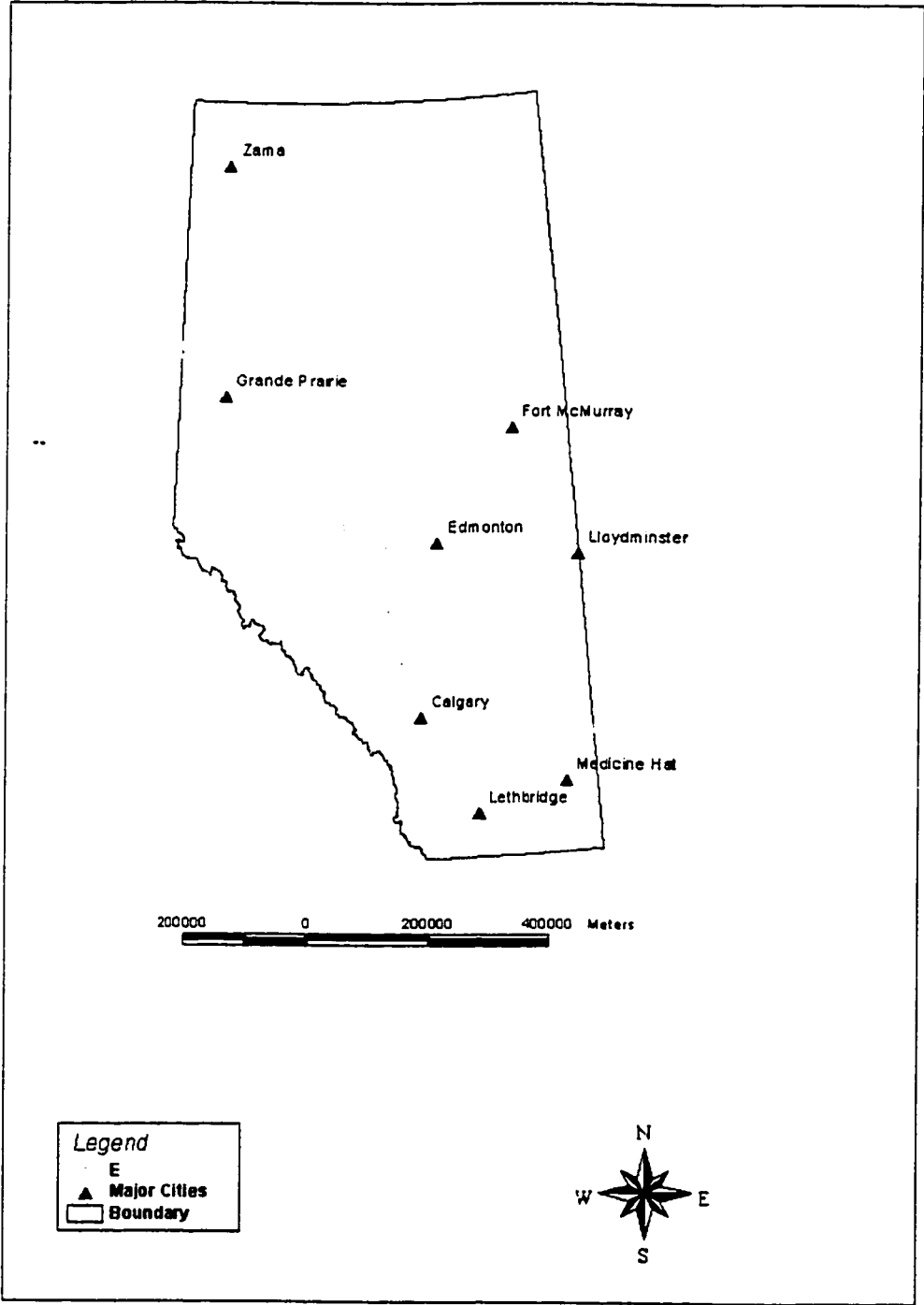
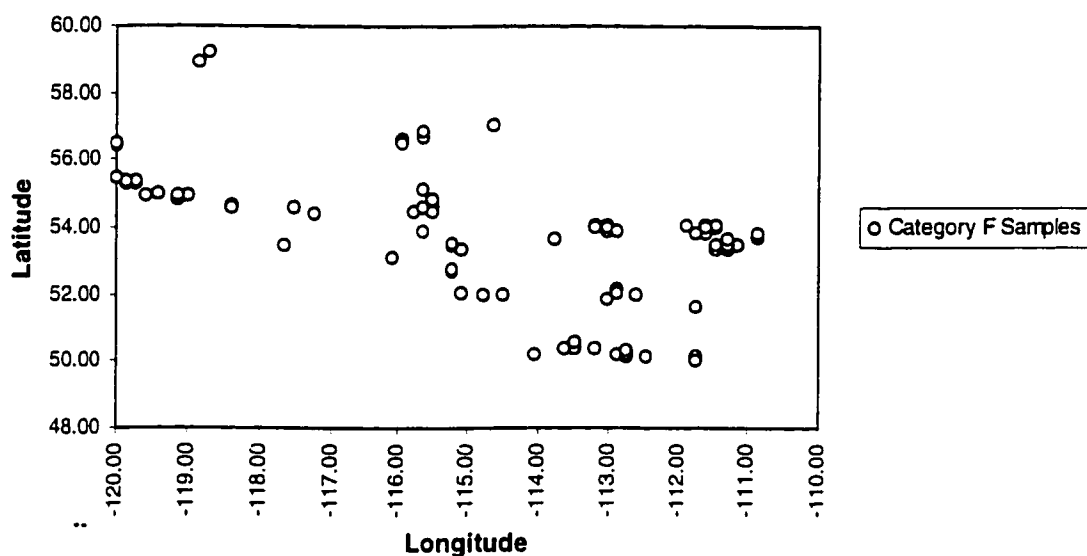


Figure A10-16: 146 Category F Sample Locations in Alberta**Figure A10-17: 146 Category F Sample Locations in Alberta
and Entire Flare Pit Database, Alberta Locations**

146 Category F Samples, 552 Flare Pit Samples

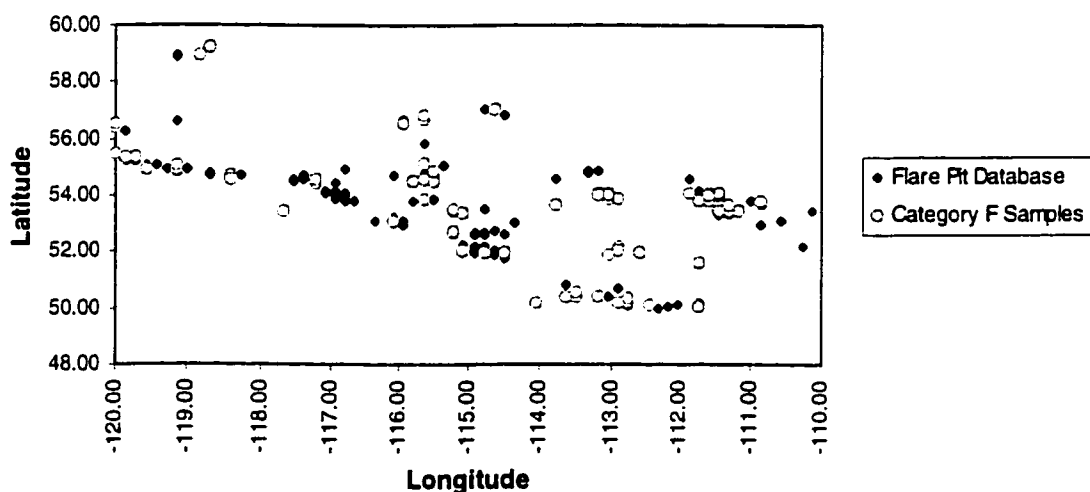


Figure A10-18
Category F Sample Locations

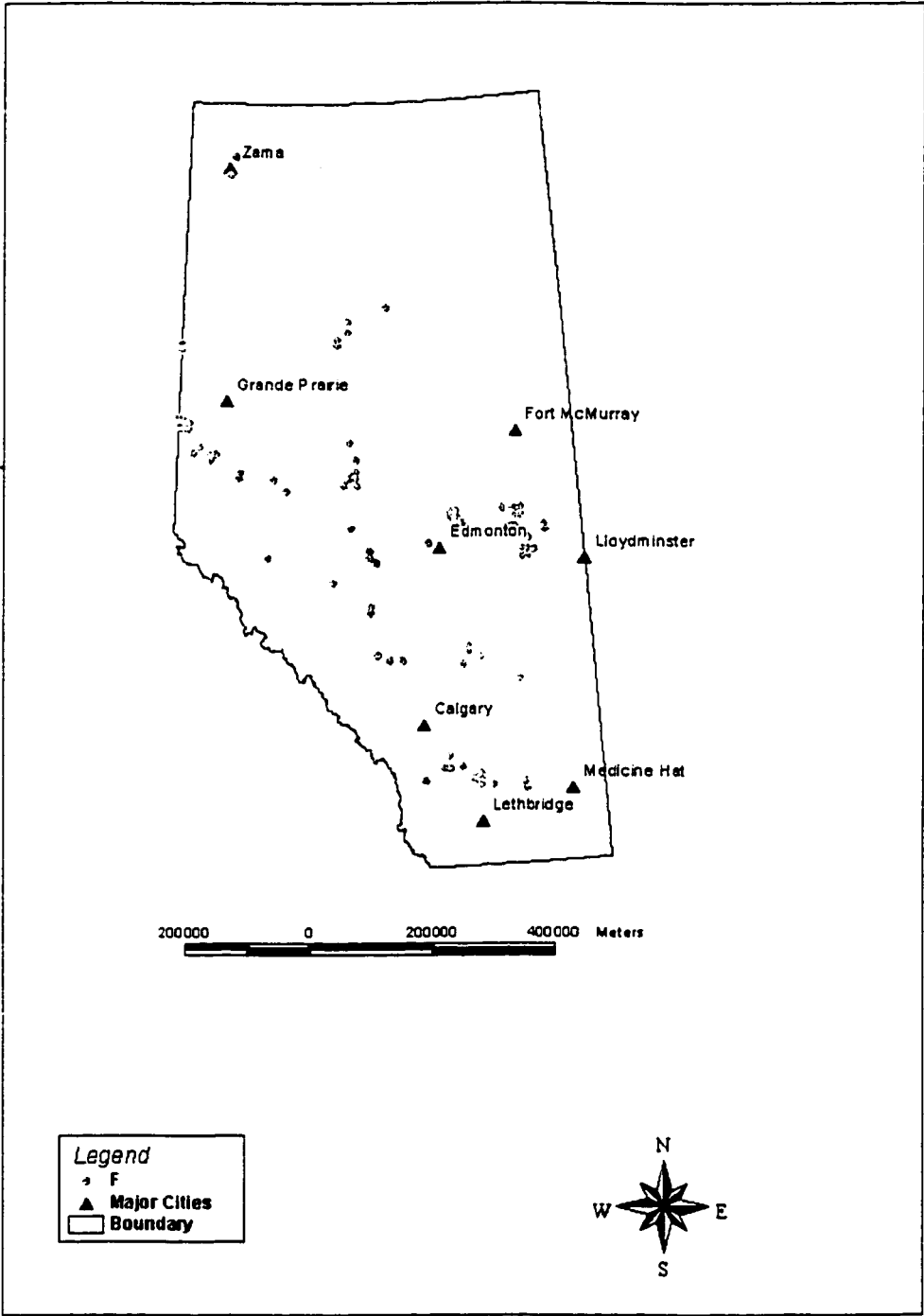
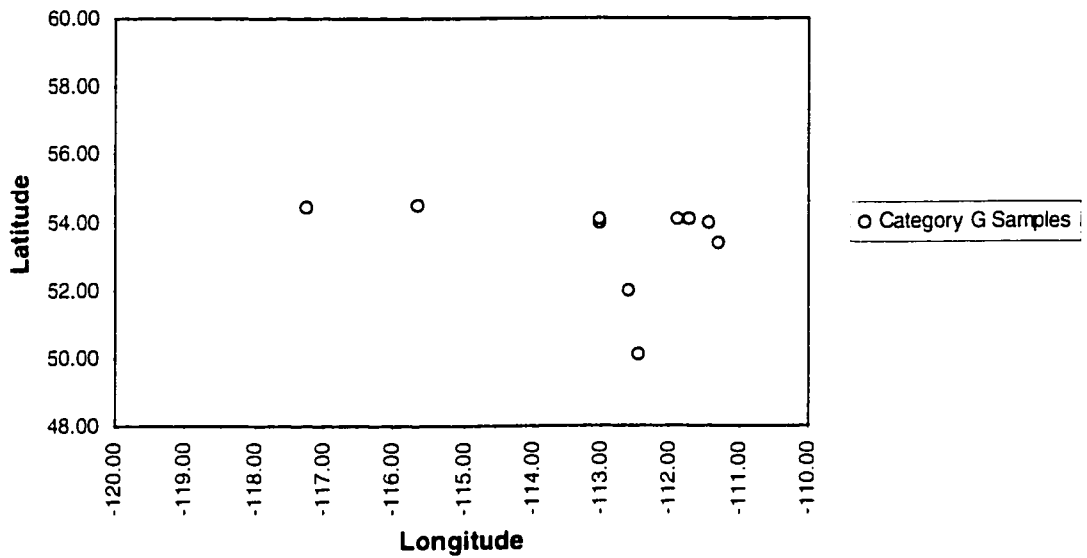


Figure A10-19: 11 Category G Sample Locations in Alberta**Figure A10-20: 11 Category G Sample Locations in Alberta
and Entire Flare Pit Database, Alberta Locations**

11 Category G Samples, 552 Flare Pit Samples

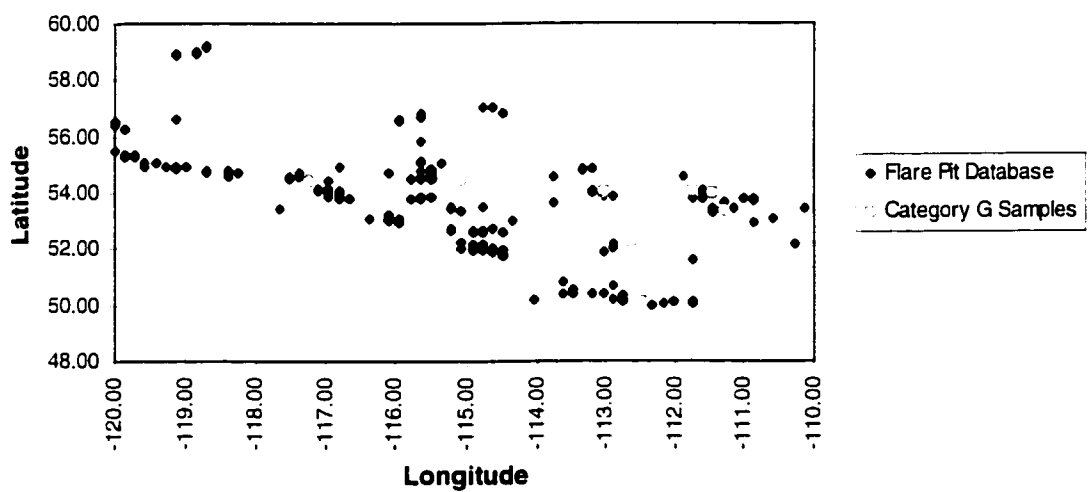


Figure A10-21
Category G Sample Locations

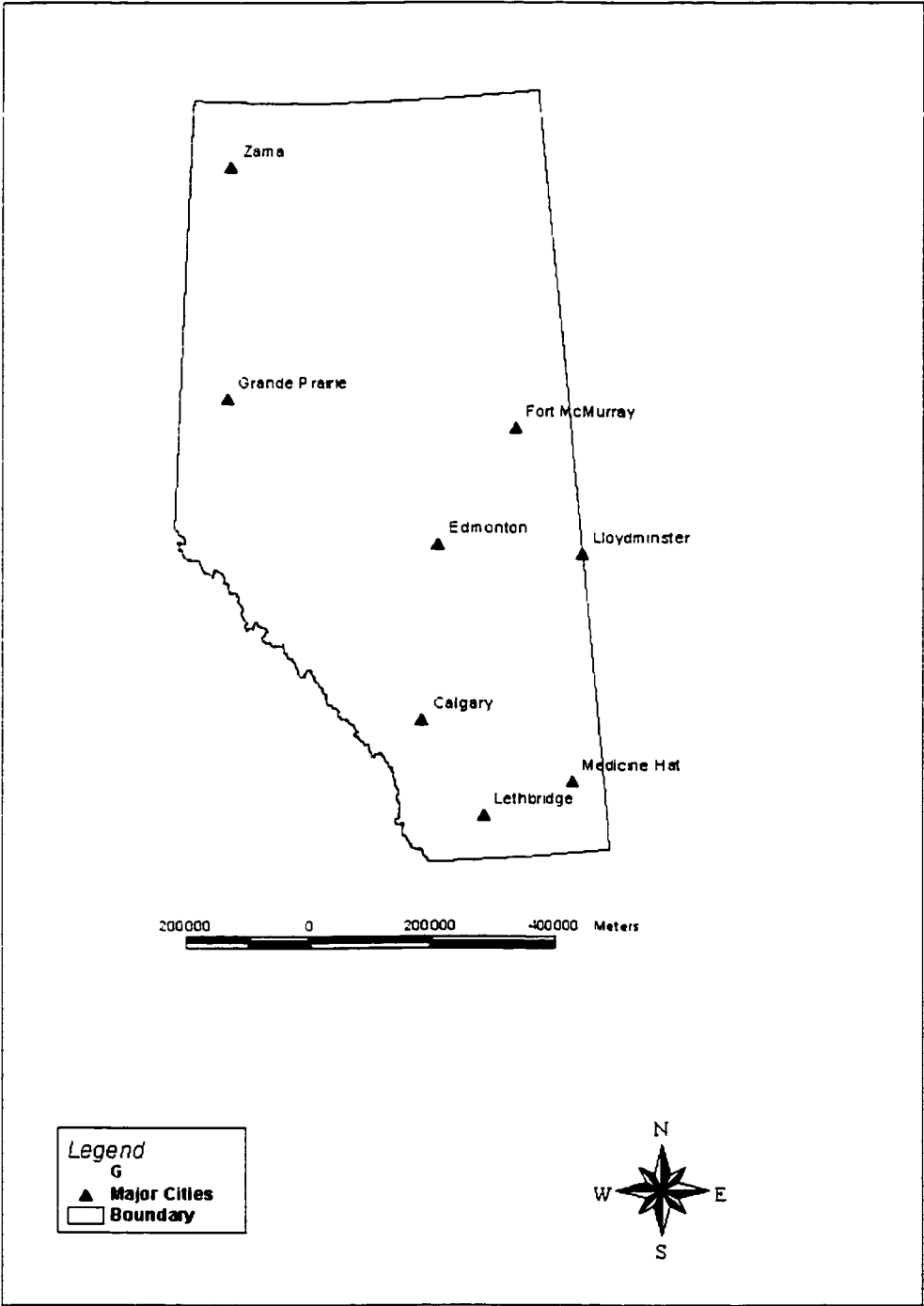
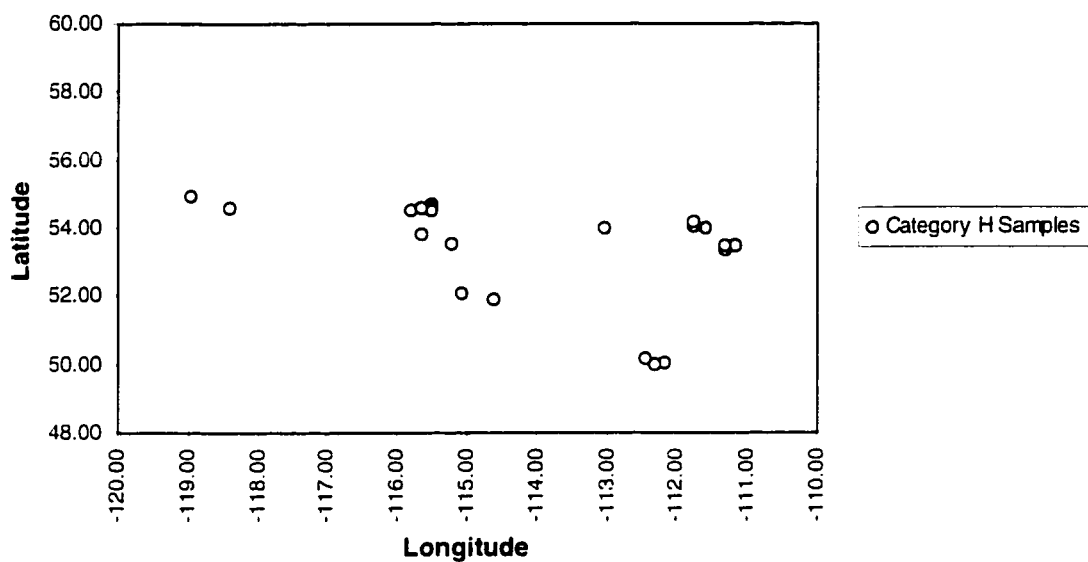


Figure A10-22: 32 Category H Sample Locations in Alberta**Figure A10-23: 32 Category H Sample Locations in Alberta and Entire Flare Pit Database, Alberta Locations**

32 Category H Samples, 552 Flare Pit Samples

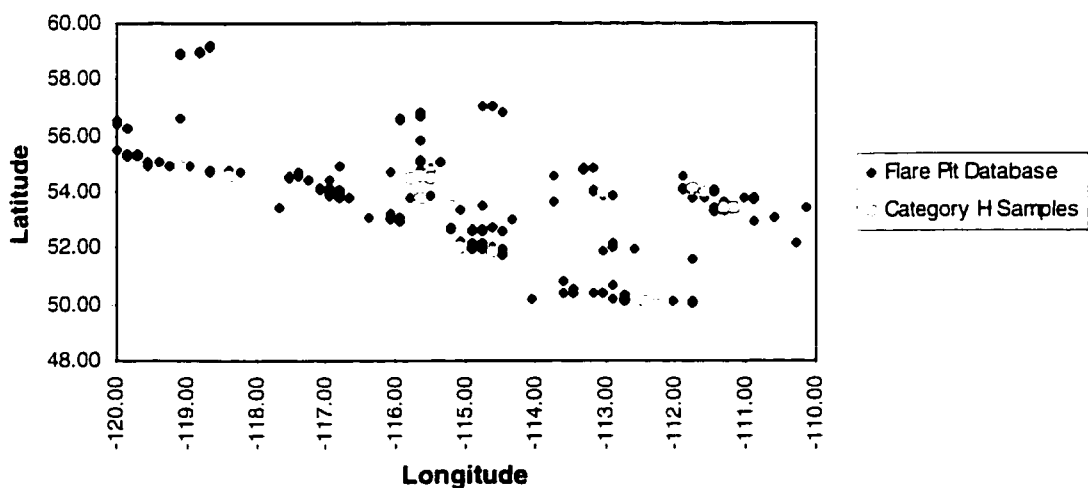


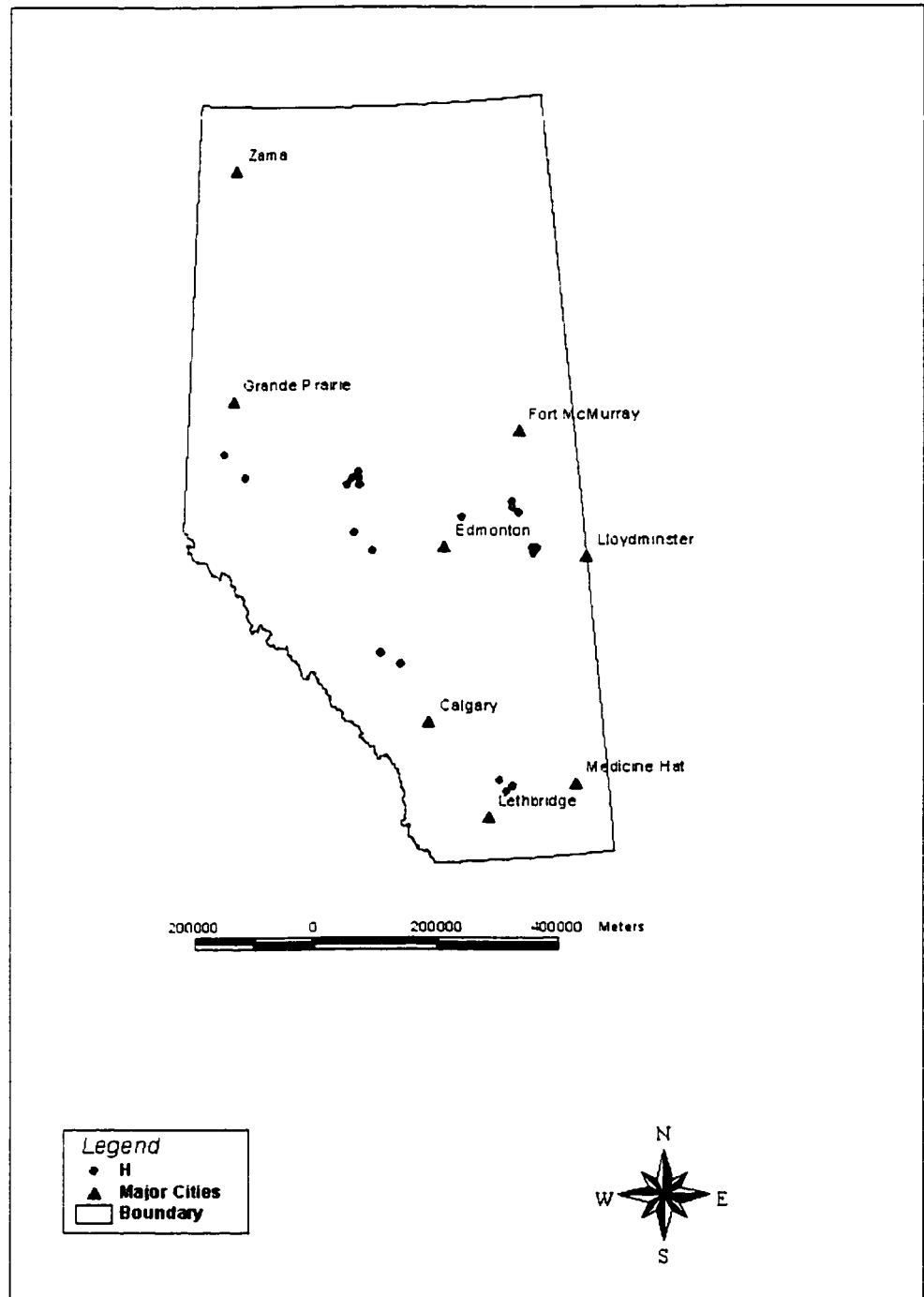
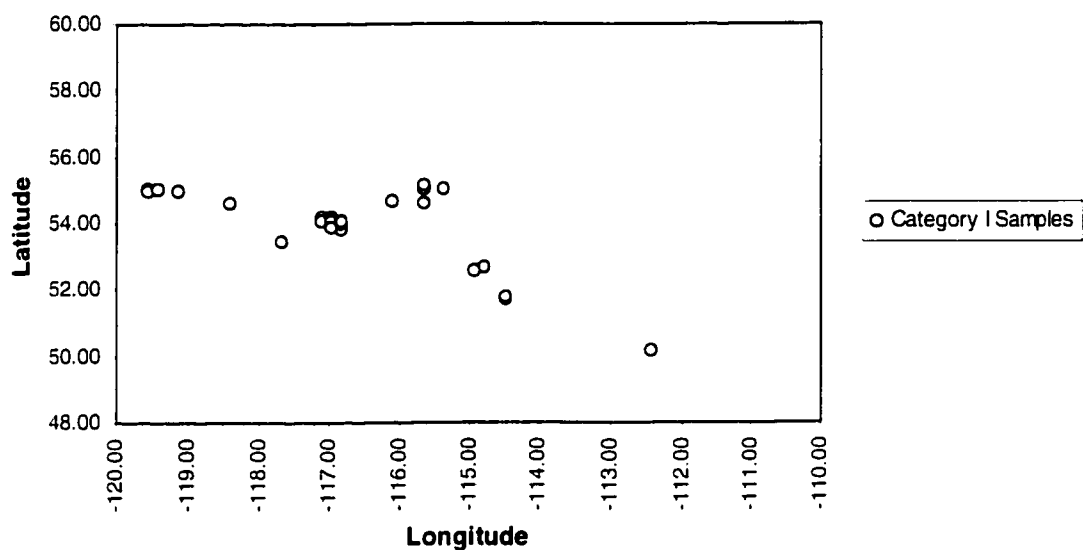
Figure A10-24**Category H Sample Locations**

Figure A10-25: 43 Category I Sample Locations in Alberta**Figure A10-26: 43 Category I Sample Locations in Alberta and Entire Flare Pit Database, Alberta Locations**

43 category I, 8 Samples, 552 Flare Pit Samples

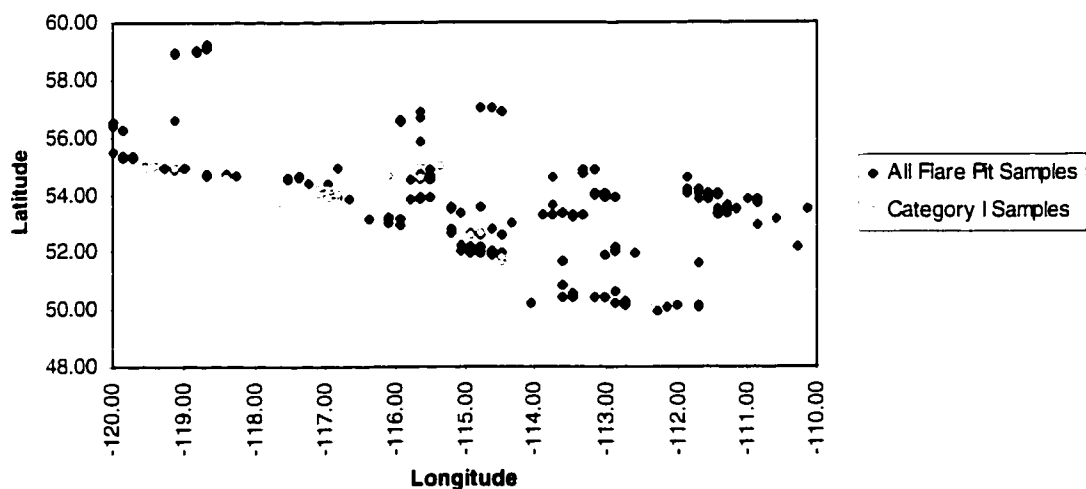


Figure A10-27
Category I Sample Locations

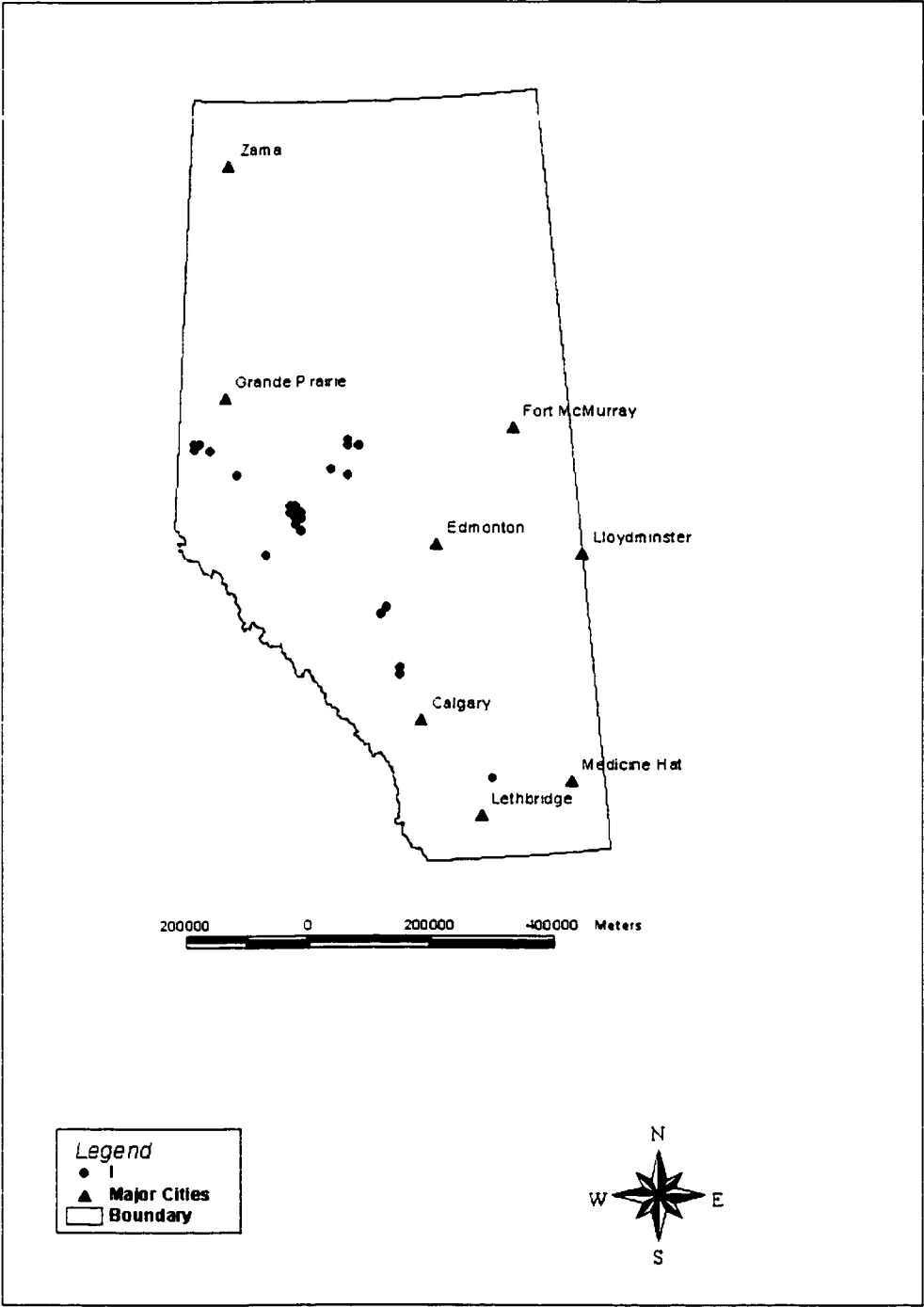
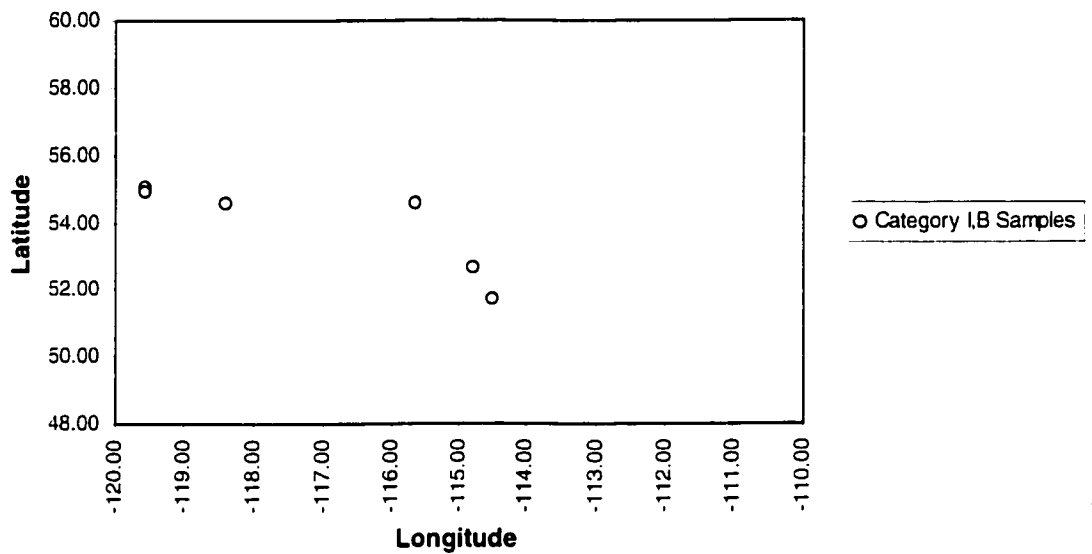
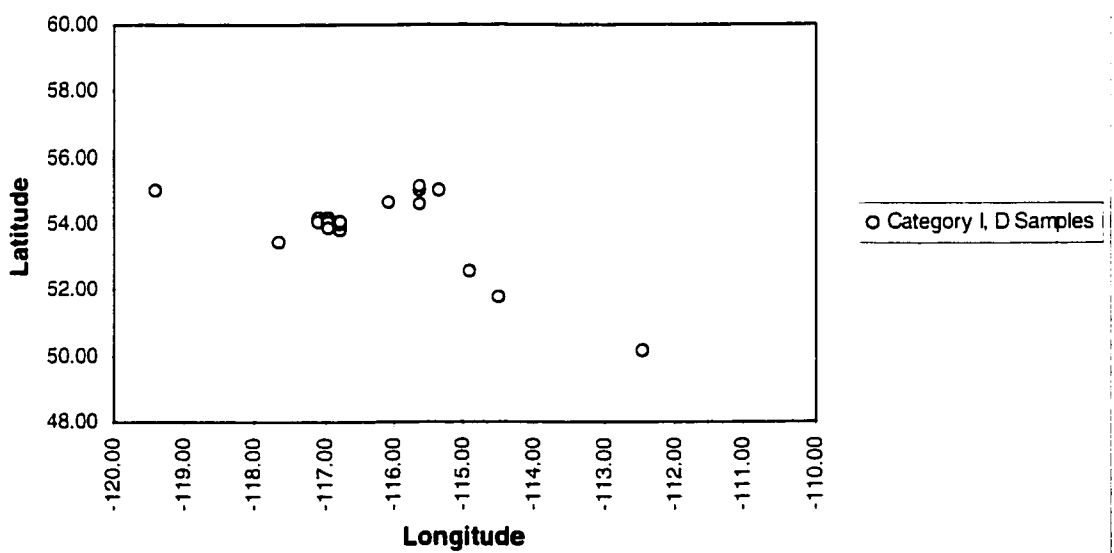
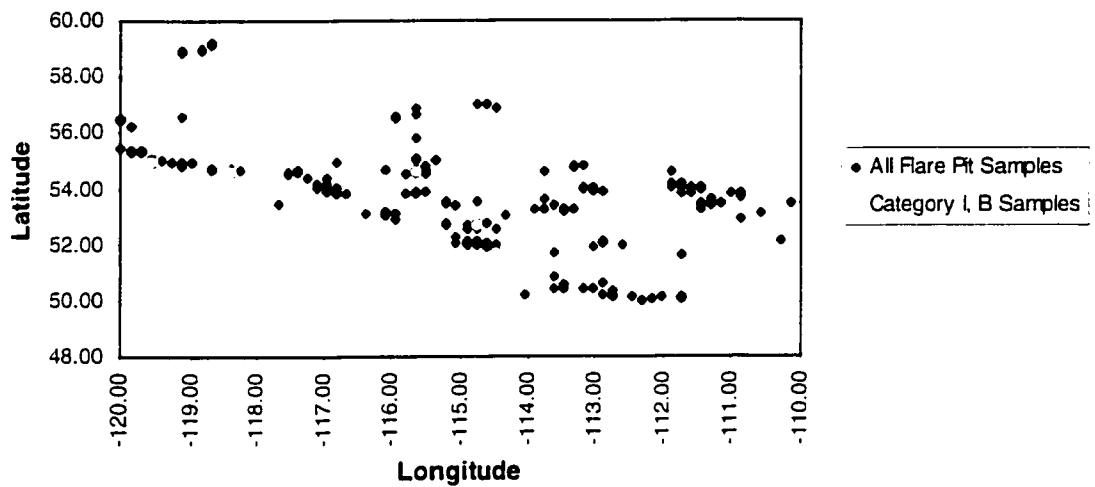


Figure A10-28: 6 Category I, B Sample Locations in Alberta**Figure A10-29: 36 Category I, D Sample Locations in Alberta**

**Figure A10-30: 6 Category I,B Sample Locations in Alberta
and Entire Flare Pit Database, Alberta Locations**
6 category I, B Samples, 552 Flare Pit Samples



**Figure A9-31: 36 Category I, D Sample Locations in Alberta
and Entire Flare Pit Database, Alberta Locations**
36 category I,D Samples, 552 Flare Pit Samples

