CHEMICAL AND PHYSICAL CHARACTERIZATION OF BOTTOM ASH FROM THE BURNABY INCINERATOR

By

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B. Eng. Sc., University of Western Ontario, 1989

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF APPLIED SCIENCE

in

THE FACULTY OF GRADUATE STUDIES

DEPARTMENT OF CIVIL ENGINEERING

We accept this thesis as conforming

to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

November 1995

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Date November 16, 1995

DE-6 (2/88)

ABSTRACT

A ten month field and laboratory study was undertaken to chemically and physically describe desifted bottom ash (i.e. bottom ash without grate siftings) from the Burnaby, British Columbia incinerator. The main purpose of the research was to determine if the removal of grate siftings had any effect on leachable metal concentrations in the residual bottom ash stream. Chemical and physical results from a 1992-93 study of bottom ash that had the siftings removed were compared to a 1991 study that contained the grate siftings.

Field work consisted of sampling bottom ash from September 17, 1992 to March 25, 1993. In total, 252 bottom ash samples were obtained on twelve different days. Each sample consisted of fine fractions of bottom ash which were less than 9.5 mm (3/8") and coarse fractions which were greater than 9.5 mm (3/8"). During the same time period 180 grate siftings samples were collected with particle sizes less than 12.5 mm (1/2").

American Society for Testing and Materials (ASTM) methods were used to evaluate the physical characteristics of the desifted bottom ash. Desifted bottom ash was determined to be a well graded material with consistent physical properties. Compaction densities were constant over the long term. Optimum Proctor densities ranged between 1.87 to 1.91 g/cm^3 at water contents of approximately 12%. Physical testing included sorting the coarse fractions of ash into ten different categories to analyze its composition. The three coarser fractions of bottom ash examined consisted primarily of glass and glass mixtures, averaging approximately 35% by weight, followed by ferrous materials (25%).

The chemical characteristics and leaching potential of the finer fractions of desifted bottom ash and grate siftings less than a 9.5 mm sieve were tested. Samples were subjected to a Leachate Extraction Procedure (LEP), as outlined in the Special Waste Regulations governed by British Columbia's Ministry of the Environment, Lands and Parks (MOELP). It was determined that lead is the only metal of regulatory concern. Other metals tested for were: cadmium, chromium, copper, iron, manganese, nickel and zinc.

It was determined that the desifted bottom ash without grate siftings is not a Special Waste. However, when the ash was graded into different size fractions, leachable heavy metals were observed at higher concentrations in the finer fractions of the ash. The lead concentrations were high enough in the > 4.75 mm and > 2.36 mm fractions to be of regulatory concern. On several occasions, all three fractions had samples or grabs which failed the Leachate Extraction Procedure (LEP). If the desifted bottom ash stream is separated into different size fractions and small volumes are sampled from individual fractions there are Special Waste implications. Certain fractions of grate siftings are of regulatory concern and do not pass the (LEP).

Sixty, seventy, and eighty percent reductions in leachable lead were observed in the > 9.5 mm , > 4.75 mm , and > 2.36 mm fractions of bottom ash respectively when comparing the 1991 and 1992-93 LEP data. Mass balance calculations show that the removal of grate siftings from the bottom ash cannot fully account for the reduced lead levels because only 38% of the leachable lead can be attributed to the grate siftings. What is significant is that 38% of the leachable lead originates from the grate siftings which are approximately 6.1% by weight of the bottom ash stream. This suggests that lead partitions to the grate siftings.

Copper and zinc also partition to the grate siftings. The grate siftings are not a significant source of leachable copper because approximately 2% of the leachable copper present in bottom ash can be attributed to the grate siftings. The grate siftings are a "concentrated" source of leachable zinc because approximately 45% of it comes from the siftings.

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ACRONYMS

Acid Neutralizing Capacity	ANC
Aqua Regia Digestion	ARD
American Society for Testing and Materials	ASTM
Bottom Ash	BA
British Columbia	BC
BC Master Municipal Specifications	BCMMS
Code of Federal Regulations	CFR
Desifted Bottom Ash	DBA
Flame Atomic Absorption Spectrophotometry	Flame AA
Grain Size Distribution	GSD
Grate Siftings	GS
Greater Vancouver Regional District	GVRD
Federal Republic of Germany	FRG
Induced Coupled Plasma	ICP
Leachate Extraction Procedure	LEP
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Volatile Fatty Acids	VFA's
Waste Analysis, Sampling, Testing and Evaluation	WASTE
Waste Flow and Recycling Audit	WFRA

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ACKNOWLEDGMENTS

I would like, first of all to thank my parents, Robert and Mary Miller, who through their support have made it possible for me to complete this research.

Secondly, the Greater Vancouver Regional District (GVRD), in particular Mike Stringer, who provided technical support and funding for the research.

Montenay Inc. and the staff at the Burnaby incinerator also need to be recognized for their assistance with sample collection and making space available at the plant for sample storage and processing.

Lastly, the Civil Engineering Department at the University of British Columbia, and in particular Professor Jim Atwater and Susan Harper.

1. INTRODUCTION

1.1 BACKGROUND

Mass burning of Municipal Solid Waste (MSW) is practiced to reduce MSW's volume and weight, preserve landfill capacity, and in most instances, to recover energy (steam). There is also a stabilization of organic waste through the destruction and controlled release of greenhouse gases. Incineration is an option to be considered in an integrated solid waste management plan, but it is essential to realize that the resulting residues are not chemically inert materials. Typically, bottom ash (BA), fly ash, or combined ash streams contain leachable metals and salts that may adversely impact ground water quality if improperly managed. It is important to physically and chemically characterize incineration residuals to ensure that the residues are properly managed and to mitigate environmental concerns associated with the utilization or disposal of the residues.

The Greater Vancouver Regional District's (GVRD) Municipal Solid Waste (MSW) incinerator is located at 5150 Thorne Avenue in Burnaby, British Columbia (Figure 1.1). This facility burned 241,488 tonnes of refuse and generated 45,837 tonnes of bottom ash and 7,321 of fly ash in 1992 (Montenay, 1992). On average, 711 tonnes per day of MSW are incinerated. The plant operated for a total of 339 days in 1992, providing a plant availability of 93%. Figure 1.2 details the flow of incoming MSW and the resulting residual streams. Bottom ash is the heavy residual stream left over after combustion that gets collected at the bottom of the boiler. It is quenched, passed under a magnet to remove ferrous metals, and stored in a bunker at the incinerator. Fly ash is a lighter residual that gets entrained in the flue gases along with lime added to neutralize acid gases. It is collected in the Air Pollution Control (APC) plant. The resulting residues were approximately 22% of the initial weight and 10% of the initial volume of the refuse burned (i.e. 78% weight reduction and 90% volume reduction). Approximately 86% and 14% of the resulting residue is bottom and fly ash respectively. In total 7,825 tonnes of ferrous material was recovered by a magnetic separation system that is in operation at the plant. Of the bottom ash, approximately 6.1% is grate siftings, which are comprised of sand, small stones, pieces of glass and ceramics, and ferrous and non-ferrous metals. Grate siftings are typically less than 12.5 mm in size and small enough to fall through the "grates" which are used to push, agitate, and support the municipal solid waste (MSW) as it is incinerated. The residue from the Burnaby incinerator is classified as "well burned-out", a term coined by Collins (1978), meaning it has a low carbon content. Subsequent sections in the literature review titled "Bottom Ash" and "Grate Siftings" provide greater detail about these residues and their source in the incineration process.

This thesis is a continuation of work done previously by Ting (1994) for the GVRD. Ting's field work done in 1991 included the characterization and chemical analysis of bottom ash from the Burnaby Incinerator. The regular bottom ash (RBA) examined, during the period between January 2, 1991 to December 17, 1991 included grate siftings (GS). Under normal incineration operation bottom ash contains grate siftings. The desifted bottom ash (DBA) studied for this thesis, between September 17, 1992 to March 25, 1993, had the grate siftings (GS) removed. Grate siftings were diverted from the bottom ash stream and then analyzed independently of the bottom ash. Previous studies, for example the WASTE Program (1992), have shown that the grate siftings contain concentrated heavy metals like lead.

Grate siftings are thought to be a concentrated source of certain heavy metals, in particular lead, because some metals' melting temperatures are below grate bed temperatures which results in the liquefaction and passage of certain metals through the grates. Grate siftings, which make up 6.1% by weight of the bottom ash stream, may contribute a greater proportion of leachable and/or total metals to the bottom ash stream if heavy metals concentrate in the siftings. If so, it may be possible to divert the siftings to mitigate regulatory and environmental concerns.

The 1991 Grain Size Distribution (GSD) and Leachate Extraction Procedure (LEP) results for regular bottom ash (RBA) were obtained from Ting (1994). At the time of writing this thesis only Ting's results were available and no data interpretation had been done. It was necessary for the author to process Ting's results as well as the results from the 1992-93 study. This allowed the author to make comparisons between the two data sets and comment on the effect of removing the grate siftings from the bottom ash stream.

Information describing the waste going to the Burnaby Incinerator has been included in the literature review in the "FEEDSTOCK" section. The origin of the wastes streams must be identified because bottom ash from two different time periods is being compared and waste origins could be a potential source of variability. The composition of the incoming waste must be considered because the type of material incinerated will dictate what type of residuals are generated. Physical test results from the two studies will be easy to compare. If the residuals from the 1991 and 1992-93 studies are physically similar then their grain size distributions and their composition should be similar. Metal leachabilities and total metal concentrations will tell us if bottom ash from the 1991 and 1992-93 studies is chemically different.

Bottom ash from the Burnaby Incinerator is currently going to the Port Mann Landfill (PML) and is being used to build roads and as intermediate cover.

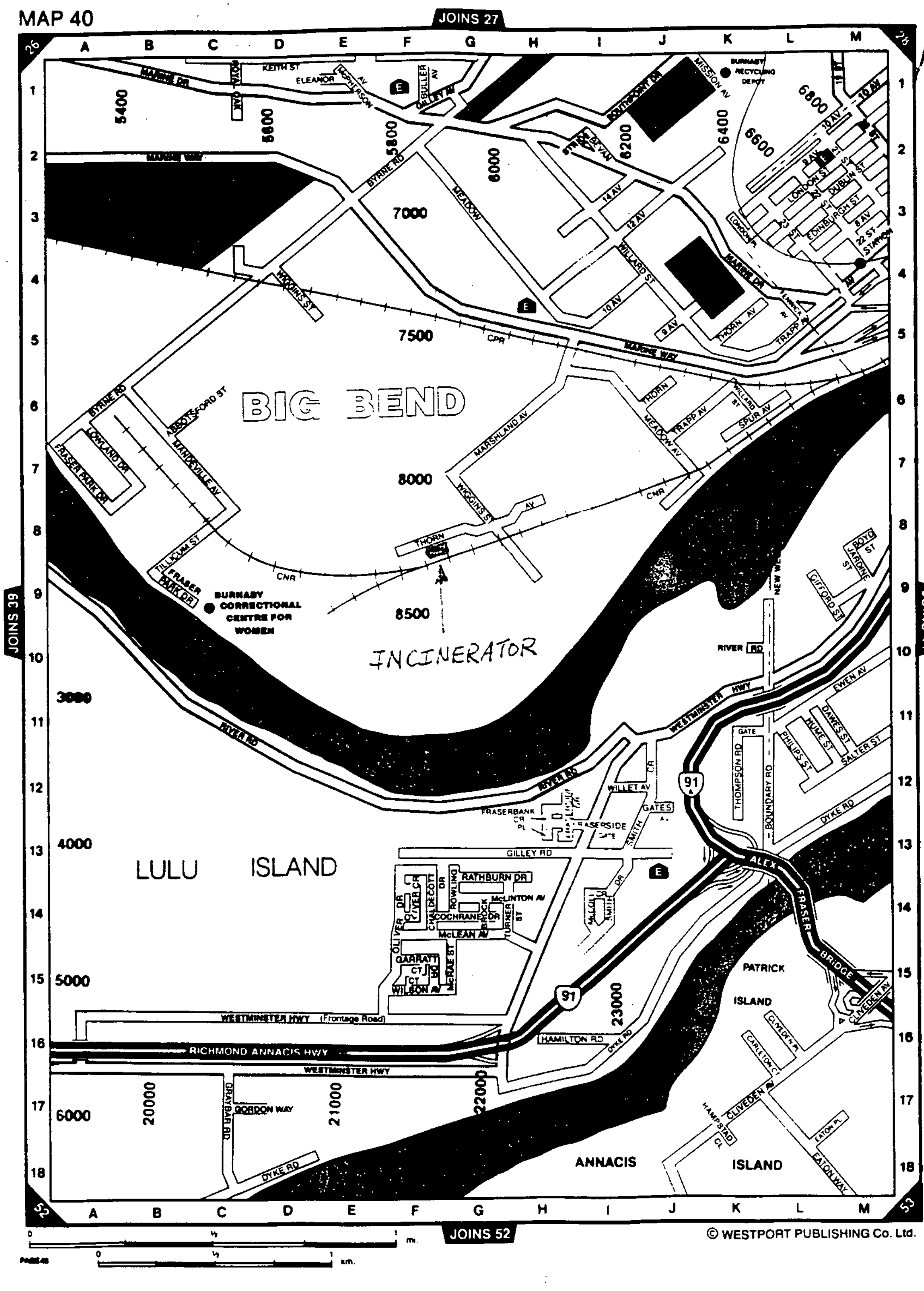
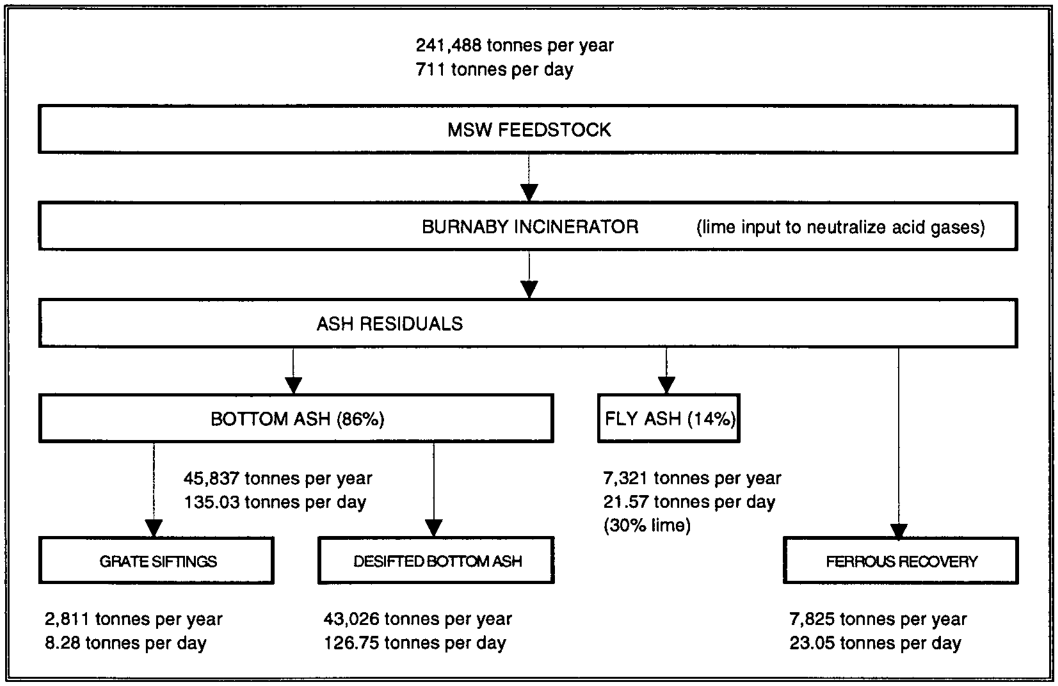


Figure 1.1 LOCATION OF THE BURNABY INCINERATOR WITHIN THE LOWER MAINLAND



NOTES:
(1) Excludes APC Plant air emissions (ie stack)
(2) Grates Siftings flow rates determined as part of thesis

Figure 1.2 FLOW OF MSW AND RESIDUALS AT THE BURNABY INCINERATOR

1.1.1 HISTORICAL DEFICIENCIES WITH ASH STUDIES

This thesis provides some of the information required to make better ash management and utilization decisions based on almost three years of bottom ash data from the Burnaby Incinerator. There has been very little work done on grate siftings as a separate incineration residual stream, creating a major deficiency in the body of knowledge available about incineration residuals and it is this lack of information about grate siftings that has created the need for this research. A detailed long term examination or characterization of bottom ash and grate siftings establishing it's physical and chemical properties for potential utilization has never been carried out. Typically, one or two days of sampling with subsequent compositing, mixing, and analysis of the samples has been used to describe MSW incinerator ash. This procedure may provide misleading and inaccurate information in light of the fact that there may be variable feedstock, seasonal variation, and variable incinerator performance.

The information available today from different sources is not easily comparable because of the different waste characteristics, incineration technologies, processes, and test methods used. **Therefore, it is necessary to examine incinerators and their residuals on a plant by plant basis**. The environmental regulatory framework we have today has necessitated that a great deal of sampling, testing, and laboratory work be performed in order to characterize incinerator residue and this is a problem because it is extremely costly. Also, the test methods and criteria that regulators use to measure a residues potential environmental impact do not accurately reflect what happens in the field. This can lead to mismanagement of incineration residues.

Another problem is that there are many different incineration and air pollution control technologies in use today, utilizing different processes such as wet vs. dry scrubbing, primary and secondary combustion, and bag houses vs. electrostatic precipitators, to mention a few. Different technologies make consistent characterization and regulation of incineration residues extremely difficult. To complicate residuals studies and management further, there are a whole host of residuals combinations such as bottom ash on its own, fly ash on its own, and/or a combination of the two. The array of different regulatory tests that are available and legislated has further complicated the residuals management issue.

The number of samples taken that are used to describe a residuals' characteristics is important. Often, in the past a large enough sample set has not been analyzed to statistically and correctly describe the incineration residuals from a RIP. Economic, operational, and time restraints limit the duration and number of samples. In order to obtain the information to facilitate the appropriate environmental management and disposal of incineration residues it is necessary to study residual streams over the long-term.

Industry and government have been moving ahead to address environmental issues, concerns, and problems. There is a continual push for more definite regulations for the disposal of incineration residues. Several factors contributing to the push for more definitive regulations (Sawell et al, 1990) are:

- Residue sampling and analytical protocols have not been well established, thereby compounding the variability of data.
- The inherent variability of ash characteristics results in often contradictory laboratory results.
- Different combustion technologies and air pollution control systems produce additional variations in the data base, on an incinerator by incinerator basis.
- Because the issue of potential groundwater contamination through improper ash disposal was considered minor for many years, cursory studies provided an inadequate data base.
- In addition to immediate environmental impacts, the management of these residues must consider the contentious issue of potential long-term effects.

1.2 OBJECTIVES OF STUDY

This study was undertaken to examine the physical and chemical characteristics of the residual bottom ash stream at the Burnaby Incinerator in greater detail than previous studies have. This improves the data base of information concerning bottom ash's physical and chemical characteristics. Including the above, the objectives of this study are to:

- Determine what the physical properties of bottom ash are by using ASTM standard test procedures in order to determine if bottom ash can be used to replace natural aggregates for certain applications. Compare physical test results to British Columbia's Master Municipal Specifications (1991) and use these specifications to judge bottom ash's usefulness in BC. ASTM standards are used in BC to set minimum material requirements for aggregates or substitutes.
- Determine the composition of the coarser fractions of bottom ash (percent by weight basis).
- Determine what the chemical leaching characteristics of desifted bottom ash and grate siftings are by using BCMOELP's Leachate Extraction Procedure (LEP) for the fine fractions examined.
- Quantify the mass generation rate of grate siftings.
- Quantify the contribution of heavy metals from the grate siftings to the bottom ash residual stream using the leachable heavy metal concentrations and the mass generation rate for the grate siftings.
- Investigate the impact that removing the grate siftings from the bottom ash stream has on leachable metal concentrations. The removal and separate analysis of the grate siftings may provide more insight into the speciation and partitioning of metals within the ash stream.
- Determine if the removal of grate siftings results in a better product or residual with fewer regulatory concerns when considering physical and chemical results.
- Provide and summarize detailed information about the physical and chemical properties of bottom ash and grate siftings to ensure their proper management.

- Determine if metals, for example lead, concentrate in certain fractions of bottom ash or grate siftings, and if so, do they constitute a regulatory concern.
- Suggest how grate siftings should be managed if they are of regulatory concern (Special Waste), and if they should be removed or diverted from the bottom ash stream,.
- Recombine 1992-93 desifted bottom ash and grate sifting leachable metal concentration results on a mass basis, and then compare these results to the work done on regular bottom ash (RBA) in 1991.
- Comment on the LEP testing regime used and determine if the results represent the material being examined and if the results have a direct correlation with an identified impact (i.e. soluble metal or salt release).
- Provide some insight into how certain heavy metals partition between the different fractions of desifted bottom ash and grate siftings.
- Recommend whether or not the grate siftings should be removed from the bottom ash stream and if the bottom ash or grate siftings streams should be separated into several different size fractions.
- Recommend long term utilization and management opportunities for bottom ash and grate siftings. The current option of landfilling the Burnaby Incinerator bottom ash at the Port Mann Landfill (PML) in Surrey, BC will end within 5 years once the landfill closes.

A thorough understanding of the physical, chemical, and structural properties of ash is required to estimate potential environmental threats from these materials and to develop appropriate management strategies (Ontiveros et al,1989).

1.2.1 GENERAL OBJECTIVES OF ENVIRONMENTAL STUDIES

According to Gilbert (1987), the purpose of environmental pollution studies is one, some, or all of the following:

- Assess the adequacy of controls on the release or containment of pollutants.
- Detect long-term trends, unplanned releases, or accidents and their causes.
- Provide a spatial or temporal summary of average or extreme conditions.
- Demonstrate or enforce compliance with emission or ambient standards.
- Establish base-line data for future reference and long-range planning.
- Indicate whether and to what extent additional information is required.
- Assure the public that effluent releases or environmental levels are being adequately controlled.

- Use the information obtained from studies to make utilization and/or disposal recommendations.

1.3 SCOPE OF INVESTIGATION

To satisfy the objectives mentioned above, a 7 month field project was undertaken beginning in September of 1992 and finishing in March of 1993. The field study consisted of sampling bottom ash and grate siftings from the Burnaby Incinerator. In total, 252 bottom ash and 180 grate siftings samples were obtained on twelve different sampling days. A large sampling of residuals over a prolonged time period was undertaken to provide validity and confidence in the test results.

Desifted bottom ash (DBA) was obtained from the end of a vibratory discharge conveyor after it had passed underneath a magnetic belt separator to remove ferrous material. Grate siftings were obtained from discharge ducts that run alongside and underneath the boiler.

American Society for Testing and Materials (ASTM) requirements governing the amount of sample to collect based on the particle sizes of the residuals were followed. The laboratory study consisted of using ASTM test methods to evaluate the physical characteristics of the desifted bottom ash and grate siftings. ASTM standard test methods were used because incineration residuals are similar, from a material properties point of view, to natural aggregates. Literature reviewed quite often cites the same ASTM standards that were used in this study. The grain size distributions (GSD) of the desifted bottom ash and the grate siftings were determined at the incinerator using scales and a sieve machine. The desifted bottom ash was graded into the following fractions:

i) > 50 mm (2")
ii) < 50 mm (2")
iii) < 25 mm (1")
iv) < 12.5 mm (1/2")
v) < 9.5 mm (3/8")
vi) < 4.75 mm (No.4)
vii) < 2.36 mm (No.8)

Similarly, the grate siftings were graded into the following fractions:

i) > 12.5 mm (1/2")
ii) < 12.5 mm (1/2")
iii) < 9.5 mm (3/8")
iv) < 4.75 mm (No.4)
v) < 2.36 mm (No.8)

Compaction density tests were performed by the author in the UBC soils lab and also by Terra Engineering Ltd., an independent materials/geotechnical engineering firm located in Burnaby, BC.

The composition of the coarser fractions of DBA were determined by sorting and classifying the ash into one of ten different material categories. The categories used for this study were:

i) Magnetic
ii) Other (non identifiable)
iii) Rock
iv) Porcelain and Tile
v) Concrete
vi) Brick
vii) Paper and Wood
viii) Non-ferrous Metals
ix) Glass
x) Glass Mixtures

The British Columbia Ministry of the Environment, Lands, and Parks (BC MOELP) Leachate Extraction Procedure (LEP) was used to examine the leachable metals concentrations in desifted bottom ash and grate siftings. In all cases the finest three fractions of DBA and GS were used, specifically the < 9.5 mm (P3/8"), < 4.75 mm (P4), and < 2.36 mm (P8) fractions. The LEPs and subsequent metals analysis for desifted bottom ash were performed in UBC's Environmental Engineering Laboratory. After the LEPs were completed the solids remaining were subjected to an Aqua Regia Digestion (ARD). All of the ARDs (i.e. for both desifted bottom ash and grate siftings) were done by Quanta Trace Laboratories, Burnaby, BC. Quanta Trace did all of the analysis on the grate siftings, including the initial LEP. The leachates and digestions were analyzed for the following eight heavy metals:

i) cadmium (Cd)
ii) chromium (Cr)
iii) copper (Cu)
iv) iron (Fe)
v) manganese (Mn)
vi) nickel (Ni)
vii) lead (Pb)
viii) zinc (Zn)

1.4 SCOPE OF CONTENTS

A large literature review was undertaken as part of this thesis because of the number of different topics that had to be addressed concerning incineration residuals and their management, utilization, or disposal. The literature review first describes a number of items dealing specifically with the Burnaby Incinerator. For example, the feedstock or waste burned, the incinerator's design, and the residuals that are generated are described. Following this, physical and chemical test procedures and results are presented. ASTM tests that are applicable to this study are mentioned as are some leachate extraction procedures. Results from other research already done, both at the Burnaby Incinerator and off site using the residuals, are highlighted. Analytical and statistical methods used for this study are covered. The final portion of the literature review discusses the utilization of incineration residuals.

The field, laboratory, and statistical methods used in this study are discussed in the "Material and Methods" chapter in detail.

The physical test results for coarse bottom ash fractions are presented in the "Results and Discussion" chapter. This includes grain size distribution, characterization, and compaction - density results. A sample calculation to familiarize the reader with the process used to analyze the chemical, metal leachate data is given in this chapter. Chemical results are associated with the fine fractions of ash and grate siftings. All leachable metals concentration data was normalized and interpreted in the same way. Bottom ash test results are presented, followed by grate siftings results. The Leachate Extraction Procedure (LEP) results are listed followed by the Aqua Regia Digestions (ARD) of the LEP solids.

Comparisons are made between the 1991 and 1992-93 results where similar procedures were used. This chapter ends by comparing results from the analysis and suggesting appropriate ash management options.

The raw tabulated leachable concentration data, statistical results, clerical data entry forms, and "P", "T", and "Z" values used for Z-Score plots are presented in the Appendices. Tables containing the descriptive statistics and the Z-Score plots used to check metals data for normalcy are also included. The appendices for this thesis are bound in a separate volume and copies may be obtained from the author, the UBC library, the GVRD's Solid Waste Department, or Professor Jim Atwater from the UBC Civil Engineering Department.

2. LITERATURE REVIEW

The Literature Review is presented to provide available background information about incineration residuals, the incineration process, previous leachate studies and test results, some of the regulations that govern bottom ash disposal and utilization, and test methods used.

The topics covered as part of this literature review include:

- advantages of mass-burn incineration
- the feedstock going to the Burnaby Incinerator
- the incinerators location and layout
- a detailed description of incineration residuals, specifically bottom ash and grate siftings
- flux of metals and partitioning of metals through the incineration process
- Grain Size Distribution (GSD) and physical properties
- previous heavy metal spiking experiments
- leachate tests (column vs. batch)
- Leachate Extraction Procedure (LEP)
- chemical composition of incineration residuals
- leachate studies of monofilled ash
- test methods used to chemically and physically characterize bottom ash
- bottom ash utilization

Work done in the past has been referenced wherever possible and compared to the results presented here. One key point to be made is that for most facilities in the past, in the United States in particular, all residue streams (i.e. bottom, fly, and boiler ash and grate siftings) were disposed of together into what was commonly called "combined ash". In most literature reviewed this "combined ash" is also referred to as incineration or incinerator residue or residuals. Therefore, one cannot directly compare, for example, bottom ash lead LEP values to "combined ash" or "incineration residuals" lead LEP values. It is now more common for incineration residual streams to be managed separately because each stream has different physical and chemical characteristics. This has caused some residuals management problems, while appropriate uses or disposal options were explored. If grate siftings are to be removed from the bottom ash stream the same types of management, utilization, and/or disposal questions have to be addressed.

An addition to the reasons already given for examining incineration residuals on a plant by plant basis is that individual incinerators receive waste from different geographical areas with varying proportions of waste originating from commercial and residential sectors of the economy. This variation in "FEEDSTOCKS" means that it may be inappropriate to compare incineration residual test results from one facility to another. Origins of the MSW going to the Burnaby Incinerator will be given.

A summary of physical and chemical characteristics will be compiled from the available literature and compared to the results obtained with this thesis.

2.1 ADVANTAGES OF MASS BURN INCINERATION

A list of advantages of mass burn incineration is offered as background and answers the question "Why do we incinerate MSW?". Beckman (1986) provide a comprehensive and detailed list of fourteen advantages of mass burning MSW. It is as follows:

1) "The technology is well proven.

2) The end product is solid, odorless, completely inert, small volume, and ideal for landfilling.

3) There is very little pre-handling and no presorting of the refuse with associated high investment and maintenance costs for hammer mills or shredders.

4) Thermal energy is recovered equal to one and one-half barrels of oil per ton of waste. This heat is available as high pressure steam for heating, process, or electric power generation.

5) Flue gases are easily freed of dust and/or chemically purified. Existing technology is available to meet the most stringent air quality standards. The fly ash produced may be used for concrete blocks or other construction material.

6) The process is relatively noiseless and odorless, making it acceptable for any industrial type neighborhood.

7) Systems are designed for municipal waste assuring good performance and low maintenance.

8) The grate design of some systems allows the co-firing of coal or sludge from sewage treatment plants.

9) Refractory furnaces ensure stable combustion and even steam production over a wide range of refuse quality.

10) Design of the combustion chamber allows the co-firing of natural gas, oil, or waste oil.

11) Boilers are specifically designed for the particular nature of flue gases from firing municipal waste. Wear, clogging, and corrosion are avoided by using the proper material, tube spacing , gas velocity, and tube cleaning techniques. Reliability of the boilers is outstanding.

12) Ash handling systems provide for a dust-free inert residue, which may be further processed to remove ferrous material and provide a fill material suitable for foundations of roads, parking lots and buildings.

13) The process can be fully automatic and is controlled from a centralized operation room with synoptic panel and closed loop TV.

14) Much attention is given to the architectural aspect of the facility making it acceptable in any industrial neighborhood. Most European plants are located close to populated areas to cut down on hauling costs and reduce steam line runs for central heating systems. Ideally, the plant should be located close to the source of waste and close to the energy customer."

Exception is taken with point #2 because the end products of incineration are not completely inert and must therefore be managed and disposed of properly. This list has been reproduced because it closely fits the site and situation at the Burnaby incinerator. The inherent advantages associated with incineration make it a viable solid waste management alternative to landfilling.

2.2 ORIGINS OF WASTE GOING TO THE BURNABY INCINERATOR

As described by Chandler (1992), the feedstock, or Municipal Solid Waste (MSW) for an incinerator can be considered as coming from a "WASTESHED". The wasteshed that is serviced by the Burnaby incinerator includes direct-hauled wastes from Burnaby, New Westminster, and Paperboard Industries Ltd. and transferred wastes from the North Shore Transfer Station (NSTS) and the Coquitlam Resource

Recovery Plant (RRP). Some waste is also direct hauled from Surrey and Coquitlam. The GVRD's Solid Waste Management Plan "Transfer Summary for Burnaby RIP" documents the flows or tonnage and sources of MSW going to the incinerator. Table 2.1 shows the waste flows in tonnes at the Refuse Incineration Plant (RIP) for the previous three years.

Table 2.1 TRANSFER SUMMARY FOR BURNABY INCINERATOR

TRANSFER OF WASTE GOING TO BURNABY RIP														
TO: BURNABY RIP (tonnes)		YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
FROM:	COQUITLAM RRP	1991	8723	7634	6896	7780	8195	6894	5342	8192	7998	7923	8876	7715
		1992	7495	6618	7501	7044	6474	4771	2325	3007	4269	5387	4057	5658
		1993	5346	4211	6477	6183	5050	5020	3218	4512	4322	4637	5467	5820
	NORTH SHORE DH	1991	5821	4480	6326	6501	6668	6318	6464	6896	6516	6764	6680	5450
		1992	6799	5899	7292	7513	7822	9846	8896	9245	10105	9653	10252	9707
		1993	7954	6532	8065	9516	10348	10365	9237	9653	9244	9096	9480	7120
	SURREY TS	1991	0	0	0	0	0	0	0	0	0	0	0	0
		1992	0	0	0	0	0	0	0	0	0	0	0	0
		1993	0	0	0	0	0	0	0	0	0	0	0	0
	RICHMOND DH	1991	0	0	0	0	0	0	0	0	0	14	34	0
		1992	0	0	0	0	0	0	0	0	0	0	0	0
		1993	0	0	0	0	0	0	0	0	0	0	0	0
	SURREY DH	1991	99	764	439	902	589	798	302	771	755	794	639	385
		1992	306	253	77	56	0	274	592	573	570	480	506	229
		1993	92	532	1123	867	667	391	55	612	349	475	643	450
	BURNABY DH	1991	3817	3613	3438	4442	4857	4288	4920	4520	4635	4684	4455	3793
		1992	4675	3669	4754	4641	5079	4662	4963	4200	4908	5014	5020	4379
		1993	3448	3574	4061	4312	5795	5847	5236	5190	4946	4695	4460	4120
	COQUITLAM DH	1991	0	0	0	0	0	190	187	60	36	60	79	48
		1992	0	31	9	22	55	206	241	199	207	227	254	268
		1993	161	113	213	89	52	51	51	89	53	21	0	130
	NEW WESTMINISTER DH	1991	778	718	673	802	845	738	818	751	754	780	732	696
		1992	780	669	777	782	797	849	918	741	785	746	822	718
		1993	686	644	741	752	833	866	748	746	721	685	751	730
	PAPERBOARD DH	1991	174	106	350	518	719	415	365	416	352	403	419	430
		1992	481	356	401	347	304	685	360	451	320	330	350	300
		1993	665	546	608	668	742	739	751	711	664	595	337	840

SOURCE: SOLID WASTE MANAGEMENT PLAN DATA BASE

2.3 HISTORICAL STUDY DATA DESCRIBING THE COMPOSITION OF MSW

MSW is comprised of combustible and organic fractions (paper, wood, food waste, yard waste, etc.) and non-combustible and inorganic fractions (metals, glass, ceramics, tiles, rocks, etc.). The composition and moisture content of the refuse varies significantly with time, depending on the weather and on the season. The combustible fraction normally represents from 60 to 80 percent by weight of the incoming refuse (Collins,1978).

A number of sorting and sampling studies have been undertaken to estimate the composition of MSW. Four specific studies that are referenced here include:

1) CH2MHILL's "Waste Flow and Recycling Audit" (WFRA) (CH2MHILL,1993)
2) Waste Analysis, Sampling, Testing, and Evaluation (WASTE) Program (1992)
3) Municipal Refuse Statistics for Canadian Communities of Over 100,000 (1976-1977) (Bird and Hale,1979)
4) Work done by Law and Gordon (1979)

CH2MHILL's WFRA (CH2MHILL,1992) done for the GVRD in January 1992 shows that the majority of MSW is organic and combustible. Table 2.2 shows paper and organic material as being 38.60% and 27.90% of the MSW stream respectively, for a total of 66.5%. Because CH2MHILL's audit is specific to the Burnaby Incinerator it will provide the most accurate feedstock data. However, there are limitations to the audit because it was done for one week and only provides a snapshot on the type of waste going to the incinerator.

Results from the WASTE Program carried out at the Burnaby Incinerator during the last week in June, 1991 indicate that 69% of the waste stream is paper and organic. The total of the percentages from the WASTE study shown in Table 2.2 do not equal 100% due to data transformations and rounding (see Volume I, Appendix A, Test Average Sort Data Summary, WASTE Program Consortium, 1992).

Bird and Hale (1979) examined MSW across Canada and reported Canadian and provincial material or commodity percentages. This work was done as part of their study entitled "Municipal Refuse Statistics for Canadian communities of Over 100,000 (1976-1977)". This data is being used for historical comparisons and annual data for both their national and British Columbia studies are listed (Table 2.2). The composition of typical refuse presented by Law and Gordon (1979) in their study "Sources of Metals in Municipal Incinerator Emissions", is interesting because they report an unusually high percentage of paper of 55.20%, which is 20% higher than the other figures listed (Table 2.2).

In general the percentages reported for paper are quite consistent to one another, between roughly 33% to 38%. Plastics use has increased tremendously in packaging in all sectors of the economy and as a result has almost doubled in quantity disposed of from 1979 to 1992-93, making up just under 10% of the MSW stream. The percentages reported for metals vary somewhat, and the variability seems to be associated with the non-ferrous metals. Ferrous metals make up between 6% to 7.5% of the MSW stream. Glass percentages have decreased from 1979 to present day. This is to be expected because plastics have replaced significant amounts of glass and to a lesser extent glass recycling has become a prominent practice. The low value of 1.68% for glass reported by the WASTE Program is suspect because other studies cited list glass as being between 3.5% to 10.5% of the MSW stream. The ten category composition analysis performed on the bottom ash as part of this study can be used to check the 1.68% figure reported by the WASTE Program for glass. Differences in percentages of organics may be due to seasonal variation (especially yard waste), interpretation of categories, and/or the increase in backyard composting for certain wastesheds.

A discrepancy in metals percentages between the two most recent studies done at the Burnaby Incinerator is significant. The WFRA (1993) and the WASTE PROGRAM (1992) report MSW metal percentages of 11.00% and 3.95% respectively.

Table 2.2 REPORTED COMPOSITION OF MSW (by weight)

	WASTE FLOW AND RECYCLING AUDIT 1993 (%)	WASTE PROGRAM 1992 (%)	BIRD AND HALE (NATIONAL) 1979 (%)	BIRD AND HALE (BC) 1979 (%)	LAW AND GORDON 1979 (%)
CATEGORY					
SUB CATEGORY					
PAPER	**38.60**	**36.23**	**36.45**	**32.88**	**55.20**
KRAFT PAPER	11.80		9.11	6.36	
NEWSPRINT	8.20		8.54	10.28	
FINE PAPER			6.00	3.12	
OTHER/MIXED	18.60		12.80	13.12	
PLASTIC	**8.40**	**9.03**	**4.65**	**4.67**	**5.00**
CONTAINERS			0.86	1.06	
SHEET / FILM / OTHER			3.78	3.61	
ORGANIC	**27.90**	**32.82**	**42.12**	**41.50**	**9.50**
LUMBER			4.18	5.23	
PUTRESCIBLE	10.10		27.59	23.92	4.40
YARD WASTE / BRUSH	7.10		6.09	7.85	2.60
OTHER COMBUSTIBLE	10.70				
TEXTILES / LEATHER / RUBBER			4.26	4.50	2.50
METALS	**11.00**	**3.95**	**6.63**	**7.43**	**8.90**
FERROUS	6.60		6.06	7.01	7.60
BEER CANS			0.04	0.00	
SOFT DRINK CANS			0.66	0.22	
FOOD CANS			2.77	3.08	
OTHER			2.59	3.71	
NONFERROUS METALS	4.40		0.57	0.42	1.30
ALUMINUM			0.52	0.40	1.10
OTHER			0.05	0.02	0.20
GLASS	**3.50**	**1.68**	**6.61**	**7.72**	**10.50**
BEER CONTAINERS			0.20	0.07	
REUSEABLE SOFT DRINK			0.28	0.31	
NONREUSEABLE SOFT DRINK			1.06	0.19	
LIQUOR AND WINE			1.43	2.96	
FOOD CONTAINERS			2.22	2.58	
OTHER CONTAINERS			0.34	0.65	
FLAT AND CULLET			1.08	0.96	
OTHER / MISC	**10.60**	**10.80**	**3.54**	**5.80**	**10.90**
INORGANIC / NONCOMBUST	3.30	1.47	1.80	3.06	
OVERSIZE / BULKY	1.80	0.06			
SMALL APPLIANCE	0.40	0.27			
DLC (Res), Wood (ICI)	4.60				
HHW - total	0.50	1.49	0.56	0.35	
HW - container		0.40			
FINES		7.11	1.18	2.39	
TOTAL	100.00	94.51	100.00	100.00	100.00

2.4 FACILITY LOCATION AND LAYOUT

The location of the Burnaby Incinerator within the lower mainland of the Province of British Columbia is shown in Figure 2.1 and a full schematic of the Burnaby Incinerator, showing the sequence of the incineration process and the plant layout is shown in Figure 2.2. Figure 2.3 is similar to Figure 2.2, except it does not include the Air Pollution Control (APC) plant and it shows the grates more clearly. Figure 2.2 will be used to reference points within the incinerator process numbered chronologically and Figure 2.3 will be referred to because it shows a magnified section of the grates. Figure 2.4 shows the Martin grate system used at the Burnaby Incinerator in the greatest detail.

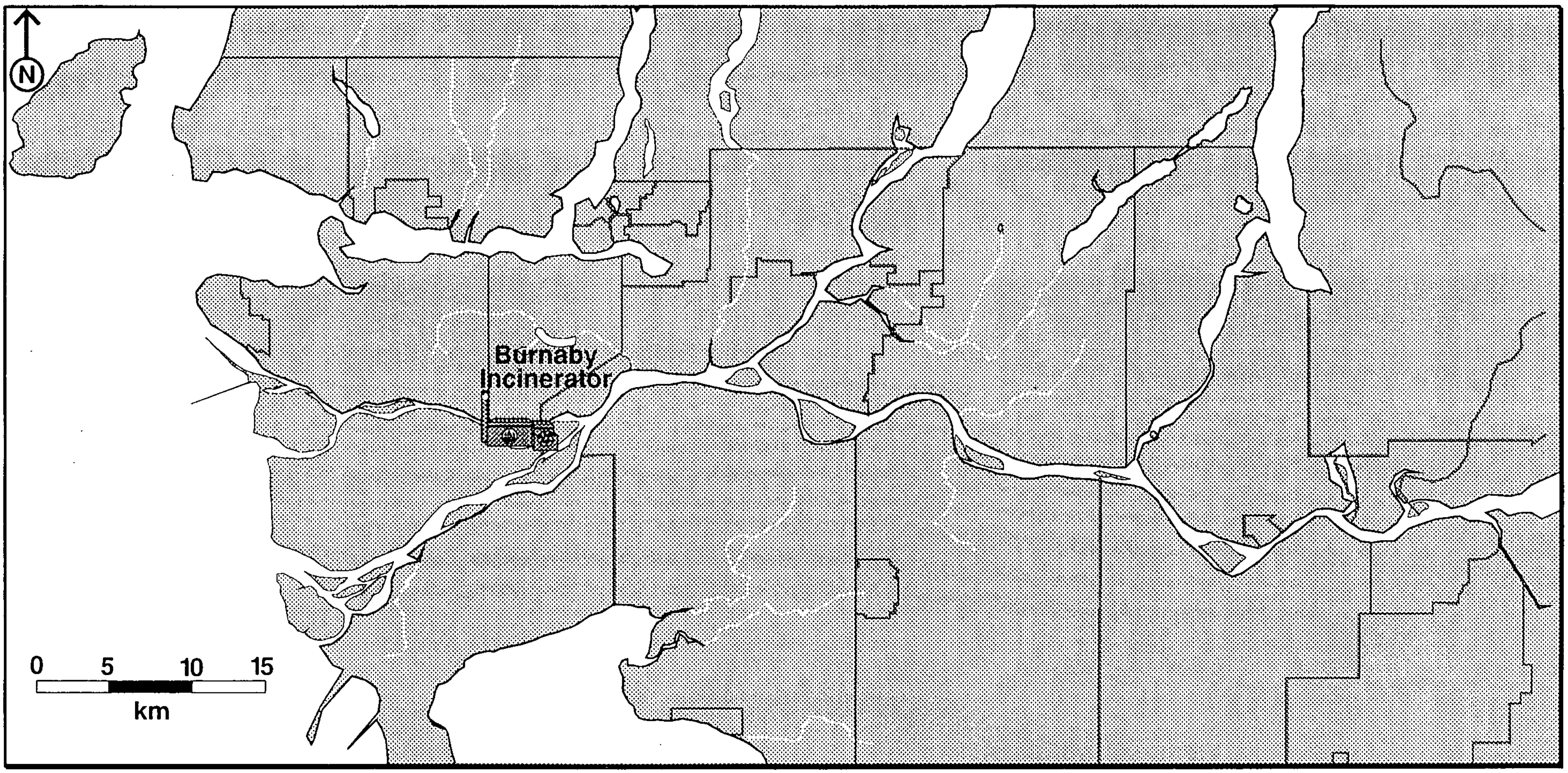
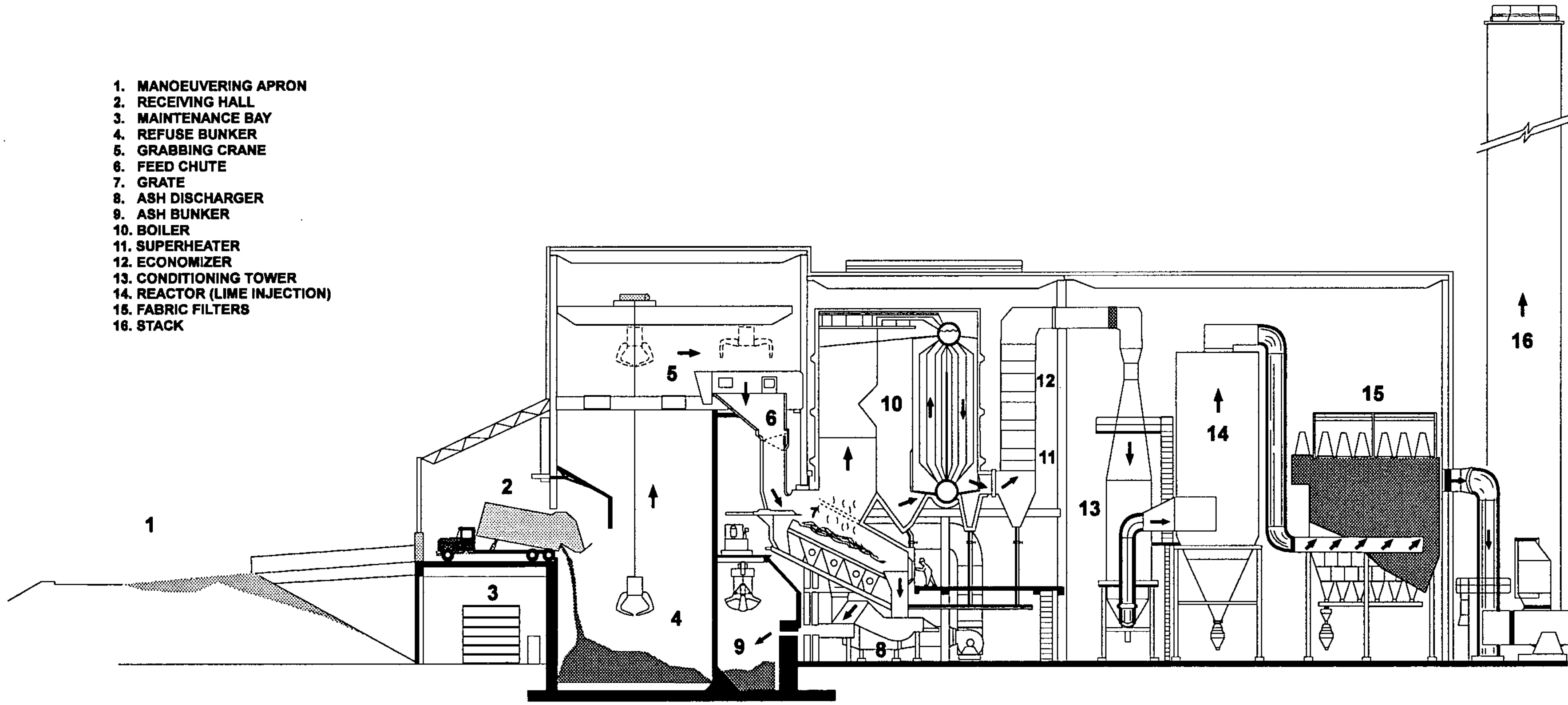


Figure 2.1 LOCATION OF BURNABY INCINERATOR WITHIN THE LOWER MAINLAND



SOURCE: MONTENAY INC.

Figure 2.2 SCHEMATIC OF BURNABY INCINERATOR LAYOUT

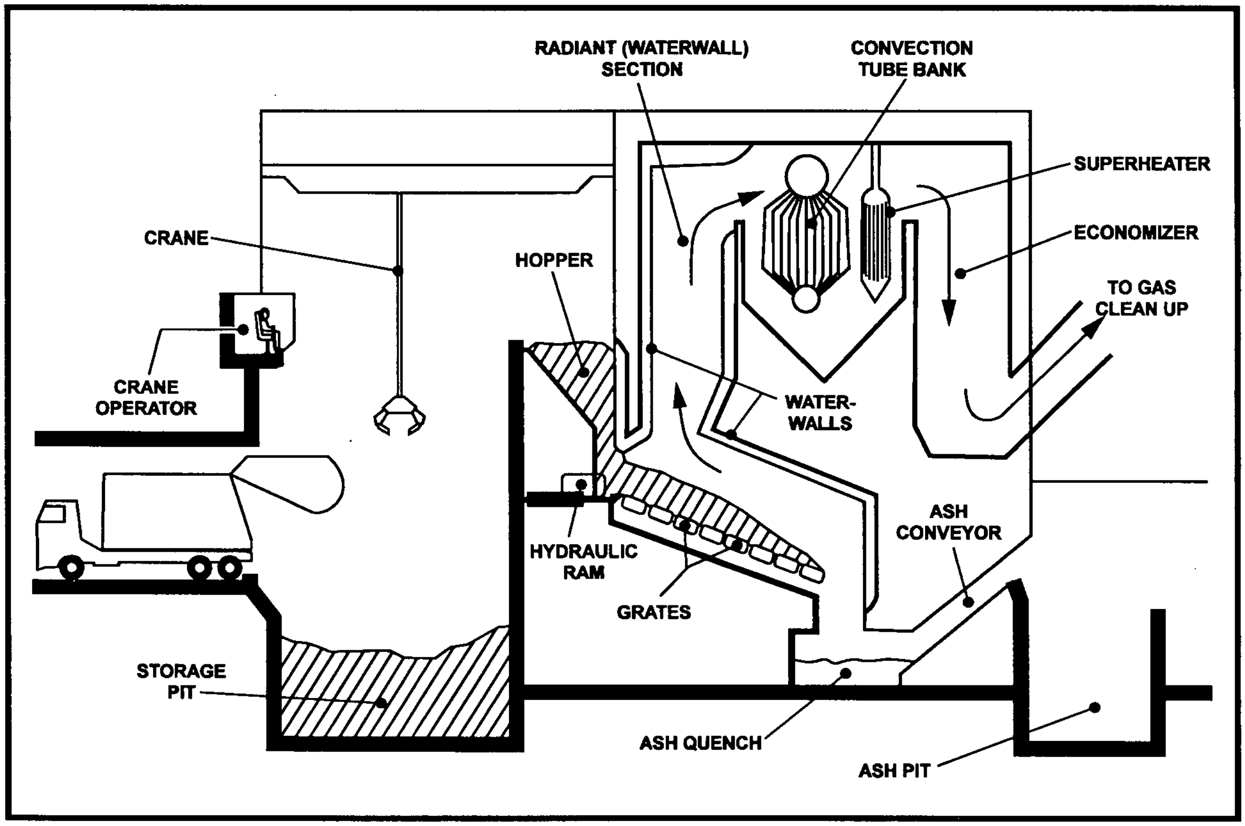


Figure 2.3 SCHEMATIC OF INCINERATION PROCESS

2.4.1 MASS BURNING AND GRATE DESIGN

MSW is delivered and deposited in the refuse bunker (Figure 2.2 item #4). From the bunker, an overhead crane (Figure 2.2 item #5) deposits the MSW into one of three feed chutes (Figure 2.2 item #6). The MSW tumbles and rolls and is pushed, agitated, and supported through the furnace by the grates (Figure 2.2 item #7). Burnt MSW (ash) is discharged onto a vibrating conveyor (Figure 2.2 item #8). Bottom ash is temporarily stored in the ash bunker (Figure 2.2 item #9).

The Burnaby incinerator is a "mass burning" facility, which by definition means waste is taken on an as-received basis and fed to the incinerator bunker with minimal preprocessing (there is an attempt at homogenization by the crane operator) and the MSW is typically burned on a grate (Figure 2.2 item #7).

There is also some removal of very large objects that the feed and ash handling systems can not accommodate.

The three mass burning furnaces at the Burnaby incinerator incorporate inclined reciprocating grates, by Martin (Figure 2.4), and water wall boilers, by Babcock and Wilcox. Forced air is used both above and below the grates and refuse during combustion. It is through gaps between the grate bars, labeled "GRATES" in Figure 2.3 and "COMBUSTION GRATE" in Figure 2.4, that the "grate siftings" fall. At the present time the siftings are combined with the bottom ash. The effective "burnout" (low carbon residual), low emissions, and trouble-free operation of mass burning incinerators depends to a large extent upon the grate design.

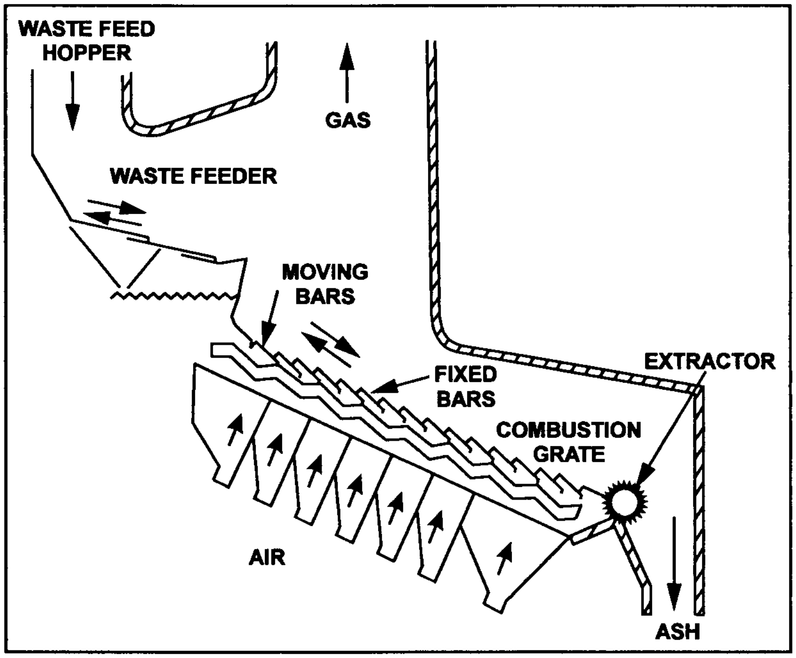


Figure 2.4 MARTIN GRATE SYSTEM

The three main purposes of the grate system, as outlined in CH2MHILL's (1993) Technical Memorandum on Incineration, are:

- To move the waste/ash bed from one end of the furnace to the other without becoming jammed by tramp material or by slagging caused by localized high temperature zones.
- To provide enough agitation to the waste pile to enhance the rate of drying, pyrolysis, and combustion.
- To distribute underfire air uniformly without creating excessive carryover of particulate or being susceptible to excessive plugging.

Grate designs are summarized by Brunner (1991) who maintains that the grates serve the same functions, as listed above. Grate designs are mechanically complex in larger facilities such as the one at Burnaby and grates are typically fabricated from chrome steel and are cooled by the underfire air as it passes between them. This air cooled structure permits mechanically complex movements, like rocking, and allows for better controlled agitation and movement and improved burnout of the combustible material.

There are a number of different types and designs of incinerator grates. Grate systems are usually classified into one of several categories; 1) rocking grates, 2) reciprocating grates, and 3) roller systems. The Burnaby incinerator uses a reciprocating grate system where flat plates reciprocate back and forth (Figure 2.4). All grate systems have some sort of grate-partitioning system to control the relative flows to, and temperatures of, different numbers of drying, pyrolysis, burning, and burnout zones (CH2MHILL,1993).

The effect that grates have on overall combustion efficiency and the ability to handle various types of wastes are discussed by CH2MHILL (1993). For example, better carbon burnout and higher combustion efficiencies for problematic wet wastes can be obtained if the ability to provide effective agitation and distribution of the waste exists. Grate design also affects facility emissions due to the implications for local temperatures and their distribution.

Manipulating individual air rates to separate grate sections that make up the furnace controls a number of inter-related parameters including slagging of the MSW, blockage of grates, pile temperature, and oxygen content. When pile temperatures and local oxygen content is controlled it is possible to maintain slagging at acceptable levels and eliminate blockage of the grates. Normal operating pile temperatures at the Burnaby incinerator range between 1,000 to 1,200 degrees Celsius. Typically, 40 to 60 percent of the total air in the furnace is introduced up through the grates. The remainder is fed as secondary air from a point further up the furnace to mix and burn out the volatile gases rising from the bed of garbage.

Ash fusion temperatures are discussed by Brunner (1991) that include the initial deformation, softening, and fluidizing temperatures for refuse and these are reproduced in Table 2.3. The initial deformation temperatures listed are within the range of normal pile temperatures mentioned. A dry waste with a high calorific value will produce more heat and therefore it is possible to be within the softening temperature range listed. The "fluid" range is not expected to be present at the incinerator. Air and pile temperatures are closely monitored and controlled.

Table 2.3 ASH FUSION TEMPERATURES

	REDUCING ATMOSPHERE,°C (°F)	OXIDIZING ATMOSPHERE,°C (°F)
INITIAL DEFORMATION	1,025 - 1,125 (1,880 - 2,060)	1,110 - 1,150 (2,030 - 2,100)
SOFTENING	1,200 - 1,300 (2,190 - 2,370)	1,240 - 1,320 (2,260 - 2,410)
FLUID	1,315 - 1,405 (2,400 - 2,560)	1,360 - 1,480 (2,480 - 2,700)

Melting and boiling points of the eight metals examined are listed in Table 2.4. Cadmium, lead, and zinc have melting temperatures well below the grate pile temperature range of 1,000 to 1,200 degrees Celsius. It is expected that these metals can melt and pass through the grates to become part of the grate siftings. To a large extent, cadmium and zinc are expected to vaporize and partition to the flue gases and fly ash. Mercury is not examined as part of this work, but because it is of environmental concern it is listed here. Essentially any mercury present in the furnace is vaporized and carried via the flue gases to the fly ash. It should be noted that the Burnaby Incinerator uses an advanced granular activated carbon system to effectively capture almost all of the mercury present.

Table 2.4 MELTING AND VAPORIZATION TEMPERATURES FOR METALS EXAMINED

METAL	MELTING POINT (°C)	BOILING POINT (°C)
Cadmium (Cd)	321	765
Chromium (Cr)	1,857	2,672
Copper (Cu)	1,084	2,567
Iron (Fe)	1,535	2,750
Manganese (Mn)	1,244	1,962
Nickel (Ni)	1,453	2,732
Lead (Pb)	328	1,740
Zinc (Zn)	420	907
Mercury (Hg)	-41	357

SOURCE: "The Elements", Emsley (1989)

2.5 RESIDUALS DESCRIPTION

2.5.1 BOTTOM ASH

Bottom ash is a dark gray colored heterogeneous mixture made up of "clinker", the fused minerals left from the combustion of organic material and non-combustibles such as metals, glass, ceramics, and stones, and unburned organic matter (between 1% to 4%). The term "well-burned-out" can be used to describe the bottom ash from the Burnaby Incinerator because an efficient combustion process exists and a high percentage of the organic or carbonaceous material is burned. Bottom ash is chemically similar to basalt rock, but it has a somewhat higher metals content (Stampfli et al, 1990). The physical composition of larger fractions can be determined by sorting it into its constituent categories, for example, rock, ferrous metals, glass, tile, etc. The ash portion remaining after combustion predominates in the finer fractions and originates from the mineral content of the organic material. It has very alkaline characteristics, due primarily to the high levels of calcium, magnesium, sodium, and potassium oxides present.

By definition bottom ash is any material which passes through or is discharged off the burning grate of an incinerator (Sawell and Constable, 1990). Stegemann and Schneider (1990 and 1991) define bottom ash as "a highly alkaline alumino-silicate based material which is similar in many ways to cement-based solidified wastes; the major difference is its physical structure, which is particulate rather than monolithic. Heavy metal contaminants in a solidified waste are usually immobilized chemically by the highly alkaline environment, and also physically trapped in a monolithic matrix of low hydraulic conductivity. In bottom ashes, however, a relatively high hydraulic conductivity can potentially result in rapid advective leaching of soluble contaminants" (an environmental concern). Incinerator residue (combined ash) is described by Maynard (1977) as an inert, non-plastic, well-graded, granular material which, when placed in a landfill, will remain a stable mass.

Bottom ash is collected and slaked, the disintegration of quicklime (CaO) by chemical combination with water, in the ash bunker (Figure 2.2 item #9) at the incinerator. The ash is cooled or quenched with sealing water, contained in a trough or quench tank that houses the ram discharger (Figure 2.2 item #8).

The nature of the residuals is primarily controlled by the following factors: the incineration process utilized, and the 3 T's, or Temperature, Time, and Turbulence (Collins,1978). Buekens and Schoeters (1979) discuss the influence of these operating conditions or factors on the burn-out of incineration residues. Beckman (1986) discusses the 3 T's, as they pertain to the combustion process. Adequate temperature is provided by the heat of combustion of the refuse. The reciprocating grate action provides the turbulence, and retention time is provided by controlling the flow of waste through the furnace. According to Buekens and Schoeters (1979) "high temperatures cause the sintering and the partial melting of the slag (vitreous bottom ash). The main consequence of sintering and melting is to decrease the solubility of ash in ground water, thus reducing the water pollution potential of tipped ash. High temperatures also enhance the rate of oxidation of ferrous scrap, the diffusion of tin in iron, and the evaporation of heavy metals and of their volatile salts."

2.5.2 GRATE SIFTINGS

The grate siftings are comprised of sand, small stones, pieces of glass and ceramics, and ferrous and non-ferrous metals. The non-ferrous metals present include low melting temperature metals like aluminum, lead, and zinc (coatings). These metals usually form small particles of elemental metal which can fall through the grates after they cool.

Grate siftings gather or fall into the funnel-shaped plenum chambers, which distribute the primary air to the various grate sections. A sequenced and timed pneumatic purge conveys the grate siftings and normally combines them with the bottom ash. It is possible to divert or separate the grate siftings and bottom ash streams.

The amount of siftings generated depends on the size distribution and chemical make-up of the incoming refuse and on the openings that are present between the grates, which can be a function of mechanical wear. Generally, siftings represent 5 to 7 percent of the roughly 45,000 tonnes per year of bottom ash generated at the Burnaby Incinerator.

The temperatures listed in Table 2.3 "Ash Fusion Temperatures" are higher than the low melting points for metals such as lead (MP = 328°C) and aluminum (MP = 660°C) meaning that these metals melt and pass through the grates along with materials that can physically pass through the grates and into the air distribution box. The classifying action created by the upward underfire air stream prevents lighter materials from passing through the grates. For this reason, the grate siftings are more dense than the bulk of the bottom ash (1,056 kg/m^3 compared to 617.3 kg/m^3 bulk density) (CH2MHILL,1993). Grate siftings are currently collected and pneumatically transported to be combined with the bottom ash stream , but they are also a separate waste stream with separate physical and chemical characteristics and waste management possibilities.

2.6 GRAIN SIZE DISTRIBUTION

Bottom ash grain size distribution (GSD) information from several different studies and incinerators is presented in Table 2.5. The findings of several authors are discussed in more detail here.

ASTM standards were used by Brand (1977) to exam the gradation, the compaction/density relationship, and the specific gravity of old incinerator fill that was used on a site for the construction of dikes to create disposal lagoons. He found that the material was well graded within a narrow range and suitable for compaction. Benoit and Eighmy (1991) used ASTM grain size distribution (GSD) standards to examine incinerator ash and found the material to be generally well graded. Collins (1978) found that screened incinerator residues were generally sufficiently well graded to meet specification requirements for construction materials in various applications. He also found that bottom ash was quite friable, reaching this conclusion after performing sieve analyses on ash samples before and after compaction tests, that indicated a considerable amount of particle degradation occurred during testing.

Stegemann and Schneider (1991) found that for the Goppingen bottom ash they studied, 12% of the total mass of ash was smaller than 0.4 mm, 13% was between 0.4 and 2 mm, 23% was between 2 and 8 mm, and 52% was larger than 8 mm. They examined the relationship between particle size, surface area, and leachability. One would expect that a metal contaminant or leachate concentration would increase with decreasing particle size, for a given sample mass of material, because an increased surface area exposes more of a potential contaminant to leaching media. Stegemann and Schneider (1991) found that the total amount of leachable metal was greater for smaller bottom ash particles than larger sizes. Van Der Sloot et al (1989) found that the chemical composition of the leachate is dictated by the incinerator ash matrix and solubility controls are not strongly dependent on the amount of exposed surface area. An attempt will be made to relate the GSD information obtained as part of this work to leachable metal concentrations and solubilities.

Terra Engineering Ltd. (1994), a local Burnaby BC Geotechnical firm, provided the author with GSD information and Ministry of Transportation and Highways (MoTH) specified limits on select granular sub-base, 50 mm well graded granular sub-base, and 25 mm well graded granular base materials. Bottom ash GSD's will be compared to MoTH's and BC's Mater Municipal Specifications (BCMMS) (1991) for natural aggregates in the "RESULTS AND DISCUSSION" section to determine bottom ash's suitability for natural aggregate replacement. The BCMMS (1991) requirements for pit-run gravel, select granular sub-base and granular base materials are also listed in Table 2.5.

Table 2.5 SUMMARY OF REPORTED GRAIN SIZE DISTRIBUTIONS

AUTHOR	GRAVEL SIZES (mm, inches, sieves)							SAND SIZES & FINES (mm or µm where noted)								
	75 mm 3"	50 mm 2"	37.5 mm 1.5"	25 mm 1"	19 mm 0.75"	12.5 mm 0.5"	9.5 mm 0.375"	4.75 mm No.4	2.36 mm No.8	2.00 mm	1.18 mm No.16	850 µm	600 µm No.30	300 µm No.50	150 µm No.100	75 µm No.200
ASH SAMPLES																
Benoit & Eighmy (1989) (1)						100	100	80	55-65		35-50		20-35	10-20	>10-15	5-10
Benoit & Eighmy (1989) (2)						85-100	60-70	50-55	35-45		25-35		15-25	10-15	>10	5-10
Lauer (1979) (3)				95	89	82	60	34	24		18		12.5	9.6	5.7	3.2
Stegemann & Schneider (1991) (4)		100		90	85	65	47	40	28		20		15	10	6	3.5
Collins (1978) (5)	89-100		68-92	62-89	58-81	51-72	47-65	35-50	25-39				11-22		4-11	3-9
Brand (1977) (6)	100				85-95		68-72	60-62			40-50			23-37		17-21
Maynard (1977) (7)	100	100	100	98	95	93	92	80	70		50		25	17	10	9
Maynard (1977) (8)	100	98	90	88	82	74	65	49	44		33		25	20	15	10
Crushed Stone (9)	100	100	100	98	96	90	85	55	50		44		35	30	20	15
AGGREGATE SAMPLES																
Terra Engineering Ltd. (1994) (10)	100				100		97.5						36.3	16.4		2.3
Terra Engineering Ltd. (1994) (11)		100	98.7		79.4		59.8	41.9	31.1		21.9			10.2		4.2
Terra Engineering Ltd. (1994) (12)				100	99.5		74.1	56.0	45.0		33.3			12.6		4.1
SPECIFIED LIMITS																
MoTH Sub-Base	100				15 - 100		0 - 100						0 - 100	0 - 15		0 - 5
MoTH 50 mm Sub-Base		100	80 - 100		50 - 100		35 - 75	25 - 55	20 - 40		15 - 30			5 - 15		0 - 5
MoTH 25 mm Base				100	80 - 100		50 - 100	35 - 70	25 - 50		15 - 35			5 - 20		0 - 5
BCMMS Pit Run Gravel	100	70 - 100		50 - 100				25 - 100		10 - 80						2 - 8
BCMMS Sub-Base	100			50 - 85											0 - 15	0 - 8
BCMMS Base					100	75 - 100	60 - 90	40 - 70	27 - 55			10 - 35		5 - 20		2 - 8

NOTES:
(1) bottom ash and dewatered municipal sludge (5:1 volume/volume), Lamprey Regional Solid Waste Cooperative Incinerator 7 Somersworth wastewater sludges.
(2) bottom ash, Lamprey Regional Solid Waste Cooperative Incinerator 7 Somersworth wastewater sludges.
(3) combined ash, incinerator not identified.
(4) bottom ash, Goppingen incinerator, FRG.
(5) assumed combined ash, incinerator not identified.
(6) 26 year old incinerator ash used as fill, Mill Creek, Cincinnati, Ohio.
(7) combined ash, Southwest Incinerator, Chicago.
(8) combined ash, Northwest Incinerator, Chicago.
(9) reference material provided by Maynard (1977)
(10) select granular sub-bas, sample data provided by Terra (1994), Londsdale Interchange: Project No. C-3687
(11) 50 mm well graded granular sub-base, sample data provided by Terra (1994), Londsdale Interchange: Project No. C-3687
(12) 25 mm well graded base, sample data provided by Terra (1994), Londsdale Interchange: Project No. C-3687

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2.7 COMPACTION DENSITY RELATIONSHIPS

Laboratory compaction density tests are used to determine optimum moisture contents and density. Typically, the specification for field compaction is for the attainment of a certain percentage of the optimum density obtained by a laboratory test, for example 95% of ASTM D1557. For reference, this same value, 95%, is specified by BC's Master Municipal Specifications (1991) for placing aggregates or suitable substitutes as road sub-base. With a knowledge of the moisture-density relationship as determined by a laboratory test, better control of the field compaction of the fill is possible because the optimum water content and the density which should be obtained using this water content are known. Modified proctor compaction - density tests are used to ensure that materials are placed and compacted in the field to an optimum density, usually 90% or 95% of the laboratory value because this ensures that settling is minimized.

Table 2.6 summarizes the compaction - density test results of several authors. A range of dry density values for bottom ash given by Gress et al (1991) are: 1,724 to 1,782 kg/m^3 at water contents of 11% to 17% respectively. Maximum lab dry densities on test pit samples of old incinerator fill obtained by Brand (1977) were approximately 1,480 kg/m^3 at a water content of 24%. Hardy BBT Ltd. (1988) have investigated the insitu wet and dry densities of the Burnaby Incinerator's bottom ash at a landfill site in Coquitlam, British Columbia. A number of different field compaction methods and pieces of machinery were employed and therefore a range of densities were obtained. Test results for bottom ash compaction indicate that the most effective compaction method would be to fill cells in a number of lifts 1 m in thickness and compact each lift. The dry density values obtained range from 1,392 kg/m^3 to 1,659 kg/m^3. Hartlen and Rogbeck (1989) conducted compaction and density studies on varying ages of incinerator residue. They found that the maximum recorded values were of the same order of magnitude for the different ages of incinerator ash, 1,790 kg/m^3 to 1,820 kg/m^3. Moisture contents for the maximum densities ranged between 13% to 19%. Maynard (1977) performed moisture-density relationship tests (ASTM D698-70, Method C) on incinerator residues (combined ash) from the City of Chicago's Northwest and Southwest Incinerators. The Northwest Incinerator residue has an approximate maximum dry density of 1,701.5 kg/m^3 at a 15% optimum moisture and the Southwest Incinerator residue has an approximate dry density of 1,380.5 kg/m^3 at a 26% optimum moisture content. Reasons for the differences were not given. Lauer (1979) determined the density of both coarse (1,280 kg/m^3) and fine (960 kg/m^3) combined incinerator residues.

Compaction - density values for high quality crushed gravel (dry density values of 2,250 kg/m^3) and for river sand (1,600 kg/m^3) were obtained from Terra Engineering Ltd. (1994). The values presented here will be used for comparison purposes in the "RESULTS AND DISCUSSION" section.

Table 2.6 SUMMARY OF REPORTED COMPACTION - DENSITIES FOR BOTTOM ASH

AUTHOR	WATER CONTENT (%)	DRY DENSITY kg/m^3)
Gress et al (1991)	11 - 17	1,724 - 1,782
Hartlen & Rogbeck (1989)	13 - 19	1,790 - 1,820
Brand (1977)	22	1,525
Maynard (1977)	15 - 26	1,380 - 1,701
Lauer (1979) (1)	NA	1,280
Lauer (1979) (2)	NA	960
Hardy BBT (1988) (3)	NA	1,392 - 1,659
Benoit & Eighmy (1989) (4)	30 - 60	1,250

NOTES:
(1) coarse bottom ash
(2) fine bottom ash
(3) field test result
(4) field - bottom ash and dewatered municipal sludge (5:1 volume/volume)

2.8 SPECIFIC GRAVITY

Specific gravities (SG) determined by authors examining incineration residuals are presented and summarized below in Table 2.7. Gress et al (1991) report a range of values for bulk specific gravity for both fine and coarse bottom ash samples. The bulk specific gravity of their fine fraction (<4.75 mm, <No.4, ASTM C128) was between 1.30 to 2.06. Haynes and Ledbetter (1977), in their study of utilizing

incinerator residue in asphalt base construction, performed specific gravity tests using ASTM's C127 (coarse fractions) and they obtained an average specific gravity of 2.13. Lauer (1979) provides specific gravity values, based on ASTM standards, for the following fractions and sieve sizes 9.5 mm (3/8") SG - 2.57, 4.75 mm (No.4) SG - 2.50, and 2.36 mm (No. 8) SG - 2.13. Benoit and Eighmy (1991) report a specific gravity, using ASTM C127, of 2.34. Brand (1977) reports an average specific gravity of 2.56.

Table 2.7 SUMMARY OF REPORTED SPECIFIC GRAVITIES FOR BOTTOM ASH

AUTHOR	ASTM C128 FINES < 4.75 mm	ASTM C127 COARSE > 4.75 mm
Gress et al (1991)	1.30 - 2.06	2.03 - 2.43
Haynes & Ledbetter (1977)		2.13
Lauer (1979) (1)	1.74	2.54
Benoit & Eighmy (2)		1.92
Benoit & Eighmy (3)		2.46
Benoit & Eighmy (4)		2.34
Brand (1977)		2.56

NOTES:
(1) fines - average of 2.13, 1.75, and 1.34; coarse - average of 2.57 and 2.50
(2) laboratory - bottom ash and dewatered municipal sludge (5:1 volume/volume)
(3) field - bottom ash and dewatered municipal sludge (5:1 volume/volume)
(4) bottom ash, same value for fresh and aged ash

2.9 MATERIALS COMPOSITION IN BOTTOM ASH

A major deficiency in the body of knowledge describing the materials composition of bottom ash exists. Two other authors who present material composition data are Maynard (1977) and Collins (1978) and this information is summarized in Table 2.8. For future reference and clarity the material categories used as part of this thesis are included in Table 2.8. Maynard (1977) and Collins (1978) found that the major component of bottom ash was ceramics, slag, minerals, and ash. Magnetic material made up a significant portion of the bottom ash stream; between 5.3% to 13.8%. Clearly, more information on the materials composition of bottom ash is required. The material composition of bottom ash from the Burnaby Incinerator will be compared to Maynard's (1977) and Collins (1978) findings in the "Results and Discussion" section. It is unclear why Maynard's composition data does not total 100%; his reported percentage values are based on a "10 sieve composition."? Maynard lists other material as being: "Plastic, Ceramic, Slag, etc. - Non Burned."

Table 2.8 SUMMARY OF PHYSICAL COMPOSITION OF INCINERATION RESIDUALS

AUTHOR	MATERIAL REPORTED AS PERCENTAGE									
	MAGNETIC	OTHER	ROCK	PORCELAIN & TILE	CONCRETE	BRICK	PAPER & WOOD	NON-FERROUS METALS	GLASS	GLASS MIXTURES
Maynard (1977) (1)	6.2	36.2					0.3		19.5	
Maynard (1977) (2)	5.3	25.5					1.6		10.2	
Collins (1978) (3)	13.8	39.5					3.5	3.3	39.9	

NOTES:
(1) Northwest Incinerator, "OTHER" is listed as plastics, ceramics, and slag - partially burned.
(2) Southwest Incinerator, "OTHER" is listed as plastics, ceramics, and slag - partially burned.
(3) "OTHER" is listed as minerals and ash.

2.10 LEACHATE EXTRACTION PROCEDURES

Given today's ever changing regulatory framework different bottom ash test procedures have been required in the past, present, and will be in the future, depending on the country, province, or state that a waste to energy facility is located in. The myriad of procedures in place, primarily to estimate the leaching potential of ashes or other materials, makes it difficult to compare test results between facilities, meaning that a good database of information characterizing incineration residues is not available. For this reason it was necessary to study the Burnaby Incinerator residue in detail.

The choice of the Leachate Extraction Procedure (LEP) as the regulatory tool used to chemically classify bottom ash does not consider the intent of the anticipated utilization or disposal scenarios. If it did, the BC Special Waste Regulations would stipulate the use of a mild synthetic acid rain leaching media instead of acetic acid. The use of the LEP assumes that the solid waste in question is going to be codisposed with MSW. The dilute acetic acid used is only appropriate for evaluating a co-disposal situation where bottom ash is disposed of with MSW, and there is biological activity, producing volatile fatty acids (VFA's), such as acetic acid, which can dissolve heavy metals present in the bottom ash. In the case of a monofill for a well burned out bottom ash, there is likely very little biological degradation of the residue because there is no significant carbon source, and therefore little or no acetic acid produced, compared to a MSW landfill.

The LEP is a regulatory test with limits that are used as benchmarks to classify solid wastes as "Special Waste" or not. One of the shortcomings of the procedure is that it tells nothing about what can or will ultimately leach out into the environment. The LEP addresses regulatory concerns but does not address long term environmental concerns adequately.

The most important factors governing the leaching of metal constituents from incinerator residue are:

1) the pH of the extraction media,

2) the liquid to solid ratio (L:S),

3) the redox environment of the leachate test,

4) particle size and surface area.

Proving point 1) above, Dipietro et al (1989) concluded that the effect of pH produces the most noticeable change in soluble metal concentrations. "Except for Na and Al, metal concentrations decreased with increasing pH. In general, higher pH results in greater adsorption and precipitation while lower pH results in less adsorption and less precipitation (Dipietro et al, 1989)." Roethel et al (1991) are in agreement. Major findings include the fact that leachate metal concentrations were found to be primarily dependent on the final pH of the leachate and therefore in the case of bottom ash, alkalinity. Roethel et al (1991) adds to the list of factors that affect the leaching of metal constituents from incinerator residue. To be included in the above list are 5) the speciation of the metal, and 6) the availability for leaching (surface area or matrix associated). Roethel et al (1991) conclude that no one test can adequately address all five of these factors affecting the leachability of metals, and it is therefore necessary to subject samples to several leaching protocols in an effort to better understand the leachability of metals from the ash. Roethel et al (1991) did not discuss or make conclusions as to the appropriateness of any one test to model field conditions or which test may be the most suitable for regulatory purposes.

A summary of the five leaching protocols examined and used by Roethel et al is:

1) Toxicity Characteristics Leaching Procedure (TCLP)

- acetic acid pH 2.8
- contact time 18 hours
- L:S 20:1
- mixing: tumbling
- one (1) extraction

2) US EPA Extraction Procedure Toxicity Test (EP-tox) (very similar to LEP)

- acetic acid pH 5
- contact time 24 hours
- L:S 20:1
- mixing: tumbling
- one (1) extraction

3) SW-924 Monofilled Waste Extraction Procedure - MWEP

- synthetic acid rain SAR, distilled-de ionized water
- contact time 18 hours
- mixing: tumbling
- L:S 10:1
- four (4) extractions

4) ASTM leaching procedure

- synthetic acid rain (SAR), distilled-de ionized water
- contact time 48 hours
- mixing: tumbling
- L:S 4:1
- one (1) extraction

5) Sequential Chemical Extraction (SCE) test

- $MgCl_2$, acetic acid, NH_2OH-HCl, HNO_3/H_2O_2, HF/H_3BO_3
- contact time variable
- mixing: shaking
- L:S variable
- five (5) extractions (sequential)

Some of the tests require a relatively small mass of sample to be tested, which can lead to a loss of reproducibility and representative results. For this reason a number of researchers double the mass of sample (i.e. 100 g instead of 50 g) and the volume of extraction fluid used (i.e. 2 L instead of 1 L) to reduce variability, increase reproducibility, and still maintain the specified L:S ratio. This is inappropriate since a standard test procedure has been altered, but there is reason to argue that a larger sample mass should be tested to better represent the initial sample.

For both the EP-tox and TCLP tests, the contaminant metal concentrations in the extracted leachates are compared to regulatory limits that are set to define special wastes. The limits for the LEP for the eight metals examined in this thesis are listed in Table 2.9. If an extraction leachate exceeds these limits then the solid waste analyzed, in this case desifted bottom ash, is classified as a "special waste". Historically, the basis for regulatory limits has been the Department of Health and Welfare's "Guidelines for Canadian Drinking Water Quality" (1989). The reason for this is that if leachates are generated they can migrate to groundwater aquifers. This potential migration must be mitigated by imposing limits on the strength or concentrations of possible leachates.

Table 2.9 LEACHATE LIMITS SET FOR LEP BY BCMOELP

METAL	**LEP LIMIT** (ppm or mg/l)	**DRINKING WATER LIMIT** (mg/kg) (2)
Cadmium (Cd)	0.5	10
Chromium (Cr)	5.0	100
Copper (Cu)	100	2,000
Iron (Fe)	NR (1)	NR (1)
Manganese (Mn)	NR (1)	NR (1)
Nickel (Ni)	NR (1)	NR (1)
Lead (Pb)	5	100
Zinc (Zn)	500	10,000

NOTE: (1) NR denotes "Not Regulated"
(2) Drinking water limit normally expressed in mg/l or ppm, but for comparison purposes the limit was multiplied by 20 to use mg/kg.
SOURCE: BC Provincial Government, "Waste Management Act, Special Waste Regulation" (1988).

2.10.1 TOXICITY CHARACTERISTIC LEACHING PROCEDURE

A newer version of the US EP-tox test, the Toxicity Characteristic Leaching Procedure (TCLP), is outlined in the USEPA's (1992) Code of Federal Regulations (CFR). The extraction solution is either buffered or unbuffered depending on the alkalinity of the material to be tested. According to US CFR 40, metal concentrations observed in the extract often reflect the pH-dependent solubility constraints of the specific element. The TCLP is designed to determine the mobility of both organic and inorganic constituents that may be present in liquid, solid, or multiphase wastes. The USEPA has adopted this procedure as Method 1311, and will incorporate it in "Test Methods for Evaluating Solid Waste Physical Chemical Methods - SW-846" (Pirages, 1990).

2.10.2 SEQUENTIAL CHEMICAL EXTRACTION (SCE)

The Sequential Chemical Extraction (SCE) subjects samples to increasingly aggressive extraction fluids in an attempt to assess the metal association characteristics and the leaching potential of the ash (Roethel et al, 1991). The metals that leach out in the first two stages of the procedure are readily available in the short term. Likewise, for the third stage the metals are available for leaching over a long-term period. It is felt that the metals from the fourth and fifth stages are not leachable, or environmentally available. The five stages or fractions examined by the SCE are:

FRACTION A - Exchangeable Metals

FRACTION B - Bound to Carbonates

FRACTION C - Bound to Fe and Mn Oxides

FRACTION D - Bound to Organic Matter

FRACTION E - Matrix Metals

Sawell and Constable (1989) used the SCE as part of the National Incinerator Testing and Evaluation Program (NITEP). They provide essentially the same summary, description, and interpretation of the SCE as has been given above. Chandler et al (1992) used the SCE extensively during the WASTE Program. Stegemann and Schneider (1990 and 1991) used the SCE to investigate bottom ash from the Goppingen regional energy-from-waste facility. All authors agree, and it has been suggested that the amount of contaminant contained in fractions A and B represent a conservative estimate of the fraction of the contaminant which is ultimately available for leaching in a segregated landfill, while the amount contained in fraction C might be environmentally available under the more severe reducing conditions of codisposal with MSW, and fractions D and E are environmentally unavailable for leaching.

2.10.3 BATCH vs. COLUMN LEACHATE TESTS

A batch test is the mechanical mixing, either stirring or rotation in closed vessels, of a unit volume of water or some other suitable extraction fluid with a unit mass of waste. A column extraction procedure involves the continuous flow of an extraction liquid through a fixed bed of solid waste.

Both column and batch leachate tests have inherent advantages and disadvantages. Column tests have the advantage of better representing actual field conditions while batch tests are faster and easier to perform and the results are more reproducible. The disadvantages of column tests are that they take a long time to perform and that it is difficult to obtain reproducible results (Dipietro et al,1989). More reproducible results and lower experimental variation are desirable from a regulatory and standardization perspective. Jackson et al (1984) also state that batch extraction tests offer advantages because of their greater reproducibility and simplistic design, but column tests are more realistic and representative in simulating leaching processes which occur under field conditions. The uses of laboratory leaching tests are:

1) to evaluate leachability for materials of concern,
2) provide guidance on how to dispose of a particular waste, and
3) predicting the impact a particular waste may have on ground water, should a landfill liner fail.

A leaching test must posses the following characteristics:

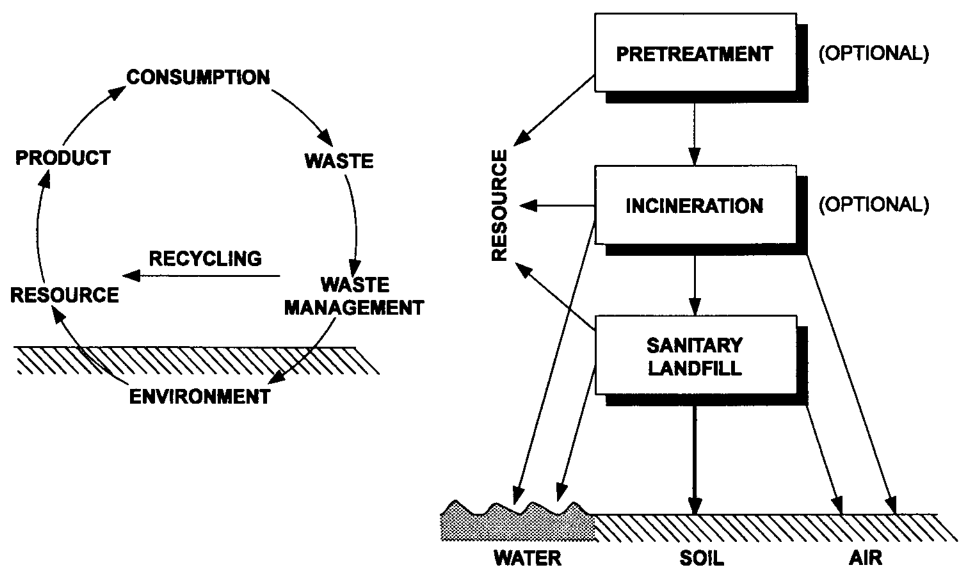
1) the leaching media must be representative of field conditions. (author's note: the British Columbia MOELP's LEP does not do this because acetic acid is used which is not present in an ash monofill),
2) the test procedure must minimize the alteration (reduction) of particle size. (author's note: the BC MOELP's LEP does not do this because it specifically says to cut, crush, or grind the sample in question to pass a 9.5 mm sieve),
3) an optimal liquid to solid ratio (L:S) must be chosen so that dilution effects and experimental variability are minimized, and
4) the tests should be easy to perform.

Jackson et al (1984) also discuss reasons or sources of variability: inhomogenity of the initial analyte, physical differences in samples, operator differences in handling of samples, random differences in the way a sample actually leaches, and finally experimental error.

2.11 FLUX OF METALS THROUGH INCINERATION PROCESS

The primary goals of incineration are waste volume and weight reduction as well as stabilizing waste from further organic breakdown. This goal encompasses the concentration and potential immobilization of heavy metals as well as the complete oxidation of organic carbon. Some metals are not completely immobilized and not all of the carbon is oxidized because the combustion process is never 100%.

According to Brunner and Monch (1986), in order to prevent the rise in concentration of metals in the major environmental sinks, specifically soils and sediment, it is necessary to know how the contribution from each stage in the global cycling of materials impacts the environment. Figure 2.5 shows how waste treatment, and in this case incineration, is one of several processes in the cycling of elements and materials. Brunner and Monch (1986) state that because "the anthropogenic utilization of materials has increased considerably in this century, the contribution of waste management to the load of the environment with metals and non-metals became more important. Today the global natural fluxes of some elements are exceeded by anthropogenic fluxes."



The position of waste management relative to the global cycling of materials. Total flux of materials to the environment can be reduced by increasing the recycling rate, by decreasing resource exploitation, or by improving waste treatment in a way that yields more inert, ore-like materials that do not enter the hydrological cycle (Source Brunner and Monch, 1986).

Figure 2.5 GLOBAL CYCLING OF MATERIALS

Brunner and Monch (1986) provide the following partitioning percentages for metals going to bottom ash or slag: Iron 99%, Copper 89%, Zinc 51%, Lead 58%, and Cadmium 12%. The balance of the metals go to fly ash and flue gases, but these streams are not examined in this thesis and are not discussed. Brunner and Monch (1986) found that it is possible to control incineration so that certain elements are concentrated in a specific product of incineration. Typically, when waste or fuel with higher calorific value was incinerated, higher metal concentrations resulted in the flue gases, and therefore fly ashes. No mention was given as to the effect this had on metal concentration in the bottom ash, but it assumed that they would be lower. For this reason the moisture content of fuels plays an important role in the incineration process. In Vancouver, during the winter months, the rain is known to affect the calorific values of waste received at the incinerator. This in turn affects the incineration process, and metals concentrations. An analysis relating the calorific value of feedstocks with varying moisture contents to metals partitioning in the residual streams was not part of the scope of work done in this thesis.

Another factor or property affecting the partitioning of elements is the concentration of halogens, in particular, chlorine. "During incineration, metals may be transformed to halides which in general have higher vapor pressures than the oxides or elements, and are readily soluble in water. Therefore, a high concentration of chlorine-containing waste materials (e.g. polyvinyl chloride) can increase the emission of volatile metal chlorides like $CdCl_2$, $ZnCl_2$, and $HgCl_2$, and can increase the water-soluble fractions of such metals in a scrubber system (Brunner and Monch,1986)"

Examples of additional waste properties affecting incineration residues are the silicate content, which affects the formation of insoluble slag and the sulfur content which affects the formation of submicronic sulfate particles. Brunner and Monch (1986) state that "the fate of metals during combustion, gas cooling, and gas cleaning is determined by the composition of the municipal waste, the physical-chemical behavior of the individual metals, and the operating conditions of the incinerator." They also say that "besides volume reduction and energy recovery, the goal of modern waste incineration must include the complete mineralization of carbonaceous materials and the concentration of metals in an insoluble form."

Franklin (1990) presents data from studies which characterize sources of heavy metals in MSW, specifically lead, cadmium, and mercury. Franklin (1990) lists the major sources of lead as lead-acid batteries (64.7%), consumer electronics (27.4%), glass and ceramics (3.7%), plastics (1.5%), soldered cans (1.0%), pigments (0.5%), and other (1.1%). Sixty-six percent of the lead in non-combustible products is from lead-acid batteries and 71.0% of the lead in combustible products is from plastics (including pigments). Franklin (1990) fails to mention yard waste (organic) as a source of lead, which is thought to be of significance in the lower mainland where lead bioaccumulates; the Fraser River drainage basin collects lead containing sediment from a large portion of BC (WASTE Program,1992) Furthermore, there is a well established lead acid battery recovery and recycling program being run by the GVRD and a high percentage of these batteries are not part of the MSW stream going to disposal. Rigo and Chandler, as part of the WASTE Program (1992), report that 10% of the cadmium in the MSW waste stream is in an organic form. The results for lead are startling, 54% of the lead in the MSW waste stream is from organic sources such as plant material and yard trimmings.

"The sources of metals in refuse are diverse. Consumer products such as batteries may contain cadmium, lead, mercury, and zinc. Printing inks, paints, glass, pigments, and plastic stabilizers may contain cadmium, chromium, lead, and zinc. Some of the metal compounds used in these various products are considered to be volatile at the temperatures inherent in MSW incinerators. In addition, the physical disposition of these metals on and in readily combustible materials such as plastics and paper, increases the probability that they will be exposed to temperatures sufficient for volatilization. Conversely, some of the metal compounds (such as chromium and nickel) are considered 'heat stable' and do not volatize, and remain in bottom ash (Sawell et al, 1990)".

Law and Gordon (1979) discuss sources of metals in municipal incinerator emissions. They promote the separation of combustible and non combustible streams within urban refuse as a means of reducing concentrations of heavy metals in the effluent streams from the combustion process. They base this recommendation on the assumption that the removal of the non combustible components of MSW by some recycling operation prior to burning the combustible components for energy recovery should reduce metal emissions.

Sawell et al (1990) state that the distribution of metals in MSW incinerator ashes depends on the following four major factors:

1) the thermochemical properties of the metal compounds,

2) the physical disposition of the metals in the waste,

3) the design of the incinerator and APC system, and

4) the operating conditions of the incinerator and APC system.

2.11.1 WASTE PROGRAM LEAD AND CADMIUM SPIKING

Chandler et al (1992) have published results from the Waste Analysis, Sampling, Testing and Evaluation (WASTE) Program (1992). The refuse entering the furnace was spiked with sufficient lead acid batteries (estimated to be 40% lead by weight) during two test runs to raise the lead flux to approximately seven times normal. The grate siftings appeared to capture most of the lead spike with a small amount going to the boiler hoppers. There was no increase in the total lead concentrations in the desifted bottom ash. Three cadmium spiking tests were also performed where the cadmium flux was increased 3 to 13 times the background amount using cadmium PVC pellets (0.7% cadmium by weight) or cadmium benzoate stabilizer solution (13.6% cadmium by weight). The results indicated that the cadmium tended to follow the flue gases through the furnace and that the bottom ash and grate siftings were not affected by the spiking.

Sawell et al (1992) offer the following explanation as to what happened to the batteries. "It appears that the lead plates in the batteries were reduced to elemental lead in the fuel bed, melted, and dripped through the grates ending up in the grate siftings hoppers. Lead sulfate particles from the batteries could also account for a portion of the elevated lead concentrations in the grate siftings. Based on these results, lead acid batteries do not appear to increase the concentrations of lead in most of the incinerator residue streams with the exception of the grate siftings". This may support the idea that the grate siftings should be separated from the bottom ash to permit better utilization of the bottom ash stream, especially if the bottom ash is to be graded or sifted. It may be that without the removal of grate siftings, finer fractions of sifted bottom ash could be labeled as a "Special Waste", making disposal or utilization more difficult and costly. Sawell et al (1992) argue that even though the amount of lead has increased in the grate siftings, the amount available for leaching did not increase. This is true because much of the lead would be in the form of elemental lead, which is not as soluble as lead sulfate, chloride, and hydroxide compounds.

This was the only study found where grate siftings were analyzed separately by diverting them from the regular bottom ash stream. Desifted bottom ash and grate siftings results are listed in the section entitled "SUMMARY OF INCINERATION RESIDUALS METAL DATA". The point needs to be made that this lack of information about grate siftings has created the need for this research.

2.11.2 SUMMARY OF INCINERATION RESIDUALS METAL DATA

Summarizing or comparing the information available that characterizes metals concentrations of incineration residuals will highlight several problems. First, a number of studies have used different metals extraction protocols. Either leachate extractions or acid digestions were performed and often it is not clear which chemical or analytical test method was used. For example, total metals may be reported, but it is not certain what type of digestion or acid was used. Second, there are different incineration technologies employed at the plants visited to obtain bottom ash samples.

The literature reviewed detailing test results from different authors is presented below in tabular form (Table 2.10). The author , incinerator site, test used, and metals results are summarized. The only study found that examined grate siftings independently of bottom ash was done by Sawell et al (1992).

Table 2.10 SUMMARY OF REPORTED METALS DATA FOR INCINERATOR RESIDUES

AUTHOR	SITE LOCATION	TEST PERFORMED	PROCESS	ASH TYPE	UNITS	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Brunner and Monch (1986)	SWITZERLAND	TOTALS (1)	mass burn	COMBINED	g/kg	3.8		0.91	230			0.89	3.5
Sawell and Constable (1989)	SWARU (2)	TOTALS (3)	RDF	BOTTOM	ppm	18						1320	4620
Sawell and Constable (1989)	LVH-EFW (4)	TOTALS (3)	two-stage	BOTTOM	ppm	<5						1970	6280
Sawell and Constable (1990)	UNKNOWN	SBEP (5)	two stage	BOTTOM	µg/g	ND-70 (6)	108-430					1300-4300	4800-7600
Sawell and Constable (1990)	UNKNOWN	SBEP	mass burn	BOTTOM	µg/g	ND-18	984-3170					1000-9900	1300-5210
Sawell and Constable (1990)	UNKNOWN	SBEP	RDF	BOTTOM	µg/g	ND-18	540-1260					1320-6400	1850-4620
Sawell et al (1992)	GVRD	TOTALS	mass burn	DBA (7)	µg/g	<5.0							1900-5200
Sawell et al (1992)	GVRD	TOTALS	mass burn	GS (8)	µg/g	<5.0-12.4							
Stegemann&Schneider(1990)	Goppingen(FRG)	TOTALS (9)	mass burn	BOTTOM	mg/kg	10	320	2200			210	1400	3900
Law & Gorden (1979)	NA	TOTALS (10)	mass burn	BOTTOM	ppm	41±15	520±240	450±190	16000±6000	3100±1700	210±250	1700±800	5500±1500

NOTES:
(1) samples crushed in ball mill, sieved 0.5 mm, digested refluxing Aqua Regia
(2) Hamilton-Wentworth Solid Waste Reduction Unit (SWARU)
(3) samples ground to pass No.100 sieve, digested with aqua Regia and hydrofluoric acid
(4) London Victoria Hospital - Energy From Waste Facility (LVH-EFW)
(5) Sequential Batch Extraction Procedure (SBEP) (ASTM D4793-88)
(6) ND = non-detectable
(7) Desifted Bottom Ash - examining only non-spiked runs
(8) Grate Siftings - examining only non-spiked runs
(9) samples finely ground (<0.2 mm)
(10) it is not clear which tests were performed

2.1 2 CHEMICAL COMPOSITION (ASH CHEMISTRY)

2.12.1 OXIDES

Average chemical composition of incinerator residue, reported by Collins (1978) and Tay (1988), are presented in Table 2.11. Collins' analyses are based on the "carbon-free" portion of incinerator residue since the amount of combustible or carbonaceous matter present in the residue is a major variable. Neither author states exactly which digestion or analytical technique was used to determine the results listed. It is assumed that percent chemical compositions represent TOTAL metals. It is not clear why there are large differences in the results reported. Since only "incinerator residue" is mentioned it may be that different combinations of bottom, fly, and/or boiler ash were examined. Also, different geographical and economic regions will have different "Wastesheds" and therefore, different MSW compositions (feedstocks). Roffman (1992) states that municipal waste combustor ash, by nature of it's origin, consists predominately of silicon oxides (SiO_2 i.e. glass). This is confirmed by Collin's and Tay's data.

Table 2.11 CHEMICAL COMPOSITION OF INCINERATOR RESIDUE

COMPOUND	COLLINS PERCENT	TAY PERCENT
SiO_2	59.8	32.3
CaO	11.9	4.8
Al_2O_2	9.8	
Al_2O_3		25.5
Fe_2O_2	4.0	
Fe_2O_3		28.1
TiO_2	1.0	
MgO	3.0	1.3
ZnO	0.4	0.5
PbO	0.1	0.13
CnO	0.1	
MnO	0.3	
Na_2O	6.1	1.9
K_2O	0.5	
SO_3	0.9	
P_2O_5	0.5	
OTHERS	1.6	5.5

2.12.2 AQUEOUS PHASE CONCENTRATIONS

Batch leachate extraction experiments on incinerator residue done by DiPietro et al (1989) indicate that pH has a significant influence on the aqueous phase concentrations of Ca, Zn, Cd, Cu, Ni, Fe, Pb, and Al. Aqueous metal concentrations were higher for ash exposed to acidic reducing conditions compared to alkaline reducing conditions. Dipietro et al (1989) classify the speciation of metals in aqueous solutions containing MSW incinerator residues as: 1) free ions, 2) soluble complexes, 3) adsorbed species, and 4) solid phases and precipitates.

It should be noted that characteristics of MSW such as feedstock, wasteshed, and chemical composition, the type of combustion process, and the type of leaching media used (i.e. concentrated or dilute, acidic or alkaline) all affect aqueous metal concentration and test results.

Other mechanisms that may be at work and are possible explanations for the different chemical compositions are metal speciation, mobility, dilution, complexation with inorganic and organic ligands, precipitation dissolution, adsorption-desorption, and ion-exchange with inorganic and organic solids, and oxidation-reduction reactions. Dipietro et al (1989) state that the principle master variables in the aqueous environment that influence chemical speciation processes and the ultimate fate of metals include pH, oxidation-reduction potential (ORP), ionic strength, and temperature.

Stegemann and Schneider (1990) show that bottom ash can neutralize about 2 meq of acid per gram, before reaching a neutral pH, where heavy metals will be more soluble. A one kg sample of ash is capable of neutralizing approximately 20,000 L of pH 4 groundwater. The study included a comparison between stored and fresh bottom ash samples and it was found that the stored bottom ash had a lower pH than the fresh bottom ash. They also examined the relationship between particle size and Acid Neutralizing Capacity (ANC). They found that the smallest particle size fraction appeared to have a greater ANC. Stegemann and Schneider (1990) postulate that "the excess alkalinity present in fresh bottom ashes may be neutralized by carbonation, and perhaps also consumed by alumino-silicate reactions, in the presence of water, during the outdoor storage period. If true, this has the advantage of providing an initial pH around 10, where heavy metal contaminants have their minimum solubility, in bottom ashes conditioned by outdoor storage." This in an important factor regarding utilization of BA as an aggregate substitute.

2.13 LEACHATE STUDIES OF IN-SITU MONOFILLED ASH

A number of studies have examined the chemical and physical properties of incinerator ash after it has been disposed of in its in-situ environment. Examples of this include Bagchi et al (1989) who examined the physical and chemical characteristics of fluidized bed incinerator ash that had been disposed of in lagoons. Roffman et al (1990 and 1991) present 4 years of leachate data from the Woodburn Ash-Monofill in Marion County, Oregon. The significant findings of these long-term characterizations are that the concentration range of dissolved solids and major ions (chloride and sulfate) in the leachate is "comparable" to the chloride and sulfate concentrations in sea water. The most significant finding was that all metal concentrations in all leachate samples were below the EP-Toxicity (EP-tox) "Maximum Allowable Limits." This would tend to support the idea that monofilled ash is not an environmental or regulatory problem, and that subjecting bottom ash to the LEP is not appropriate because the LEP was designed to model the release of contaminants in a biologically active MSW landfill. Goodwin (1992) also evaluated the data from the Woodburn Oregon monofill ash study. His major findings and conclusions are in agreement with the studies and published data that Roffman (1990 and 1991) has put forth. To summarize:

- **The analysis of long-term leachate monitoring results show most heavy metals achieve non-detectable levels within 2 to 3 years.**
- **Compelling field results demonstrate that MSW incinerator ash is neither hazardous or toxic and does not pose a threat to the environment or to the public health.**
- **Field studies of MSW incinerator ash strongly support its benign characteristics.**
- **Issues raised by the US EPA's devised laboratory leachate tests (LEP, EP-tox) do not occur in the real world and that actual field results prove the ash exhibits environmentally benign characteristics.**

Roffman (1992) compares test results from different facilities throughout the US, and arrives at the conclusion that bottom ash is clearly a regulatory “special case”, and should be regulated differently. No clarification was provided about the type of bottom ash examined, therefore one should assume combined ash was studied. She states “the data obtained by these studies indicate that the leachates are rich in salts. The main constituents are chloride, sulfate, sodium, calcium, and carbonate. The leachates all met the RCRA maximum allowable limits in cases in which there are such limits specified. Often, although not always, the leachates met the primary drinking water standards for the metals which were examined in cases where no such limits are specified. Metal levels, mainly lead and cadmium, were often lower in the actual field leachates than in the corresponding laboratory test extracts (Roffman, 1992)."

The LEP or Solid Waste Extraction Procedure (SWEP) or US EP-tox test is an inappropriate leachate model for incinerated MSW because it does not reflect what happens to monofilled ash in the field. The

LEP was designed to model the codisposal of solid wastes at sanitary landfill sites. Beckman and Dragovitch (1986) agree with this and state "incineration of MSW produces a residue which may have a high concentration of certain heavy metals, but combustion does not produce the metals: it only concentrates what is already in the waste. The EP-tox test is not an appropriate test for incinerator residue, ..."

The articles written by Roffman and Goodwin discuss the monofilling of combined bottom and fly ash streams. Fly ash from dry lime flue gas scrubbing systems contains unreacted lime, which combines with the ashes' other pozzolanic (i.e. concrete-like) reactants to form a low permeability end-product. The bottom and fly ash streams from the Burnaby incinerator are not combined and are disposed of separately. However, the bottom ash still possesses some of these "concrete-like" properties because of cementaceous (mainly calcium) oxides created in the incineration process.

2.13.1 THE GVRD'S BOTTOM ASH MONOFILL TEST CELL RESULTS

The GVRD (April,1994) monitored ash monofills containing regular and desifted bottom ash at the Port Mann Landfill (PML), Surrey, British Columbia. Early findings indicate that high salts levels and low heavy metal concentrations are present in the leachate coming from the monofills. Test results and sample dates are shown in Tables 2.12 and 2.13; cells 5 and 6 were filled with regular bottom ash and cells 7 and 8 with desifted bottom ash. Reference will be made to this information in the "RESULTS AND DISCUSSION" section. These in-situ metal leachate results tend to support the hypothesis that monofilling bottom ash is environmentally acceptable because the leachates may meet guidelines for drinking water quality after a short period of time. The removal of the siftings did not appear to make an appreciable difference in the leaching characteristics of the bottom ash, when considering the salts and metals examined here.

Before the monofills were constructed samples of the bottom ash placed into the various cells were collected and stored. These “initial” samples must be subjected to a LEP to determine initial metal and salt concentrations. After the field study was completed “final” samples of the bottom ash were collected and stored from the various cells. These “final” samples must be subjected to a LEP to determine final metal and salt concentrations in the bottom ash. Once this information is obtained LEPs for regular and desifted bottom ash can be compared to their respective in-situ leachate results and a mass balance should be performed. When these results are available a clear picture of the relationship between “initial” LEP test results, field leaching characteristics, and “final” LEP results can be presented. This will provide insight into the effect aging has on leachable metals concentrations in bottom ash.

The most notable and rapid drops in concentration are for the chloride and sodium ions. Chloride concentrations were initially in the 1,400 to 1,600 mg/l range for all cells and sodium concentrations ranged between approximately 500 to 1,300 mg/l. The first leachate samples were collected on October 28, 1992 and in one months time, when the second set of samples were taken, the concentrations for both chloride and sodium dropped to about 200 mg/l. Sodium and chloride concentrations dropped to below 50 mg/l for the last two samples taken.

Peak manganese and iron leachate concentrations were observed in cells 5, 6, 7 and 8. The significance of these peaks is quite small in comparison to the low concentration of these metals in the leachate. Iron and manganese "spikes" were observed in cell 5 (RBA) from the November 16, 1993 leachate sample (Table 2.12). In cell 6 the concentration of both metals in the leachates, after the initial high concentrations of the first sample, are under 2 mg/l. The iron and manganese concentrations from cell 7 (DBA) are consistent with those from cell 5 (RBA), suggesting that the removal of the siftings did not affect the leaching patterns of these metals significantly. Data is not available from cell 8 (Table 2.13) for the November or January sampling periods. The remainder of the metals (Cd, Cr, Cu, Ni, Pb, and Zn) do not appear to pose an environmental threat because the concentration of these metals in the leachate from each cell is extremely low.

An explanation for the initial high release of salts and metals may be flushing effects, due to heavy rainfall after prolonged dry spells. Flushing effects would be capable of washing out the chemical constituents under review.

Table 2.12 PORT MANN LANDFILL LEACHATE TEST RESULTS (regular bottom ash)

	CELL 5 (regular bottom ash)							
Sample Date	28-Oct-92	30-Nov-92	27-Jan-93	23-Mar-93	15-Jun-93	16-Nov-93	5-Jan-94	23-Feb-94
pH	6.9	6.5	7.0	7.0		7.8	7.0	7.3
Alkalinity Total	438	148	119	113		716	235	210
Chloride	1530	244	135	101		149	30	23
Sulphate	2400	941	622	670		972	632	500
Calcium	160	139	144	151	187	327	246	207
Cadmium	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Chromium	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Copper	0.02	0.02	0.02	0.02	0.02	0.31	0.05	0.05
Iron	5.39	1.06	0.1	0.11	0.23	3.99	3.28	1.27
Manganese	2.46	0.46	0.5	0.4	1.01	5.01	1.16	0.72
Sodium	474	270	146	145	144	340	59	41.6
Nickel	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.04
Lead	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Zinc	0.02	0.03	0.07	0.04	0.02	0.16	0.20	0.25
	CELL 6 (regular bottom ash)							
Sample Date	28-Oct-92	30-Nov-92	27-Jan-93	23-Mar-93	15-Jun-93	16-Nov-93	5-Jan-94	23-Feb-94
pH	6.9	6.5	6.5	6.7		7.8	7.3	7.5
Alkalinity Total	475	706	927	884		219	123	120
Chloride	1370	158	160	130		113	22	16
Sulphate	130	834	392	437		908	322	240
Calcium	235	409	392	341	148	244	116	106
Cadmium	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Chromium	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Copper	0.17	0.51	0.37	0.52	0.02	0.02	0.02	0.02
Iron	4.47	9.94	27.5	25.6	0.61	1.62	1.16	0.47
Manganese	2.7	4.78	4.61	3.83	0.81	0.80	0.07	0.03
Sodium	1280	195	162	146	142	226	40	28.2
Nickel	0.05	0.08	0.08	0.09	0.02	0.02	0.02	0.03
Lead	0.06	0.07	0.08	0.06	0.06	0.06	0.06	0.06
Zinc	0.04	2.81	3.43	3.08	0.1	0.16	0.05	0.05

Note: all values except pH are in mg/l or ppm.

Table 2.13 PORT MANN LANDFILL LEACHATE TEST RESULTS (desifted bottom ash)

	CELL 7 (desifted bottom ash)							
Sample Date	28-Oct-92	30-Nov-92	27-Jan-93	23-Mar-93	15-Jun-93	16-Nov-93	5-Jan-94	23-Feb-94
pH	7.5	7.0		6.7		7.5	6.8	7.3
Alkalinity Total	462	209		178		633	292	330
Chloride	1560	210		78		111	24	38
Sulphate	112	964		631		846	517	330
Calcium	351	244		200	227	342	225	188
Cadmium	0.01	0.01		0.01	0.01	0.01	0.01	0.01
Chromium	0.01	0.01		0.01	0.01	0.01	0.01	0.01
Copper	0.02	0.02		0.02	0.02	0.3	0.07	0.12
Iron	3.96	0.42		0.21	0.33	6.64	2.69	1.99
Manganese	8.17	0.86		0.62	1.41	4.02	0.94	1.40
Sodium	1160	258		109	116	221	40	27.2
Nickel	0.06	0.04		0.04	0.02	0.02	0.02	0.03
Lead	0.06	0.06		0.06	0.06	0.06	0.06	0.06
Zinc	0.04	0.17		0.27	0.09	0.28	0.12	0.16
	CELL 8 (desifted bottom ash)							
Sample Date	28-Oct-92	30-Nov-92	27-Jan-93	23-Mar-93	15-Jun-93	16-Nov-93	5-Jan-94	23-Feb-94
pH	6.6	11.6	9.0	8.6				7.3
Alkalinity Total	290	326	98	103				200
Chloride	1370	236	115	95				19
Sulphate	940	375	342	354				430
Calcium	290	167	116	125	196			193
Cadmium	0.01	0.01	0.01	0.01	0.01			0.01
Chromium	0.01	0.01	0.01	0.03	0.01			0.01
Copper	0.02	0.08	0.05	0.04	0.02			0.02
Iron	3.05	1.08	0.04	0.05	0.41			0.25
Manganese	5.98	0.23	0.04	0.09	0.63			0.12
Sodium	765	187	86	89.6	113			28.5
Nickel	0.04	0.02	0.02	0.02	0.02			0.02
Lead	0.06	0.06	0.06	0.06	0.06			0.06
Zinc	0.05	0.01	0.02	0.04	0.03			0.08

Note: all values except pH are in mg/l or ppm.

Canadian Water Quality Guidelines (Health and Welfare Canada, 1989) were referenced (Table 2.14) for the parameters examined as part of the PML study to compare the leachate concentrations to drinking water standards. Generally, the leachates from the regular and desifted bottom ash cells at the PML tend to be above regulatory guidelines initially, but salt concentrations drop with time to below regulatory guideline concentrations. Data to support this is contained in Tables 2.12 and 2.13. Initially leachates should be collected for testing and to capture contaminants released in the early stages of a monofills life. After the leachate is below regulatory limits it can be discharged to sanitary sewers without costly treatment.

Table 2.14 CANADIAN DRINKING WATER QUALITY GUIDELINES & COMPARISON TO RESULTS

PARAMETER	MAC (1)	IMAC (2)	AO(3)	STATUS (4)	1st 6 MONTHS PML	2nd 6 MONTHS PML
HARDNESS (5)					98 - 927	120 - 633
CADMIUM	0.005				0.01	0.01
CALCIUM (6)				PROPOSED	116 - 409	106 - 342
CHLORIDE			≤250		1,560 - 95	16 - 149
CHROMIUM	0.05				0.01 - 0.03	0.01
COPPER			≤1.0	UNDER REVIEW	0.02 - 0.52	0.02 - 0.31
IRON			≤0.3	PROPOSED	0.1 - 27.5	0.25 - 6.64
LEAD	0.01			PROPOSED	0.06 - 0.08	0.06
ZINC			≤5.0	PROPOSED	0.02 - 2.81	0.02 - 0.28
MANGANESE			≤0.05	PROPOSED	0.04 - 8.17	0.03 - 5.01
SODIUM			≤200	PROPOSED	86 - 1280	27.2 - 340
SULFATE			≤500	PROPOSED	112 - 2400	240 - 972

NOTES:
All values reported are in mg/l or ppm.
(1) MAC - Maximum Acceptable Concentration
(2) IMAC - Interim Maximum Acceptable Concentration
(3) AO - Aesthetic Objectives
(4) STATUS - Indicates whether the guidelines are proposed or under review
(5) Public acceptance of harness varies considerably. Generally hardness levels between 80 and 100 mg/l (as $CaCO_3$) are considered acceptable; levels greater than 200 mg/l are considered poor but can be tolerated; those in excess of 500 mg/l are normally considered unacceptable.
(6) Assessment of data indicates no need to set a numerical guideline.

CH2MHILL (1993) states that there is disagreement about the appropriateness of the Solid Waste Extraction Procedure (SWEP) technique used for classification of bottom ash because the acetic acid used in the Leachate Extraction Procedure (LEP) or the TCLP tests, is not representative of landfill conditions and heavy metal concentrations in the leachate are not often elevated above drinking water standards (Hasselriis, 1988). If the in-situ leachate results from the PML are compared to the above guidelines this point is confirmed.

2.14 UTILIZATION OF BOTTOM ASH

The long-term disposal or utilization of bottom ash is of concern because markets or uses have not been fully developed. Providing more data and information about bottom ashes' chemical and physical characteristics so that utilization options can be pursued was one of the objectives for this research. The Burnaby Incinerator's bottom ash is currently being utilized at the Port Mann Landfill in Surrey, BC to build roads, but this option will not be possible when the landfill closes in approximately 5 years. A summary of authors and their suggested utilization schemes is listed in Table 2.15. A "YES" in Table 2.15 denotes that the author listed studied and agreed with the utilization option listed, a "NO" means the utilization option was studied and rejected, and a "blank" means the option was not investigated or commented on.

Most authors discussing utilization of bottom ash agree that additional processing is required to remove oversize, unburned organic, and ferrous material. Buekens and Schoeters (1979) suggest that the separation of the residue into marketable fractions becomes attractive because the cost and difficulty of finding suitable tipping sites are eliminated or reduced, although the generated revenue is small. A list of processes, and recent developments for the upgrading of the incinerator residue provided by Buekens and Schoeters (1979) includes:

- wet magnetic separation
- washing out of unburned material by means of spiral classifiers, sink/float separators or jigs
- grading according to density by means of air tables, jigs, fluidized beds or heavy medium
- separation of brittle glass from malleable aluminum by means of roll mills. The flattened metal remains on the sieve, whereas the ground slag or glass is sieved off.

Buekens and Schoeters (1979) conclude that the "direct utilization of incinerator residue is possible only in exceptional cases. Upgrading the residue to construction materials after removal of the ferrous scrap is a most satisfactory solution, because it allows a saving of raw materials and eliminates a possible source of water pollution." They also state that the problems with using ash as a construction material are its variable composition and properties and the fact that the ash has to compete with inexpensive and plentiful raw materials.

Collins (1978) suggests that incinerator residue should be used as fill material because properly prepared incinerator residue can be well compacted. Usually, properly prepared incinerator residues means that ferrous scrap has been removed and that the bottom ash has been graded and aged. When utilized as cover material or in haul roads at a landfill, bottom ash can satisfy all functional requirements for daily and intermediate cover (Atwater and Sims,1993 and Collins,1978). "It spreads easily, handles and compacts well, has no objectionable odor, presents no unusual dusting problem, and causes no damage to compaction equipment or the tires of refuse hauling trucks (Collins, 1978)." Another advantage highlighted by Atwater and Sims (1993) is that bottom ash is relatively free draining.

Atwater and Sims (1993) discuss types of asphalt pavement or asphalt concrete as well as the large body of research that the US Federal Highways Administration sponsored and supported in the 1970's. Also discussed are the ASTM's tests applicable to aggregate materials used in asphalt. Collins (1978) discusses in detail bituminous paving mixtures, and concludes that utilization of incinerator residue as aggregate for paving is a practical and promising means of using the material. One of the largest problems with this use is however that there is a high percentage of glass particles which allows the asphalt to strip away from the smooth surfaces on the glass. Lime, about 2%, is usually added as an anti-stripping agent.

Gress et al (1991) authored an article entitled "Municipal Solid Waste Ash As An Aggregate Substitute In Asphalt Concrete". They examined a number of time-dependent physical properties of bottom ash to test its suitability for use in asphalt. Tests performed included particle size distribution (ASTM C136), moisture (ASTM D2216), LOI - Loss On Ignition (ASTM C114), ferrous content, absorption and specific gravity (ASTM C127, C128), moisture density (ASTM D1557), CBR - California Bearing Ratio (ASTM D1863), sodium sulfate soundness (ASTM C88), LA abrasion (ASTM C131), unconfined compressive strength (ASTM D2166), and Marshal Stability (ASTM D1559). Time dependent environmental properties that were examined included elemental composition, acid neutralizing capacity (ANC), static pH leach tests (pH 7,4; L:S 100), and several others. The study examined various levels of bottom ash substitution in place of natural aggregates (i.e. 0, 25, 50, 75, and 100% bottom ash). A variety of percent asphalt cement levels were also investigated (4 to 12% by total weight). Their study concluded that bottom ash is a suitable lightweight aggregate and that the physical properties of bottom ash are reasonably uniform. The results suggest that a blend consisting of 75% bottom ash and 25% natural aggregate with 9%

asphalt cement (by weight) is a technically good hot mix blend. The benefits of the encapsulating properties of bitumen in controlling salt release are apparent.

Testing of bottom ash as a concrete aggregate (Portland cement concrete) has highlighted several potential problems. The most significant problem is hydrogen gas generation caused by a reaction with free aluminum in the ash causing detrimental expansion and cracking (Atwater and Sims, 1993 and Collins,1978). Therefore, the use of incinerator ash as an aggregate in Portland cement concrete has not been recommended.

Pavlovich et al (1977) used incinerator residue (combined ash) as a base course paving material in Washington, DC. Their preliminary results indicated that, with proper precautions, incinerator residue could be used as an aggregate substitute or extender in bituminous base construction. They also state that its use will be governed by a combination of economic, environmental and energy factors. This is of course true for all utilization projects or possibilities.

Requardt and Harrington (1962) utilized incinerator ash (combined ash) long ago as landfill cover material. They cite the major advantages of using ash as cover as being:

1) it is compactable over a broad range of weather conditions,
2) it has greater internal strength after compaction and is free from shrinkage upon drying (as opposed to sandy clay), and
3) it possesses good surface rigidity and prevents muddiness at the landfill during rainy weather.

Stegemann and Schneider (1991) report that approximately half of the bottom ash in the Federal Republic of Germany (FRG) is used in road construction, amounting to almost 1.5 million tonnes. They do not say for what purpose nor do they distinguish between road base or sub-base, although bottom ash is typically utilized as sub-base. In their view, the primary characteristics of concern from a utilization standpoint are content and leachability of heavy metals and salts.

Stoelhorst (1991) conducted a detailed study utilizing slag (combined incinerator residue). It was concluded that large quantities of residue could not be used in reinforced concrete because of the high chloride content, which increases the risk of corrosion of steel reinforcements. It was argued that to replace sand and/or gravel, and to use incinerator residue, it would be necessary to crush and screen the ash as well as remove as much iron as possible. Other potential problems highlighted were gas formation in an alkaline environment due to metallic zinc and aluminum, the effect on the setting of the cement due to organic components and zinc salts, the sulfate content, and free CaO and MgO which might cause destructive expansion of the concrete. To minimize the impacts of some of these problems it was thought that the ash could be stored and aged outdoors to alter its properties. For example, it was found that aging resulted in the CaO and $Ca(OH)_2$ being almost completely converted into $CaCO_3$.

Teague (1978) published data indicating that incinerator refuse used in a bituminous base (littercrete) was performing in an excellent manner, almost identical to the conventional blackbase control section used. Tests performed after 3 years of service included visual examinations, Marshall Stability, splitting tensile strength values, Hveem stability, and Resilient Modulus tests.

In many cases bottom ash has been stabilized and/or solidified with materials like concrete or asphalt to reduce its leachability and improves its physical characteristics, thereby facilitating its utilization. Solidification and Stabilization (S/S) processes is described as a technology where additives or processes are used to transform a waste into a more manageable form or less toxic form by physically and/or chemically immobilizing the waste constituents. "Most commonly used additives include combinations of hydraulic cements, lime, pozzolans, gypsum, silicates, and similar materials. Other types of binders, such as epoxies, polyesters, asphalts, etc. have also been used, but not routinely (Wiles et al, 1991)". Kosson et al (1991) have investigated a number of S/S processes which cover individual incineration residues and their combinations. Processes investigated include S/S with Portland cement and polymeric additives, S/S with Portland cement and soluble silicates, S/S with quality controlled waste pozzolans, a reaction with soluble phosphate, and finally S/S with Portland cement only. The USEPA's regulatory leaching test (TCLP) was used to evaluate the effectiveness of the various treatments. With respect to bottom ash, their findings indicated that untreated and S/S treated MSW incinerated bottom ash pass TCLP criteria.

Hartlen and Lundgren (1991) suggest properties and procedures, applications, and guidelines for the utilization of bottom ash. They are as follows:

Suggested Properties and Procedures:

1) pre-screened ash with the separation of magnetic materials,
2) maximum grain size 50 mm (2 in),
3) no more than 19% of the particles smaller than 0.06 mm,
4) the content of metals in leachates from laboratory tests must not exceed those in leachates studied in the field (lab must be worst case scenario),
5) loss on incineration less than 4%; the ash must be kept in storage for at least 3 months.

Suggested Applications:

1) embankment fill for roads,
2) reinforcement material for low traffic roads and bicycle paths,
3) fill under light buildings and floor structures.

Suggested Guidelines:

1) the thickness of the fill should be limited to 3.0 m,
2) the bottom ash should be placed primarily above the ground water level and below pavement,
3) the bottom ash should be primarily in urban areas as fill.

Table 2.15 BOTTOM ASH UTILIZATION INVESTIGATIONS OR SUGGESTED USES

AUTHOR	APPLICATION									
	BULK FILL	ROAD SUB-BASE	BITUMINOUS TOP OR BOTTOM LAYER	BLOCKS & BRICKS	LANDFILL COVER	LANDFILL ROADS	SLAG WOOL	CONCRETE	PORTLAND CEMENT	FUSED AGGREGATE
Atwater and Sims (1993)	YES	YES	YES	YES	YES	YES		NO	NO	NO
Buekens and Schoeter (1979)	YES	YES	YES	YES			YES	YES		
Collins (1978)	YES	YES	YES	YES	YES	YES	YES		YES	YES
Lauer (1979)		YES		YES				YES	YES	
Gress et al (1991)			YES							
Pavolich et al (1977)		YES								
Requart & Harrington (1962)					YES					
Stegeman & Schnieder (1991)		YES								
Stoelhorst (1991)							NO			
Teague (1978)			YES							

2.15 SIGNIFICANCE OF LITERATURE REVIEW

The literature review provides the reader with some understanding of the incineration process and why it is beneficial to use incineration as part of solid waste management plans. Two residual streams, specifically bottom ash and grate siftings, have been defined because they are the basis for this work. Physical, chemical, and analytical procedures used to characterize incineration residuals have been discussed. Any relevant results from other studies examined have been summarized and these summaries may be used in the "RESULTS AND DISCUSSION" section to make comparisons to the findings from this study. The "CONCLUSIONS' section will also reference the significant findings of other studies and authors in order to state whether or not there is agreement between study results.

3. MATERIALS AND METHODS

Bottom ash is very similar in nature to natural aggregates and may be able to replace natural aggregates in certain applications that are governed by, for example, ASTM standards or the BCMMS (1991). In order to comment on whether or not bottom ash can be used to replace natural aggregates it was necessary to use these same ASTM test standards. If bottom ash is to be utilized in place of natural aggregates it must meet or exceed the standards that natural aggregates subscribe to. In addition, legislation typically mandates that some form of leachate test be performed to ensure incinerator residues do not harm the environment. For example, the BC MOELP's LEP must be used to test samples of bottom ash before they are utilized or disposed of.

3.1 AN OVERVIEW OF ANALYTICAL PROCEDURES

To date, the work done to characterize bottom ash from Municipal Solid Waste (MSW) mass burn incinerators has provided varying results. This characterization has included the chemical and physical examination of Municipal Solid Waste (MSW) and the resulting ash. The studies performed here provide detailed qualitative and quantitative analyses of desifted bottom ash (DBA) and grate siftings (GS). Work performed includes:

- Grain Size Distribution (GSD) study of the desifted bottom ash and the grate siftings. ASTM GSD tests were used because they are what natural aggregates are tested with.
- A categorization or sorting of the 3 coarsest fractions based on 10 materials (1991 and 1992-93 studies). The coarse fractions were defined as the plus 9.5 mm fraction because it was possible to visually sort this particle size. It was not feasible to determine the classification of fine particles.
- Compaction density relationship for bottom ash passing a 25 mm (1") sieve; which is based on ASTM standards.
- Leachate Extraction Procedure (LEP) on the 3 finest fractions of desifted bottom ash and grate siftings and subsequent metals analysis from the 1992-93 study. The fine fractions were defined as the minus 9.5 mm fraction because this is the fraction that must be tested under the BCMOELP Special Waste legislation.

- Aqua Regia Digestion (ARD) of the solids remaining after the LEP and subsequent metals analysis from the 1992-93 study.

The bottom ash LEP leachates were analyzed for metals. Heavy metals analysis were performed at the University of British Columbia's Environmental Engineering laboratory using flame atomic absorption spectrophotometry (flame AA). The metals selected for analysis were:

1) cadmium (Cd)
2) chromium (Cr)
3) copper (Cu)
4) iron (Fe)
5) manganese (Mn)
6) nickel (Ni)
7) lead (Pb)
8) zinc (Zn)

The grate siftings were also subjected to a LEP and ARD of the LEP solids, but this analytical work was performed by Quanta Trace Labs, Burnaby, BC. Quanta also performed the ARD of the bottom ash LEP solids. The digestate was then returned to UBC for metals analysis.

3.2 SAMPLE COLLECTION AND PREPARATION

The flowcharts in Figures 3.1 and 3.2 outline the sampling methodology followed in order to obtain representative desifted bottom ash and grate sifting samples. The process used is almost identical to the one used for the 1991 study to ensure that results from both the 1991 and 1992-93 studies were directly comparable.

The 1992/93 sampling session ran for 7 months from September 1992 to March 1993. Samples were obtained on 12 different days. Initially, 9 grabs of desifted bottom ash were taken on each sample day, and then allowed to air dry on pallets at the incinerator. Following this, each grab was sifted into 7 different size fractions. Weights of each fraction were recorded and used to generate grain size distributions. Similar fractions from grabs 1, 2, and 3 were combined or composited. Similarly, grabs 4, 5, and 6 and grabs 7, 8, and 9 were composited. Each composite of three grabs represented one sample that consisted of 7 fractions, or sub samples. The plus 50 mm (2") fractions were examined and left at the incinerator. Eighteen sub samples per sample day, representing 6 fractions of ash per each of the 3 composited samples, were bagged and taken back to UBC. In total, 216 sub samples required physical or chemical characterization. The fractions greater than 9.5 mm (3/8") were defined as the coarse fractions and subjected to physical analysis. The fractions smaller than 9.5 mm were considered the fine fractions and underwent chemical analysis. Half (108) of the samples were plus 9.5 mm in size and were visually classified according to 10 material types (physical testing). The other half were minus 9.5 mm and were subjected to an LEP and an ARD of the LEP solids (chemical testing).

In 1991, Ting (1994) sampled on eighteen (18) different days between January and December 1991. A similar compositing of samples was used, except Ting (1994) took 12 grabs. Ting (1994) obtained 4 samples with 7 sub samples or different size fractions per sample for a total of 28 sub samples for each sample day.

Desifted bottom ash (DBA) samples were taken off the end of the discharge conveyor after the ferrous recovery belt magnet using the ash bunker crane. Once a sufficient amount of sample was collected the crane was moved outside and the ash was shoveled into a bucket (Figure 3.3). The bottom ash is quenched prior to being discharged to the ash bunker, therefore, it was necessary to air-dry the ash for between seven to ten days so that the sieves would not clog. This was done on plastic sheets on top of wooden pallets (Figure 3.4). Each of the grabs was spread out to increase its' surface area and improve the drying process. Drying took place in the Air Pollution Control (APC) Plant.

In order to obtain statistically representative samples several "grabs" of bottom ash were combined and then appropriate mixing, coning, and quartering (ASTM C702-87) was performed. Each grab of desifted bottom ash was between 50 and 60 Kg (ASTM D75-87). Sawell and Constable (1989) used a similar approach for the National Incinerator Testing and Evaluation Program (NITEP). They collected grab samples from the finishing grate, prior to the quench tank, and composited randomly selected coned and quartered samples.

The USEPA's SW-846 (1986) outlines a procedure and methodology for sampling and analyzing solid wastes. Many authors have used SW-846 (1986) and it is followed as closely as possible for this thesis. Work done by Fiesenger and Visalli (1989) discusses the USEPA's SW-846 and some ASTM standards that are relevant for sampling incineration residuals. This discussion was also used to help design the methodology used here.

The sampling procedure for the grate siftings was similar to that for the bottom ash. The major differences were the collection location and number of sieve sizes used. Grate siftings were collected in two 205 L (45 gallon) drums, one for each side of the furnace. The drums sat on the concrete floor, and were connected to the discharge ports with flexible 9" diameter heat resistant tubing. Specially modified lids were used to connect the tubing to the drums and ensure that all of the siftings that were blown down were collected. It was not necessary to air dry the grate siftings because they did not pass through the quench tank when they were pneumatically discharged. Grate siftings discharges, and therefore samples obtained, ranged between 5 and 25 Kg.

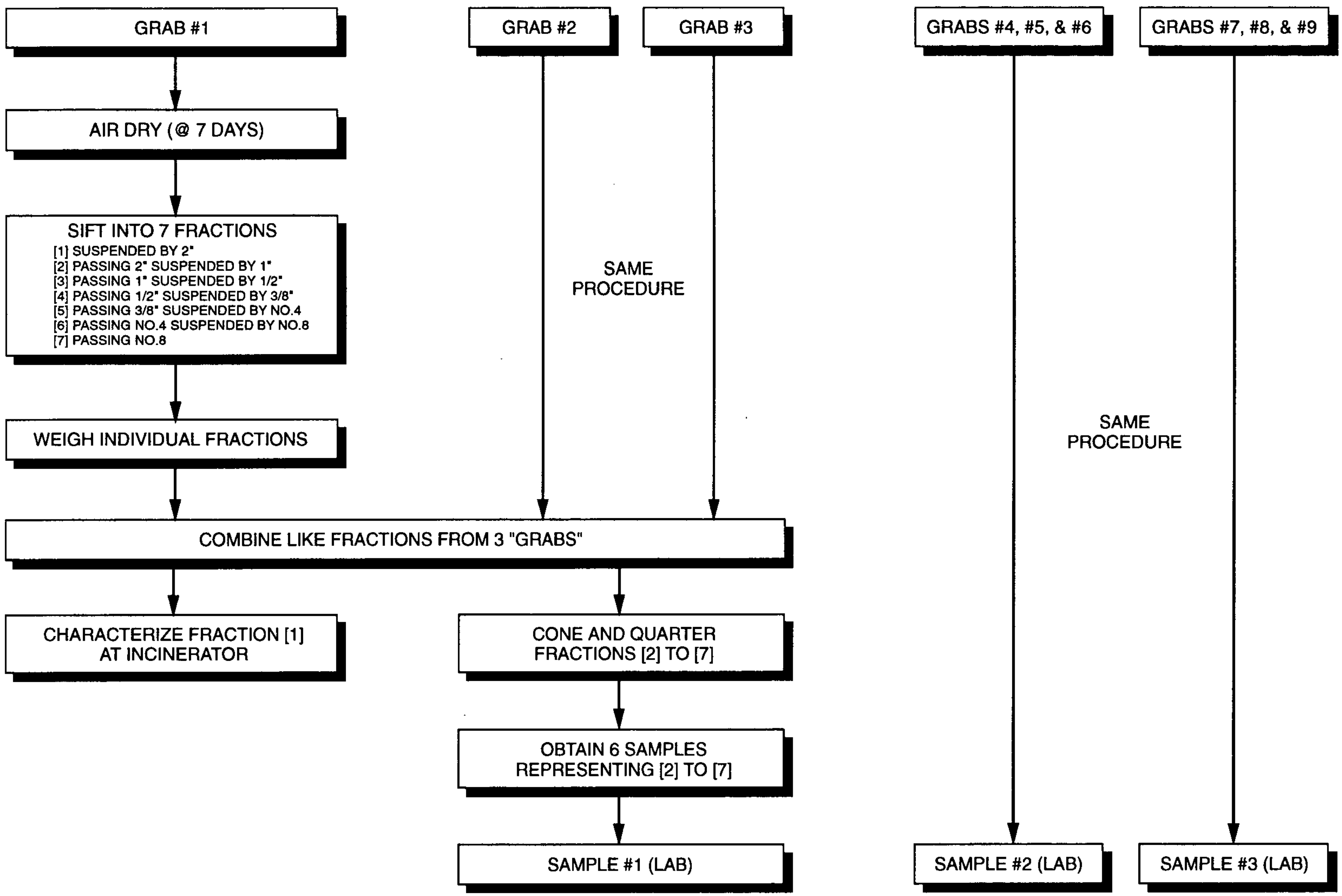


Figure 3.1 BOTTOM ASH SAMPLING PROCEDURE

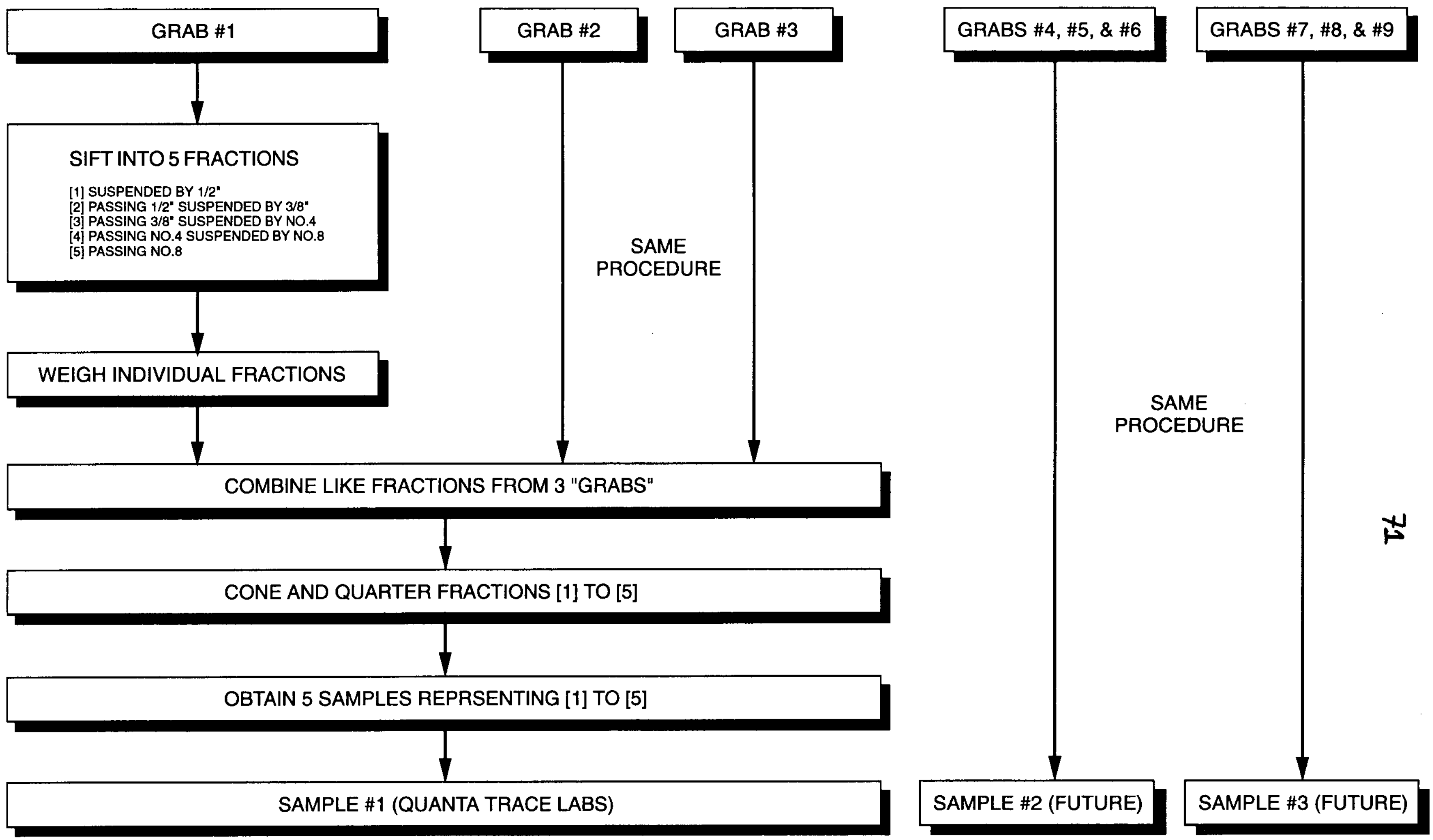


Figure 3.2 GRATE SIFTINGS SAMPLING PROCEDURE

Figure 3.3 ASH SAMPLE TAKEN FROM BOTTOM ASH CRANE

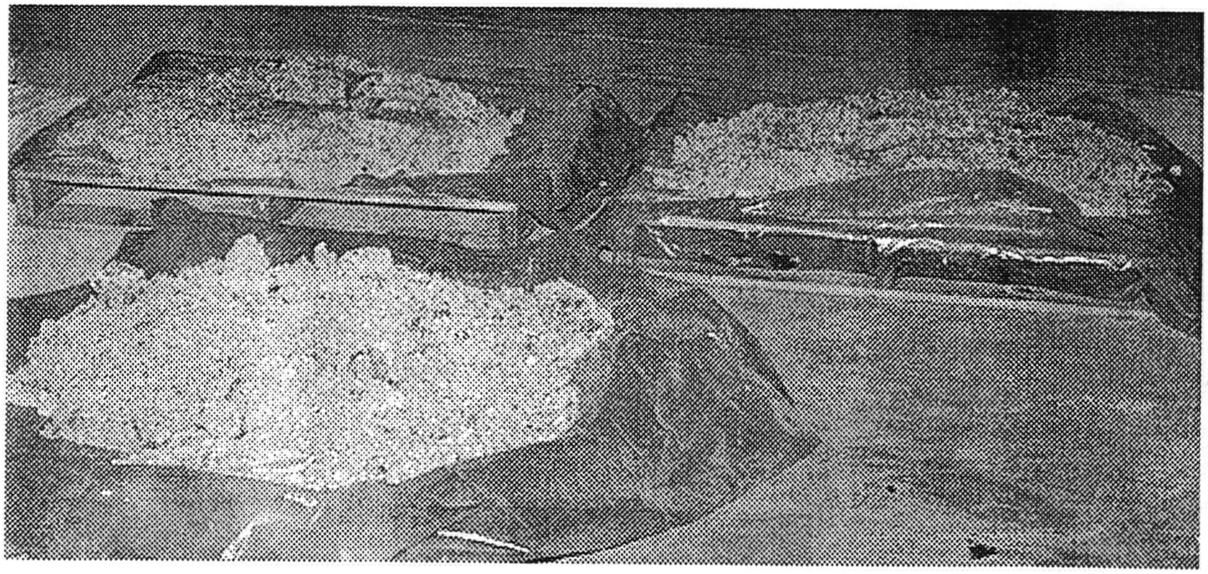


Figure 3.4 ASH SAMPLE AIR DRIED

3.3 GRAIN SIZE DISTRIBUTIONS

A sieve analysis generally consists of shaking a sample, soil, aggregate, bottom ash, etc. through a stack of wire screens with openings of known sizes. By definition, the "particle diameter" is the side dimension of a square hole.

Once dry (Figure 3.5), the following sets of sieves were used for sifting the DBA samples:

1) 50 mm (2")
2) 25 mm (1")
3) 12.5 mm (1/2")
4) 9.5 mm (3/8")
5) 4.75 mm (No.4)
6) 2.36 mm (No.8)

Similarly, the following sets of sieves were used to sift the grate siftings (GS):

1) 12.5 mm (1/2")
2) 9.5 mm (3/8")
3) 4.75 mm (No.4)
5) 2.36 mm (No.8)

The apparatus shown in Figure 3.6 is the sifting machine used at the Burnaby Incinerator to sieve the desifted bottom ash and grate siftings. Each fraction of desifted bottom ash and grate siftings was laid out on a plastic sheet (Figure 3.7) and then weighed (see Figure 3.8). The mass information was used to generate grain size distribution (GSD) curves, which commonly show percent retained or alternatively, percent passing (finer), depending on the format desired.

Figure 3.9 shows several fractions of ash before coning and quartering. Each fraction was coned and quartered (Figures 3.10 to 3.13) to obtain representative samples for the lab. The coning and quartering procedure is also shown in Figure 3.14 which has been reproduced from ASTM D75.

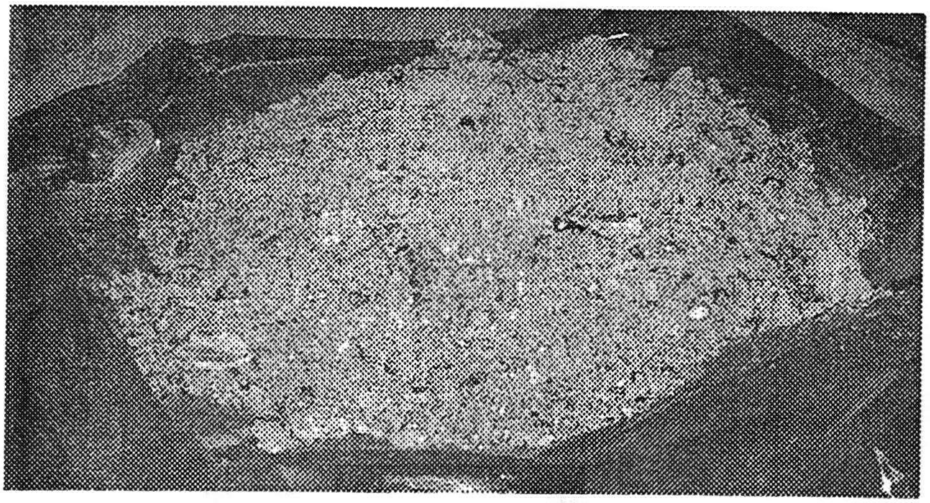


Figure 3.5 DRIED ASH READY FOR SIFTING

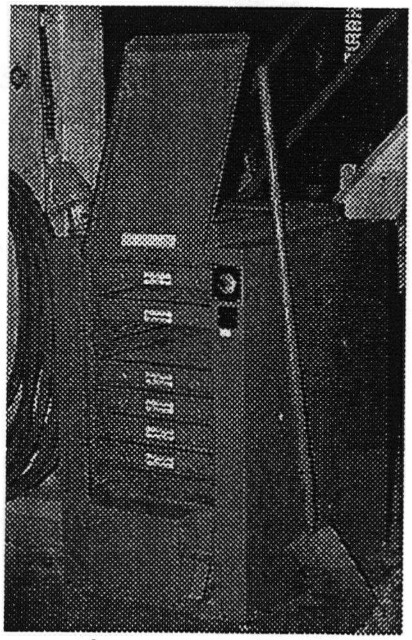


Figure 3.6 SIFTING MACHINE AT THE BURNABY INCINERATOR

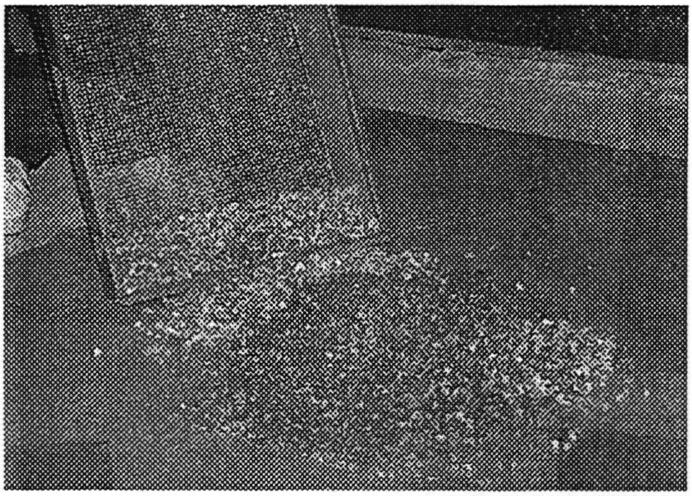


Figure 3.7 SINGLE, SIEVED FRACTION OF ASH

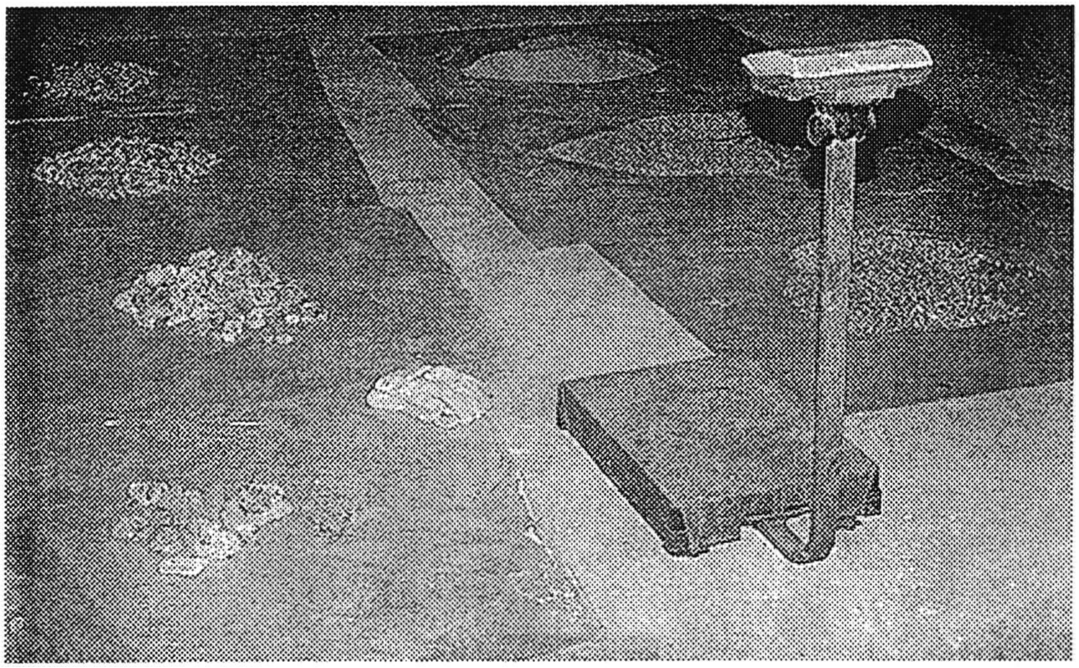


Figure 3.8 SCALE USED TO WEIGH BOTTOM ASH FRACTIONS FOR GSD

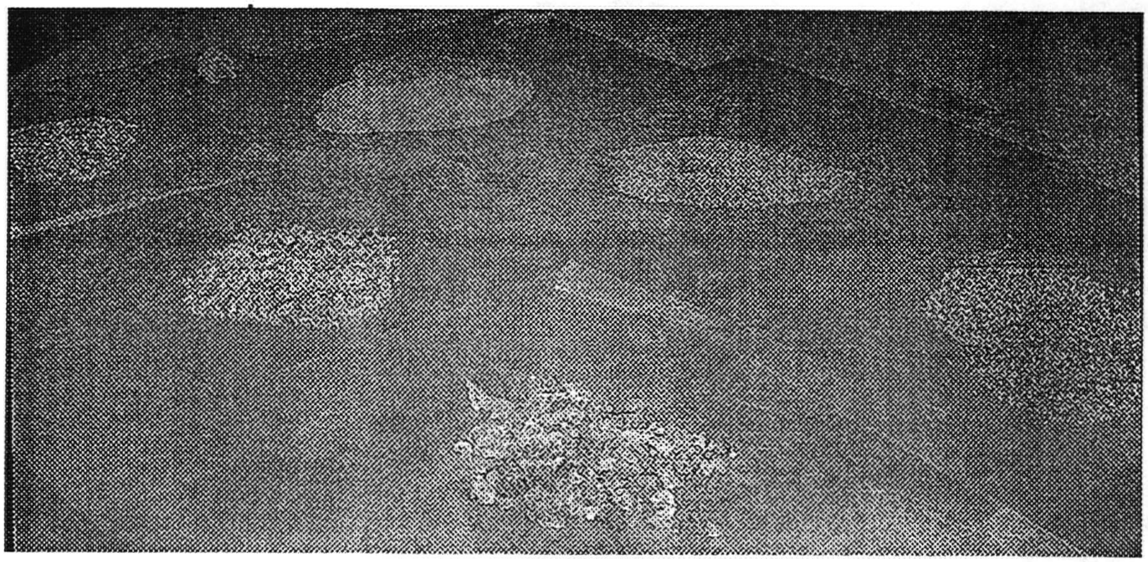


Figure 3.9 ASH BEFORE CONING AND QUARTERING

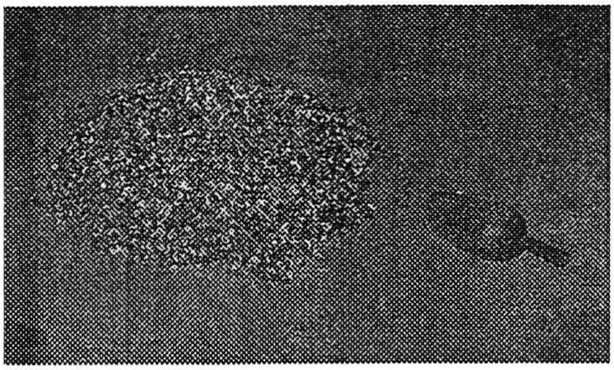


Figure 3.10 "CONED" FRACTION OF ASH

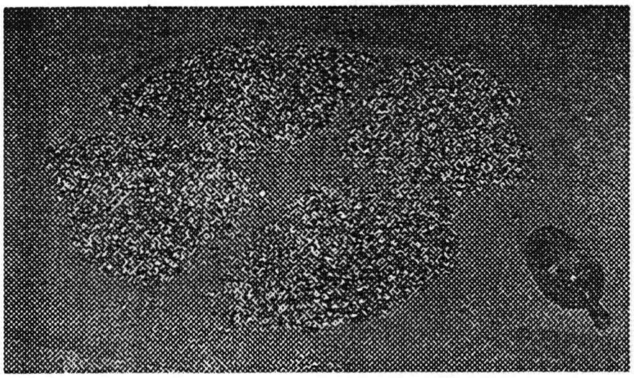


Figure 3.11 "QUARTERED" FRACTION OF ASH

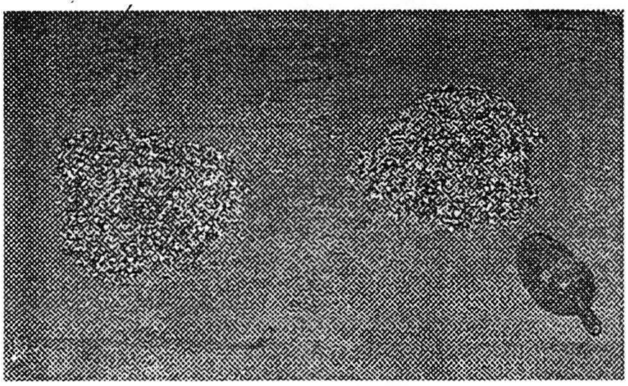


Figure 3.12 DISCARD TWO FRACTIONS

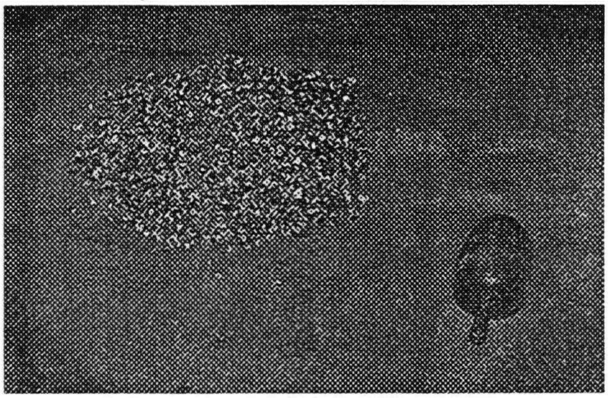
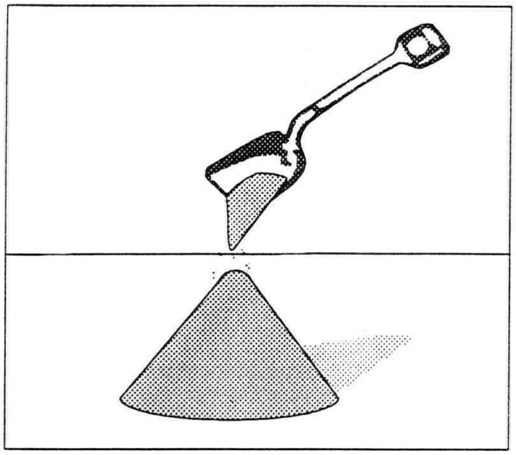
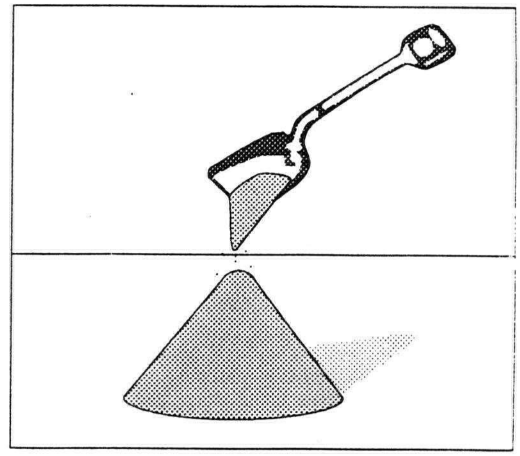


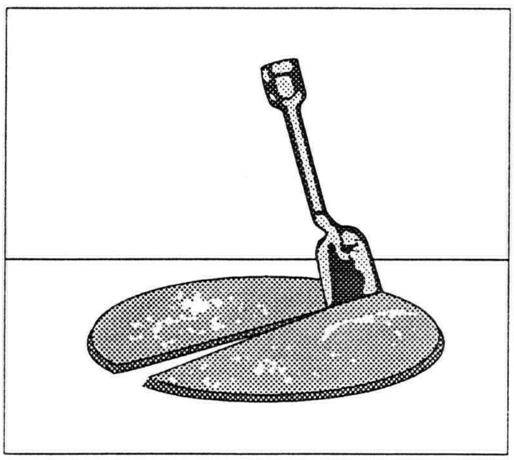
Figure 3.13 RECOMBINATION OF SAMPLE



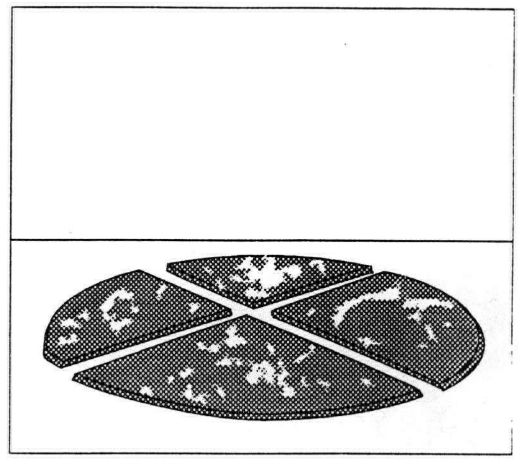
Cone Sample on Hard Clean Surface



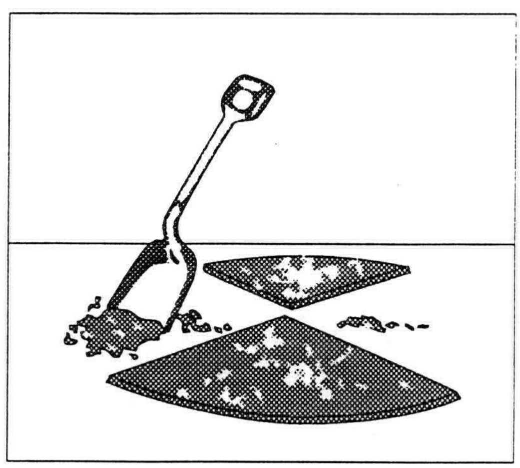
Mix by Forming New Cone



Quarter After Flattening Cone



Sample Divided into Quarters



Retain Opposite Quarters
Reject the Other Two Quarters

Figure 3.14 ASTM D75 CONING AND QUARTERING PROCEDURE

3.4 GRATE SIFTINGS GENERATION RATES

In total, nine grate siftings grabs were taken for each sampling day. The siftings from both 205 L (45 gallon) drums were combined each time a sample was collected and the amount of time taken to collect the grate sifting sample was recorded. After sampling, the grate siftings were sieved to obtain grain size distributions. The total mass for each grab was divided by a respective time value to obtain a "grab" generation rate. The generation rates from each of the nine grabs were then summed and averaged, and these are the generation rates results reported.

3.5 LABORATORY ANALYSIS OF SAMPLES

The plus 50 mm fraction of desifted bottom ash was removed, examined, and discarded at the incinerator. For the purposes of the laboratory work done the coarse fractions of ash were defined as those that pass a 50 mm, 25 mm, and 12.5 mm sieve and were subjected to physical testing. Similarly, the fine fractions of ash were defined as those that pass a 9.5 mm, 4.75 mm, and 2.36 mm sieve and were subjected to chemical testing.

The coarse fractions of ash were subjected to a visual sort based on ten (10) material categories and ASTM's D1557 compaction - density test. The compaction density tests were performed on separate samples taken specifically for these tests as noted on Figure 3.15. The fine desifted bottom ash (DBA) and grate siftings (GS) fractions were subjected to the Leachate Extraction Procedure (LEP) and an Aqua Regia Digestion (ARD) of the LEP solids. The DBA was analyzed following the procedure outlined in Figure 3.15. The GS analysis is outlined in Figure 3.16, but note Induced Coupled Plasma (ICP) was used to analyze for metals.

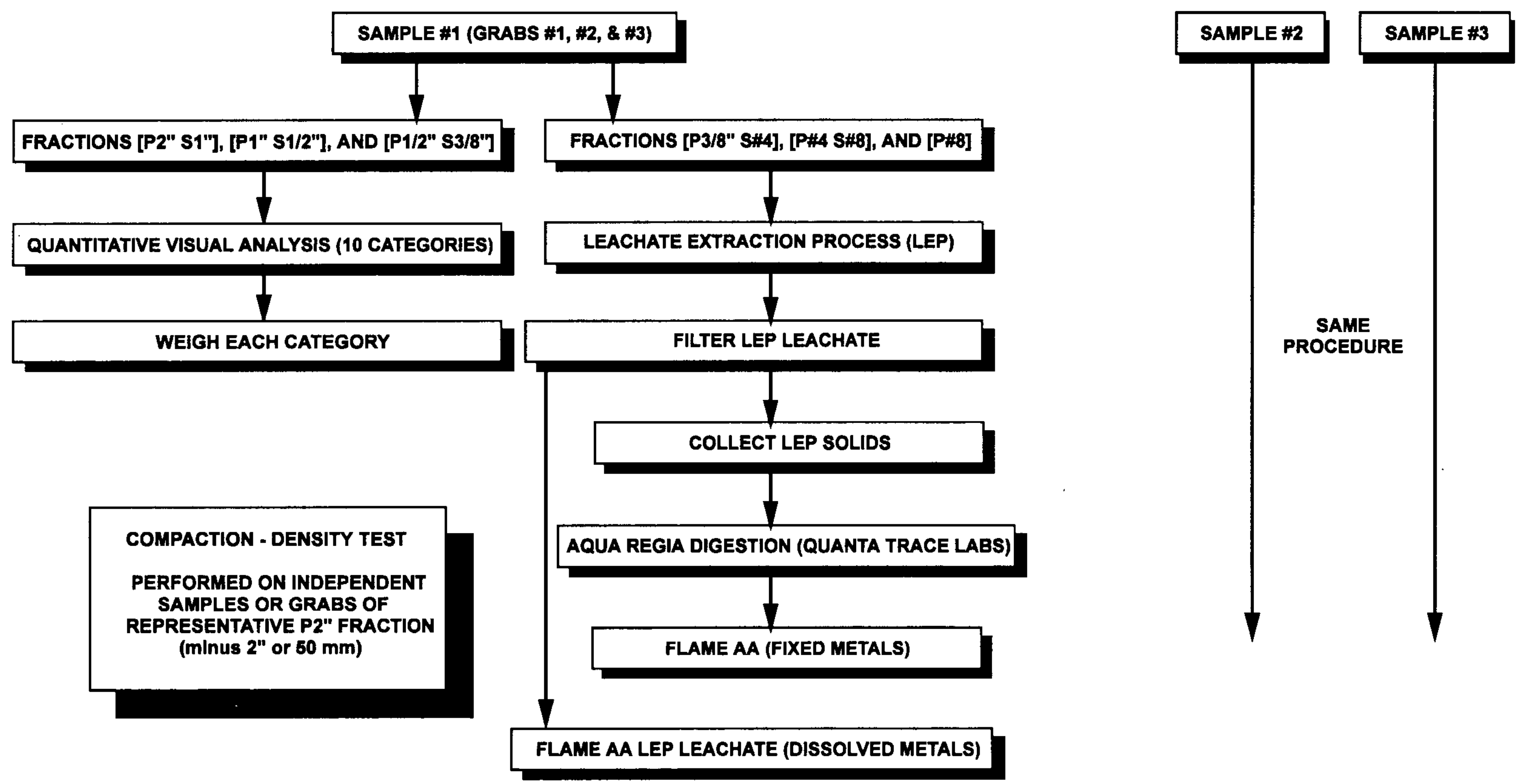


Figure 3.15 DESIFTED BOTTOM ASH LABORATORY ANALYSIS

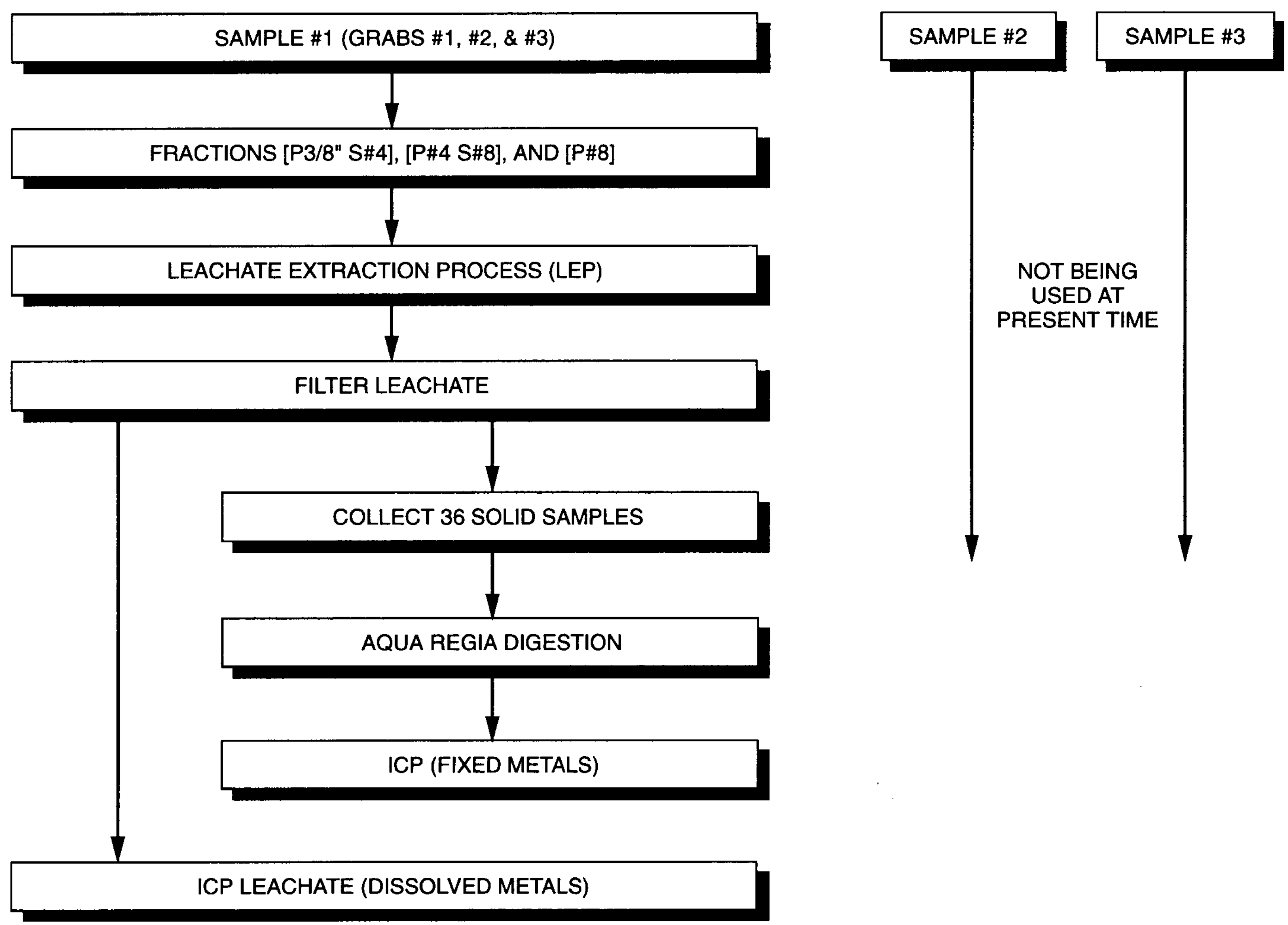


Figure 3.16 GRATE SIFTINGS LABORATORY ANALYSIS

3.6 PHYSICAL TESTS PERFORMED

3.6.1 CATEGORIZATION (10 COMPONENTS VISUAL SORT)

The coarsest fraction of ash, plus 50 mm (retained on 2" sieve), was weighed and discarded at the incinerator. The next three fractions of ash minus 50 mm (P2"), minus 25 mm (P1"), and minus 12.5 mm (P1/2") were bagged (approximately 3 kg) and taken back to the Environmental laboratory at UBC for a visual sort into ten material categories. Two (2) kg of the minus 50 mm (P2"), one (1) kg of the minus 25 mm (P1"), and one half (1/2) kg of the minus 12.5 mm (P1/2") fractions were sorted in the lab. Some unidentifiable and/or composite samples were broken or cut apart in order that materials could be properly grouped. The ten materials categories used for this sorting procedure are:

1) MAGNETIC
2) OTHER
3) ROCK
4) PORCELAIN AND TILE
5) CONCRETE
6) BRICK
7) PAPER AND WOOD
8) NON-FERROUS METALS
9) GLASS
10) GLASS MIXTURES

The DBA samples were sorted on a bench (see Figure 3.17) and then each pile of material was weighed. The results (masses) were tabulated and then the percentage each material represented for the total sample was calculated. The form used to record weight data before it was entered onto a Microsoft Excel spreadsheet for interpretation is in the “FORMS” appendix. Microsoft Excel's "Descriptive Statistics" tool was used to analyze the sort data collected for the P2", P1", and P1/2" fractions.

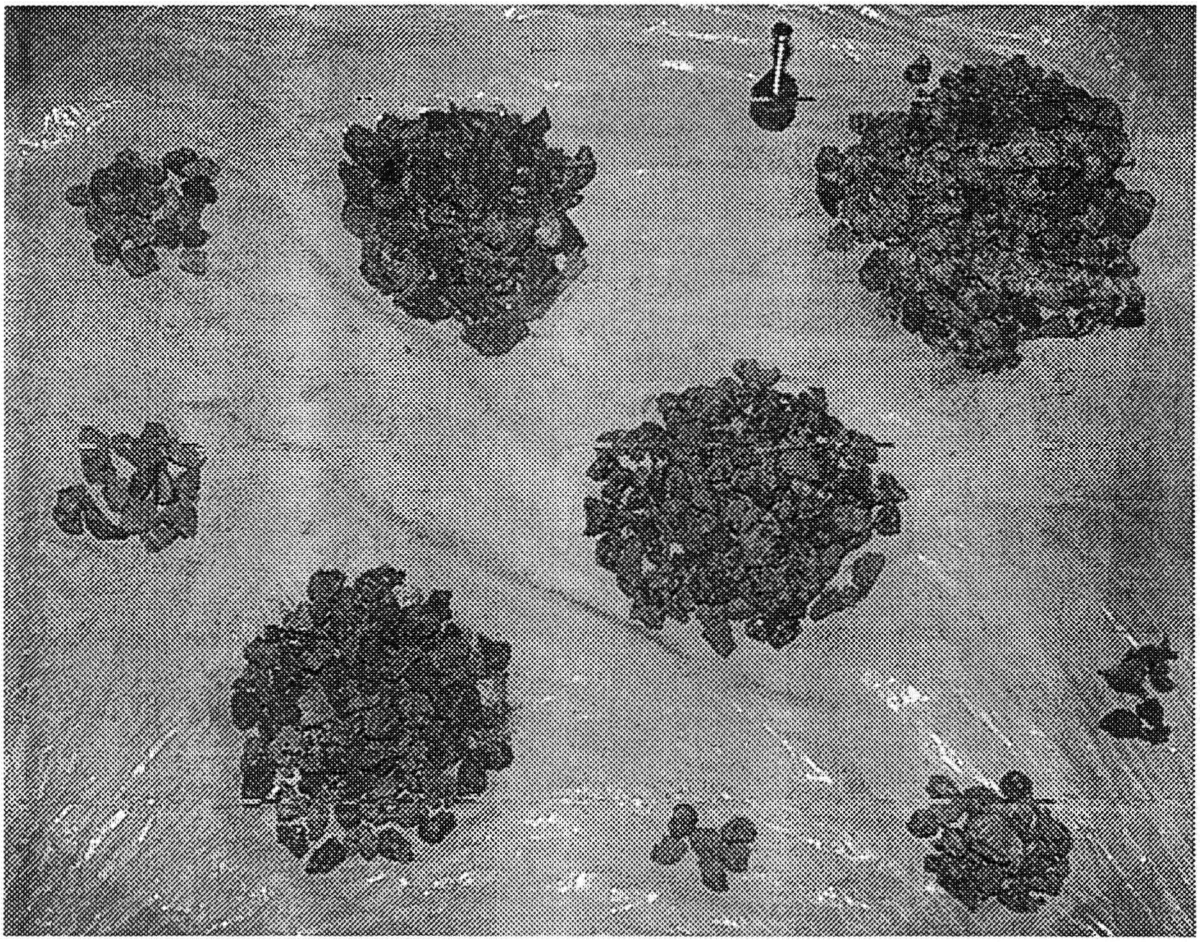


Figure 3.17 VISUAL SORTING OF COARSER FRACTIONS OF ASH

3.6.2 COMPACTION DENSITY RELATIONSHIP

Samples for compaction - density tests were taken independently of the nine grabs and three composite samples used for other analysis. ASTM standards were used to examine the compaction - density relationship of the DBA, specifically ASTM D1557-91 "Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3))", was used by both Terra Engineering Ltd. (1993) and the author. This test method utilizes a 10 lbf (44.5 N) rammer dropping 18" (457 mm) and compacting a sample in a 6" (152.4 mm) diameter mold, producing a compaction effort of 56,000 ft-lbf/ft^3 (2,700 kN-m/m^3). Five layers of ash, with 56 blows per layer, were used. The form used to record test data while the test were being run at the UBC Soils Engineering Laboratory is contained in the “FORMS” appendix.

3.6.3 SPECIFIC GRAVITY TEST

The specific gravity of a soil is the ratio of weight in air of a given volume of soil particles to the weight in air of an equal volume of distilled water at 4 ^{O}C. The use of the specific gravity of a soil is to relate its' weight to its' volume. The specific gravities presented in this report were obtained from Terra Engineering Ltd. (1993). ASTM standards C127-88 for coarse aggregate and C128-88 for fine aggregate were used. Note that the ASTM definitions of "coarse" and "fine" are different from the classification made in this thesis. ASTM C127-88 defines coarse aggregate as greater than a No.4 (4.75 mm) sieve and C128-88 defines fine aggregate as less than a No.4 sieve.

3.7 CHEMICAL TESTS PERFORMED

The Leachate Extraction Procedure (LEP) results reported are analogous to "dissolved" or leachable metals and can be considered as environmentally available in the short term (months). The solids left over from the LEP were aqua regia digested (ARD) and can be compared to "fixed" or digestible metals and can be considered as environmentally available over the long term (years). These sources of metal added together can be defined for purposes here as "total" metals (i.e. dissolved + fixed = total).

3.7.1 LEACHATE EXTRACTION PROCEDURE (LEP)

The LEP procedure is defined in British Columbia's Waste Management Act, Schedule 4, Analytical Methods, Part 1, Leachate Extraction Procedure (1988). For this test, a solid sample with particle sizes less than 9.5 mm (3/8") in size is extracted with dilute acetic acid (0.5N) at a 20:1 liquid to solid ratio (1000 ml to 50 g). Only a fixed quantity of acid is used for the extraction, and therefore, the final pH of the extract may vary widely. A maximum of 4 ml of acid per gram of waste can be used, therefore, a maximum of 200 ml of dilute acetic acid can be used in the LEP.

Samples are tumbled at 10 rpm for a 24 hour period (see tumbling apparatus in Figure 3.18). The pH of each sample is tested and recorded at 15 minutes, 1, 3, 6, and 22 hours. If possible (i.e. not over 200 ml of acetic acid already added) acetic acid is added at these times to maintain or lower the pH to 5.0 +/- 0.2. Finally, at 24 hours the procedure is stopped and the final pH is recorded.

The sample was separated into its component liquid and solid phases using a vacuum filtration unit and 0.45 μm pore size membrane filters (see Figure 3.19). The leachate was collected and analyzed for heavy metals using Flame AA (see Figure 3.20). If the metals analysis was not performed immediately the samples were acidified using concentrated nitric acid to a pH of approximately 2.0 and stored at 4 ^{o}C.

Metals results were initially recorded in "mg/l" and then converted to and reported as "mg/kg" by multiplying the "mg/l" value by a factor of 20. For example, an LEP value of 60 mg/l would be 1,200 mg/kg.

Forms were made to streamline the two day LEP process and were used to ensure that pH's were recorded at the proper times and the amount of acid added was noted (see "FORMS" appendix).

The 1992-93 LEP solids were collected and dried and subsequently subjected to an Aqua Regia Digestion. Approximately 50 grams of sample were collected, along with the filter papers, and the entire sample was digested with no particle size degradation (i.e. sample was not ground). This procedure was recommended by Quanta because it was a less labor intensive and costly alternative to grinding and homogenizing the entire 50 g sample to obtain a 1 g sample for digesting.

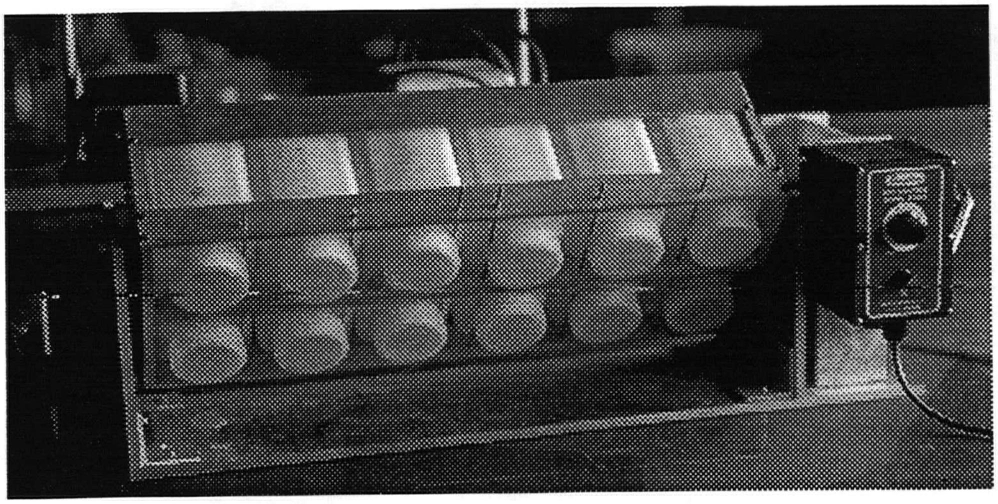


Figure 3.18 LEP TUMBLING APPARATUS - UBC LAB

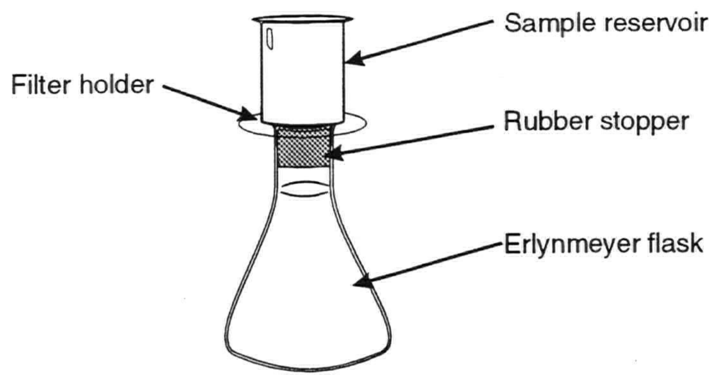


Figure 3.19 FILTERING OF LEP

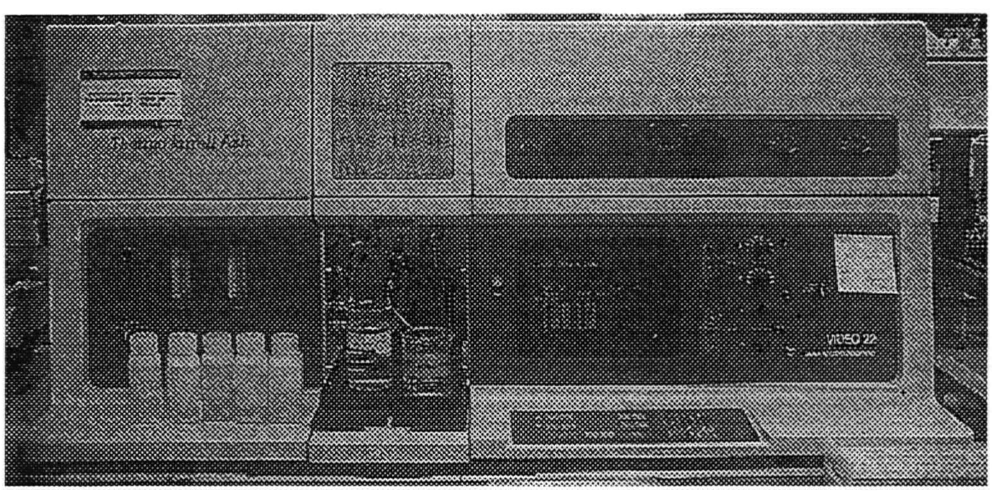


Figure 3.20 FLAME AA AT UBC

3.7.2 AQUA REGIA DIGESTION (ARD) OF LEP SOLIDS

Both the desifted bottom ash (DBA) and grate siftings (GS) LEP solids were collected, dried and then subjected to an open beaker Aqua Regia Digestion (ARD) (HCl and HNO_3 in a 3:1 ratio). Forty-five (45) ml of HCl and fifteen (15) ml of HNO_3 were added to the sample and refluxed at 90 °C for 2 hours in a beaker covered with a watch glass. When the digestion was complete the desifted bottom ash and grate siftings samples were made to a final volume of 500 ml with distilled deionized water.

3.8 METALS BY FLAME AA AND ICP

The eight heavy metals studied in this project were derived from DBA and GS samples using digestive aqueous laboratory techniques, yielding the LEP and the ARD of the LEP solids. Several analytical tools available today for examining aqueous metal chemistry are Flame Atomic Absorption Spectrophotometry (Flame AA), Graphite Furnace AA, or Induced Coupled Plasma (ICP). Flame AA has the advantage of lower detection limits and sensitivity over ICP for most elements. The problem is that typically only two metals can be analyzed at the same time using two different lamps with flame AA. ICP has the advantage of being able to analyze upwards of twenty metals simultaneously.

Standard Methods for the Examination of Water and Wastewater, 18th Edition 1992 (Greenberg, 1992) was used for Flame AA and ICP. Specifically, methods . "3111 B Direct Air-Acetylene Flame Method" and "3120 B Inductively Coupled Plasma (ICP) Method" were used.

The operations and procedures manual for the Flame AA and ICP equipment used were also followed.

3.9 STATISTICAL PROCESSING OF DATA

The US EPA's SW-846 "Test Methods for Evaluating Solid Waste" (1986) was applicable and used extensively for this study. This procedure results in the Upper Confidence Level of the Mean (UCLM) being calculated, representing the statistically correct (normalized) value that can be compared to regulatory limits for contaminant levels.

Based on the size of the sample set analyzed, different tabulated "student-t" values (Table 9-2, US EPA SW-846,1986) are used in the calculations. For seventy-two (72) samples a "student-t" value of 1.288 was used in the statistical calculations. Likewise for thirty-six (36) and nine (9) samples "student-t" values of 1.307 and 1.397 respectively were used. Only the "plus" or positive portion of the UCLM equation is examined because the "Upper" Confidence Limit of the Mean (UCLM) is being calculated. The UCLM value determined is based on the following equation:

UCLM = XBAR ± ("t") x (SE) (equation (6) US EPA SW-846, 1986, pNINE-3)

where
- XBAR = sample mean
- "t" = tabulated "student-t" value
- SE = standard error

This procedure is similar to the updated USEPA CFR 40 (1992) statistical methodology for Bevill Residue determinations. In CFR 40 the Upper Tolerance Limit (UTL) is calculated and then compared to regulatory limits.

An example of simple random sampling and the required number of samples needed to be within a prescribed margin of error is given by Gilbert (1987), Section 4.4.2. Another good example, similar to Gilbert's (1987), can be found in the US EPA's SW-846 Chapter NINE (1986).

Gilbert (1987) discusses normal and log normal distributions and probability plotting. He states that a method for estimating normal quantiles and checking for normal distributions is to use probability plotting. "The procedure is to first order or rank the untransformed data from smallest to largest. Let $x_{[1]} \leq x_{[2]} \leq \ldots$

$\leq x_{[n]}$ denote the ordered set. Then plot $x_{[i]}$ versus (i-0.5)100/n on normal probability paper. If the data are from a normal distribution, the plotted points should lie approximately on a straight line. If so, a best fitting straight line is drawn subjectively by eye (Gilbert, 1987)." A similar procedure may be used for log-normally transformed distributions, only for log-normal distributions log-probability paper should be used.

An alternative to normal probability and log-normal probability plotting is to plot the data, ranked or sequenced smallest to largest, against the normal deviate (Z-score) associated with the median rank of each sequenced point (Rigo, 1989). The Z-Score is the number of standard deviations a given cumulative probability is found above or below zero. The equations provided by Rigo for a sequenced data set containing N data points are as follows:

for $P \leq 0.5$ $\quad T = SQRT[-2.0 \times \ln(P)]$

$$Z = T - (2.30753 + 0.27061T)/(1 + 0.99229T + 0.04481T^2)$$

for $P > 0.5$ $\quad T = SQRT[-2.0 \times \ln(1-P)]$

$$Z = (2.30753 + 0.27061T)/(1 + 0.99229T + 0.04481T^2) - T$$

where $P = (i - 0.3)/(N + 0.4)$ (probability)
T = intermediate transformation used in calculation
Z = Z-Score

The median rank of each point can be approximated for the i^{th} point using the formula for P provided above. If the data is normally distributed, the plot of the data versus Z will be reasonably close to a straight line. This graphical approach also has another advantage in that if a full set of descriptive statistics has not been run, then the mean can be found at Z = 0 and the standard deviation can be taken as one third the difference between the values at Z = -1.5 and Z = 1.5.

Outliers, or extreme values are discussed by both Rigo (1989) and Gilbert (1987). Gilbert dedicates a whole chapter "Outlier Detection and Control Charts" and warns that discarding of high or low values has to be done with extreme care. Gilbert states that several unusually large measurements may be an indication that the data set should be modeled by a skewed distribution such as the log normal. According to Rigo (1989), "when looking at ash data, eliminating apparent 'outliers' from the analysis on statistical grounds is very dangerous because a value much in excess of the average is not necessarily an outlier. Despite the best sampling program design and execution and laboratory analysis, a large lead value can result, for example, if the waste being burned contains an unusual number of batteries, coated cans or if the sampler has the misfortune to grab a sample with a lead wine foil. As a result, valid lead data sets are likely to be tailed to the right (large values) for elements that are found in specific waste components and which may not be uniformly dispersed. This is an inherent consequence of the heterogeneous nature of the waste being burned." Both Rigo and Gilbert discuss "Windsorizing" as a way of dealing with outliers. This technique was not used here, and all values were included in the statistical evaluations. Windsorizing entails replacing the lowest value with the second lowest value and the highest value with the second highest. This process is repeated until a normal data set results.

Trends and seasons are discussed by Gilbert (1987). In order to comment on seasons and trends, it is necessary to collect three years of data, with samples taken every month. For this reason, “seasonality” will not be addressed in this report.

Transformations are simple mathematical functions, for example natural log or arcsine, that are used on data sets to try to normalize them. Transformations are discussed by Gilbert , Rigo, and the US EPA's SW-846. Gilbert (1987) provides four reasons for using nonlinear transformations which are:

1) to obtain a more accurate and meaningful graphical display of the data,
2) to obtain a straight-line relationship between two variables,
3) to better fulfill the assumptions underlying statistical tests and procedures, such as normality, additive statistical models, and equal spreads (variance) in different data sets, and
4) to efficiently estimate quantities such as the mean and variance of a log normal distribution.

Gilbert (1987) highlights three inherent problems that may arise when a nonlinear transformation is used and these are:

1) estimating quantities such as means, variances, confidence limits, and regression coefficients in the transformed scale typically leads to biased estimates when they are transformed back into the original scale,
2) it may be difficult to understand or apply results of statistical analyses expressed in the transformed scale,
3) more calculations are required.

Many authors, for example Stegemann and Schneider (1990) and Rigo (1989) report approximately log-normally distributed heavy metal leachate results. **It was determined that log normal transformations were the most appropriate for the work done as part of this thesis** (provided normal distributions).

The metal concentrations data (LEP and ARD of the LEP solids) was processed following the procedures outlined in USEPA's SW-846 (1986). As a first step, the concentration data was ranked from smallest to largest and then plotted on a Z-SCORE plot to check for a normally distributed data set (straight line plot). If a straight line plot was not observed the data was log-normally transformed and then replotted on a new Z-SCORE plot to check for a normally distributed data set. Once a normally distributed data set was obtained, Microsoft Excel's "Descriptive Statistics" function under the "Options" and "Tools" menus was used to process the data. This information has been tabulated for both the untransformed and transformed < 9.5 mm, < 4.75 mm, and < 2.36 mm fractions of ash. Upper Confidence Limits of the Mean (UCLM) values are calculated for the LEP and the ARD of the LEP solids metal concentration data.

3.10 DUPLICATES

In order to comment on the homogeneous or heterogeneity of the metal concentrations obtained duplicates of several samples were run. In total, eleven (11) samples from the 1992-93 DBA study were run through the LEP as duplicates. A random "Monte Carlo" type selection of samples to run as duplicates was performed and the eleven samples selected as duplicates are listed in Table 3.1. Duplicates will provide insight into how precise or reproducible the data obtained is. Generally speaking, a large number of samples or, in the case of bottom ash, a large sample mass will yield more precise results. Accuracy is a measure of how close the values or results obtained are to the real values. A result could be very precise or reproducible but very inaccurate. Flame AA is an accurate and robust analytical tool because it is calibrated with known standard concentrations (linear calibration curve) and therefore, should introduce a minimal error due to analytical factors. A certified solid was not digested and run through the analytical procedure to verify the accuracy of the results obtained. It will be possible to determine if the results are precise or reproducible by comparing the duplicate metal LEP concentrations to the sample LEP metal concentrations. The duplicate leachable concentration results will be provided with the raw tabulated concentration data.

Table 3.1 RANDOM SAMPLE SELECTION FOR DUPLICATES

DATE	GRAB	FRACTION
October 18, 1992	[1]	Passing 3/8"
October 18, 1992	[3]	Passing No.4
October 30, 1992	[1]	Passing No.4
November 30,1992	[3]	Passing No.4
January 21, 1993	[1]	Passing No.8
February 4, 1993	[1]	Passing No.4
February 4, 1993	[3]	Passing No.8
February 19, 1993	[2]	Passing 3/8"
February 19, 1993	[2]	Passing No.8
March 9, 1993	[2]	Passing 3/8"
March 25, 1993	[3]	Passing 3/8"

4. RESULTS AND DISCUSSION

Results from the 1991 regular bottom ash (RBA) and the 1992-93 desifted bottom ash (DBA) studies are interpreted here. The physical characteristics of the 1992-93 DBA are presented in this chapter. Specifically, the grain size distributions of the DBA and GS, 10 category characterization and sort of three coarser fractions of the DBA, and the compaction - density relationships curves for DBA. The LEP and ARD of the LEP solids results are used to chemically characterize regular and desifted bottom ash and grate siftings.

The information obtained will allow the different ash streams from 1991 and 1992-93 to be compared. The effect of removing the grate siftings from the 1992-93 bottom ash (desifted) stream will be examined. The 1992-93 desifted bottom ash (DBA) and the 1992-93 grate siftings (GS) LEP results will be recombined on a mass basis. The metals mass balance and comparison (i.e. 1991 RBA = 1992-93 DBA + GS) will yield similar metals concentrations if the following are true:

- the ash streams from both studies are similar,
- the generation rate for grate siftings calculated is accurate,
- the leachable metal concentrations from both studies are accurate,
- the sample sets were representative and large enough, and
- the experimental and analytical errors are small enough.

4.1 GRAIN SIZE DISTRIBUTIONS (GSD)

Tables 4.1 and 4.2 contain the GSD information for the 1991 RBA and 1992-93 DBA respectively and Table 4.3 the GSDs for GS. Each table contains the following information:

1) The average mass of a fraction for each sample day (% by weight).

2) The average mass of a fraction over the course of the sampling period (% by weight).

3) The cumulative percent retained (used for graphical purposes).

4) The cumulative percent passing.

Figure 4.1 is a plot of the average annual grain size distributions (GSDs) for the 1991 RBA, the 1992-93 DBA and the 1992-93 GS. It shows that RBA and DBA are coarser than the GS. Bottom ash is consistently well graded over the course of large sampling periods (i.e. annual) because virtually identical grain size distribution curves are obtained. Figure 4.2 shows detailed DBA GSD information for each sample day in 1992-93.

In Tables 4.1 and 4.2 "S2" denotes material that is suspended on 50 mm sieve. Similarly, "P1/2 S3/8" denotes material which passes a 12.5 mm sieve and is retained on a 9.5 mm sieve. The "P8" fraction is the material that passes a 2.36 mm (No.8) sieve and is collected on the bottom pan in the sifting machine. When dealing with sieve analyses a number of different formats for presenting the data and terminology can be used. For example, "percent retained" or "percent passing" can be plotted against sieve sizes to obtain grain size distribution plots. The terms "suspended" or "retained" are synonymous with the "plus" fraction and "passing" is synonymous with the "minus" fraction.

The largest fraction of bottom ash is the passing 25 mm fraction which represents nearly a quarter of the ash produced for both desifted and regular bottom ash. Next in magnitude are the passing 9.5 mm and 2.36 mm fractions which represent roughly 18 to 19 and 15 to 20 percent of the ash respectively. The remaining fractions represent between 8 to 12 percent of the ash. The bulk of the grate siftings are fine in nature, with over 60 percent passing the 2.36 mm (No.8) sieve, but a finer and more detailed sieve analysis was not performed on the grate siftings. The grate siftings grain size distribution is plotted in Figure 4.1 which shows percent retained.

Table 4.1 REGULAR BOTTOM ASH GRAIN SIZE DISTRIBUTION (1991 DATA)

SIEVE SIZE RETAINED BY (mm)	S2 50	P2 S1 25	P1 S1/2 12.5	P1/2 S3/8 9.5	P3/8 S4 4.75	P4 S8 2.36	P8 0
DATE							
4-Feb-91	5.23	10.36	32.24	13.94	21.83	10.28	6.13
18-Feb-91	5.13	8.39	26.35	11.49	26.49	14.82	7.33
6-Mar-91	11.15	14.38	29.67	10.90	17.40	6.36	10.13
30-Mar-91	6.34	10.25	22.73	10.15	21.52	11.81	17.19
12-Apr-91	10.12	11.79	22.57	9.64	20.07	10.69	15.13
21-Apr-91	9.60	12.96	24.39	10.63	20.01	10.10	12.31
29-Apr-91	13.77	16.49	25.61	9.58	15.45	6.83	12.26
6-Jun-91	12.18	16.70	23.78	8.77	14.79	7.15	16.63
7-Jul-91	12.23	18.86	27.10	9.42	14.86	6.64	10.89
10-Aug-91	10.70	11.77	25.01	11.08	18.45	8.35	14.63
30-Aug-91	6.67	7.75	24.35	12.74	21.32	9.08	18.08
13-Sep-91	9.75	10.55	22.52	11.66	21.99	8.90	14.63
26-Sep-91	8.45	9.08	19.50	9.54	18.82	10.35	24.26
16-Nov-91	13.07	13.36	19.67	7.83	15.62	11.64	18.81
17-Dec-91	7.42	10.08	16.90	8.86	20.60	13.57	22.57
SUM	141.81	182.77	362.39	156.23	289.22	146.57	220.98
AVERAGE	9.45	12.18	24.16	10.42	19.28	9.77	14.73
% RETAINED (CUM)	9.45	21.64	45.80	56.21	75.49	85.27	100.00
% PASSING	90.55	78.36	54.20	43.79	24.51	14.73	0.00

Table 4.2 DESIFTED BOTTOM ASH GRAIN SIZE DISTRIBUTION (1992-93 DATA)

SIEVE SIZE RETAINED BY (mm)	S2 50	P2 S1 25	P1 S1/2 12.5	P1/2 S3/8 9.5	P3/8 S4 4.75	P4 S8 2.36	P8 0
DATE							
17-Sep-92	8.09	10.68	22.55	11.11	19.64	8.23	19.70
18-Oct-92	14.07	18.27	29.00	9.00	12.12	4.74	12.81
30-Oct-92	12.45	11.01	24.66	8.94	15.44	8.16	19.33
13-Nov-92	6.89	11.27	26.09	10.42	17.32	7.78	20.23
30-Nov-92	3.93	7.29	25.19	12.77	22.68	8.93	19.21
13-Dec-92	8.25	11.83	24.44	11.16	17.33	7.28	19.71
8-Jan-93	8.14	12.38	27.98	9.25	16.19	6.92	19.14
21-Jan-93	6.81	6.69	21.61	10.82	22.21	9.48	22.38
4-Feb-93	7.94	7.21	20.04	10.18	20.96	9.56	24.11
19-Feb-93	15.84	16.19	23.54	6.65	12.78	6.02	18.99
9-Mar-93	13.60	15.28	21.58	6.99	12.91	6.95	22.68
25-Mar-93	7.66	8.91	22.85	11.63	21.34	8.65	18.95
SUM	113.67	137.01	289.53	118.92	210.92	92.70	237.24
AVERAGE	9.47	11.42	24.13	9.91	17.58	7.73	19.77
% RETAINED (CUM)	9.47	20.89	45.02	54.93	72.50	80.23	100.00
% PASSING	90.53	79.11	54.98	45.07	27.50	19.77	0.00

Table 4.3 GRATE SIFTINGS GRAIN SIZE DISTRIBUTION (1992-93 DATA)

SIEVE SIZE RETAINED BY (mm)	P1 S1/2 12.5	P1/2 S3/8 9.5	P3/8 S4 4.75	P4 S8 2.36	P8 0
DATE					
17-Sep-92	2.03	2.31	14.58	22.00	59.09
18-Oct-92	0.95	1.69	13.55	21.54	62.26
30-Oct-92	2.88	2.56	12.73	17.62	64.20
13-Nov-92	1.51	1.98	15.05	22.70	58.76
30-Nov-92	0.52	0.94	9.92	24.63	63.99
13-Dec-92	9.98	3.54	15.36	20.20	50.92
8-Jan-93	0.74	1.43	11.13	21.26	65.44
21-Jan-93	1.16	1.45	10.52	20.01	66.86
4-Feb-93	0.35	0.93	8.21	23.04	67.47
19-Feb-93	1.90	1.76	12.48	23.05	60.82
9-Mar-93	2.78	2.85	16.82	21.58	55.98
25-Mar-93	2.38	2.79	15.93	23.48	55.42
SUM	27.18	24.23	156.28	261.11	731.21
AVERAGE	2.27	2.02	13.02	21.76	60.93
% RETAINED (CUM)	2.27	4.28	17.31	39.07	100.00
% PASSING	97.74	95.72	82.69	60.93	0.00

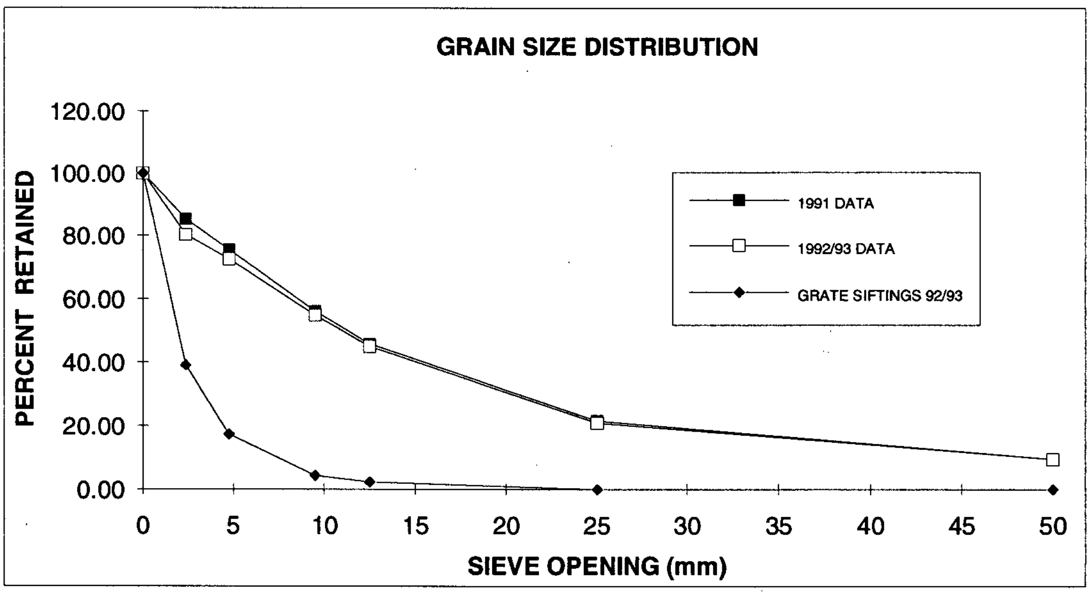


Figure 4.1 GRAIN SIZE DISTRIBUTIONS

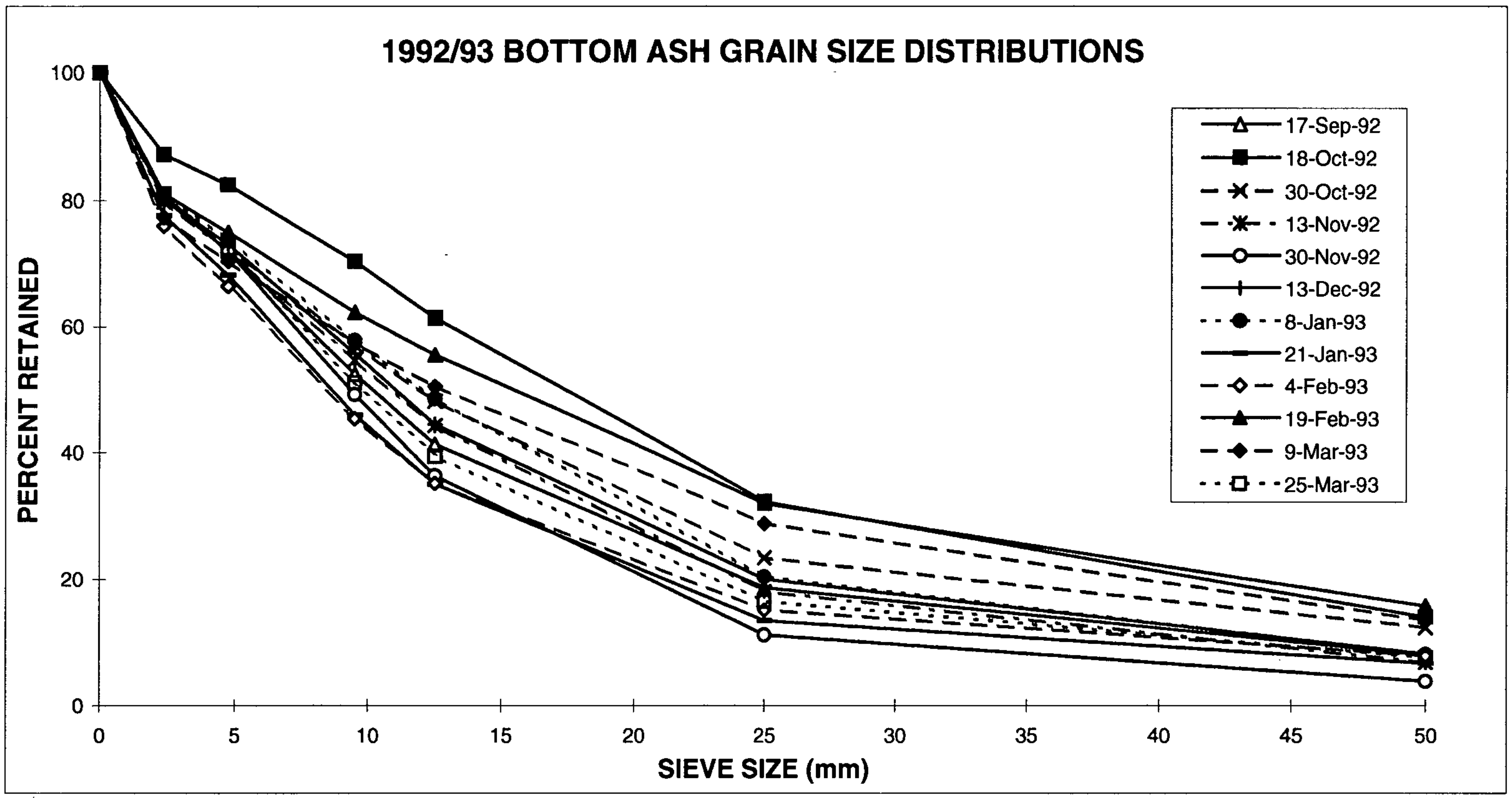


Figure 4.2 DBA GRAIN SIZE DISTRIBUTIONS FOR EACH SAMPLE DAY 1992-93

Ministry of Transportation and Highways (MoTH) and British Columbia's Master Municipal Specifications (BCMMS) (1991) provide grain size distribution requirements for select granular sub-base and pit run gravel (Tables 2.5 and 4.4). If bottom ash is to be used for road construction it's GSD must fall within these specified ranges. It is felt that bottom ash may be suitable for use as sub-base.

A comparison of DBA GSD results (Table 4.2) and the specifications (Table 4.4) shows that on an annual average RBA and DBA meets the BCMMS for pit run gravel. Nine of the daily averages for RBA do not meet the range specified for pit run gravel for a 4.75 mm (No.4) sieve (25 to 100%). Only one of the daily averages for DBA fails to meet the range specified for pit run gravel for a 4.75 mm (No.4) sieve. The RBA from 1991 contains too many fines to meet the MoTH sub-base gradation ranges. Half (6/12) of the daily averages for DBA do not meet the MoTH specification for sub-base passing a 2.36 mm (No.8) sieve. The annual average for DBA passing a 2.36 mm (No.8) sieve is 20%, which just barely meets the specified 20 to 40% range. No definitive comment can be made regarding whether or not RBA or DBA meets BCMMS or MoTH standards for sub-base because detailed information for the fines is not available. The BCMMS state that the fine fractions for sub-base must be between 0 to 15% and 0 to 8% for the 0.150 mm and 0.075 mm fractions respectively. Similarly, the MoTH gradation specifications state that 5 to 15% and 0 to 5% of a material must pass 0.300 mm and 0.075 mm sieves respectively.

In summary, only DBA meets the limits specified by BCMMS for pit run gravel on a load by load basis. More information is required to determine if DBA passes either the BCMMS or MoTH specification for sub-base.

Blending crushed bottom ash with crushed concrete in a 70 to 30 crushed concrete to bottom ash ratio is currently being investigated because the bottom ash provides the necessary fines. This 70:30 blend is known to meet the sub-base specifications and road tests, sponsored by the GVRD, are currently under way with such a blend at the Coquitlam Landfill.

Grain size distributions of incinerator residue put forth by several authors are summarized in Table 4.5 and compared to the 1991 RBA and 1992-93 DBA results. Collins (1978) provides a gradation range for combined ash (Table 4.5). There is good agreement between his results and the 1991 and the 1992-93 coarse bottom ash fractions. The inclusion of fly ash, and therefore finer particles, means that Collins is reporting larger values for the finer fractions than were obtained in 1991 and 1992-93. This is true for all of the GSD information found. The term incinerator residue is used by Haynes and Ledbetter (1977), therefore, it can be assumed that there is a combination of all ash streams. Haynes and Ledbetter (1977) report that 100% of the bottom ash they examined passed a 1" (25 mm) sieve, meaning the ash is not very coarse. It is assumed that a post incineration processing was performed to obtain 100% 25 mm minus material. The gradation ranges presented by Lauer (1979) are for combined ash. The "plus" 25 mm fraction is small at only 5%. Gress et al (1991) provide an average grain size distribution for 29 hourly and daily composite samples of bottom ash and data for the finer fractions of ash is presented. Sieve analysis results show approximately 32% passing a No.8 (2.36 mm) sieve and approximately 43% passing a No.4 (4.76 mm) sieve. Roethel et al (1991) found that the particle size distribution of bottom ash from two different facilities he was examining did not differ significantly, but did not provide GSD information.

TABLE 4.4 GSD SUMMARY: MoTH AND BCMM SPECS, DESIFTED BOTTOM ASH

BOTTOM ASH GRAIN SIZE DISTRIBUTION (units: Percentage PASSING by Weight)

SIEVE SIZE (in) SIEVE SIZE (mm)	3" 75.0	2" 50.0	1.5" 37.5	1" 25.0	3/4" 19.0	1/2" 12.5	3/8" 9.5	No. 4 4.75	No. 8 2.36	2.00	No.16 1.18	0.850	0.600	0.300	0.150	0.075
MoTH AGG SPEC																
SUB-BASE	100				15 - 100		0 - 100						0 - 100	0 - 15		0 - 5
50 mm SUB-BASE		100	80 - 100		50 - 100		35 - 75	25 - 55	20 - 40		15 - 30			5 - 15		0 - 5
25 mm BASE				100	80 - 100		50 - 100	35 - 70	25 - 50		15 - 35			5 - 20		0 - 5
BCMMS (1991) AGG SPEC																
PIT RUN GRAVEL	100	70 - 100		50 - 100				25 - 100		10 - 80						2 - 8
SELECT GRANULAR SUB-BASE	100			50 - 85											0 - 15	0 - 8
GRANULAR BASE					100	75 - 100	60 - 90	40 - 70	27 - 55			10 - 35		5 - 20		2 - 8
BA 1991 YEAR AVERAGE		91		78		54	44	25	15							
DBA 92-93 YEAR AVERAGE		91		79		55	45	28	20							
BA 1991 DAILY AVERAGES																
4-Feb-91		95		84		52	38	16	6							
18-Feb-91		95		86		60	49	22	7							
6-Mar-91		89		74		45	34	17	10							
30-Mar-91		94		83		61	51	29	17							
12-Apr-91		90		78		56	46	26	15							
21-Apr-91		90		77		53	42	22	12							
29-Apr-91		86		70		44	35	19	12							
6-Jun-91		88		71		47	39	24	17							
7-Jul-91		88		69		42	32	18	11							
10-Aug-91		89		78		53	41	23	15							
30-Aug-91		93		86		61	48	27	18							
13-Sep-91		90		80		57	46	24	15							
26-Sep-91		92		82		63	53	35	24							
16-Nov-91		87		74		54	46	30	19							
17-Dec-91		93		83		66	57	36	23							
DBA 92-93 DAILY RANGE & (AVG)																
17-Sep-92		89 - 94 (92)		77 - 85 (81)		54 - 65 (59)	43 - 54 (48)	24 - 33 (28)	17 - 23 (20)							
18-Oct-92		83 - 90 (86)		66 - 71 (68)		38 - 40 (39)	29 - 30 (30)	16 - 20 (18)	11 - 15 (13)							
30-Oct-92		84 - 90 (88)		71 - 80 (77)		47 - 61 (52)	39 - 52 (43)	23 - 34 (28)	17- 24 (19)							
13-Nov-92		89 - 98 (93)		75 - 89 (82)		50 - 61 (56)	41 - 48 (45)	26 - 30 (28)	19 - 22 (20)							
30-Nov-92		95 - 98 (96)		88 - 91 (89)		63 - 65 (64)	50 - 52 (51)	27 - 29 (28)	19 - 20 (19)							
13-Dec-92		91 - 93 (92)		77 - 83 (80)		48 - 65 (55)	38 - 53 (44)	22 - 33 (27)	16 - 25 (20)							
8-Jan-93		90 - 94 (92)		77 - 81 (79)		49 - 57 (52)	39 - 48 (42)	22 - 31 (26)	16 - 23 (19)							
21-Jan-93		89 - 98 (93)		84 - 91 (87)		63 - 68 (65)	53 - 56 (54)	32 - 32 (32)	22 - 23 (22)							
4-Feb-93		89 - 94 (92)		81 - 87 (85)		62 - 67 (65)	53 - 57 (55)	32 - 36 (34)	23 - 26 (24)							
19-Feb-93		82 - 89 (84)		64 - 74 (68)		41 - 50 (44)	34 - 42 (38)	22 - 28 (25)	16 - 21 (19)							
9-Mar-93		85 - 90 (86)		68 - 75 (71)		47 - 53 (50)	41 - 45 (43)	28 - 32 (30)	22 - 24 (23)							
25-Mar-93		91 - 93 (92)		80 - 86 (83)		56 - 63 (61)	46 - 51 (49)	26 - 29 (28)	18 - 20 (19)							

Table 4.5 COMPARISON OF REPORTED GRADATION RANGES

SOURCE	FRACTION (percent passing)			
	25 mm P1"	12.5 mm P1/2"	4.75 mm P4	2.36 mm P8
Collins (1978)	62-88%	50-72%	33-50%	25-39%
Haynes & Ledbetter (1977)	100%	80%	46%	25%
Lauer (1979)	95%	89%	34%	24%
Gress et al (1991)			43%	32%
Average 1991 RBA	78.4%	54.2%	24.5%	14.7%
Average 1992-93 DBA	79.1%	55.0%	27.5%	19.8%

4.1.1 GRATE SIFTINGS GENERATION RATE

The grate siftings generation rates obtained for 1992/93 were quite varied, ranging from 54.74 kg/hr to 155.54 kg/hr. The average generation rate over the course of the sampling was determined to be 114.57 kg/hr or approximately 8,250 kg per day for all three units. The GS generation rates determined by the WASTE Program Consortium (1992) ranged from a low of 33.2 kg/hr to a high of 111.7 kg/hr. The average calculated is 66.6 kg/hr, which is approximately 42% less than observed during the 1992/93 study. Table 4.6 summarizes the generation rates and Figure 4.3 shows a plot of the GS generation rates calculated.

There is a large variation in the grate siftings generation rates, which can be attributed to the nature of the MSW flux through the furnace. Initially, it was felt that the grate siftings generation rate would increase with time, a result of increased wear and therefore larger openings between the grates. After maintenance, it was suspected that the generation rate would drop, a result of the bars being properly aligned and spaced. This occurred on the two occasions when work was done on the grate bars, the first being to fix a breakdown on November 26, 1992, and the second, a scheduled shutdown between January 24, 1993 to February 2, 1993. Figure 4.3 shows both dates for these occurrences and the subsequent drop in generation rates. It is interesting to note that the shutdown maintenance did not seem to lower the generation rate as much as fixing the breakdown on November 26, 1992.

One would expect the mechanical wearing of the grates to allow more material to pass and that an increase in the amount of larger particles would occur. This did not appear to happen; the grain size distributions of the grate siftings varied, but probably more as a function of the incoming composition of MSW. It is apparent that the grate siftings generation rates are most dependent on the feedstock of waste and it's composition. The generation rate could be affected by hard materials that can wedge themselves between the bars, allowing more siftings to pass through the grates. The GSD for the minus 12.5 mm fraction of GS is plotted on a secondary axis in Figure 4.3 to examine any correlation between GS generation rate and percent passing for the minus 12.5 mm fraction. The only observation that can be made is that the amount of GS (percent passing the 12.5 mm sieve) dropped to below 1% for this fraction. The point of Figure 4.3 is to show that there appears to be no correlation between GS GSD and GS generation rate.

Table 4.6 GRATE SIFTINGS GENERATION RATES

SAMPLE DATE	GENERATION RATE (kg/hr)
SEPT.17, 92	NOT AVAILABLE
OCT.18, 92	NOT AVAILABLE
OCT.30, 92	153.45
NOV.13, 92	81.88
NOV.30, 92	54.74
DEC.13, 92	96.61
JAN.8, 93	118.19
JAN.21, 93	133.20
FEB.4, 93	102.80
FEB.19, 93	155.54
MAR.9, 93	143.25
MAR.25, 93	106.03

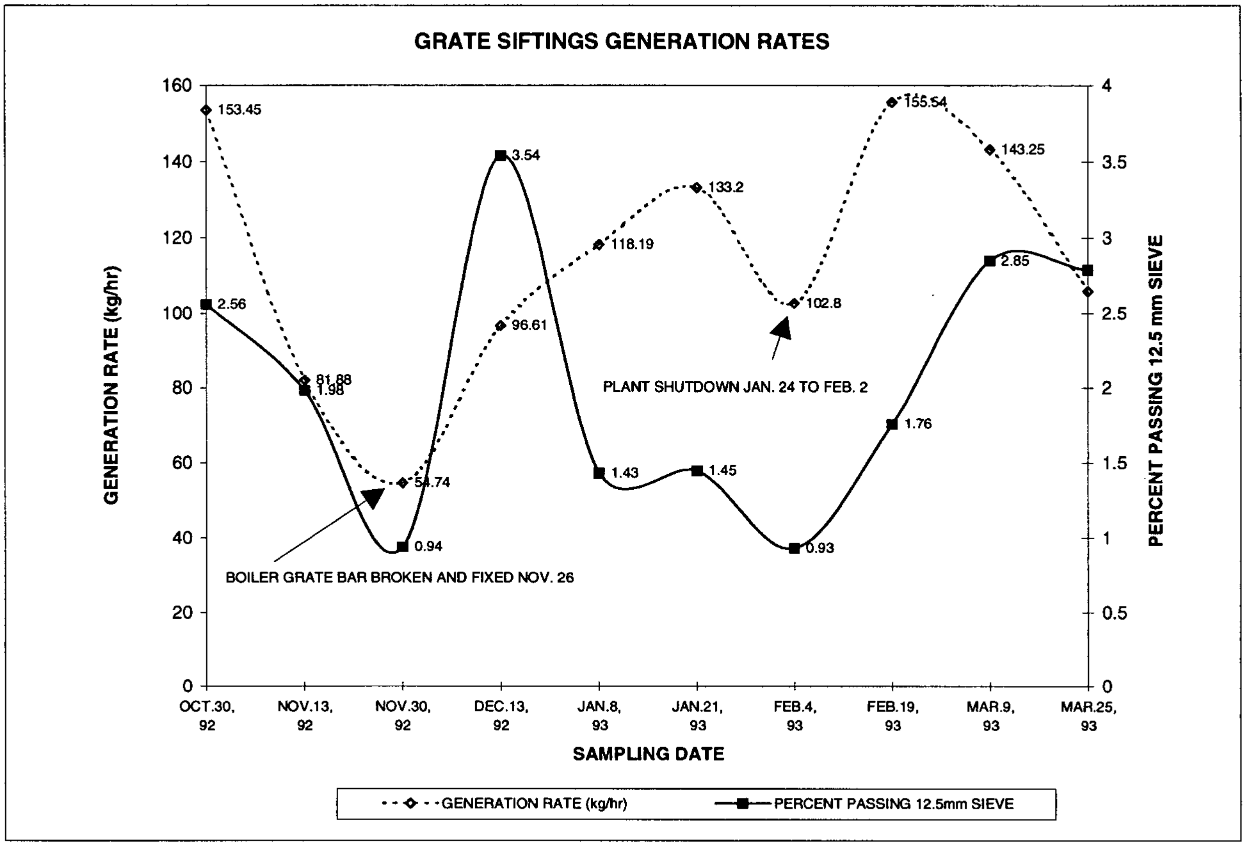


Figure 4.3 GRATE SIFTINGS GENERATION RATES

4.2 BOTTOM ASH CHARACTERIZATION (10 categories)

The literature review contained a section on the origins of waste (FEEDSTOCK) which showed that the tonnages coming from the sources identified fluctuated slightly, but the overall tonnages going to the Burnaby Incinerator remained constant. Even though the tonnages of waste collected from various sources varied slightly from month to month and year to year, it is felt that the composition of MSW generated by and within the GVRD would remain fairly constant. If present, variability in the residual streams could be a function of the composition of the incoming MSW, seasonal feedstock fluctuations, origin of the waste, or a combination of all of these factors.

Table 4.7 lists a summary of the 10 category material sort that was used to describe the composition of the coarser fractions of bottom ash in 1991 and 1992-93. The percentages presented are average values for each fraction examined on a given sample day. The fractions examined were passing or minus 12.5, 25, and 50 mm. Detailed information about the composition of the plus 50 mm (2") fraction is not available and is therefore not discussed.

Table 4.7 DESIFTED BOTTOM ASH MATERIAL CHARACTERIZATION

DESIFTED BOTTOM ASH MATERIAL CHARACTERIZATION						
	1991 SUMMARY			1992-93 SUMMARY		
SORT CATEGORY	P 1/2"	P 1"	P 2"	P 1/2"	P 1"	P 2"
MAGNETIC	23.0	25.8	30.4	17.5	16.3	22.9
OTHERS	15.0	16.3	26.9	21.5	21.2	25.5
ROCK	4.3	5.4	10.1	5.4	5.4	7.0
PORCELIN & TILE	3.3	7.8	8.5	3.7	9.0	9.6
CONCRETE	1.2	1.2	4.2	0.5	1.7	7.1
BRICKS	0.2	0.4	1.8	0.6	1.0	2.6
PAPER & WOOD	0.2	0.2	0.5	0.7	0.6	1.3
NON-FERROUS METALS	3.4	3.7	2.6	4.7	6.0	6.2
GLASS	22.7	14.1	3.7	30.8	23.5	4.6
GLASS MIXTURES	26.7	25.1	11.8	14.6	15.3	13.2

NOTE: VALUES ARE PERCENT BY WEIGHT AND ARE A SUMMARY OF YEARLY AVERAGES

The majority of material in the coarse bottom ash fractions is either ferrous, other, glass, or glass mixtures. The largest proportion of material is glass and glass mixtures. The totals of glass and glass mixture percentages for the three fractions examined are listed in Table 4.8 and are as follows: the minus 12.5 mm (1/2") fraction ranges between 45% to 49%, the minus 25 mm fraction is 39% , and the minus 50 mm fraction is between 15% to 18%. The fact that glass is non-combustible and easily identified explains the high percentages found in the ash. In 1991 two people were responsible for the sorting of the bottom ash. In 1992-93 as many as five different people sorted the bottom ash fractions. The increased number of people in 1992-93 may have introduced variability in the sorting results because different people sorted differently. It is a known fact that one individual broke apart samples of glass and glass mixtures in 1992-93, thereby increasing the glass fraction and reducing the glass mixture fraction. This would explain why the glass values are significantly higher for the 1992-93 vs. 1991 results. However, a comparison of the sum of glass and glass mixtures for 1992-93 and 1991 shows that the results are similar (Table 4.8).

Table 4.8 GLASS & GLASS MIXTURES

	RBA 1991		DBA 1992-93	
FRACTION	COMPOSITION	GRAIN SIZE	COMPOSITION	GRAIN SIZE
MINUS 12.5 mm (1/2")	49.41%	10.42%	45.46%	9.91%
MINUS 25 mm (1")	39.21%	24.16%	38.81%	24.13%
MINUS 50 mm (2")	15.49%	15.49%	17.80%	11.42%

The next most abundant materials are "magnetic" and "others" (both inert), accounting for between 16% to 31% of the bottom ash's makeup depending on which year and which fraction are examined. On average the Passing 1/2", 1" and 2" fractions in 1992-93 contained 17.5%, 16.3% and 22.9% of magnetic material respectively. OTHER material is defined as unidentifiable because it could not be classified into one of the other 9 categories. Typically, it consisted of fused conglomerates of particles and tended to be brittle and friable.

Appreciable amounts of porcelain and tile are present in the bottom ash, between 8% and 10%, in the minus 25 mm (1") and 50 mm (2") fractions and 3.3% to 3.7% in the minus 12.5 mm (1/2") fraction. The desifted bottom fractions contained the following average amounts of porcelain and tile in 1992-93: minus 12.5 mm 3.7%, minus 25 mm 9.0%, and minus 50 mm 9.6% (Table 4.7).

The percentages of paper and wood in 1992-93 were roughly 3 times what they were in 1991. It is hypothesized that the amount of paper and wood presented for 1992-93 is slightly higher because bottom ash samples were collected over a wetter time period or season (September 1992 to March 1993). Samples collected in 1991 included the dryer summer months of June, July, and, August meaning a proportionately lower amount of wet paper and wood was present in the bottom ash and it burned more completely. The October 1992-93 samples contained water logged newspaper, cardboard, and wet yard waste.

On average the minus 12.5 mm, 25 mm, and 50 mm fractions of DBA contained 5.4%, 5.4% and 7.0% rock respectively. Very small amounts of concrete were present in the minus 12.5 mm and 25 mm fractions of the DBA (Table 4.7), on average 0.5% and 1.6% respectively. A significant amount, approximately 7.1%, of concrete was present in the minus 50 mm fraction of the DBA.

Only a trace of brick material was present in the desifted bottom ash, especially the minus 12.5 mm fraction. The average amounts of brick in DBA were 0.6%, 1.0% and 2.6% for the 12.5 mm (P1/2"), minus 25 mm (P1"), and minus 50 mm (P2") fractions respectively (Table 4.7). Large quantities of brick are not expected in MSW and therefore bottom ash because brick materials are designated as being construction wastes and are not accepted at the Burnaby Incinerator.

Non-ferrous metals are present in the desifted bottom ash at moderate levels. Approximately 4.6%, 6.0% and 6.2% of the minus 12.5, 25, and 50 mm fractions respectively of DBA is non-ferrous metal (Table 4.7). Non-ferrous metals were typically pieces of copper, and lead. Copper was often in the form of packing staples or wire. Lead was easily identifiable because of its dense and malleable nature but it was difficult to identify which metals other non-metallics were.

Collins (1978) provides data on the physical composition of "well-burned" incinerator residue, but only does a 5 category sort without different fractions, with the following results: glass 39.9%, minerals and ash 39.5%, ferrous metal 13.8%, non-ferrous metal 3.3%, and combustible and organic matter 3.5%. Collins (1978) states that it is significant that well burned residue contained approximately equal amounts of glass and mineral matter. Hartlen and Lundgren (1991) report that about 40% of graded bottom ash is vitreous material. Their study was conducted on bottom ash graded into the following fractions 5.6 - 8 mm, 8 - 11.2 mm, and 11.2 - 16 mm, which is not comparable to the coarse fractions which were visually sorted and examined as part of this study. Haynes and Ledbetter (1977) found that the municipal incinerator residue from the Holmes Road Incinerator Plant in the City of Houston, Texas consisted of 45% glass and appreciable fines. Lauer (1979) states that the coarse fraction of (combined) ash can contain as much as 50 percent glass, which is higher than the percentage reported here. This was observed as part of this thesis, if you consider glass and glass mixtures together as one category. Walter (1976) provides data from work done by the US Bureau of Mines. The composition analyses performed show that typical incinerator residue is composed of 30.5% ferrous material, 2.8% nonferrous material, 49.6% glass, and 17.1% ash, including small quantities of organic material.

Pie charts were made of the characterization and sort information presented in Table 4.7. The yearly mean values for the 1991 and 1992-93 results are plotted for each individual fraction (Figures 4.4 to 4.9). It is important to examine the composition results graphically because it highlights each individual fractions composition, rather than material type.

Figure 4.4 shows that magnetic, other, glass, and glass mixtures make up 89% of the minus 12.5 mm fraction in 1991. The same four categories constitute 82% of the minus 25 mm fraction for the same year (Figure 4.5). In Figure 4.6, the 1991 minus 50 mm fraction, the glass mixtures proportion (12%) is reduced significantly. The most predominant material is magnetic (30%) then "other (27%). Rock (10%) and porcelain and tile (8%) are constitute proportions.

Similar trends are visible in the 1992-93 pie charts, for example, the same four predominant categories, magnetic, other, glass, and glass mixtures constitute 83% of the mass for the 1992-93 minus 12.5 mm (1/2") fraction (Figure 4.7). Non-ferrous materials contribute 6.2% of the mass. Similarly, magnetic, other, glass, and glass mixtures constitute 76% of the mass of the minus 25 mm fraction in 1992-93 (Figure 4.8), which reflects what happened in 1991. Porcelain and tile made up 9% of this fraction. Finally, the minus 50 mm fraction for 1992-93 shows that the mass contribution from the glass mixtures category has again dropped, this time to 13% (Figure 4.9). Other and magnetic materials are the major contributors to the mass of this fraction at 25% and 23% respectively. Brick, glass, non-ferrous metals, concrete, and porcelain and tiles constitute between 3% to 10% of this fraction.

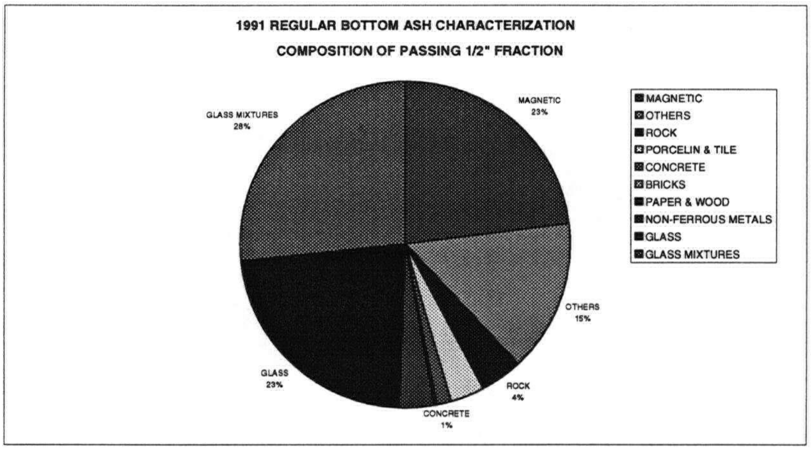


Figure 4.4 COMPOSITION OF 1991 RBA P1/2"

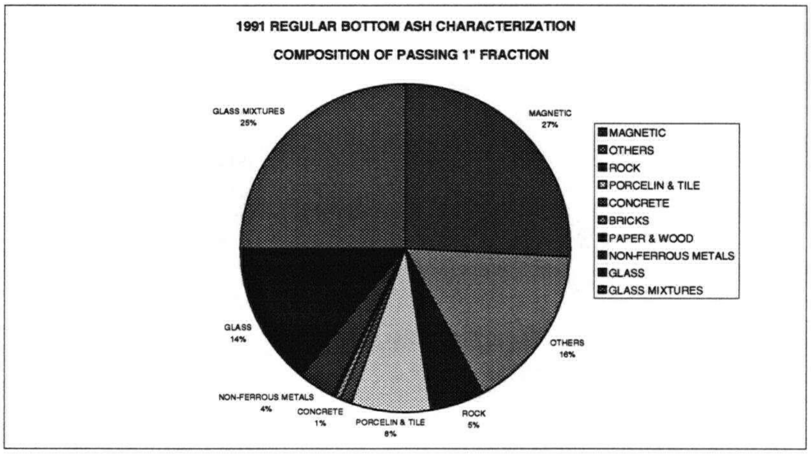


Figure 4.5 COMPOSITION OF 1991 RBA P1"

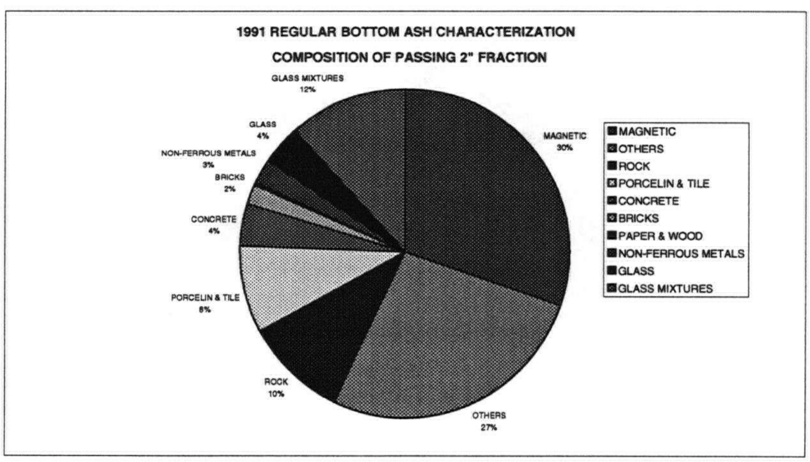


Figure 4.6 COMPOSITION OF 1991 RBA P2"

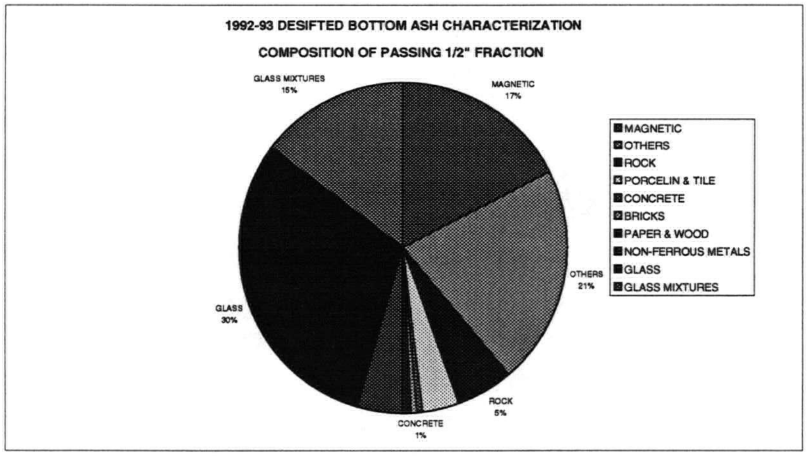


Figure 4.7 COMPOSITION OF 1992-93 DBA P1/2"

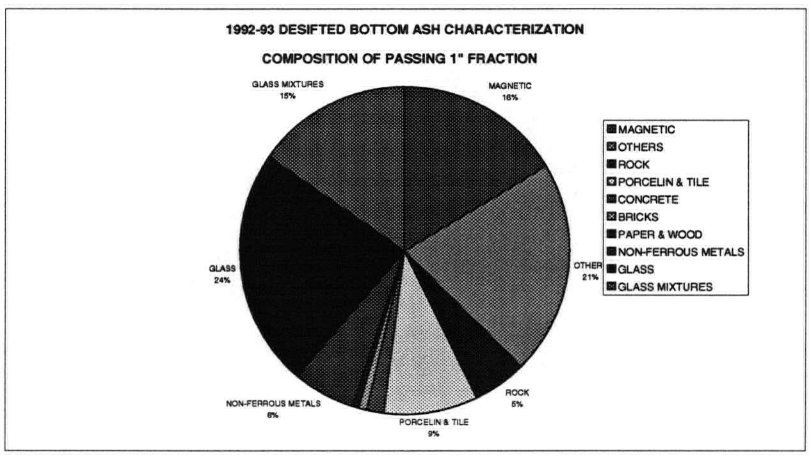


Figure 4.8 COMPOSITION OF 1992-93 DBA P1"

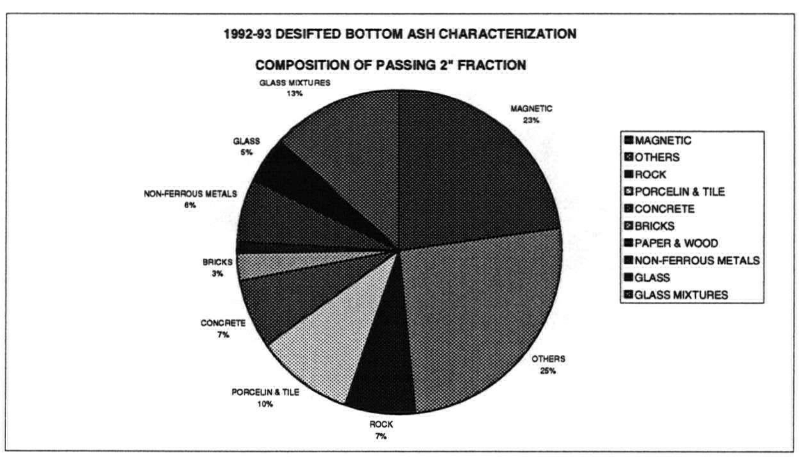


Figure 4.9 COMPOSITION OF 1992-93 DBA P2"

4.2.1 COMPOSITION MASS FLOW COMPARISON: MSW TO BOTTOM ASH

A crude mass balance can be performed to compare the "percent by weight" of inert materials in MSW presented in studies by others (WFRA,1993 and WASTE,1992) and examined in the coarse fractions of bottom ash. Inert, non-combustible materials such as glass and metal should pass through the incineration process relatively unchanged.

Glass, ferrous, and metal percent compositions of MSW from the "COMPOSITION OF MSW GOING TO INCINERATORS" section of the Literature Review were used in conjunction with mass fluxes of incinerator residues to perform crude materials balances. This information is shown in Table 4.9 which lists the reported percent compositions of glass, ferrous, and metal materials found in MSW. These percentages are multiplied by the yearly tonnage of MSW incinerated in 1992-93 (241,488 tonnes) to estimate the expected amounts of these materials in the MSW going to the Burnaby Incinerator. Initially, glass makes up a very small percentage of MSW on a mass basis, between 3.5% to 1.7% as reported by the WFRA (1993) and WASTE (1992) Program respectively and paper and organics made up between 75% to 78% of the MSW. When burned, the organics are volatized or reduced to ash and other "inert" materials, such as glass, metal, and rocks, remain. Therefore, one would expect that materials such as glass and metal could make up a significant portion of the coarser fractions of bottom ash on a proportional mass basis, given the fact that incineration reduces the initial MSW's mass by approximately 80%.

Table 4.9 REPORTED COMPOSITION PERCENTAGES CONVERTED TO TONNAGES

STUDY	MATERIAL COMPOSITION		
	GLASS	FERROUS	METALS
WFRA (1993)	3.5%	6.60%	11.0%
MASS (tonnes)	8,452	15,938	26,564
WASTE PROGRAM (1992)	1.7%	NA	3.95%
MASS (tonnes)	4,105	NA	9,539

Table 4.10 lists grain size distributions and the yearly average bottom ash material percentages from the sort data. The 1992-93 yearly generation of bottom ash, 45,837 tonnes, was multiplied by each fractions composition percentage as well as grain size distribution to estimate the mass of material expected in bottom ash for each fraction.

Table 4.10 TONNAGE OF MATERIALS GENERATED BASED ON SORT RESULTS

FRACTION	GSD	1992-93 COMPOSITION (by weight)			
		GLASS	GLASS & GLASS MIX	FERROUS	TOTAL METAL
P12.5 mm	9.91%	30.8%	45.46%	17.5%	22.2%
	MASS (tonnes)	1,328	2,065	795	1,008
P25 mm	24.13%	23.5%	38.81%	16.3%	22.3%
	MASS (tonnes)	2,599	4,293	1,803	2,466
P50 mm	11.42%	4.6%	17.80%	22.9%	29.1%
	MASS (tonnes)	240	932	1,199	1,523
	TOTAL MASS	4,167	7,290	3,797	4,997

The total amount of glass estimated to be in MSW before it was incinerated in 1992-93 is between 4,105 to 8,452 tonnes. Estimates based on material sorting and examination of the bottom ash predict that between 4,167 to 7,290 tonnes of glass and/or glass mixtures were produced. These two ranges are extremely close and a material mass balance for glass seems possible. Mechanically degradable or crushable material is reduced in size as it passes through the incineration process and as a result, the amount of brittle, crushable materials like glass and glass mixtures present in the smaller size coarse fractions increases. Physically stable material like iron is not easily reduced in size and is less likely to be present in the finer fractions and concentrates in the coarser fractions.

The reported ferrous recovery from bottom ash for 1992-93 is 7,825 tonnes. This value must be added to the value of ferrous material in bottom ash reported in Table 4.10, 3,797 tonnes, to give a total of 11,622 tonnes. The ferrous mass listed in Table 4.9 for MSW (15,938 tonnes) does not compare favorably to the total mass of 11,622 tonnes in the bottom ash. The mass balance exercise using ferrous material did not generate satisfactory results. The amount of metal observed in bottom ash in 1992-93 amounts to 4,997 tonnes plus the amount of ferrous recovery (7,825 tonnes) for a total of 12,822 tonnes. This value is between the range calculated using the reported percentages of metal in MSW (9,539 to 26,564). It is clear that the two studies which examined MSW were not in agreement, therefore the WFRA (1993) and WASTE (1992) results do not compare favorably.

4.2.2 COMPARISON OF FERROUS RECOVERY: 1991 TO 1992-93

Approximately 6,003 additional tonnes of ferrous material could have been recovered in 1991 based on the amount of magnet attractable material reported (Table 4.11). Using the same process for the 1993-92 data shows that a 36.7% improvement in ferrous recovery has occurred and approximately 3,797 tonnes of ferrous material remains in the DBA (Table 4.12). The magnetic belt/conveyor separator was lowered after the 1991 study indicated that an improvement in ferrous recovery could be achieved. This improvement has been realized, but ferrous material is still present in the bottom ash. Given the layout of the ash discharge system it may not be possible to recover more ferrous material at the Burnaby Incinerator because there are practical limits to how low the magnetic separator can be lowered. A secondary magnetic separation after bottom ash is removed from the ash bunker should be considered if it is desirable and cost effective to increase the ferrous recovery.

Table 4.11 TONNAGE OF FERROUS MATERIAL IN 1991 RBA

FRACTION	COMPOSITION	GSD	MASS (tonnes)
P1/2"	23.0%	10.42%	1,079
P1"	25.8%	24.16%	2,805
P2"	30.4%	15.49%	2,119
TOTAL			**6,003**

NOTE: 1991 MASS OF RBA GENERATED 45,000 tonnes

Table 4.12 TONNAGE OF FERROUS MATERIAL IN 1992/93 DBA

FRACTION	COMPOSITION	GSD	MASS (tonnes)
P1/2"	17.5%	9.91%	795
P1"	16.3%	24.13%	1,803
P2"	22.9%	11.42%	1,199
TOTAL			**3,797**

NOTE: 1992-93 MASS OF RBA GENERATED 45,837 tonnes

4.3 COMPACTION DENSITY RELATIONSHIP

The compaction density results for tests run by Terra Engineering and by the author are listed in Table 4.13. Plotted in Figure 4.10 are the relationship between unit weights and water content as a percentage. Three samples were subjected to compaction - density tests (ASTM D1557) by Terra Engineering. Results provided by the author tend to be somewhat higher with optimum densities of between 2.00 to 2.10 g/cm^3 at a water content of approximately 13%. Optimum densities for Terra Engineering's results tend to be between 1.87 to 1.91 g/cm^3 at water contents of approximately 12.2%, which are slightly less dense and drier values. The January 21, 1993 sample run by the author was started from an initially dry state. A sufficient quantity of sample was not available to reach an optimum density point. The February 4 , 1993 (Run # 2) sample was a second run of the February 4, 1993 sample using the already compacted material left over from the first test. This sample was reused to examine the effect that crushing and compaction had on the original sample, and the compaction density relationship. Figure 4.10 shows that for the February 4, 1993 and February 4, 1993 (Run # 2) tests a noticeable change in the moisture density relationship is apparent. The "rerun" sample attained approximately a 10% higher optimum density, at a water content of 12%. This is due to the particle size reductions of the friable materials present in the desifted bottom ash.

Terra Engineering reports the following maximum dry densities at the given moisture contents for the samples analyzed: January 8, 1993 - 1.84 g/cm^3 at 13.7%, March 9, 1993 - 1.87 g/cm^3 at 13.0%, and March 25, 1993 - 1.912 g/cm^3 at 11.7%. An average value is 1.874 g/cm^3 with a moisture content of 12.8%. Maximum densities are used to ensure that construction materials placed in the field are compacted to an appropriate or specified degree. For example, the BC Master Municipal Specifications (1991) state that material for road sub-base must be compacted in the field to a density of within 95% of the optimum density laboratory value.

Table 4.13 COMPACTION DENSITY VALUES OF DESIFTED BOTTOM ASH

RUN	1	2	3	4	5	6	7
SAMPLES RUN AT TERRA ENGINEERING LTD.							
SAMPLE DATE: JAN. 8, 93							
WATER CONTENT %	11.60	12.50	13.40	14.40			
UNIT WEIGHT (g/cm^3)	1.80	1.82	1.84	1.83			
SAMPLE DATE: MAR. 9, 93							
WATER CONTENT %	11.50	12.60	14.00	15.20			
UNIT WEIGHT (g/cm^3)	1.84	1.87	1.86	1.82			
SAMPLE DATE: MAR. 25, 93							
WATER CONTENT %	10.70	11.90	12.90	13.90			
UNIT WEIGHT (g/cm^3)	1.90	1.91	1.91	1.90			
TEST SAMPLES RUN AT UBC							
SAMPLE DATE: JAN. 21, 93							
WATER CONTENT %	3.87	6.63	10.98	12.82	14.00	14.31	15.14
UNIT WEIGHT (g/cm^3)	1.74	1.73	1.71	1.76	1.92	1.81	1.94
SAMPLE DATE: FEB. 4, 93							
WATER CONTENT %	10.14	12.86	13.81	14.08	18.13		
UNIT WEIGHT (g/cm^3)	1.95	2.00	1.89	1.98	1.87		
SAMPLE DATE: FEB. 4, 93 (RUN #2)							
WATER CONTENT %	10.35	11.93	12.19	13.16	13.79	16.46	
UNIT WEIGHT (g/cm^3)	2.02	2.11	2.09	2.11	2.13	2.08	
SAMPLE DATE: FEB. 19, 93							
WATER CONTENT %	7.91	10.04	13.78	18.11			
UNIT WEIGHT (g/cm^3)	2.04	2.09	2.08	1.96			

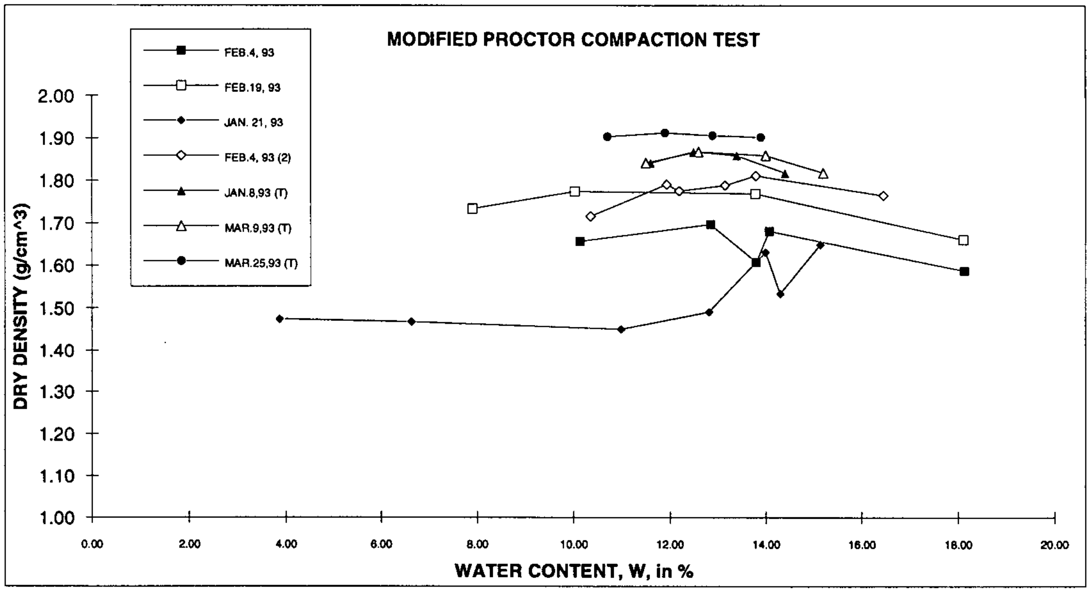


Figure 4.10 PLOT OF DESIFTED BOTTOM ASH COMPACTION DENSITY RESULTS

Terra Engineering performed grain size distribution analyses on the samples they received prior to performing the compaction density tests and these results can be found in Table 4.14. The 1991 and 1992-93 data has been included with corrections made to the data to account for the different set of sieves used and this grain size information is plotted in Figure 4.11. Similar grain size distributions are present, testifying to the fact that bottom ash is well graded. This has beneficial implications when considering the utilization opportunities of desifted or regular bottom ash.

Table 4.14 GSD: 1991 & 1992/93 UBC DATA COMPARED TO TERRA ENGINEERING

GRAIN SIZE DISTRIBUTION: 1991 & 1992/93 UBC DATA vs TERRA ENGINEERING							
	P2 S1		P1 S1/2	P 1/2 S3/8	P3/8 S4	P4 S8	P8
SIEVE SIZE	1"	3/4"	1/2"	3/8"	No. 4	No. 8	PAN
SIEVE SIZE (mm)	25	19	12.5	9.5	4.75	2.36	0
1991 UBC DATA YEARLY AVERAGE							
AVG % RETAINED			24.16	10.42	19.28	9.77	14.73
% RETAINED (CORRECTED)			30.83	13.29	24.61	12.47	18.80
CUM % RETAINED	0.00	14.80	30.83	44.12	68.73	81.20	100.00
% FINER (PASSING)	100.00	85.20	69.17	55.88	31.27	18.80	0.00
1992-93 UBC DATA YEARLY AVERAGE							
AVG % RETAINED			24.13	9.91	17.58	7.73	19.77
% RETAINED (CORRECTED)			30.50	12.53	22.22	9.76	24.99
CUM % RETAINED	0.00	14.64	30.50	43.03	65.24	75.01	100.00
% FINER (PASSING)	100.00	85.36	69.50	56.97	34.76	24.99	0.00
TERRA ENGINEERING DATA							
JAN. 8, 1993							
CUM % RETAINED	0.00	11.60	36.30	49.30	70.80	78.50	100.00
% FINER (PASSING)	100.00	88.40	63.70	50.70	29.20	21.50	0.00
MAR. 9, 1993							
CUM % RETAINED	0.00	12.30	33.20	46.20	64.50	72.70	100.00
% FINER (PASSING)	100.00	87.70	66.80	53.80	35.50	27.30	0.00
MAR. 25, 1993							
CUM % RETAINED	0.00	7.40	25.40	40.80	67.40	78.10	100.00
% FINER (PASSING)	100.00	92.60	74.60	59.20	32.60	21.90	0.00

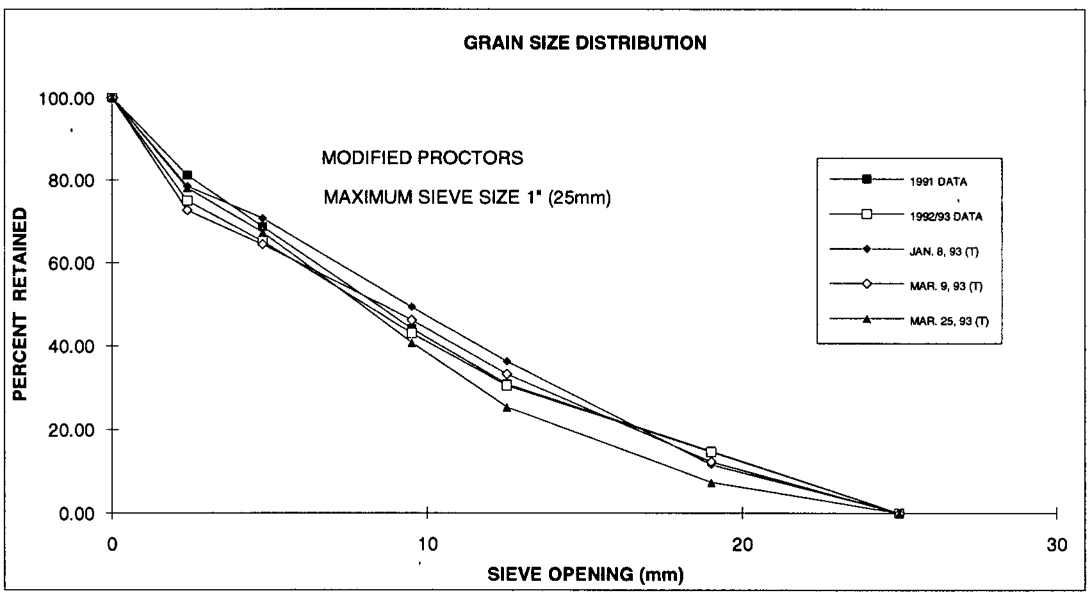


Figure 4.11 GSD OF RBA, DBA, AND DBA USED IN COMPACTION TESTS

4.4 STATISTICAL TREATMENT OF RESULTS - SAMPLE CALCULATION

A sample calculation is included here for the 1991 regular bottom ash lead results. The raw data used for these calculations can be found in Table 4.15. First, the LEP leachable metal concentration results are plotted with time for each fraction of ash. These plots can be found in Figures 4.12, 4.13, and 4.14 for the Passing 3/8", Passing No.4, and Passing No.8 fractions of ash respectively. Note that in Table 4.15 the LEP failures for lead are bolded for clarity. For future comparative purposes the fractions and grabs for sample days when the bottom ash failed the LEP for cadmium are underlined (there are only four such cases).

Table 4.15 1991 BOTTOM ASH LEP: LEAD CONCENTRATIONS

BOTTOM ASH LEACHATE EXTRACTION PROCEDURE: LEAD CONCENTRATIONS (mass basis)

SAMPLE DATE	GRAB # 1 P 3/8" (mg/Kg)	GRAB # 1 P No.4 (mg/Kg)	GRAB # 1 P No.8 (mg/Kg)	GRAB # 2 P 3/8" (mg/Kg)	GRAB # 2 P No.4 (mg/Kg)	GRAB # 2 P No.8 (mg/Kg)	GRAB # 3 P 3/8" (mg/Kg)	GRAB # 3 P No.4 (mg/Kg)	GRAB # 3 P No.8 (mg/Kg)	GRAB # 4 P 3/8" (mg/Kg)	GRAB # 4 P No.4 (mg/Kg)	GRAB # 4 P No.8 (mg/Kg)
2-Jan-91	78.0	**664.6**	**832.6**	**136.6**	**144.8**	**312.6**	**240.6**	83.3	**728.6**	45.5	65.0	**226.6**
14-Jan-91	**106.0**	**260.8**	**564.0**	**224.2**	**870.0**	**3680.0**	**482.0**	**870.0**	**1171.0**	**215.8**	**544.0**	**709.8**
22-Jan-91	7.2	92.4	**497.2**	12.6	55.4	86.6	**128.2**	21.2	**103.2**	49.3	36.2	**511.2**
4-Feb-91	**106.6**	**216.2**	**136.3**	45.4	**147.4**	64.0	85.2	56.8	**148.0**	**250.8**	**178.6**	28.0
18-Feb-91	**1540.0**	**720.0**	**118.0**	**184.0**	**300.0**	**254.0**	28.0	**660.0**	**160.0**	79.2	**286.0**	94.0
6-Mar-91	3.2	41.6	14.8	43.4	**150.6**	15.0	26.8	**102.2**	25.8	12.6	79.0	17.4
30-Mar-91	23.2	81.2	5.8	2.0	**244.0**	1.0	4.4	**301.6**	18.8	40.4	31.6	1.0
12-Apr-91	**222.6**	66.2	7.8	70.2	**1056.4**	**701.4**	6.6	35.2	7.2	**129.2**	**336.0**	10.6
21-Apr-91	**248.0**	48.8	21.6	**560.0**	**334.8**	**435.6**	41.4	**447.2**	30.4	15.0	**440.8**	**234.6**
29-Apr-91	**698.0**	94.2	**156.2**	1.2	81.4	**367.4**	**163.4**	91.4	**231.4**	18.2	84.2	33.4
6-Jun-91	45.4	**824.0**	**1090.0**	57.6	**1660.0**	**1444.0**	98.6	**1058.0**	**1024.0**	57.2	**1416.0**	**616.0**
7-Jul-91	**195.6**	**1428.0**	**1318.0**	0.8	**1154.0**	**516.0**	88.8	**730.0**	**538.0**	8.4	**438.0**	**150.4**
8-Aug-91	4.0	19.6	20.6	37.8	**467.4**	92.6	16.0	**193.2**	23.2	27.2	25.4	18.8
30-Aug-91	9.0	25.8	59.8	**306.4**	**500.0**	90.2	8.2	**201.4**	**158.6**	44.2	45.0	**120.8**
13-Sep-91	3.2	**157.2**	**144.8**	37.0	60.2	14.2	7.8	124.6	30.2	22.4	**125.8**	9.4
26-Sep-91	0.2	46.6	30.6	2.2	93.4	47.8	1.2	27.8	24.6	1.0	63.4	21.8
16-Nov-91	26.2	**906.0**	**1012.0**	17.4	52.2	11.4	4.4	**186.0**	60.8	18.0	**216.4**	**184.4**
17-Dec-91	2.8	49.6	17.0	6.0	81.2	14.0	6.4	**414.2**	63.8	7.8	**151.0**	14.0

NOTE: BOLD VALUES INDICATE THAT THE SAMPLE FAILED THE LEP FOR LEAD; REGULATORY LIMIT IS 100 mg/kg (5 ppm)
UNDERLINED VALUES REPRESENT SAMPLES THAT FAILED LEP FOR CADMIUM

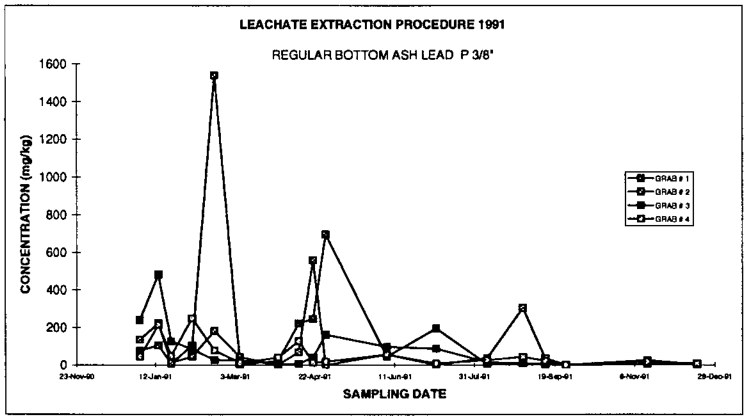


Figure 4.12 1991 RBA LEP P3/8" LEAD RESULTS

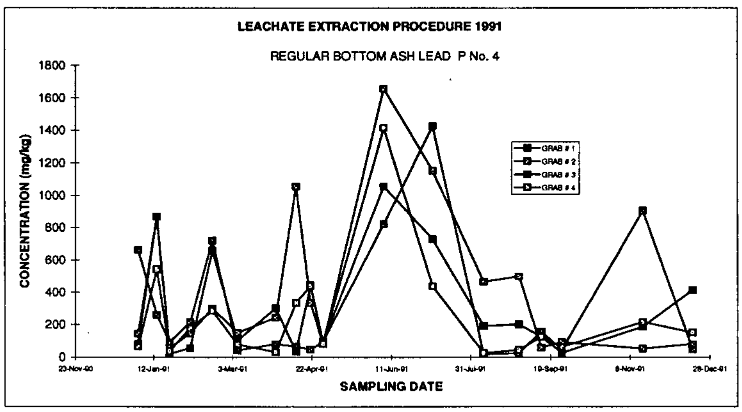


Figure 4.13 1991 RBA LEP P4 LEAD RESULTS

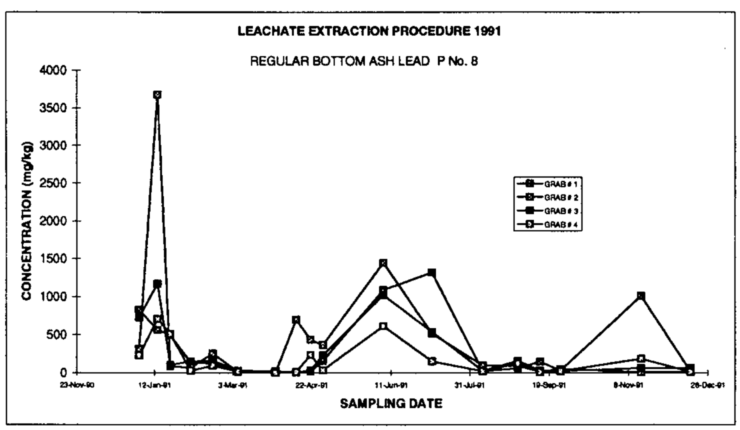


Figure 4.14 1991 RBA LEP P8 LEAD RESULTS

4.4.1 SPATIAL VARIABILITY RATING (SVR)

A Spatial Variability Rating (SVR) criteria was designed by the author to quantify and compare the spatial concentration relationships between grabs of RBA and DBA. The rating was termed “spatial” because initially the variability in concentrations was identified graphically as high or low concentrations that varied from average values. This rating is actually a measure of the magnitude of the difference a concentration is from the average concentration for the sample day in question. The following discussion and example outlines the procedure used to determine "SVR's".

This method for identifying high and low values has limitations. For example, if a peak value is large enough then its influence on the calculation can mean that a high and a low value are determined for the same day. This problem occurred several times, especially in the 1992-93 study where only three grabs per sample day were taken. It was possible to have a "middle" value that was three times greater than a low value and also three times smaller than a high value. This fact only strengthens the argument that the spatial agreement between grabs was not good for that particular sample day. A more sophisticated statistical analysis of the spatial variation between grabs was not performed, perhaps it may have been more useful and easier to use standard deviations.

By definition, for the purposes of the SVR for 1991 RBA, if the average of three of four concentrations from the grabs of a particular sample day differs with one grabs' concentration by more than 200%, then a high or a low value exists. A high value exists when the average of three of the four concentrations are 200% (three times) below the concentration being examined. Conversely, a low concentration is defined when the average of three of four concentrations for a given sample day is 200% (three times) above the concentration being examined. For example a high or peak lead concentration occurred on February 18, 1991 for Grab # 1 of the Passing 3/8" fraction. This was determined using the criteria shown in Table 4.16 to quantify concentration variability between grabs. The SVR was calculated for each sample day and for each fraction of ash. The average of Grabs # 2, 3, and 4 is 97.1 mg/kg. The suspected high value, Grab # 1 [1,540 mg/kg], is more than 200% or three times greater than this average (3 x 97.1 =

291.3) and is therefore defined as a high value. Conversely, Grab # 3 is a low value using the same criteria.

Table 4.16 SPATIAL VARIATION - FEBRUARY 18, 1991 HIGH VALUE

GRAB	CONCENTRATION	AVERAGE	200% (3 TIMES)
GRAB # 1	1,540.0 mg/kg		
GRAB # 2	184.0 mg/kg	=>	
GRAB # 3	28.0 mg/kg	=>97.1 mg/kg	291.3
GRAB # 4	79.2 mg/kg	=>	

A low lead concentration occurred on April 12, 1991 for Grab # 3 of the Passing 3/8" fraction. This was determined using the data shown in Table 4.17. The average of Grabs # 1, 2, and 4 is [140.7 mg/kg]. The suspected low value, Grab # 3 [6.6 mg/kg], is less than 200% or three times (3 x 6.6 = 19.8) lower than the average [140.7 mg/kg]. Therefore, Grab # 3, [6.6 mg/kg], is defined as a low value. Conversely, Grab # 1 is a high value.

Table 4.17 SPATIAL VARIATION - APRIL 12, 1991 LOW VALUE

GRAB	CONCENTRATION	AVERAGE	200% (3TIMES)
GRAB # 1	222.6 mg/kg	=>	
GRAB # 2	70.2 mg/kg	=>140.7 mg/kg	
GRAB # 3	6.6 mg/kg		19.8
GRAB # 4	129.2 mg/kg	=>	

Two different sets of criteria were used to define the Spatial Variability Ratings for the 1991 and 1992-93 studies. A different set of criteria had to be developed for the Spatial Variability Rating" (SVR) for the 1992-93 DBA grabs because a different number of grabs 93) were taken as part of the 1992-93 study examining DBA. The Spatial Variability Ratings (SVR) used to designate the spatial concentration relationship between grabs was "Excellent", "Good", "Fair", and "Poor". Table 4.18 below summarizes the criteria to define the ratings used. Seventy-two (72) samples were taken for the 1991 study compared to thirty-six (36) for the 1992-93 study. For this reason half the number of high or low values in 1992-93 were used to define the same "Spatial Variability Rating".

Table 4.18 SUMMARY OF SPATIAL VARIABILITY RATING CRITERIA

SVR RATING	NUMBER OF HIGH OR LOW CONCENTRATIONS	
	1991 STUDY	1992-93 STUDY
EXCELLENT	0 to 3	0 to 1
GOOD	4 to 7	2 to 3
FAIR	8 to 11	4 to 5
POOR	more than 11	more than 5

4.4.2 DATA SETS AND NORMAL DISTRIBUTIONS

The raw concentration data for each fraction of ash (minus 9.5 mm or P3/8", minus 4.75 mm or P4, and minus 2.36 mm or P8) is ranked from smallest to largest. The P, T, and Z-Score values are calculated A sample calculation is provided here for the 36th ranked point of 72 points.

$$P = (i - 0.3)/(N + 0.4)$$
$$= (36 - 0.3) / (72 + 0.4)$$
$$P = 0.4930939$$

for $P \leq 0.5$ $T = SQRT[-2.0 \times \ln(P)]$

$$Z = T - (2.30753 + 0.27061T)/(1 + 0.99229T + 0.04481T^2)$$

$$T = SQRT[-2.0 \times \ln(0.4930939)]$$
$$T = 1.1891641$$

$$Z = T - (2.30753 + 0.27061T)/(1 + 0.99229T + 0.04481T^2)$$

$$= \frac{1.1891641 - (2.30753 + 0.27061 \times 1.1891641)}{1 + 0.99229 \times 1.1891641 + 0.04481 \times 1.1891641^2}$$

$$Z = 0.0171153$$

for $P > 0.5$ $T = SQRT[-2.0 \times \ln(1-P)]$

$$Z = (2.30753 + 0.27061T)/(1 + 0.99229T + 0.04481T^2) - T$$

The Z-Score values were used to linearize the probability plotting process by allowing a probability plot to be done on an X - Y scatter plot, instead of using probability paper. The Z-Score plots for both the raw untransformed and log normally transformed data can be found in Figures 4.15 and 4.16 respectively. Figure 4.15 shows that the raw untransformed data set is skewed (i.e. it is a curve), an effect caused by peak values. This means that the raw untransformed data set is not normally distributed and therefore this data set should not be used to describe the lead concentrations for this portion of the 1991 regular bottom ash. Figure 4.16 shows that the plots of the transformed data for all three fractions of ash are linear. Therefore, the transformed data is normally distributed and this data set can be used to perform regulatory UCLM calculations to determine whether or not the bottom ash is in compliance with regulatory limits for lead.

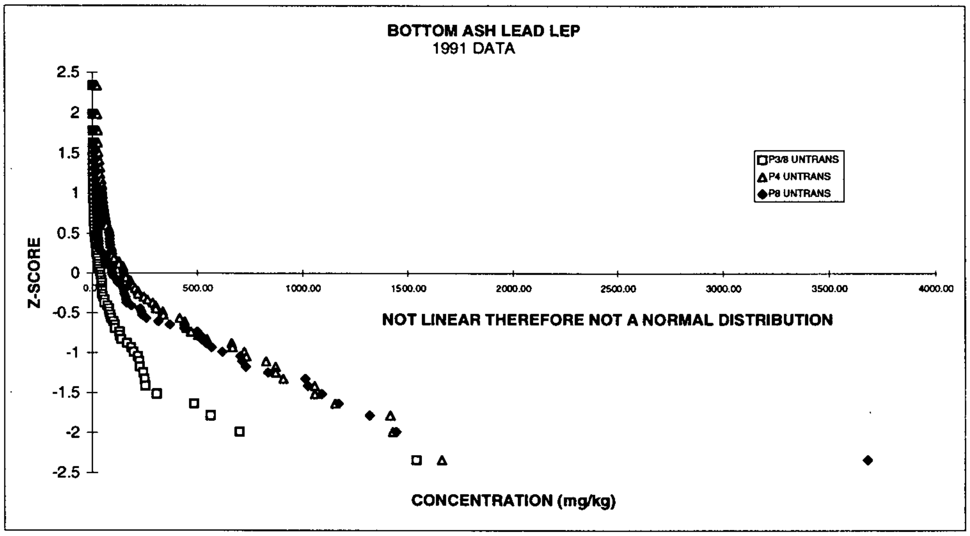


Figure 4.15 Z-SCORE PLOT OF UNTRANSFORMED LEAD DATA

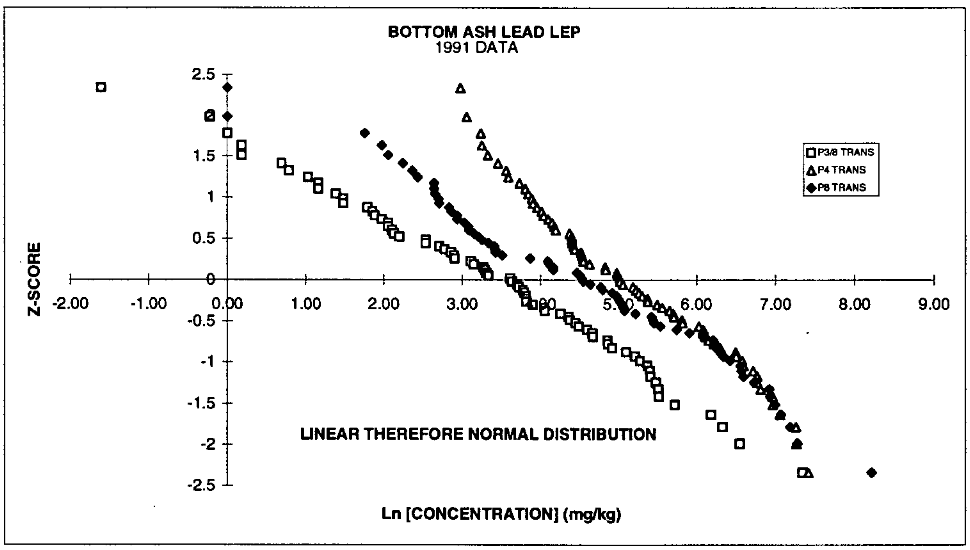


Figure 4.16 Z-SCORE PLOT OF TRANSFORMED LEAD DATA

4.4.3 UPPER CONFIDENCE LIMIT OF THE MEAN (UCLM)

Microsoft Excel's "Descriptive Statistics" function was used to process the concentration data. This information has been tabulated for both the untransformed and transformed fractions of ash examined (Table 4.19). This table provides a host of statistical information, which includes the:

- MEAN
- STANDARD ERROR
- MEDIAN
- STANDARD DEVIATION
- VARIANCE
- KURTOSIS
- SKEWNESS
- RANGE
- MINIMUM
- MAXIMUM
- CONFIDENCE LEVEL (95%)

Upper Confidence Limits of the Mean (UCLM) values are calculated based on the concentration data contained in these statistical tables. The method followed is outlined in the USEPA's SW-846 (1986). For seventy-two (72) samples a "student-t" value of 1.288 was used in the statistical calculations. The UCLM value determined in all cases is based on the following equation:

UCLM = XBAR ± ("t") x (SE) (equation (6) USEPA SW-846, 1986, pNINE-3)

where
XBAR = sample mean
"t" = tabulated "student-t" value
SE = standard error

The transformed $UCLM_{trans}$ value of 3.62 for the P3/8 fraction (minus 9.5 mm) of ash shown in Table 4.19 was calculated as follows:

$$UCLM_{trans} = XBAR \pm (\text{"t"}) \times (SE)$$
$$= 3.35 + 1.288 \times 0.213$$
$$UCLM_{trans} = 3.62$$

This $UCLM_{trans}$ value has been calculated for the log normally transformed data set. It is necessary to "untransform" this value using the inverse mathematical function. In the case of the natural log, the inverse function is the exponential exp(x) or "e^x". The UCLM value transformed back to a real value is:

$$\begin{aligned} UCLM &= \exp(UCLM_{trans}) \\ &= \exp(3.62) \\ UCLM &= 37.45 \end{aligned}$$

This UCLM value and all subsequent UCLM values calculated are the leachable metal concentrations, which are in turn compared to regulatory thresholds for specific metals contained in the BC MOELP's Waste Management Act - Special Waste Regulations (1988).

Table 4.19 STATISTICAL INFORMATION FOR 1991 LEAD DATA

P3/8 UNTRANS		*P4 UNTRANS*		*P8 UNTRANS*	
Mean	104.78	Mean	324.48	Mean	302.01
Standard Error	25.34	Standard Error	45.05	Standard Error	63.10
Median	37.40	Median	150.80	Median	93.30
Standard Deviation	215.06	Standard Deviation	382.28	Standard Deviation	535.39
Variance	46249.02	Variance	146134.78	Variance	286647.52
Kurtosis	28.66	Kurtosis	2.42	Kurtosis	22.02
Skewness	4.81	Skewness	1.71	Skewness	4.02
Range	1539.80	Range	1640.40	Range	3679.00
Minimum	0.20	Minimum	19.60	Minimum	1.00
Maximum	1540.00	Maximum	1660.00	Maximum	3680.00
Confidence Level (95%)	49.67	Confidence Level (95%)	88.30	Confidence Level (95%)	123.67
UCLM	137.60	UCLM	382.82	UCLM	383.72

P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	3.35	Mean	5.12	Mean	4.46
Standard Error	0.21	Standard Error	0.14	Standard Error	0.21
Median	3.62	Median	5.02	Median	4.54
Standard Deviation	1.81	Standard Deviation	1.19	Standard Deviation	1.77
Variance	3.28	Variance	1.42	Variance	3.13
Kurtosis	-0.21	Kurtosis	-1.02	Kurtosis	-0.43
Skewness	-0.30	Skewness	0.15	Skewness	-0.17
Range	8.95	Range	4.44	Range	8.21
Minimum	-1.61	Minimum	2.98	Minimum	0.00
Maximum	7.34	Maximum	7.41	Maximum	8.21
Confidence Level (95%)	0.42	Confidence Level (95%)	0.28	Confidence Level (95%)	0.41
UCLM	3.62	UCLM	5.30	UCLM	4.73
UCLM TRANS BACK	37.45	UCLM TRANS BACK	200.95	UCLM TRANS BACK	112.86

4.5 BOTTOM ASH RESULTS

4.5.1 LEACHATE EXTRACTION PROCEDURE

The Leachate Extraction Procedure (LEP) is used to model the possible environmental impact the leachate from a landfilled solid waste might have on the environment. The LEP was used because it is the regulatory test that solid wastes in British Columbia must conform to, but other jurisdictions, and authors, are using different tests. In some cases these other tests like the SCE or TCLP are more appropriately suited for monofilled bottom ash and they model the possible groundwater impact of bottom ash disposal better than the LEP. For example, Sawell and Constable (1989) and Sawell et al (1990) used the Sequential Chemical Extraction (SCE) procedure. Their results are comparable to the LEP, especially for the first extraction (FRACTION A) of the SCE. They verified previous findings, that the solubility of cadmium and zinc is affected by the pH of the leaching environment. In their case, as well as here, the pH of the leaching environment was determined by the buffering capacity of the ash. Sawell and Constable (1989) found that "cadmium, which is not amphoteric, and zinc, which is mildly amphoteric, were readily soluble under mildly acidic to neutral pH conditions but not under alkaline conditions. **Lead is considered strongly amphoteric and was more soluble under highly alkaline conditions than under mildly acidic to neutral conditions where only small fractions (less than 0.25%) were solubilized**."

The fact that lead is strongly amphoteric and is soluble under highly alkaline conditions is very important, especially when you consider the methodology of the LEP. The first step of the LEP is to tumble and wet a 50 gram sample of solid waste in 800 ml of distilled water. Because bottom ash is alkaline it will influence the solubility of lead. This will be addressed further in the LEP pH EFFECTS section where the initial 15 minute and the final 24 hour pH values of the LEP are compared.

Sawell et al (1990) use lead as an example of how speciation can influence a metal solubility. Lead hydroxide is soluble under acidic ($pH < 5.0$) and highly alkaline conditions, whereas the lead in a lead silicate compound is strongly bound in a solid matrix and is not available for leaching under most environmental conditions.

Van Der Sloot et al (1989) report that copper and lead results vary considerably because of the occurrence of solid metal particles. Copper particles, for example packing staples and wire, were easily identifiable and were observed in the 1991 and 1992-93 ash samples taken. Lead on the other hand was more difficult to distinguish from other non-ferrous metals in the samples. However, particles of elemental lead were evident and verified because they were gray in color, dense, and malleable.

4.5.1.1 REGULAR BOTTOM ASH (RBA)

A synopsis of Ting's (1994) results is presented in order to familiarize the reader with the leachable metal concentrations in 1991 RBA (Table 4.20). Ting's (1994) tabulated raw leachable metal concentrations, which the following calculations are based on, is not presented here in order to save space but it is contained in the Appendix. This table lists each of the three fractions of ash and the eight metals examined and the parameters listed include the:

- minimum leachable concentration
- maximum leachable concentration
- range in concentration
- average concentration
- Upper Confidence Limit of the Mean (UCLM)
- transformation used (none or log normal)
- spatial variability rating (SVR) (poor, fair, good, excellent)

The fact that the finer two fractions of RBA in 1991 are Special Wastes has ash management implications. All three of the finer fractions of RBA had numerous LEP lead failures, therefore, it may be undesirable to grade bottom ash into various fractions. The frequency of 1991 LEP failures for lead were as follows: P3/8" 19/72 or 26.4%, P4 40/72 or 55.6%, and P8 33/72 or 45.8% and the average was 92/216 or 42.6%. Removing the coarser fractions (plus 9.5 mm) of bottom ash for use as fill and leaving behind the finer fractions (minus 9.5 mm) creates Special Wastes. This point will be discussed in more detail in the "ASH MANAGEMENT AND UTILIZATION SECTION". If the 1991 RBA fractions above 3/8" (9.5 mm) had been crushed, ground, or cut to pass a 3/8" sieve and included in the LEP sample, as the regulations specify, then the regular bottom ash may not have been classified as a Special Waste (Rigo, 1990 and Miller, 1993).

Table 4.20 METALS ANALYSIS SUMMARY: 1991 LEP OF REGULAR BOTTOM ASH

METAL	ASH FRACTION	CONCENTRATIONS (mg/kg) MIN	MAX	RANGE	AVG	UCLM	TRANSFORMATION USED	SPATIAL VARIABILITY RATING	HIGH/LOW
Cd - CADMIUM	P 3/8"	0.2 (1)	4.6	4.4	1.0	0.8	LOGNORMAL	EXCELLENT	0
	P No. 4	0.2 (1)	14.0	13.8	1.9	1.5	LOGNORMAL	EXCELLENT	0
	P No. 8	0.2 (1)	71.8	71.5	5.6	3.9	LOGNORMAL	EXCELLENT	2
Cr - CHROMIUM	P 3/8"	0.2 (1)	3.8	3.6	0.8	0.5	LOGNORMAL	GOOD	5
	P No. 4	0.2 (1)	4.2	4.0	1.3	0.9	LOGNORMAL	EXCELLENT	1
	P No. 8	0.2 (1)	3.4	3.2	1.2	1.1	LOGNORMAL	EXCELLENT	1
Cu - COPPER	P 3/8"	2.8	530.0	527.2	57.9	37.8	LOGNORMAL	GOOD	7
	P No. 4	2.8	630.0	627.2	63.7	50.8	LOGNORMAL	EXCELLENT	1
	P No. 8	2.8	194.6	191.8	47.8	44.0	LOGNORMAL	EXCELLENT	0
Fe - IRON	P 3/8"	0.2 (1)	900.0	899.8	142.9	65.1	LOGNORMAL	GOOD	5
	P No. 4	0.2 (1)	1,819.6	1,819.4	143.7	61.1	LOGNORMAL	GOOD	5
	P No. 8	0.2 (1)	700.0	699.8	22.4	3.4	LOGNORMAL	FAIR	8
Mn - MANGANESE	P 3/8"	5.4	2,110.0	2,104.6	102.5	45.4	LOGNORMAL	GOOD	5
	P No. 4	5.4	1,657.8	1,652.4	164.1	91.5	LOGNORMAL	FAIR	10
	P No. 8	42.6	1,870.0	1,827.4	178.7	134.9	LOGNORMAL	GOOD	7
Ni - NICKEL	P 3/8"	0.6	482.0	481.4	23.0	7.0	LOGNORMAL	FAIR	9
	P No. 4	0.8	870.0	869.2	35.2	10.1	LOGNORMAL	GOOD	6
	P No. 8	0.6	3,680.0	3,679.4	94.1	12.0	LOGNORMAL	EXCELLENT	2
Pb - LEAD	P 3/8"	0.2 (1)	1,540.0	1,539.8	104.8	37.5	LOGNORMAL	POOR	14
	P No. 4	19.6	1,660.0	1,640.4	324.5	201.0	LOGNORMAL	FAIR	9
	P No. 8	1.0	3,680.0	3,679.0	302.0	112.9	LOGNORMAL	FAIR	9
Zn - ZINC	P 3/8"	35.6	4,096.0	4,060.4	668.3	496.1	LOGNORMAL	POOR	12
	P No. 4	49.4	2,912.0	2,862.6	925.9	844.8	LOGNORMAL	GOOD	5
	P No. 8	162.8	3,104.0	2,941.2	1,126.6	1,080.2	LOGNORMAL	EXCELLENT	0

NOTES: (1) AT OR BELOW DETECTION LIMIT
(2) MIN, MAX, RANGE, AND AVG VALUES LISTED ARE FOR UNTRANSFORMED RAW DATA; UCLM VALUES LISTED ARE BASED ON TRANSFORMED DATA SETS WHICH HAVE BEEN TRANSFORMED BACK TO REAL NUMBER SYSTEM

4.5.1.2 DESIFTED BOTTOM ASH (DBA)

Three (3) grabs of desifted bottom ash (DBA) were taken on 12 sample days for a total of thirty-six (36) DBA samples, collected and analyzed. Samples were collected over the course of seven months from September 17, 1992 to March 25, 1993. The 1992-93 results are summarized in Table 4.21 which lists each of the three fine fractions of ash and the eight metals examined. The parameters listed include the:

- minimum leachable concentration
- maximum leachable concentration
- range in concentration
- average concentration
- Upper Confidence Limit of the Mean (UCLM)
- transformation used (none or log normal)
- spatial variability rating (SVR) (poor, fair, good, excellent)

Duplicates were run for 11 randomly selected samples which are denoted by roman numerals (i) to (xi) on Tables 4.22 to 4.29. Duplicate concentrations are listed here because it was appropriate to be able to compare the duplicate values to the other grabs. Duplicates are discussed in in the APPENDIX.

Table 4.21 SUMMARY OF 1992-93 LEP OF DESIFTED BOTTOM ASH

METAL	ASH FRACTION	CONCENTRATIONS (mg/kg) MIN	MAX	RANGE	AVG	UCLM	TRANSFORMATION USED	SPATIAL VARIABILITY RATING	HIGH/LOW
Cd - CADMIUM	P 3/8"	0.2 (1)	2.6	2.4	0.7	0.6	LOGNORMAL	GOOD	3
	P No. 4	0.2 (1)	5.8	5.6	1.6	1.4	LOGNORMAL	GOOD	2
	P No. 8	0.6	18.6	18.0	5.9	5.5	LOGNORMAL	GOOD	3
Cr - CHROMIUM	P 3/8"	0.2 (1)	0.4	0.2	0.2	0.2	LOGNORMAL	EXCELLENT	0
	P No. 4	0.2 (1)	2.4	2.2	0.5	0.4	LOGNORMAL	EXCELLENT	1
	P No. 8	0.2 (1)	1.6	1.4	0.7	0.7	LOGNORMAL	EXCELLENT	0
Cu - COPPER	P 3/8"	0.3	4.3	75.4	22.1	16.5	LOGNORMAL	POOR	9
	P No. 4	1.0	134.0	133.0	38.9	31.9	LOGNORMAL	POOR	6
	P No. 8	10.6	77.4	66.8	26.7	25.9	LOGNORMAL	EXCELLENT	0
Fe - IRON	P 3/8"	16.4	1,275.0	1,258.6	270.8	231.0	LOGNORMAL	POOR	8
	P No. 4	3.4	745.0	741.6	197.7	143.1	LOGNORMAL	FAIR	5
	P No. 8	2.6	40.0	37.4	7.9	7.0	LOGNORMAL	EXCELLENT	0
Mn - MANGANESE	P 3/8"	5.8	51.0	45.2	15.6	15.2	LOGNORMAL	EXCELLENT	1
	P No. 4	14.2	994.0	979.8	200.5	112.3	LOGNORMAL	POOR	10
	P No. 8	54.8	626.0	571.2	217.8	197.6	LOGNORMAL	FAIR	4
Ni - NICKEL	P 3/8"	1.2	50.0	48.8	8.8	8.3	LOGNORMAL	GOOD	2
	P No. 4	4.2	32.8	28.6	13.1	13.2	LOGNORMAL	EXCELLENT	1
	P No. 8	13.6	50.2	36.6	21.7	22.1	LOGNORMAL	EXCELLENT	0
Pb - LEAD	P 3/8"	0.2 (1)	716.0	715.8	56.6	13.4	LOGNORMAL	POOR	12
	P No. 4	0.2 (1)	446.8	446.6	108.3	58.1	LOGNORMAL	POOR	12
	P No. 8	0.2 (1)	284.2	284.0	38.4	22.5	LOGNORMAL	EXCELLENT	0
Zn - ZINC	P 3/8"	40.4	1,448.0	1,407.6	223.8	174.4	LOGNORMAL	POOR	9
	P No. 4	149.8	2,490.0	2,340.2	679.6	622.6	LOGNORMAL	POOR	7
	P No. 8	338.0	1,656.0	1,318.0	959.2	969.9	LOGNORMAL	EXCELLENT	0

NOTES: (1) AT OR BELOW DETECTION LIMIT
(2) MIN, MAX, RANGE, AND AVG VALUES LISTED ARE FOR UNTRANSFORMED RAW DATA; UCLM VALUES LISTED ARE BASED ON TRANSFORMED DATA SETS WHICH HAVE BEEN TRANSFORMED BACK TO REAL NUMBER SYSTEM

4.5.1.2.1 CADMIUM: DBA LEP

Cadmium is present in the DBA at extremely low levels, in a number of cases at or below detection level. All "0.2" values reported (Table 4.22) represent zero or non-detect values and were used to facilitate the statistical analyses (you cannot do "0" log normal calculations). The best spatial agreement is obtained for the P4 fraction, only two high/low values were recorded. The P3/8" fraction has a higher degree of variation, which may simply be a result of the low or non-detectable values obtained for this fraction. The P8 fraction contains the highest levels of cadmium. The concentration range for the P8 fraction is [0.6 to 18.6 mg/kg] (Table 4.21). The concentration ranges for the P3/8" and P4 fractions are [0.2 to 2.6] and [0.2 to 5.8 mg/kg] respectively.

The untransformed data is not normally distributed because straight line z-Score plots were not obtained. When a Z-Score plot of the transformed data is done, the data linearizes well, and therefore it is normally distributed. There are groupings of points on the Z-SCORE plots, especially for the coarser P3/8" fraction, which are a result of the "0.2" substitution for non-detects and zero values. The P8 fraction did not have any non-detect or zero values. The UCLM concentration data, based on the transformed and normalized data sets, are: P3/8" [0.6 mg/kg], P4 [1.4 mg/kg], and P8 [5.5 mg/kg] (Table 4.21). Concentration can be seen to be increasing with decreasing particle size.

The regulatory limit for cadmium is 0.50 mg/l or 10 mg/kg, therefore the three DBA fractions do not constitute a special waste with respect to cadmium when considering the UCLM. However, there are several occurrences when individual grabs of the P8 fraction exceed the regulatory limit. For example, the leachable cadmium concentrations on September 17, 1992 for Grabs 1, 2 and 3 were [11.2 mg/kg], [10.2 mg/kg] and [11.6 mg/kg] respectively. The highest concentration occurred on February 19, 1993 for Grab 1 P8 [18.6 mg/kg] and failures are bolded for clarity in Table 4.22. The underlined values correspond to LEP failures for lead. It would seem that there is no correlation between cadmium and lead failures, and that when considered together the cadmium and lead LEP failures strengthen the argument not to sift bottom ash into several different fractions because it "creates" more days where grabs of ash fail the LEP.

The leachable cadmium concentrations obtained here are not as high as those reported by Bagchi and Sopich (1989) for combined ash, which were between 0.18 to 171.2 mg/kg (0.009 to 8.56 mg/l). Roethel et al. (1991) observed that cadmium on occasion exceeded regulatory thresholds, when conducting acetic acid leaching tests. After examining ash from two different facilities they found that total cadmium concentrations measured were relatively similar.

Table 4.22 1992-93 DESIFTED BOTTOM ASH, LEP RESULTS FOR CADMIUM

1992-93 DESIFTED BOTTOM ASH LEP: CADMIUM CONCENTRATIONS (mass basis)									
	GRAB # 1			**GRAB # 2**			**GRAB # 3**		
SAMPLE DATE	P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)	P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)	P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)
17-Sep-92	1.00	1.80	**11.20**	1.00	3.00	**10.20**	1.80	5.80	**11.60**
18-Oct-92	0.60 i	1.60	4.60	1.20	3.20	**14.40**	0.60	1.40 ii	5.40
30-Oct-92	2.60	3.20 iii	5.20	1.00	3.20	0.60	0.80	3.60	6.80
13-Nov-92	0.40	1.40	3.00	1.20	1.40	2.40	0.40	0.80	2.40
30-Nov-92	0.20	0.80	2.20	1.20	0.80	2.00	0.20	0.80 iv	2.20
13-Dec-92	0.40	0.80	4.60	0.40	0.40	5.20	0.40	0.80	**17.20**
8-Jan-93	0.20	1.20	4.40	0.40	0.20	3.80	0.40	1.60	6.00
21-Jan-93	0.40	1.80	4.20 v	2.60	1.80	4.00	0.20	2.40	7.00
4-Feb-93	0.40	1.60 vi	**12.00**	0.60	1.00	6.80	0.40	2.00	5.60 vii
19-Feb-93	0.80	2.60	**18.60**	0.20 vii	0.40	4.60 ix	0.20	0.40	4.20
9-Mar-93	0.20	0.60	4.20	0.20 x	0.40	4.40	0.20	0.40	5.20
25-Mar-93	0.20	0.80	2.60	0.40	1.40	2.40	0.40 xi	0.40	2.80

DUPLICATES (mg/kg)
(i) 0.2, (ii) 0.8, (iii) 2.4, (iv) 1.0, (v) 4.0, (vi) 1.2, (vii) 5.8, (viii) 0.8, (ix) 4.8, (x) 0.4, (xi) 0.4
Regulatory Limit: 0.50 mg/l or 10 mg/kg
Bold values represent LEP failures for Cd
Underlined values represent samples that failed the LEP for Pb

4.5.1.2.2 CHROMIUM: DBA LEP

There was very little leachable chromium present in the P3/8" fraction of the DBA (Table 4.23). Non-detects or zero values were represented by a "0.2" mg/kg value. The P4 fraction contained detectable amounts of leachable chromium early in the sample period, until December, but after that it was non detectable. The P8 fraction contained chromium at measurable, but low levels. There was "Excellent" spatial agreement between each of the three grabs taken. The concentration ranges for each fraction were: P3/8" [0.2 to 0.4 mg/kg], P4 [0.2 to 2.4 mg/kg], and P8 [0.2 to 1.6 mg/kg] (Table 4.21). The transformed data sets were normally distributed, although with the number of non-detects or zero values in the coarser two fractions it is difficult to tell which data set is normally distributed. Chromium concentrations increased with decreasing particle size, and the UCLM values were: P3/8" [0.2 mg/kg], P4 [0.4 mg/kg], and P8 [0.7 mg/kg] (Table 4.21). There were no chromium LEP failures.

Table 4.23 1992-93 DESIFTED BOTTOM ASH, LEP RESULTS FOR CHROMIUM

1992-93 DESIFTED BOTTOM ASH LEP: CHROMIUM CONCENTRATIONS (mass basis)									
SAMPLE DATE	**GRAB # 1** P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)	**GRAB # 2** P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)	**GRAB # 3** P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)
17-Sep-92	0.40	0.40	1.20	0.40	0.80	1.20	0.40	1.60	1.60
18-Oct-92	0.20 i	0.60	1.00	0.20	2.40	1.20	0.20	0.20 ii	0.80
30-Oct-92	0.20	0.80 iii	1.60	0.20	1.40	1.60	0.40	0.80	1.60
13-Nov-92	0.20	0.80	1.00	0.20	0.60	1.00	0.20	0.60	1.00
30-Nov-92	0.20	0.60	0.40	0.20	0.20	0.40	0.20	0.40 iv	0.40
13-Dec-92	0.20	0.20	0.20	0.20	0.20	0.40	0.20	0.20	0.40
8-Jan-93	0.20	0.20	0.40	0.20	0.20	0.60	0.20	0.20	0.40
21-Jan-93	0.20	0.20	0.40 v	0.20	0.20	0.60	0.20	0.20	0.40
4-Feb-93	0.20	0.20 vi	0.40	0.20	0.20	0.80	0.20	0.20	0.60 vi
19-Feb-93	0.20	0.20	0.20	0.20 vii	0.20	0.20 ix	0.20	0.20	0.20
9-Mar-93	0.20	0.20	0.40	0.20 x	0.20	0.40	0.20	0.20	0.40
25-Mar-93	0.20	0.20	0.40	0.20	0.20	0.40	0.20 xi	0.20	0.40

DUPLICATES (mg/kg)
(i) 0.2, (ii) 0.2, (iii) 0.4, (iv) 0.2, (v) 0.2, (vi) 0.2, (vii) 0.6, (viii) 0.2, (ix) 0.4, (x) 0.2, (xi) 0.2
Regulatory Limit: 5.0 mg/l or 100 mg/kg

4.5.1.2.3 COPPER: DBA LEP

Table 4.24 contains the concentration results from the LEP for DBA. Spatial variability for the copper fractions and samples decreases significantly with particle size (Table 4.21). The P3/8" fractions' leachable concentrations are variable whereas the P8 fraction has 3 grabs that are virtually identical in concentration with a SVR of "Excellent". Variability in the P3/8" fraction may have been caused by sample heterogeneity given the fact that fifty (50) grams of the P8 fraction would be less variable in composition than 50 grams of the P3/8" fraction due to particle size. It is possible that pieces of copper metal, for example packing staples used on corrugated cardboard boxes or electrical wire , had an impact on the P3/8" fraction. Concentration ranges for each fraction were: P3/8" [1.4 to 76.8 mg/kg], P4 [1.0 to 134 mg/kg], and P8 [10.6 to 77.4 mg/kg] (Tables 4.21 and 4.24). The transformed data was used to calculate the UCLM copper concentrations after examining Z-Score plots. The UCLM values are: P3/8" [16.5 mg/kg], P8 [31.9 mg/kg], and P8 [25.6 mg/kg]. The highest copper concentration is in the middle, P4 fraction (Table 4.21). The sifted ash samples cannot be classified as a special waste with respect to copper because the UCLM concentrations do not exceed the regulatory limit of 2,000 mg/kg (100 mg/l; nor do individual LEP test results.

Table 4.24 1992-93 DESIFTED BOTTOM ASH, LEP RESULTS FOR COPPER

1992-93 DESIFTED BOTTOM ASH LEP: COPPER CONCENTRATIONS (mass basis)									
	GRAB # 1			GRAB # 2			GRAB # 3		
SAMPLE DATE	P 3/8" (mg/Kg)	P No.4 (mg/Kg)	P No.8 (mg/Kg)	P 3/8" (mg/Kg)	P No.4 (mg/Kg)	P No.8 (mg/Kg)	P 3/8" (mg/Kg)	P No.4 (mg/Kg)	P No.8 (mg/Kg)
17-Sep-92	76.80	23.60	23.60	11.80	22.40	21.20	67.80	66.80	14.80
18-Oct-92	21.80 i	56.80	26.20	3.60	63.40	29.40	1.80	16.00 ii	31.40
30-Oct-92	11.40	134.00 iii	48.80	8.60	62.20	34.60	10.20	73.20	39.00
13-Nov-92	40.60	39.40	11.60	11.00	33.60	10.60	73.20	33.80	12.00
30-Nov-92	2.80	76.00	16.20	30.20	35.60	17.80	68.20	113.00 iv	19.60
13-Dec-92	44.00	11.60	15.00	1.40	1.00	15.60	17.20	44.00	18.80
8-Jan-93	2.80	2.60	16.40	2.20	7.60	24.00	14.80	32.20	28.00
21-Jan-93	37.20	22.60	18.00 v	8.60	116.40	30.80	56.20	39.00	22.20
4-Feb-93	3.60	15.20 vi	75.60	2.60	38.60	77.40	25.00	36.60	71.00 vi
19-Feb-93	10.00	24.80	28.80	11.80 vii	6.40	27.20 ix	9.20	50.60	28.00
9-Mar-93	21.40	38.40	11.80	30.20 x	1.80	13.40	5.20	4.00	17.40
25-Mar-93	19.20	14.40	17.80	7.80	18.20	20.20	25.20 xi	24.60	25.40

DUPLICATES (mg/kg)
(i) 4.4, (ii) 36.0, (iii) 60.2, (iv) 28.8, (v) 17.8, (vi) 33.2, (vii) 66.6, (viii) 3.4, (ix) 24.0, (x) 10.0, (xi) 66.8
Regulatory Limit: 100 mg/l or 2000 mg/kg

4.5.1.2.4 IRON: DBA LEP

Iron is most concentrated in the middle P4 fraction. "Excellent" spatial agreement can be seen for each of the three grabs of the P8 fraction and like copper, all three P8 grabs are virtually identical in concentration. A high value of [1,275 mg/kg] occurs for Grab # 2 of the P3/8" fraction on March 9, 1993

(Table 4.25). High leachable iron concentrations may be attributed to the heterogeneity of the ash samples and variability. Concentration ranges were P3/8" [16.4 to 1,275 mg/kg], P4 [3.4 to 754 mg/kg], and P8 [2.6 to 40 mg/kg] (Tables 4.21). This shows that the leachable iron concentrations exhibited a significant decrease in concentration as the particle size decreased. The transformed data is normally distributed and the UCLM values for each fraction are: P3/8" [231 mg/kg], P4 [143.1 mg/kg], and P8 [7.0 mg/kg] (Table 4.21). Iron is not a heavy metal of regulatory concern because it is not limited by the BC MOELP Special Waste Regulations (1988) and no maximum value for the LEP is specified.

Table 4.25 1992-93 DESIFTED BOTTOM ASH, LEP RESULTS FOR IRON

1992-93 DESIFTED BOTTOM ASH LEP: IRON CONCENTRATIONS (mass basis)									
SAMPLE DATE	GRAB # 1 P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)	GRAB # 2 P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)	GRAB # 3 P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)
17-Sep-92	297.2	101.0	3.2	23.4	74.6	3.4	531.2	24.4	3.4
18-Oct-92	154.4 i	106.8	2.6	278.0	5.8	4.8	171.4	116.8 ii	2.6
30-Oct-92	123.4	331.6 iii	4.8	525.6	634.4	5.4	378.2	19.8	5.8
13-Nov-92	284.6	7.4	3.4	125.2	24.2	5.0	19.4	3.4	3.4
30-Nov-92	260.4	122.6	5.8	217.8	134.6	4.4	76.0	361.0 iv	5.6
13-Dec-92	55.6	336.0	4.2	396.0	570.0	5.2	339.0	463.0	6.2
8-Jan-93	153.4	94.6	7.0	85.8	105.6	5.4	16.4	36.4	3.8
21-Jan-93	264.2	29.2	5.8 v	93.2	123.8	9.4	123.6	32.0	8.0
4-Feb-93	365.0	198.4 vi	3.8	303.8	82.6	6.0	66.2	105.8	7.0 vi
19-Feb-93	234.4	200.0	34.4	101.4 vii	236.6	23.8 ix	319.6	100.2	40.0
9-Mar-93	171.6	398.0	9.0	1275.0 x	444.0	15.4	372.0	745.0	6.0
25-Mar-93	439.0	159.6	10.2	450.0	258.6	5.2	659.0 xi	330.0	5.0

DUPLICATES (mg/kg)
(i) 707.0, (ii) 424.0, (iii) 150.4, (iv) 397.0, (v) 5.6, (vi) 131.8, (vii) 7.8, (viii) 357.0, (ix) 6.4, (x) 1177.0, (xi) 468.0
Regulatory Limit: Not Specified

4.5.1.2.5 MANGANESE: DBA LEP

The manganese LEP concentration data for DBA is contained in Table 4.26. The best spatial agreement for manganese can be found in the P3/8" fraction and as a result a SVR of "Excellent" is given to this fraction (Table 4.21). The P4 and P8 fractions are variable and contain frequent high and low values. The largest concentration range was found in the middle P4 fraction [14.2 to 994 mg/kg]. The smallest range in concentration was [5.8 to 51 mg/kg] in the P3/8" fraction, and next was the P8 fraction at [54.8 to

626 mg/kg] (Table 4.21). Both the untransformed and transformed P3/8" data are normally distributed. The untransformed P4 and P8 fractions were not normally distributed, and even the log normally transformed data is slightly skewed. The P3/8" untransformed and transformed UCLM's values [15.2 mg/kg] are the same because they both come from normally distributed data sets representing the same analysis. The P4 and P8 UCLM's are [112.3 mg/kg] and [197.6 mg/kg] respectively (Table 4.21). Manganese is not regulated in the Special Waste Regulations.

Table 4.26 1992-93 DESIFTED BOTTOM ASH, LEP RESULTS FOR MANGANESE

1992-93 DESIFTED BOTTOM ASH LEP: MANGANESE CONCENTRATIONS (mass basis)									
	GRAB # 1			GRAB # 2			GRAB # 3		
SAMPLE DATE	P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)	P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)	P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)
17-Sep-92	9.2	17.0	60.0	7.8	21.0	108.0	26.0	105.4	146.2
18-Oct-92	18.6 i	266.0	544.0	18.6	994.0	146.4	15.6	862.0 ii	624.0
30-Oct-92	34.2	378.0 iii	286.0	51.0	99.6	138.6	34.2	87.8	123.2
13-Nov-92	25.0	65.2	85.0	17.0	70.6	112.6	8.0	220.2	64.2
30-Nov-92	16.4	778.0	163.8	14.8	528.0	161.8	6.6	33.0 iv	54.8
13-Dec-92	10.2	18.8	514.0	12.0	254.0	268.0	18.6	25.2	187.2
8-Jan-93	6.8	14.2	150.4	9.0	500.0	486.0	5.8	161.6	170.0
21-Jan-93	23.0	61.2	81.2 v	12.8	43.8	158.0	17.8	137.6	626.0
4-Feb-93	13.8	29.8 vi	266.0	12.2	272.0	138.8	11.8	21.4	128.6 vi
19-Feb-93	14.4	24.4	210.6	8.0 vii	16.0	80.4 ix	7.6	20.4	129.4
9-Mar-93	7.2	23.2	160.2	13.0 x	478.0	170.0	7.6	22.8	338.0
25-Mar-93	11.0	19.0	101.8	11.4	17.2	64.0	24.0 xi	530.0	592.0

DUPLICATES (mg/kg)
(i) 24.4, (ii) 1462.0, (iii) 149.6, (iv) 29.4, (v) 91.0, (vi) 24.8, (vii) 110.8, (viii) 8.2, (ix) 77.0, (x) 23.0, (xi) 12.6
Regulatory Limit: Not Specified

4.5.1.2.6 NICKEL: DBA LEP

A high leachable nickel concentration of 50 mg/kg occurred on September 17, 1992 for Grab # 2 of the P3/8" fraction (Table 4.27), otherwise, there is "Excellent" spatial agreement between all grabs for each fraction. The most spatially consistent concentrations, like copper and iron, occur in the P8 fraction. The nickel concentration ranges were: P3/8" [1.2 to 50 mg/kg], P4 [4.2 to 32.8 mg/kg], and P8 [13.6 to 50.2 mg/kg] (Tables 4.21). The transformed data set is used for calculating the UCLM values and these are as follows: P3/8" [8.3 mg/kg], P4 [13.2 mg/kg], and P8 [22.1 mg/kg] (Table 4.21). The DBA does not constitute a special waste with respect to nickel because no regulatory limit for nickel has been established.

Table 4.27 1992-93 DESIFTED BOTTOM ASH, LEP RESULTS FOR NICKEL

1992-93 DESIFTED BOTTOM ASH LEP: NICKEL CONCENTRATIONS (mass basis)									
	GRAB # 1			GRAB # 2			GRAB # 3		
SAMPLE DATE	P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)	P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)	P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)
17-Sep-92	7.60	11.20	27.20	50.00	10.80	23.80	7.20	15.40	17.80
18-Oct-92	10.00 i	10.60	24.00	9.40	8.80	19.80	3.60	8.60 ii	19.80
30-Oct-92	8.20	25.00 iii	38.00	10.00	24.40	31.00	14.60	32.80	50.20
13-Nov-92	1.20	8.20	15.60	8.00	18.40	18.60	3.60	6.80	18.40
30-Nov-92	8.20	6.40	17.00	10.20	9.60	13.60	5.20	7.60 iv	14.00
13-Dec-92	15.20	8.80	22.40	9.20	12.00	29.00	8.60	16.00	20.00
8-Jan-93	2.80	17.40	18.60	4.80	4.20	18.40	3.80	15.00	16.60
21-Jan-93	9.00	9.40	25.60 v	10.80	19.20	29.60	10.00	14.80	27.00
4-Feb-93	4.20	12.80 vi	15.00	7.80	12.20	16.00	8.60	6.00	21.00 vii
19-Feb-93	10.20	10.60	17.20	8.40 viii	13.80	22.40 ix	5.20	13.80	18.60
9-Mar-93	7.40	24.00	21.00	2.80 x	13.40	27.80	6.80	11.00	15.60
25-Mar-93	8.80	12.60	13.80	7.60	9.00	19.60	7.20 xi	12.60	18.00

DUPLICATES (mg/kg)
(i) 6.4, (ii) 10.8, (iii) 31.0, (iv) 14.0, (v) 23.4, (vi) 15.4, (vii) 17.2, (viii) 11.8, (ix) 18.2, (x) 7.4 (xi) 6.6
Regulatory Limit: Not Specified

4.5.1.2.7 LEAD: DBA LEP

The P3/8" and P4 leachable lead concentrations of DBA have a high spatially variability and therefore a SVR of "Poor" was assigned to these fractions (Table 4.21). One high lead value occurs on September 17, 1993 for Grab # 2 [716 mg/kg] (Table 4.28). The P4 fraction leachable concentration is variable and there is no spatial consistency for this fraction. The P8 fraction shows excellent spatial agreement between all three grabs. A noticeable "hump" occurs in the lead values for all three fractions in late January and early February. Two non-detect or zero values were found in the P3/8" fraction and a "0.2" mg/kg value was substituted in their place as a minimum value (Table 4.28). The concentration ranges for each of the three fractions were: P3/8" [0.2 to 716 mg/kg], P4 [3.4 to 446 mg/kg], and P8 [4.6 to 284.2 mg/kg] (Table 4.21). The UCLM values for each fraction, based on the log normally transformed data, are: P3/8" [13.4 mg/kg], P4 [58.1 mg/kg], and P8 [22.5 mg/kg] (Table 4.21). The significance of this result is that **large sample volumes of desifted bottom ash are not Special Wastes** under BCMOELP's Special Waste Regulations (1988) because the limit for lead is 100 mg/kg (5.00 mg/l or ppm). The highest average concentration of lead is in the middle P4 fraction. Fifteen of the 108 grabs (14%) analyzed for lead (Table 4.28) failed the LEP, therefore it is important to realize that small volumes of DBA still pose management or utilization concerns. If bottom ash is sifted into different fractions then the frequency or occurrence of LEP failures ,and therefore special wastes, increases. This is especially of concern for the month of February because leachable lead concentrations have consistently been elevated above regulatory limits for this month. This also happened for the 1991 January - February LEP results. The effect of seasons cannot be addressed scientifically because not enough data exists (Gilbert, 1987), however, there appears to be a seasonally high amount of lead in the bottom ash during January and February. The LEP grabs that failed are bolded in Table 4.28 and corresponding failures for cadmium are underlined. Note that there appears to be no correlation between lead and cadmium LEP failures. The initial pH of the LEP may affect lead solubility and if there is a correlation between pH and lead solubility it will be examined and discussed in the "LEP pH EFFECTS" section.

Bagchi and Sopich (1989) showed that lead can be quite mobile, and that EP-tox acid extraction results range from 0.60 to 782.0 mg/kg or 03 to 39.10 mg/l for bottom ash which is much smaller than the ranges observed here. Roethel et al (1991) state that bottom ash occasionally exceeded limits for lead during their LEP tests. They found that for bottom ash, there were significant differences in leachate concentrations, one of the samples was found to produce a leachate that was below detection limits for lead, while the other sample was determined to have lead concentrations ranging between 100 to 200 mg/kg (5 mg/l to 10 mg/l). This result is consistent with the results observed as part of this study.

Table 4.28 1992-93 DESIFTED BOTTOM ASH, LEP RESULTS FOR LEAD

1992-93 DESIFTED BOTTOM ASH LEP: LEAD CONCENTRATIONS (mass basis)

SAMPLE DATE	GRAB # 1 P 3/8" (mg/kg)	GRAB # 1 P No.4 (mg/kg)	GRAB # 1 P No.8 (mg/kg)	GRAB # 2 P 3/8" (mg/kg)	GRAB # 2 P No.4 (mg/kg)	GRAB # 2 P No.8 (mg/kg)	GRAB # 3 P 3/8" (mg/kg)	GRAB # 3 P No.4 (mg/kg)	GRAB # 3 P No.8 (mg/kg)
17-Sep-92	92.4	70.0	<u>31.6</u>	**716.0**	38.6	<u>53.0</u>	19.4	**438.2**	<u>50.4</u>
18-Oct-92	4.4 i	30.6	20.2	92.2	**443.0**	<u>44.4</u>	2.8	68.4 ii	21.4
30-Oct-92	3.8	32.0 iii	16.8	7.8	**446.8**	13.2	66.0	19.0	22.8
13-Nov-92	3.8	19.0	15.8	63.2	56.6	15.0	5.8	**161.2**	18.0
30-Nov-92	0.2	6.8	5.0	2.2	4.2	4.6	1.0	45.0 iv	6.0
13-Dec-92	1.0	**385.0**	21.4	5.8	11.0	27.6	7.0	**304.8**	<u>20.2</u>
8-Jan-93	5.2	9.2	8.8	20.0	3.4	8.4	1.4	27.4	9.4
21-Jan-93	3.0	92.6	15.4 v	**275.6**	59.4	24.8	4.0	**336.0**	22.6
4-Feb-93	4.6	30.0 vi	**<u>257.8</u>**	**324.0**	**208.0**	**284.2**	**173.4**	**308.0**	**258.4** vi
19-Feb-93	3.0	48.0	<u>22.8</u>	64.2 vii	70.0	10.4 ix	7.8	8.0	10.0
9-Mar-93	38.4	5.4	10.0	0.6 x	66.6	6.6	8.0	8.0	5.6
25-Mar-93	0.2	22.0	7.0	9.0	5.6	5.4	1.4 xi	12.0	6.0

DUPLICATES (mg/kg)
(i) 4.6, (ii) 3.6, (iii) 260.2, (iv) 2.0, (v) 14.8, (vi) 279.0, (vii) 329.8, (viii) 143.0, (ix) 11.4, (x) 0.8, (xi) 2.8
Regulatory Limit: 5.0 mg/l or 100 mg/kg
Bold values represent LEP failures for Pb
Underlined values represent samples that failed the LEP for Cd

4.5.1.2.8 ZINC: DBA LEP

One high leachable zinc concentration, [1,448 mg/kg], occurs in the P3/8" fraction on September 17, 1992 for Grab # 1 (Table 4.29). Three large peaks, [1,576 mg/kg] on September 17, 1992, Grab #3, [2,146 mg/kg] on November 30, Grab #2, and [4,290 mg/kg] on March 25, 1993 Grab # 3, occurred in the P4 fraction. As before, there is "Excellent" spatial agreement among the grabs taken for the P8 fraction (Table 4.21). Zinc concentration ranges can be found in Table 4.21 and are: P3/8" [40.4 to 1,448 mg/kg], P4 [149.8 to 2,490 mg/kg], and P8 [338 to 1,656 mg/kg]. The transformed data is normally distributed and the UCLM values for each fraction are: P3/8" [174.4 mg/kg], P4 [622.6 mg/kg], and P8 [969.6 mg/kg]. Zinc concentrations increased with decreasing particle size (Table 4.21). DBA is not a special waste with respect to zinc because the UCLM values for all three fractions are below the regulatory limit of 10,000 mg/kg (500 mg/l).

Table 4.29 1992-93 DESIFTED BOTTOM ASH, LEP RESULTS FOR ZINC

1992-93 DESIFTED BOTTOM ASH LEP: ZINC CONCENTRATIONS (mass basis)									
SAMPLE DATE	GRAB # 1 P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)	GRAB # 2 P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)	GRAB # 3 P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)
17-Sep-92	1448.0	472.6	888.0	104.2	417.8	948.0	157.0	1576.0	1084.0
18-Oct-92	53.6 i	740.0	828.0	121.0	792.0	1492.0	62.8	197.6 ii	1104.0
30-Oct-92	128.8	904.0 iii	1132.0	85.4	812.0	772.0	183.0	470.6	1112.0
13-Nov-92	82.8	692.0	540.0	471.0	560.0	454.6	227.6	220.6	488.8
30-Nov-92	244.8	508.0	582.0	258.8	2146.0	452.0	79.2	612.0 iv	338.0
13-Dec-92	580.0	762.0	926.0	40.8	254.2	1214.0	182.8	326.0	1100.0
8-Jan-93	458.0	1196.0	1620.0	54.8	263.6	1400.0	53.6	476.0	846.0
21-Jan-93	642.0	946.0	556.0 v	201.8	598.0	822.0	132.6	724.0	894.0
4-Feb-93	71.0	251.0 vi	1522.0	64.0	758.0	1448.0	162.0	1146.0	996.0 vi
19-Feb-93	299.4	558.0	1656.0	64.6 vii	216.4	1146.0 ix	40.4	361.6	1142.0
9-Mar-93	46.0	237.4	1088.0	157.0 x	1064.0	1124.0	301.0	149.8	1294.0
25-Mar-93	145.6	410.0	444.0	610.0	157.6	362.0	40.8 xi	2490.0	714.0

DUPLICATES (mg/kg)
(i) 98.8, (ii) 962.0, (iii) 1314.0, (iv) 586.0, (v) 582.0, (vi) 1290.0, (vii) 1034.0, (viii) 102.8, (ix) 952.0, (x) 33.6,(xi) 788.0
Regulatory Limit: 500 mg/l or 10,000 mg/kg

4.5.1.3 LEP pH EFFECTS

One of the major disadvantages of using the LEP is that it is not representative of monofill field conditions. It does not represent what actually occurs in field situations because of solubility constraints. Final metal concentrations in the extraction leachates are more a function of final pH's than of total metal concentration.

Roethel et al (1991) observed that when the leachate concentration was plotted against the final pH, cadmium solubility was observed only when the leachate exhibited acidic characteristics. "When a final pH > 6 was produced, cadmium concentrations were extremely low regardless of the initial concentration of metal, the particle size, or ash type." They also found that lead exhibited minimum solubility when the pH range was between 6 to 9. "The amphoteric nature of lead can be clearly observed as its solubility increases under both acetic and alkaline conditions. As noted for the cadmium data, lead solubility appears to be principally controlled by pH." Van Der Sloot et al (1989) state that the safe pH range under oxidizing conditions for minimum leaching of metals is between 8 to 10. If the pH is above 10 then the potential for lead, zinc, and copper to leach is increased. Also, for pH values below 7 a sharp increase in leachability is observed. Under reducing conditions heavy metals may be effectively retained as sulfides. Van Der Sloot et al (1989) conclude that the relationship between leachability and pH is indicative of the systematic leaching of incinerator residues.

Table 4.30 lists the pH values recorded after the first fifteen minutes of the LEP and the results show that the DBA is alkaline in nature. This means that if lead is present in the sample it should solubilize readily during the first fifteen minutes of the LEP because lead is amphoteric. The bolded pH's correspond to the LEP failures for lead (Table 4.28) and the italicized pH's correspond to LEP failures for Cd. A LEP failure occurred for an initial pH as low as 8.93. The pH's for the failures listed are within the range of the pH values for all of the LEP's performed. Therefore, failures are likely a function of whether or not lead is present in the sample to begin with (i.e. a LEP lead failure cannot occur if there is no lead). The pH values recorded for October 30, 1992 appear to be alkaline when compared to other values in Table 4.30. It could be that a higher than normal application of lime occurred on this day.

Table 4.31 lists the final pH values obtained from the 1992-93 LEP after 24 hours of extraction. The majority of pH's were near a pH of 5 for the P3/8" and P4 fractions. The finer P8 fractions were typically slightly greater than a pH of 6.0.

The fact that the alkaline nature of the bottom ash is predominant in the first 15 minutes of the LEP, because only 800 ml of distilled water is used, can affect metal chemistry and solubility. For example, lead is amphoteric and it is possible that the readily leachable lead can solubilize within the first 15 minutes of the LEP because of the alkaline pH's present. This also would have been true if an acidic and low pH environment predominated. Acetic acid is also known to have an affinity for lead and easily dissolves lead.

Table 4.30 INITIAL (15 minute) pH VALUES BEFORE ACID ADDITION

	GRAB # 1			GRAB # 2			GRAB # 3		
DATE	**P3/8"**	**P4**	**P8**	**P3/8"**	**P4**	**P8**	**P3/8"**	**P4**	**P8**
SEPT.17,92	9.67	10.21	*10.82*	**10.45**	10.49	*11.05*	10.18	**10.67**	*10.74*
OCT.18,92	10.01	10.45	10.80	9.98	**10.45**	*10.72*	9.70	10.46	10.61
OCT.30, 92	8.87	8.75	8.65	9.01	**8.93**	8.52	8.71	8.76	8.42
NOV.13, 92	9.41	10.16	10.74	10.28	10.12	10.86	9.82	**10.33**	10.71
NOV.30, 92	9.60	10.22	10.90	10.08	10.22	11.03	9.66	10.32	*10.72*
DEC.13, 92	9.83	**10.23**	10.47	10.17	10.03	10.42	9.79	**10.32**	10.76
JAN.8, 93	9.66	9.92	10.18	9.51	9.72	10.15	9.21	9.81	9.95
JAN.21, 93	9.84	10.21	10.45	**10.15**	10.26	10.57	9.47	**9.51**	8.77
FEB.4, 93	9.98	10.01	***10.46***	**9.78**	**10.32**	**10.42**	**9.86**	**10.24**	**10.43**
FEB.19, 93	9.68	10.33	*10.95*	10.25	10.13	10.85	10.07	10.24	10.93
MAR.9, 93	10.04	10.41	10.73	9.77	10.28	10.43	9.98	10.18	10.25
MAR.25, 93	10.01	10.63	11.22	10.20	10.40	11.15	10.16	10.49	11.20

NOTE: Bold values represent LEP failures for Pb
Italicized values represent LEP failures for Cd

Table 4.31 FINAL pH VALUES AFTER LEP

	GRAB # 1			GRAB # 2			GRAB # 3		
DATE	**P3/8"**	**P4**	**P8**	**P3/8"**	**P4**	**P8**	**P3/8"**	**P4**	**P8**
SEPT.17,92	5.01	5.03	6.24	5.29	5.10	6.19	5.15	5.12	6.32
OCT.18,92	5.13	5.06	6.28	5.06	5.14	6.17	5.15	5.15	6.22
OCT.30, 92	5.02	5.02	5.73	5.00	5.02	5.90	5.07	5.02	5.79
NOV.13, 92	5.16	5.13	6.55	5.39	5.20	6.49	5.14	5.21	6.59
NOV.30,92	5.09	5.11	6.87	5.16	5.04	6.71	5.15	5.05	6.70
DEC.13, 92	5.21	5.10	6.35	5.06	5.07	6.30	5.01	5.09	6.47
JAN.8, 93	5.18	5.27	6.15	5.11	5.16	6.11	5.06	5.02	5.98
JAN.21, 93	5.09	5.15	6.24	5.18	5.02	6.10	5.02	5.21	6.21
FEB.4, 93	5.16	5.10	5.73	5.15	5.08	5.60	5.02	5.03	5.61
FEB.19, 93	5.05	5.09	6.18	5.13	5.05	6.32	5.09	5.03	6.33
MAR.9, 93	5.08	5.07	6.32	5.19	5.03	6.28	5.03	5.04	6.34
MAR.25, 93	5.29	5.22	6.67	5.17	5.19	6.67	5.19	5.08	6.61

4.5.2 AQUA REGIA DIGESTION (ARD) OF LEP SOLIDS

4.5.2.1 ARD OF 1992-93 RBA LEP SOLIDS

A summary of the aqua regia digestion (ARD) of the LEP solids concentration data is contained in Table 4.32. As expected, the acid digested metal concentration data is much higher than the LEP concentration data. Table 4.32, like Tables 4.20 and 4.21, summarizes the minimum, maximum, average, and UCLM concentrations. This table also contains information about the transformation used to normalize the data set and the Spatial Variability Rating (SVR). Duplicates are provided and are denoted by roman numerals (i) to (xi). Duplicate concentrations are listed and discussed in the APPENDIX. The ARD procedure is limited in its ability to attack the silica matrix of the ash and is not as aggressive as some other acid digestions used for total metals analysis.

Table 4.32 METALS ANALYSIS SUMMARY: 1992-93 ARD OF LEP SOLIDS - DBA

METALS ANALYSIS SUMMARY: 1992-93 ARD OF LEP SOLIDS - DESIFTED BOTTOM ASH									
	ASH	CONCENTRATIONS (mg/kg)					TRANSFORMATION	SPATIAL VARIABILITY	
METAL	FRACTION	MIN	MAX	RANGE	AVG	UCLM	USED	RATING	HIGH/LOW
Cd - CADMIUM	P 3/8"	0.5	4.8	4.3	2.0	2.0	LOGNORMAL	EXCELLENT	0
	P No. 4	1.6	25.1	23.6	4.6	4.0	LOGNORMAL	GOOD	3
	P No. 8	5.0	24.6	19.7	10.7	10.8	LOGNORMAL	EXCELLENT	0
Cr - CHROMIUM	P 3/8"	7.3	3,400.0	3,392.8	333.9	127.3	LOGNORMAL	POOR	8
	P No. 4	39.3	1,034.7	995.4	202.6	168.2	LOGNORMAL	POOR	6
	P No. 8	49.5	217.5	168.0	129.8	139.4	NONE	EXCELLENT	0
Cu - COPPER	P 3/8"	223.4	85,173.0	84,949.6	12,156.0	6,666.0	LOGNORMAL	POOR	9
	P No. 4	3,178.4	84,560.6	81,382.2	17,222.7	14,303.0	LOGNORMAL	POOR	9
	P No. 8	1,531.9	6,215.9	4,683.9	3,511.9	3,768.0	NONE	EXCELLENT	0
Fe - IRON	P 3/8"	6,045.1	101,745.1	95,700.0	59,602.6	64,736.0	NONE	EXCELLENT	1
	P No. 4	17,750.5	103,122.6	85,372.0	64,616.0	69,194.0	NONE	EXCELLENT	1
	P No. 8	20,934.4	94,508.1	73,573.7	60,662.0	64,714.0	NONE	EXCELLENT	1
Mn - MANGANESE	P 3/8"	165.6	1,101.8	936.2	592.3	633.0	NONE	EXCELLENT	0
	P No. 4	391.2	1,835.8	1,444.6	793.2	807.0	LOGNORMAL	EXCELLENT	1
	P No. 8	591.5	2,867.9	2,276.4	1,195.0	1,214.0	LOGNORMAL	EXCELLENT	0
Ni - NICKEL	P 3/8"	29.5	2,077.1	2,047.6	275.1	201.0	LOGNORMAL	POOR	6
	P No. 4	71.5	825.2	753.7	273.5	259.0	LOGNORMAL	EXCELLENT	1
	P No. 8	94.4	392.4	298.0	203.7	221.0	NONE	EXCELLENT	0
Pb - LEAD	P 3/8"	84.2	6,033.3	5,949.1	1,347.2	842.0	LOGNORMAL	POOR	9
	P No. 4	285.7	9,160.8	8,875.1	3,392.7	2,711.0	LOGNORMAL	POOR	10
	P No. 8	698.1	5,272.7	4,574.6	1,988.2	1,880.0	LOGNORMAL	EXCELLENT	0
Zn - ZINC	P 3/8"	175.2	45,232.1	45,056.9	5,732.4	2,173.0	LOGNORMAL	POOR	9
	P No. 4	725.7	13,676.8	12,951.1	3,507.5	3,204.0	LOGNORMAL	FAIR	4
	P No. 8	1,725.4	5,275.5	3,550.1	2,999.5	3,070.0	LOGNORMAL	EXCELLENT	0

NOTES: (1) AT OR BELOW DETECTION LIMIT
(2) MIN, MAX, RANGE, AND AVG VALUES LISTED ARE FOR UNTRANSFORMED RAW DATA; UCLM VALUES LISTED ARE BASED ON TRANSFORMED DATA SETS WHICH HAVE BEEN TRANSFORMED BACK TO REAL NUMBER SYSTEM

4.5.2.1.1 CADMIUM: ARD DBA LEP SOLIDS

All three fractions show little spatial variation and several high values occur for the P4 fraction. Peaks occur on January 21 and February 4 for the P4 fraction, Grab # 3. A peak value also occurs on March 25 for the P4 fraction, Grab # 2 (Table 4.33). Although these peaks represent different grabs, they are very similar in magnitude. Digestible concentration ranges for the three fractions of ash were: P3/8" [0.52 to 4.82 mg/kg], P4 [1.58 to 25.13 mg/kg], and P8 [4.95 to 24.61 mg/kg] (Tables 4.32 and 4.33). The Z-SCORE plots of the ranked data show that only the transformed data is normally distributed. The UCLM values calculated are P3/8" [2.0 mg/kg], P4 [4.0 mg/kg], and P8 [10.8 mg/kg] (Table 4.32). The cadmium concentrations for the ARD of the LEP solids increased with decreasing particle size.

Table 4.33 1992-93 DBA, ARD OF LEP SOLIDS RESULTS FOR CADMIUM

1992-93 DESIFTED BOTTOM ASH ARD OF LEP SOLIDS: CADMIUM CONCENTRATIONS (mass basis)									
SAMPLE DATE	GRAB # 1 P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)	GRAB # 2 P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)	GRAB # 3 P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)
17-Sep-92	2.14	4.36	14.84	3.17	4.32	13.07	3.04	7.07	22.79
18-Oct-92	1.94 i	2.80	8.09	2.53	4.08	12.75	2.01	3.92 ii	7.37
30-Oct-92	4.82	4.82 iii	12.79	3.37	6.36	14.06	2.90	8.12	13.07
13-Nov-92	1.63	2.87	4.95	2.43	2.75	9.83	1.61	1.58	8.35
30-Nov-92	1.41	2.11	6.67	3.34	2.02	5.40	1.21	2.10 iv	7.20
13-Dec-92	1.73	2.05	7.71	0.91	2.15	6.70	1.01	2.05	16.27
8-Jan-93	1.41	3.07	8.05	2.61	3.62	4.96	1.24	2.44	8.95
21-Jan-93	0.52	2.36	11.23 v	1.77	1.92	9.48	1.61	13.86	9.71
4-Feb-93	1.81	4.81 vi	21.45	1.51	3.81	10.33	1.71	16.75	9.59 vi
19-Feb-93	2.33	6.59	24.61	1.82 vii	2.65	9.55 ix	2.31	2.44	10.13
9-Mar-93	1.71	1.83	8.50	1.80 x	2.13	6.68	1.41	2.44	9.62
25-Mar-93	1.40	2.27	6.93	1.41	25.13	17.77	1.22 xi	1.86	6.57

DUPLICATES (mg/kg)
(i) 2.33, (ii) 2.98, (iii) 5.50, (iv) 2.86, (v) 15.29, (vi) 3.71, (vii) 9.55, (viii) 3.44, (ix) 8.56, (x) 1.91, (xi) 1.72

4.5.2.1.2 CHROMIUM: ARD DBA LEP SOLIDS

A substantial amount of chromium seems to be present in the bottom ash that is not readily leachable with the LEP. The ARD of the LEP solids results show that there are large amounts of chromium present in the DBA. For the P3/8" fraction the following peaks exist: for Grab # 2: [1,155 mg/kg] on October 18, [1,643 mg/kg] on October 30, and [2,695 mg/kg] on February 4 and for Grab # 3 [3,400 mg/kg] on January 8. Several peaks were recorded for the P4 fraction and are as follows: Grab # 2 [1,034 mg/kg] on September 17, [609 mg/kg] on October 18, [579 mg/kg] on March 9, and [478 mg/kg] on March 25, and for Grab # 3 [656 mg/kg] on September 17 (Table 4.34). The P8 fraction shows very little spatial variability. The transformed P3/8" and P4 and untransformed P8 data is normally distributed. The UCLM chromium concentrations are: P3/8" [127 mg/kg], P4 [168 mg/kg], and P8 [139 mg/kg] (Table 4.32). The highest chromium concentration is in the middle P4 fraction and the increasing concentration with decreasing particle size relationship does not apply for chromium.

Table 4.34 1992-93 DBA, ARD OF LEP SOLIDS RESULTS FOR CHROMIUM

1992-93 DESIFTED BOTTOM ASH ARD OF LEP SOLIDS: CHROMIUM CONCENTRATIONS (mass basis)									
	GRAB # 1			GRAB # 2			GRAB # 3		
SAMPLE DATE	P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)	P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)	P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)
17-Sep-92	41.8	1034.7	105.9	62.4	89.5	112.0	43.6	656.6	148.0
18-Oct-92	86.8 i	609.3	151.5	1155.2	164.2	109.9	251.4	274.3 ii	168.2
30-Oct-92	61.5	97.4 iii	122.2	1643.0	109.6	102.6	44.6	96.5	94.0
13-Nov-92	76.5	39.3	49.5	70.6	69.9	152.2	39.3	218.8	109.3
30-Nov-92	399.0	150.7	214.2	452.8	94.5	94.0	46.4	218.5 iv	196.3
13-Dec-92	13.2	64.7	123.1	44.7	123.1	85.5	12.1	253.0	71.1
8-Jan-93	37.1	102.8	90.9	71.3	95.2	75.0	3400.0	98.7	83.8
21-Jan-93	7.2	235.0	73.7 v	119.6	52.4	146.3	36.1	65.6	120.5
4-Feb-93	68.4	169.9 vi	140.1	2695.2	94.6	165.1	56.3	68.4	113.0 vii
19-Feb-93	54.7	304.3	163.7	319.8 viii	90.9	164.8 ix	115.6	47.9	217.5
9-Mar-93	139.6	574.9	111.8	48.0 x	140.7	94.5	165.8	151.7	124.1
25-Mar-93	69.2	478.5	164.1	29.1	98.4	215.8	40.8 xi	59.8	199.3

DUPLICATES (mg/kg)
(i) 118.0, (ii) 190.0, (iii) 240.0, (iv) 742.0, (v) 153.0, (vi) 324.0, (vii) 148.0, (viii) 502.0, (ix) 155.0, (x) 70.0 (xi) 23.0

4.5.2.1.3 COPPER: ARD DBA LEP SOLIDS

High copper concentrations, in the range of 80,000 mg/kg, occur on March 25 for the P3/8" fraction of Grab # 1 and on November 30 and December 13 for the P4 fraction of Grab # 3 (Table 4.35). The untransformed P8 and the transformed P3/8" and P4 data sets are normally distributed. The UCLM values are as follows: P3/8" [6,666 mg/kg], P4 [14,030 mg/kg], and P8 [3,768 mg/kg] (Table 4.32). The

P8 fraction exhibits very little spatial variation and was given a SVR of "Excellent" (Table 4.32). The highest copper concentration is in the middle P4 fraction. This may be a result of copper wire and/or packing staples being collected within this fraction. Packing staples and wire were visible in samples from time to time.

Table 4.35 1992-93 DBA, ARD OF LEP SOLIDS RESULTS FOR COPPER

1992-93 DESIFTED BOTTOM ASH ARD OF LEP SOLIDS: COPPER CONCENTRATIONS (mass basis)									
	GRAB # 1			GRAB # 2			GRAB # 3		
SAMPLE DATE	P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)	P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)	P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)
17-Sep-92	8198	12175	2440	6053	3178	1913	18143	14490	2162
18-Oct-92	3300 i	12952	5196	2432	19522	1532	2635	3547 ii	2765
30-Oct-92	1825	20748 iii	2615	643	15865	2962	2799	7843	2155
13-Nov-92	14425	8694	2667	2868	8159	4694	35206	7288	4995
30-Nov-92	534	19980	4308	12918	6554	5169	38978	84561 iv	5447
13-Dec-92	39345	16613	4279	223	11265	3744	3108	78886	3062
8-Jan-93	954	4727	3509	603	5601	1961	3905	4823	2812
21-Jan-93	5600	3182	2937 v	5553	43486	2270	12517	24029	4620
4-Feb-93	603	3275 vi	4357	1514	12612	3459	7486	22006	4248 vii
19-Feb-93	47306	6807	4585	1548 viii	4769	3581 ix	1256	24757	6216
9-Mar-93	12364	33158	3039	24997 x	8412	1878	2221	6333	3142
25-Mar-93	85173	8466	4726	11425	11865	3289	18955 xi	39387	3694

DUPLICATES (mg/kg)
(i) 2286, (ii)12696 , (iii) 3109, (iv) 9574, (v) 2858, (vi) 5868, (vii) 3320, (viii) 739, (ix) 2567, (x) 11482 (xi) 29591

4.5.2.1.4 IRON: ARD DBA LEP SOLIDS

All three of the fractions seem to have similar digestible iron concentration ranges and show "Excellent" spatial agreement (Table 4.32). Concentration ranges for the P3/8", P4, and P8 fractions are: [6,045 to 101,745 mg/kg], [17,750 to 103,122 mg/kg], and [20,934 to 94,508 mg/kg] respectively (Tables 4.32 and 4.36). For the first time in the statistical analysis of the metal concentrations all of the untransformed concentration data is normally distributed and therefore the UCLM calculations are based on this data. The iron UCLM values are: P3/8" [64,736 mg/kg], P4 [69,194 mg/kg], and P8 [64,714 mg/kg] (Table 4.32). No inference can be made here as to whether or not concentration increases with decreasing particle size, although the iron concentration was slightly higher in the middle P4 fraction.

Table 4.36 1992-93 DBA, ARD OF LEP SOLIDS RESULTS FOR IRON

1992-93 DESIFTED BOTTOM ASH ARD OF LEP SOLIDS: IRON CONCENTRATIONS (mass basis)									
SAMPLE DATE	GRAB # 1 P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)	GRAB # 2 P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)	GRAB # 3 P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)
17-Sep-92	50789	77663	48250	59373	59664	48881	55293	76809	59617
18-Oct-92	62171 i	82674	83500	51305	84196	40064	74878	103123 ii	71239
30-Oct-92	55421	63175 iii	70448	71821	89972	51502	79600	64588	39100
13-Nov-92	32643	23063	20934	93357	65039	78649	51438	37682	86942
30-Nov-92	68580	54554	48812	57191	17751	29206	36214	55547 iv	51833
13-Dec-92	13572	66667	69394	37937	66532	49704	13645	67261	27772
8-Jan-93	89597	39154	60751	80703	41658	52089	40017	43226	63912
21-Jan-93	6045	52808	24819 v	44704	38782	59212	32251	52374	60556
4-Feb-93	87723	78320 vi	74319	66502	85682	94508	49395	60534	60342 vii
19-Feb-93	65588	100385	68745	94720 vii	77879	90014 ix	81955	50888	81563
9-Mar-93	87552	78976	86363	101745 x	93434	60053	75861	97740	75544
25-Mar-93	65275	66987	69038	59397	66823	61552	51437 xi	44565	64605

DUPLICATES (mg/kg)
(i) 113903, (ii) 125833, (iii) 96999, (iv) 72640, (v) 69671, (vi) 101143, (vii) 69762, (viii) 61506, (ix) 73145, (x) 101754 (xi) 51437

4.5.2.1.5 MANGANESE: ARD DBA LEP SOLIDS

A high digestible manganese concentration, [1,102 mg/kg] occurred on March 25 for the P4 fraction of Grab # 3 (Table 4.37). All of the grabs were very close spatially and a SVR of "Excellent" was given (Table 4.32). The P3/8" untransformed data is normally distributed and its UCLM value is [633 mg/kg]. The P4 and P8 transformed data is normally distributed and the UCLM's are: [807 mg/kg] and [1,214 mg/kg] respectively (Table 4.32). The increasing concentration with decreasing particle size relationship is applicable for manganese. The digestable concentration ranges for the three fractions of ash are: P3/8" [165.6 to 1,101.8 mg/kg], P4 [391.2 to 1,835.8 mg/kg], and P8 [591.5 to 2,867.9 mg/kg] (Tables 4.37 and 4.32).

Table 4.37 1992-93 DBA, ARD OF LEP SOLIDS RESULTS FOR MANGANESE

1992-93 DESIFTED BOTTOM ASH ARD OF LEP SOLIDS: MANGANESE CONCENTRATIONS (mass basis)									
	GRAB # 1			GRAB # 2			GRAB # 3		
SAMPLE DATE	P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)	P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)	P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)
17-Sep-92	509	661	591	505	547	749	710	1008	1159
18-Oct-92	562 i	746	1367	808	1412	1013	684	921 ii	1659
30-Oct-92	564	963 iii	1519	745	805	968	723	878	722
13-Nov-92	663	468	820	740	714	1615	466	930	1033
30-Nov-92	957	1201	2868	556	818	1492	525	820 iv	976
13-Dec-92	823	542	1426	487	800	1129	303	522	735
8-Jan-93	462	499	1323	614	799	1696	433	1119	872
21-Jan-93	166	560	828 v	321	391	930	472	978	1602
4-Feb-93	774	757 vi	1023	515	916	1415	372	735	879 vi
19-Feb-93	405	680	1149	789 vii	745	1103 ix	479	570	1025
9-Mar-93	681	600	1002	580 x	665	864	553	723	1391
25-Mar-93	612	647	982	663	579	923	1102 xi	1836	2169

DUPLICATES (mg/kg)
(i) 931, (ii) 1439, (iii) 1734, (iv) 753, (v) 1400, (vi) 877, (vii) 853, (viii) 527, (ix) 901, (x) 975 (xi) 465

4.5.2.1.6 NICKEL: ARD DBA LEP SOLIDS

There appears to be some spatial variation within the ARD of the LEP solids nickel concentration data for the P3/8" fraction. The P4 and P8 fractions show essentially no spatial variation between grabs, which can be attributed to homogeneous samples. Two high values for the P3/8" fraction are January 8 Grab # 3 [2,077 mg/kg] and February 4 Grab # 2 [1,160 mg/kg] (Table 4.38). The transformed data sets were used to calculate the UCLM values for the P3/8" and P4 fractions while the untransformed data was used to calculate the UCLM value for the P8 fraction. These UCLM values can be found in Table 4.32 and are: P3/8" [201 mg/kg], P4 [259 mg/kg], and P8 [221 mg/kg]. The nickel concentration did not increase with decreasing particle size. In fact, the nickel concentrations in the LEP solids are almost equal in concentration between fractions.

Table 4.38 1992-93 DBA, ARD OF LEP SOLIDS RESULTS FOR NICKEL

1992-93 DESIFTED BOTTOM ASH ARD OF LEP SOLIDS: NICKEL CONCENTRATIONS (mass basis)									
	GRAB # 1			GRAB # 2			GRAB # 3		
SAMPLE DATE	P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)	P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)	P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)
17-Sep-92	186.7	409.4	230.1	535.8	175.0	225.9	110.6	546.8	294.6
18-Oct-92	127.9 i	482.8	192.5	618.1	139.6	147.1	182.2	249.5 ii	192.9
30-Oct-92	137.9	216.0 iii	320.0	938.8	321.8	337.5	222.9	765.7	392.4
13-Nov-92	119.4	79.5	94.4	148.0	232.6	222.4	339.3	172.5	213.2
30-Nov-92	220.3	182.4	188.2	447.5	133.5	141.6	119.9	185.9 iv	200.3
13-Dec-92	157.5	97.6	187.0	93.6	169.2	135.9	46.2	355.4	144.3
8-Jan-93	52.6	225.4	136.3	194.7	85.2	94.5	2077.1	71.5	104.2
21-Jan-93	42.1	825.2	294.4 v	180.1	238.0	371.7	29.5	267.7	257.1
4-Feb-93	64.1	241.0 vi	124.9	1160.9	122.0	132.9	43.0	121.5	128.6 vii
19-Feb-93	136.2	418.7	153.0	211.0 vii	163.3	194.2 ix	151.6	220.0	290.8
9-Mar-93	165.9	507.6	141.3	167.5 x	519.3	142.3	211.4	245.9	216.7
25-Mar-93	62.2	363.6	209.1	76.6	139.0	229.4	125.2 xi	154.4	253.0

DUPLICATES (mg/kg)
(i) 101, (ii) 148, (iii) 287, (iv) 338, (v) 330, (vi) 291, (vii) 132, (viii) 578, (ix) 183, (x) 94 (xi) 72

4.5.2.1.7 LEAD: ARD DBA LEP SOLIDS

The P8 fraction of the ARD of the LEP solids exhibits "Excellent" spatial agreement between grabs (Table 4.32). The P3/8" and P4 grabs are not in agreement spatially and have both been given SVR's of "Poor". Concentration ranges for the three fractions are: P3/8" [84 to 6,033 mg/kg], P4 [285 to 9,160 mg/kg] and P8 [698 to 5,272 mg/kg] (Tables 4.32 and 4.39). Only the transformed data sets can be considered as normally distributed. The UCLM values are: P3/8" [842 mg/kg], P4 [2,711 mg/kg], and P8 [1,880 mg/kg]. The highest lead concentration is in the middle P4 fraction of the ash (Table 4.32).

Table 4.39 1992-93 DBA, ARD OF LEP SOLIDS RESULTS FOR LEAD

1992-93 DESIFTED BOTTOM ASH ARD OF LEP SOLIDS: LEAD CONCENTRATIONS (mass basis)									
	GRAB # 1			GRAB # 2			GRAB # 3		
SAMPLE DATE	P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)	P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)	P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)
17-Sep-92	3013	3312	1338	4114	693	1570	924	4858	2728
18-Oct-92	277 i	744	1971	1941	7530	1389	462	3294 ii	2050
30-Oct-92	251	760 iii	1268	604	5443	1023	1652	677	833
13-Nov-92	430	422	851	3115	2301	2253	1991	5902	2551
30-Nov-92	134	659	1029	85	479	752	272	4824 iv	954
13-Dec-92	175	7839	5273	755	586	2956	325	6946	2108
8-Jan-93	199	1705	913	2326	1596	844	131	947	1024
21-Jan-93	470	3999	1734 v	2325	3570	1961	190	8670	4216
4-Feb-93	264	1681 vi	5185	5972	7157	3196	6033	9161	4532 vi
19-Feb-93	1408	7745	2766	1592 vii	2904	2171 ix	1542	607	3935
9-Mar-93	4363	1303	2216	606 x	4689	963	126	441	837
25-Mar-93	249	5664	753	97	2744	698	84 xi	286	731

DUPLICATES (mg/kg)
(i) 290, (ii) 301, (iii) 6241, (iv) 373, (v) 3178, (vi) 6499, (vii) 4293, (viii) 4592, (ix) 1414, (x) 288, (xi) 488

4.5.2.1.8 ZINC: ARD DBA LEP SOLIDS

Several high digestable zinc concentrations occur with the highest values occurring in the P3/8" fraction (Table 4.40). The smallest concentration range was for the P8 fraction [1,725 to 5,275 mg/kg] (Table 4.32). The P8 fraction received a SVR of "Excellent", while the P4 and P8 fractions were listed as "Poor" (Table 4.32). The transformed data sets are normally distributed and the corresponding UCLM values from Table 4.32 are: P3/8" [2,173 mg/kg], P4 [3,204 mg/kg], and P8 [3,070 mg/kg]. The highest UCLM zinc concentration is for the middle P4 fraction.

Table 4.40 1992-93 DBA, ARD OF LEP SOLIDS RESULTS FOR ZINC

1992-93 DESIFTED BOTTOM ASH ARD OF LEP SOLIDS: ZINC CONCENTRATIONS (mass basis)									
SAMPLE DATE	GRAB # 1 P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)	GRAB # 2 P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)	GRAB # 3 P 3/8" (mg/kg)	P No.4 (mg/kg)	P No.8 (mg/kg)
17-Sep-92	45232	2317	2980	1401	3010	3022	619	3772	5276
18-Oct-92	317 i	4559	2814	537	3369	2760	342	897 ii	3457
30-Oct-92	851	1840 iii	2969	1204	3180	2685	425	2336	3222
13-Nov-92	326	1584	1725	4038	3380	3207	2914	726	3503
30-Nov-92	4312	5195	3699	21570	8201	2655	1816	13677 iv	3147
13-Dec-92	27063	5288	2358	386	4206	2542	505	1639	2567
8-Jan-93	3975	5978	4555	522	1480	2146	175	1984	2100
21-Jan-93	11593	5625	2469 v	2329	1593	2645	311	3280	3193
4-Feb-93	493	1198 vi	2523	384	5473	2830	1399	11120	2443 vi
19-Feb-93	2625	3095	5096	658 vii	2502	2660 ix	683	1813	2915
9-Mar-93	854	1111	3296	1629 x	2551	2224	8722	1609	3177
25-Mar-93	36164	3919	3281	19756	1549	2931	235 xi	1217	2908

DUPLICATES (mg/kg)
(i) 516, (ii) 1758, (iii) 1998, (iv) 5673, (v) 3046, (vi) 10539, (vii) 2251, (viii) 1195, (ix) 2168, (x) 513, (xi) 18898

4.6 GRATE SIFTINGS RESULTS

4.6.1 LEP OF GRATE SIFTINGS IN 1992-93

The same number (36) of grate siftings (GS) samples as DBA samples were collected. Not all the samples collected were sent out for laboratory analysis. Only the first grab (GRAB # 1) from the first nine of twelve samples were sent out for analysis. More accurate results could be obtained if the remaining twenty-seven grate siftings samples are analyzed. Table 4.41 contains a summary of the concentration data for the LEPs performed on the grate siftings. It is not possible to comment on spatial variability of the grate siftings because only one of the three grabs taken was analyzed.

Table 4.41 METALS ANALYSIS SUMMARY: 1992-93 LEP OF GRATE SIFTINGS

METALS ANALYSIS SUMMARY: 1992-93 LEP OF GRATE SIFTINGS							
METAL	ASH FRACTION	CONCENTRATIONS (mg/kg)					TRANSFORMATION USED
		MIN	MAX	RANGE	AVG	UCLM	
Cd - CADMIUM	P 3/8"	0.04	0.12	0.08	0.08	0.10	NONE
	P No. 4	0.08	2.34	2.26	0.40	0.30	LOGNORMAL
	P No. 8	0.08	4.14	4.06	1.66	2.30	NONE
Cr - CHROMIUM	P 3/8"	0.12 (1)	0.12 (1)	0.00	0.12	0.12	NONE
	P No. 4	0.12 (1)	0.12 (1)	0.00	0.12	0.12	NONE
	P No. 8	0.12 (1)	0.18	0.06	0.13	0.13	LOGNORMAL
Cu - COPPER	P 3/8"	3.54	29.60	26.06	14.46	16.20	LOGNORMAL
	P No. 4	0.30	14.12	13.82	7.59	9.90	NONE
	P No. 8	0.16	2.22	2.06	0.46	0.50	LOGNORMAL
Fe - IRON	P 3/8"	36.60	400.00	363.40	178.20	198.00	LOGNORMAL
	P No. 4	100.80	400.00	299.20	191.00	212.00	LOGNORMAL
	P No. 8	16.80	400.00	383.20	132.10	141.00	LOGNORMAL
Mn - MANGANESE	P 3/8"	2.80	25.20	22.40	10.20	11.40	NONE/LOGNORMAL
	P No. 4	11.40	41.00	29.60	26.50	30.20	NONE/LOGNORMAL
	P No. 8	14.90	42.20	27.30	28.70	31.50	NONE/LOGNORMAL
Ni - NICKEL	P 3/8"	1.10	10.00	8.90	3.50	3.70	LOGNORMAL
	P No. 4	2.50	17.80	15.30	6.30	6.90	LOGNORMAL
	P No. 8	2.60	12.00	9.40	6.80	7.80	LOGNORMAL
Pb - LEAD	P 3/8"	0.40	482.00	481.60	171.90	68.40	LOGNORMAL
	P No. 4	2.00	496.00	494.00	186.40	224.80	LOGNORMAL
	P No. 8	0.4 (1)	900.00	899.60	188.10	90.50	LOGNORMAL
Zn - ZINC	P 3/8"	0.02 (1)	1838.00	1837.98	772.90	1193.00	LOGNORMAL
	P No. 4	310.00	1572.00	1262.00	796.00	904.00	LOGNORMAL
	P No. 8	252.00	2320.00	2068.00	860.00	961.00	LOGNORMAL

NOTES: (1) AT OR BELOW DETECTION LIMIT

(2) MIN, MAX, RANGE, AND AVG VALUES LISTED ARE FOR UNTRANSFORMED RAW DATA; UCLM VALUES LISTED ARE BASED ON TRANSFORMED DATA SETS WHICH HAVE BEEN TRANSFORMED BACK TO REAL NUMBER SYSTEM

4.6.1.1 CADMIUM: GS LEP

Cadmium LEP concentration ranges for the grate siftings were as follows P3/8" [0.04 to 0.12 mg/kg], P4 [0.08 to 2.34 mg/kg] and P8 [0.08 to 4.14 mg/kg] (Table 4.41). These values are all very low when compared to the regulatory limit of 10 mg/kg (0.5 mg/l) for cadmium. The untransformed and transformed P3/8" data sets are both normally distributed and the UCLM values are [0.10 mg/kg]. The P4 transformed data set is normally distributed and its UCLM value is [0.30 mg/kg]. The untransformed P8 data set is normally distributed and its UCLM value is [2.3 mg/kg] (Table 4.41). Based on the data collected the grate siftings are not a special waste with respect to cadmium.

4.6.1.2 CHROMIUM: GS LEP

All but one of the chromium values obtained was at or below detection limits. The detection limit for the Induced Coupled Plasma (ICP) performed by Quanta Trace Labs was 0.06 mg/l which is equivalent to the 0.12 mg/kg values reported here. Intuitively, if all but one of the values are 0.12 mg/kg then the UCLM values should also be 0.12 mg/kg. Only the P8 fraction has one value above the "below detection limit" values reported, [0.18 mg/kg]. The UCLM value for the P8 fraction is [0.13 mg/kg] (Table 4.41). Since the regulatory limit for chromium is 100 mg/kg (5.00 mg/l) the grate siftings are not a special waste with respect to chromium.

4.6.1.3 COPPER: GS LEP

LEP concentration ranges for copper are provided in Table 4.41 and were: [3.54 to 29.5 mg/kg] for the P3/8" fraction, [0.30 to 14.12 mg/kg] for the P4 fraction, and [0.16 to 2.22 mg/kg] for the P8 fraction. The P4 untransformed data is normally distributed and the P3/8" and P8 transformed data is normally distributed. The UCLM values are: P3/8" [16.2 mg/kg], P4 [9.9 mg/kg], and P8 [0.5 mg/kg] (Table 4.41). These values are well below the special waste regulatory limit of 2,000 mg/kg (100 mg/l) and therefore the grate siftings are not a special waste when considering copper as a metal of concern. Copper concentrations increased with increasing particle size.

4.6.1.4 IRON: GS LEP

Iron concentrations in the grate siftings fluctuated the most in the P3/8" and P8 fractions (Table 4.41). The grate siftings LEP concentration ranges, listed in Table 4.41, were: P3/8" [36.6 to 400 mg/kg], P4 [100.8 to 400 mg/kg], and P8 [16.8 to 400 mg/kg]. The transformed data sets were log normally distributed and the corresponding UCLM values were P3/8" [198 mg/kg], P4 [212 mg/kg], and P8 [141 mg/kg] (Table 4.41). None of the grate siftings fractions can be deemed a special waste when examining iron because there is no regulatory limit set for iron. There appears to be no correlation between particle size and concentration for iron in the GS.

4.6.1.5 MANGANESE: GS LEP

The grate siftings LEP manganese concentration ranges for each fraction are: P3/8" [2.8 to 25.2 mg/kg], P4 [11.4 to 41 mg/kg], and P8 [14.92 to 42.2 mg/kg] (Table 4.41). The untransformed and transformed data sets are normally distributed. The UCLM values calculated are: P3/8" [11.4 mg/kg], P4 [30.2 mg/kg], and P8 [31.5 mg/kg] (Table 4.41). The average concentration in the P4 and P8 fractions is essentially the same. The grate siftings are not a special waste with respect to manganese because manganese is not covered by the Special Waste Regulations. The P3/8" fraction had the lowest manganese LEP concentrations, and the P4 and P8 fractions UCLM values are essentially equal (30.2 and 31.5 mg/kg), therefore, there does not appear to be a relationship between particle size and concentration.

4.6.1.6 NICKEL: GS LEP

Nickel LEP concentrations did not vary significantly. The leachable nickel concentration ranges in the GS were: P3/8" [1.1 to 10 mg/kg], P4 [2.54 to 17.8 mg/kg], and P8 [2.6 to 12.04 mg/kg] (Table 4.41). The log normal transformed data is normally distributed and the UCLM values are: P3/8" [3.7 mg/kg], P4 [6.9

mg/kg], and P8 [7.8 mg/kg] (Table 4.41). Nickel is not governed by the Special Waste Regulations therefore nickel levels are not of regulatory concern.

4.6.1.7 LEAD: GS LEP

There is a high degree of variability in the lead concentration data obtained for the grate siftings, due in part to the small number of samples examined and the fact that some non-detect or zero values were reported. The non-detect or zero values were replaced by a "0.40" mg/kg value, but, it may have been more appropriate to replace these values with the lowest recorded value, 1.20 mg/kg. The concentration ranges, or minimum to maximum values, were: P3/8" [0.4 to 482 mg/kg], P4 [2 to 496 mg/kg], and P8 [0.4 to 900 mg/kg] (Table 4.41). The untransformed and transformed data sets were not normally distributed. There appears to be too much variability in the nine samples taken to obtain a normal distribution, however, the transformed data set was used as a basis for the UCLM concentrations. The UCLM concentrations for lead in the grate siftings were: [68.4 mg/kg], [224.8 mg/kg] and [90.5 mg/kg] for the P3/8", P4, and P8 fractions respectively (Table 4.41). The regulatory limit for lead is 100 mg/kg (5.00 mg/l), but, based on the information presented here it is not certain if the P3/8" and P8 fractions of the grate siftings are not special wastes (more samples are required to obtain a normally distributed data set). The P4 fraction of the grate siftings should be considered as a special waste for the following reasons: 1) seven of the nine samples taken were well above the 100 mg/kg limit, 2) lead is the primary heavy metal of concern, and 3) only nine samples were taken, therefore these results should be considered cautiously. The range in concentration also brings into question the validity of the results, although large variations for a metal like lead are not uncommon. In order to be more confident with the UCLM values for leachable lead concentrations in the grate siftings more samples should be analyzed.

4.6.1.8 ZINC: GS LEP

A large variation in leachable zinc concentrations was observed and Table 4.41 contains the respective ranges for the P3/8", P4, and P8 fractions. These ranges are: [0.02 to 1,838 mg/kg], [310 to 1,572 mg/kg], and [252 to 2,320 mg/kg] for the P3/8", P4, and P8 fractions of grate siftings respectively. For the P3/8" fraction a zero value was changed to 0.02 mg/kg in order to perform log normal calculations. The transformed data is normally distributed. The zero value in the P3/8" fraction can be considered as an outlier, but its value was included in the UCLM calculations. The P3/8", P4, and P8 UCLM values are: [1,193 mg/kg], [904 mg/kg], and [961 mg/kg] respectively (Table 4.41).

4.6.2 ARD OF GS LEP SOLIDS IN 1992-93

Table 4.42 contains a summary of the minimum, maximum, average, and UCLM values and the transformation used to normalize the data. The raw metal concentration data for the aqua regia digestions of the LEP solids is contained in the Appendix. Due to the small number of grate siftings samples analyzed, the LEP and the ARD of the LEP solids results were combined on the same spreadsheets, tables, figures, and graphs. Descriptive statistical information, including Z-SCORE plots, is in the Appendix. As mentioned earlier, only nine samples from the first grab were sent out for analysis, twenty-seven remain. The "P", "T", and "Z-SCORE" values for nine data points are contained in the Appendix.

Table 4.42 METALS SUMMARY: 1992-93 ARD OF LEP SOLIDS - GRATE SIFTINGS

METALS ANALYSIS SUMMARY: 1992-93 ARD OF LEP SOLIDS - GRATE SIFTINGS							
METAL	ASH FRACTION	CONCENTRATIONS (mg/kg) MIN	MAX	RANGE	AVG	UCLM	TRANSFORMATION USED
Cd - CADMIUM	P 3/8"	1.20	4.40	3.20	2.00	2.20	LOGNORMAL
	P No. 4	1.60	4.80	3.20	3.10	3.60	NONE
	P No. 8	3.60	20.10	16.50	6.90	7.50	LOGNORMAL
Cr - CHROMIUM	P 3/8"	13.60	285.00	271.40	72.40	71.60	LOGNORMAL
	P No. 4	45.90	162.00	116.10	90.30	101.70	LOGNORMAL
	P No. 8	40.00	132.00	92.00	76.30	85.70	LOGNORMAL
Cu - COPPER	P 3/8"	8,150	44,900	36,750	23,216	26,385	LOGNORMAL
	P No. 4	8,450	63,100	54,650	27,716	31,314	LOGNORMAL
	P No. 8	4,750	19,600	14,850	7,683	8,480	LOGNORMAL
Fe - IRON	P 3/8"	15,000	109,000	94,000	52,011	59,274	LOGNORMAL
	P No. 4	5,810	64,000	58,190	33,527	38,213	LOGNORMAL
	P No. 8	2,000	31,000	29,000	22,089	27,088	LOGNORMAL
Mn - MANGANESE	P 3/8"	242.00	1,220.00	978.00	553.70	621.40	LOGNORMAL
	P No. 4	554.00	900.00	346.00	756.70	806.60	LOGNORMAL
	P No. 8	592.00	794.00	202.00	682.90	712.30	LOGNORMAL
Ni - NICKEL	P 3/8"	70.30	506.00	435.70	255.70	290.80	LOGNORMAL
	P No. 4	156.00	1,090.00	934.00	537.60	607.70	LOGNORMAL
	P No. 8	131.00	483.00	352.00	229.10	255.70	LOGNORMAL
Pb - LEAD	P 3/8"	146	42,600	42,454	9,990	6,275	LOGNORMAL
	P No. 4	2,500	29,000	26,500	12,044	13,418	LOGNORMAL
	P No. 8	1,000	18,000	17,000	6,190	6,490	LOGNORMAL
Zn - ZINC	P 3/8"	2,710	97,100	94,390	37,501	51,733	NONE
	P No. 4	4,140	117,000	112,860	26,888	25,803	LOGNORMAL
	P No. 8	2,060	6,520	4,460	4,264	4,870	NONE

NOTES: (1) AT OR BELOW DETECTION LIMIT

(2) MIN, MAX, RANGE, AND AVG VALUES LISTED ARE FOR UNTRANSFORMED RAW DATA; UCLM VALUES LISTED ARE BASED ON TRANSFORMED DATA SETS WHICH HAVE BEEN TRANSFORMED BACK TO REAL NUMBER SYSTEM

4.6.2.1 CADMIUM: ARD OF GS LEP SOLIDS

All of results are under 10 mg/kg except for one digestible concentration of [20.10 mg/kg] for the P8 fraction. The P3/8" and P4 results are all under 5 mg/kg. The transformed P3/8" and P8 fractions are considered normally distributed, while the P4 untransformed data is normally distributed. The corresponding UCLM values are: P3/8" [2.2 mg/kg], P4 [3.6 mg/kg], and P8 [7.5 mg/kg] (Table 4.42). The cadmium concentrations in the grate siftings are increasing with decreasing particle size.

4.6.2.2 CHROMIUM: ARD OF GS LEP SOLIDS

Chromium is present in the grate siftings at "digestible" levels. All three fractions of grate siftings have chromium concentrations that are similar in magnitude. The largest range is for the P3/8" fraction at between [13.6 to 285 mg/kg] (Table 4.42). Only the log normally transformed data is normally distributed. The calculated UCLM values are: P3/8" [71.6 mg/kg], P8 [101.7 mg/kg], and P8 [85.7 mg/kg] (Table 4.42). Concentration does not increase with decreasing particle size because the maximum UCLM concentration of 101.7 mg/kg occurs in the middle P4 fraction.

4.6.2.3 COPPER: ARD OF GS LEP SOLIDS

The results of the ARD of the LEP solids indicate that the digestible copper concentrations in the grate siftings are high. Only the transformed data is normally distributed. The corresponding UCLM values for the three fractions of siftings examined are: P3/8" [26,385 mg/kg], P4 [31,314 mg/kg], and P8 [8,480 mg/kg] (Table 4.42). The largest copper concentration in the grate siftings is in the middle P4 fraction. It is interesting to note that the "increasing concentration with decreasing particle size" relationship was not observed for copper here; the P8 ARD of the LEP solids was approximately half of the P3/8" and P4 concentrations.

4.6.2.4 IRON: ARD OF GS LEP SOLIDS

The ARD of the LEP solids iron concentrations ranges tended to be quite variable and were: P3/8" [15,000 to 109,000 mg/kg], P4 [5,810 to 64,000 mg/kg], and P8 [2,000 to 31,000 mg/kg] (Table 4.42). The log-normally transformed data is normally distributed and the UCLM values, listed in Table 4.42, are: P3/8" [59,274 mg/kg], P4 [38,213 mg/kg], and P8 [27,088 mg/kg]. Iron concentrations in the siftings decrease by a factor of 7 with decreasing particle size, which is not the usual trend observed with other metals.

4.6.2.5 MANGANESE: ARD OF GS LEP SOLIDS

Table 4.42 summarizes the descriptive statistics analysis and lists the maximum, minimum, average, and UCLM concentrations for manganese. The transformed data was used to determine the UCLM values for the three fractions of siftings and the UCLM values are: P3/8" [621.4 mg/kg], P4 [806.6 mg/kg], and P8 [712.3 mg/kg]. For manganese, the "digestible" concentration in the siftings does not increase with decreasing particle size, and the maximum concentration occurs in the middle P4 fraction.

4.6.2.6 NICKEL: ARD OF GS LEP SOLIDS

Digestible nickel concentrations vary and concentration ranges are: P3/8" [70.3 to 506 mg/kg], P4 [156 to 1,090 mg/kg] and P8 [131 to 483 mg/kg] (Table 4.42). The transformed data sets are normally distributed, and the UCLM values for nickel in the ARD of the LEP solids are: P3/8" [290.8 mg/kg], P4 [607.7 mg/kg], and P8 [255.7 mg/kg]. These results as well as other descriptive statistics can be found in Table 4.42. The maximum UCLM concentration was determined to be the middle P4 fraction, which is not the trend observed for the other metals.

4.6.2.7 LEAD: ARD OF GS LEP SOLIDS

The lead concentrations are variable over the course of the sampling period. The transformed data is normally distributed and is used to calculate the UCLM values which are: [6,275 mg/kg], [13,418 mg/kg], and [6,490 mg/kg] (Table 4.42) for the P3/8", P4 and P8 fractions of grate siftings respectively. The maximum UCLM concentration occurred in the middle P4 fraction.

4.6.2.8 ZINC: ARD OF GS LEP SOLIDS

Table 4.42 provides a summary of the descriptive statistics for the zinc ARD of LEP solids for the P3/8", P4, and P8 fractions of the grate siftings. The P3/8" and P8 untransformed data sets are normally distributed as is the transformed P4 data set. Appropriate UCLM values corresponding to the normally distributed data sets have been calculated and are listed in Table 4.42. The digestible UCLM values for zinc are: P3/8" [51,733 mg/kg], P4 [25,803 mg/kg], and P8 [4,870 mg/kg]. Zinc is another anomaly, since concentration decreases with decreasing particle size (increasing surface area).

4.6.3 MASS BALANCE FOR 1992-93 DBA & GS LEP

The grain size distribution (GSD) and yearly generation rates of desifted bottom ash (DBA) and grate siftings (GS) were used to "recombine" the DBA and GS Leachate Extraction Procedure (LEP) results on a mass basis. This was done to see if the 1991 LEP of regular bottom ash (RBA) results are comparable to the recombination of the 1992-93 DBA and GS results. The methodology used is outlined in Table 4.43, which shows how the grain size distributions of the three fractions of ash were used in conjunction with the yearly generation rates of DBA and GS. The GSD information used in the mass balance calculations was obtained from the "GRAIN SIZE DISTRIBUTIONS" section.

Table 4.43 shows the mass percent contributed for each fraction of ash called the "WEIGHTED MULTIPLICATION FACTORS" (based on DBA and GS mass flow rates). For the P9.5 mm (3/8") fraction of bottom ash, 95.4% of the mass comes from DBA and 4.6% from the GS. Similarly, for the P4.75 mm (No.4) fraction - 84.5% from DBA and 15.5% from GS. Finally, for the P2.36 mm (No.8) fraction - 83.2% of the mass generated comes from DBA and 16.8% from the GS.

The largest sources of error for this comparison are the generation rates used for the ash streams, especially the grate siftings generation rate which was calculated to be 115 kg/hr or 8.28 tonnes per day for all three lines (covered in the section on "GRATE SIFTINGS GENERATION RATES"). The GS sample size was also very small, only nine samples were analyzed, and it is possible that these results do not reflect the true nature and leachable metal concentrations of the grate siftings.

Table 4.43 MASS BALANCE CALCULATIONS

MASS BALANCE FRACTIONS		
DBA GRAIN SIZE DISTRIBUTIONS (GSD)		
FRACTION	DESIFTED BOTTOM ASH	GRATE SIFTINGS
P 3/8	17.58%	13.02%
P 4	7.73%	21.76%
P 8	19.77%	60.93%
MASS FLOWS (MF)		
REGULAR BOTTOM ASH (RBA)	(DBA MF = RBA MF - GS MF)	
TONNES PER YEAR	45837	
INCINERATOR AVAILABILITY	93.00%	
DAYS PER YEAR	339.45	
MASS FLOW (MF)	135.03	tonnes per day (3 lines)
GRATE SIFTINGS (GS)		
GENERATION RATE	115	kg/hr
GS MASS FLOW (MF)	8.28	tonnes per day (3 lines)
DESIFTED BOTTOM ASH (DBA)		
DBA MASS FLOW (MF)	126.75	tonnes per day (3 lines)
WEIGHTED MASS CONTRIBUTION OF EACH FRACTION		
X = (DBA MF) x (DBA FRACTION'S GSD)		
Y = (GS MF) x (GS FRACTION'S GSD)		
WEIGTHED = X / (X + Y) x (DBA LEP RESULT) + Y / (X + Y) x (GS LEP RESULT)		
WEIGHTED MULTIPLICATION FACTORS		
FRACTION	X / (X + Y) BOTTOM ASH	Y / (X + Y) GRATE SIFTINGS
P 3/8	0.954	0.046
P 4	0.845	0.155
P 8	0.832	0.168

4.6.4 UCLM METAL CONCENTRATION SUMMARY AND INTERPRETATION

A summary of the UCLM LEP and ARD of the LEP solids is provided in Table 4.44 for both the DBA and the GS. This data is used to estimate the weighted total concentrations for each metal and fraction examined. The following definitions are provided for clarity.

LEP WEIGHTED: the weighted average of the UCLM LEP DBA and UCLM LEP GS concentrations on a mass basis, considering Grain Size Distributions (GSD) and generation rates.

ARD WEIGHTED: the weighted average of the UCLM ARD DBA and UCLM ARD GS concentrations on a mass basis, considering Grain Size Distributions (GSD) and generation rates.

DBA TOTAL: the summation of the leachable (LEP) and digestible (ARD of LEP solid) UCLM concentrations for DBA.

GS TOTAL: the summation of the leachable (LEP) and digestible (ARD of LEP solid) UCLM concentrations for GS.

WEIGHTED TOTAL: the weighted average of the "TOTAL" UCLM concentration, recombining the LEP and ARD for both the DBA and GS.

The results presented in Table 4.44 are presented graphically in Figures 4.17 to 4.24 which combines leachable and digestible concentrations for each metal fraction and shows how they contribute to the total amount of metal in the ash. Note that certain graphs use a log scale on the vertical concentration axis because there are differences in orders of magnitude for several of the metal concentrations.

A ratio analysis examining the partitioning of metals between the leachable (LEP) and digestible (ARD) fractions of DBA and GS is contained in Section 4.7.4 "LEACHABLE AND DIGESTIBLE PARTITIONING OF METALS BETWEEN DBA AND GS".

Table 4.44 METAL CONCENTRATION SUMMARY BASED ON UCLM VALUES

METAL CONCENTRATION SUMMARY BASED ON UCLM VALUES										
MASS FRACTION		95.4%	4.6%	100.0%	84.5%	15.5%	100.0%	83.2%	16.8%	100.0%
FRACTION		P3/8	P3/8	P3/8	P4	P4	P4	P8	P8	P8
METAL		**DBA**	**GS**	**WEIGHTED**	**DBA**	**GS**	**WEIGHTED**	**DBA**	**GS**	**WEIGHTED**
CADMIUM	LEP	0.60	0.09	0.58	1.40	0.30	1.23	5.50	2.27	4.96
	ARD	2.00	2.20	2.01	4.00	3.60	3.94	10.80	7.50	10.25
	TOTAL	2.60	2.29	2.59	5.40	3.90	5.17	16.30	9.77	15.20
CHROMIUM	LEP	0.20	0.12	0.20	0.40	0.12	0.36	0.70	0.14	0.61
	ARD	127.30	71.60	124.74	168.20	101.70	157.89	139.40	85.70	130.38
	TOTAL	127.50	71.72	124.93	168.60	101.82	158.25	140.10	85.84	130.98
COPPER	LEP	16.50	16.20	16.49	31.90	9.90	28.49	25.60	0.50	21.38
	ARD	6666.00	26385.00	7573.07	14030.00	31314.00	16709.02	3768.00	8480.00	4559.62
	TOTAL	6682.50	26401.20	7589.56	14061.90	31323.90	16737.51	3793.60	8480.50	4581.00
IRON	LEP	231.00	198.00	229.48	143.10	212.00	153.78	7.00	141.00	29.51
	ARD	64736.00	59274.00	64484.75	69194.00	38213.00	64391.95	64714.00	27088.00	58392.83
	TOTAL	64967.00	59472.00	64714.23	69337.10	38425.00	64545.72	64721.00	27229.00	58422.34
MANGANESE	LEP	15.10	11.40	14.93	112.30	30.20	99.57	197.60	31.50	169.70
	ARD	633.00	621.00	632.45	807.00	806.60	806.94	1214.00	712.30	1129.71
	TOTAL	648.10	632.40	647.38	919.30	836.80	906.51	1411.60	743.80	1299.41
NICKEL	LEP	8.30	3.70	8.09	13.20	6.90	12.22	22.10	7.80	19.70
	ARD	201.00	290.80	205.13	259.00	607.70	313.05	221.00	255.70	226.83
	TOTAL	209.30	294.50	213.22	272.20	614.60	325.27	243.10	263.50	246.53
LEAD	LEP	13.40	68.40	15.93	58.10	224.80	83.94	22.50	90.50	33.92
	ARD	842.00	6275.00	1091.92	2711.00	13418.00	4370.59	1880.00	6490.00	2654.48
	TOTAL	855.40	6343.40	1107.85	2769.10	13642.80	4454.52	1902.50	6580.50	2688.40
ZINC	LEP	174.40	1193.00	221.26	622.60	904.00	666.22	969.90	961.00	968.40
	ARD	2173.0	51733.0	4452.76	3204.0	25803.0	6706.85	3070.0	4870.0	3372.40
	TOTAL	2347.40	52926.00	4674.02	3826.60	26707.00	7373.06	4039.90	5831.00	4340.80

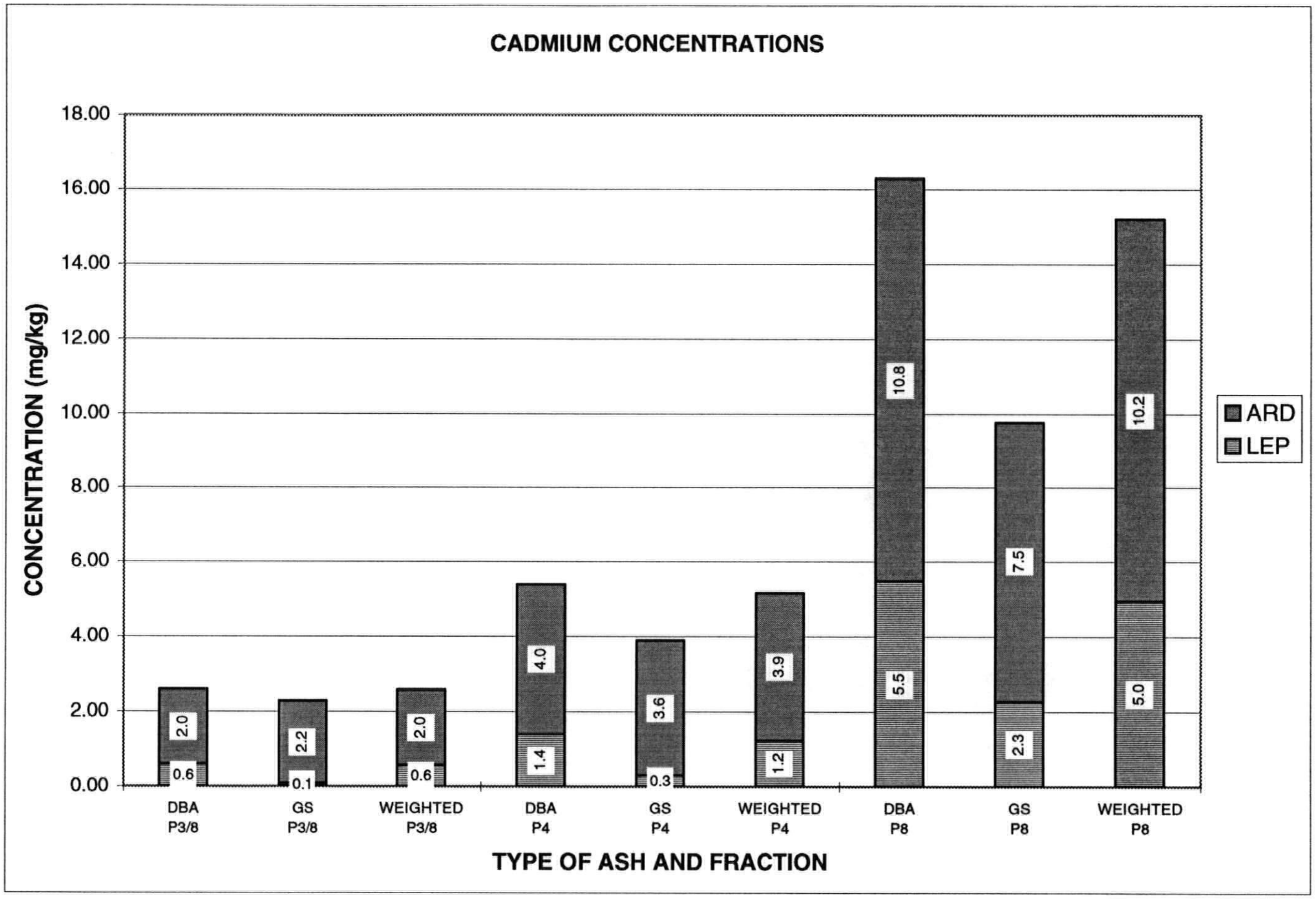


Figure 4-17 LEACHABLE, DIGESTIBLE, & WEIGHTED CADMIUM CONCENTRATIONS

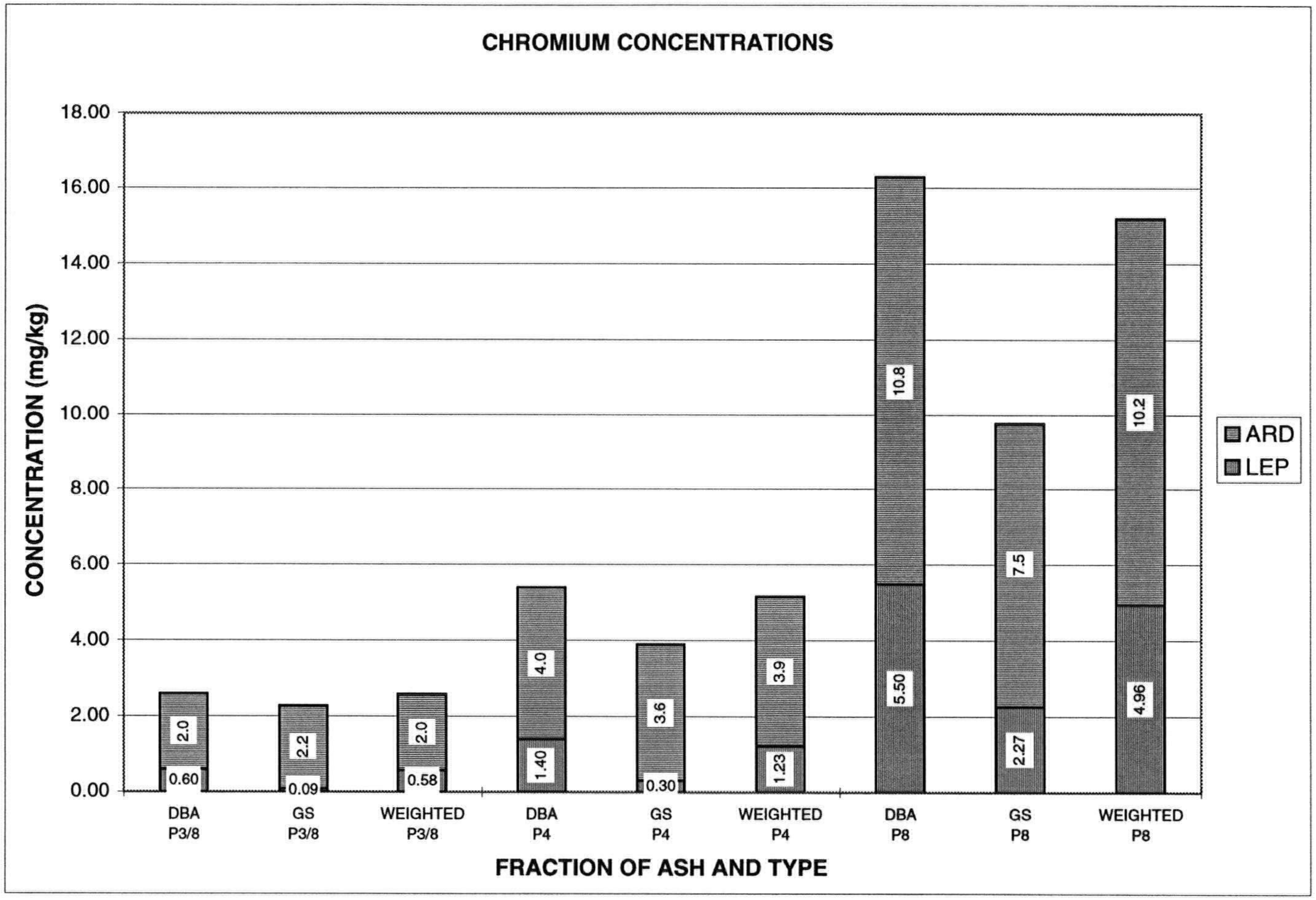


Figure 4-18 LEACHABLE, DIGESTIBLE, & WEIGHTED CHROMIUM CONCENTRATIONS

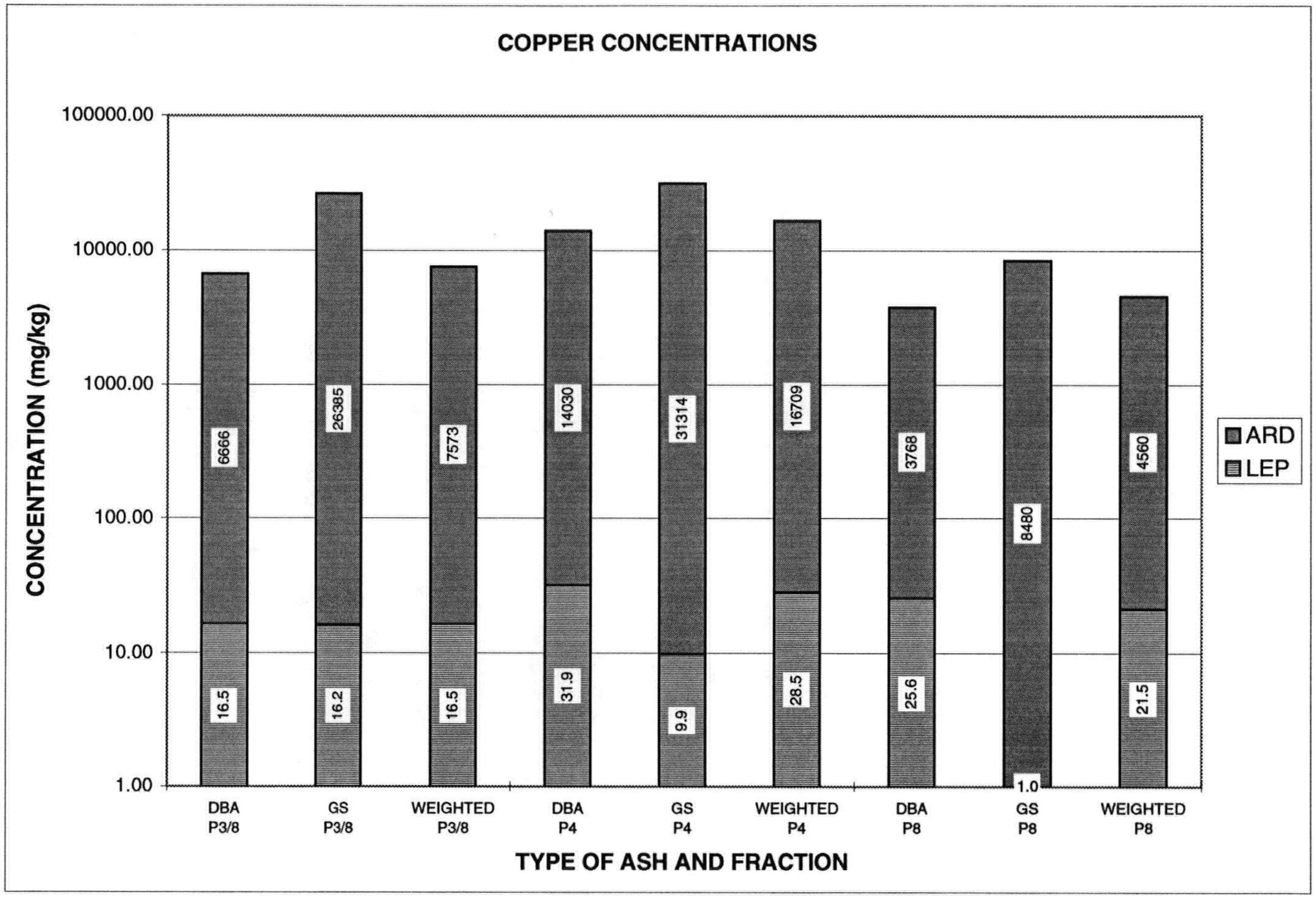


Figure 4-19 LEACHABLE, DIGESTIBLE, & WEIGHTED COPPER CONCENTRATIONS

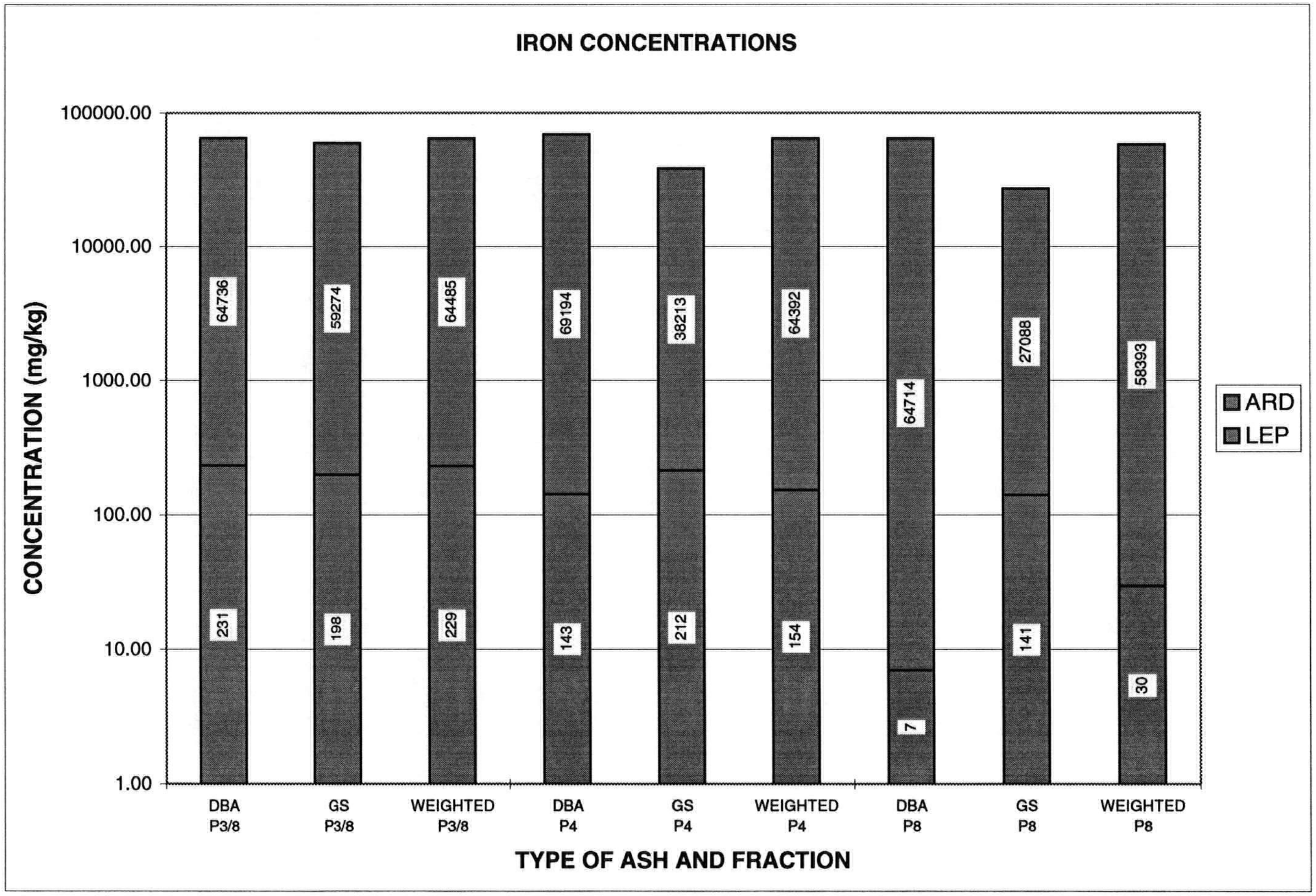


Figure 4-20 LEACHABLE, DIGESTIBLE, & WEIGHTED IRON CONCENTRATIONS

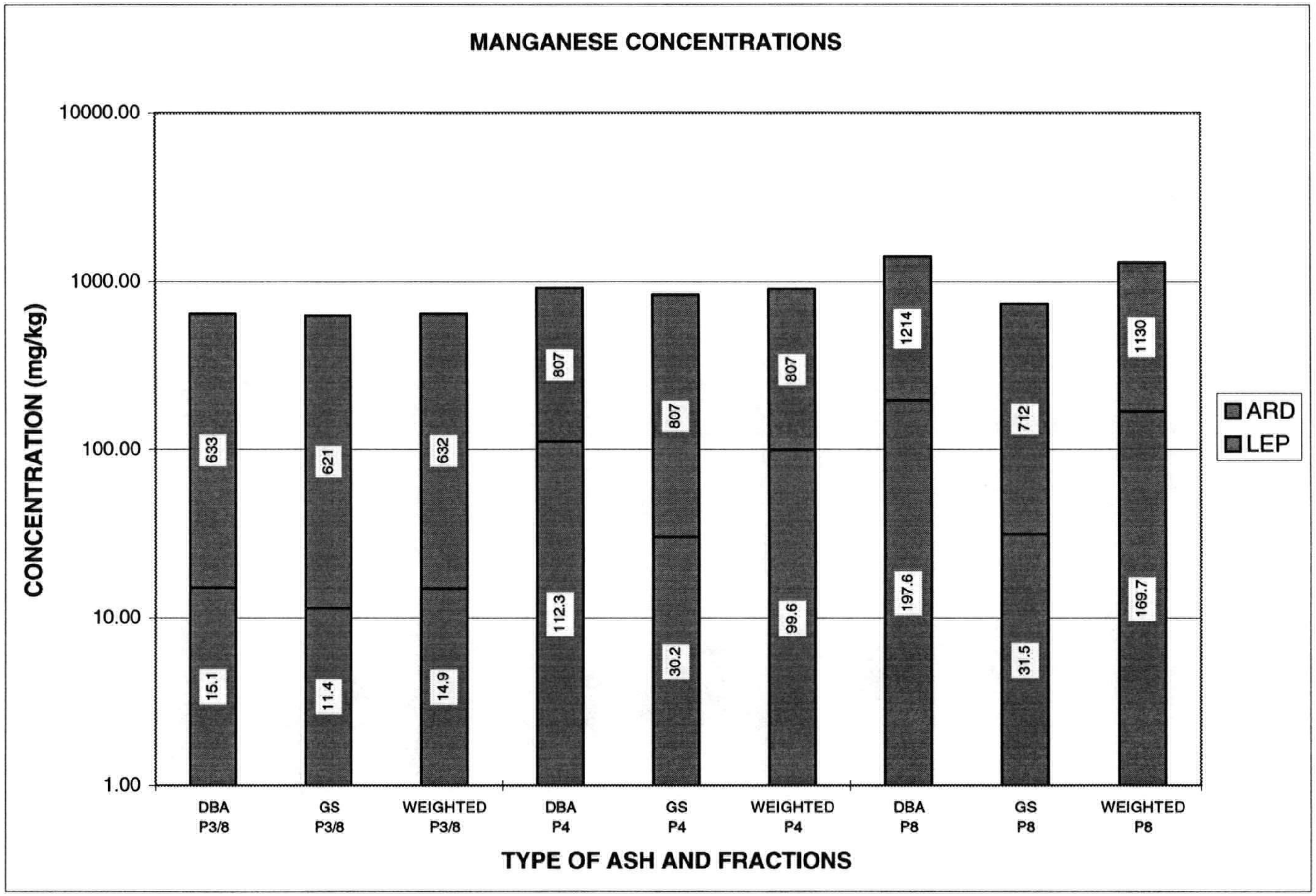


Figure 4-21 LEACHABLE, DIGESTIBLE, & WEIGHTED MANGANESE CONCENTRATIONS

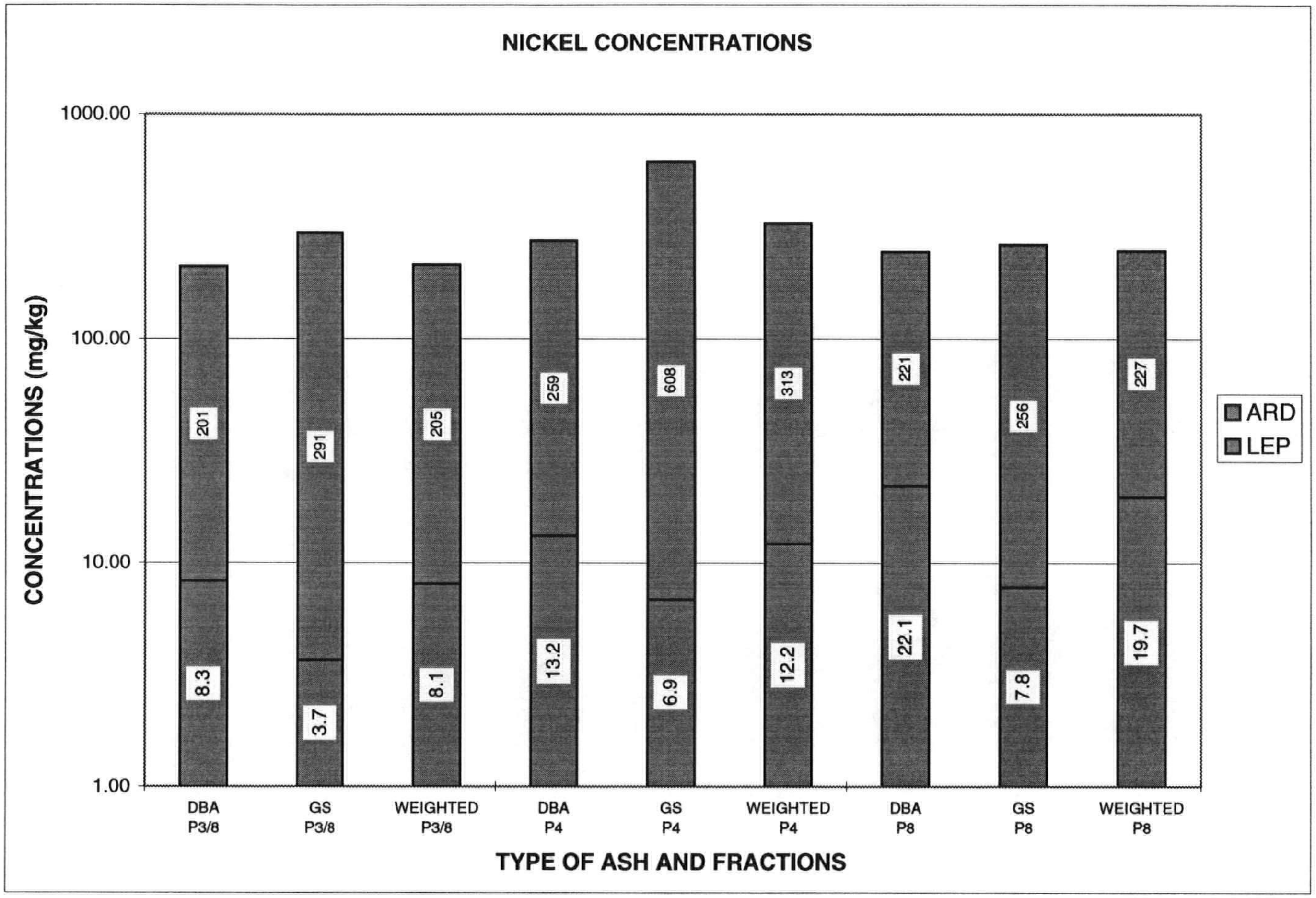


Figure 4-22 LEACHABLE, DIGESTIBLE, & WEIGHTED NICKEL CONCENTRATIONS

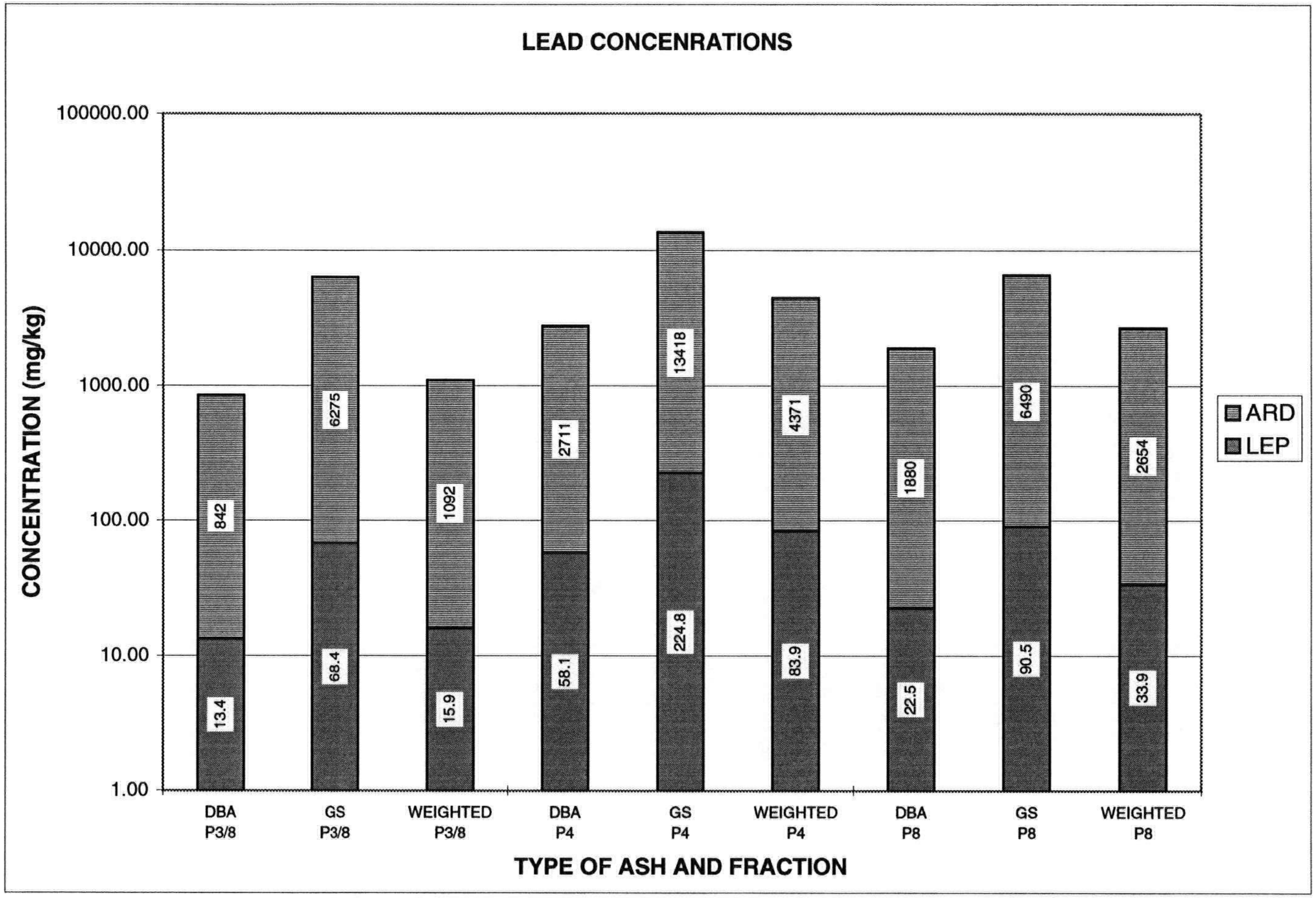


Figure 4-23 LEACHABLE, DIGESTIBLE, & WEIGHTED LEAD CONCENTRATIONS

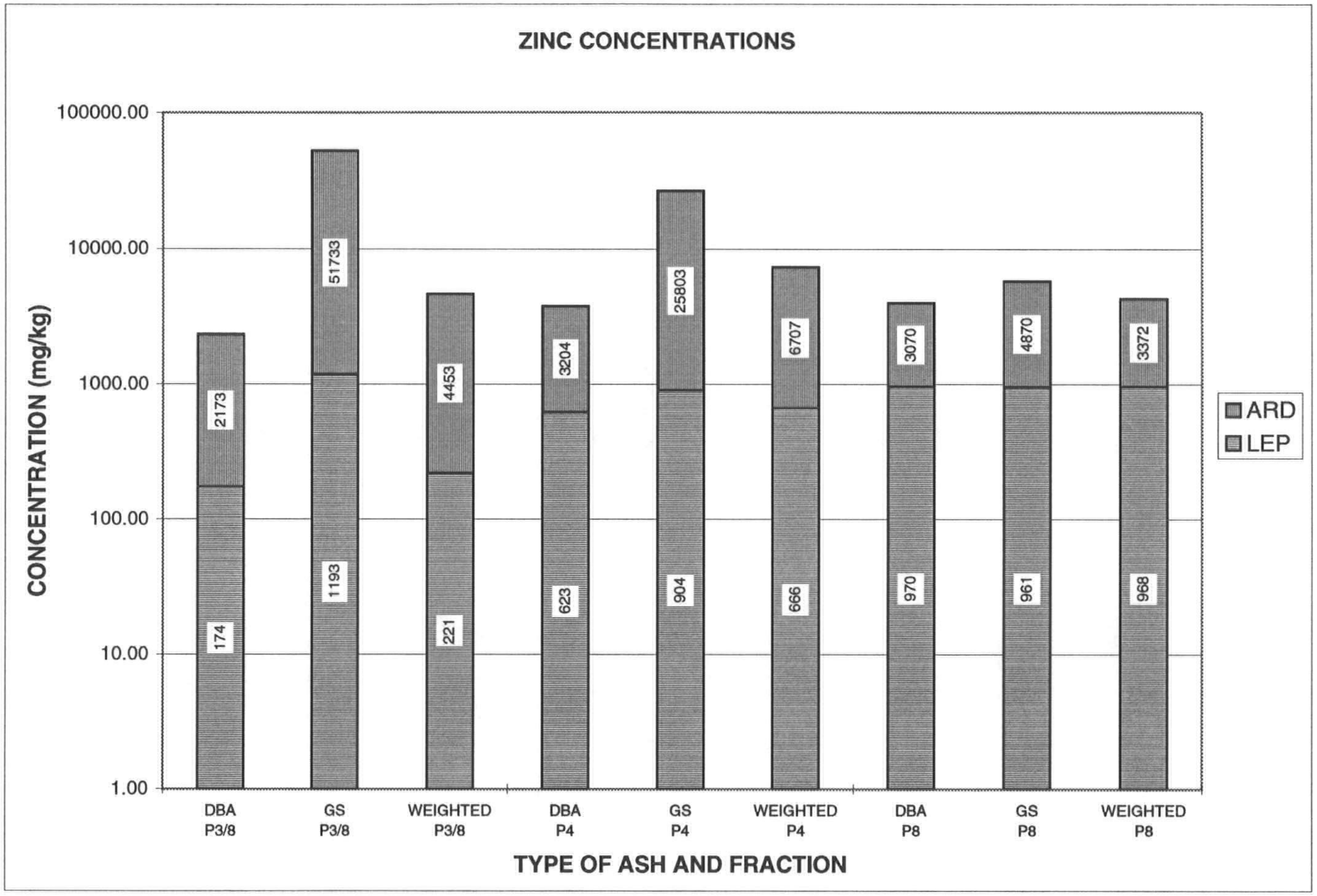


Figure 4-24 LEACHABLE, DIGESTIBLE, & WEIGHTED ZINC CONCENTRATIONS

4.7 COMPARISON OF UCLM CHEMICAL RESULTS

In order to comment on variability of the chemical properties of incineration residuals it is necessary to examine the feedstock going to the Burnaby Incinerator. The total tonnage of waste going to or accepted at the incinerator from it's three largest sources did not vary significantly; this is a constraint imposed by the fixed capacity of the Burnaby Incinerator which can incinerate approximately 240,000 tonnes of refuse per year. The three largest and most significant sources of MSW were the Coquitlam Resource Recovery Plant (RRP), the North Shore Transfer Station (NSTS) and direct haul (DH) from Burnaby. Changes in seasons and the sources (wastesheds) of MSW going to the incinerator have an affect on the day to day blend or mix and composition of MSW incinerated. Sorting studies have been done to examine the composition of MSW; however, one problem with these studies is that they are snapshots of very limited time frames. More information is required over longer sampling periods to determine how variable the composition of MSW going to the incinerator is over the course of time and how seasons and sources (wastesheds) change the composition of MSW.

It is assumed that over the course of the sampling performed in 1991 and 1992-93 the **average** composition of MSW going to the Burnaby Incinerator remained constant and that the feedstock was not a source of variation for the UCLM metal concentrations calculated. The affects of various blends of waste from the three major sources and the changing seasons over the sampling periods would be averaged out or reduced given several months of sampling. This assumption is based on the GSDs obtained.

4.7.1 1991 RBA TO 1992-93 DBA: LEP

The range of leachable metal concentrations obtained in 1992-93 is smaller than for the 1991 LEP values. Whether or not this can be attributed to the grate siftings as a source of variability is unknown because only nine of twelve samples from one of three grabs of the grate siftings were subjected to metals analysis. Tables 4.20 and 4.21 summarized the concentration, transformation, and spatial variability rating information discussed for the 1991 and 1992-93 studies.

Table 4.45 is a summary of all of the UCLM values obtained in 1991 for regular bottom ash (RBA) and 1992-93 for desifted bottom ash (DBA). The only metal of regulatory concern is lead because its LEP limit of 100 mg/kg (5 mg/l or ppm) is exceeded on several occasions. The P4 and P8 fractions of the 1991 regular bottom ash can be classified as special wastes under the BC MOELP regulations (1988). The 1992-93 results show that no fraction of the DBA is a special waste on an annualized basis. However, it must be remembered that for several sample days leachable lead concentrations were known to be a problem.

Table 4.45 UPPER CONFIDENCE LIMIT OF THE MEAN (UCLM) METAL CONCENTRATIONS

METAL	1991 LEP DATA				1992-93 LEP DATA		
	P3/8	P4	P8		P3/8	P4	P8
CADMIUM	0.8	1.5	3.9		0.6	1.4	5.5
CHROMIUM	0.5	0.9	1.1		0.2	0.4	0.7
COPPER	37.8	50.8	44.0		16.5	31.9	25.6
IRON	65.1	61.1	3.4		231.0	143.1	7.0
MANGANESE	45.4	91.5	134.9		15.1	112.3	197.6
NICKEL	7.0	10.1	12.0		8.3	13.2	22.1
LEAD	37.5	201.0	112.9		13.4	58.1	22.5
ZINC	496.1	844.7	1080.2		174.4	622.6	969.9

Units: mg/kg

Of importance is whether or not the removal of the grate siftings resulted in the lower leachable metal concentrations in the bottom ash, particularly if the metal in question, for example lead, is a special waste problem. The concentration reductions, or increases designated by a minus "-" sign, in Table 4.46 show that for the majority of cases leachable metal levels were reduced in the bottom ash stream not containing the grate siftings. Fifteen leachable UCLM metal concentrations, of twenty-four, decreased and nine increased. The impact the removal of the grate siftings had on these reductions was addressed with mass balance calculations in Section 4.6.3 "MASS BALANCE FOR 1992-93 DBA & GS LEP". The changes in UCLM concentrations for each metal are examined in more detail in the following discussion.

Table 4.46 UCLM PERCENT REDUCTIONS

METAL	1991 DATA USED AS BASELINE		
	P3/8	P4	P8
CADMIUM	25.0%	6.7%	-41.0%
CHROMIUM	60.0%	55.6%	36.4%
COPPER	56.3%	37.2%	41.8%
IRON	-254.8%	-134.2%	-105.9%
MANGANESE	66.7%	-22.7%	-46.5%
NICKEL	-18.6%	-30.7%	-84.2%
LEAD	64.3%	71.1%	80.1%
ZINC	64.8%	26.3%	10.2%

4.7.1.1 CADMIUM: COMPARE RBA & DBA UCLM LEPs

The cadmium concentrations decreased in the P3/8" and P4 fractions by 25% and 6.7% respectively (Table 4.46). Cadmium levels increased by just over 40% in the P8 fraction, but due to the extremely low levels present to begin with, this is not a matter of regulatory concern. It may be that the measured levels are so low that this increase can be attributed to a combination sampling and analytical error. It is likely that cadmium partitions to the flue gases given its low boiling temperature of 765 °C, however, cadmium can be expected to partition into the grate siftings; it has a melting point of 321 oC. Because cadmium levels are extremely low it is difficult to comment on partitioning. Both sampling periods show an increase in concentration with a decrease in particle size. The relative magnitudes of the 1991 and 1992-93 like fractions are very close for all three fractions meaning the leachable cadmium concentrations did not appear to change significantly when comparing the 1991 and 1992-93 results. Therefore, the removal of the siftings did not appear to significantly impact leachable cadmium concentrations and cadmium does not appear to partition in the grate siftings.

4.7.1.2 CHROMIUM: COMPARE RBA & DBA UCLM LEPs

Large decreases in the chromium concentrations were observed when comparing the 1991 and 1992-93 LEP metals data. Reductions of 60%, 55.6%, and 36.4% were calculated for the P3/8", P4, and P8 fractions respectively (Table 4.46). Due to the extremely low levels of chromium present which were at or near detection limits in many cases, the accuracy of these figures is somewhat questionable. however, one can be confident in the fact that chromium is present at low concentrations and is not of environmental concern, and that removing the grate siftings lowers potential impacts even further. Leachable chromium concentrations increased with decreasing particle size for both sets of data. The removal of the grate siftings did not appear to affect the partitioning of this metal because the relative magnitudes of chromium in the 1991 and 1992-93 bottom ash samples are close. This seems logical because chromium's melting point is 1,857° C which is above the grate bed temperatures.

4.7.1.3 COPPER: COMPARE RBA & DBA UCLM LEPs

The amount of copper present in bottom ash decreased between 1991 and 1992-93. The largest decrease was 56.3% for the P3/8" fraction, then 41.8% for the P8 fraction, and finally 37.2% for the P4 fraction (Table 4.46). It would appear that the removal of the grate siftings has had a significant impact on leachable copper concentrations and that copper may partition to the grate siftings. Copper's melting temperature is 1,084° C would suggest that it could partition to the grate siftings. Other explanations for the decreases may be improved copper recovery from the MSW stream before it reaches the incinerator, a result of improved old corrugated cardboard recovery and recycling. Old corrugated cardboard (OCC) boxes often contain large copper packing staples which were common, visible and identifiable in the DBA and GS residual streams. It may be that improved OCC recycling and therefore a decrease in the amount of copper packing staples has contributed slightly to this reduction in copper. Copper concentrations did not increase with decreasing particle size. For both data sets the largest copper concentrations were present in the middle P4 fractions (Table 4.45).

4.7.1.4 IRON: COMPARE RBA & DBA UCLM LEPs

Leachable iron concentrations increased when you compare the 1991 and 1992-93 results. For the P3/8", P4, and P8 fractions the respective increases from 1991 to 1992-93 were 254%, 134%, and 106% (Table 4.46). The increases got progressively smaller as the particle size decreased. Increases in leachable iron concentrations of this magnitude are not possible to explain. It may be that physical effects such as scouring and chemical effects such as corrosion at the incinerator were greater for the 1992-93 study than in 1991, but this is unlikely. Iron's melting point is 1,535° C and it is not expected to partition preferentially into the grate siftings.

4.7.1.5 MANGANESE: COMPARE RBA & DBA UCLM LEPs

There was a 66.7% reduction in leachable manganese concentrations for the P3/8" fraction, but for the P4 and P8 there were 22.7% and 46.5% increases in the desifted bottom ash, as compared to regular bottom ash (Table 4.46). Overall, it would appear that the removal of the grate siftings did not have a large impact on leachable manganese concentrations. Manganese concentrations increased with decreasing particle sizes for both sampling periods. Manganese melts at 1,244° C, therefore it is not expected to partition into the grate siftings.

4.7.1.6 NICKEL: COMPARE RBA & DBA UCLM LEPs

The concentrations between 1991 and 1992-93 increased slightly for all three fractions, and the increases were larger in the smaller fractions of ash. The P3/8" concentration increased 18.6%, the P4 fraction 30.7%, and the P8 fraction 84.2% (Table 4.46). In 1991 the LEP leachates were examined using a nickel graphite furnace, which is more accurate and sensitive than regular flame AA and the 1992-93 LEP leachates were analyzed using regular flame AA. It could be that there is more nickel in the DBA, but intuitively this seems unlikely. Leachable nickel concentrations are small and range between 8.3 to 22.1 mg/kg for both the 1991 and 1992-93 studies. The percent differences in UCLM concentrations calculated mislead one to think the nickel concentrations are quite different when in fact they are very close to one another and the removal of the grate siftings did not have a significant impact. Increasing leachable concentrations with decreasing particle sizes were observed for both data sets. Nickel's melting point is 1,453° C, therefore it is not expected to partition preferentially into the grate siftings.

4.7.1.7 LEAD: COMPARE RBA & DBA UCLM LEPs

Lead levels in the DBA were significantly lower than in the RBA for all three fractions of ash. The results show that there was a 60%, 70%, and 80% reduction in the P3/8", P4, and P8 fractions of bottom ash respectively when comparing the 1991 RBA and 1992-93 DBA results (Table 4.46). These results warrant further partitioning investigation, especially in light of the fact that lead's melting point is 328 °C. The reductions cannot be attributed to the removal of the grate siftings alone because the grate siftings represent a small portion of the bottom ash stream (about 6% by weight). However, this is a significant finding given that this small residual stream contains the bulk of the lead on a weight basis. Like copper, the largest lead concentrations were in the middle P4 fraction for both sampling periods (Table 4.45).

After spiking experiments at the Burnaby Incinerator, Sawell et al (1992) found that "concentrations of lead in most of the residue streams collected during the spiking were not substantially different than those measured in the residues from the test runs without the lead acid spikes. The obvious exception was the grate siftings, which contained substantially higher concentrations during the spiking" meaning that lead partitioned to the siftings. The removal of siftings from the bottom ash stream in 1992-93 appeared to have a noticeable effect on the UCLM lead concentrations in the desifted bottom ash stream compared to the 1991 regular bottom ash. It is uncertain why Sawell et al (1992) did not observe higher lead concentrations in the desifted bottom ash stream they examined after spiking. One explanation could be that Sawell's experiments were performed over a relatively short period of time and spiking is not a steady state process. Mass balance relationships are expected to play a role in the partitioning of lead and if the siftings are removed this should have an effect on the resulting desifted bottom ash. It is not certain how large a sample of DBA or GS Sawell et al (1992) collected and this could be a reason for not observing higher lead levels in the DBA. Notably, Sawell's experiment was performed over a very short time frame versus the 1992-93 study which generated UCLM values from a prolonged sample period. This makes the results of the two studies difficult to compare directly.

Possible reasons for lead reductions may be the introduction of a lead acid battery recovery program in June of 1991 or the amount of green waste (known to be a source of lead) going to the incinerator was reduced significantly. More likely, lead reductions can be attributed to a reduction of soluble (liquid) lead in paints and inks versus elemental lead in batteries. Together, lead reductions in paints, pigments, and inks and an increase in battery recycling have combined to lower lead levels in MSW.

The 1992-93 samples did not extend through April to July when much of the green waste is generated; therefore an attempt will be made to correct for this before comparisons are made between the 1991 RBA and 1992-93 DBA LEPs. Ting (1994) sampled over the course of twelve months, therefore, some of his RBA samples were taken in the summer. It has been hypothesized that green wastes and soil from the lower mainland bioaccumulates lead, and when incinerated this contributes to the amount of lead in the ash stream. Any lead present in an organic form should partition to the fly ash because it is volatile. In order to make direct comparison between Ting's (1994) RBA data and the author's DBA data, the effect of the summer months was removed. Ting's (1994) data was re-analyzed without data from the summer months. Only data collected during the same months as the author's was used. Table 4.47 lists the "adjusted" 1991 data set for RBA. It is assumed that the underlying distribution for this data is not normal because the original full data set was not normally distributed and it must be transformed to be normalized before descriptive statistics can be used. The descriptive statistics information for this "adjusted" data set is shown in Table 4.48.

By removing the summer months samples from the 1994 RBA UCLM calculations, reductions in lead levels were still observed. These reductions were 10.7%, 16.2%, and 14.2% for the P3/8", P4, and P8 fractions of ash respectively (Table 4.49). The 1992-93 DBA UCLM lead levels remain well below the adjusted 1991 RBA lead levels. Two "outliers" or high values, one for Grab #1 P3/8" of 1,540 mg/kg and the other for Grab #2 P8 of 3,680 mg/kg, may effect the data somewhat, however, there simply appears to be less lead in the 1992-93 DBA samples. The UCLM LEP GS and WEIGHTED values are shown as well. The P3/8" and P4 1992-93 WEIGHTED UCLM lead concentrations are approximately half of the 1991 ADJUSTED DATA (P3/8" - 15.9/33.5 = 47.5% and P8 - 84.0/168.5 = 49.9%). Similarly the P8 1992-93 WEIGHTED UCLM lead concentration is approximately one third of the 1991 ADJUSTED DATA (P8 - 33.9/96.9 = 35.0%).

Table 4.47 1991 RBA LEP RESULTS, ADJUSTED DATA, LEAD CONCENTRATIONS (summer months removed)

ADJUSTED 1991 REGULAR BOTTOM ASH LEP DATA: LEAD CONCENTRATIONS (mass basis) (units mg/kg)												
SAMPLE DATE	GRAB # 1			GRAB # 2			GRAB # 3			GRAB # 4		
	P3/8	P4	P8	P3/8	P4	P8	P3/8	P4	P8	P3/8	P4	P8
2-Jan-91	78.0	664.6	832.6	136.6	144.8	312.6	240.6	83.3	728.6	45.5	65.0	226.6
14-Jan-91	106.0	260.8	564.0	224.2	870.0	3680.0	482.0	870.0	1171.0	215.8	544.0	709.8
22-Jan-91	7.2	92.4	497.2	12.6	55.4	86.6	128.2	21.2	103.2	49.3	36.2	511.2
4-Feb-91	106.6	216.2	136.3	45.4	147.4	64.0	85.2	56.8	148.0	250.8	178.6	28.0
18-Feb-91	1540.0	720.0	118.0	184.0	300.0	254.0	28.0	660.0	160.0	79.2	286.0	94.0
6-Mar-91	3.2	41.6	14.8	43.4	150.6	15.0	26.8	102.2	25.8	12.6	79.0	17.4
30-Mar-91	23.2	81.2	5.8	2.0	244.0	1.0	4.4	301.6	18.8	40.4	31.6	1.0
13-Sep-91	3.2	157.2	144.8	37.0	60.2	14.2	7.8	124.6	30.2	22.4	125.8	9.4
26-Sep-91	0.2	46.6	30.6	2.2	93.4	47.8	1.2	27.8	24.6	1.0	63.4	21.8
16-Nov-91	26.2	906.0	1012.0	17.4	52.2	11.4	4.4	186.0	60.8	18.0	216.4	184.4
17-Dec-91	2.8	49.6	17.0	6.0	81.2	14.0	6.4	414.2	63.8	7.8	151.0	14.0

Table 4.48 STATISTICAL INFORMATION FOR ADJUSTED LEAD DATA

STATISTICAL INFORMATION FOR ADJUSTED 1991 LEAD DATA					
P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	3.147	Mean	4.929	Mean	4.217
Standard Error	0.281	Standard Error	0.152	Standard Error	0.274
Median	3.277	Median	4.905	Median	4.157
Standard Deviation	1.861	Standard Deviation	1.009	Standard Deviation	1.821
Variance	3.464	Variance	1.019	Variance	3.315
Range	8.949	Range	3.755	Range	8.211
Minimum	-1.609	Minimum	3.054	Minimum	0.000
Maximum	7.340	Maximum	6.809	Maximum	8.211
Confidence Level (95%)	0.550	Confidence Level (95%)	0.298	Confidence Level (95%)	0.538
UCLM	3.512	UCLM	5.127	UCLM	4.574
UCLM TRANS BACK	33.531	UCLM TRANS BACK	168.454	UCLM TRANS BACK	96.925

NOTE: A student-t value of 1.302 was used for the adjusted data set UCLM calculation

Table 4.49 COMPARISON OF ADJUSTED UCLM LEAD DATA: 1991 to 1992-93

DATA	P3/8" (1)	P4	P8
1991 RBA (original)	37.5	201.0	112.9
1991 ADJUSTED RBA	33.5	168.5	96.9
AMOUNT REDUCED	4.0	32.5	16.0
1991 % REDUCED (2)	10.7%	16.2%	14.2%
1992-93 DBA	13.4	58.1	22.5
1992-93 GS	68.4	224.8	90.5
1992-93 WEIGHTED (3)	15.9	84.0	33.9

NOTES: (1) Units are mg/kg
(2) The 1991 RBA results were reduced by removing the summer data.
(3) Recombination of DBA and GS results on a mass basis.

4.7.1.8 ZINC: COMPARE RBA & DBA UCLM LEPs

As the particle size decreased the zinc reductions decreased. The largest decrease in concentration was for the P3/8" fraction and was 64.8%. The P4 and P8 concentrations decreased by 26.3% and 10.2% respectively (Table 4.46). Both sample sets had increasing zinc concentrations with decreasing particle size (Table 4.45). It is suspected that leachable zinc concentrations are affected by the removal of the grate siftings and that zinc may partition to the siftings because of it's lower melting temperature (420 °C). The results indicate that further partitioning analysis for zinc is recommended.

4.7.2 1991 RBA LEP COMPARED TO 1992-93 DBA LEP PLUS GS LEP

The results of the recombination of the 1992-93 DBA LEP and GS LEP results and the comparison of this analysis with the 1991 LEP results are shown in Table 4.50. There is close agreement for cadmium, chromium, manganese, and nickel. The copper results in 1992-93 are approximately half of the 1991 LEP for each fraction. Iron results reflect the high leachable concentrations determined in 1992-93 and do not compare favorably to the 1991 LEP concentrations. Lead results were higher in 1991, even after the grate siftings were added back to the DBA numbers. The zinc concentrations were higher in 1991 for the P3/8" and P4 fractions, but the P8 fractions are similar in magnitude.

Table 4.50 MASS BALANCE COMPARISON OF 1991 AND 1992-93 LEP DATA

COMPARISON OF 1991 AND 1992-93 LEP DATA							
	1991 LEP DATA BOTTOM ASH				1992-93 WEIGHTED LEP DATA (DBA AND GS)		
METAL	P3/8	P4	P8		P3/8	P4	P8
CADMIUM	0.8	1.5	3.9		0.58	1.23	4.96
CHROMIUM	0.5	0.9	1.1		0.20	0.36	0.61
COPPER	37.8	50.8	44.0		16.49	28.48	21.39
IRON	65.1	61.1	3.4		229.48	153.80	29.46
MANGANESE	45.4	91.5	134.9		14.93	99.55	169.76
NICKEL	7.0	10.1	12.0		8.09	12.22	19.70
LEAD	37.5	201.0	112.9		15.94	83.99	33.90
ZINC	496.1	844.7	1080.2		221.41	666.31	968.41

4.7.3 1991 RBA TO 1992-93 DBA: ARD OF LEP SOLIDS

A direct comparison between the 1991 and 1992-93 data cannot be made. In 1991, the solids remaining after the LEP were collected, air dried, and then subjected to a mortar and pestle grinding operation. Any solid pieces of metal were removed and discarded, which biases the metal concentration results. After grinding, a one gram representative sample was taken and then subjected to ARD, followed by Flame AA for metals analysis.

For the 1992-93 study the entire LEP solid sample remaining after the LEP was microwave digested without performing any mechanical size reduction. It was hoped that by digesting the entire sample any problems associated with obtaining a representative one gram sample, as done previously, would be avoided.

4.7.4 LEACHABLE AND DIGESTIBLE PARTITIONING OF METALS BETWEEN DBA AND GS

The partitioning of metals in residuals streams is known to be affected by different incineration processes and the physical properties of these metals (elements). The literature review provided melting and boiling temperatures for the eight metals examined. The pile temperature range given, 1,000 to 1,200 ^{o}C, is above or near the melting temperatures for the following three metals: 1) copper (1,083.5 ^{o}C), 2) lead (327.5 ^{o}C), and 3) zinc (419.6 ^{o}C). Cadmium's melting temperature of 321 ^{o}C is passed and so is its boiling temperature of 765 ^{o}C. Cadmium is a metal that partitions to fly ash and it is not present in bottom ash or grate siftings in large quantities (concentrations). A detailed partitioning analysis for Cu, Pb, and Zn will be provided in this section because these metals are capable of melting but do not boil, and therefore, can pass through the grates. Some zinc may vaporize and partition to the fly ash stream because its boiling temperature is 907 ^{o}C. Figure 4.25 is the partitioning worksheet used to show metals concentrations in the various residual streams. The following interpretation of the data lists the parameters required to examine the partitioning of all eight metals, but because it appears only Cu, Pb, and Zn exist in appreciable amounts and seem to partition a complete analysis for Cd, Cr, Fe, Mn, and Ni was not done. Lead is the most important metal to examine because of it's environmental and regulatory concerns.

The weighted contributions for each fraction of ash, calculated in Section 4.6.3 "MASS BALANCE FOR 1992-93 DBA + GS LEP", are used here in combination with the concentration ratios to quantify metals partitioning.

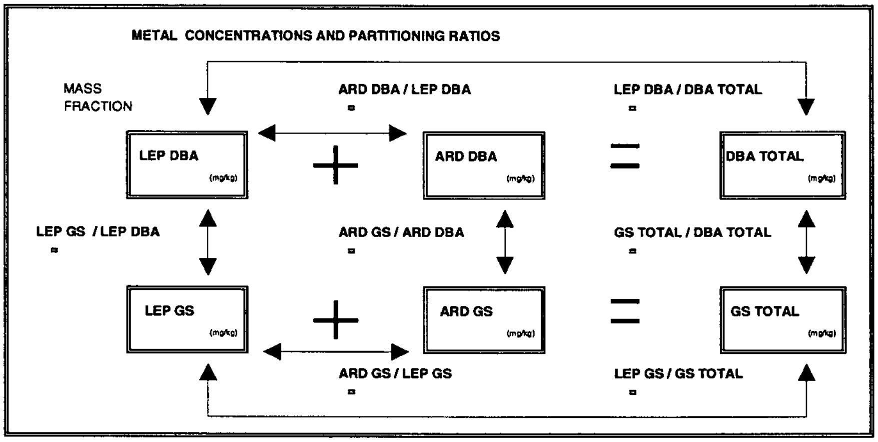


Figure 4.25 METALS PARTITIONING WORKSHEET

4.7.4.1 LEP FOR DBA & GS

A comparison between the desifted bottom ash and grate siftings LEP results has been performed. The ratio of the grate siftings (GS) and desifted bottom ash (DBA) LEP UCLM concentrations has been examined. If the ratio is greater than one then there is a higher leachable metal concentration in the grate siftings and if the ratio is less than one there is a higher leachable metal concentration in the DBA. The results are tabulated in Table 4.51.

Table 4.51 COMPARISON OF LEP FOR DBA AND GS

METAL	P3/8"	P 4	P8
	LEP GS / LEP DBA	LEP GS / LEP DBA	LEP GS / LEP DBA
CADMIUM	0.15	0.21	0.41
CHROMIUM	0.60	0.30	0.20
COPPER	0.98	0.31	0.02
IRON	0.86	**1.48**	**20.14**
MANGANESE	0.75	0.27	0.16
NICKEL	0.45	0.52	0.35
LEAD	**5.10**	**3.87**	**4.02**
ZINC	**6.84**	**1.45**	0.99

NOTE: Bold values represent significant partitioning to GS (leachable).

Most (17 of 24) leachable metal concentrations appear to be greater in the desifted bottom ash. The most significant exceptions to this are for iron, lead, and zinc, which appear to be 1.5 to 20 times greater in leachable concentration in the grate siftings (Table 4.51). Lead and zinc's melting temperatures are exceeded in the boiler and at the grates, therefore, lead and zinc can pass through the grates and concentrate in the siftings. The P3/8" leachable concentration for zinc is almost seven times higher in the siftings, the P4 almost 1.5 greater, and the P8 essentially equal in concentration.

Iron has a lower concentration in the P3/8" fraction in the grate siftings, but it is greater in the siftings for the P4 and P8 fractions. The leachable iron concentration for the P8 fraction appears to be 20 times greater in the grate siftings than in the desifted bottom ash. This could mean that a considerable amount of fine iron particulate pass through the grates and into the siftings.

4.7.4.2 ARD OF LEP SOLIDS FOR DBA & GS

The ratios of ARD GS to ARD DBA have been summarized in Table 4.52. These ratios represent the "fixed" or nonleachable portion of the residues examined.

Table 4.52 COMPARISON OF ARD OF LEP SOLIDS FOR DBA AND GS

METAL	P3/8"	P4	P8
	ARD GS / ARD DBA	ARD GS / ARD DBA	ARD GS / ARD DBA
CADMIUM	**1.10**	0.90	0.69
CHROMIUM	0.56	0.60	0.61
COPPER	**3.96**	**2.23**	**2.25**
IRON	0.92	0.55	0.42
MANGANESE	0.98	1.00	0.59
NICKEL	**1.45**	**2.35**	**1.16**
LEAD	**7.45**	**4.95**	**3.45**
ZINC	**23.81**	**8.05**	**1.59**

NOTE: Bold values represent significant partitioning to GS (digestible).

Half of the digestible or fixed metal concentrations are greater in the grate siftings. If the ratio given above (ARD GS/ARD DBA) is greater than one then the digestible metal concentration in the grate siftings is greater than the digestible metal concentration in the desifted bottom ash.

Notably, the copper, nickel, lead, and zinc concentrations are significantly greater in the grate siftings. The zinc concentration in the grate siftings P3/8" fraction is apparently almost 24 times greater than in the bottom ash. Melting temperatures for copper, lead, and, zinc are thought to be having a partitioning effect on these metals. Nickel's melting temperature of 1,453 ^{o}C is not surpassed in the furnace, therefore it was not expected to partition to the siftings. Perhaps fine particulate containing nickel alloys are able to pass through the grates.

4.7.4.3 LEP & ARD OF LEP SOLIDS FOR DBA

A UCLM comparison between the LEP results and the ARD of the LEP solids has been made (Table 4.53). The ARD concentration has been divided by the LEP concentration, and as expected for all cases this ratio is greater than (1) one, meaning the more aggressive aqua regia acid digestion dissolved more metals than the less aggressive leachate extraction procedure which used dilute acetic acid.

The metals present in the leachate from the LEP are defined as "dissolvable" for purposes here and the metals present in the ARD of the LEP solids are defined as "digestible" or "fixed" metals. These two sources of metals have been added together and are designated "DBA TOTAL" in Table 4.53. Based on the results shown in Table 4.53 varying amounts of cadmium, manganese, nickel, lead, and zinc are leachable. Metals that are not readily leachable are chromium, copper, and iron. Solubility of DBA is addressed in more detail in Section 4.8 "METAL SOLUBILITY".

Table 4.53 SUMMARY OF 1992-93 DBA UCLM METAL CONCENTRATIONS

METAL	PASSING 3/8"		PASSING No.4		PASSING No.8	
	ARD DBA / LEP DBA	LEP DBA / DBA TOTAL	ARD DBA / LEP DBA	LEP DBA / DBA TOTAL	ARD DBA / LEP DBA	LEP DBA / DBA TOTAL
CADMIUM	3.33	23.08%	2.86	25.93%	1.96	33.74%
CHROMIUM	636.50	0.16%	420.50	0.24%	199.14	0.50%
COPPER	404.00	0.25%	439.81	0.23%	147.19	0.67%
IRON	280.24	0.36%	483.54	0.21%	9244.86	0.01%
MANGANESE	41.92	2.33%	7.19	12.22%	6.14	14.00%
NICKEL	24.22	3.97%	19.62	4.85%	10.00	9.09%
LEAD	62.84	1.57%	46.66	2.10%	83.56	1.18%
ZINC	12.46	7.43%	5.15	16.27%	3.17	24.01%

4.7.4.4 LEP & ARD OF LEP SOLIDS FOR GS

A similar comparison to the one done in Table 4.53 has been done for the grate siftings and similar trends were observed for "leachability" groupings. Specifically, iron, copper, and chromium seemed to be the least leachable because there was a much greater concentration in the ARD of the LEP solids than in the LEP leachate. This is evident when examining the percentage LEP GS / GS TOTAL values contained in Table 4.54. Manganese, nickel, lead, and zinc in the GS have similar "leachabilities" compared to the DBA, but to a lesser degree. The solubility of the grate siftings is discussed in more detail in Section 4.8 "METAL SOLUBILITY".

Table 4.54 SUMMARY OF 1992-93 GS UCLM METAL CONCENTRATIONS

METAL	PASSING 3/8"		PASSING No. 4		PASSING No.8	
	ARD GS / LEP GS	LEP GS / GS TOTAL	ARD GS / LEP GS	LEP GS / GS TOTAL	ARD GS / LEP GS	LEP GS / GS TOTAL
CADMIUM	24.44	3.93%	12.00	7.69%	3.30	23.23%
CHROMIUM	596.67	0.17%	847.50	0.12%	612.14	0.16%
COPPER	1628.70	0.06%	3163.03	0.03%	16960.00	0.01%
IRON	299.36	0.33%	180.25	0.55%	192.11	0.52%
MANGANESE	54.51	1.80%	26.71	3.61%	22.61	4.24%
NICKEL	78.59	1.26%	88.07	1.12%	32.78	2.96%
LEAD	91.74	1.08%	59.69	1.65%	71.71	1.38%
ZINC	43.36	2.25%	28.54	3.38%	5.07	16.48%

4.8 METAL SOLUBILITY

The percentages leachable (LEP DBA / DBA TOTAL) were listed previously in Table 4.53. These values provide more information about each metals solubility. It can be seen that cadmium is the most soluble metal and becomes more soluble with decreasing particle size (P3/8" - 23.08%, P4 - 25.93%, and P8 - 33.74%). Chromium, copper, and iron appear to be very insoluble, with less than 0.70% dissolvable in the LEP leachates for all three fractions. Manganese and nickel solubility's increase in the leachate with decreasing particle size. For manganese the percentages are: P3/8" - 2.33%, P4 - 12.22%, and P8 - 14.00% and for nickel P3/8" - 3.97%, P4 -4.85%, and P8 - 9.09%. Lead is relatively insoluble because 1.57%, 2.10%, and 1.18% of the "TOTAL" lead was LEP available in the P3/8", P4, and P8 fractions respectively. Zinc, like cadmium, was very LEP soluble. A maximum of 24.01% of the zinc was leachable in the finest P8 fraction.

After performing LEP's and acid digestions on ash samples Sawell et al. (1988) found that up to 6.7% of the cadmium, 29% of the copper, 17% of the lead, and 21% of the zinc were leached with the acetic acid media they used. For comparison purposes, the 1992-93 ranges are particularly different for these metals and are as follows:

Cd	23.1% to 33.7%
Cu	0.23% to 0.67%
Pb	1.25 to 2.1%
Zn	7.4 % to 24.0%.

The results presented by Sawell et al (1988) are not directly comparable to work done here because the same size fractions of ash were not examined and it is assumed the ash they examined included grate siftings. Furthermore, it is not certain if the LEP's and acid digestions performed were sequential ("matchable") or if any mechanical homogenization had been done. For the 1992-93 results a sample was first subjected to a LEP and then each LEP solid sample was carried through an acid digestion (the acid digestion was "matchable" to the LEP). This ensured an accurate correlation between dissolvable and total metals was made. By definition "TOTAL" concentrations presented are simply the addition of the LEP and the ARD of the LEP solids metal concentrations (a sequential process was followed).

For both the DBA and GS the ARD of the LEP solids concentrations are greater than the LEP concentrations. Solubility's were introduced by Roethel et al (1991) who used a set of criteria to designate bottom ash leachate as "SS" or slightly soluble, "MS" or moderately soluble, and "HS" or highly soluble. A similar solubility summary is presented in Tables 4.55 and 4.56 for both the DBA and GS. The criteria used to designate the metals soluble (SOL), moderately soluble (MSOL), or insoluble (INSOL) was designed by the author. If the LEP / TOTAL percentages from Tables 4.53 and 4.54 for the DBA or the GS were less than or equal to 2.5% then the ratio was designated insoluble (INSOL), between 2.5% to less than or equal to 7.5% moderately soluble (MSOL), and greater than 7.5% soluble (SOL).

The solubility results obtained indicate that the majority of metals are either moderately soluble or insoluble. Lead has been listed as insoluble in both the desifted bottom ash and the grate siftings. Cadmium, manganese, nickel, and zinc were the only metals with "SOLUBLE" ratings, but this is not of concern because none of these metals had LEP UCLM failures.

Table 4.55 RELATIVE SOLUBILITY OF BOTTOM ASH

SOLUBILITY OF BOTTOM ASH			
METAL	**PASSING 3/8"**	**PASSING No.4**	**PASSING No.8**
CADMIUM	SOL	SOL	SOL
CHROMIUM	INSOL	INSOL	INSOL
COPPER	INSOL	INSOL	INSOL
IRON	INSOL	INSOL	INSOL
MANGANESE	MSOL	SOL	SOL
NICKEL	MSOL	MSOL	SOL
LEAD	INSOL	INSOL	INSOL
ZINC	MSOL	SOL	SOL

INSOL ==> INSOLUBLE (LEP/TOTAL: 0 to 2.5%)
MSOL ==> MODERATELY SOLUBLE (LEP/TOTAL: >2.5 to 7.5%)
SOL ==> SOLUBLE (LEP/TOTAL: >7.5%)

Table 4.56 RELATIVE SOLUBILITY OF GRATE SIFTINGS

SOLUBILITY OF GRATE SIFTINGS			
METAL	**PASSING 3/8"**	**PASSING No.4**	**PASSING No.8**
CADMIUM	MSOL	SOL	SOL
CHROMIUM	INSOL	INSOL	INSOL
COPPER	INSOL	INSOL	INSOL
IRON	INSOL	INSOL	INSOL
MANGANESE	INSOL	MSOL	MSOL
NICKEL	INSOL	INSOL	MSOL
LEAD	INSOL	INSOL	INSOL
ZINC	INSOL	MSOL	SOL

INSOL ==> INSOLUBLE (LEP/TOTAL: 0 to 2.5%)
MSOL ==> MODERATELY SOLUBLE (LEP/TOTAL: >2.5 to 7.5%)
SOL ==> SOLUBLE (LEP/TOTAL: >7.5%)

4.8.1.1 LEP & ARD OF LEP SOLIDS FOR TOTALS (DBA+GS)

Table 4.57 summarizes the "TOTAL" metals for DBA and GS and shows the ratio of GS TOTAL divided by DBA TOTAL. A profound result observed here is that the copper, nickel, lead, and zinc TOTAL concentrations are significantly greater in the grate siftings. One possible explanation for this is that the pile temperature is greater than the melting points for these metals, except nickel, and they are liquefied and can flow through the grates to solidify and become part of the grate siftings residual stream. The GS TOTAL / DBA TOTAL ratios for **copper, nickel, lead, and zinc** have been **bolded** for clarity in Table 4.57.

It is unusual that the nickel GS TOTAL / DBA TOTAL ratios are greater than one. It was assumed that nickel would not partition into the siftings because it's melting point of 1,453 °C is not expected to occur under normal operating pile temperatures. However, nickel may be present as metallic pieces which could fall through the grates or in alloys with copper or zinc which have lower melting points. If nickels' melting point is reached, then one would expect manganese to preferentially partition into the siftings as well. Manganese did not appear to partition into the siftings based on the results in Table 4.57; manganese's melting temperature is 1,244 °C.

Table 4.57 SUMMARY OF DBA & GS TOTAL UCLM METAL CONCENTRATIONS

METAL	PASSING 3/8"	PASSING No. 4	PASSING No.8
	GS TOTAL / DBA TOTAL	GS TOTAL / DBA TOTAL	GS TOTAL / DBA TOTAL
CADMIUM	0.88	0.72	0.60
CHROMIUM	0.56	0.60	0.61
COPPER	**3.95**	**2.23**	**2.24**
IRON	0.92	0.55	0.42
MANGANESE	0.98	0.91	0.53
NICKEL	**1.41**	**2.26**	**1.08**
LEAD	**7.42**	**4.93**	**3.46**
ZINC	**22.55**	**6.98**	**1.44**

NOTE: Bold values represent significant partitioning to GS (TOTAL).

4.8.1.2 PARTITIONING SUMMARY

The metals partitioning worksheet created (Figure 4.25) was used for copper, lead, and zinc partitioning analyses. The results from examining the concentration ratios are summarized in the following partitioning ratio tables. The ratios examined and summarized are:

- LEP GS / LEP DBA
- ARD GS / ARD DBA
- GS TOTAL / DBA TOTAL
- ARD DBA / LEP DBA
- ARD GS / LEP GS
- LEP DBA / DBA TOTAL
- LEP GS / GS TOTAL

The LEP information was used to estimate what percentage of the total leachable copper, lead, and zinc came from the GS. The result of this analysis will provide insight into the impact the removal the grate siftings will have on LEP results, which is significant when considering regulatory issues. Proportionately, it is felt that the grate siftings, which constitute approximately 6.1% of the bottom ash stream on an annual mass basis, contribute a large percentage of the leachable (LEP) copper, lead, and zinc because these metals have melting temperatures below the grate bed temperatures and these metals preferentially partition to the siftings. Similarly, the mass fractions and total metal concentrations in the DBA and GS were used to calculate the percentage of total copper, lead, and zinc contributed to the bottom ash stream by the GS for the minus 9.5 mm, 4,75 mm, and 2.36 mm fractions. The total metals analysis addresses environmental concerns more adequately than the LEP leachable metal results because a distinction can be made between the leachable and fixed metals which are potentially available for long term leaching. In addition, a better understanding of what form the metal is in is available.

4.8.1.2.1 COPPER RATIOS AND PARTITIONING

The results from Figures 4.26 to 4.28 , specifically the LEP GS / LEP DBA and GS TOTAL / DBA TOTAL ratios, were used to predict how much leachable and total copper comes from the GS. Table 4.58 shows that approximately 4.52%, 5.39%, and 0.39% of the leachable copper present in the DBA and GS streams comes from the GS for the minus 9.5 mm, 4.75 mm, and 2.36 mm fractions respectively. Similarly, Table 4.59 shows that approximately 16.00%, 29.01%, and 31.10% of the total copper present in the DBA and GS streams comes from the GS for the same fractions. The total metal results are significant because they show that the siftings, which represent 6.1% by mass, of the bottom ash stream contribute at least 16% to a maximum of 31% of the copper.

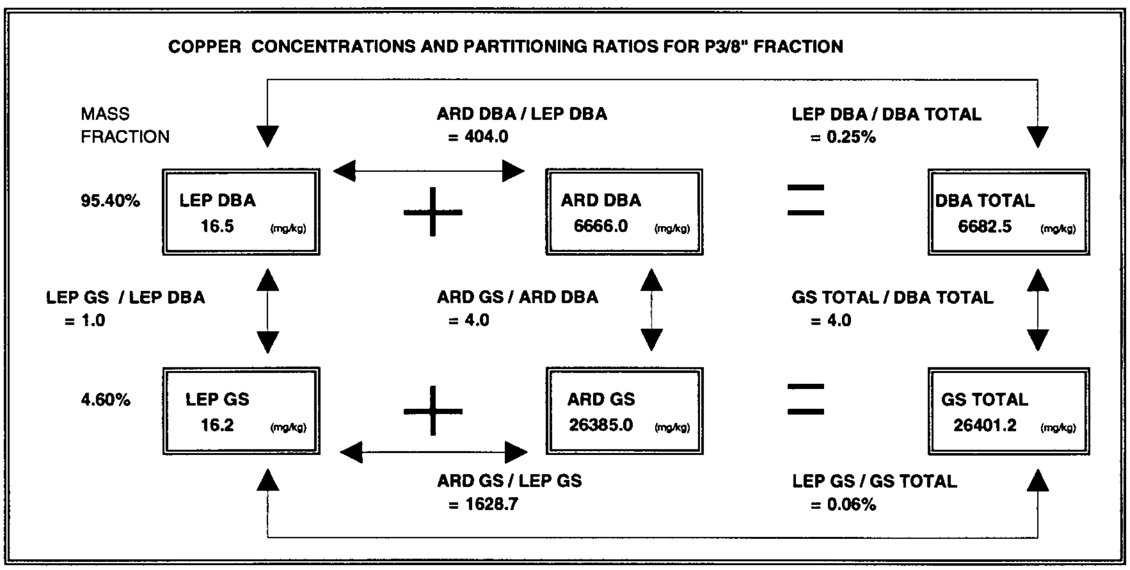


Figure 4.26 COPPER PARTITIONING FOR P9.5 mm (3/8") FRACTION

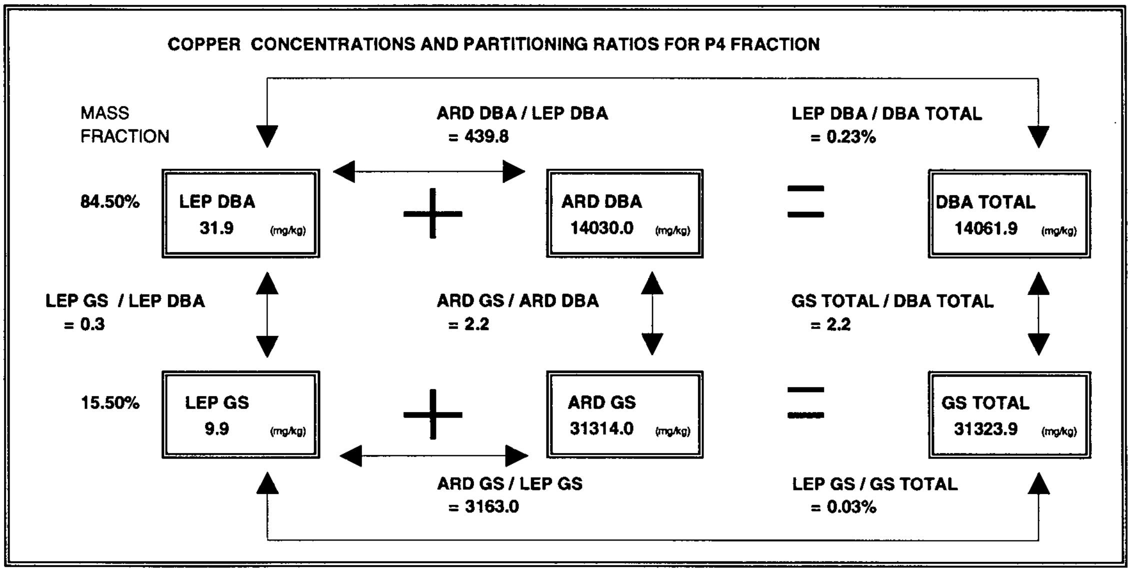


Figure 4.27 COPPER PARTITIONING FOR P4.75 mm (No.4) FRACTION

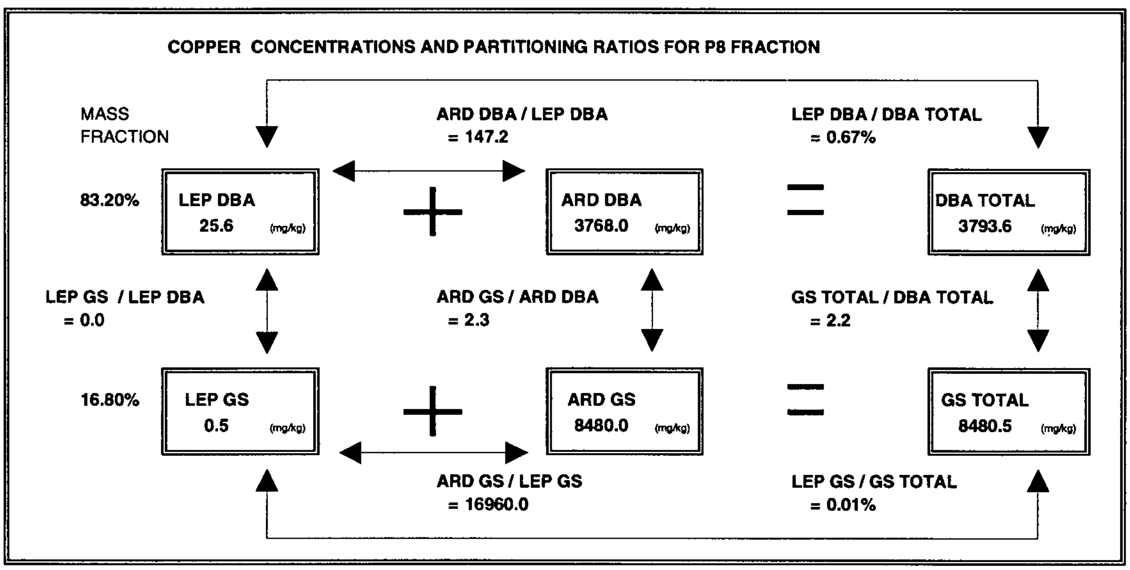


Figure 4.28 COPPER PARTITIONING FOR P2.36 mm (NO.8) FRACTION

Table 4.58 PERCENTAGE OF LEP COPPER COMING FROM GS

GS CONTRIBUTION FOR LEP COPPER					
FRACTION	LEP CONCENTRATION GS (mk/kg)	DBA (mg/kg/)	FRACTIONAL MASS % GS	MASS % DBA	GS CONTRIBUTION TO LEP (as %age)
P9.5 mm (3/8")	16.2	16.5	4.60%	95.40%	4.52%
P4.75 mm (No.4)	9.9	31.9	15.50%	84.50%	5.39%
P2.36 mm (No.8)	0.5	25.6	16.80%	83.20%	0.39%

Table 4.59 PERCENTAGE OF TOTAL COPPER COMING FROM GS

GS CONTRIBUTION FOR TOTAL COPPER					
FRACTION	TOTAL CONCENTRATION GS (mk/kg)	DBA (mg/kg/)	FRACTIONAL MASS % GS	MASS % DBA	GS CONTRIBUTION TO TOTAL (as %age)
P9.5 mm (3/8")	26401.2	6682.5	4.60%	95.40%	16.00%
P4.75 mm (No.4)	31323.9	14061.9	15.50%	84.50%	29.01%
P2.36 mm (No.8)	8480.5	3793.6	16.80%	83.20%	31.10%

4.8.1.2.2 LEAD RATIOS AND PARTITIONING

Figures 4.29 to 4.31 show the partitioning ratios calculated for lead. The LEP GS / LEP DBA and GS TOTAL / DBA TOTAL ratios were used to predict how much lead comes from the GS. The proportions of LEP leachable lead contributed to the bottom ash stream from the grate siftings are as follows: 19.75%, 41.51%, and 44.82% for the minus 9.75 mm, 4.75 mm, and 2.36 mm fractions respectively (Table 4.60). The total lead contribution to the bottom ash stream from the grate siftings, based on concentration and mass ratios, is estimated to be 26.34%, 47.47%, and 41.12% for the minus 9.5 mm (P3/8"), 4.75 mm (P4), and 2.36 mm (P8) fractions respectively (Table 4.61). The significance of this is that **in order to reduce leachable and total lead in the bottom ash the minus 4.75 mm and 2.36 mm fractions of grate siftings could be removed because they contribute the bulk of the lead.**

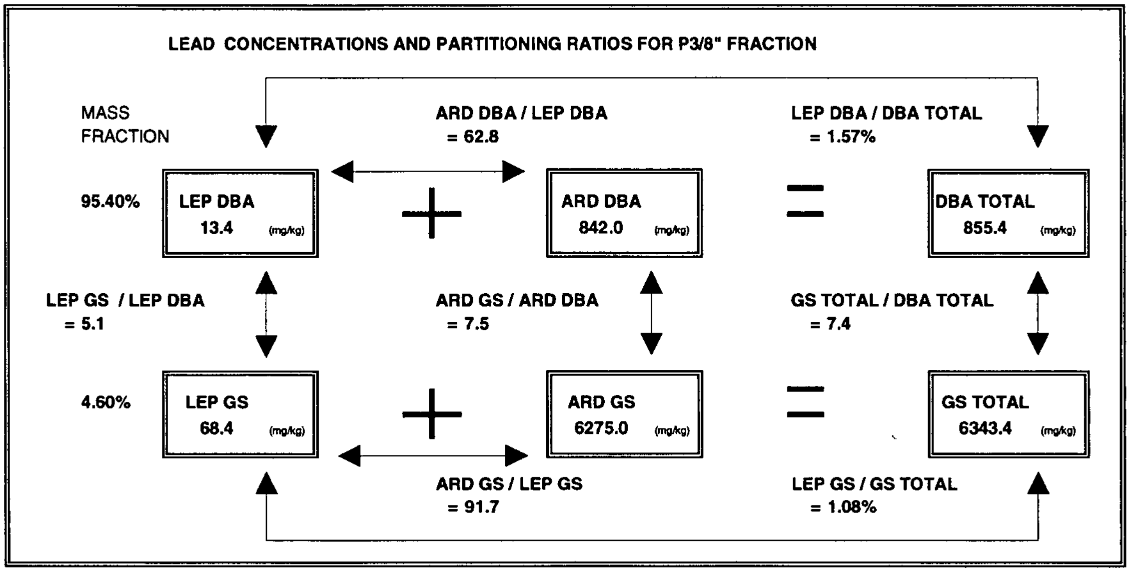


Figure 4.29 LEAD PARTITIONING FOR P9.5 mm (3/8") FRACTION

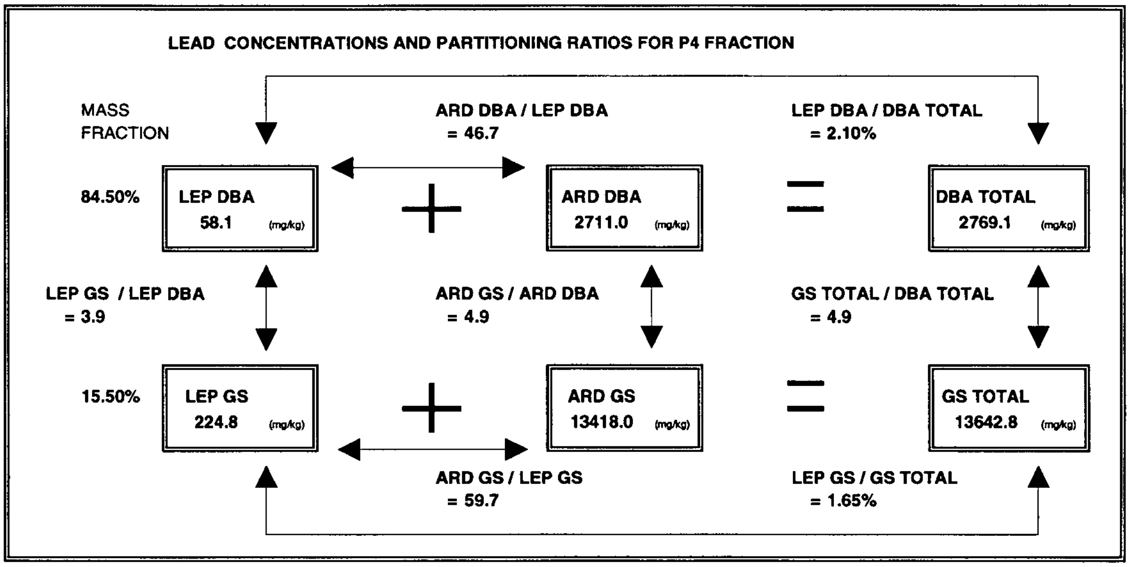


Figure 4.30 LEAD PARTITIONING FOR P4.75 mm (No.4) FRACTION

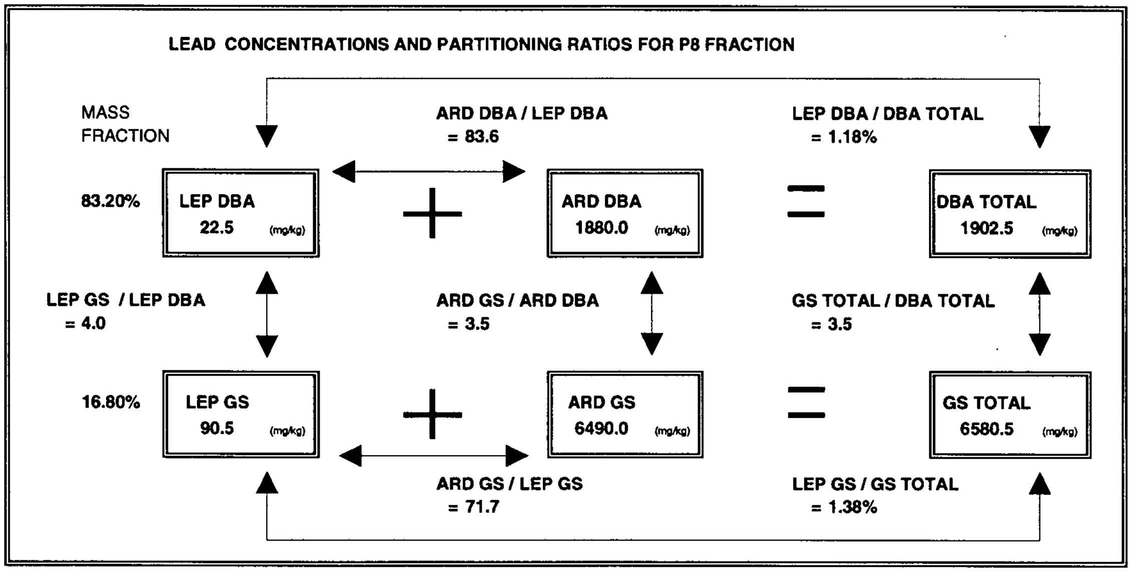


Figure 4.31 LEAD PARTITIONING FOR P2.36 mm (No.8) FRACTION

Table 4.60 PERCENTAGE OF LEP LEAD COMING FROM GS

GS CONTRIBUTION FOR LEP LEAD					
FRACTION	LEP CONCENTRATION GS (mg/kg)	DBA (mg/kg)	FRACTIONAL MASS % GS	MASS % DBA	GS CONTRIBUTION TO LEP (as %age)
P9.5 mm (3/8")	68.4	13.4	4.60%	95.40%	19.75%
P4.75 mm (No.4)	224.8	58.1	15.50%	84.50%	41.51%
P2.36 mm (No.8)	90.5	22.5	16.80%	83.20%	44.82%

Table 4.61 PERCENTAGE OF TOTAL LEAD COMING FROM GS

GS CONTRIBUTION FOR TOTAL LEAD					
FRACTION	CONCENTRATION GS (mg/kg)	DBA (mg/kg)	FRACTIONAL MASS % GS	MASS % DBA	GS CONTRIBUTION TO TOTAL (as %age)
P9.5 mm (3/8")	6343.4	855.4	4.60%	95.40%	26.34%
P4.75 mm (No.4)	13642.8	2769.1	15.50%	84.50%	47.47%
P2.36 mm (No.8)	6580.5	1902.5	16.80%	83.20%	41.12%

4.8.1.2.3 ZINC RATIOS AND PARTITIONING

Figures 4.32 to 4.34 show the partitioning ratios in leachable, digestible, and total zinc and the UCLM concentrations for the minus 9.5 mm, 4.74 mm, and 2.36 mm fractions of bottom ash. The results from Tables 4.62 and 4.63 were used to predict how much leachable and total zinc is contributed to bottom ash from the GS. Table 4.62 shows that approximately 24.8%, 21.0%, and 16.7% of the leachable zinc present in the combined DBA and GS streams comes from the GS. Zinc is expected to concentrate in the siftings because of it's melting point, and this has occurred. The total zinc contributed from the GS to the bottom ash stream for the minus 9.5 mm, 4.75 mm, and 2.36 mm fractions is 52.09%, 56.14%, and 22.57% respectively (Table 4.63). The fact that over half of the zinc in the bottom ash for the minus 9.5 mm and 4.75 mm fractions is coming from the siftings is significant, given they contribute only 4.6% and 15.5% of the fractional mass respectively.

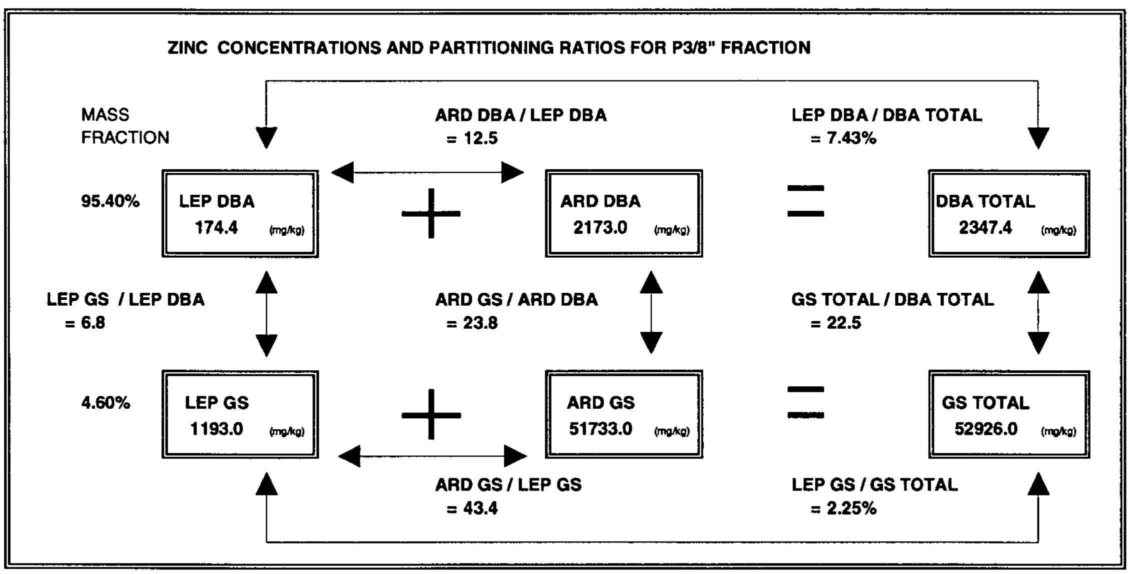


Figure 4.32 ZINC PARTITIONING FOR P9.5 mm (3/8") FRACTION

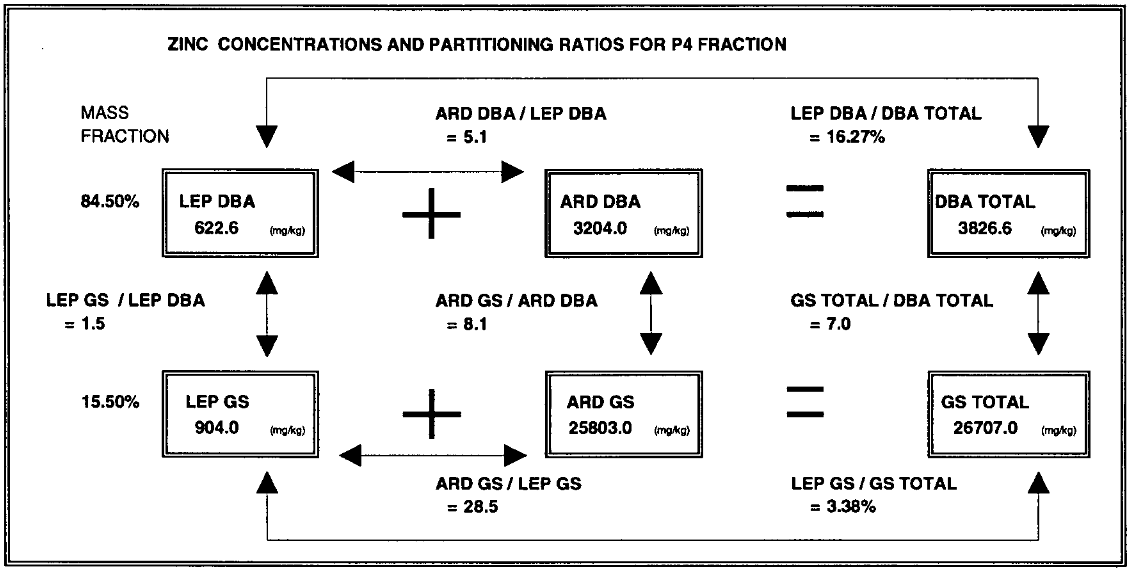


Figure 4.33 ZINC PARTITIONING FOR P4.75 mm (No.4) FRACTION

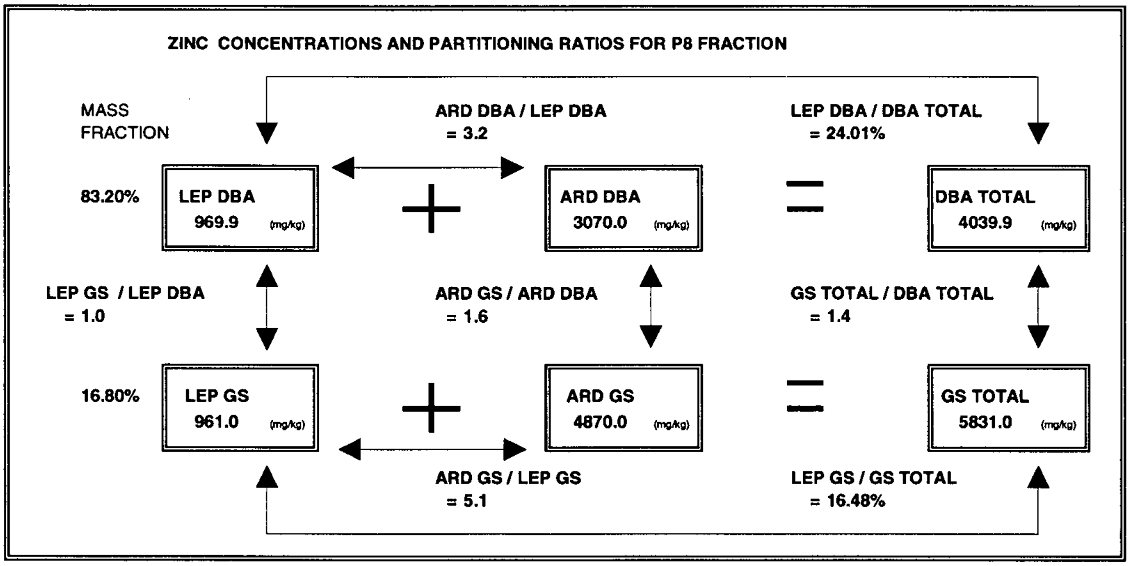


Figure 4.34 ZINC PARTITIONING FOR P2.36 mm (No.8) FRACTION

Table 4.62 PERCENTAGE OF LEP ZINC COMING FROM GS

GS CONTRIBUTION FOR LEP ZINC					
FRACTION	LEP CONCENTRATION GS (mg/kg)	DBA (mg/kg)	FRACTIONAL MASS % GS	MASS % DBA	GS CONTRIBUTION TO LEP (as %age)
P9.5 mm (3/8")	1193.0	174.4	4.60%	95.40%	24.80%
P4.75 mm (No.4)	904.0	622.6	15.50%	84.50%	21.03%
P2.36 mm (No.8)	961.0	969.9	16.80%	83.20%	16.67%

Table 4.63 PERCENTAGE OF TOTAL ZINC COMING FROM GS

GS CONTRIBUTION FOR TOTAL ZINC					
FRACTION	CONCENTRATION GS (mg/kg)	DBA (mg/kg)	FRACTIONAL MASS % GS	MASS % DBA	GS CONTRIBUTION TO TOTAL (as %age)
P9.5 mm (3/8")	52926.0	2347.4	4.60%	95.40%	52.09%
P4.75 mm (No.4)	26707.0	3826.6	15.50%	84.50%	56.14%
P2.36 mm (No.8)	5831.0	4039.9	16.80%	83.20%	22.57%

4.9 ISSUES OF RESIDUALS MANAGEMENT AND PROCESSING

The two major concerns with utilizing bottom ash are it's physical and chemical characteristics. From a physical point of view, bottom ash's grain size distribution seems to be appropriate to use as a natural aggregate substitute in many applications, for example as road sub-base. However, some comment should be made on the composition of material in bottom ash before it is recommended for this use. Bottom ash's chemistry is also of concern, especially if it fails the regulatory LEP. The frequency of LEP failures for the fine minus 9.5 mm fractions will help determine if the finer fractions of bottom ash should be removed and dealt with as a separate residual stream. The test results from the in-situ bottom ash monofill leachate study at the PML should be relied on heavily to determine if bottom ash can be utilized "as is" with minimal processing, sifting, and segregation. The strength of bottom ash, i.e. its resistance to abrasion ($MgSO_4$ test), should be considered as part of future work.

The sorting of coarse plus 9.5 mm fractions of bottom ash can be used to judge it's suitability for utilization. Certain materials in unprocessed bottom ash are deemed "undesirable" depending on bottom ash's final use. For example, most civil engineering applications such as road construction or fill require relatively inert materials. Bottom ash that contains iron that can oxidize or organics that can decompose is not inert. These materials have been deemed "undesirable" for most applications, but their impact may be minimal if small quantities are present. Glass may also be "undesirable" for certain applications because it can break into smaller particles which could lead to settling. "Other" material may also be undesirable because it tended to be friable. One way to solve this problem would be to provide adequate compaction of bottom ashes being used for fill or road applications.

The 1991 and 1992-93 characterization results were examined to comment on the suitability of using bottom ash for civil works. Depending on which application ash is being considered for it may be possible to include glass materials, for others it may be necessary to remove glass. In all cases, as much magnetic material as possible should be removed. Generally, the "burnout" of the bottom ash is sufficient and there is an acceptable amount of organic material present in bottom ash. An examination of the percentage of undesirable material, including and excluding glass, is given in Tables 4.64 to 4.67.

If glass is included as an undesirable material then 30.5% and 24.5% of the material in bottom ash in 1991 and 1992-93 respectively is undesirable (Tables 4.64 and 4.65). This may be an unacceptable amount of contaminant for utilization applications, but this will depend on the material specifications required. If glass is deemed to be acceptable then the amount of undesirable material in bottom ash is reduced significantly. In 1991 the percent of undesirable material in the bottom ash, excluding glass, was 13.4% (Table 4.66) and in 1992-93 it was 7.3% (Table 4.67). The fact that the ferrous recovery system at the Burnaby Incinerator was improved after the 1991 study has made bottom ash a much more acceptable material. If glass in the coarser fractions is acceptable then it may be possible to use bottom ash for applications such as road sub-base. However, the BCMMS (Table 4.4) require that 0 to 15% and 0 to 8% by weight of an aggregate must pass 0.150 mm and 0.075 mm sieves repectively. Therefore, a more detailed grain size distribution analysis of the fine fractions of bottom ash is required.

The GVRD and Bel Construction Ltd. (Vancouver) are currently assessing a trial of mixing bottom ash with crushed concrete in a 70:30 blend of crushed concrete to bottom ash. The concrete and bottom ash were crushed, screened to minus 75 mm (3"), and then passed through a magnetic separation process. The crushed concrete is also visually inspected and "undesirable" materials, for example organics like pieces of wood, are removed. The blended material mentioned is currently undergoing a field trial in a test section of roadbed at the old Coquitlam Landfill in Coquitlam, BC.

Table 4.64 1991 COARSE FRACTION MATERIAL ACCEPTABILITY (includes glass)

1991 UNDESIRABLE MATERIAL (INCLUDES GLASS)				
FRACTION		**P12.5 mm**	**P25 mm**	**P50 mm**
GSD		10.42%	24.16%	15.49%
TONNES RBA	45000	4689	10872	6971
MAGNETIC		23.00%	25.80%	30.40%
PAPER AND WOOD		0.20%	0.20%	0.20%
GLASS		22.70%	14.10%	3.70%
GLASS & GLASS MIXTURES		26.70%	25.10%	11.80%
	TOTALS	72.60%	65.20%	46.10%
TONNES UNDESIRABLE	13706	3404	7089	3213
PERCENTAGE UNDESIRABLE	30.46%			

Table 4.65 1992/93 COARSE FRACTION MATERIAL ACCEPTABILITY (includes glass)

1992/93 UNDESIRABLE MATERIAL (INCLUDES GLASS)				
FRACTION		**P12.5 mm**	**P25 mm**	**P50 mm**
GSD		9.91%	24.13%	11.42%
TONNES DBA	45837	4542	11060	5235
MAGNETIC		17.50%	16.30%	11.42%
PAPER AND WOOD		0.70%	0.60%	1.30%
GLASS		30.80%	23.50%	15.30%
GLASS & GLASS MIXTURES		14.60%	15.30%	13.20%
	TOTALS	63.60%	55.70%	41.22%
TONNES UNDESIRABLE	11207	2889	6161	2158
PERCENTAGE UNDESIRABLE	24.45%			

Table 4.66 1991 COARSE FRACTION MATERIAL ACCEPTABILITY (excludes glass)

1991 UNDESIRABLE MATERIAL (EXCLUDES GLASS)				
FRACTION		P12.5 mm	P25 mm	P50 mm
GSD		10.42%	24.16%	15.49%
TONNES RBA	45000	4689	10872	6971
MAGNETIC		23.00%	25.80%	30.40%
PAPER AND WOOD		0.20%	0.20%	0.20%
	TOTALS	23.20%	26.00%	30.60%
TONNES UNDESIRABLE	6048	1088	2827	2133
PERCENTAGE UNDESIRABLE	13.44%			

Table 4.67 1992/93 COARSE FRACTION MATERIAL ACCEPTABILITY (excludes glass)

1992/93 UNDESIRABLE MATERIAL(EXCLUDES GLASS)				
FRACTION		P12.5 mm	P25 mm	P50 mm
GSD		9.91%	24.13%	11.42%
TONNES DBA	45837	4542	11060	5235
MAGNETIC		17.50%	16.30%	11.42%
PAPER AND WOOD		0.70%	0.60%	1.30%
	TOTALS	18.20%	16.90%	12.72%
TONNES UNDESIRABLE	3362	827	1869	666
PERCENTAGE UNDESIRABLE	7.33%			

The frequency of LEP failures for RBA, DBA, and GS will be useful in discussing the impact removing the grate siftings has on residuals management. In 1991 43.1% of the LEPs performed failed to meet prescribed regulatory limits for lead and cadmium (Table 4.68). The "CORRECTED PERCENTAGE" given takes into account failures for lead and cadmium that occurred for the same day, fraction, and grab. This ensured that double counting of failures was not calculated. The LEP frequency of failure was reduced significantly in 1992-93 for DBA, and was 20.4% (Table 4.69), however, there still appears to be a one in five chance that any given load, grab, or sample of minus 9.5 mm bottom ash will fail the LEP. Neither set of "odds" is satisfactory enough to allow sifted minus 9.5 mm bottom ash to be utilized in small quantities, for example truckloads. The fact that the LEP failure rate for DBA decreased is expected because lead is known to concentrate in the grate siftings. The LEP rate of failure for grate siftings was 51.9% which means this material requires special disposal precautions even though the minus 9.5 mm and 2.36 mm fractions grate siftings pass the LEP (Table 4.70). UCLM concentrations for grate siftings were: 68.4 mg/kg, 224.8 mg/kg, and 90.5 mg/kg for the minus 9.5 mm, 4.75 mm, and 2.36 mm fractions respectively. The minus 9.5 mm and 2.36 mm fractions may pass the LEP based on UCLM's, but lead was present in the siftings in high concentrations when failures occurred.

The "best" results obtained to date are for the bottom ash samples that were cut, crushed, or ground to pass a 9.5 mm sieve in an earlier study done by the GVRD (Rigo,1990 and Miller,1993b). The results of this study showed that the UCLM LEP concentration for lead and the LEP rate of failure were significantly lower than for RBA and DBA which strengthens the argument that bottom ash should not be sifted and it should be utilized "as is". Of nineteen samples collected and tested, three failed the LEP, meaning the rate of failure was 15.8%. The UCLM lead concentration for the LEPs performed was 44 mg/kg (2.2 mg/l), well below any of the 1991 RBA and 1992-93 DBA and GS results. This means that there is a one in six chance of failing the LEP but statistically you don't fail the LEP. From an ash management point of view it is not acceptable to use small loads of bottom ash because there is a good chance (1/6) that a load will fail. This tends to support the argument that there is no monetary benefit to segregating bottom ash from the siftings or separating the bottom ash into several different fractions. However, **there are definite environmental and ash management benefits for removing the grate siftings.**

If grate siftings were removed from the bottom ash and "full dilution" occurred (i.e. coarse plus 9.5 mm fraction not removed) one could be assured that the best possible material would be obtained, from an environmental and regulatory perspective. The 1/6 chance of failing the LEP would be significantly lower and it would be possible to utilize "truck loads" of bottom ash without harming the environment. Metals would not be a problem but salts would still need to be addressed; possibly through washing or aging the bottom ash. If bottom ash is utilized above the water table and capped with asphalt then the leaching of salt is no longer a significant problem.

If three years of monthly LEP data was available for all of the fractions in question it would be possible to determine what the minimum size of bottom ash loads and mixtures should be to safely utilize small loads of ash (i.e. truckloads). It should be possible to stockpile ash from a three or four month period in order to reduce the 1/6 or 15% LEP failure rate. Bottom ash would then have an acceptably low probability of failure allowing small quantities of various fractions to be utilized. At the present time it is felt that he entire bottom ash stream is “regulatory safe” to use but for individual fractions this is not the case. If the grate siftings were removed with a subsequent reduction in lead, then the DBA is more acceptable. An adequate data base has not been compiled on the entire bottom ash stream because there is currently no regular bottom ash monitoring program in place; with or without grate siftings. This is something the GVRD may wish to address in future.

If bottom ash is split or sifted into different fractions and the siftings are removed a greater frequency of LEP failures result than if the entire bottom ash stream had been left untouched. The grate siftings' minus 4.75 mm fraction is a special waste and would have to be disposed of accordingly or incur costly processing to remove lead. Sifting bottom ash creates a higher proportion of “undesirable” material on a mass basis because the mass contribution of the minus 9.5 mm fractions are removed. It is generally felt that the minus 9.5 mm fractions of bottom ash are desirable from a material properties point of view, and therefore should not be removed or segregated.

Preliminary leachate results from the PML in-situ bottom ash monofill indicate that salts and not metals may pose an environmental problem and that regular and desifted bottom ash produces leachate that is almost identical. In order to mitigate the concern with salt release, bottom ash could be washed before it is used to dissolve and remove the salts. Washing the ash could have an additional benefit by lowering LEP metal concentrations; certain metals are known to exist as soluble metal salts and washing the ash could potentially reduce them. Wash water would have to be collected and treated; perhaps it could be discharged to the sanitary sewer system, but this would require analysis

The entire bottom ash stream, including grate siftings, can be utilized in large quantities because it does not appear to pose a threat to the environment or be of regulatory concern. To improve bottom ash's characteristics (i.e. lower LEP failure rate and smaller acceptable load size) the siftings can be removed. Sifting bottom ash into several different fractions does not appear to offer significant benefits.

Table 4.68 NUMBER OF LEP FAILURES IN 1991 FOR REGULAR BOTTOM ASH

FREQUENCY OF FAILURES 1991 REGULAR BOTTOM ASH FINE FRACTIONS				
METAL	P9.5 mm	P4.75 mm	P2.36 mm	TOTALS
Cd	0	1/72	3/72	4/216
Cr	0	0	0	0
Cu	0	0	0	0
Fe	0	0	0	0
Mn	0	0	0	0
Ni	0	0	0	0
Pb	19/72	40/72	33/72	92/216
Zn	0	0	0	0
TOTALS	19/72	41/72	36/72	96/216
CORRECTED	19/72	40/72	34/72	**93/216**
PERCENT				**43.06%**

Table 4.69 NUMBER OF LEP FAILURES IN 1992/93 FOR DESIFTED BOTTOM ASH

FREQUENCY OF FAILURES 1992/93 DESIFTED BOTTOM ASH FINE FRACTIONS				
METAL	P9.5 mm	P4.75 mm	P2.36 mm	TOTALS
Cd	0	0	7/36	7/108
Cr	0	0	0	0
Cu	0	0	0	0
Fe	0	0	0	0
Mn	0	0	0	0
Ni	0	0	0	0
Pb	4/36	9/36	3/36	16/108
Zn	0	0	0	0
TOTALS	4/36	9/36	10/36	23/108
CORRECTED	4/36	9/36	9/36	**22/108**
PERCENT				**20.37%**

Table 4.70 NUMBER OF LEP FAILURES IN 1992/93 FOR GRATE SIFTINGS

FREQUENCY OF FAILURES 1992/93 GRATE SIFTINGS				
METAL	P9.5 mm	P4.75 mm	P2.36 mm	TOTALS
Cd	0	0	0	0
Cr	0	0	0	0
Cu	0	0	0	0
Fe	0	0	0	0
Mn	0	0	0	0
Ni	0	0	0	0
Pb	4/9	7/9	3/9	14/27
Zn	0	0	0	0
TOTALS	4/9	7/9	3/9	14/27
CORRECTED	4/9	7/9	3/9	**14/27**
PERCENT				**51.85%**

5. CONCLUSIONS

5.1 PHYSICAL RESULTS

5.1.1 GRAIN SIZE DISTRIBUTION

Nearly identical RBA and DBA grain size distributions were obtained in 1991 and 1992-93, meaning that even though bottom ash is heterogeneous in nature its grain size distribution is predictable.

The largest fraction of ash, almost 25%, is the minus 25 mm (P1") fraction. A decreasing particle size did not always result in an increased metal leachate concentration, meaning that other chemical reactions or properties are governing solubility of heavy metals.

In order to use desifted bottom ash as road sub-base the approximately 15% of oversized material (plus 25 mm) must be removed or crushed to meet BC's Master Municipal Specifications (1991).

5.1.2 COMPACTION DENSITY

Optimum densities obtained by the author ranged betwen 2.00 to 2.10 g/cm^3 at a water content of approximately 13%. Based on Terra Engineering results, the average optimum dry unit weight of the desifted bottom ash is 1.87 g/cm^3 at a water content of 12.2%.

5.1.3 CHARACTERIZATION

The physical composition of bottom ash is consistent over large sampling periods which has a favorable impact on engineering properties.

Glass and glass mixtures make up the majority of bottom ash and accounted for approximately 25% or 7,290 of the 45,837 tonnes of bottom ash generated in 1992-93. Glass accounted for 9.1% or 4,167 tonnes and glass mixtures 15.9% or 7,290 tonnes. A significant amount of ferrous material is bypassing the magnetic belt separator (6,003 tonnes in 1991 and 3,797 tonnes in 1992-93), but there was a 36.7% increase in recovery after 1991. An increase in the ferrous material recovery has taken place because the magnetic belt/conveyor separator was lowered in order to capture more material. It may be that this method of recovery has reached its optimum level given that the belt can only be lowered so much. It is physically impractical to go too low because of the types of residue that are discharged and must pass underneath the separator. A secondary magnetic separation process may be warranted and should be examined as an option to enhance the utilization of bottom ash and add value to the product.

5.2 CHEMICAL RESULTS

5.2.1 LEACHATE EXTRACTION PROCEDURE

For the majority of bottom ash and desifted bottom ash samples taken there tended to be low spatial variability in the LEP metal concentrations. Variability decreased in the finer fractions because surface area to mass of sample ratios decreased and better particle mixing is possible. Both regular bottom ash and desifted bottom ash LEP concentrations increased with decreasing particle size as a general rule, but exceptions to this rule were iron, copper, and lead. Iron concentrations decreased with decreasing particle size. Both copper and lead had their highest concentrations in the middle minus 4.75 mm (P4) fraction of ash.

Significant reductions in leachable lead were obtained when comparing the 1991 RBA and 1992-93 DBA LEP results. These reductions were not solely due to the removal of the grate siftings from the bottom ash stream since it has been shown that on a mass basis, the siftings do not contain enough lead to account for the entire reduction. Factors such as the removal of lead from paints, pigments, and inks, combined with improved battery recycling initiatives has contributed to reductions in the amount of lead in the feedstock, which in turn has reduced the amount of lead in incineration residuals, and therefore bottom ash.

The 90% Upper Confidence Limit of the Mean (UCLM), as prescribed and defined in the USEPA's SW-846 (1986) was used to interpret the metal concentration data collected. Based on these calculations, the regulatory limits set, and the information presented **the desifted bottom ash from the Burnaby Incinerator is not a special waste** or of regulatory concern. However, several samples and certain fractions did fail the LEP and are of environmental concern. The minus 4.75 mm (P4) and minus 2.36 mm (P8) fractions of regular bottom ash exceed the LEP criteria for Special Wastes. The minus 4.75 mm fraction of the grate siftings is a "Special Waste" based on the results of this study. The UCLM LEP lead concentrations for the minus 9.5 mm (68.4 mg/kg) and the 2.36 mm (90.5 mg/kg) fractions of grate siftings are close to the limit (100 mg/kg) so this conclusion should be considered carefully, especially since more analysis of the grate siftings is recommended.

If the grate siftings had not been removed from the bottom ash stream in 1992-93 there would have been more LEP failures.

The LEP does not model monofill field leaching test results well. Based on monofill field leachate studies done at the Port Mann Landfill (PML) in BC, lead concentrations, as well as the other metals examined, should not be viewed as a regulatory or environmental concern. In-situ bottom ash monofill results indicate that very little lead is leachable. In the first six months of a study done at PML field leachates ranged between 0.06 to 0.08 mg/l for lead. This range is far below the maximum concentration of lead allowed for in the LEP (5.00 mg/l).

5.2.2 AQUA REGIA DIGESTION OF LEP SOLIDS

The ARD procedure used here is not as an aggressive or rigorous digestion as the Sequential Chemical Extraction (SCE), which in its final stages digests the metals which are tightly bound to silica matrices, and are essentially unavailable for leaching in a naturally occurring environment (i.e. stable metals). It was felt that if the metals are not available for leaching their environmental impact would be negligible. The ARD of the LEP solids is aggressive enough to dissolve any metals that may be environmentally available and left over after the LEP. The ARD of the LEP solids results were necessary to comment on "total" metals and were used in the partitioning analysis. Iron is present in the bottom ash and grate siftings at the highest concentration, followed by copper and then zinc.

5.2.3 PARTITIONING

Copper, nickel, lead, and zinc clearly partition in the grate siftings. Copper can melt and pass through the grates given normal operating pile temperatures. Melting point temperatures for lead and zinc are exceeded at the grates. UCLM total copper concentrations have been shown to be two to four times greater in the siftings than in desifted bottom ash. UICLM total lead is estimated to be approximately 7.4, 4.9, and 3.5 times greater in concentration in the siftings than in the DBA for the minus 9.5 mm (P3/8"), 4,75 mm (P4), and 2.36 mm (P8) fractions of ash respectively. UCLM concentration values for total zinc were 22.5, 7.0, and 1.4 times greater in the siftings versus the DBA for the minus 9.5 mm, 4.75 mm, and 2.36 mm fractions respectively.

It was determined that approximately 20%, 42%, and 45% of the lead in the minus 9.5 mm, 4.75 mm, and 2.36 mm fractions respectively of bottom ash originates from the grate siftings. This is of significance given the grate siftings account for only 6.1% of the bottom ash stream by weight.

5.2.4 METAL SOLUBILITY

Certain metals and fractions were deemed to be LEP soluble after comparing UCLM LEP metal concentrations to UCLM total metal concentrations. For DBA the following metals and fractions were listed as being soluble:

cadmium	minus 9.5 mm, 4.75 mm, and 2.36 mm
manganese	minus 4.75 mm and 2.36 mm
nickel	minus 2.36 mm
zinc	minus 4.75 mm and 2.36 mm.

Only the minus 4.75 mm and 2.36 mm fractions for cadmium and the minus 2.36 mm fraction for zinc for the grate siftings were listed as being soluble. The bulk of the fractions and metals examined were listed as being LEP insoluble given the criteria used.

The driving force behind a metals leachability or solubility was it's initial presence in the sample. If lead, for example, was present in a grab or a sample this was reflected in the LEP concentration. Lead was listed as being insoluble in the bottom ash and grate siftings.

5.3 UTILIZATION AND MANAGEMENT

When considering ash management on a large scale, for example on an annual basis, one can be confident that bottom and desifted ash is not a special waste. If ash management was ever to take on a truck load by truck load philosophy, then one could not be sure of the residues' environmental "acceptability", because a given truck load of ash may not always pass regulatory tests for leachable metals. Compounding this management dilemma, is the question of sifting the ash into a number of different fractions which can concentrate leachable metals in the finer fractions. Diverting the grate siftings from the bottom ash stream significantly reduces the chances of smaller volumes of desifted bottom ash ever being classified a special waste but it creates a new problem because the siftings are a special waste. Bottom ash that includes the siftings and has not been segregated into several fractions passes the LEP but still has a 1/6 LEP failure rate. Undiluted (i.e. entire residual stream) bottom ash with the grate siftings removed is expected to have an even "better" or lower LEP failure rate.

In order to comment on seasonally high LEP concentrations three years of monthly data is required so trends can be identified accurately. Seasonal data would provide the information required to determine how small a load of bottom ash could be so that it would not fail the LEP.

Metals such as copper, lead, and iron were observed in the bottom ash in elemental form, therefore, a portion of these metals could potentially be removed and recovered with some form of mechanical separation.

5.4 GENERAL

The chemical nature or characteristics of bottom ash (BA) are of importance for two reasons. First, if BA has an adverse effect on the environment or does not pass regulatory tests it cannot be utilized and diverted from landfills. Secondly, the chemical nature of bottom ash will dictate which uses it is most suited for. For example, the chemical composition of ash is extremely important if it is to be used in the concrete or cement industry.

The Leachate Extraction Procedure (LEP) is used to assess the leaching characteristics of metals from incineration residuals and is a regulatory test which, when combined with criteria, is used to classify Special Wastes in BC.

One of the shortcomings associated with deficient environmental sampling programs and subsequent analysis is that a residue or waste can be described as being within regulatory limits when it may actually be above the limit and out of compliance (the opposite is also possible). This may happen if a sampling program is not statistically valid or the analytical results are not interpreted correctly.

The intent of this study was to shed some light into the physical makeup as well as the metal chemistry of bottom ash and grate siftings. The characterization of bottom ash and grate siftings from an environmental perspective will lead to more appropriate or alternative uses for these residue streams. Aside from the fact that bottom ash should not be sifted or segregated, possible uses for the coarse bottom ash fractions are as an aggregate for concrete or fill material. Fine fractions might possibly be used in the manufacture of Portland cement, but issues of concern are the alkalinity, the sodium and silica content, and the metals present in the fine fractions.

If bottom ash is to be used as a substitute for natural aggregates it will have to be less expensive than natural aggregates. It will also have to overcome the stigma of being a residual material and uncertainty regarding its performance. Possible future environmental liability will have to be mitigated with more testing and analysis, especially of the grate siftings.

6. RECOMMENDATIONS

In order to make comparisons between LEP and TOTAL metals analysis for a given sample the solids remaining after the LEP must be collected and subjected to the acid digestion used to determine TOTAL metals. If this is not done the same samples are not being compared. Duplicate work performed has proven that two 50 gram samples from a properly collected grab provide different metals concentrations. It is extremely important to collect filtered solids after a LEP and carry these through the digestion procedure used to determine TOTAL metals. The leachabilty ratio (leachable fraction) can be determined, the ratio of the mass of a metal in the leachate to the mass of that metal present in the ash sample. The SCE protocol provides an excellent stepwise look into how the ash behaves and the sum of all five extractions provides total metal information. Wherever possible this test procedure should be used.

More work needs to be done examining the effects of conditioning or storing the bottom ash to allow specific comparisons between the chemistry of fresh and aged bottom ash. The GVRD should analyze the “initial” and “final” samples taken from the ash monofills at the Port Mann Landfill expeditiously, in conjunction with aging studies. Other authors have stated that aging improves the environmental acceptability of incineration residuals. The problem with aging is additional costs are required due to a need for storage space and leachate collection. Stegemann and Schneider (1990) found that conditioning bottom ash by several months did not affect the total amount of metals present, but did appear to reduce the initial leachability of the metals. Alumino-silicate and carbonation reactions, which lower the bottom ashes pH and minimize metals solubility, may cause this reduction in leachability and solubility. This needs to be clarified because lead, for example, is amphoteric and may still leach at lower pHs.

It is recommended that the economic feasibility of removing and recovering elemental metals be examined. It was not within the scope of the work performed to comment on the cost of ash benefaction.

Additional grate siftings samples should be collected and tested to increase the accuracy and precision (increase confidence) in the LEP concentration results..

A 50 gram sample of minus 9.5 mm material represents a small number of particles. The material in each of these particles, for example an elemental metal, can have a significant effect on LEP results. The inverse relationship between particle size and UCLM LEP concentration is not effected as greatly for the finer minus 2.36 mm fraction. for this reason, a larger LEP sample mass would improve precision or reproducibility for larger fractions because bottom ash is so heterogeneous. Larger masses of sample and volumes of extraction fluid should be used to meet required liquid to solid (L:S) ratios. For example, instead of using fifty (50) grams of sample with one (1) litre of extraction fluid, use one hundred (100) grams in two (2) litres for a 50:1 L:S. In the case of the minus 9.5 mm (P3/8") fraction this would decrease the variability in concentration results.

Bottom ash blended with crushed concrete should be studied in detail as a suitable natural aggregate substitute for road sub-base. The GVRD is currently monitoring a road test section at the old Coquitlam landfill to determine if a 70:30 blend of crushed concrete and bottom ash meets physical and environmental standards.

If bottom ash is to be used as road sub-base it is felt that removing the siftings from the bottom ash will not improve it's physical or environmental properties significantly for this purpose. Depending on the final use of bottom ash, the grate siftings may have to be removed to improve the 15.8% (1/6) LEP failure rate. Removing the siftings will add some cost to materials management practices but provide a significant environmental benefit. This benefit should be explored further, and undiluted desifted bottom ash should be studied to determine its LEP failure rate.

Utilization opportunities (such as road sub-base) that do not require separation of bottom ash into different fractions should be pursued. Removing the grate siftings from bottom ash creates a special waste because lead concentrates in the siftings. Grate siftings account for 2,800 of the roughly 45,000 tonnes of bottom ash produced a year and there may be an effective method of recovering lead from this residual stream. The leachable metal results from this study examined the P3/8", P4, and P4 fractions of the bottom ash stream which represent only 45% of the total bottom ash stream. When the remaining 55% of the bottom ash stream is included it is known that the bottom ash is not a special waste, therefore the should not be diluted or separated into finer fractions.

Bottom ash should be utilized in controlled dry environments, for example, as road base material above the water table and it should be capped by asphalt. Care should be taken to capture or mitigate runoff and leachate during utilization.

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WASTE Program Consortium, Waste Analysis, Sampling, Testing, and Evaluation (WASTE) Program: Effect of Waste Stream Characteristics on MSW Incineration: The Fate and Behavior of Metals, Mass Burn MSW Incineration (Burnaby, BC), Final Report Environment Canada, US Environmental Protection Agency, The International Lead Zinc Research Organization, and the Greater Vancouver Regional District, A Project Designed and Conducted by a Consortium including: A.J. Chandler and Associates Ltd., Rigo and Rigo Associates Inc., The Environmental Research Group-University of New Hampshire, and Wastewater Technology Center, Volumes I, II, III, and IV, 1992.

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Appendix A REGULAR BOTTOM ASH DATA

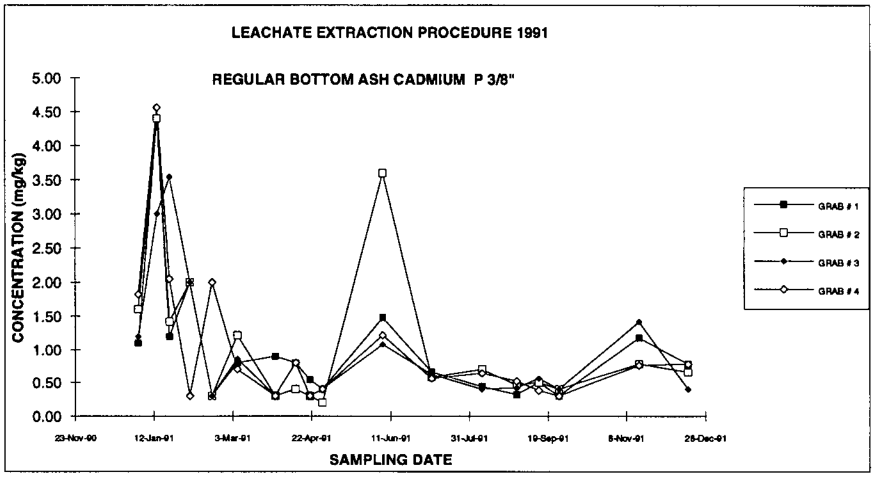

Figure A.1 RBA LEP Cd P3/8"

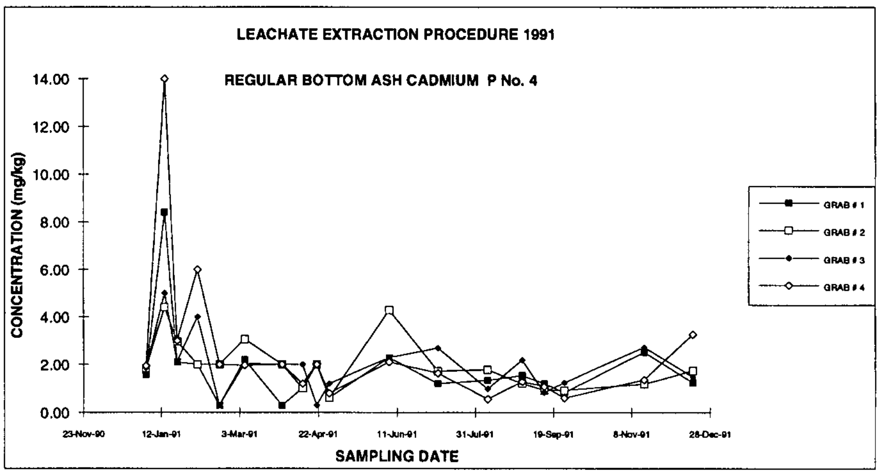

Figure A.2 RBA LEP Cd P4

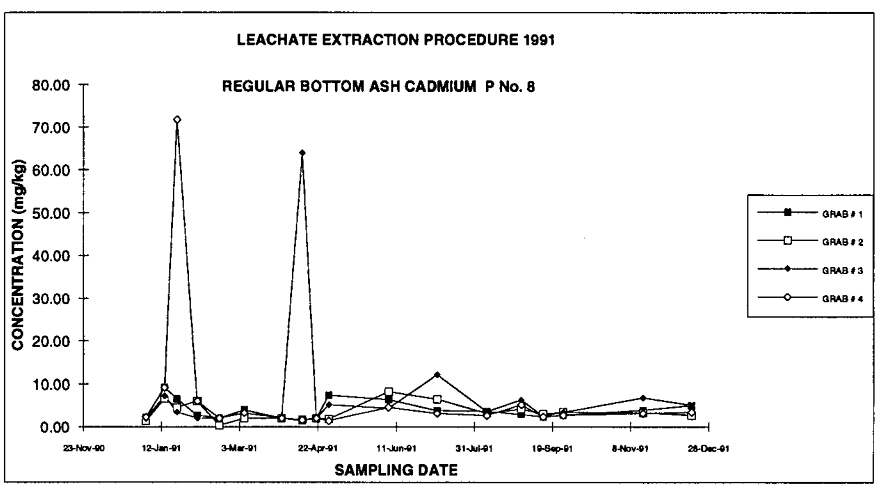

Figure A.3 RBA LEP Cd P8

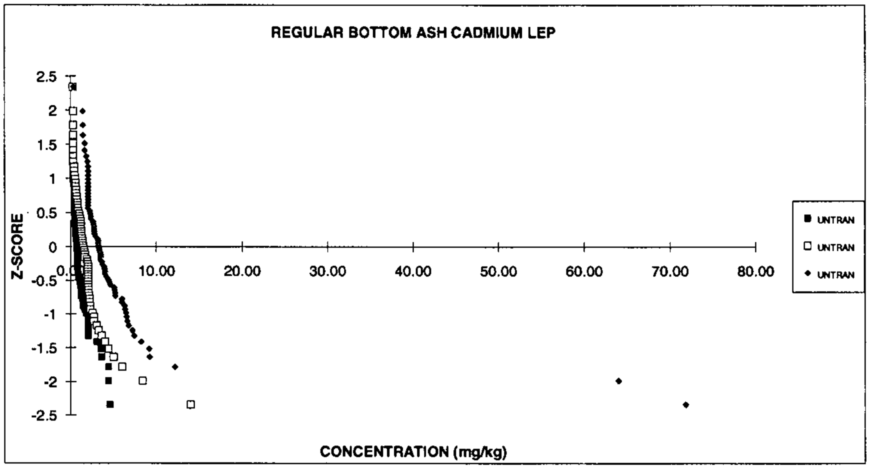

Figure A.4 RBA UNTRANSFORMED Z-SCORE Cd

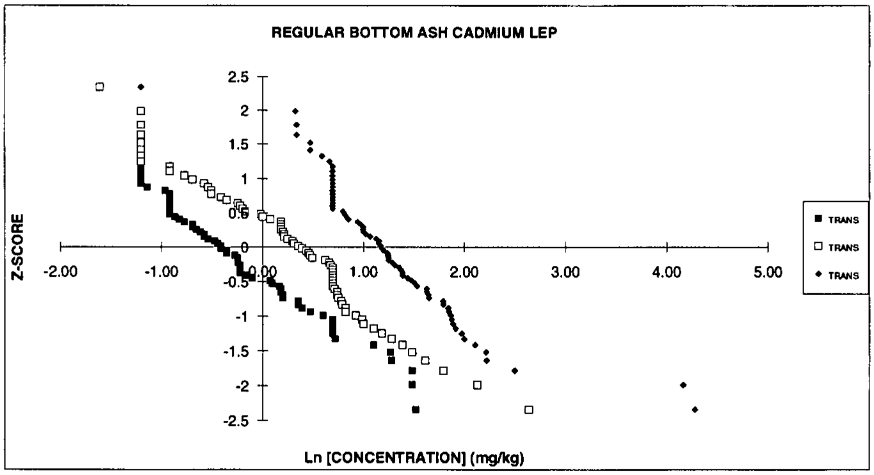

Figure A.5 RBA TRANSFORMED Z-SCORE Cd

Table A.1 DESCRIPTIVE STATISTICS FOR RBA LEP Cd DATA

DESCRIPTIVE STATISTICS FOR RBA LEP Cd DATA					
P3/8 UNTRANS		*P4 UNTRANS*		*P8 UNTRANS*	
Mean	1.032083333	Mean	1.8672222	Mean	5.5577778
Standard Error	0.120027373	Standard Error	0.2362707	Standard Error	1.2795121
Median	0.66	Median	1.45	Median	3.24
Mode	0.3	Mode	2	Mode	2
Standard Deviation	1.018466034	Standard Deviation	2.0048232	Standard Deviation	10.85702
Variance	1.037273063	Variance	4.0193161	Variance	117.87489
Kurtosis	4.305133473	Kurtosis	19.681926	Kurtosis	30.98568
Skewness	2.144344157	Skewness	3.845338	Skewness	5.5362839
Range	4.36	Range	13.8	Range	71.5
Minimum	0.2	Minimum	0.2	Minimum	0.3
Maximum	4.56	Maximum	14	Maximum	71.8
Sum	74.31	Sum	134.44	Sum	400.16
Count	72	Count	72	Count	72
Confidence Level (95%)	0.23524898	Confidence Level (95%)	0.4630813	Confidence Level (95%)	2.507794
UCLM	1.187518782	UCLM	2.1731928	UCLM	7.214746
P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	-0.30667444	Mean	0.2629245	Mean	1.2510345
Standard Error	0.091922358	Standard Error	0.1010259	Standard Error	0.0911558
Median	-0.41551544	Median	0.3713495	Median	1.1755543
Mode	-1.2039728	Mode	0.6931472	Mode	0.6931472
Standard Deviation	0.779987071	Standard Deviation	0.8572336	Standard Deviation	0.7734824
Variance	0.608379831	Variance	0.7348494	Variance	0.5982751
Kurtosis	-0.32791628	Kurtosis	0.0836838	Kurtosis	5.5360211
Skewness	0.667326781	Skewness	-0.0568274	Skewness	1.1945441
Range	3.126760536	Range	4.2484952	Range	5.4778573
Minimum	-1.60943791	Minimum	-1.6094379	Minimum	-1.2039728
Maximum	1.517322624	Maximum	2.6390573	Maximum	4.2738845
Sum	-22.0805595	Sum	18.930563	Sum	90.074482
Count	72	Count	72	Count	72
Confidence Level (95%)	0.180164244	Confidence Level (95%)	0.1980069	Confidence Level (95%)	0.1786618
UCLM	-0.18763498	UCLM	0.3937531	UCLM	1.3690812
UCLM TRANS BACK	0.828917221	UCLM TRANS BACK	1.4825345	UCLM TRANS BACK	3.9317366

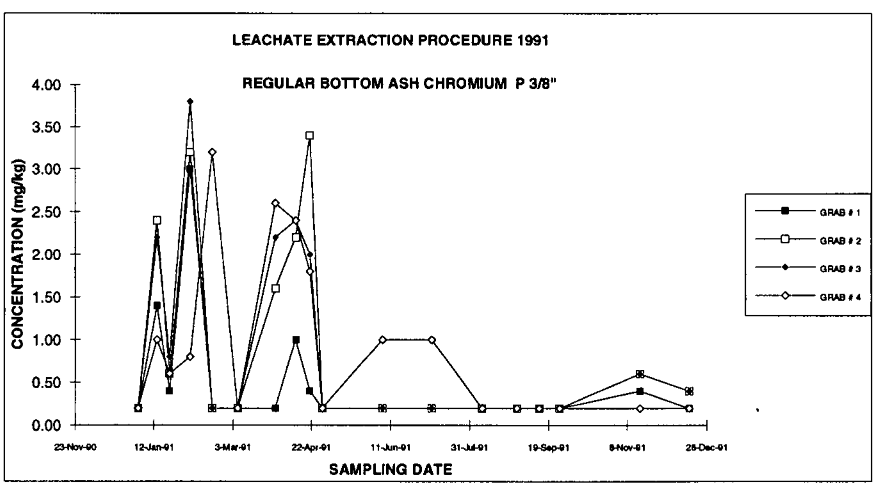

Figure A.6 RBA LEP Cr P3/8"

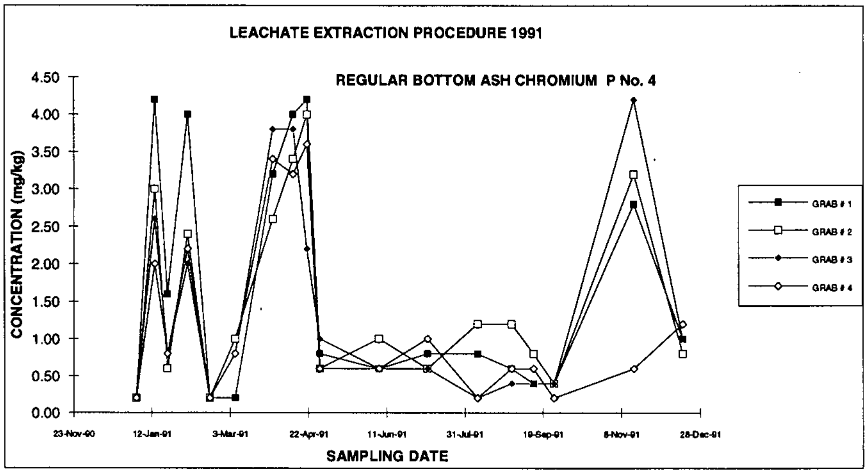

Figure A.7 RBA LEP Cr P4

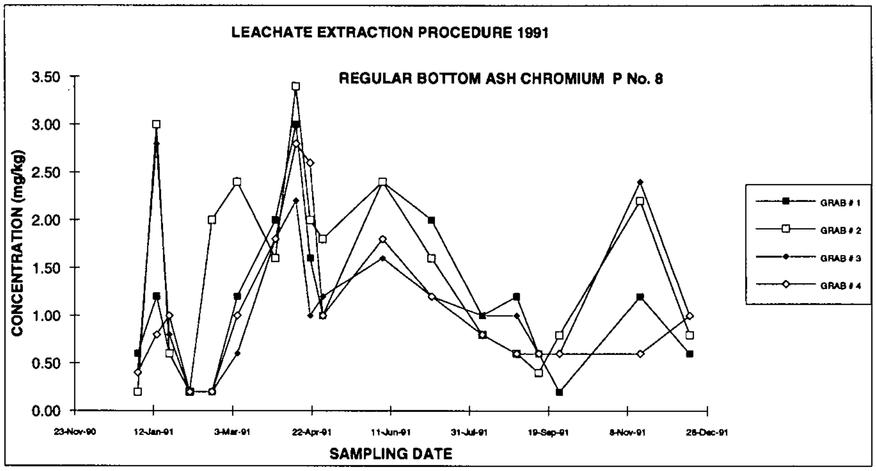

Figure A.8 RBA LEP Cr P8

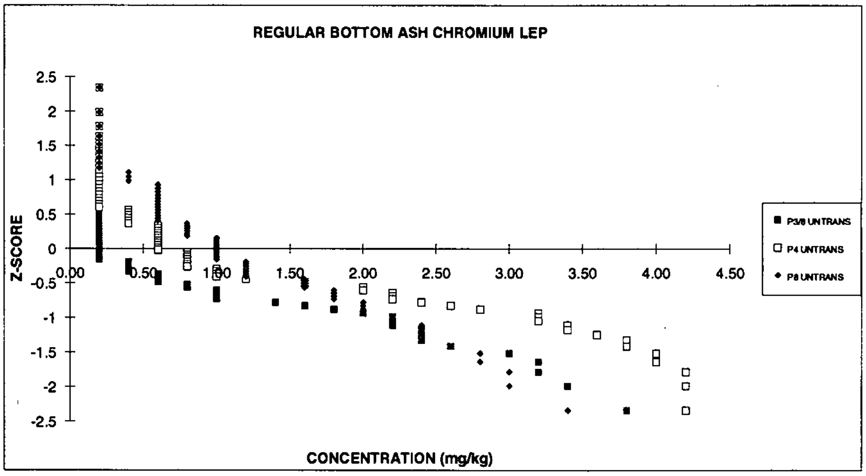

Figure A.9 RBA UNTRANSFORMED Z-SCORE Cr

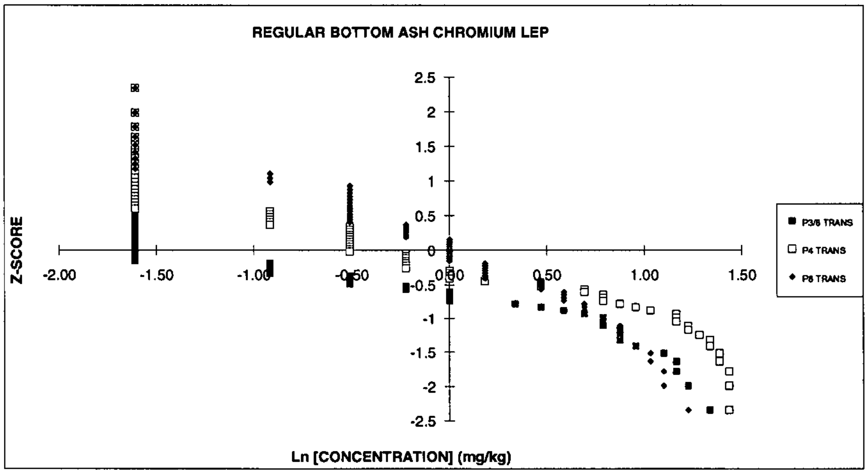

Figure A.10 RBA TRANSFORMED Z-SCORE Cr

Table A.2 DESCRIPTIVE STATISTICS FOR RBA LEP Cr DATA

DESCRIPTIVE STATISTICS FOR RBA Cr DATA

P3/8 UNTRANS		*P4 UNTRANS*		*P8 UNTRANS*	
Mean	0.805555556	Mean	1.3	Mean	1.2111111
Standard Error	0.115535917	Standard Error	0.1548385	Standard Error	0.0966488
Median	0.2	Median	0.6	Median	1
Mode	0.2	Mode	0.2	Mode	0.6
Standard Deviation	0.980354763	Standard Deviation	1.3138482	Standard Deviation	0.820092
Variance	0.961095462	Variance	1.7261972	Variance	0.6725509
Kurtosis	1.265034004	Kurtosis	-0.2981998	Kurtosis	-0.2630515
Skewness	1.573928446	Skewness	1.080329	Skewness	0.786084
Range	3.6	Range	4	Range	3.2
Minimum	0.2	Minimum	0.2	Minimum	0.2
Maximum	3.8	Maximum	4.2	Maximum	3.4
Sum	58	Sum	93.6	Sum	87.2
Count	72	Count	72	Count	72
Confidence Level (95%)	0.226445901	Confidence Level (95%)	0.3034774	Confidence Level (95%)	0.1894278
UCLM	0.955174568	UCLM	1.5005159	UCLM	1.3362713

P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	-0.81999455	Mean	-0.2801002	Mean	-0.075262
Standard Error	0.122379488	Standard Error	0.1272184	Standard Error	0.0936026
Median	-1.60943791	Median	-0.5108256	Median	0
Mode	-1.60943791	Mode	-1.6094379	Mode	-0.5108256
Standard Deviation	1.038424387	Standard Deviation	1.0794836	Standard Deviation	0.7942444
Variance	1.078325208	Variance	1.1652848	Variance	0.6308242
Kurtosis	-0.88951171	Kurtosis	-1.3125252	Kurtosis	-0.4535156
Skewness	0.859422068	Skewness	0.1841911	Skewness	-0.5111415
Range	2.944438979	Range	3.0445224	Range	2.8332133
Minimum	-1.60943791	Minimum	-1.6094379	Minimum	-1.6094379
Maximum	1.335001067	Maximum	1.4350845	Maximum	1.2237754
Sum	-59.0396078	Sum	-20.167213	Sum	-5.4188671
Count	72	Count	72	Count	72
Confidence Level (95%)	0.239859033	Confidence Level (95%)	0.249343	Confidence Level (95%)	0.1834575
UCLM	-0.66151312	UCLM	-0.1153524	UCLM	0.0459533
UCLM TRANS BACK	0.51606987	UCLM TRANS BACK	0.8910521	UCLM TRANS BACK	1.0470255

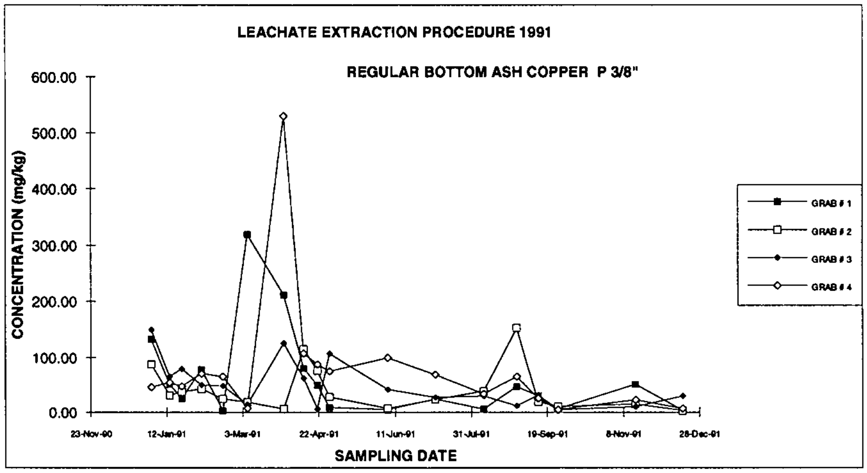

Figure A.11 RBA LEP Cu P3/8"

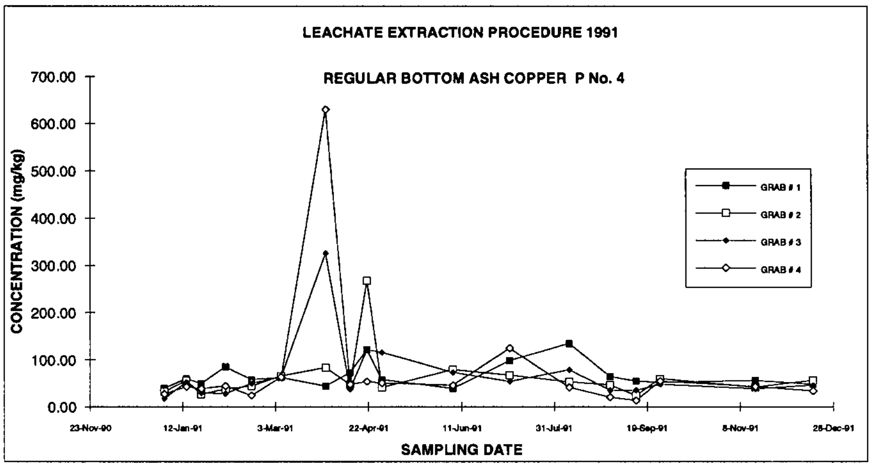

Figure A.12 RBA LEP Cu P4

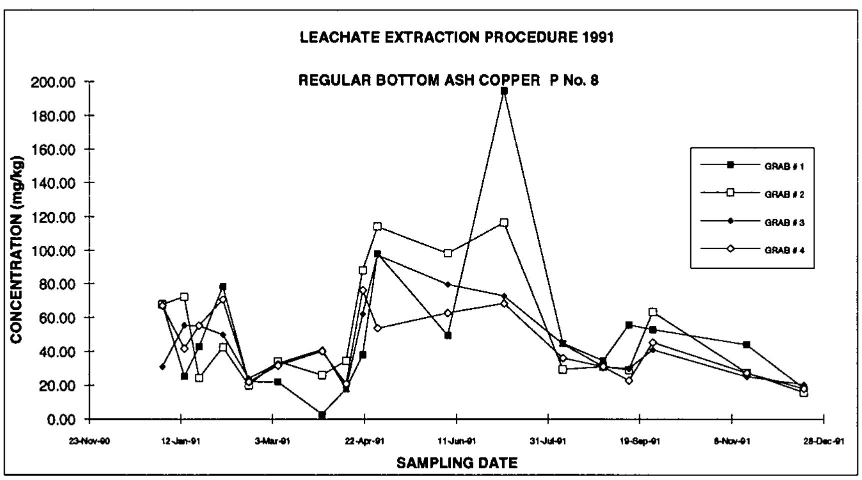

Figure A.13 RBA LEP Cu P8

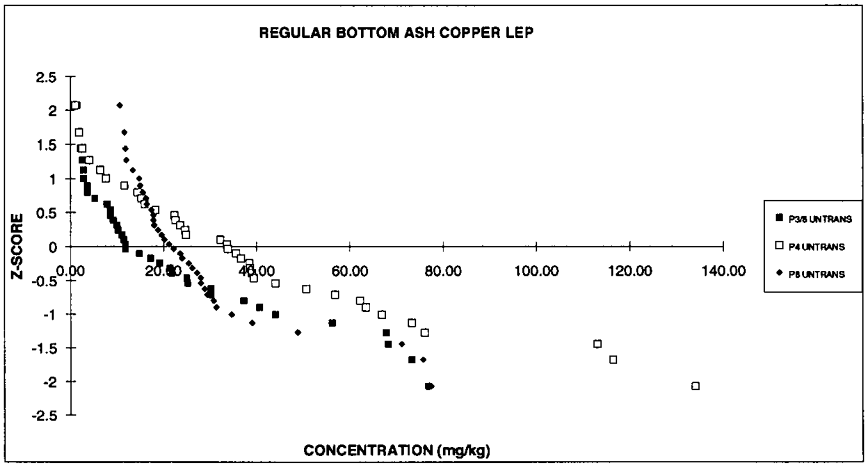

Figure A.14 RBA UNTRANSFORMED Z-SCORE Cu

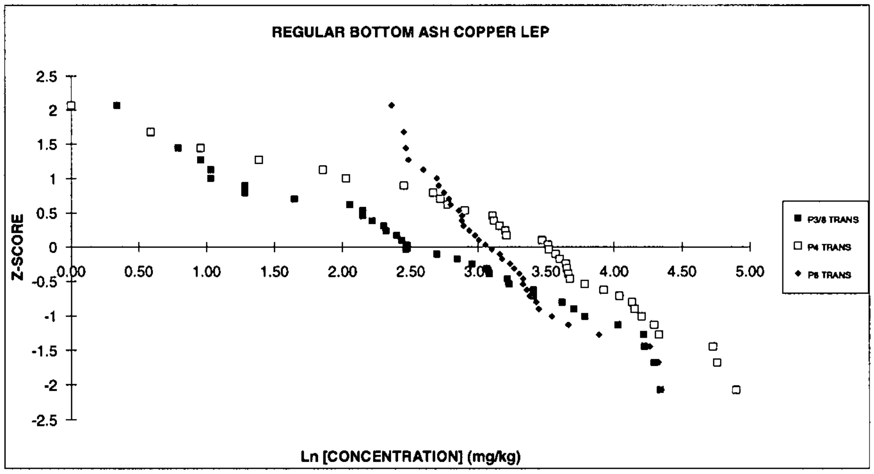

Figure A.15 RBA TRANSFORMED Z-SCORE Cu

Table A.3 DESCRIPTIVE STATISTICS FOR RBA LEP Cu DATA

DESCRIPTIVE STATISTICS FOR RBA LEP Cu DATA					
P3/8 UNTRANS		*P4 UNTRANS*		*P8 UNTRANS*	
Mean	57.93055556	Mean	63.694444	Mean	47.783333
Standard Error	9.112441545	Standard Error	9.5955682	Standard Error	3.5770345
Median	37.7	Median	46.8	Median	40.9
Mode	2.8	Mode	24	Mode	31
Standard Deviation	77.32163052	Standard Deviation	81.421096	Standard Deviation	30.352145
Variance	5978.634546	Variance	6629.3949	Variance	921.25268
Kurtosis	20.56942177	Kurtosis	34.470186	Kurtosis	6.7353292
Skewness	3.966213976	Skewness	5.3587147	Skewness	2.0187921
Range	527.2	Range	627.2	Range	191.8
Minimum	2.8	Minimum	2.8	Minimum	2.8
Maximum	530	Maximum	630	Maximum	194.6
Sum	4171	Sum	4586	Sum	3440.4
Count	72	Count	72	Count	72
Confidence Level (95%)	17.86003079	Confidence Level (95%)	18.80694	Confidence Level (95%)	7.0108485
UCLM	69.73116736	UCLM	76.120705	UCLM	52.415593
P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	3.452745311	Mean	3.8018084	Mean	3.6889541
Standard Error	0.138503581	Standard Error	0.0968278	Standard Error	0.0739279
Median	3.629572138	Median	3.8457371	Median	3.7111271
Mode	1.029619417	Mode	3.1780538	Mode	3.4339872
Standard Deviation	1.175241853	Standard Deviation	0.8216113	Standard Deviation	0.6272991
Variance	1.381193414	Variance	0.6750451	Variance	0.3935042
Kurtosis	-0.36788752	Kurtosis	2.7069936	Kurtosis	3.4363776
Skewness	-0.26982964	Skewness	-0.2679501	Skewness	-0.7457593
Range	5.243257589	Range	5.4161004	Range	4.2413268
Minimum	1.029619417	Minimum	1.0296194	Minimum	1.0296194
Maximum	6.272877007	Maximum	6.4457198	Maximum	5.2709462
Sum	248.5976624	Sum	273.73021	Sum	265.60469
Count	72	Count	72	Count	72
Confidence Level (95%)	0.271461628	Confidence Level (95%)	0.1897788	Confidence Level (95%)	0.1448958
UCLM	3.632107448	UCLM	3.9272004	UCLM	3.7846907
UCLM TRANS BACK	37.79237822	UCLM TRANS BACK	50.76466	UCLM TRANS BACK	44.022053

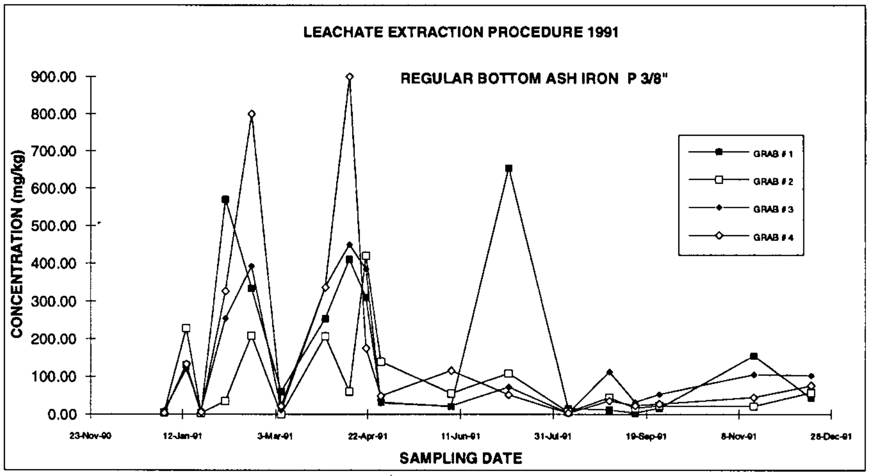

Figure A.16 RBA LEP Fe P3/8"

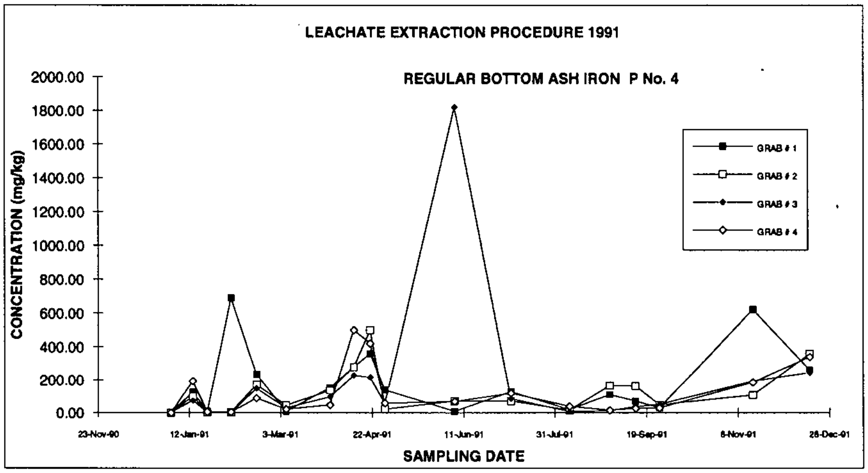

Figure A.17 RBA LEP Fe P4

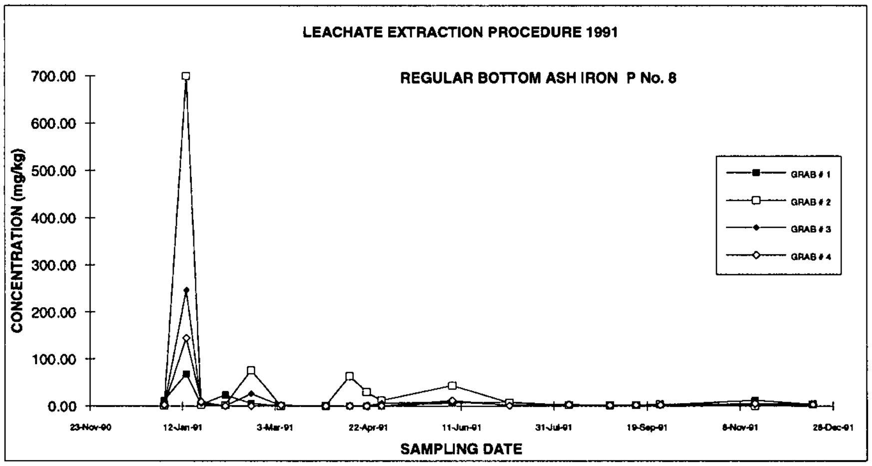

Figure A.18 RBA LEP Fe P8

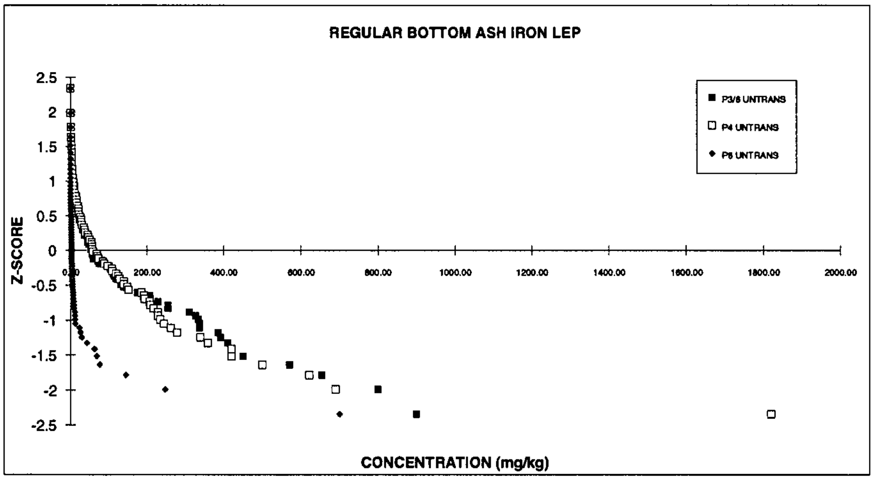

Figure A.19 RBA UNTRANSFORMED Z-SCORE Fe

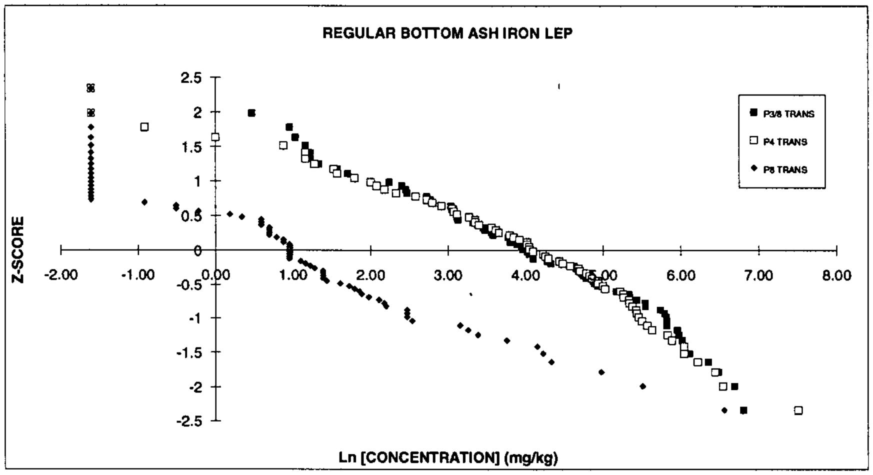

Figure A.20 RBA TRANSFORMED Z-SCORE Fe

Table A.4 DESCRIPTIVE STATISTICS FOR RBA LEP Fe DATA

DESCRIPTIVE STATISTICS FOR RBA LEP Fe DATA					
P3/8 UNTRANS		*P4 UNTRANS*		*P8 UNTRANS*	
Mean	142.8930556	Mean	143.66944	Mean	22.398611
Standard Error	22.63714258	Standard Error	29.232107	Standard Error	10.423672
Median	54.2	Median	58.8	Median	2.6
Mode	3.4	Mode	0.2	Mode	0.2
Standard Deviation	192.0825243	Standard Deviation	248.04265	Standard Deviation	88.447792
Variance	36895.69615	Variance	61525.156	Variance	7823.012
Kurtosis	4.291510709	Kurtosis	29.552044	Kurtosis	50.362384
Skewness	2.027534816	Skewness	4.766522	Skewness	6.7856417
Range	899.8	Range	1819.4	Range	699.8
Minimum	0.2	Minimum	0.2	Minimum	0.2
Maximum	900	Maximum	1819.6	Maximum	700
Sum	10288.3	Sum	10344.2	Sum	1612.7
Count	72	Count	72	Count	72
Confidence Level (95%)	44.36791848	Confidence Level (95%)	57.293791	Confidence Level (95%)	20.429992
UCLM	172.2081552	UCLM	181.52502	UCLM	35.897267
P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	3.912818789	Mean	3.82454	Mean	0.9315013
Standard Error	0.203425878	Standard Error	0.2220988	Standard Error	0.2283106
Median	3.992347196	Median	4.0739336	Median	0.9555114
Mode	1.223775432	Mode	-1.6094379	Mode	-1.6094379
Standard Deviation	1.726125816	Standard Deviation	1.8845704	Standard Deviation	1.9372795
Variance	2.979510333	Variance	3.5516056	Variance	3.7530518
Kurtosis	0.204622027	Kurtosis	0.8531237	Kurtosis	0.1136683
Skewness	-0.58519862	Skewness	-0.9136235	Skewness	0.4796977
Range	8.411832676	Range	9.1158099	Range	8.1605182
Minimum	-1.60943791	Minimum	-1.6094379	Minimum	-1.6094379
Maximum	6.802394763	Maximum	7.506372	Maximum	6.5510803
Sum	281.7229528	Sum	275.36688	Sum	67.068094
Count	72	Count	72	Count	72
Confidence Level (95%)	0.398706805	Confidence Level (95%)	0.4353049	Confidence Level (95%)	0.4474798
UCLM	4.176255301	UCLM	4.1121579	UCLM	1.2271635
UCLM TRANS BACK	65.1215355	UCLM TRANS BACK	61.078378	UCLM TRANS BACK	3.411539

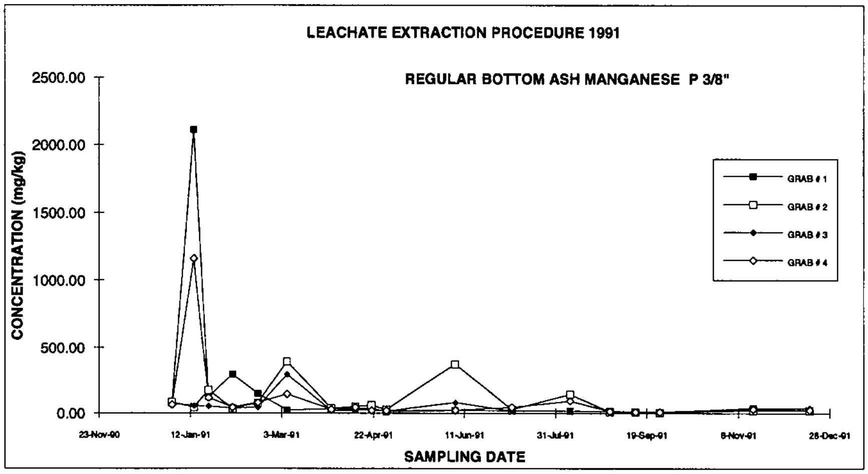

Figure A.21 RBA LEP Mn P3/8"

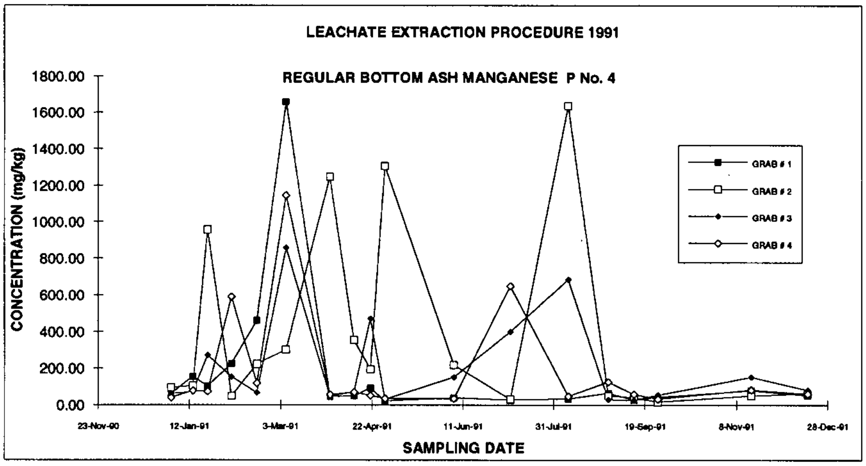

Figure A.22 RBA LEP Mn P4

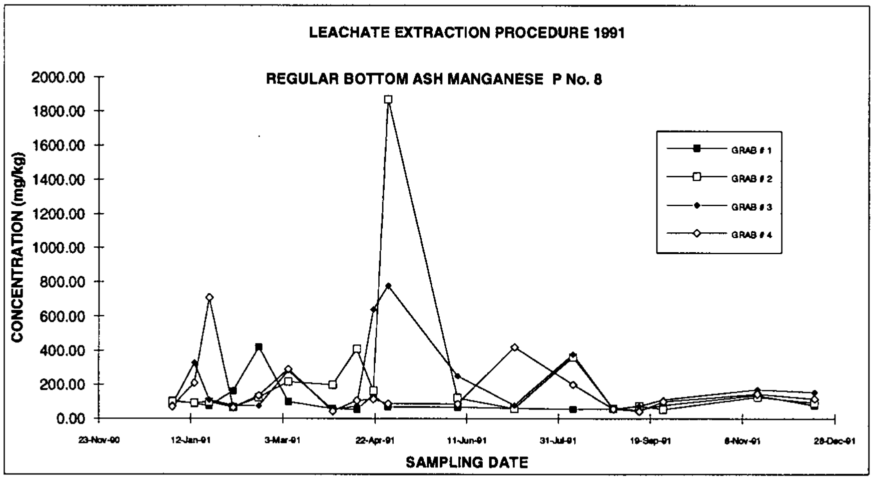

Figure A.23 RBA LEP Mn P8

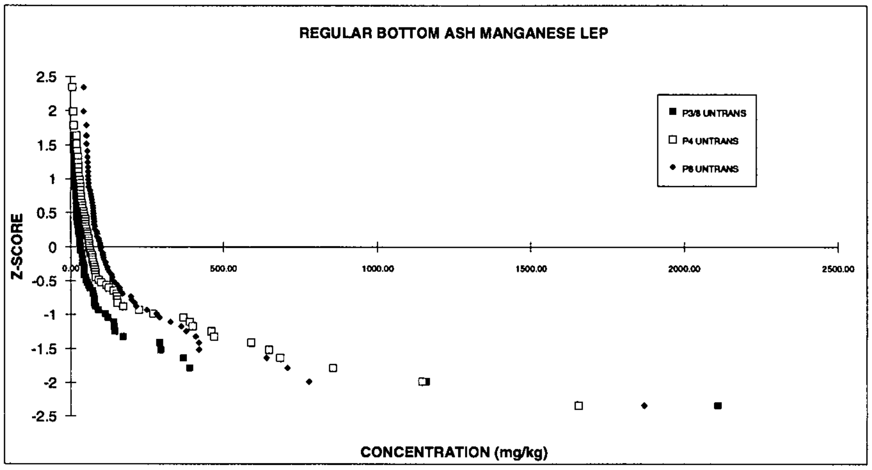

Figure A.24 RBA UNTRANSFORMED Z-SCORE Mn

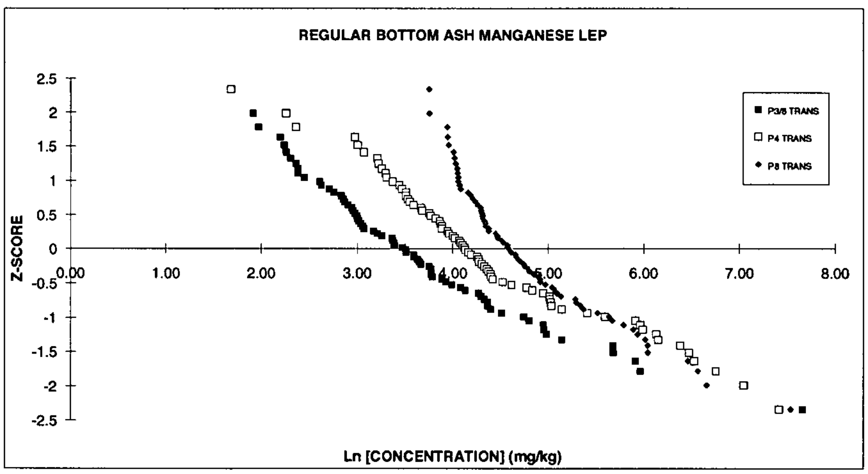

Figure A.25 RBA UNTRANSFORMED Z-SCORE Mn

Table A.5 DESCRIPTIVE STATISTICS FOR RBA LEP Mn DATA

DESCRIPTIVE STATISTICS FOR RBA LEP Mn DATA

P3/8 UNTRANS		P4 UNTRANS		P8 UNTRANS	
Mean	102.5208333	Mean	164.11111	Mean	178.73611
Standard Error	33.42056871	Standard Error	32.538883	Standard Error	29.687992
Median	32.7	Median	61.9	Median	97.8
Mode	10.8	Mode	33.4	Mode	57.8
Standard Deviation	283.5829292	Standard Deviation	276.10158	Standard Deviation	251.91097
Variance	80419.27773	Variance	76232.082	Variance	63459.136
Kurtosis	38.36092257	Kurtosis	13.569697	Kurtosis	29.0423
Skewness	5.909940789	Skewness	3.4024003	Skewness	4.8084317
Range	2104.6	Range	1652.4	Range	1827.4
Minimum	5.4	Minimum	5.4	Minimum	42.6
Maximum	2110	Maximum	1657.8	Maximum	1870
Sum	7381.5	Sum	11816	Sum	12869
Count	72	Count	72	Count	72
Confidence Level (95%)	65.50301402	Confidence Level (95%)	63.774945	Confidence Level (95%)	58.187309
UCLM	145.8004698	UCLM	206.24896	UCLM	217.18206

P3/8 TRANS		P4 TRANS		P8 TRANS	
Mean	3.639108076	Mean	4.3420056	Mean	4.786435
Standard Error	0.136589124	Standard Error	0.1343385	Standard Error	0.0911165
Median	3.487258164	Median	4.1255084	Median	4.5828723
Mode	2.379546134	Mode	3.5085559	Mode	4.0569888
Standard Deviation	1.158997154	Standard Deviation	1.1398997	Standard Deviation	0.7731493
Variance	1.343274402	Variance	1.2993713	Variance	0.5977598
Kurtosis	1.701463356	Kurtosis	0.3981822	Kurtosis	1.4918441
Skewness	1.102009693	Skewness	0.6393561	Skewness	1.2525216
Range	5.968044273	Range	5.7268477	Range	3.7818395
Minimum	1.686398954	Minimum	1.686399	Minimum	3.7518543
Maximum	7.654443226	Maximum	7.4132467	Maximum	7.5336937
Sum	262.0157814	Sum	312.6244	Sum	344.62332
Count	72	Count	72	Count	72
Confidence Level (95%)	0.267709368	Confidence Level (95%)	0.2632982	Confidence Level (95%)	0.1785848
UCLM	3.815990992	UCLM	4.5159739	UCLM	4.9044309
UCLM TRANS BACK	45.42174666	UCLM TRANS BACK	91.466602	UCLM TRANS BACK	134.88612

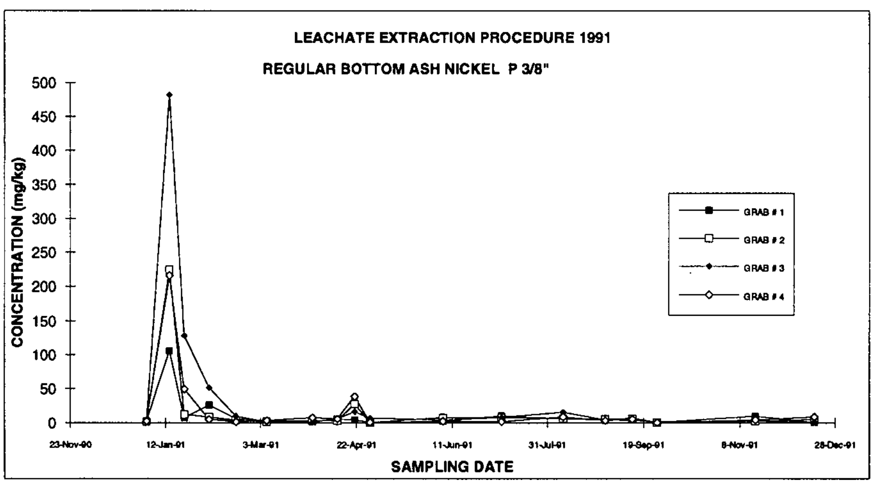

Figure A.26 RBA LEP Ni P3/8"

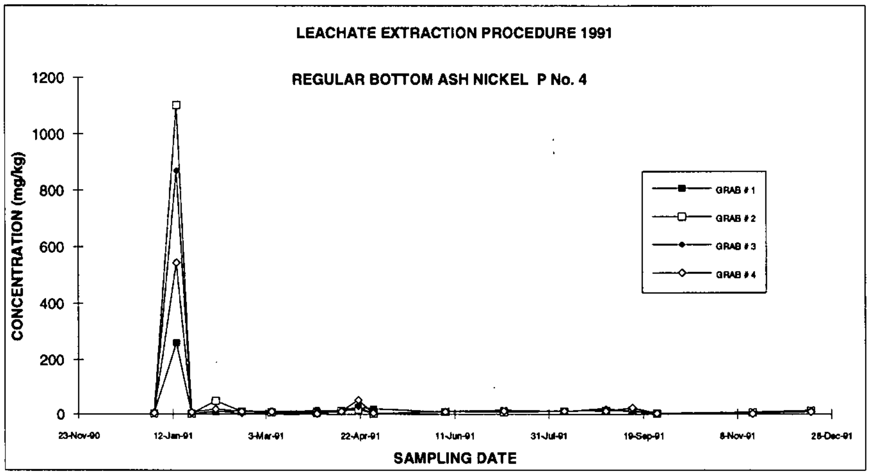

Figure A.27 RBA LEP Ni P4

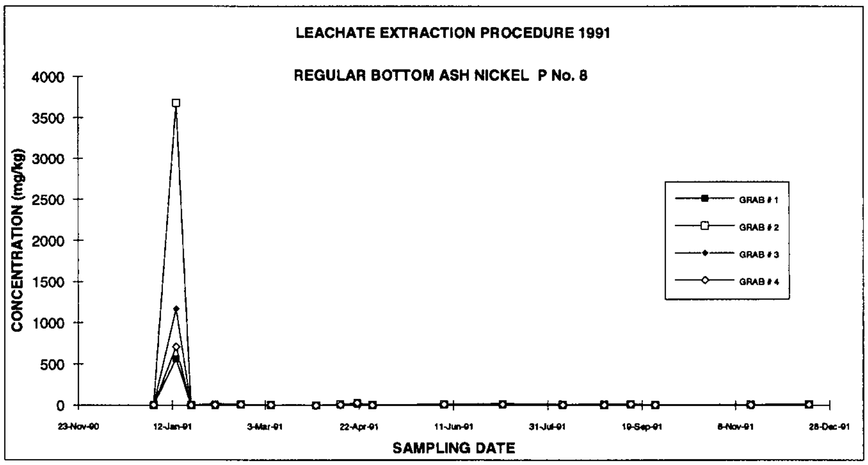

Figure A.28 RBA LEP Ni P8

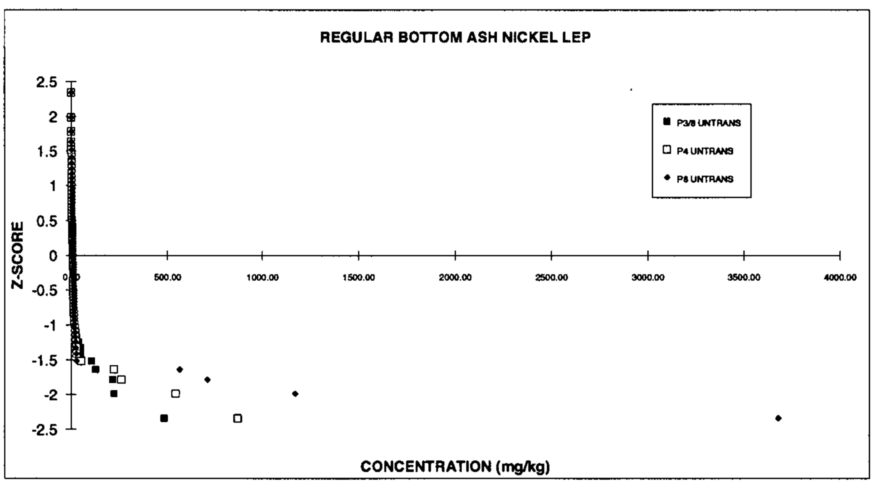

Figure A.29 RBA UNTRANSFORMED Z-SCORE Ni

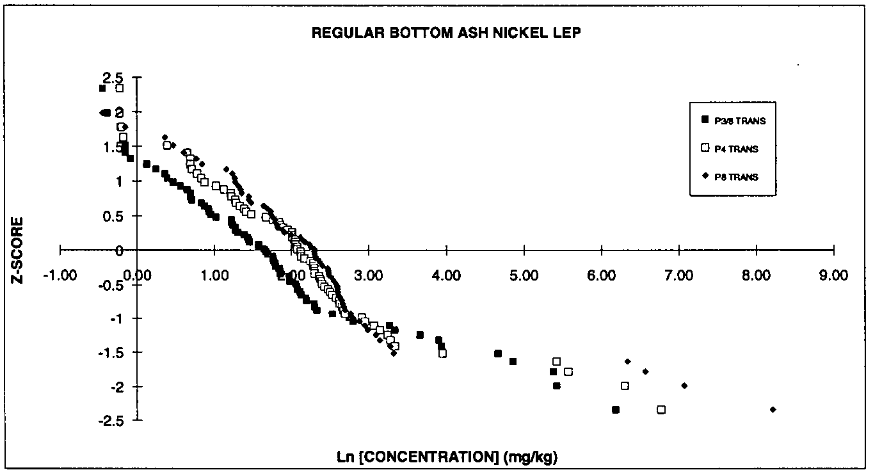

Figure A.30 RBA TRANSFORMED Z-SCORE Ni

Table A.6 DESCRIPTIVE STATISTICS FOR RBA LEP Ni DATA

DESCRIPTIVE STATISTICS FOR RBA LEP Ni DATA					
P3/8 UNTRANS		*P4 UNTRANS*		*P8 UNTRANS*	
Mean	22.97444444	Mean	35.238472	Mean	94.107917
Standard Error	8.023884411	Standard Error	14.617164	Standard Error	54.361225
Median	5.26	Median	8.16	Median	9.995
Mode	0.86	Mode	10	Mode	0.64
Standard Deviation	68.08491694	Standard Deviation	124.03075	Standard Deviation	461.27029
Variance	4635.555915	Variance	15383.627	Variance	212770.28
Kurtosis	30.81832136	Kurtosis	32.908137	Kurtosis	53.368556
Skewness	5.205847454	Skewness	5.543769	Skewness	7.0340973
Range	481.36	Range	869.2	Range	3679.36
Minimum	0.64	Minimum	0.8	Minimum	0.64
Maximum	482	Maximum	870	Maximum	3680
Sum	1654.16	Sum	2537.17	Sum	6775.77
Count	72	Count	72	Count	72
Confidence Level (95%)	15.72650117	Confidence Level (95%)	28.649073	Confidence Level (95%)	106.54589
UCLM	33.36537476	UCLM	54.1677	UCLM	164.5057
P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	1.736978221	Mean	2.117198	Mean	2.2681338
Standard Error	0.163569279	Standard Error	0.1537366	Standard Error	0.169374
Median	1.660065964	Median	2.0990008	Median	2.3020848
Mode	-0.15082289	Mode	2.3025851	Mode	-0.4462871
Standard Deviation	1.387931354	Standard Deviation	1.3044983	Standard Deviation	1.4371864
Variance	1.926353444	Variance	1.7017158	Variance	2.0655047
Kurtosis	1.521801791	Kurtosis	3.2685867	Kurtosis	6.1647717
Skewness	1.08988045	Skewness	1.2117595	Skewness	1.8761666
Range	6.624231217	Range	6.9916368	Range	8.6569551
Minimum	-0.4462871	Minimum	-0.2231436	Minimum	-0.4462871
Maximum	6.177944114	Maximum	6.7684932	Maximum	8.210668
Sum	125.0624319	Sum	152.43826	Sum	163.30563
Count	72	Count	72	Count	72
Confidence Level (95%)	0.320589421	Confidence Level (95%)	0.3013177	Confidence Level (95%)	0.3319665
UCLM	1.948800437	UCLM	2.3162869	UCLM	2.4874732
UCLM TRANS BACK	7.020261285	UCLM TRANS BACK	10.137961	UCLM TRANS BACK	12.030838

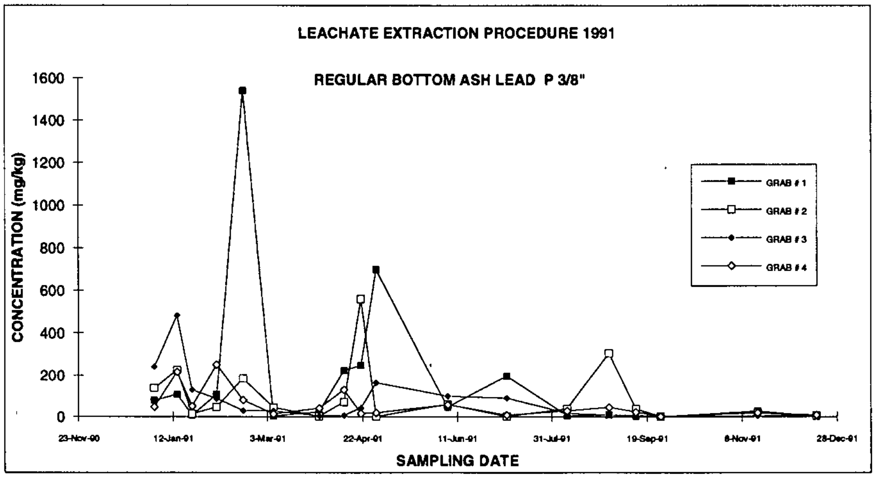

Figure A.31 RBA LEP Pb P3/8"

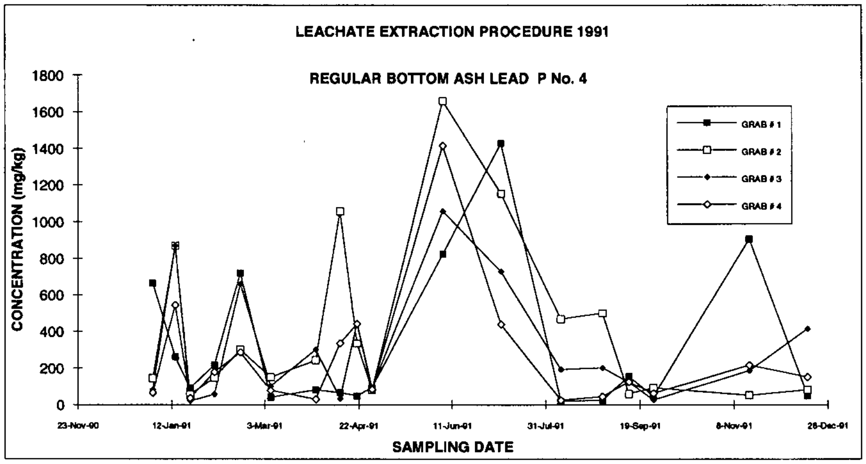

Figure A.32 RBA LEP Pb P4

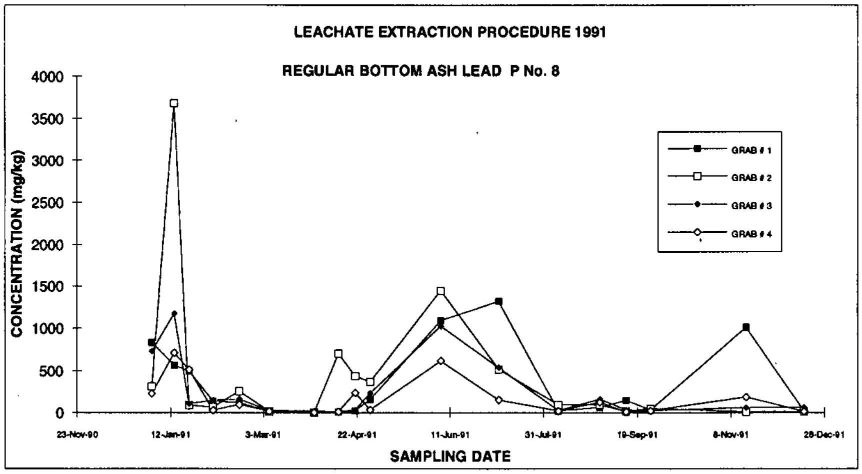

Figure A.33 RBA LEP Pb P8

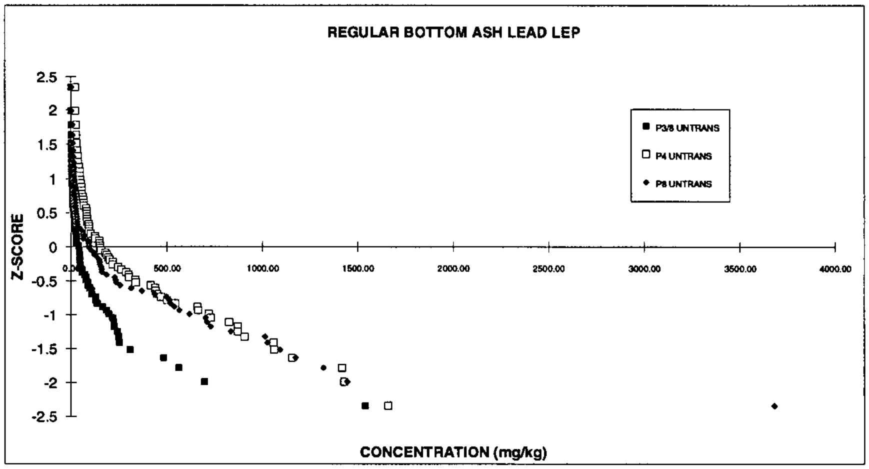

Figure A.34 RBA UNTRANSFORMED Z-SCORE Pb

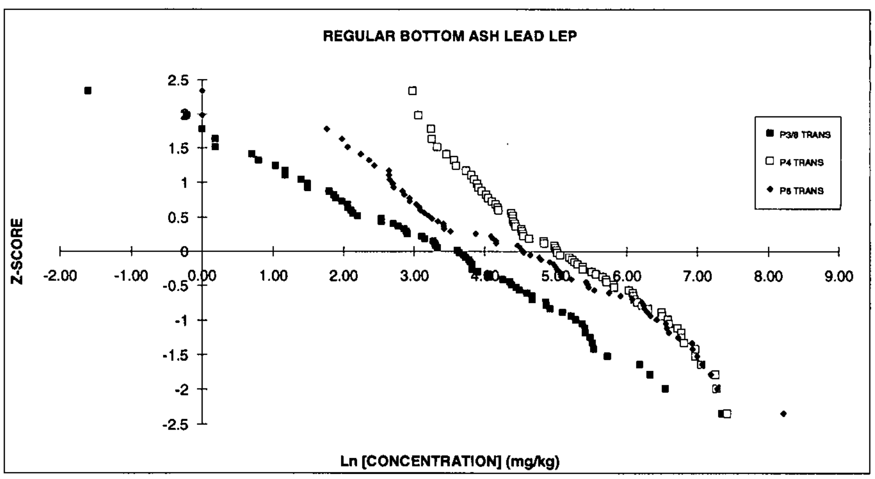

Figure A.35 RBA TRANSFORMED Z-SCORE Pb

Table A.7 DESCRIPTIVE STATISTICS FOR RBA LEP Pb DATA

DESCRIPTIVE STATISTICS FOR RBA LEP Pb DATA					
P3/8 UNTRANS		*P4 UNTRANS*		*P8 UNTRANS*	
Mean	104.7809722	Mean	324.47917	Mean	302.00972
Standard Error	25.34457522	Standard Error	45.051634	Standard Error	63.096875
Median	37.4	Median	150.8	Median	93.3
Mode	1.2	Mode	81.2	Mode	1
Standard Deviation	215.0558521	Standard Deviation	382.27579	Standard Deviation	535.39474
Variance	46249.0195	Variance	146134.78	Variance	286647.52
Kurtosis	28.65958931	Kurtosis	2.4239254	Kurtosis	22.024908
Skewness	4.811212269	Skewness	1.7145128	Skewness	4.0221537
Range	1539.8	Range	1640.4	Range	3679
Minimum	0.2	Minimum	19.6	Minimum	1
Maximum	1540	Maximum	1660	Maximum	3680
Sum	7544.23	Sum	23362.5	Sum	21744.7
Count	72	Count	72	Count	72
Confidence Level (95%)	49.67438108	Confidence Level (95%)	88.29945	Confidence Level (95%)	123.66742
UCLM	137.6021971	UCLM	382.82103	UCLM	383.72018
P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	3.34671315	Mean	5.1209936	Mean	4.4561652
Standard Error	0.213417092	Standard Error	0.1406038	Standard Error	0.2084554
Median	3.621613508	Median	5.0159536	Median	4.535792
Mode	0.182321557	Mode	4.3969152	Mode	0
Standard Deviation	1.810904077	Standard Deviation	1.1930627	Standard Deviation	1.7688031
Variance	3.279373577	Variance	1.4233986	Variance	3.1286643
Kurtosis	-0.2100312	Kurtosis	-1.0204037	Kurtosis	-0.4266011
Skewness	-0.29944562	Skewness	0.1529525	Skewness	-0.1728373
Range	8.948975608	Range	4.4390433	Range	8.210668
Minimum	-1.60943791	Minimum	2.9755296	Minimum	0
Maximum	7.339537695	Maximum	7.4145729	Maximum	8.210668
Sum	240.9633468	Sum	368.71154	Sum	320.84389
Count	72	Count	72	Count	72
Confidence Level (95%)	0.418289195	Confidence Level (95%)	0.2755779	Confidence Level (95%)	0.4085646
UCLM	3.623088285	UCLM	5.3030755	UCLM	4.726115
UCLM TRANS BACK	37.4530551	UCLM TRANS BACK	200.9539	UCLM TRANS BACK	112.85626

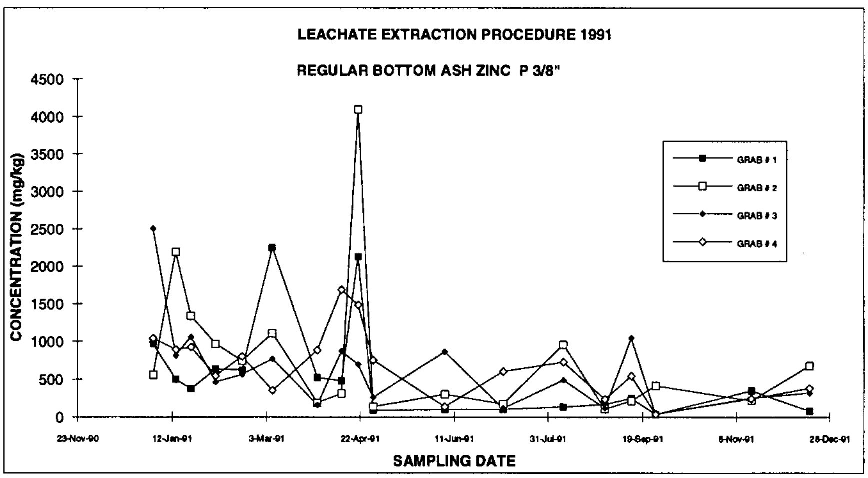

Figure A.36 RBA LEP Zn P3/8"

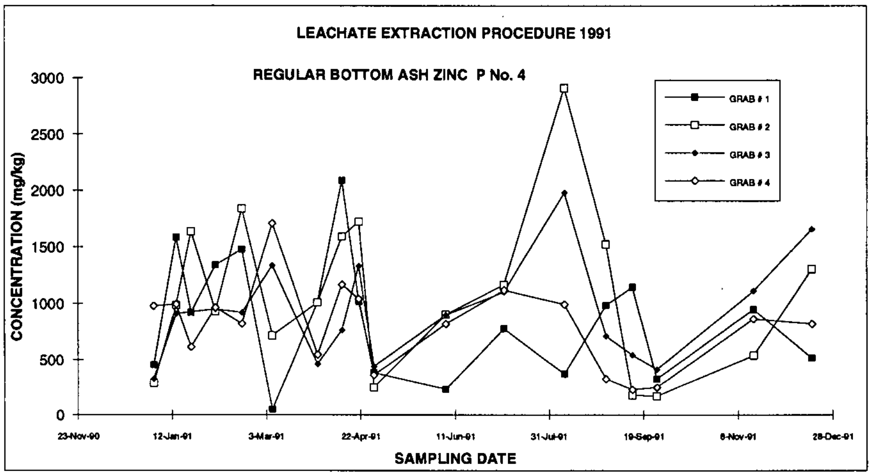

Figure A.37 RBA LEP Zn P4"

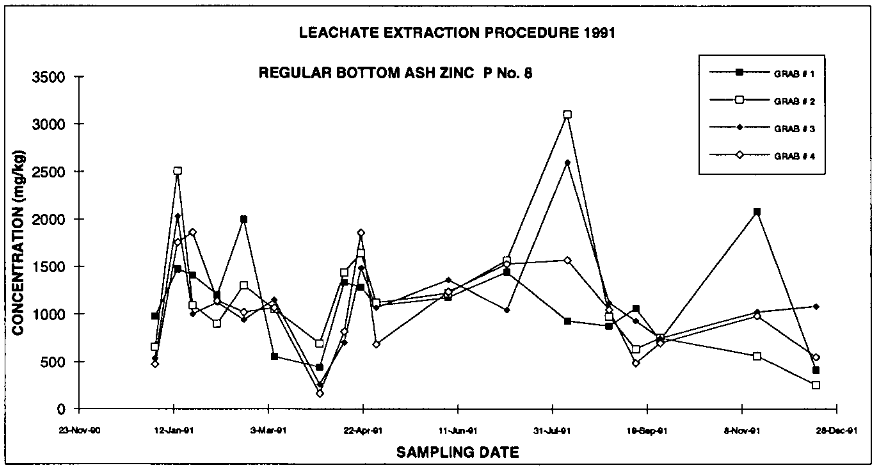

Figure A.38 RBA LEP Zn P8

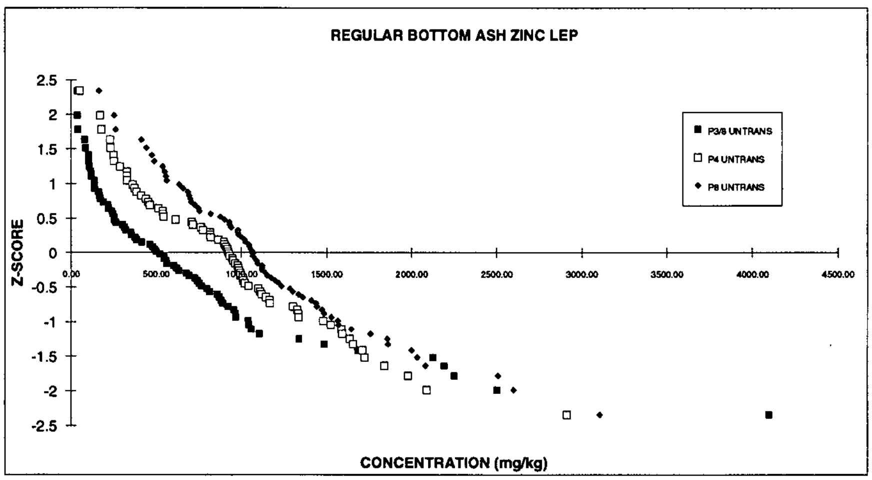

Figure A.39 RBA UNTRANSFORMED Z-SCORE Zn

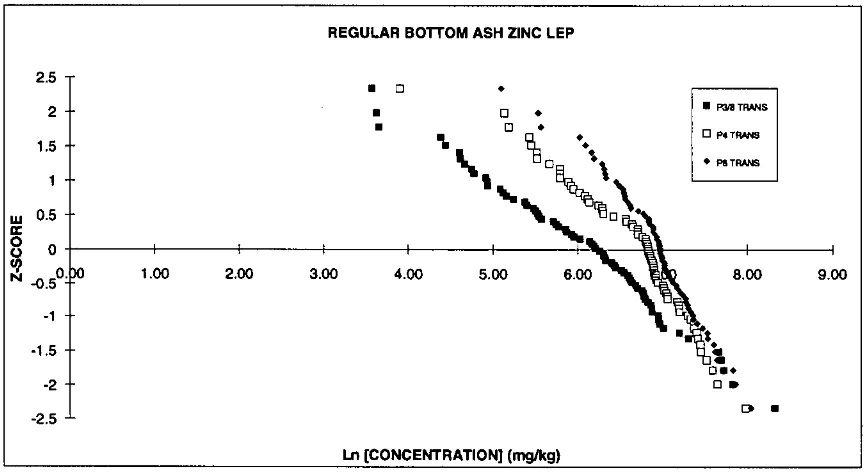

Figure A.40 RBA TRANSFORMED Z-SCORE Zn

Table A.8 DESCRIPTIVE STATISTICS FOR RBA LEP Zn DATA

DESCRIPTIVE STATISTICS FOR RBA LEP Zn DATA					
P3/8 UNTRANS		*P4 UNTRANS*		*P8 UNTRANS*	
Mean	668.3486111	Mean	925.94167	Mean	1126.622222
Standard Error	80.33338824	Standard Error	62.647169	Standard Error	64.33288325
Median	510	Median	924	Median	1065
Mode	#N/A	Mode	326	Mode	980
Standard Deviation	681.651403	Standard Deviation	531.57886	Standard Deviation	545.882616
Variance	464648.6352	Variance	282576.08	Variance	297987.8305
Kurtosis	8.891708226	Kurtosis	1.6017638	Kurtosis	2.099758622
Skewness	2.537211571	Skewness	0.9035107	Skewness	1.1096839
Range	4060.4	Range	2862.6	Range	2941.2
Minimum	35.6	Minimum	49.4	Minimum	162.8
Maximum	4096	Maximum	2912	Maximum	3104
Sum	48121.1	Sum	66667.8	Sum	81116.8
Count	72	Count	72	Count	72
Confidence Level (95%)	157.4503146	Confidence Level (95%)	122.78601	Confidence Level (95%)	126.0899475
UCLM	772.3803489	UCLM	1007.0698	UCLM	1209.933306
P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	6.049833112	Mean	6.6304355	Mean	6.904046143
Standard Error	0.121115001	Standard Error	0.0838635	Standard Error	0.062457943
Median	6.234133832	Median	6.8287097	Median	6.970729637
Mode	#N/A	Mode	5.7868974	Mode	6.887552572
Standard Deviation	1.027694861	Standard Deviation	0.7116057	Standard Deviation	0.529973222
Variance	1.056156728	Variance	0.5063827	Variance	0.280871617
Kurtosis	-0.12197301	Kurtosis	1.943811	Kurtosis	1.64889766
Skewness	-0.38357922	Skewness	-1.1111381	Skewness	-0.83029046
Range	4.745420529	Range	4.076645	Range	2.947924428
Minimum	3.572345638	Minimum	3.8999504	Minimum	5.092522454
Maximum	8.317766167	Maximum	7.9765954	Maximum	8.040446881
Sum	435.5879841	Sum	477.39136	Sum	497.0913223
Count	72	Count	72	Count	72
Confidence Level (95%)	0.237380688	Confidence Level (95%)	0.1643693	Confidence Level (95%)	0.122415138
UCLM	6.206677038	UCLM	6.7390388	UCLM	6.984929179
UCLM TRANS BACK	496.0501538	UCLM TRANS BACK	844.74839	UCLM TRANS BACK	1080.229912

Appendix B

DESIFTED BOTTOM ASH LEACHATE EXTRACTION PROCEDURE RESULTS

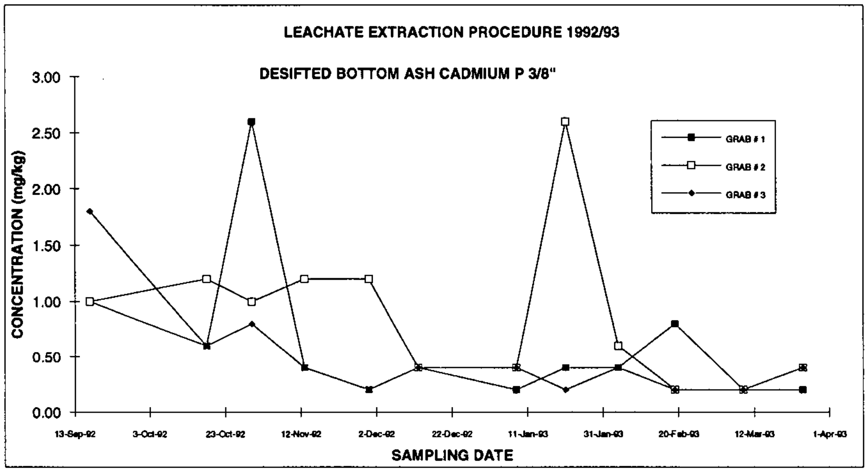

Figure B.1 DBA LEP Cd P3/8"

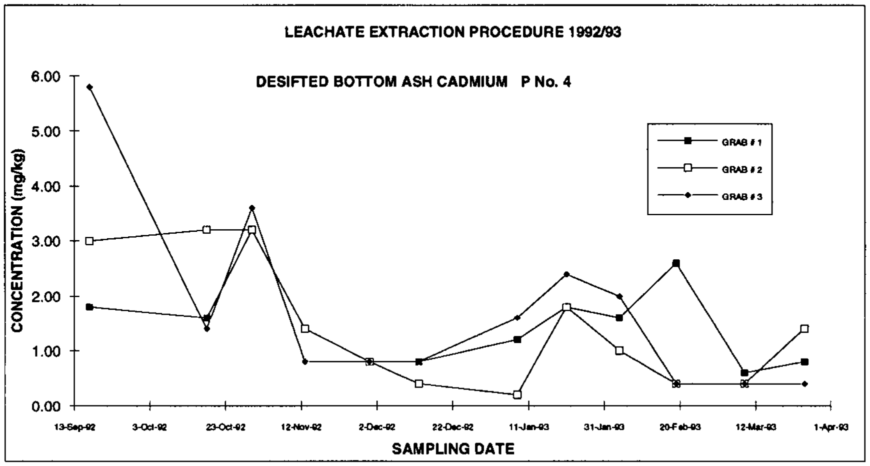

Figure B.2 DBA LEP Cd P4

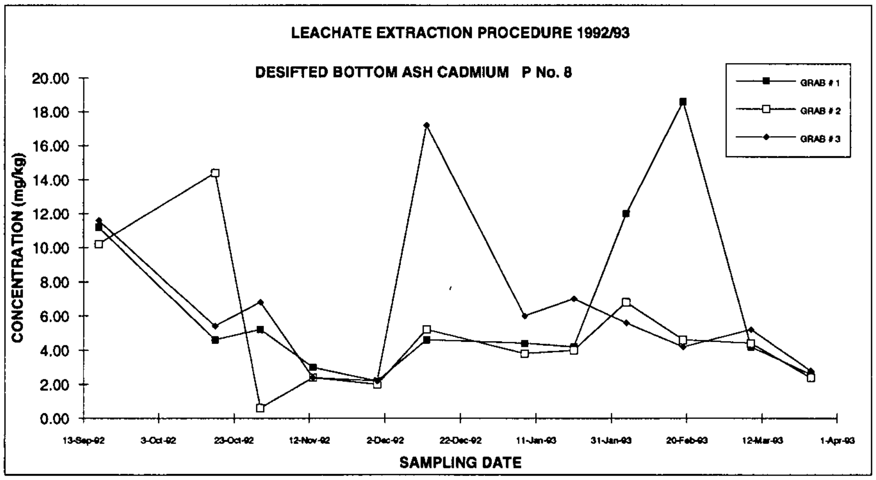

Figure B.3 DBA LEP Cd P8

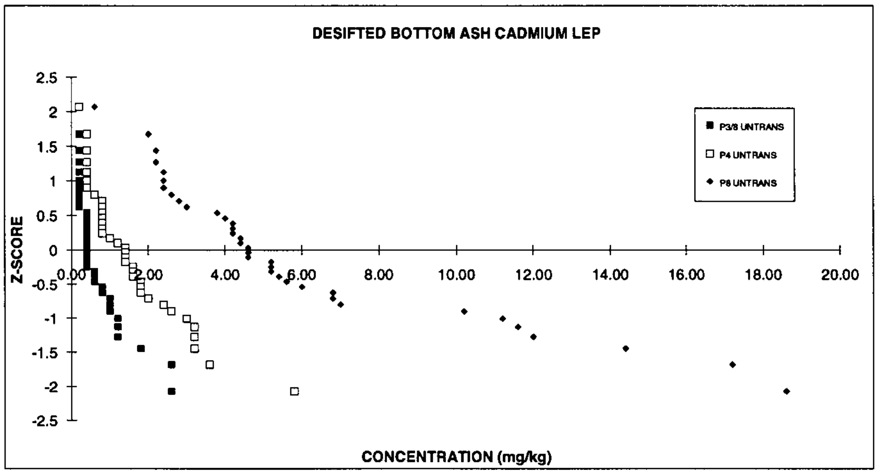

Figure B.4 DBA UNTRANSFORMED Z-SCORE Cd

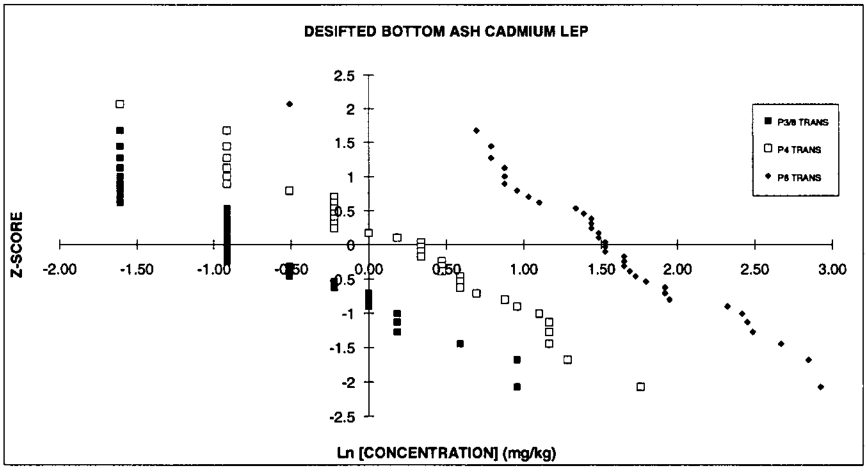

Figure B.5 DBA TRANSFORMED Z-SCORE Cd

Table B.1 DBA LEP RANKED Cd CONCENTRATIONS

DBA LEP Cd CONCENTRATIONS (mg/kg)					
P3/8" UNTRAN	P3/8" TRANS	P4 UNTRAN	P4 TRANS	P8 UNTRAN	P8 TRANS
0.20	-1.61	0.20	-1.61	0.60	-0.51
0.20	-1.61	0.40	-0.92	2.00	0.69
0.20	-1.61	0.40	-0.92	2.20	0.79
0.20	-1.61	0.40	-0.92	2.20	0.79
0.20	-1.61	0.40	-0.92	2.40	0.88
0.20	-1.61	0.40	-0.92	2.40	0.88
0.20	-1.61	0.40	-0.92	2.40	0.88
0.20	-1.61	0.60	-0.51	2.60	0.96
0.20	-1.61	0.80	-0.22	2.80	1.03
0.20	-1.61	0.80	-0.22	3.00	1.10
0.40	-0.92	0.80	-0.22	3.80	1.34
0.40	-0.92	0.80	-0.22	4.00	1.39
0.40	-0.92	0.80	-0.22	4.20	1.44
0.40	-0.92	0.80	-0.22	4.20	1.44
0.40	-0.92	0.80	-0.22	4.20	1.44
0.40	-0.92	1.00	0.00	4.40	1.48
0.40	-0.92	1.20	0.18	4.40	1.48
0.40	-0.92	1.40	0.34	4.60	1.53
0.40	-0.92	1.40	0.34	4.60	1.53
0.40	-0.92	1.40	0.34	4.60	1.53
0.40	-0.92	1.40	0.34	5.20	1.65
0.40	-0.92	1.60	0.47	5.20	1.65
0.60	-0.51	1.60	0.47	5.20	1.65
0.60	-0.51	1.60	0.47	5.40	1.69
0.60	-0.51	1.80	0.59	5.60	1.72
0.80	-0.22	1.80	0.59	6.00	1.79
0.80	-0.22	1.80	0.59	6.80	1.92
1.00	0.00	2.00	0.69	6.80	1.92
1.00	0.00	2.40	0.88	7.00	1.95
1.00	0.00	2.60	0.96	10.20	2.32
1.20	0.18	3.00	1.10	11.20	2.42
1.20	0.18	3.20	1.16	11.60	2.45
1.20	0.18	3.20	1.16	12.00	2.48
1.80	0.59	3.20	1.16	14.40	2.67
2.60	0.96	3.60	1.28	17.20	2.84
2.60	0.96	5.80	1.76	18.60	2.92

Table B.2 DESCRIPTIVE STATISTICS FOR DBA LEP Cd DATA

DESCRIPTIVE STATISTICS FOR DBA LEP Cd DATA

P3/8 UNTRANS		*P4 UNTRANS*		*P8 UNTRANS*	
Mean	0.661111111	Mean	1.55	Mean	5.9444444
Standard Error	0.10167469	Standard Error	0.1989456	Standard Error	0.7153026
Median	0.4	Median	1.4	Median	4.6
Mode	0.4	Mode	0.8	Mode	2.4
Standard Deviation	0.610048138	Standard Deviation	1.1936738	Standard Deviation	4.2918158
Variance	0.37215873	Variance	1.4248571	Variance	18.419683
Kurtosis	4.254783488	Kurtosis	3.2289197	Kurtosis	1.9813999
Skewness	2.058928803	Skewness	1.568745	Skewness	1.5648298
Range	2.4	Range	5.6	Range	18
Minimum	0.2	Minimum	0.2	Minimum	0.6
Maximum	2.6	Maximum	5.8	Maximum	18.6
Sum	23.8	Sum	55.8	Sum	214
Count	36	Count	36	Count	36
Confidence Level (95%)	0.199278435	Confidence Level (95%)	0.3899257	Confidence Level (95%)	1.4019653
UCLM	0.79399993	UCLM	1.8100219	UCLM	6.879345
P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	-0.72285716	Mean	0.1575709	Mean	1.5575967
Standard Error	0.126994547	Standard Error	0.1311888	Standard Error	0.1156781
Median	-0.91629073	Median	0.3364722	Median	1.5260563
Mode	-0.91629073	Mode	-0.2231436	Mode	0.8754687
Standard Deviation	0.761967283	Standard Deviation	0.7871329	Standard Deviation	0.6940687
Variance	0.58059414	Variance	0.6195782	Variance	0.4817313
Kurtosis	-0.45997413	Kurtosis	-0.5392425	Kurtosis	1.1870899
Skewness	0.566738134	Skewness	-0.1768796	Skewness	-0.2744271
Range	2.564949357	Range	3.3672958	Range	3.4339872
Minimum	-1.60943791	Minimum	-1.6094379	Minimum	-0.5108256
Maximum	0.955511445	Maximum	1.7578579	Maximum	2.9231616
Sum	-26.0228577	Sum	5.6725524	Sum	56.073481
Count	36	Count	36	Count	36
Confidence Level (95%)	0.24890437	Confidence Level (95%)	0.257125	Confidence Level (95%)	0.2267246
UCLM	-0.55687528	UCLM	0.3290347	UCLM	1.708788
UCLM TRANS BACK	0.572996721	UCLM TRANS BACK	1.3896261	UCLM TRANS BACK	5.5222644

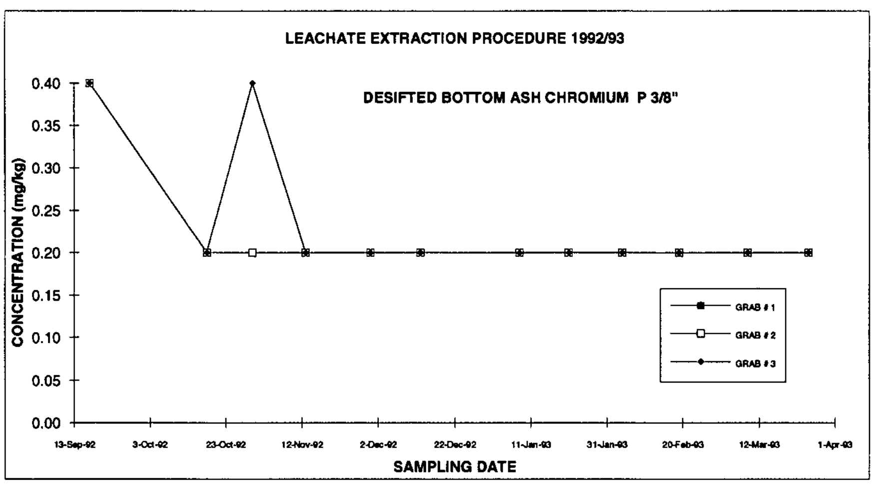

Figure B.6 DBA LEP Cr P3/8"

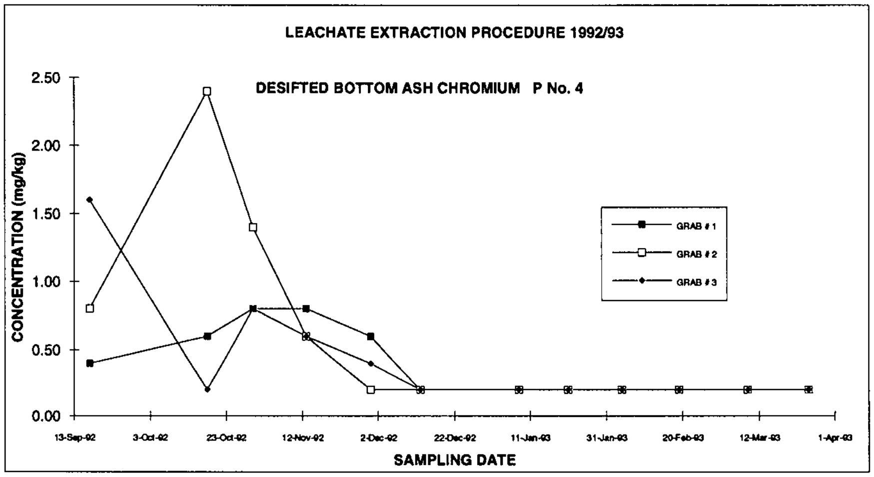

Figure B.7 DBA LEP Cr P4

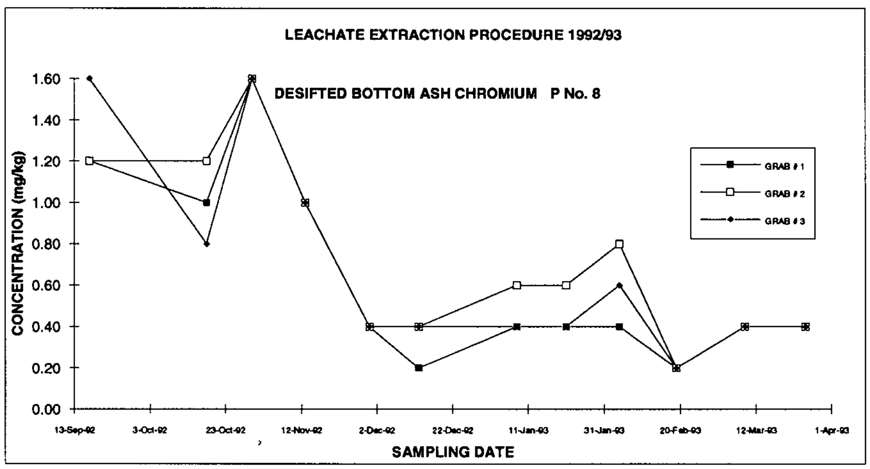

Figure B.8 DBA LEP Cr P8

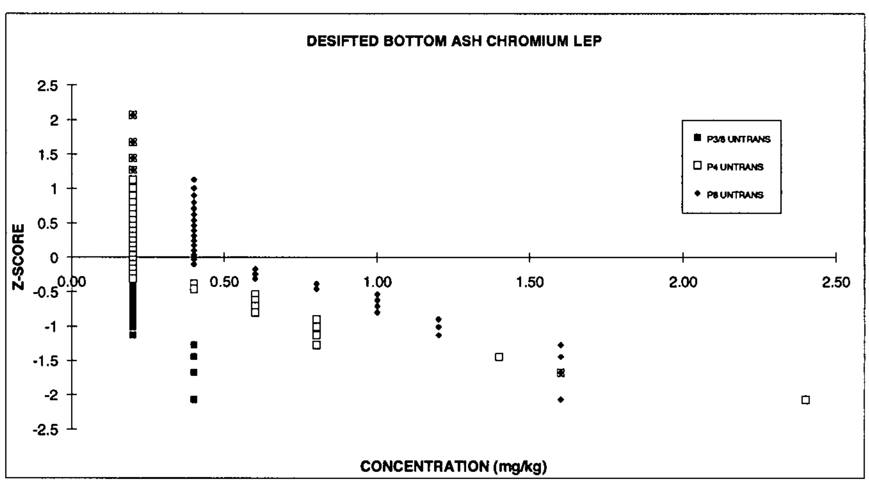

Figure B.9 DBA UNTRANSFORMED Z-SCORE Cr

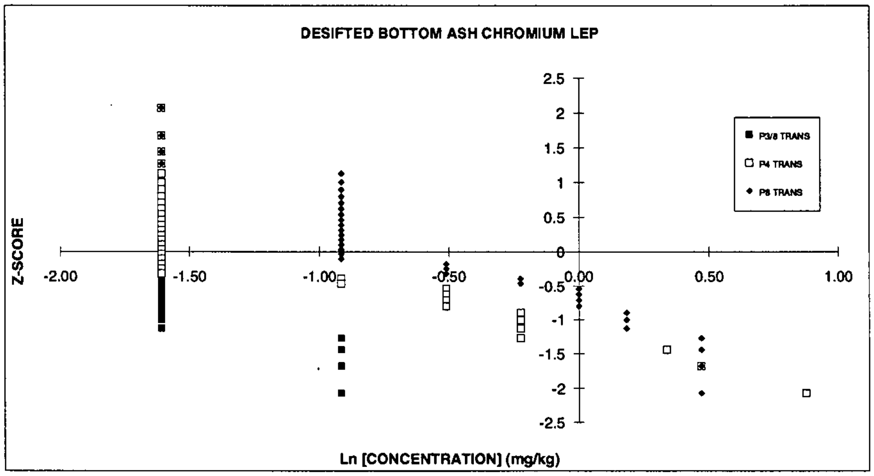

Figure B.10 DBA TRANSFORMED Z-SCORE Cr

Table B.3 DBA LEP RANKED Cr CONCENTRATIONS

DBA LEP Cr RANKED CONCENTRATIONS (mg/kg)					
P3/8" UNTRAN	P3/8" TRANS	P4 UNTRAN	P4 TRANS	P8 UNTRAN	P8 TRANS
0.20	-1.61	0.20	-1.61	0.20	-1.61
0.20	-1.61	0.20	-1.61	0.20	-1.61
0.20	-1.61	0.20	-1.61	0.20	-1.61
0.20	-1.61	0.20	-1.61	0.20	-1.61
0.20	-1.61	0.20	-1.61	0.40	-0.92
0.20	-1.61	0.20	-1.61	0.40	-0.92
0.20	-1.61	0.20	-1.61	0.40	-0.92
0.20	-1.61	0.20	-1.61	0.40	-0.92
0.20	-1.61	0.20	-1.61	0.40	-0.92
0.20	-1.61	0.20	-1.61	0.40	-0.92
0.20	-1.61	0.20	-1.61	0.40	-0.92
0.20	-1.61	0.20	-1.61	0.40	-0.92
0.20	-1.61	0.20	-1.61	0.40	-0.92
0.20	-1.61	0.20	-1.61	0.40	-0.92
0.20	-1.61	0.20	-1.61	0.40	-0.92
0.20	-1.61	0.20	-1.61	0.40	-0.92
0.20	-1.61	0.20	-1.61	0.40	-0.92
0.20	-1.61	0.20	-1.61	0.40	-0.92
0.20	-1.61	0.20	-1.61	0.40	-0.92
0.20	-1.61	0.20	-1.61	0.40	-0.92
0.20	-1.61	0.20	-1.61	0.60	-0.51
0.20	-1.61	0.20	-1.61	0.60	-0.51
0.20	-1.61	0.20	-1.61	0.60	-0.51
0.20	-1.61	0.40	-0.92	0.80	-0.22
0.20	-1.61	0.40	-0.92	0.80	-0.22
0.20	-1.61	0.60	-0.51	1.00	0.00
0.20	-1.61	0.60	-0.51	1.00	0.00
0.20	-1.61	0.60	-0.51	1.00	0.00
0.20	-1.61	0.60	-0.51	1.00	0.00
0.20	-1.61	0.80	-0.22	1.20	0.18
0.20	-1.61	0.80	-0.22	1.20	0.18
0.20	-1.61	0.80	-0.22	1.20	0.18
0.40	-0.92	0.80	-0.22	1.60	0.47
0.40	-0.92	1.40	0.34	1.60	0.47
0.40	-0.92	1.60	0.47	1.60	0.47
0.40	-0.92	2.40	0.88	1.60	0.47

Table B.4 DESCRIPTIVE STATISTICS FOR DBA LEP Cr DATA

DESCRIPTIVE STATISTICS FOR DBA LEP Cr DATA					
P3/8 UNTRANS		*P4 UNTRANS*		*P8 UNTRANS*	
Mean	0.222222222	Mean	0.4555556	Mean	0.6833333
Standard Error	0.010624254	Standard Error	0.079925	Standard Error	0.073625
Median	0.2	Median	0.2	Median	0.4
Mode	0.2	Mode	0.2	Mode	0.4
Standard Deviation	0.063745526	Standard Deviation	0.4795501	Standard Deviation	0.4417498
Variance	0.004063492	Variance	0.2299683	Variance	0.1951429
Kurtosis	4.948195187	Kurtosis	7.6035993	Kurtosis	-0.2468047
Skewness	2.583803023	Skewness	2.6017232	Skewness	0.9853082
Range	0.2	Range	2.2	Range	1.4
Minimum	0.2	Minimum	0.2	Minimum	0.2
Maximum	0.4	Maximum	2.4	Maximum	1.6
Sum	8	Sum	16.4	Sum	24.6
Count	36	Count	36	Count	36
Confidence Level (95%)	0.020823125	Confidence Level (95%)	0.1566499	Confidence Level (95%)	0.1443021
UCLM	0.236108123	UCLM	0.5600175	UCLM	0.7795612
P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	-1.53242156	Mean	-1.1139885	Mean	-0.5736163
Standard Error	0.03682086	Standard Error	0.1225536	Standard Error	0.1047107
Median	-1.60943791	Median	-1.6094379	Median	-0.9162907
Mode	-1.60943791	Mode	-1.6094379	Mode	-0.9162907
Standard Deviation	0.220925158	Standard Deviation	0.7353217	Standard Deviation	0.628264
Variance	0.048807925	Variance	0.540698	Variance	0.3947156
Kurtosis	4.948195187	Kurtosis	0.3008348	Kurtosis	-0.8777489
Skewness	2.583803023	Skewness	1.2040259	Skewness	0.1945845
Range	0.693147181	Range	2.4849066	Range	2.0794415
Minimum	-1.60943791	Minimum	-1.6094379	Minimum	-1.6094379
Maximum	-0.91629073	Maximum	0.8754687	Maximum	0.4700036
Sum	-55.1671761	Sum	-40.103586	Sum	-20.650188
Count	36	Count	36	Count	36
Confidence Level (95%)	0.072167452	Confidence Level (95%)	0.2402003	Confidence Level (95%)	0.2052288
UCLM	-1.4842967	UCLM	-0.9538109	UCLM	-0.4367595
UCLM TRANS BACK	0.226661697	UCLM TRANS BACK	0.38527	UCLM TRANS BACK	0.6461268

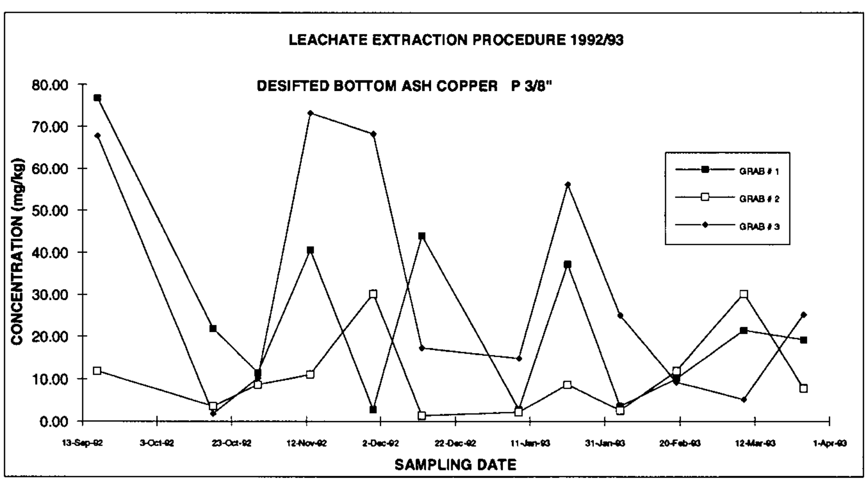

Figure B.11 DBA LEP Cu P3/8"

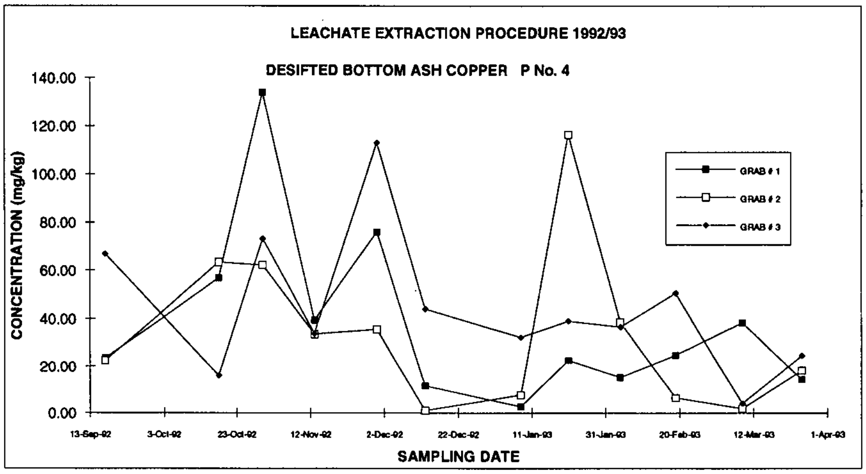

Figure B.12 DBA LEP Cu P4

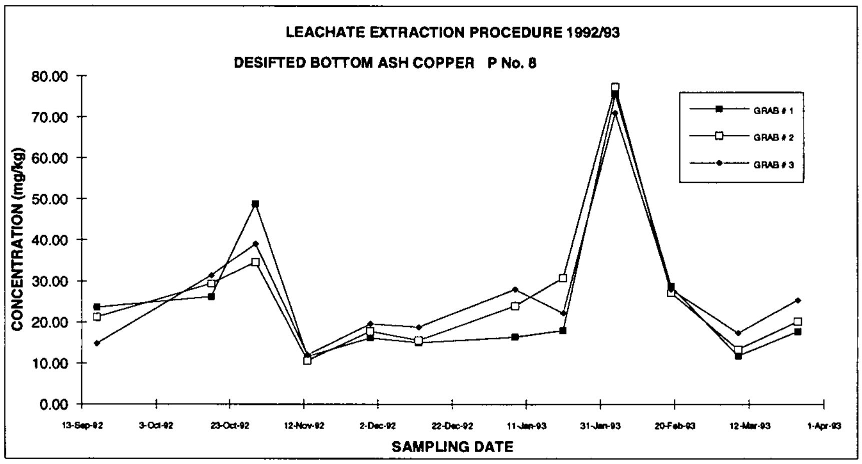

Figure B.13 DBA LEP Cu P8

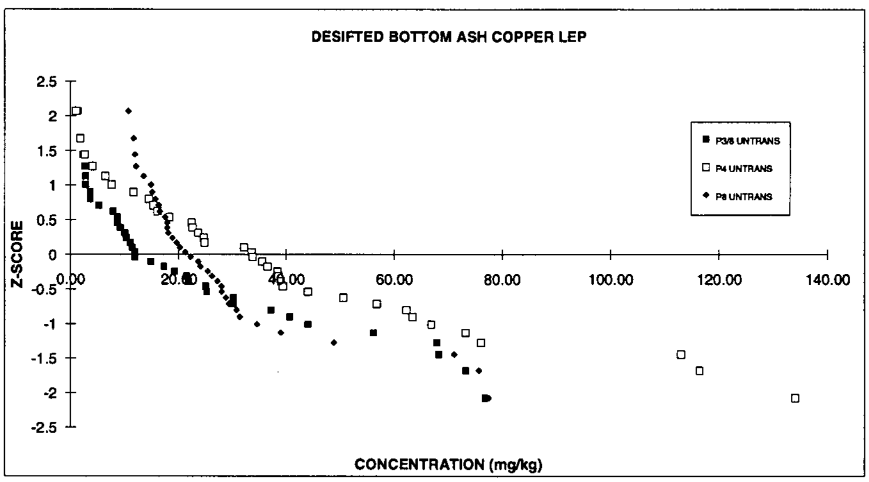

Figure B.14 DBA UNTRANSFORMED Z-SCORE Cu

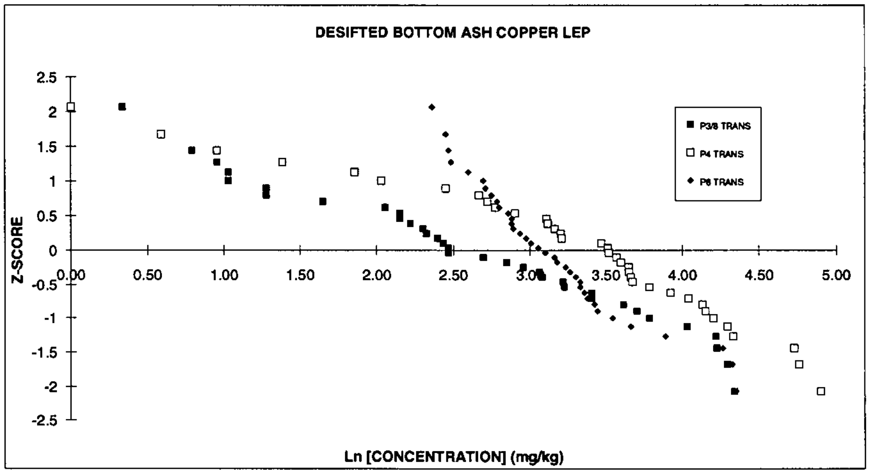

Figure B.15 DBA TRANSFORMED Z-SCORE Cu

Table B.5 DBA LEP RANKED Cu CONCENTRATIONS

DBA LEP Cu RANKED CONCENTRATIONS (mg/kg)					
P3/8" UNTRAN	P3/8" TRANS	P4 UNTRAN	P4 TRANS	P8 UNTRAN	P8 TRANS
1.40	0.34	1.00	0.00	10.60	2.36
1.80	0.59	1.80	0.59	11.60	2.45
2.20	0.79	2.60	0.96	11.80	2.47
2.60	0.96	4.00	1.39	12.00	2.48
2.80	1.03	6.40	1.86	13.40	2.60
2.80	1.03	7.60	2.03	14.80	2.69
3.60	1.28	11.60	2.45	15.00	2.71
3.60	1.28	14.40	2.67	15.60	2.75
5.20	1.65	15.20	2.72	16.20	2.79
7.80	2.05	16.00	2.77	16.40	2.80
8.60	2.15	18.20	2.90	17.40	2.86
8.60	2.15	22.40	3.11	17.80	2.88
9.20	2.22	22.60	3.12	17.80	2.88
10.00	2.30	23.60	3.16	18.00	2.89
10.20	2.32	24.60	3.20	18.80	2.93
11.00	2.40	24.80	3.21	19.60	2.98
11.40	2.43	32.20	3.47	20.20	3.01
11.80	2.47	33.60	3.51	21.20	3.05
11.80	2.47	33.80	3.52	22.20	3.10
14.80	2.69	35.60	3.57	23.60	3.16
17.20	2.84	36.60	3.60	24.00	3.18
19.20	2.95	38.40	3.65	25.40	3.23
21.40	3.06	38.60	3.65	26.20	3.27
21.80	3.08	39.00	3.66	27.20	3.30
25.00	3.22	39.40	3.67	28.00	3.33
25.20	3.23	44.00	3.78	28.00	3.33
30.20	3.41	50.60	3.92	28.80	3.36
30.20	3.41	56.80	4.04	29.40	3.38
37.20	3.62	62.20	4.13	30.80	3.43
40.60	3.70	63.40	4.15	31.40	3.45
44.00	3.78	66.80	4.20	34.60	3.54
56.20	4.03	73.20	4.29	39.00	3.66
67.80	4.22	76.00	4.33	48.80	3.89
68.20	4.22	113.00	4.73	71.00	4.26
73.20	4.29	116.40	4.76	75.60	4.33
76.80	4.34	134.00	4.90	77.40	4.35

Table B.6 DESCRIPTIVE STATISTICS FOR DBA LEP Cu DATA

DESCRIPTIVE STATISTICS FOR DBA LEP Cu DATA					
P3/8 UNTRANS		*P4 UNTRANS*		*P8 UNTRANS*	
Mean	22.09444444	Mean	38.9	Mean	26.655556
Standard Error	3.680756359	Standard Error	5.4214828	Standard Error	2.8095259
Median	11.8	Median	33.7	Median	21.7
Mode	2.8	Mode	#N/A	Mode	17.8
Standard Deviation	22.08453815	Standard Deviation	32.528897	Standard Deviation	16.857155
Variance	487.7268254	Variance	1058.1291	Variance	284.16368
Kurtosis	0.70282317	Kurtosis	1.6901119	Kurtosis	3.8063574
Skewness	1.316367663	Skewness	1.3461099	Skewness	2.0285568
Range	75.4	Range	133	Range	66.8
Minimum	1.4	Minimum	1	Minimum	10.6
Maximum	76.8	Maximum	134	Maximum	77.4
Sum	795.4	Sum	1400.4	Sum	959.6
Count	36	Count	36	Count	36
Confidence Level (95%)	7.214139217	Confidence Level (95%)	10.625895	Confidence Level (95%)	5.5065614
UCLM	26.90519301	UCLM	45.985878	UCLM	30.327606
P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	2.555979623	Mean	3.2134111	Mean	3.1422822
Standard Error	0.189154834	Standard Error	0.190654	Standard Error	0.0842862
Median	2.468099531	Median	3.5174934	Median	3.0770467
Mode	1.029619417	Mode	#N/A	Mode	2.8791985
Standard Deviation	1.134929006	Standard Deviation	1.1439241	Standard Deviation	0.505717
Variance	1.288063849	Variance	1.3085624	Variance	0.2557497
Kurtosis	-0.84786054	Kurtosis	1.1332279	Kurtosis	0.5240739
Skewness	-0.2158297	Skewness	-1.1139953	Skewness	0.8332031
Range	4.004732404	Range	4.8978398	Range	1.9881328
Minimum	0.336472237	Minimum	0	Minimum	2.360854
Maximum	4.34120464	Maximum	4.8978398	Maximum	4.3489868
Sum	92.01526643	Sum	115.6828	Sum	113.12216
Count	36	Count	36	Count	36
Confidence Level (95%)	0.370736114	Confidence Level (95%)	0.3736745	Confidence Level (95%)	0.1651976
UCLM	2.803204992	UCLM	3.4625959	UCLM	3.2524442
UCLM TRANS BACK	16.49743628	UCLM TRANS BACK	31.899677	UCLM TRANS BACK	25.853454

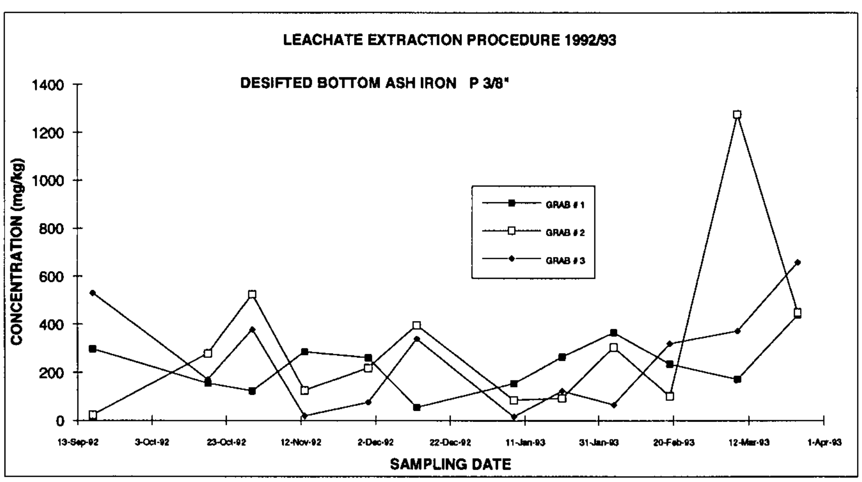

Figure B.16 DBA LEP Fe P3/8"

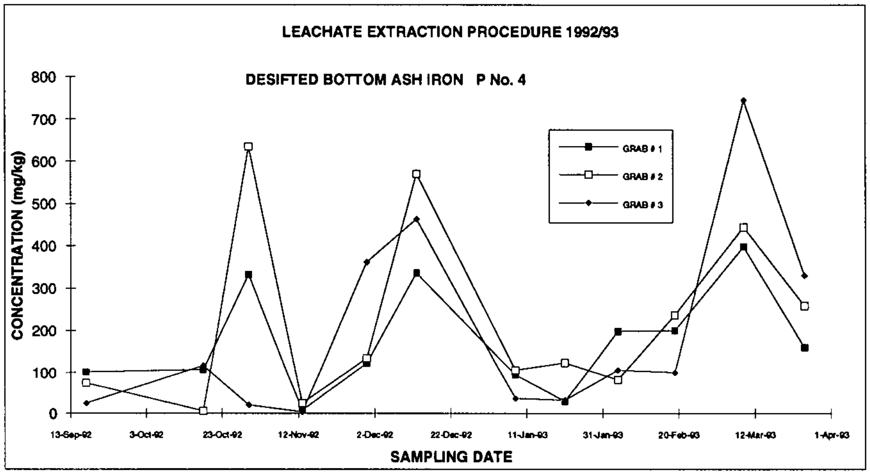

Figure B.17 DBA LEP Fe P4

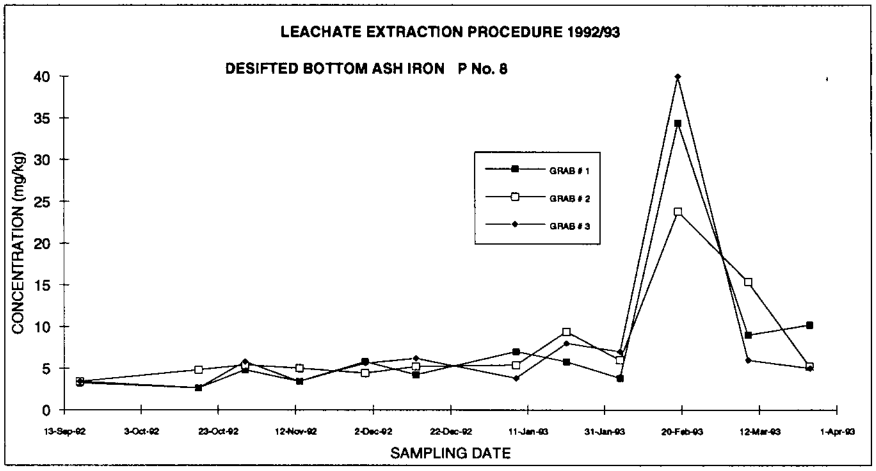

Figure B.18 RBA LEP Fe P8

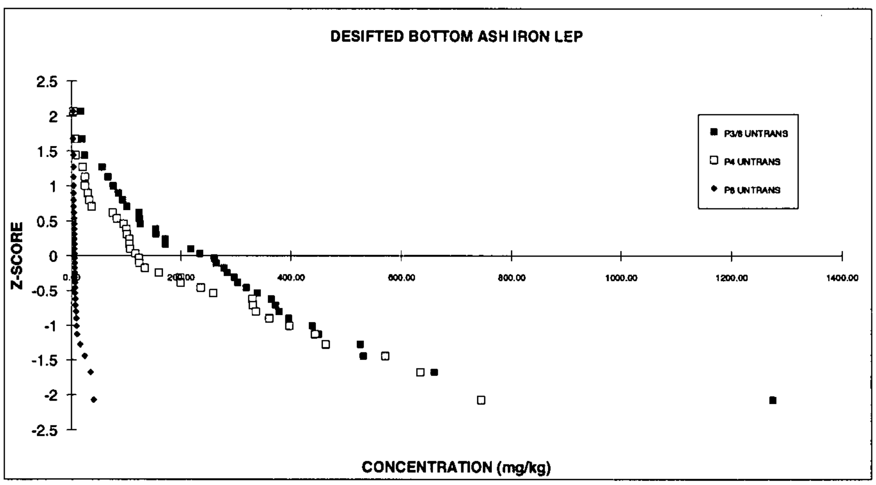

Figure B.19 DBA UNTRANSFORMED Z-SCORE Fe

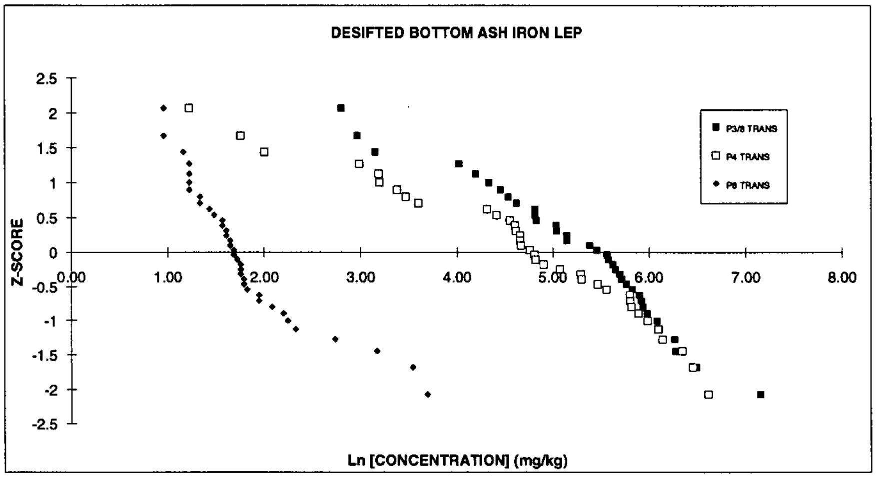

Figure B.20 DBA TRANSFORMED Z-SCORE Fe

Table B.7 DBA LEP RANKED Fe CONCENTRATIONS

DBA LEP Fe RANKED CONCENTRATIONS (mg/kg)					
P3/8" UNTRAN	P3/8" TRANS	P4 UNTRAN	P4 TRANS	P8 UNTRAN	P8 TRANS
16.40	2.80	3.40	1.22	2.60	0.96
19.40	2.97	5.80	1.76	2.60	0.96
23.40	3.15	7.40	2.00	3.20	1.16
55.60	4.02	19.80	2.99	3.40	1.22
66.20	4.19	24.20	3.19	3.40	1.22
76.00	4.33	24.40	3.19	3.40	1.22
85.80	4.45	29.20	3.37	3.40	1.22
93.20	4.53	32.00	3.47	3.80	1.34
101.40	4.62	36.40	3.59	3.80	1.34
123.40	4.82	74.60	4.31	4.20	1.44
123.60	4.82	82.60	4.41	4.40	1.48
125.20	4.83	94.60	4.55	4.80	1.57
153.40	5.03	100.20	4.61	4.80	1.57
154.40	5.04	101.00	4.62	5.00	1.61
171.40	5.14	105.60	4.66	5.00	1.61
171.60	5.15	105.80	4.66	5.20	1.65
217.80	5.38	106.80	4.67	5.20	1.65
234.40	5.46	116.80	4.76	5.40	1.69
260.40	5.56	122.60	4.81	5.40	1.69
264.20	5.58	123.80	4.82	5.60	1.72
278.00	5.63	134.60	4.90	5.80	1.76
284.60	5.65	159.60	5.07	5.80	1.76
297.20	5.69	198.40	5.29	5.80	1.76
303.80	5.72	200.00	5.30	6.00	1.79
319.60	5.77	236.60	5.47	6.00	1.79
339.00	5.83	258.60	5.56	6.20	1.82
365.00	5.90	330.00	5.80	7.00	1.95
372.00	5.92	331.60	5.80	7.00	1.95
378.20	5.94	336.00	5.82	8.00	2.08
396.00	5.98	361.00	5.89	9.00	2.20
439.00	6.08	398.00	5.99	9.40	2.24
450.00	6.11	444.00	6.10	10.20	2.32
525.60	6.26	463.00	6.14	15.40	2.73
531.20	6.28	570.00	6.35	23.80	3.17
659.00	6.49	634.40	6.45	34.40	3.54
1275.00	7.15	745.00	6.61	40.00	3.69

Table B.8 DESCRIPTIVE STATISTICS FOR DBA LEP Fe DATA

DESCRIPTIVE STATISTICS FOR DBA LEP Fe DATA					
P3/8 UNTRANS		*P4 UNTRANS*		*P8 UNTRANS*	
Mean	270.8444444	Mean	197.71667	Mean	7.9
Standard Error	39.17077475	Standard Error	31.836313	Standard Error	1.3693586
Median	247.4	Median	119.7	Median	5.4
Mode	#N/A	Mode	#N/A	Mode	3.4
Standard Deviation	235.0246485	Standard Deviation	191.01788	Standard Deviation	8.2161513
Variance	55236.5854	Variance	36487.829	Variance	67.505143
Kurtosis	8.652045362	Kurtosis	0.9899003	Kurtosis	8.836844
Skewness	2.367905496	Skewness	1.2641049	Skewness	2.9949109
Range	1258.6	Range	741.6	Range	37.4
Minimum	16.4	Minimum	3.4	Minimum	2.6
Maximum	1275	Maximum	745	Maximum	40
Sum	9750.4	Sum	7117.8	Sum	284.4
Count	36	Count	36	Count	36
Confidence Level (95%)	76.77319407	Confidence Level (95%)	62.397934	Confidence Level (95%)	2.6838895
UCLM	322.040647	UCLM	239.32673	UCLM	9.6897516
P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	5.229429036	Mean	4.6719021	Mean	1.8013659
Standard Error	0.162900925	Standard Error	0.2230775	Standard Error	0.106061
Median	5.509623984	Median	4.784695	Median	1.686399
Mode	#N/A	Mode	#N/A	Mode	1.2237754
Standard Deviation	0.97740555	Standard Deviation	1.3384653	Standard Deviation	0.6363662
Variance	0.95532161	Variance	1.7914892	Variance	0.404962
Kurtosis	0.652439602	Kurtosis	0.3252555	Kurtosis	2.5082762
Skewness	-0.80804982	Skewness	-0.8507627	Skewness	1.5350669
Range	4.353420123	Range	5.3896088	Range	2.733368
Minimum	2.797281335	Minimum	1.2237754	Minimum	0.9555114
Maximum	7.150701458	Maximum	6.6133842	Maximum	3.6888795
Sum	188.2594453	Sum	168.18847	Sum	64.849171
Count	36	Count	36	Count	36
Confidence Level (95%)	0.319279473	Confidence Level (95%)	0.4372233	Confidence Level (95%)	0.2078755
UCLM	5.442340545	UCLM	4.9634644	UCLM	1.9399876
UCLM TRANS BACK	230.9821755	UCLM TRANS BACK	143.08866	UCLM TRANS BACK	6.9586649

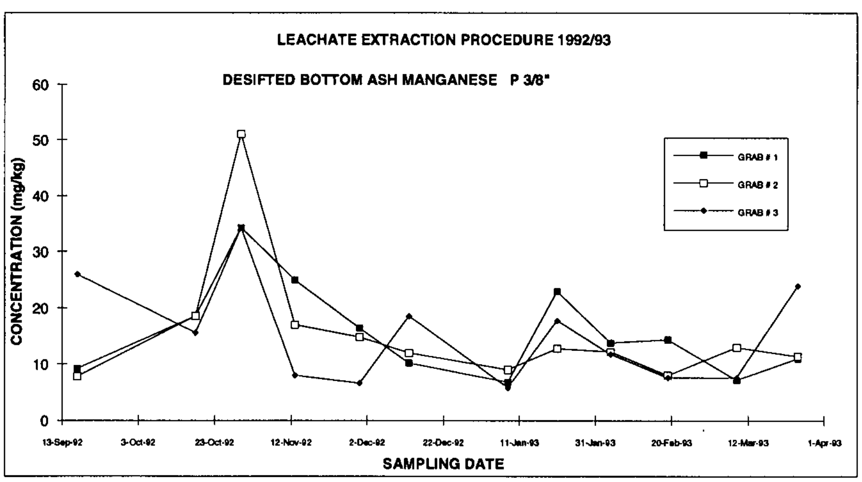

Figure B.21 DBA LEP Mn P3/8"

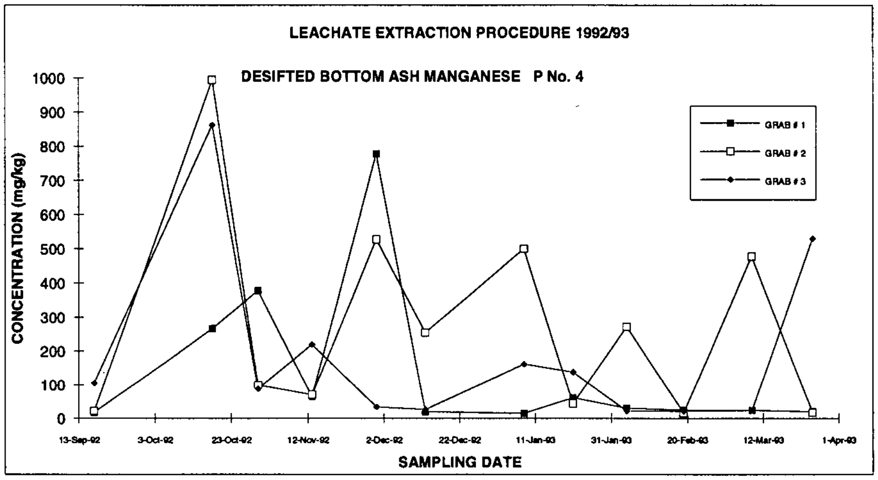

Figure B.22 DBA LEP Mn P4

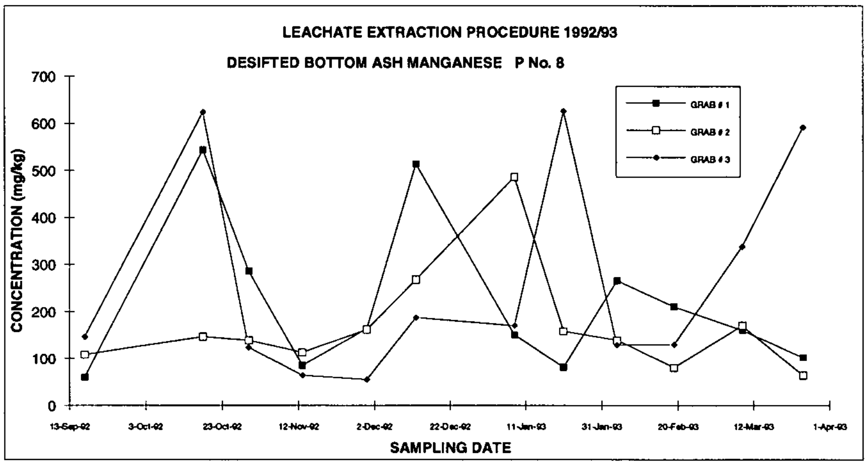

Figure B.23 DBA LEP Mn P8

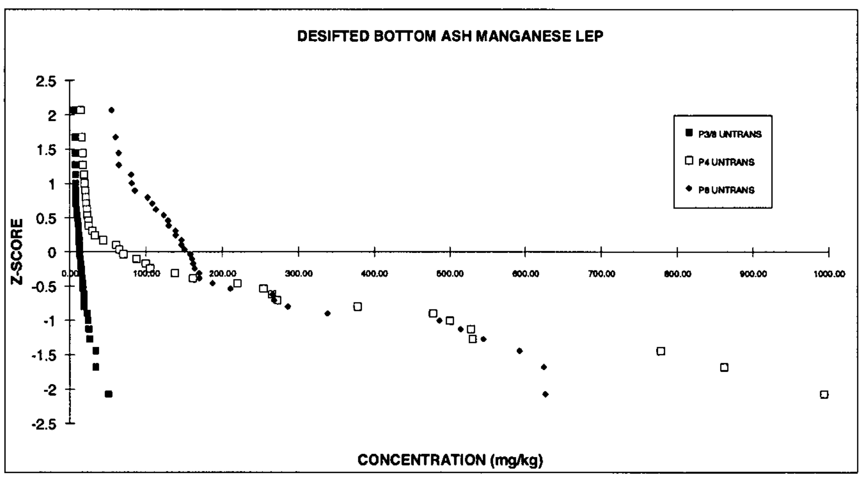

Figure B.24 DBA UNTRANSFORMED Z-SCORE Mn

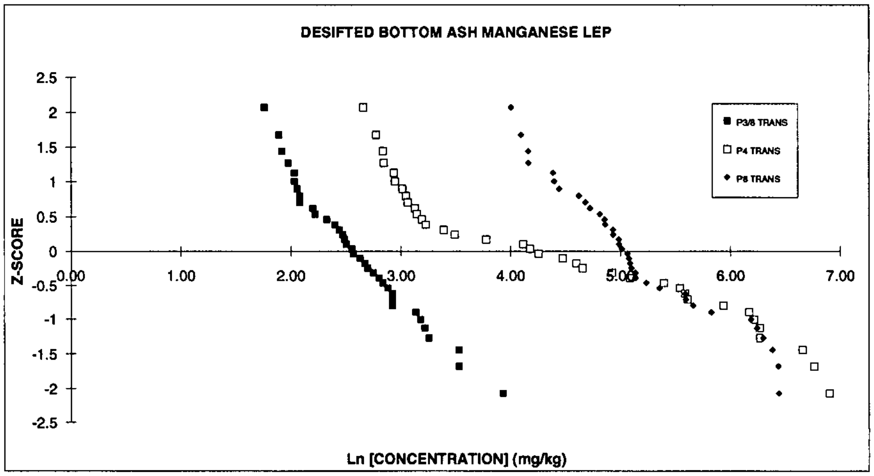

Figure B.25 DBA TRANSFORMED Z-SCORE Mn

Table B.9 DBA LEP RANKED Mn CONCENTRATIONS

DBA LEP Mn RANKED CONCENTRATIONS (mg/kg)					
P3/8" UNTRAN	P3/8" TRANS	P4 UNTRAN	P4 TRANS	P8 UNTRAN	P8 TRANS
5.80	1.76	14.20	2.65	54.80	4.00
6.60	1.89	16.00	2.77	60.00	4.09
6.80	1.92	17.00	2.83	64.00	4.16
7.20	1.97	17.20	2.84	64.20	4.16
7.60	2.03	18.80	2.93	80.40	4.39
7.60	2.03	19.00	2.94	81.20	4.40
7.80	2.05	20.40	3.02	85.00	4.44
8.00	2.08	21.00	3.04	101.80	4.62
8.00	2.08	21.40	3.06	108.00	4.68
9.00	2.20	22.80	3.13	112.60	4.72
9.20	2.22	23.20	3.14	123.20	4.81
10.20	2.32	24.40	3.19	128.60	4.86
11.00	2.40	25.20	3.23	129.40	4.86
11.40	2.43	29.80	3.39	138.60	4.93
11.80	2.47	33.00	3.50	138.80	4.93
12.00	2.48	43.80	3.78	146.20	4.98
12.20	2.50	61.20	4.11	146.40	4.99
12.80	2.55	65.20	4.18	150.40	5.01
13.00	2.56	70.60	4.26	158.00	5.06
13.80	2.62	87.80	4.48	160.20	5.08
14.40	2.67	99.60	4.60	161.80	5.09
14.80	2.69	105.40	4.66	163.80	5.10
15.60	2.75	137.60	4.92	170.00	5.14
16.40	2.80	161.60	5.09	170.00	5.14
17.00	2.83	220.20	5.39	187.20	5.23
17.80	2.88	254.00	5.54	210.60	5.35
18.60	2.92	266.00	5.58	266.00	5.58
18.60	2.92	272.00	5.61	268.00	5.59
18.60	2.92	378.00	5.93	286.00	5.66
23.00	3.14	478.00	6.17	338.00	5.82
24.00	3.18	500.00	6.21	486.00	6.19
25.00	3.22	528.00	6.27	514.00	6.24
26.00	3.26	530.00	6.27	544.00	6.30
34.20	3.53	778.00	6.66	592.00	6.38
34.20	3.53	862.00	6.76	624.00	6.44
51.00	3.93	994.00	6.90	626.00	6.44

Table B.10 DESCRIPTIVE STATISTICS FOR DBA LEP Mn DATA

DESCRIPTIVE STATISTICS FOR DBA LEP Mn DATA					
P3/8 UNTRANS		*P4 UNTRANS*		*P8 UNTRANS*	
Mean	15.58333333	Mean	200.45556	Mean	217.75556
Standard Error	1.5791574	Standard Error	43.866825	Standard Error	28.488948
Median	12.9	Median	67.9	Median	154.2
Mode	18.6	Mode	#N/A	Mode	170
Standard Deviation	9.474944402	Standard Deviation	263.20095	Standard Deviation	170.93369
Variance	89.77457143	Variance	69274.74	Variance	29218.325
Kurtosis	4.688428991	Kurtosis	2.0613112	Kurtosis	0.8324236
Skewness	1.922269316	Skewness	1.6700549	Skewness	1.438824
Range	45.2	Range	979.8	Range	571.2
Minimum	5.8	Minimum	14.2	Minimum	54.8
Maximum	51	Maximum	994	Maximum	626
Sum	561	Sum	7216.4	Sum	7839.2
Count	36	Count	36	Count	36
Confidence Level (95%)	3.095087048	Confidence Level (95%)	85.97727	Confidence Level (95%)	55.837229
UCLM	17.64729206	UCLM	257.7895	UCLM	254.99061
P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	2.604004602	Mean	4.4183544	Mean	5.1354117
Standard Error	0.086992943	Standard Error	0.2313762	Standard Error	0.115261
Median	2.557197264	Median	4.2172448	Median	5.0379467
Mode	2.923161581	Mode	#N/A	Mode	5.1357984
Standard Deviation	0.521957655	Standard Deviation	1.3882574	Standard Deviation	0.691566
Variance	0.272439794	Variance	1.9272585	Variance	0.4782636
Kurtosis	-0.15513322	Kurtosis	-1.3581299	Kurtosis	-0.4955952
Skewness	0.506844562	Skewness	0.3471469	Skewness	0.4692607
Range	2.173967715	Range	4.2484952	Range	2.4356602
Minimum	1.757857918	Minimum	2.653242	Minimum	4.0036902
Maximum	3.931825633	Maximum	6.9017372	Maximum	6.4393504
Sum	93.74416569	Sum	159.06076	Sum	184.87482
Count	36	Count	36	Count	36
Confidence Level (95%)	0.170502782	Confidence Level (95%)	0.4534884	Confidence Level (95%)	0.2259071
UCLM	2.717704378	UCLM	4.7207632	UCLM	5.2860578
UCLM TRANS BACK	15.14551394	UCLM TRANS BACK	112.25389	UCLM TRANS BACK	197.56306

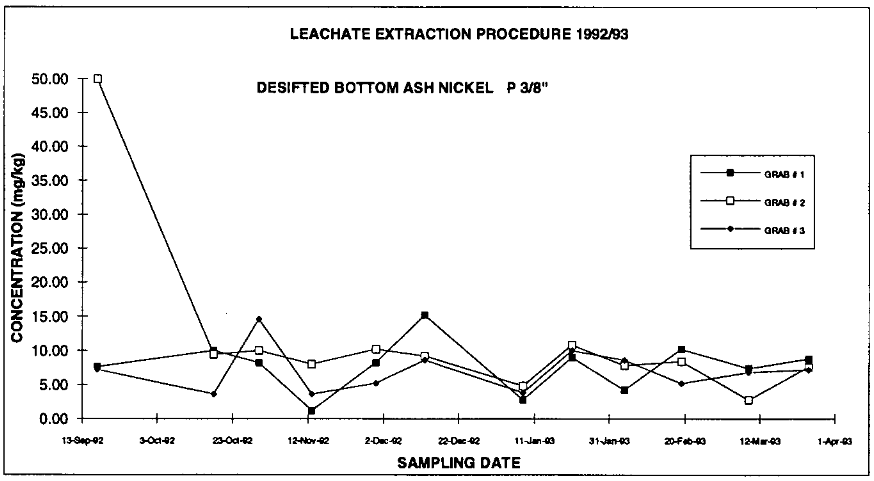

Figure B.26 DBA LEP Ni P3/8"

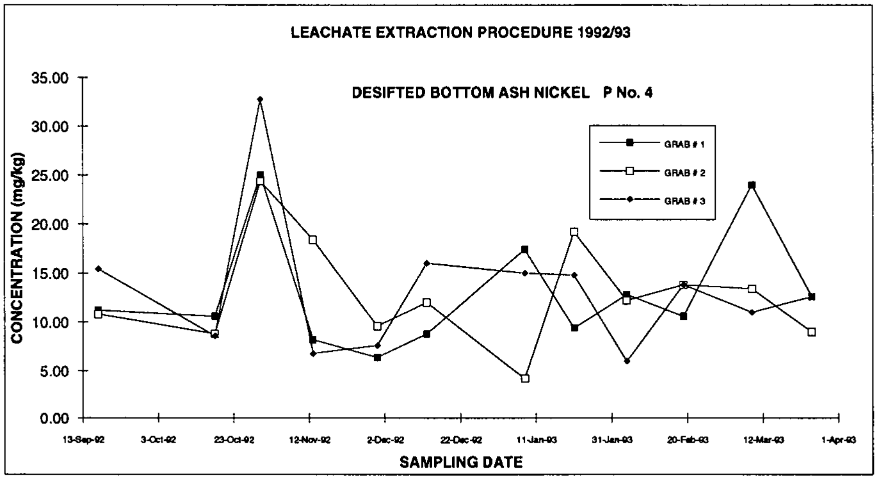

Figure B.27 DBA LEP Ni P4

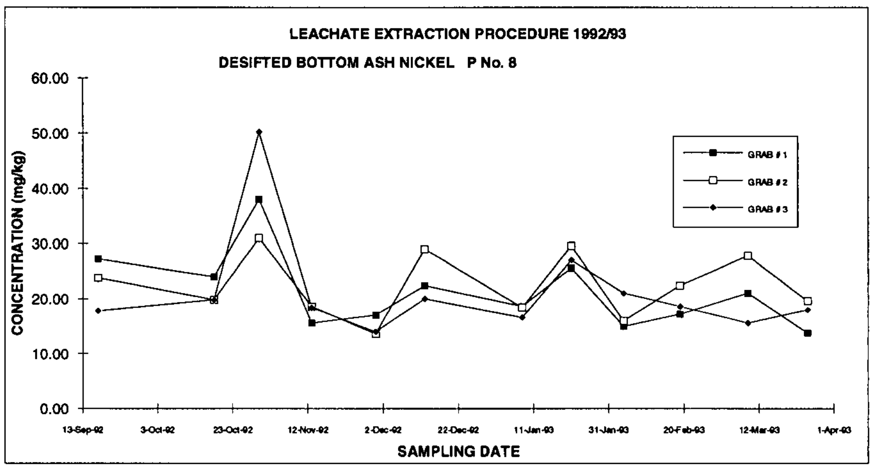

Figure B.28 DBA LEP Ni P8

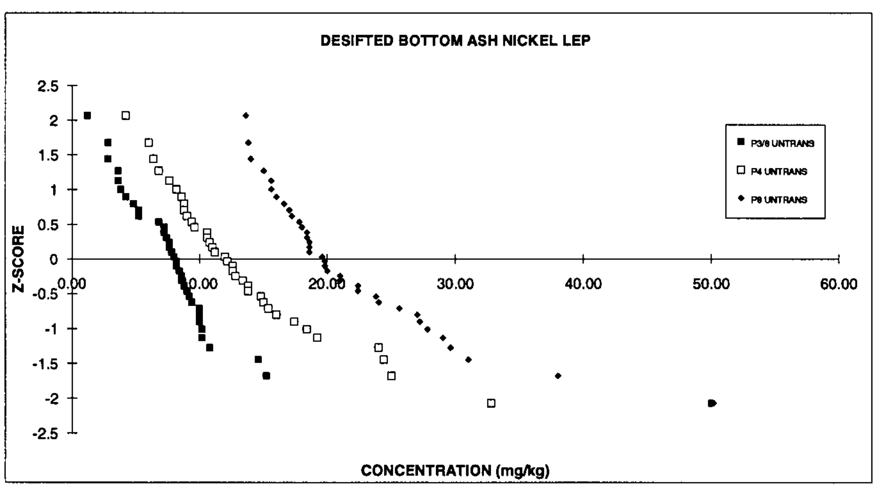

Figure B.29 DBA UNTRANSFORMED Z-SCORE Ni

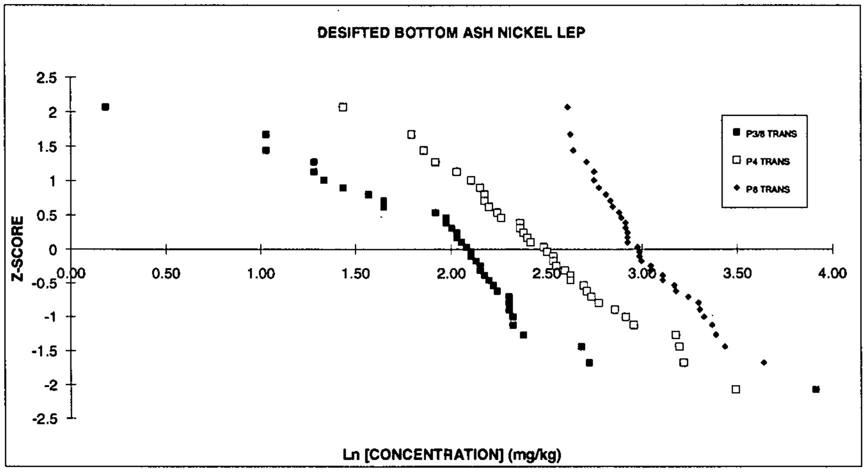

Figure B.30 DBA UNTRANSFORMED Z-SCORE Ni

Table B.11 DBA LEP RANKED Ni CONCENTRATIONS

DBA LEP NI RANKED CONCENTRATIONS (mg/kg)					
P3/8" UNTRAN	P3/8" TRANS	P4 UNTRAN	P4 TRANS	P8 UNTRAN	P8 TRANS
1.20	0.18	4.20	1.44	13.60	2.61
2.80	1.03	6.00	1.79	13.80	2.62
2.80	1.03	6.40	1.86	14.00	2.64
3.60	1.28	6.80	1.92	15.00	2.71
3.60	1.28	7.60	2.03	15.60	2.75
3.80	1.34	8.20	2.10	15.60	2.75
4.20	1.44	8.60	2.15	16.00	2.77
4.80	1.57	8.80	2.17	16.60	2.81
5.20	1.65	8.80	2.17	17.00	2.83
5.20	1.65	9.00	2.20	17.20	2.84
6.80	1.92	9.40	2.24	17.80	2.88
7.20	1.97	9.60	2.26	18.00	2.89
7.20	1.97	10.60	2.36	18.40	2.91
7.40	2.00	10.60	2.36	18.40	2.91
7.60	2.03	10.80	2.38	18.60	2.92
7.60	2.03	11.00	2.40	18.60	2.92
7.80	2.05	11.20	2.42	18.60	2.92
8.00	2.08	12.00	2.48	19.60	2.98
8.20	2.10	12.20	2.50	19.80	2.99
8.20	2.10	12.60	2.53	19.80	2.99
8.40	2.13	12.60	2.53	20.00	3.00
8.60	2.15	12.80	2.55	21.00	3.04
8.60	2.15	13.40	2.60	21.00	3.04
8.80	2.17	13.80	2.62	22.40	3.11
9.00	2.20	13.80	2.62	22.40	3.11
9.20	2.22	14.80	2.69	23.80	3.17
9.40	2.24	15.00	2.71	24.00	3.18
10.00	2.30	15.40	2.73	25.60	3.24
10.00	2.30	16.00	2.77	27.00	3.30
10.00	2.30	17.40	2.86	27.20	3.30
10.20	2.32	18.40	2.91	27.80	3.33
10.20	2.32	19.20	2.95	29.00	3.37
10.80	2.38	24.00	3.18	29.60	3.39
14.60	2.68	24.40	3.19	31.00	3.43
15.20	2.72	25.00	3.22	38.00	3.64
50.00	3.91	32.80	3.49	50.20	3.92

Table B.12 DESCRIPTIVE STATISTICS FOR DBA LEP Ni DATA

DESCRIPTIVE STATISTICS FOR DBA LEP Ni DATA					
P3/8 UNTRANS		*P4 UNTRANS*		*P8 UNTRANS*	
Mean	8.783333333	Mean	13.144444	Mean	21.722222
Standard Error	1.282764252	Standard Error	1.0071368	Standard Error	1.2292798
Median	8.1	Median	12.1	Median	19.7
Mode	10	Mode	8.8	Mode	18.6
Standard Deviation	7.696585514	Standard Deviation	6.0428207	Standard Deviation	7.3756786
Variance	59.23742857	Variance	36.515683	Variance	54.400635
Kurtosis	24.73528803	Kurtosis	2.2619022	Kurtosis	5.5002019
Skewness	4.575587524	Skewness	1.3751478	Skewness	2.006647
Range	48.8	Range	28.6	Range	36.6
Minimum	1.2	Minimum	4.2	Minimum	13.6
Maximum	50	Maximum	32.8	Maximum	50.2
Sum	316.2	Sum	473.2	Sum	782
Count	36	Count	36	Count	36
Confidence Level (95%)	2.514168012	Confidence Level (95%)	1.9739489	Confidence Level (95%)	2.4093405
UCLM	10.45990621	UCLM	14.460772	UCLM	23.328891
P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	1.978172333	Mean	2.4836515	Mean	3.0335314
Standard Error	0.101354708	Standard Error	0.0722563	Standard Error	0.0483683
Median	2.091787848	Median	2.4931713	Median	2.9806058
Mode	2.302585093	Mode	2.1747517	Mode	2.9231616
Standard Deviation	0.608128248	Standard Deviation	0.4335378	Standard Deviation	0.2902097
Variance	0.369819966	Variance	0.1879551	Variance	0.0842217
Kurtosis	3.529854367	Kurtosis	0.3058437	Kurtosis	1.1927466
Skewness	-0.05853168	Skewness	0.0754313	Skewness	0.9728249
Range	3.729701449	Range	2.055344	Range	1.3059452
Minimum	0.182321557	Minimum	1.4350845	Minimum	2.6100698
Maximum	3.912023005	Maximum	3.4904285	Maximum	3.916015
Sum	71.21420399	Sum	89.411453	Sum	109.20713
Count	36	Count	36	Count	36
Confidence Level (95%)	0.198651283	Confidence Level (95%)	0.1416196	Confidence Level (95%)	0.0948
UCLM	2.110642936	UCLM	2.5780905	UCLM	3.0967488
UCLM TRANS BACK	8.253546084	UCLM TRANS BACK	13.171962	UCLM TRANS BACK	22.125898

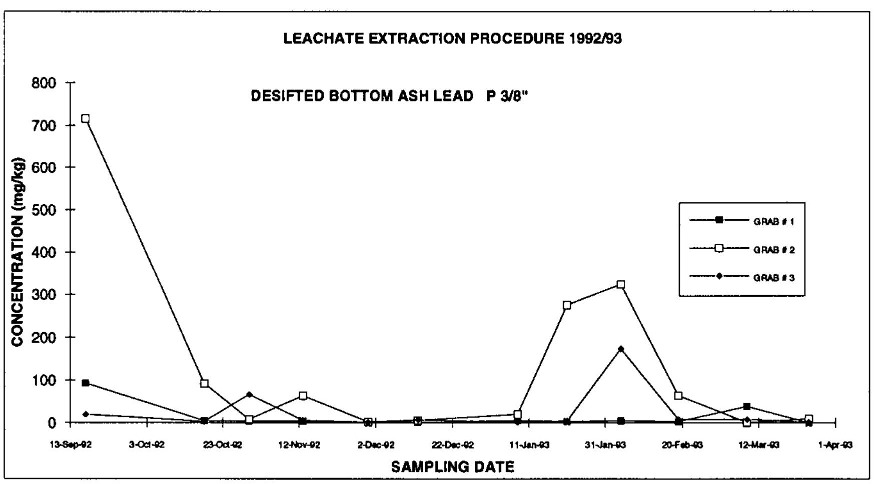

Figure B.31 DBA LEP Pb P3/8"

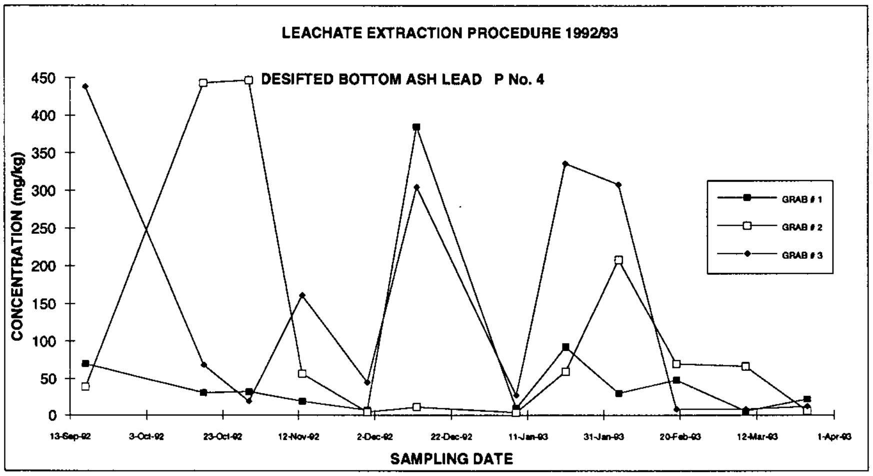

Figure B.32 DBA LEP Pb P4

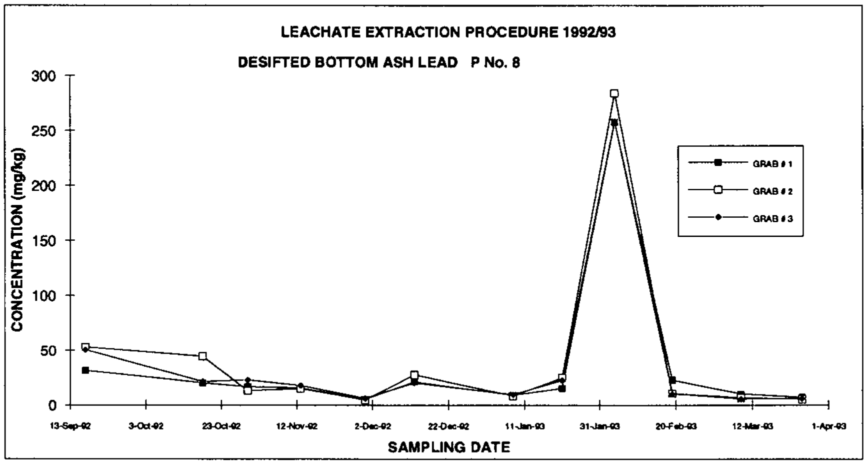

Figure B.33 DBA LEP Pb P8

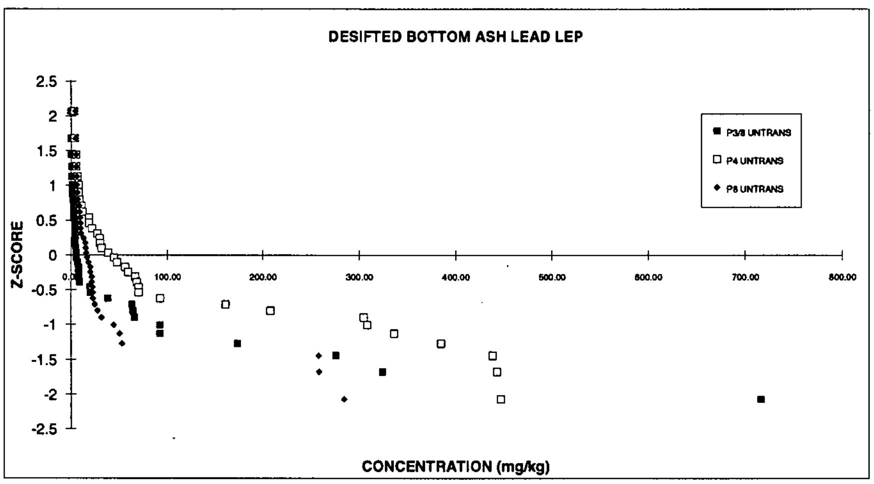

Figure B.34 DBA UNTRANSFORMED Z-SCORE Pb

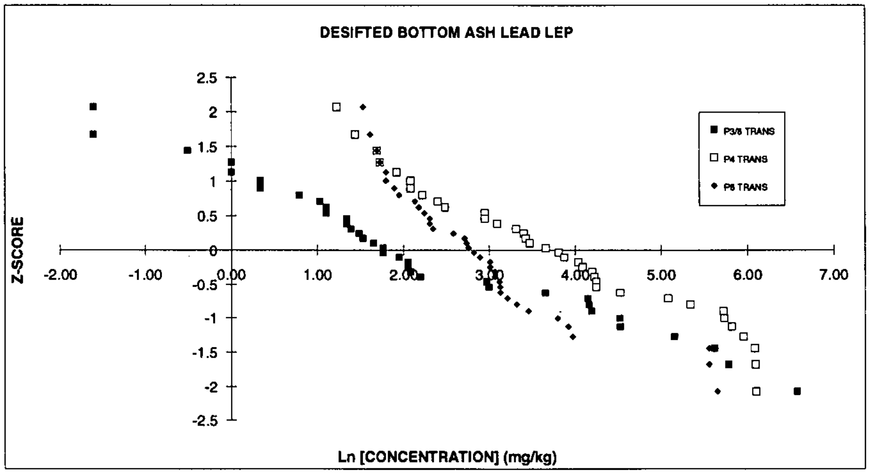

Figure B.35 DBA TRANSFORMED Z-SCORE Pb

Table B.13 DBA LEP RANKED Pb CONCENTRATIONS

DBA LEP Pb RANKED CONCENTRATIONS (mg/kg)					
P3/8" UNTRAN	P3/8" TRANS	P4 UNTRAN	P4 TRANS	P8 UNTRAN	P8 TRANS
0.20	-1.61	3.40	1.22	4.60	1.53
0.20	-1.61	4.20	1.44	5.00	1.61
0.60	-0.51	5.40	1.69	5.40	1.69
1.00	0.00	5.60	1.72	5.60	1.72
1.00	0.00	6.80	1.92	6.00	1.79
1.40	0.34	8.00	2.08	6.00	1.79
1.40	0.34	8.00	2.08	6.60	1.89
2.20	0.79	9.20	2.22	7.00	1.95
2.80	1.03	11.00	2.40	8.40	2.13
3.00	1.10	12.00	2.48	8.80	2.17
3.00	1.10	19.00	2.94	9.40	2.24
3.80	1.34	19.00	2.94	10.00	2.30
3.80	1.34	22.00	3.09	10.00	2.30
4.00	1.39	27.40	3.31	10.40	2.34
4.40	1.48	30.00	3.40	13.20	2.58
4.60	1.53	30.60	3.42	15.00	2.71
5.20	1.65	32.00	3.47	15.40	2.73
5.80	1.76	38.60	3.65	15.80	2.76
5.80	1.76	45.00	3.81	16.80	2.82
7.00	1.95	48.00	3.87	18.00	2.89
7.80	2.05	56.60	4.04	20.20	3.01
7.80	2.05	59.40	4.08	20.20	3.01
8.00	2.08	66.60	4.20	21.40	3.06
9.00	2.20	68.40	4.23	21.40	3.06
19.40	2.97	70.00	4.25	22.60	3.12
20.00	3.00	70.00	4.25	22.80	3.13
38.40	3.65	92.60	4.53	22.80	3.13
63.20	4.15	161.20	5.08	24.80	3.21
64.20	4.16	208.00	5.34	27.60	3.32
66.00	4.19	304.80	5.72	31.60	3.45
92.20	4.52	308.00	5.73	44.40	3.79
92.40	4.53	336.00	5.82	50.40	3.92
173.40	5.16	385.00	5.95	53.00	3.97
275.60	5.62	438.20	6.08	257.80	5.55
324.00	5.78	443.00	6.09	258.40	5.55
716.00	6.57	446.80	6.10	284.20	5.65

Table B.14 DESCRIPTIVE STATISTICS FOR DBA LEP Pb DATA

DESCRIPTIVE STATISTICS FORDBA LEP Pb DATA					
P3/8 UNTRANS		*P4 UNTRANS*		*P8 UNTRANS*	
Mean	56.62777778	Mean	108.32778	Mean	38.361111
Standard Error	22.54637852	Standard Error	24.054333	Standard Error	11.829164
Median	5.8	Median	41.8	Median	16.3
Mode	0.2	Mode	8	Mode	6
Standard Deviation	135.2782711	Standard Deviation	144.326	Standard Deviation	70.974987
Variance	18300.21063	Variance	20829.993	Variance	5037.4487
Kurtosis	16.65858859	Kurtosis	0.687784	Kurtosis	7.8604765
Skewness	3.841051591	Skewness	1.4710917	Skewness	3.0083028
Range	715.8	Range	443.4	Range	279.6
Minimum	0.2	Minimum	3.4	Minimum	4.6
Maximum	716	Maximum	446.8	Maximum	284.2
Sum	2038.6	Sum	3899.8	Sum	1381
Count	36	Count	36	Count	36
Confidence Level (95%)	44.19002444	Confidence Level (95%)	47.145556	Confidence Level (95%)	23.184702
UCLM	86.0958945	UCLM	139.76679	UCLM	53.821829
P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	2.161216316	Mean	3.7401017	Mean	2.8854875
Standard Error	0.334256586	Standard Error	0.2463956	Standard Error	0.1759316
Median	1.757857918	Median	3.7299574	Median	2.7906944
Mode	-1.60943791	Mode	2.0794415	Mode	1.7917595
Standard Deviation	2.005539514	Standard Deviation	1.4783738	Standard Deviation	1.0555898
Variance	4.022188741	Variance	2.185589	Variance	1.1142698
Kurtosis	-0.29531865	Kurtosis	-1.0243624	Kurtosis	1.6078867
Skewness	0.333709689	Skewness	0.1160708	Skewness	1.249918
Range	8.183118079	Range	4.8783356	Range	4.1236219
Minimum	-1.60943791	Minimum	1.2237754	Minimum	1.5260563
Maximum	6.573680167	Maximum	6.1021111	Maximum	5.6496782
Sum	77.80378736	Sum	134.64366	Sum	103.87755
Count	36	Count	36	Count	36
Confidence Level (95%)	0.655129899	Confidence Level (95%)	0.4829258	Confidence Level (95%)	0.3448191
UCLM	2.598089673	UCLM	4.0621407	UCLM	3.1154302
UCLM TRANS BACK	13.43804244	UCLM TRANS BACK	58.098552	UCLM TRANS BACK	22.543126

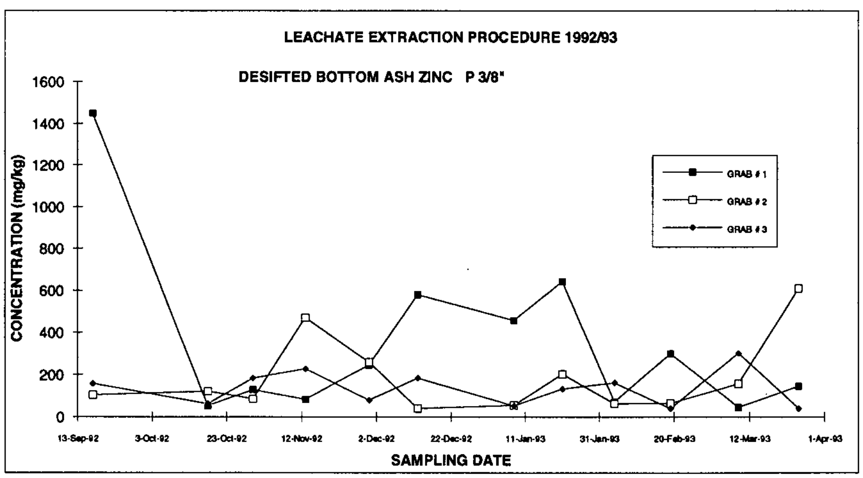

Figure B.36 DBA LEP Zn P3/8"

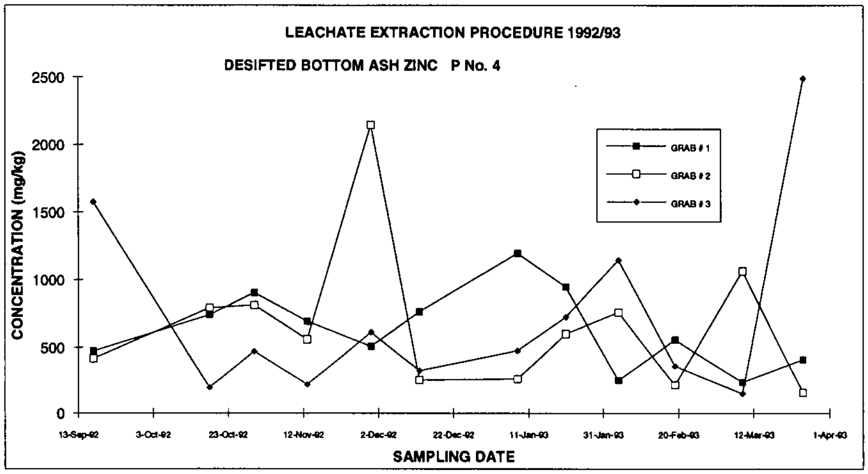

Figure B.37 DBA LEP Zn P4

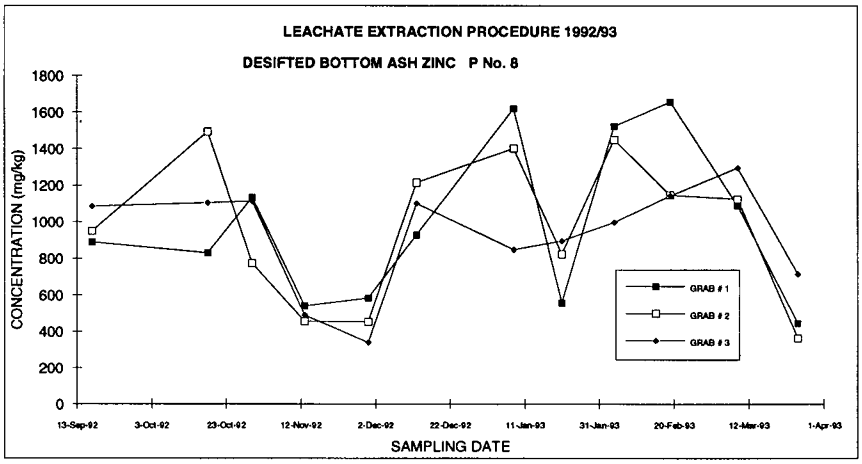

Figure B.38 DBA LEP Zn P8

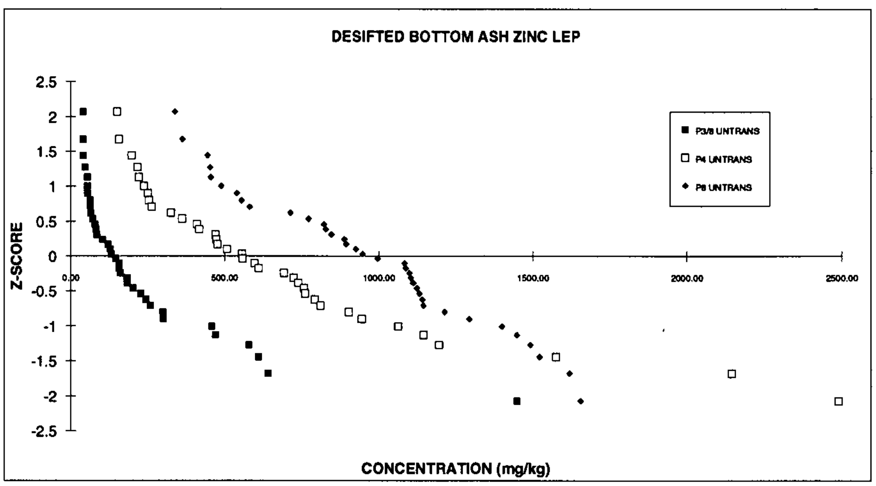

Figure B.39 DBA UNTRANSFORMED Z-SCORE Zn

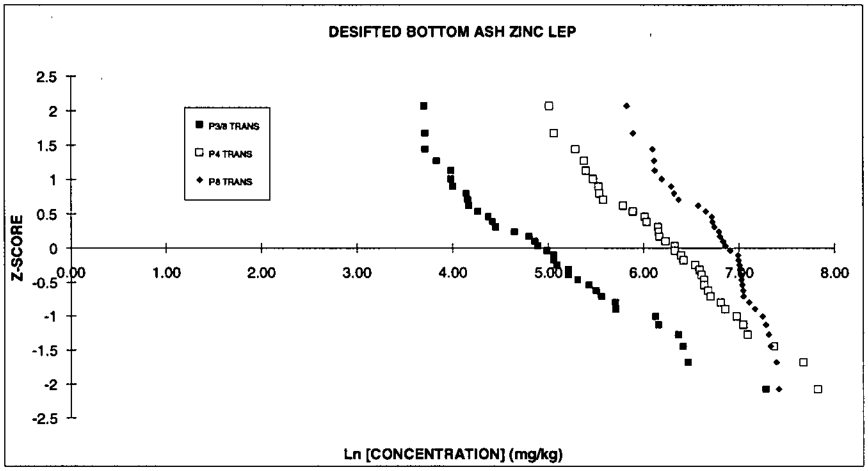

Figure B.40 DBA TRANSFORMED Z-SCORE Zn

Table B.15 DBA LEP RANKED Zn CONCENTRATIONS

DBA LEP Zn RANKED CONCENTRATIONS (mg/kg)					
P3/8" UNTRAN	P3/8" TRANS	P4 UNTRAN	P4 TRANS	P8 UNTRAN	P8 TRANS
40.40	3.70	149.80	5.01	338.00	5.82
40.80	3.71	157.60	5.06	362.00	5.89
40.80	3.71	197.60	5.29	444.00	6.10
46.00	3.83	216.40	5.38	452.00	6.11
53.60	3.98	220.60	5.40	454.60	6.12
53.60	3.98	237.40	5.47	488.80	6.19
54.80	4.00	251.00	5.53	540.00	6.29
62.80	4.14	254.20	5.54	556.00	6.32
64.00	4.16	263.60	5.57	582.00	6.37
64.60	4.17	326.00	5.79	714.00	6.57
71.00	4.26	361.60	5.89	772.00	6.65
79.20	4.37	410.00	6.02	822.00	6.71
82.80	4.42	417.80	6.04	828.00	6.72
85.40	4.45	470.60	6.15	846.00	6.74
104.20	4.65	472.60	6.16	888.00	6.79
121.00	4.80	476.00	6.17	894.00	6.80
128.80	4.86	508.00	6.23	926.00	6.83
132.60	4.89	558.00	6.32	948.00	6.85
145.60	4.98	560.00	6.33	996.00	6.90
157.00	5.06	598.00	6.39	1084.00	6.99
157.00	5.06	612.00	6.42	1088.00	6.99
162.00	5.09	692.00	6.54	1100.00	7.00
182.80	5.21	724.00	6.58	1104.00	7.01
183.00	5.21	740.00	6.61	1112.00	7.01
201.80	5.31	758.00	6.63	1124.00	7.02
227.60	5.43	762.00	6.64	1132.00	7.03
244.80	5.50	792.00	6.67	1142.00	7.04
258.80	5.56	812.00	6.70	1146.00	7.04
299.40	5.70	904.00	6.81	1214.00	7.10
301.00	5.71	946.00	6.85	1294.00	7.17
458.00	6.13	1064.00	6.97	1400.00	7.24
471.00	6.15	1146.00	7.04	1448.00	7.28
580.00	6.36	1196.00	7.09	1492.00	7.31
610.00	6.41	1576.00	7.36	1522.00	7.33
642.00	6.46	2146.00	7.67	1620.00	7.39
1448.00	7.28	2490.00	7.82	1656.00	7.41

Table B.16 DESCRIPTIVE STATISTICS FOR DBA LEP Zn DATA

DESCRIPTIVE STATISTICS FOR DBA LEP Zn DATA					
P3/8 UNTRANS		*P4 UNTRANS*		*P8 UNTRANS*	
Mean	223.7833333	Mean	679.63333	Mean	959.15
Standard Error	44.74459824	Standard Error	87.026218	Standard Error	61.284534
Median	139.1	Median	559	Median	972
Mode	40.8	Mode	#N/A	Mode	#N/A
Standard Deviation	268.4675894	Standard Deviation	522.15731	Standard Deviation	367.7072
Variance	72074.84657	Variance	272648.25	Variance	135208.59
Kurtosis	11.95788908	Kurtosis	4.3144096	Kurtosis	-0.7991867
Skewness	3.081038935	Skewness	1.9283117	Skewness	0.0460756
Range	1407.6	Range	2340.2	Range	1318
Minimum	40.4	Minimum	149.8	Minimum	338
Maximum	1448	Maximum	2490	Maximum	1656
Sum	8056.2	Sum	24466.8	Sum	34529.4
Count	36	Count	36	Count	36
Confidence Level (95%)	87.69767119	Confidence Level (95%)	170.568	Confidence Level (95%)	120.1153
UCLM	282.2645232	UCLM	793.3766	UCLM	1039.2489
P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	4.96290647	Mean	6.2811558	Mean	6.7819902
Standard Error	0.151878945	Standard Error	0.1168724	Standard Error	0.0728414
Median	4.934100107	Median	6.3261479	Median	6.8790509
Mode	3.708682081	Mode	#N/A	Mode	#N/A
Standard Deviation	0.911273668	Standard Deviation	0.7012346	Standard Deviation	0.4370482
Variance	0.830419697	Variance	0.49173	Variance	0.1910111
Kurtosis	-0.30055889	Kurtosis	-0.4003127	Kurtosis	-0.513641
Skewness	0.541686918	Skewness	0.112588	Skewness	-0.649566
Range	3.579108788	Range	2.8107369	Range	1.5891144
Minimum	3.698829785	Minimum	5.0093011	Minimum	5.8230459
Maximum	7.277938573	Maximum	7.820038	Maximum	7.4121603
Sum	178.6646329	Sum	226.12161	Sum	244.15165
Count	36	Count	36	Count	36
Confidence Level (95%)	0.297676821	Confidence Level (95%)	0.2290654	Confidence Level (95%)	0.1427663
UCLM	5.16141225	UCLM	6.4339081	UCLM	6.8771938
UCLM TRANS BACK	174.4105932	UCLM TRANS BACK	622.60236	UCLM TRANS BACK	969.90084

Appendix C

DESIFTED BOTTOM ASH AQUA REGIA DIGESTION OF LEP SOLIDS

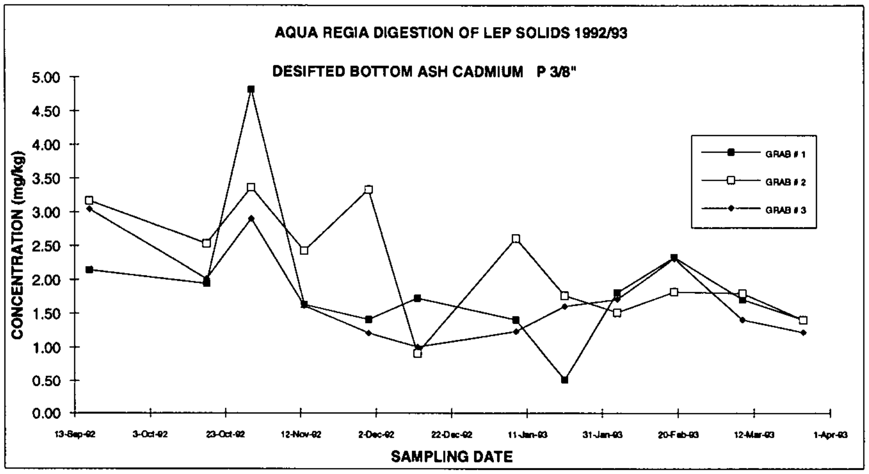

Figure C.1 DBA - ARD OF LEP SOLIDS Cd P3/8"

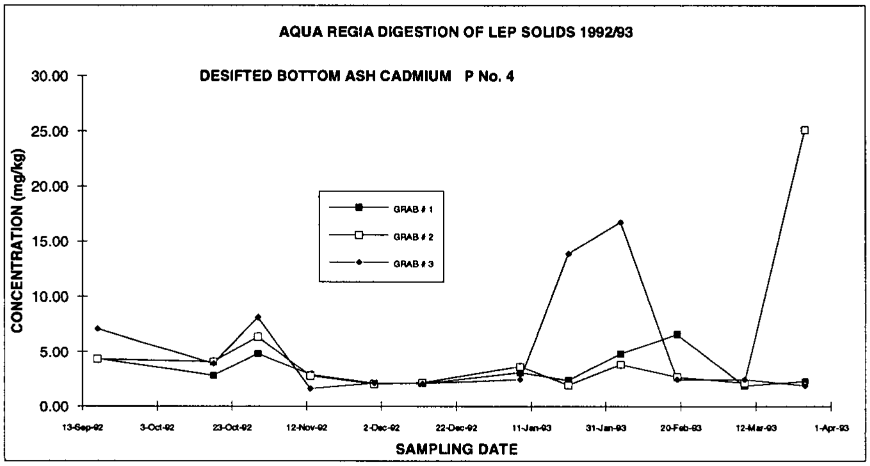

Figure C.2 DBA - ARD OF LEP SOLIDS Cd P4

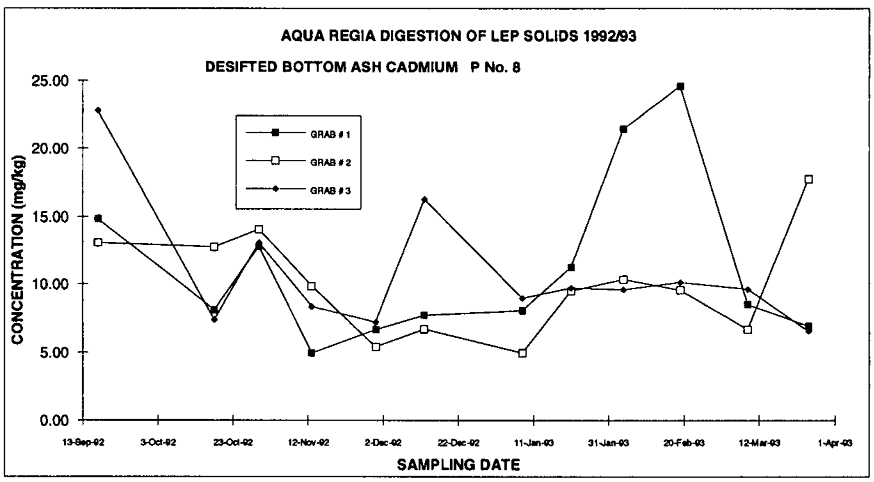

Figure C.3 DBA - ARD OF LEP SOLIDS Cd P8

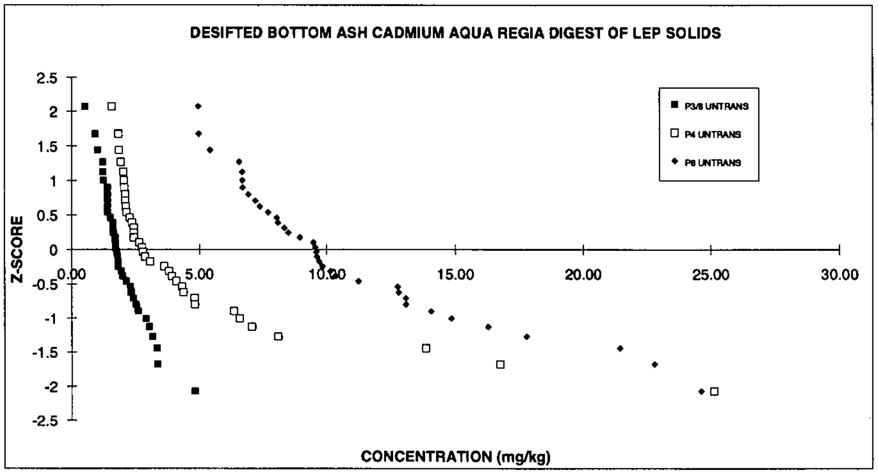

Figure C.4 DBA - ARD OF LEP SOLIDS UNTRANSFORMED Z-SCORE Cd

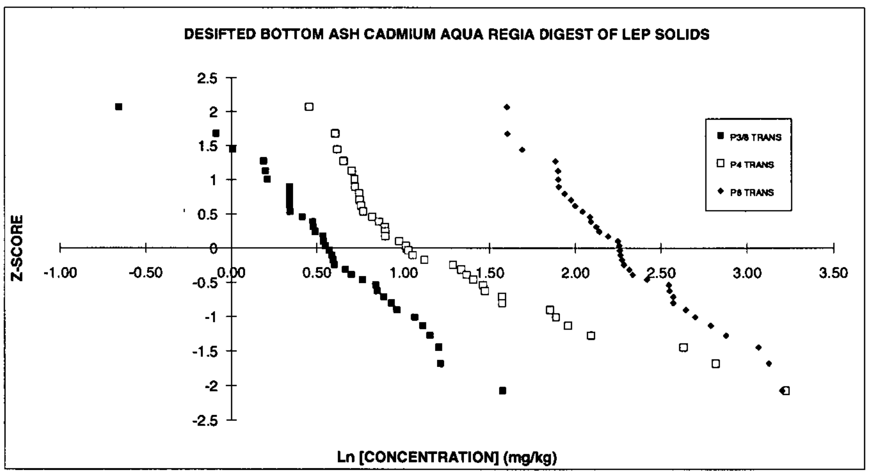

Figure C.5 DBA - ARD OF LEP SOLIDS TRANSFORMED Z-SCORE Cd

Table C.1 DBA ARD OF LEP SOLIDS Cd RANKED DATA (mg/kg)

DBA ARD OF LEP SOLIDS Cd RANKED CONCENTRATIONS (mg/kg)					
P3/8" UNTRAN	P3/8" TRANS	P4 UNTRAN	P4 TRANS	P8 UNTRAN	P8 TRANS
0.52	-0.66	1.58	0.46	4.95	1.60
0.91	-0.09	1.83	0.61	4.96	1.60
1.01	0.01	1.86	0.62	5.40	1.69
1.21	0.19	1.92	0.65	6.57	1.88
1.22	0.20	2.02	0.70	6.67	1.90
1.24	0.21	2.05	0.72	6.68	1.90
1.40	0.34	2.05	0.72	6.70	1.90
1.41	0.34	2.10	0.74	6.93	1.94
1.41	0.34	2.11	0.75	7.20	1.97
1.41	0.34	2.13	0.75	7.37	2.00
1.41	0.34	2.15	0.77	7.71	2.04
1.51	0.41	2.27	0.82	8.05	2.09
1.61	0.47	2.36	0.86	8.09	2.09
1.61	0.48	2.44	0.89	8.35	2.12
1.63	0.49	2.44	0.89	8.50	2.14
1.71	0.53	2.44	0.89	8.95	2.19
1.71	0.54	2.65	0.98	9.48	2.25
1.73	0.55	2.75	1.01	9.55	2.26
1.77	0.57	2.80	1.03	9.59	2.26
1.80	0.59	2.87	1.05	9.62	2.26
1.81	0.59	3.07	1.12	9.71	2.27
1.82	0.60	3.62	1.29	9.83	2.29
1.94	0.66	3.81	1.34	10.13	2.32
2.01	0.70	3.92	1.37	10.33	2.34
2.14	0.76	4.08	1.41	11.23	2.42
2.31	0.84	4.32	1.46	12.75	2.55
2.33	0.85	4.36	1.47	12.79	2.55
2.43	0.89	4.81	1.57	13.07	2.57
2.53	0.93	4.82	1.57	13.07	2.57
2.61	0.96	6.36	1.85	14.06	2.64
2.90	1.07	6.59	1.89	14.84	2.70
3.04	1.11	7.07	1.96	16.27	2.79
3.17	1.15	8.12	2.09	17.77	2.88
3.34	1.20	13.86	2.63	21.45	3.07
3.37	1.21	16.75	2.82	22.79	3.13
4.82	1.57	25.13	3.22	24.61	3.20

Table C.2 DESCRIPTIVE STATISTICS FOR DBA ARD OF LEP SOLIDS Cd DATA

DESCRIPTIVE STATISTICS FOR DBA ARD OF LEP SOLIDS Cd DATA					
P3/8 UNTRANS		*P4 UNTRANS*		*P8 UNTRANS*	
Mean	1.966671796	Mean	4.5972098	Mean	10.723444
Standard Error	0.140629102	Standard Error	0.7960713	Standard Error	0.8094566
Median	1.747393498	Median	2.7762878	Median	9.570077
Mode	#N/A	Mode	#N/A	Mode	#N/A
Standard Deviation	0.84377461	Standard Deviation	4.7764278	Standard Deviation	4.8567396
Variance	0.711955592	Variance	22.814263	Variance	23.587919
Kurtosis	2.493299513	Kurtosis	10.256	Kurtosis	1.6288426
Skewness	1.284945559	Skewness	3.0614642	Skewness	1.3995482
Range	4.302561842	Range	23.54756	Range	19.662925
Minimum	0.517555482	Minimum	1.5775525	Minimum	4.9470306
Maximum	4.820117324	Maximum	25.125113	Maximum	24.609955
Sum	70.80018467	Sum	165.49955	Sum	386.04398
Count	36	Count	36	Count	36
Confidence Level (95%)	0.275627566	Confidence Level (95%)	1.5602688	Confidence Level (95%)	1.5865034
UCLM	2.150474032	UCLM	5.637675	UCLM	11.781404
P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	0.591790713	Mean	1.2490284	Mean	2.2874045
Standard Error	0.07048284	Standard Error	0.1097884	Standard Error	0.067762
Median	0.558057209	Median	1.0210853	Median	2.2586389
Mode	#N/A	Mode	#N/A	Mode	#N/A
Standard Deviation	0.422897042	Standard Deviation	0.6587307	Standard Deviation	0.4065717
Variance	0.178841908	Variance	0.4339261	Variance	0.1653006
Kurtosis	1.343787725	Kurtosis	1.6673207	Kurtosis	-0.1372051
Skewness	-0.29761441	Skewness	1.3983739	Skewness	0.5019917
Range	2.231436817	Range	2.7679933	Range	1.6043635
Minimum	-0.65863855	Minimum	0.4558746	Minimum	1.5987875
Maximum	1.572798269	Maximum	3.2238679	Maximum	3.2031511
Sum	21.30446568	Sum	44.965022	Sum	82.346561
Count	36	Count	36	Count	36
Confidence Level (95%)	0.138143624	Confidence Level (95%)	0.2151811	Confidence Level (95%)	0.1328108
UCLM	0.683911786	UCLM	1.3925219	UCLM	2.3759694
UCLM TRANS BACK	1.981614241	UCLM TRANS BACK	4.0249878	UCLM TRANS BACK	10.76144

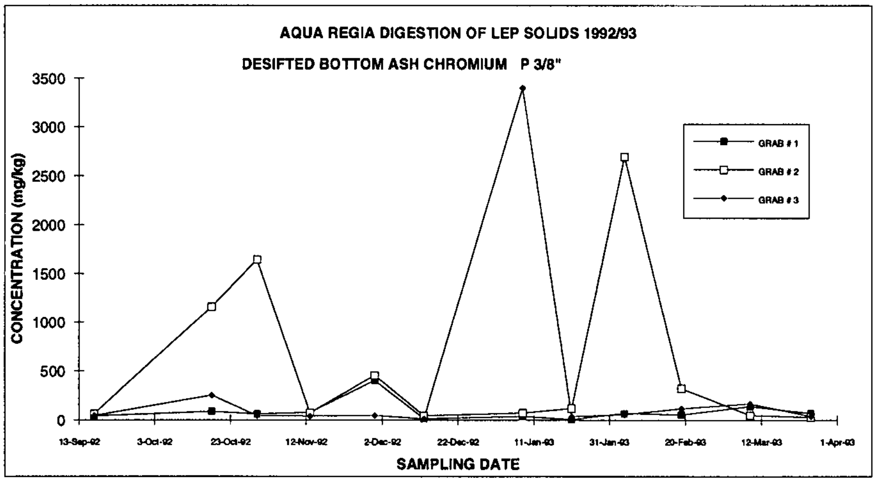

Figure C.6 DBA - ARD OF LEP SOLIDS Cr P3/8"

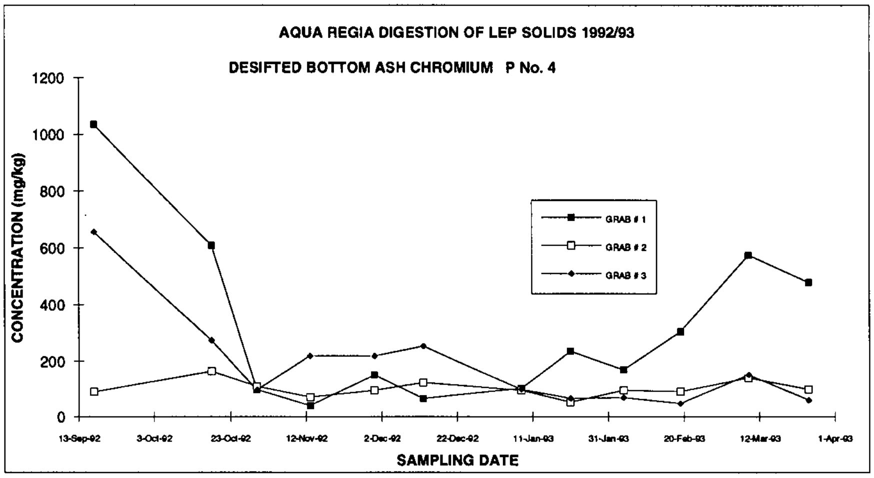

Figure C.7 DBA - ARD OF LEP SOLIDS Cr P4

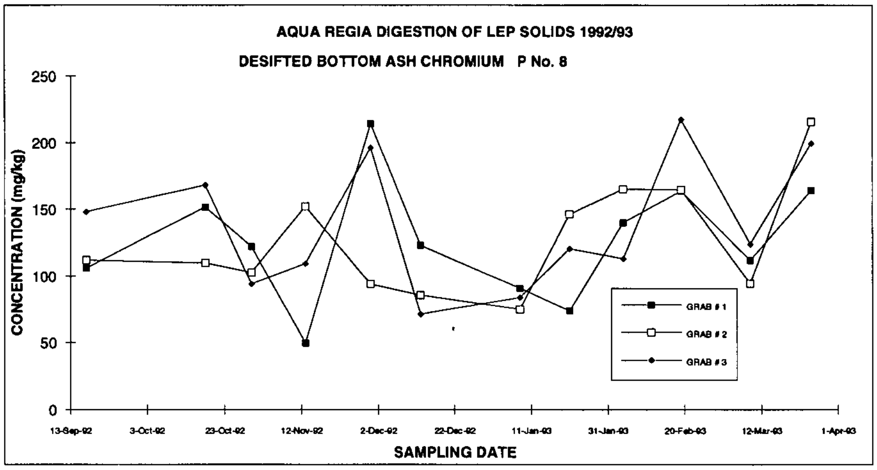

Figure C.8 DBA - ARD OF LEP SOLIDS Cr P8

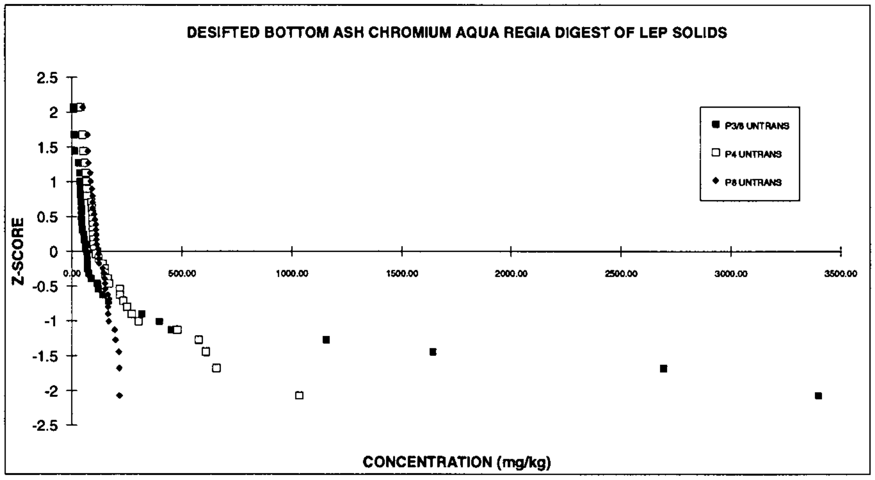

Figure C.9 DBA - ARD OF LEP SOLIDS UNTRANSFORMED Z-SCORE Cr

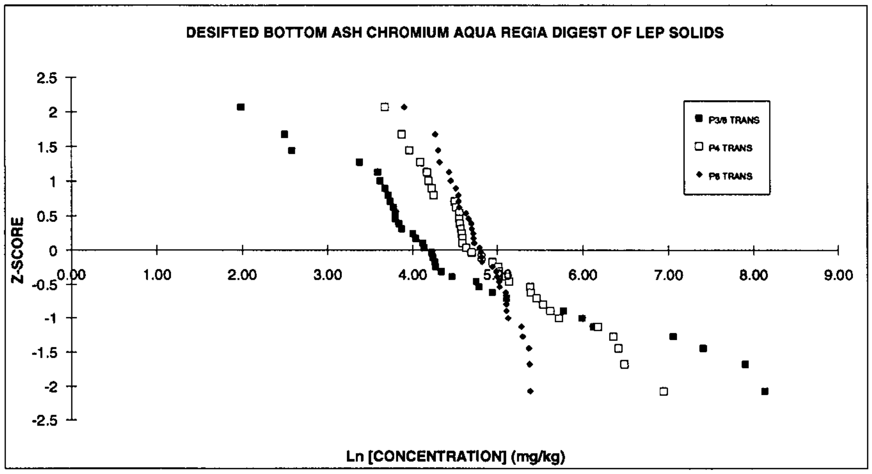

Figure C.10 DBA - ARD OF LEP SOLIDS TRANSFORMED Z-SCORE Cr

Table C.3 DBA ARD OF LEP SOLIDS Cr RANKED DATA (mg/kg)

DBA ARD OF LEP SOLIDS Cr RANKED CONCENTRATIONS (mg/kg)					
P3/8" UNTRAN	P3/8" TRANS	P4 UNTRAN	P4 TRANS	P8 UNTRAN	P8 TRANS
7.25	1.98	39.32	3.67	49.47	3.90
12.11	2.49	47.86	3.87	71.12	4.26
13.21	2.58	52.38	3.96	73.70	4.30
29.14	3.37	59.82	4.09	74.99	4.32
36.14	3.59	64.69	4.17	83.80	4.43
37.14	3.61	65.60	4.18	85.52	4.45
39.32	3.67	68.42	4.23	90.90	4.51
40.81	3.71	69.93	4.25	93.98	4.54
41.81	3.73	89.46	4.49	94.02	4.54
43.63	3.78	90.88	4.51	94.48	4.55
44.57	3.80	94.54	4.55	102.57	4.63
44.68	3.80	94.64	4.55	105.87	4.66
46.41	3.84	95.24	4.56	109.31	4.69
47.97	3.87	96.53	4.57	109.92	4.70
54.72	4.00	97.37	4.58	111.80	4.72
56.35	4.03	98.45	4.59	112.00	4.72
61.53	4.12	98.70	4.59	113.03	4.73
62.37	4.13	102.80	4.63	120.50	4.79
68.38	4.23	109.64	4.70	122.19	4.81
69.24	4.24	123.11	4.81	123.08	4.81
70.65	4.26	140.71	4.95	124.05	4.82
71.32	4.27	150.69	5.02	140.06	4.94
76.46	4.34	151.70	5.02	146.27	4.99
86.84	4.46	164.25	5.10	148.04	5.00
115.58	4.75	169.90	5.14	151.55	5.02
119.58	4.78	218.49	5.39	152.17	5.03
139.61	4.94	218.75	5.39	163.68	5.10
165.79	5.11	235.00	5.46	164.07	5.10
251.40	5.53	252.99	5.53	164.84	5.10
319.78	5.77	274.31	5.61	165.09	5.11
398.97	5.99	304.29	5.72	168.22	5.13
452.84	6.12	478.48	6.17	196.27	5.28
1155.20	7.05	574.89	6.35	199.32	5.29
1642.96	7.40	609.25	6.41	214.21	5.37
2695.23	7.90	656.56	6.49	215.79	5.37
3400.03	8.13	1034.68	6.94	217.46	5.38

Table C.4 DESCRIPTIVE STATISTICS FOR DBA ARD OF LEP SOLIDS Cr DATA

DESCRIPTIVE STATISTICS FOR DBA ARD OF LEP SOLIDS Cr DATA					
P3/8 UNTRANS		*P4 UNTRANS*		*P8 UNTRANS*	
Mean	333.8618091	Mean	202.62045	Mean	129.81533
Standard Error	124.4539926	Standard Error	35.698501	Standard Error	7.3534906
Median	65.37634087	Median	106.22095	Median	121.34538
Mode	#N/A	Mode	#N/A	Mode	#N/A
Standard Deviation	746.7239559	Standard Deviation	214.19101	Standard Deviation	44.120944
Variance	557596.6663	Variance	45877.787	Variance	1946.6577
Kurtosis	10.1477243	Kurtosis	6.0594891	Kurtosis	-0.5428195
Skewness	3.21093899	Skewness	2.3784047	Skewness	0.4524787
Range	3392.783072	Range	995.35298	Range	167.98535
Minimum	7.245776747	Minimum	39.323216	Minimum	49.470306
Maximum	3400.028849	Maximum	1034.6762	Maximum	217.45565
Sum	12019.02513	Sum	7294.3361	Sum	4673.3517
Count	36	Count	36	Count	36
Confidence Level (95%)	243.9249821	Confidence Level (95%)	69.967673	Confidence Level (95%)	14.412555
UCLM	496.5231774	UCLM	249.27839	UCLM	139.42634
P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	4.538010905	Mean	4.9509585	Mean	4.8080254
Standard Error	0.2357966	Standard Error	0.1331845	Standard Error	0.0586484
Median	4.179100841	Median	4.6650025	Median	4.7986166
Mode	#N/A	Mode	#N/A	Mode	#N/A
Standard Deviation	1.4147796	Standard Deviation	0.7991072	Standard Deviation	0.3518903
Variance	2.001601316	Variance	0.6385723	Variance	0.1238268
Kurtosis	0.934150795	Kurtosis	0.0333322	Kurtosis	-0.1541316
Skewness	1.001357883	Skewness	0.7828218	Skewness	-0.2892714
Range	6.151120414	Range	3.2700287	Range	1.4806223
Minimum	1.980418782	Minimum	3.6718151	Minimum	3.9013726
Maximum	8.131539195	Maximum	6.9418438	Maximum	5.3819949
Sum	163.3683926	Sum	178.2345	Sum	173.08891
Count	36	Count	36	Count	36
Confidence Level (95%)	0.462152159	Confidence Level (95%)	0.2610365	Confidence Level (95%)	0.1149486
UCLM	4.846197061	UCLM	5.1250306	UCLM	4.8846788
UCLM TRANS BACK	127.2555234	UCLM TRANS BACK	168.1793	UCLM TRANS BACK	132.24798

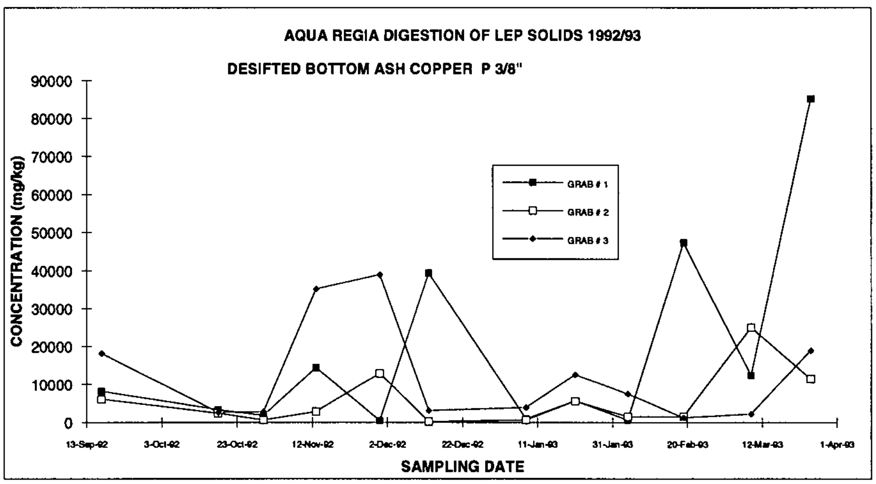

Figure C.11 DBA - ARD OF LEP SOLIDS Cu P3/8"

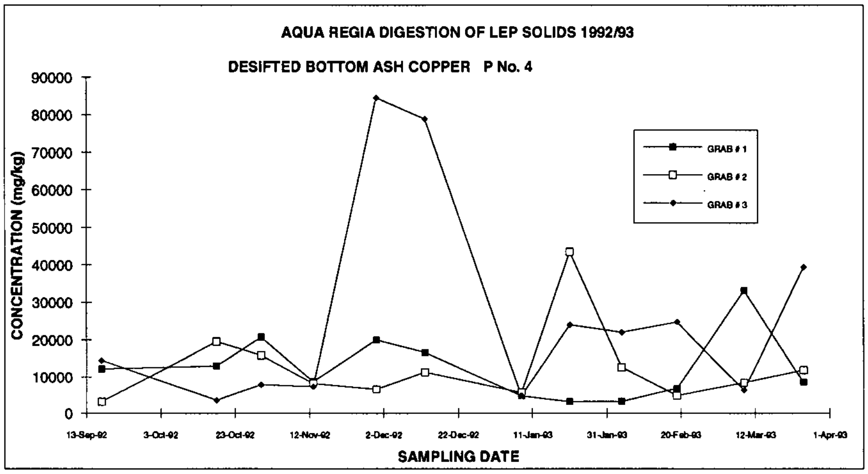

Figure C.12 DBA - ARD OF LEP SOLIDS Cu P4

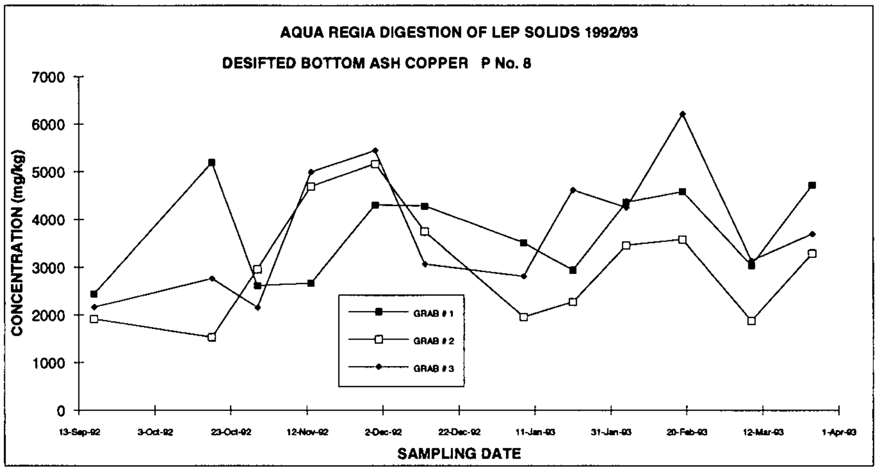

Figure C.13 DBA - ARD OF LEP SOLIDS Cu P8

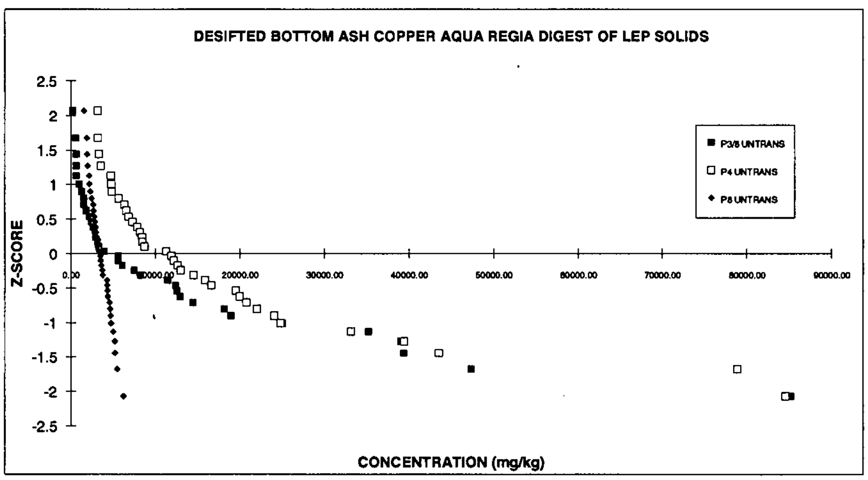

Figure C.14 DBA - ARD OF LEP SOLIDS UNTRANSFORMED Z-SCORE Cu

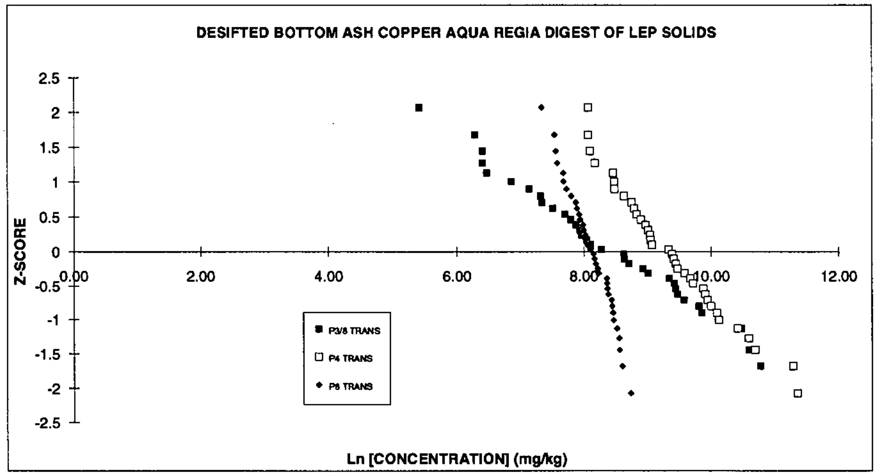

Figure C.15 DBA - ARD OF LEP SOLIDS UNTRANSFORMED Z-SCORE Cu

Table C.5 DBA ARD OF LEP SOLIDS Cu RANKED DATA (mg/kg)

DBA ARD OF LEP SOLIDS Cu RANKED CONCENTRATIONS (mg/kg)					
P3/8" UNTRAN	P3/8" TRANS	P4 UNTRAN	P4 TRANS	P8 UNTRAN	P8 TRANS
223.40	5.41	3178.41	8.06	1531.91	7.33
533.97	6.28	3182.00	8.07	1878.10	7.54
602.71	6.40	3275.27	8.09	1913.25	7.56
603.39	6.40	3547.42	8.17	1961.28	7.58
642.90	6.47	4727.00	8.46	2155.47	7.68
953.59	6.86	4768.52	8.47	2161.65	7.68
1256.36	7.14	4823.00	8.48	2270.17	7.73
1514.17	7.32	5600.65	8.63	2439.53	7.80
1548.30	7.34	6332.72	8.75	2615.11	7.87
1825.49	7.51	6554.21	8.79	2666.57	7.89
2220.57	7.71	6807.34	8.83	2764.98	7.92
2432.01	7.80	7288.29	8.89	2812.00	7.94
2634.70	7.88	7843.18	8.97	2937.00	7.99
2798.80	7.94	8159.03	9.01	2961.72	7.99
2867.99	7.96	8412.12	9.04	3039.48	8.02
3108.41	8.04	8466.19	9.04	3061.72	8.03
3300.09	8.10	8693.62	9.07	3141.66	8.05
3904.88	8.27	11264.77	9.33	3288.79	8.10
5552.90	8.62	11865.21	9.38	3459.12	8.15
5599.95	8.63	12175.11	9.41	3509.00	8.16
6052.80	8.71	12612.13	9.44	3581.01	8.18
7486.27	8.92	12951.76	9.47	3693.71	8.21
8198.06	9.01	14490.08	9.58	3744.28	8.23
11425.30	9.34	15865.18	9.67	4247.55	8.35
12363.91	9.42	16612.93	9.72	4278.91	8.36
12517.06	9.43	19521.69	9.88	4307.62	8.37
12917.96	9.47	19979.77	9.90	4357.30	8.38
14425.23	9.58	20748.18	9.94	4585.35	8.43
18143.44	9.81	22005.96	10.00	4620.00	8.44
18954.93	9.85	24029.00	10.09	4693.90	8.45
24996.50	10.13	24756.61	10.12	4725.81	8.46
35205.87	10.47	33158.01	10.41	4995.30	8.52
38978.47	10.57	39387.38	10.58	5169.17	8.55
39345.36	10.58	43485.70	10.68	5195.99	8.56
47306.34	10.76	78886.45	11.28	5447.15	8.60
85173.00	11.35	84560.60	11.35	6215.85	8.73

Table C.6 DESCRIPTIVE STATISTICS FOR DBA ARD OF LEP SOLIDS Cu DATA

DESCRIPTIVE STATISTICS FOR RBA ARD OF LEP SOLIDS Cu DATA					
P3/8 UNTRANS		P4 UNTRANS		P8 UNTRANS	
Mean	12155.97407	Mean	17222.652	Mean	3511.8726
Standard Error	2942.784957	Standard Error	3121.1844	Standard Error	195.95056
Median	4728.889865	Median	11564.99	Median	3373.955
Mode	#N/A	Mode	#N/A	Mode	#N/A
Standard Deviation	17656.70974	Standard Deviation	18727.106	Standard Deviation	1175.7034
Variance	311759398.9	Variance	350704507	Variance	1382278.4
Kurtosis	7.735760496	Kurtosis	6.6889273	Kurtosis	-0.7250352
Skewness	2.558807911	Skewness	2.5185211	Skewness	0.3143145
Range	84949.59949	Range	81382.188	Range	4683.9341
Minimum	223.3956133	Minimum	3178.4121	Minimum	1531.9129
Maximum	85172.9951	Maximum	84560.6	Maximum	6215.847
Sum	437615.0664	Sum	620015.47	Sum	126427.41
Count	36	Count	36	Count	36
Confidence Level (95%)	5767.743989	Confidence Level (95%)	6117.3999	Confidence Level (95%)	384.05547
UCLM	16002.19401	UCLM	21302.04	UCLM	3767.9799
P3/8 TRANS		P4 TRANS		P8 TRANS	
Mean	8.485541812	Mean	9.3623301	Mean	8.106556
Standard Error	0.244270426	Standard Error	0.1427808	Standard Error	0.0583402
Median	8.446029	Median	9.3554007	Median	8.1235222
Mode	#N/A	Mode	#N/A	Mode	#N/A
Standard Deviation	1.465622558	Standard Deviation	0.8566847	Standard Deviation	0.3500412
Variance	2.148049483	Variance	0.7339086	Variance	0.1225288
Kurtosis	-0.70434954	Kurtosis	-0.1752219	Kurtosis	-0.7240772
Skewness	-0.02772391	Skewness	0.4915072	Skewness	-0.2739347
Range	5.943495453	Range	3.2810867	Range	1.4005848
Minimum	5.40894425	Minimum	8.064137	Minimum	7.3342725
Maximum	11.3524397	Maximum	11.345224	Maximum	8.7348573
Sum	305.4795052	Sum	337.04388	Sum	291.83602
Count	36	Count	36	Count	36
Confidence Level (95%)	0.478760529	Confidence Level (95%)	0.2798448	Confidence Level (95%)	0.1143445
UCLM	8.80480326	UCLM	9.5489446	UCLM	8.1828067
UCLM TRANS BACK	6666.186655	UCLM TRANS BACK	14029.88	UCLM TRANS BACK	3578.8853

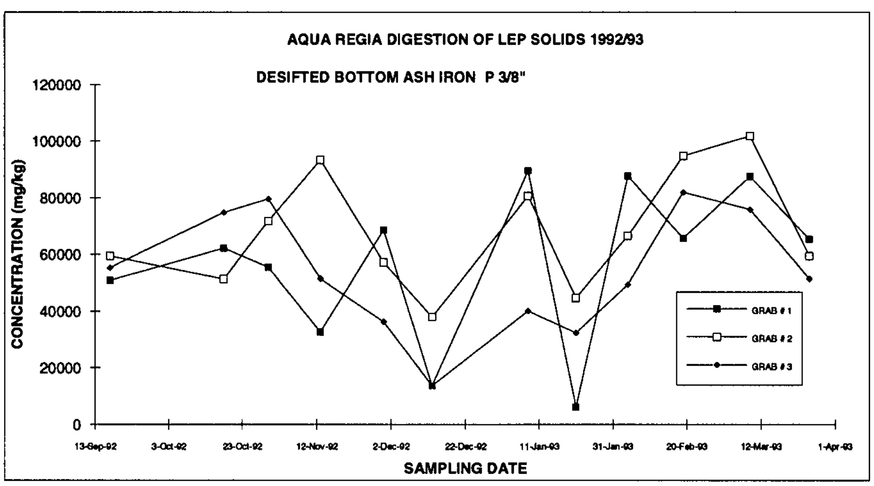

Figure C.16 DBA - ARD OF LEP SOLIDS Fe P3/8"

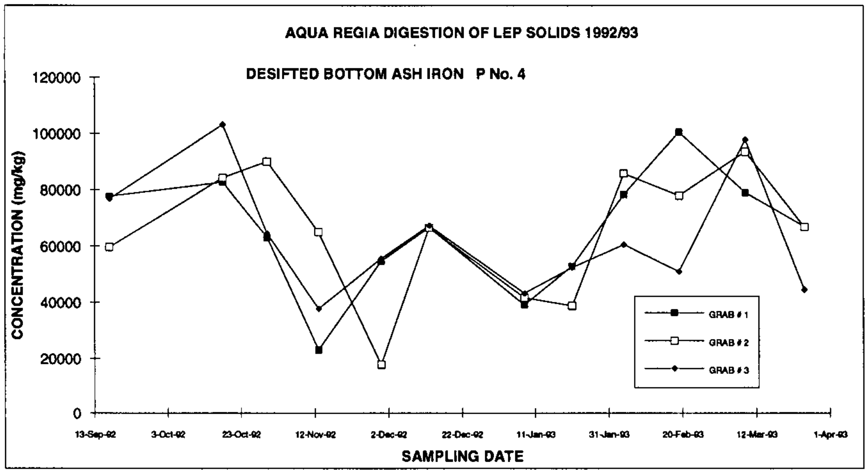

Figure C.17 DBA - ARD OF LEP SOLIDS Fe P4

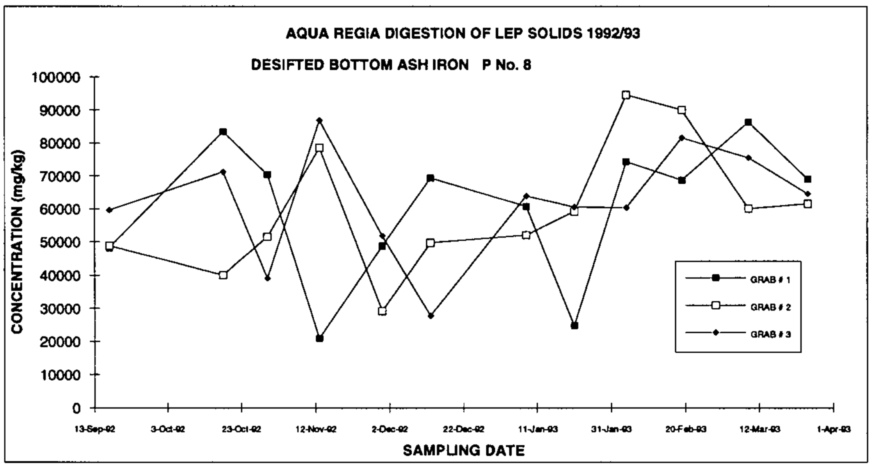

Figure C.18 DBA - ARD OF LEP SOLIDS Fe P8

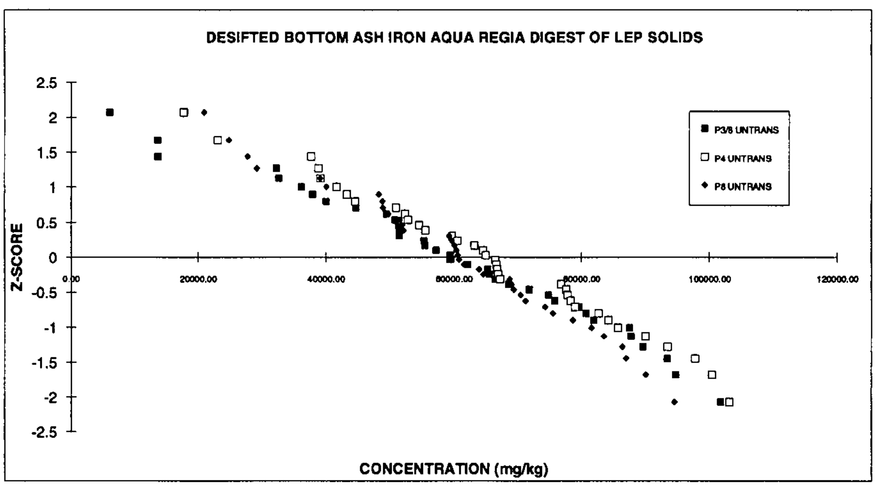

Figure C.19 DBA - ARD OF LEP SOLIDS UNTRANSFORMED Z-SCORE Fe

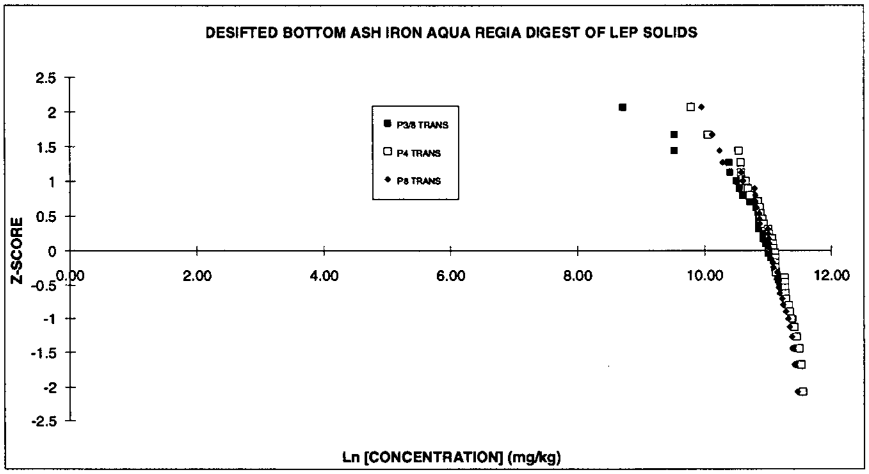

Figure C.20 DBA - ARD OF LEP SOLIDS TRANSFORMED Z-SCORE Fe

Table C.7 DBA ARD OF LEP SOLIDS Fe RANKED DATA (mg/kg)

DBA ARD OF LEP SOLIDS Fe RANKED CONCENTRATIONS (mg/kg)					
P3/8" UNTRAN	P3/8" TRANS	P4 UNTRAN	P4 TRANS	P8 UNTRAN	P8 TRANS
6045.0	8.71	17750.5	9.78	20934.39	9.95
13572.3	9.52	23062.5	10.05	24819.00	10.12
13644.7	9.52	37682.5	10.54	27771.75	10.23
32251.3	10.38	38782.2	10.57	29205.83	10.28
32642.8	10.39	39154.0	10.58	39100.12	10.57
36213.8	10.50	41658.0	10.64	40063.62	10.60
37936.6	10.54	43226.0	10.67	48249.75	10.78
40017.3	10.60	44564.8	10.70	48811.89	10.80
44703.9	10.71	50888.0	10.84	48881.22	10.80
49395.3	10.81	52374.0	10.87	49704.16	10.81
50789.2	10.84	52808.0	10.87	51501.60	10.85
51305.2	10.85	54554.5	10.91	51832.67	10.86
51437.4	10.85	55547.4	10.92	52089.34	10.86
51437.7	10.85	59663.6	11.00	59211.76	10.99
55292.9	10.92	60534.3	11.01	59616.97	11.00
55421.1	10.92	63175.5	11.05	60053.00	11.00
57190.8	10.95	64588.3	11.08	60342.07	11.01
59372.6	10.99	65039.1	11.08	60556.00	11.01
59397.5	10.99	66531.9	11.11	60751.00	11.01
62170.5	11.04	66667.4	11.11	61552.31	11.03
65274.5	11.09	66822.5	11.11	63912.00	11.07
65588.4	11.09	66987.0	11.11	64604.63	11.08
66502.5	11.10	67261.4	11.12	68745.36	11.14
68580.2	11.14	76809.4	11.25	69038.43	11.14
71820.7	11.18	77663.0	11.26	69394.28	11.15
74877.8	11.22	77879.0	11.26	70448.11	11.16
75861.1	11.24	78319.8	11.27	71239.28	11.17
79599.9	11.28	78975.8	11.28	74318.62	11.22
80703.2	11.30	82673.7	11.32	75544.32	11.23
81954.7	11.31	84196.4	11.34	78649.19	11.27
87551.7	11.38	85682.2	11.36	81562.95	11.31
87723.0	11.38	89972.2	11.41	83500.46	11.33
89596.9	11.40	93434.3	11.45	86363.11	11.37
93357.2	11.44	97739.8	11.49	86941.70	11.37
94719.6	11.46	100384.8	11.52	90014.10	11.41
101745.1	11.53	103122.6	11.54	94508.09	11.46

Table C.8 DESCRIPTIVE STATISTICS FOR DBA ARD OF LEP SOLIDS Fe DATA

DESCRIPTIVE STATISTICS FOR DBA ARD OF LEP SOLIDS Fe DATA					
P3/8 UNTRANS		*P4 UNTRANS*		*P8 UNTRANS*	
Mean	59602.62191	Mean	64616.01	Mean	60662.029
Standard Error	3927.60961	Standard Error	3502.3466	Standard Error	3100.2326
Median	59385.05972	Median	65785.513	Median	60653.5
Mode	#N/A	Mode	#N/A	Mode	#N/A
Standard Deviation	23565.65766	Standard Deviation	21014.079	Standard Deviation	18601.395
Variance	555340221.1	Variance	441591533	Variance	346011914
Kurtosis	-0.21823353	Kurtosis	-0.371614	Kurtosis	-0.3179475
Skewness	-0.36585129	Skewness	-0.1688815	Skewness	-0.3146679
Range	95700.00964	Range	85372.014	Range	73573.701
Minimum	6045.048029	Minimum	17750.536	Minimum	20934.385
Maximum	101745.0577	Maximum	103122.55	Maximum	94508.086
Sum	2145694.389	Sum	2326176.4	Sum	2183833.1
Count	36	Count	36	Count	36
Confidence Level (95%)	7697.961983	Confidence Level (95%)	6864.463	Confidence Level (95%)	6076.3352
UCLM	64736.00767	UCLM	69193.577	UCLM	64714.033
P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	10.87287355	Mean	11.012427	Mean	10.956459
Standard Error	0.098683105	Standard Error	0.0648881	Standard Error	0.0607197
Median	10.99179793	Median	11.094091	Median	11.012931
Mode	#N/A	Mode	#N/A	Mode	#N/A
Standard Deviation	0.592098632	Standard Deviation	0.3893286	Standard Deviation	0.3643181
Variance	0.35058079	Variance	0.1515767	Variance	0.1327277
Kurtosis	4.911005257	Kurtosis	2.0852596	Kurtosis	1.0955748
Skewness	-2.0370137	Skewness	-1.2550545	Skewness	-1.1570564
Range	2.823230821	Range	1.7595024	Range	1.5072924
Minimum	8.706994708	Minimum	9.784171	Minimum	9.9491483
Maximum	11.53022553	Maximum	11.543673	Maximum	11.456441
Sum	391.4234477	Sum	396.44738	Sum	394.43252
Count	36	Count	36	Count	36
Confidence Level (95%)	0.193415046	Confidence Level (95%)	0.1271781	Confidence Level (95%)	0.1190082
UCLM	11.00185237	UCLM	11.097236	UCLM	11.035819
UCLM TRANS BACK	59985.15329	UCLM TRANS BACK	65988.522	UCLM TRANS BACK	62057.674

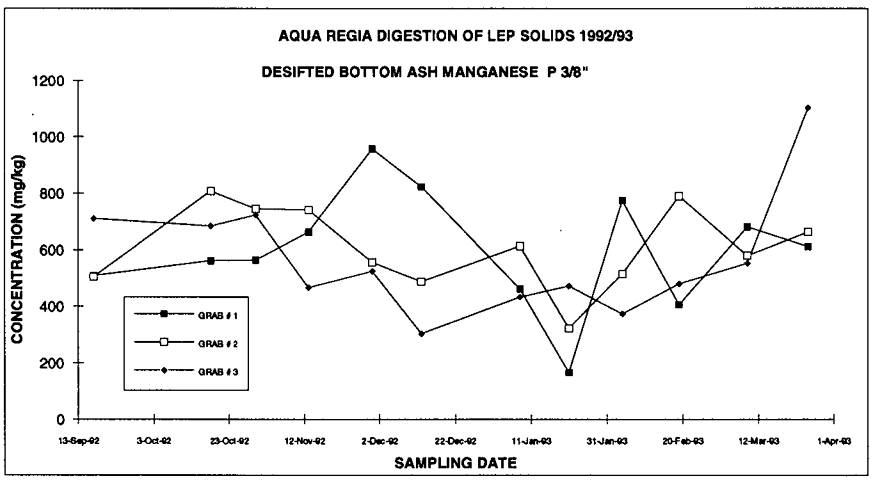

Figure C.21 DBA - ARD OF LEP SOLIDS Mn P3/8"

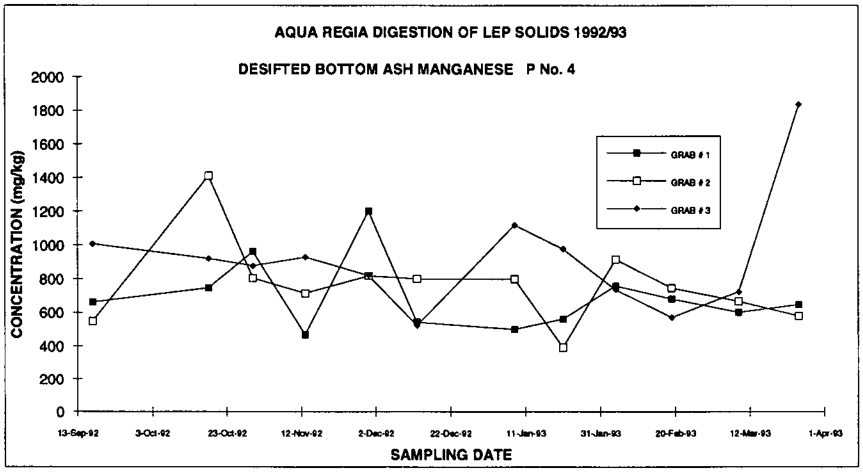

Figure C.22 DBA - ARD OF LEP SOLIDS Mn P4

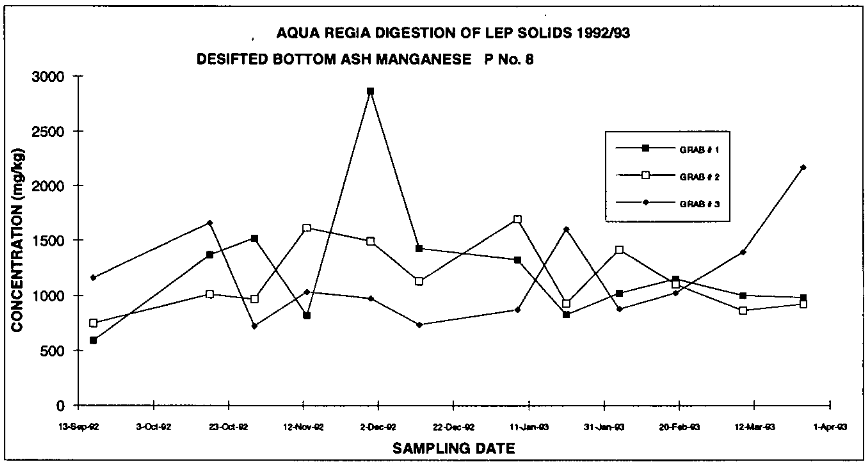

Figure C.23 DBA - ARD OF LEP SOLIDS Mn P8

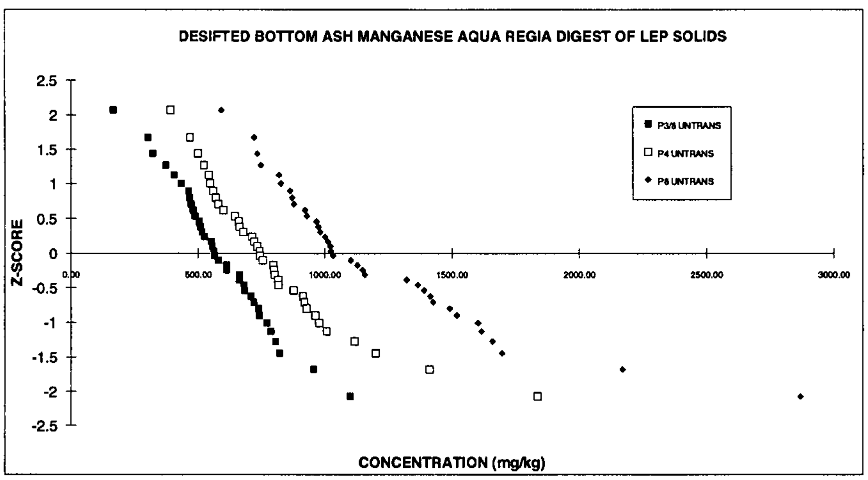

Figure C.24 DBA - ARD OF LEP SOLIDS UNTRANSFORMED Z-SCORE Mn

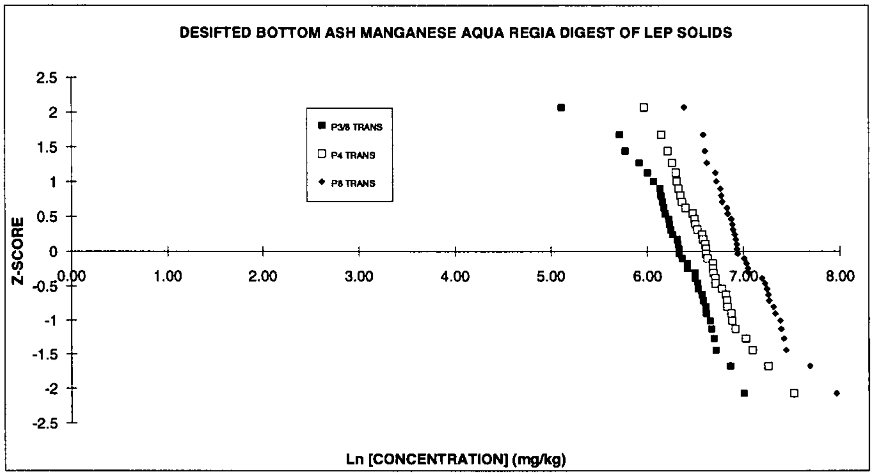

Figure C.25 DBA - ARD OF LEP SOLIDS TRANSFORMED Z-SCORE Mn

Table C.9 DBA ARD OF LEP SOLIDS Mn RANKED CONCENTRATIONS

DBA ARD OF LEP SOLIDS Mn RANKED CONCENTRATIONS (mg/kg)					
P3/8" UNTRAN	P3/8" TRANS	P4 UNTRAN	P4 TRANS	P8 UNTRAN	P8 TRANS
165.62	5.11	391.24	5.97	591.47	6.38
302.77	5.71	467.63	6.15	722.38	6.58
321.32	5.77	499.00	6.21	735.28	6.60
372.30	5.92	522.36	6.26	748.97	6.62
405.37	6.00	542.13	6.30	820.48	6.71
432.73	6.07	547.28	6.30	828.00	6.72
461.74	6.13	560.00	6.33	864.15	6.76
465.78	6.14	570.29	6.35	872.00	6.77
471.77	6.16	579.42	6.36	879.16	6.78
479.43	6.17	600.37	6.40	923.17	6.83
487.41	6.19	646.57	6.47	930.30	6.84
505.08	6.22	660.70	6.49	968.03	6.88
508.81	6.23	665.07	6.50	975.56	6.88
514.82	6.24	679.69	6.52	982.14	6.89
524.69	6.26	714.18	6.57	1001.51	6.91
552.63	6.31	722.87	6.58	1012.70	6.92
555.94	6.32	735.23	6.60	1022.63	6.93
561.94	6.33	745.40	6.61	1024.66	6.93
564.06	6.34	746.02	6.61	1033.15	6.94
579.69	6.36	757.41	6.63	1102.72	7.01
612.11	6.42	799.20	6.68	1129.06	7.03
613.76	6.42	800.23	6.68	1149.24	7.05
662.64	6.50	804.77	6.69	1158.50	7.05
663.21	6.50	817.95	6.71	1323.00	7.19
680.97	6.52	820.40	6.71	1367.37	7.22
683.82	6.53	877.56	6.78	1391.24	7.24
710.31	6.57	915.56	6.82	1415.09	7.25
722.50	6.58	920.88	6.83	1426.30	7.26
740.19	6.61	929.70	6.83	1492.01	7.31
744.94	6.61	963.04	6.87	1518.82	7.33
774.35	6.65	978.00	6.89	1602.00	7.38
789.33	6.67	1007.67	6.92	1615.36	7.39
807.63	6.69	1119.00	7.02	1659.14	7.41
822.87	6.71	1201.32	7.09	1695.93	7.44
957.12	6.86	1412.34	7.25	2169.12	7.68
1101.79	7.00	1835.81	7.52	2867.85	7.96

Table C.10 DESCRIPTIVE STATISTICS FOR DBA ARD OF LEP SOLIDS Mn DATA

DESCRIPTIVE STATISTICS FOR DBA ARD OF LEP SOLIDS Mn DATA					
P3/8 UNTRANS		*P4 UNTRANS*		*P8 UNTRANS*	
Mean	592.2620235	Mean	793.22998	Mean	1194.9582
Standard Error	31.07419403	Standard Error	46.609807	Standard Error	74.44437
Median	562.9958964	Median	745.71059	Median	1028.9027
Mode	#N/A	Mode	#N/A	Mode	#N/A
Standard Deviation	186.4451642	Standard Deviation	279.65884	Standard Deviation	446.66622
Variance	34761.79925	Variance	78209.068	Variance	199510.71
Kurtosis	0.804884042	Kurtosis	4.7125618	Kurtosis	4.638362
Skewness	0.35396502	Skewness	1.7630262	Skewness	1.7849017
Range	936.1757207	Range	1444.5656	Range	2276.3742
Minimum	165.6177542	Minimum	391.243	Minimum	591.47085
Maximum	1101.793475	Maximum	1835.8086	Maximum	2867.845
Sum	21321.43285	Sum	28556.279	Sum	43018.497
Count	36	Count	36	Count	36
Confidence Level (95%)	60.90421096	Confidence Level (95%)	91.353408	Confidence Level (95%)	145.90807
UCLM	632.8759951	UCLM	854.149	UCLM	1292.257
P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	6.329522826	Mean	6.6251346	Mean	7.0294969
Standard Error	0.058874673	Standard Error	0.0525228	Standard Error	0.0549343
Median	6.333270566	Median	6.6143375	Median	6.9362397
Mode	#N/A	Mode	#N/A	Mode	#N/A
Standard Deviation	0.35324804	Standard Deviation	0.3151371	Standard Deviation	0.329606
Variance	0.124784178	Variance	0.0993114	Variance	0.1086401
Kurtosis	3.000348596	Kurtosis	0.866923	Kurtosis	0.6177238
Skewness	-1.12106211	Skewness	0.5182012	Skewness	0.6229492
Range	1.895012115	Range	1.5459115	Range	1.5787038
Minimum	5.109682448	Minimum	5.9693288	Minimum	6.3826124
Maximum	7.004694563	Maximum	7.5152403	Maximum	7.9613162
Sum	227.8628217	Sum	238.50484	Sum	253.06189
Count	36	Count	36	Count	36
Confidence Level (95%)	0.115392069	Confidence Level (95%)	0.1029427	Confidence Level (95%)	0.1076692
UCLM	6.406472024	UCLM	6.6937819	UCLM	7.1012961
UCLM TRANS BACK	605.7528253	UCLM TRANS BACK	807.3699	UCLM TRANS BACK	1213.5389

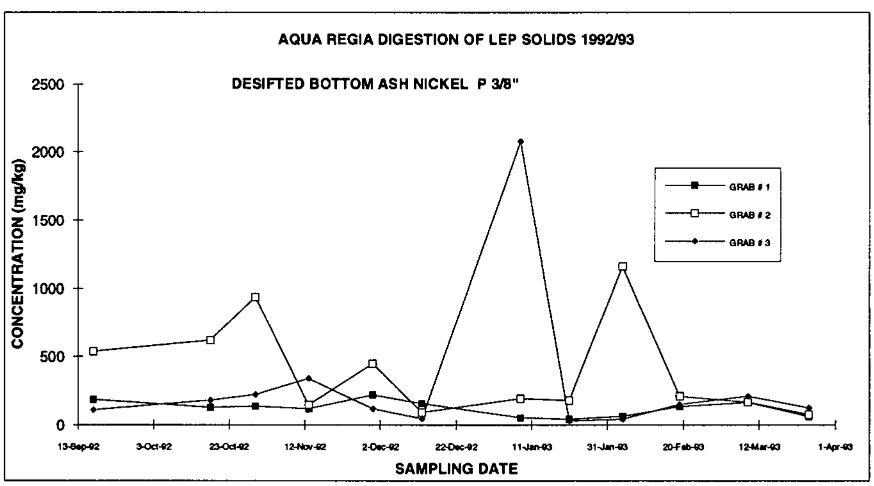

Figure C.26 DBA - ARD OF LEP SOLIDS Ni P3/8"

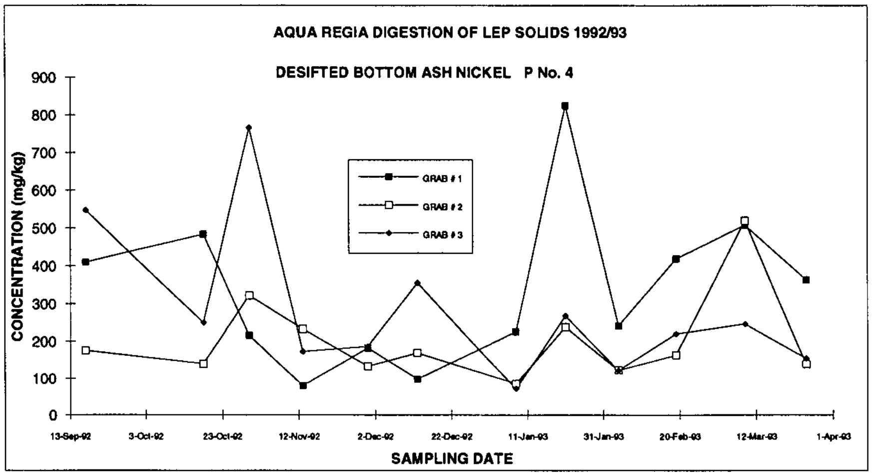

Figure C.27 DBA - ARD OF LEP SOLIDS Ni P4

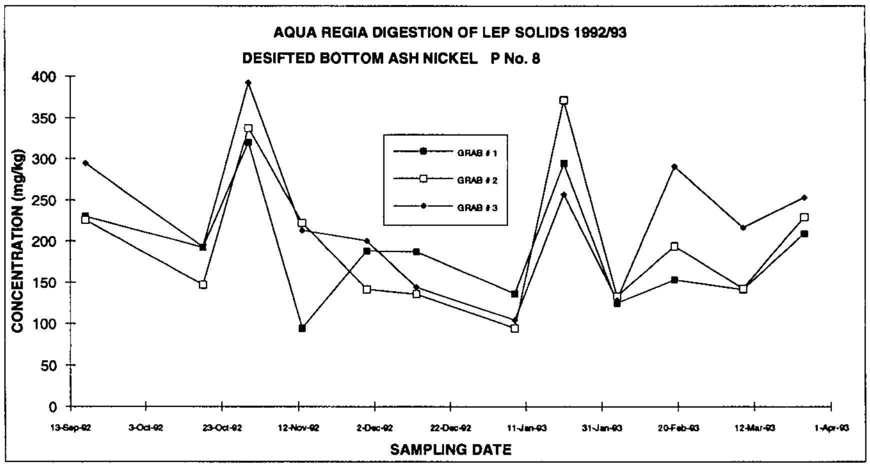

Figure C.28 DBA - ARD OF LEP SOLIDS Ni P8

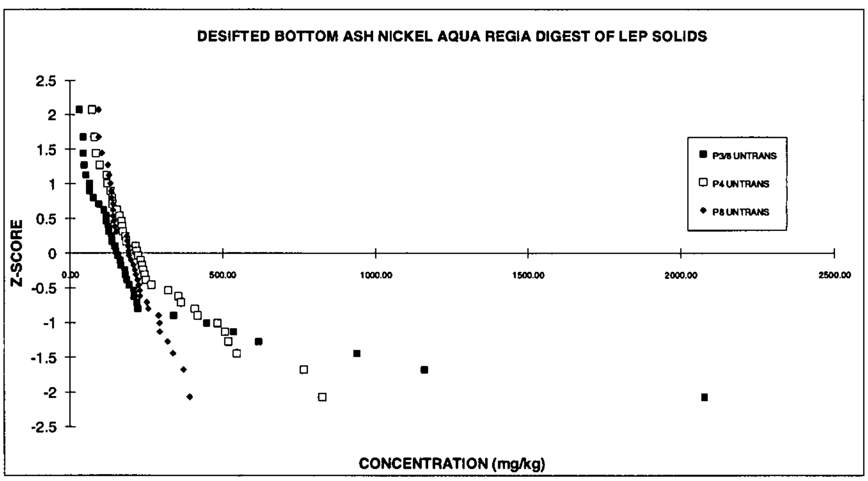

Figure C.29 DBA - ARD OF LEP SOLIDS UNTRANSFORMED Z-SCORE Ni

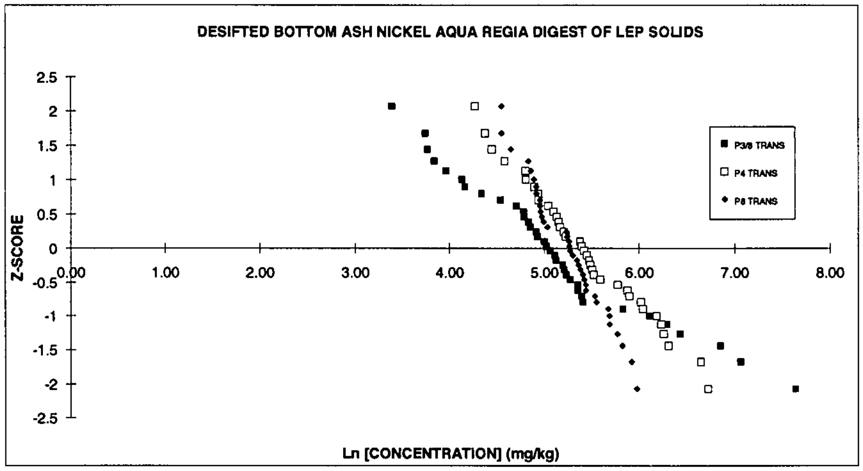

Figure C.30 DBA - ARD OF LEP SOLIDS TRANSFORMED Z-SCORE Ni

Table C.11 DBA ARD OF LEP SOLIDS Ni RANKED CONCENTRATIONS

DBA ARD OF LEP SOLIDS NI RANKED CONCENTRATIONS (mg/kg)					
P3/8" UNTRAN	P3/8" TRANS	P4 UNTRAN	P4 TRANS	P8 UNTRAN	P8 TRANS
29.51	3.38	71.50	4.27	94.36	4.55
42.13	3.74	79.50	4.38	94.49	4.55
42.97	3.76	85.20	4.45	104.20	4.65
46.22	3.83	97.64	4.58	124.94	4.83
52.60	3.96	121.52	4.80	128.56	4.86
62.21	4.13	122.01	4.80	132.86	4.89
64.06	4.16	133.53	4.89	135.90	4.91
76.57	4.34	138.96	4.93	136.30	4.91
93.62	4.54	139.56	4.94	141.26	4.95
110.61	4.71	154.39	5.04	141.56	4.95
119.38	4.78	163.27	5.10	142.30	4.96
119.87	4.79	169.18	5.13	144.28	4.97
125.18	4.83	172.48	5.15	147.11	4.99
127.92	4.85	175.02	5.16	153.00	5.03
136.20	4.91	182.41	5.21	187.03	5.23
137.94	4.93	185.93	5.23	188.22	5.24
148.04	5.00	216.04	5.38	192.46	5.26
151.57	5.02	219.97	5.39	192.87	5.26
157.46	5.06	225.40	5.42	194.17	5.27
165.92	5.11	232.59	5.45	200.34	5.30
167.51	5.12	237.95	5.47	209.14	5.34
180.11	5.19	241.04	5.48	213.21	5.36
182.22	5.21	245.88	5.50	216.69	5.38
186.70	5.23	249.45	5.52	222.40	5.40
194.68	5.27	267.70	5.59	225.86	5.42
210.99	5.35	321.80	5.77	229.41	5.44
211.41	5.35	355.41	5.87	230.14	5.44
220.34	5.40	363.60	5.90	253.03	5.53
222.87	5.41	409.40	6.01	257.10	5.55
339.25	5.83	418.69	6.04	290.78	5.67
447.48	6.10	482.84	6.18	294.40	5.68
535.75	6.28	507.61	6.23	294.56	5.69
618.13	6.43	519.30	6.25	319.98	5.77
938.83	6.84	546.77	6.30	337.54	5.82
1160.87	7.06	765.67	6.64	371.65	5.92
2077.11	7.64	825.20	6.72	392.38	5.97

Table C.12 DESCRIPTIVE STATISTICS FOR DBA ARD OF LEP SOLIDS Ni DATA

DESCRIPTIVE STATISTICS FOR DBA ARD OF LEP SOLIDS Ni DATA					
P3/8 UNTRANS		*P4 UNTRANS*		*P8 UNTRANS*	
Mean	275.1171796	Mean	273.4561	Mean	203.7356
Standard Error	65.44469833	Standard Error	30.47882	Standard Error	12.86582
Median	154.5148228	Median	222.68411	Median	193.52263
Mode	#N/A	Mode	#N/A	Mode	#N/A
Standard Deviation	392.66819	Standard Deviation	182.87292	Standard Deviation	77.194921
Variance	154188.3074	Variance	33442.506	Variance	5959.0558
Kurtosis	12.98827757	Kurtosis	2.0210567	Kurtosis	-0.058153
Skewness	3.383062105	Skewness	1.4893399	Skewness	0.733779
Range	2047.597572	Range	753.7	Range	298.02164
Minimum	29.51096121	Minimum	71.5	Minimum	94.355559
Maximum	2077.108533	Maximum	825.2	Maximum	392.3772
Sum	9904.218467	Sum	9844.4195	Sum	7334.4818
Count	36	Count	36	Count	36
Confidence Level (95%)	128.2690618	Confidence Level (95%)	59.737302	Confidence Level (95%)	25.216507
UCLM	360.6534004	UCLM	313.29192	UCLM	220.55123
P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	5.098469722	Mean	5.4216676	Mean	5.2484675
Standard Error	0.15726604	Standard Error	0.1029527	Standard Error	0.0626852
Median	5.040108006	Median	5.4056799	Median	5.2653889
Mode	#N/A	Mode	#N/A	Mode	#N/A
Standard Deviation	0.943596241	Standard Deviation	0.6177161	Standard Deviation	0.3761111
Variance	0.890373866	Variance	0.3815732	Variance	0.1414596
Kurtosis	0.731763915	Kurtosis	-0.449617	Kurtosis	-0.6883726
Skewness	0.676841753	Skewness	0.2148632	Skewness	0.0228484
Range	4.253970316	Range	2.4459283	Range	1.4251534
Minimum	3.384761761	Minimum	4.2696974	Minimum	4.5470702
Maximum	7.638732077	Maximum	6.7156258	Maximum	5.9722236
Sum	183.54491	Sum	195.18003	Sum	188.94483
Count	36	Count	36	Count	36
Confidence Level (95%)	0.308235318	Confidence Level (95%)	0.2017832	Confidence Level (95%)	0.1228605
UCLM	5.304016437	UCLM	5.5562267	UCLM	5.3303971
UCLM TRANS BACK	201.1430681	UCLM TRANS BACK	258.8443	UCLM TRANS BACK	206.51996

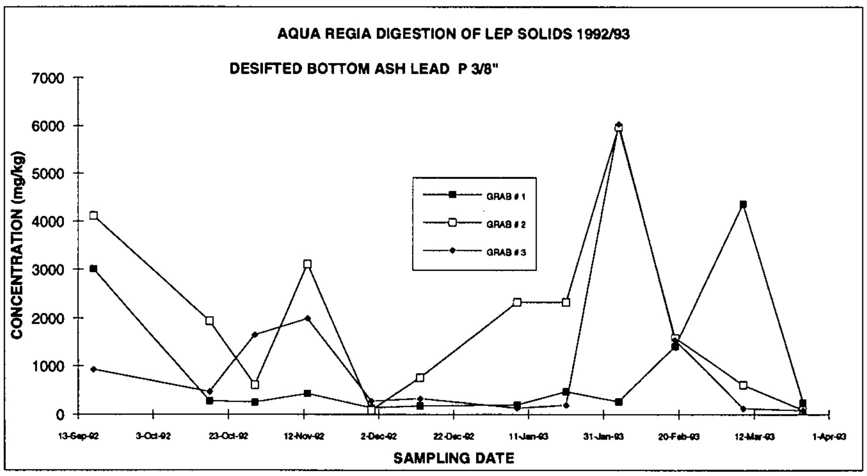

Figure C.31 DBA - ARD OF LEP SOLIDS Pb P3/8"

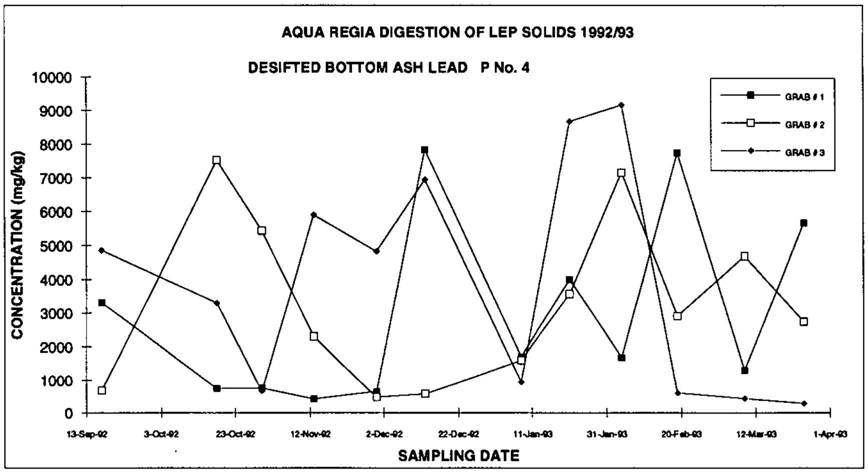

Figure C.32 DBA - ARD OF LEP SOLIDS Pb P4

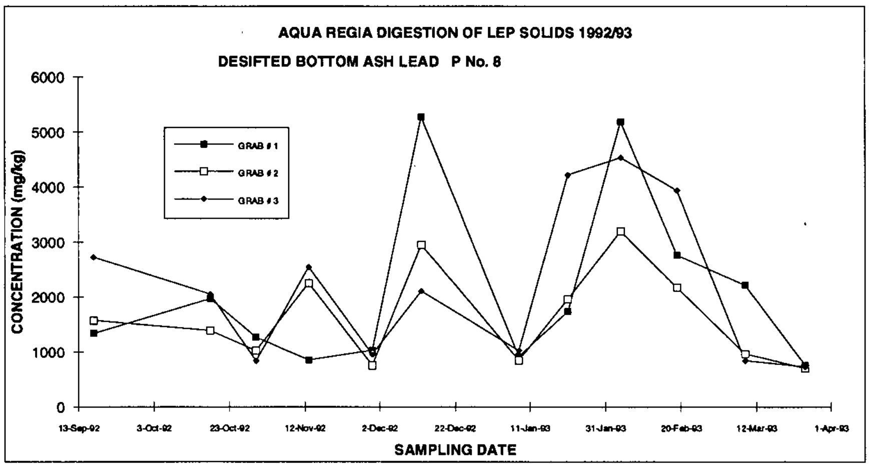

Figure C.33 DBA - ARD OF LEP SOLIDS Pb P8

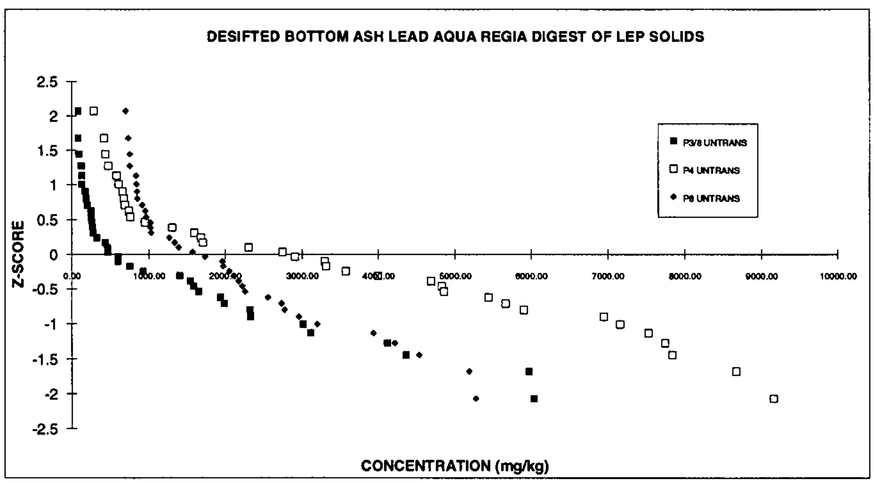

Figure C.34 DBA - ARD OF LEP SOLIDS UNTRANSFORMED Z-SCORE Pb

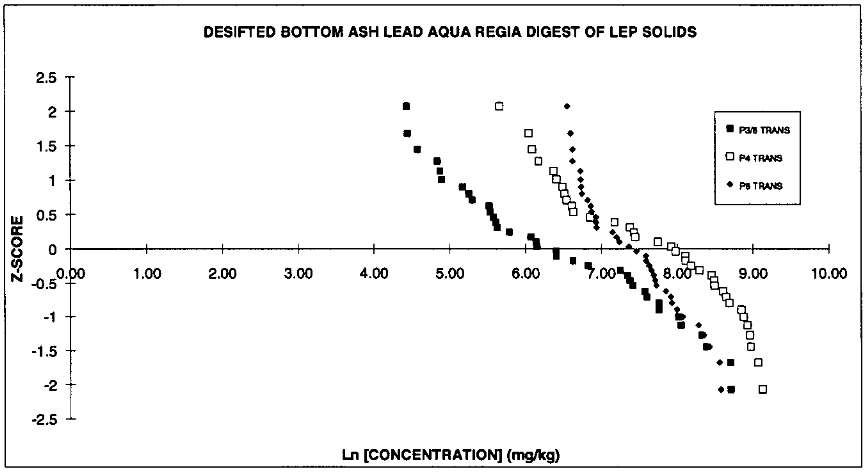

Figure C.35 DBA - ARD OF LEP SOLIDS TRANSFORMED Z-SCORE Pb

Table C.13 DBA ARD OF LEP SOLIDS Pb RANKED CONCENTRATIONS

DBA ARD OF LEP SOLIDS Pb RANKED CONCENTRATIONS (mg/kg)					
P3/8" UNTRAN	P3/8" TRANS	P4 UNTRAN	P4 TRANS	P8 UNTRAN	P8 TRANS
84.16	4.43	285.68	5.65	698.15	6.55
85.01	4.44	421.82	6.04	731.40	6.59
97.07	4.58	440.54	6.09	752.11	6.62
126.30	4.84	478.87	6.17	752.89	6.62
130.64	4.87	585.71	6.37	833.26	6.73
133.69	4.90	606.95	6.41	837.41	6.73
175.44	5.17	659.04	6.49	843.70	6.74
190.01	5.25	676.93	6.52	850.53	6.75
198.75	5.29	692.62	6.54	913.00	6.82
249.06	5.52	743.74	6.61	953.96	6.86
250.95	5.53	759.52	6.63	963.13	6.87
264.08	5.58	947.00	6.85	1023.23	6.93
271.73	5.60	1302.67	7.17	1024.00	6.93
277.29	5.63	1596.34	7.38	1028.80	6.94
325.17	5.78	1680.62	7.43	1267.59	7.14
430.41	6.06	1705.00	7.44	1338.29	7.20
462.48	6.14	2301.48	7.74	1389.25	7.24
469.73	6.15	2744.28	7.92	1570.27	7.36
603.51	6.40	2904.00	7.97	1734.00	7.46
605.87	6.41	3293.73	8.10	1961.24	7.58
755.48	6.63	3311.79	8.11	1971.29	7.59
924.42	6.83	3570.36	8.18	2049.73	7.63
1407.64	7.25	3999.00	8.29	2108.19	7.65
1541.80	7.34	4688.92	8.45	2171.34	7.68
1591.82	7.37	4823.63	8.48	2216.14	7.70
1652.33	7.41	4857.93	8.49	2253.31	7.72
1940.54	7.57	5442.62	8.60	2550.54	7.84
1991.17	7.60	5664.40	8.64	2728.23	7.91
2325.15	7.75	5902.15	8.68	2766.30	7.93
2326.47	7.75	6946.35	8.85	2956.13	7.99
3013.09	8.01	7156.82	8.88	3196.32	8.07
3114.72	8.04	7530.39	8.93	3934.69	8.28
4114.27	8.32	7745.32	8.95	4216.00	8.35
4363.02	8.38	7839.29	8.97	4531.65	8.42
5971.90	8.69	8670.00	9.07	5185.41	8.55
6033.29	8.71	9160.81	9.12	5272.72	8.57

Table C.14 DESCRIPTIVE STATISTICS FOR DBA ARD OF LEP SOLIDS Pb DATA

DESCRIPTIVE STATISTICS FOR DBA ARD OF LEP SOLIDS Pb DATA					
P3/8 UNTRANS		*P4 UNTRANS*		*P8 UNTRANS*	
Mean	1347.179751	Mean	3392.676	Mean	1988.1721
Standard Error	271.7547056	Standard Error	466.60438	Standard Error	217.17807
Median	536.6198463	Median	2824.1371	Median	1652.1326
Mode	#N/A	Mode	#N/A	Mode	#N/A
Standard Deviation	1630.528233	Standard Deviation	2799.6263	Standard Deviation	1303.0684
Variance	2658622.32	Variance	7837907.3	Variance	1697987.3
Kurtosis	2.151233086	Kurtosis	-0.974497	Kurtosis	0.596681
Skewness	1.648597245	Skewness	0.598993	Skewness	1.172708
Range	5949.120926	Range	8875.1272	Range	4574.5764
Minimum	84.16477934	Minimum	285.68482	Minimum	698.14674
Maximum	6033.285706	Maximum	9160.812	Maximum	5272.7231
Sum	48498.47103	Sum	122136.33	Sum	71574.197
Count	36	Count	36	Count	36
Confidence Level (95%)	532.6286468	Confidence Level (95%)	914.52642	Confidence Level (95%)	425.66057
UCLM	1702.363151	UCLM	4002.5279	UCLM	2272.0239
P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	6.450511677	Mean	7.6729009	Mean	7.403773
Standard Error	0.218012248	Standard Error	0.1777372	Standard Error	0.1033121
Median	6.277460873	Median	7.9455582	Median	7.408593
Mode	#N/A	Mode	#N/A	Mode	#N/A
Standard Deviation	1.308073486	Standard Deviation	1.0664233	Standard Deviation	0.6198728
Variance	1.711056245	Variance	1.1372587	Variance	0.3842423
Kurtosis	-1.24468997	Kurtosis	-1.3574275	Kurtosis	-1.0907132
Skewness	0.143011232	Skewness	-0.2893134	Skewness	0.314023
Range	4.272270498	Range	3.4678009	Range	2.0218729
Minimum	4.432776536	Minimum	5.6548892	Minimum	6.5484293
Maximum	8.705047034	Maximum	9.1226901	Maximum	8.5703022
Sum	232.2184204	Sum	276.22443	Sum	266.53583
Count	36	Count	36	Count	36
Confidence Level (95%)	0.427295521	Confidence Level (95%)	0.348358	Confidence Level (95%)	0.2024878
UCLM	6.735453685	UCLM	7.9052035	UCLM	7.538802
UCLM TRANS BACK	841.7252756	UCLM TRANS BACK	2711.3541	UCLM TRANS BACK	1879.5769

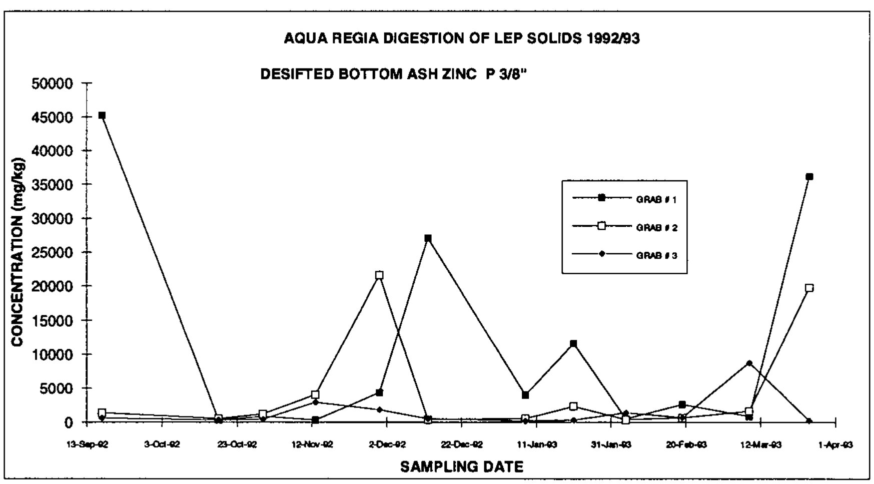

Figure C.36 DBA - ARD OF LEP SOLIDS Zn P3/8"

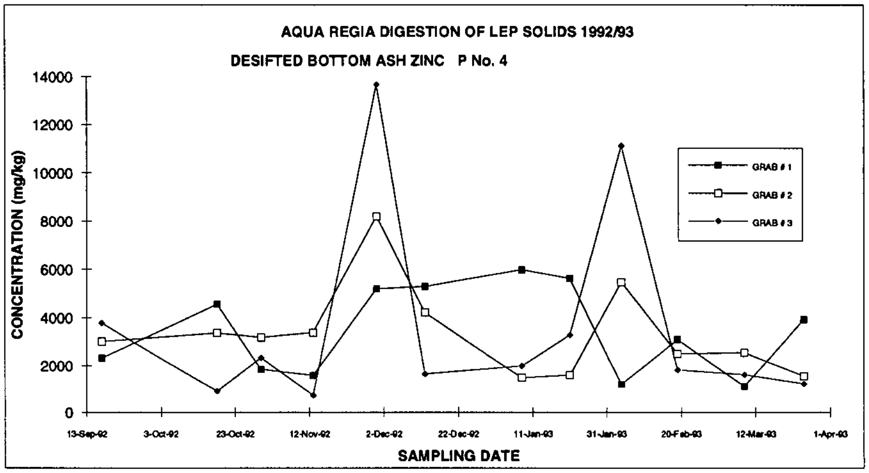

Figure C.37 DBA - ARD OF LEP SOLIDS Zn P4

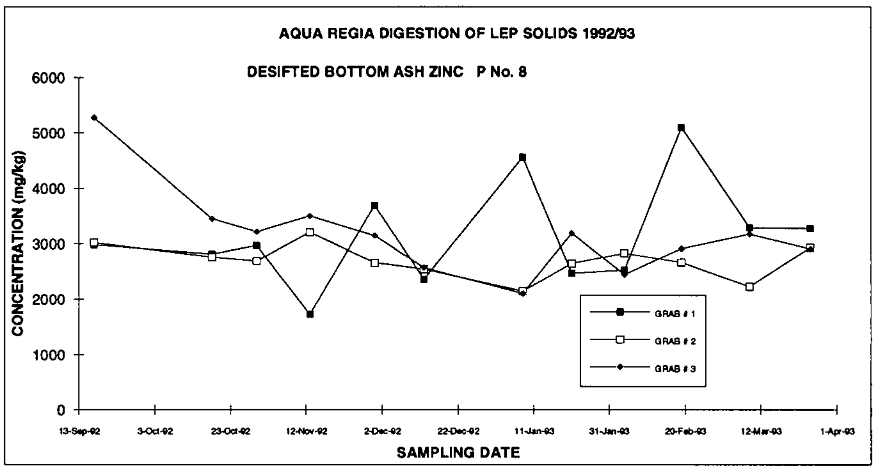

Figure C.38 DBA - ARD OF LEP SOLIDS Zn P8

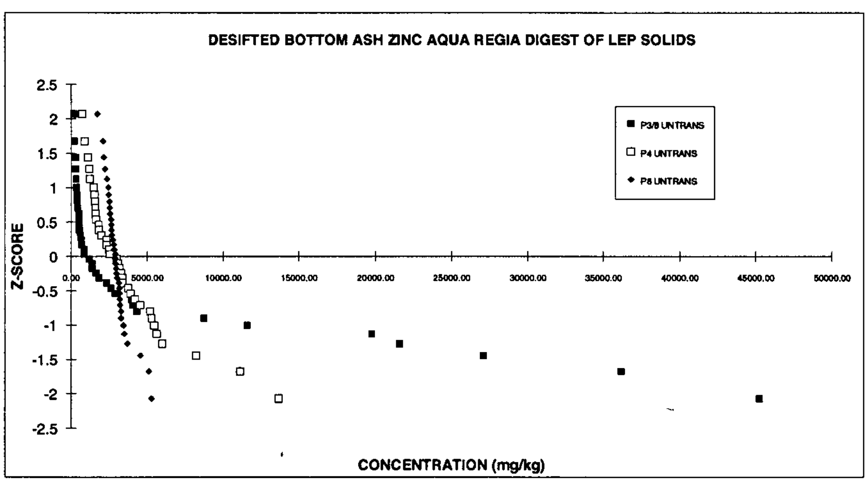

Figure C.39 DBA - ARD OF LEP SOLIDS UNTRANSFORMED Z-SCORE Zn

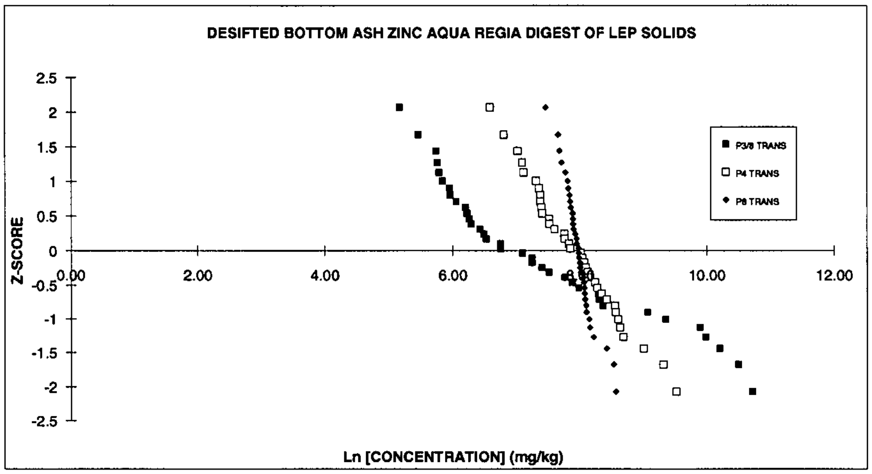

Figure C.40 DBA - ARD OF LEP SOLIDS UNTRANSFORMED Z-SCORE Zn

Table C.15 DBA ARD OF LEP SOLIDS Zn RANKED CONCENTRATIONS

DBA ARD OF LEP SOLIDS Zn RANKED CONCENTRATIONS (mg/kg)					
P3/8" UNTRAN	P3/8" TRANS	P4 UNTRAN	P4 TRANS	P8 UNTRAN	P8 TRANS
175.15	5.17	725.67	6.59	1725.43	7.45
234.64	5.46	897.17	6.80	2100.00	7.65
311.17	5.74	1111.04	7.01	2145.87	7.67
316.73	5.76	1197.52	7.09	2223.76	7.71
326.22	5.79	1217.00	7.10	2358.00	7.77
341.91	5.83	1480.39	7.30	2443.37	7.80
383.59	5.95	1548.53	7.35	2469.00	7.81
385.87	5.96	1583.56	7.37	2523.23	7.83
425.00	6.05	1592.77	7.37	2542.41	7.84
492.77	6.20	1608.63	7.38	2567.44	7.85
504.61	6.22	1638.77	7.40	2644.64	7.88
522.35	6.26	1812.70	7.50	2655.08	7.88
537.07	6.29	1840.48	7.52	2660.18	7.89
618.99	6.43	1984.00	7.59	2685.14	7.90
657.77	6.49	2316.59	7.75	2759.78	7.92
683.46	6.53	2336.50	7.76	2814.49	7.94
851.21	6.75	2501.68	7.82	2830.19	7.95
853.72	6.75	2550.97	7.84	2907.79	7.98
1204.16	7.09	3010.02	8.01	2914.59	7.98
1398.64	7.24	3095.20	8.04	2931.06	7.98
1400.73	7.24	3179.62	8.06	2969.12	8.00
1629.12	7.40	3280.00	8.10	2980.37	8.00
1816.24	7.50	3368.69	8.12	3021.54	8.01
2329.31	7.75	3380.17	8.13	3147.36	8.05
2624.75	7.87	3771.99	8.24	3176.66	8.06
2913.66	7.98	3918.58	8.27	3193.00	8.07
3974.95	8.29	4206.34	8.34	3207.30	8.07
4038.38	8.30	4559.02	8.42	3222.03	8.08
4312.08	8.37	5195.16	8.56	3281.49	8.10
8721.51	9.07	5287.80	8.57	3295.68	8.10
11593.24	9.36	5472.80	8.61	3456.54	8.15
19755.62	9.89	5625.00	8.63	3502.59	8.16
21570.37	9.98	5978.00	8.70	3698.93	8.22
27063.27	10.21	8200.73	9.01	4555.00	8.42
36164.41	10.50	11120.41	9.32	5096.12	8.54
45232.07	10.72	13676.76	9.52	5275.53	8.57

Table C.16 DESCRIPTIVE STATISTICS FOR DBA ARD OF LEP SOLIDS Zn DATA

DESCRIPTIVE STATISTICS FOR DBA ARD OF LEP SOLIDS Zn DATA

P3/8 UNTRANS		*P4 UNTRANS*		*P8 UNTRANS*	
Mean	5732.354037	Mean	3507.5069	Mean	2999.4642
Standard Error	1794.37151	Standard Error	464.86708	Standard Error	123.71866
Median	1028.938793	Median	2780.4941	Median	2911.1918
Mode	#N/A	Mode	#N/A	Mode	#N/A
Standard Deviation	10766.22906	Standard Deviation	2789.2025	Standard Deviation	742.31195
Variance	115911688.1	Variance	7779650.4	Variance	551027.03
Kurtosis	5.857634966	Kurtosis	5.0957071	Kurtosis	3.1032484
Skewness	2.505798792	Skewness	2.0929032	Skewness	1.5150917
Range	45056.92139	Range	12951.084	Range	3550.0981
Minimum	175.1530013	Minimum	725.67414	Minimum	1725.4277
Maximum	45232.07439	Maximum	13676.758	Maximum	5275.5258
Sum	206364.7453	Sum	126270.25	Sum	107980.71
Count	36	Count	36	Count	36
Confidence Level (95%)	3516.898326	Confidence Level (95%)	911.12138	Confidence Level (95%)	242.48376
UCLM	8077.5976	UCLM	4115.0881	UCLM	3161.1645

P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	7.343861451	Mean	7.9222503	Mean	7.9799778
Standard Error	0.260129526	Standard Error	0.1146059	Standard Error	0.0378155
Median	6.921569767	Median	7.9269651	Median	7.9763172
Mode	#N/A	Mode	#N/A	Mode	#N/A
Standard Deviation	1.560777158	Standard Deviation	0.6876351	Standard Deviation	0.2268929
Variance	2.436025338	Variance	0.472842	Variance	0.0514804
Kurtosis	-0.46487573	Kurtosis	-0.2223069	Kurtosis	1.473602
Skewness	0.77209173	Skewness	0.2939163	Skewness	0.6025773
Range	5.55390184	Range	2.9363521	Range	1.1176034
Minimum	5.165659885	Minimum	6.5871011	Minimum	7.4532303
Maximum	10.71956172	Maximum	9.5234532	Maximum	8.5708336
Sum	264.3790122	Sum	285.20101	Sum	287.2792
Count	36	Count	36	Count	36
Confidence Level (95%)	0.509843748	Confidence Level (95%)	0.224623	Confidence Level (95%)	0.0741169
UCLM	7.683850742	UCLM	8.0720401	UCLM	8.0294026
UCLM TRANS BACK	2172.971233	UCLM TRANS BACK	3203.6309	UCLM TRANS BACK	3069.9071

Appendix D

GRATE SIFTINGS LEACHATE EXTRACTION PROCEDURE

Table D.1 GS LEP Cd RANKED CONCENTRATIONS (mg/kg)

GS LEP Cd RANKED CONCENTRATIONS (mg/kg)					
P3/8" UNTRAN	P3/8" TRANS	P4 UNTRAN	P4 TRANS	P8 UNTRAN	P8 TRANS
0.04	-3.22	0.08	-2.53	0.08	-2.53
0.06	-2.81	0.08	-2.53	0.54	-0.62
0.06	-2.81	0.10	-2.30	0.66	-0.42
0.08	-2.53	0.10	-2.30	1.08	0.08
0.08	-2.53	0.12	-2.12	1.24	0.22
0.10	-2.30	0.14	-1.97	2.04	0.71
0.10	-2.30	0.16	-1.83	2.16	0.77
0.10	-2.30	0.44	-0.82	3.02	1.11
0.12	-2.12	2.34	0.85	4.14	1.42

Table D.2 DESCRIPTIVE STATISTICS FOR GS LEP Cd DATA

DESCRIPTIVE STATISTICS FOR GS LEP Cd DATA					
P3/8 UNTRANS		*P4 UNTRANS*		*P8 UNTRANS*	
Mean	0.08	Mean	0.3955556	Mean	1.6622222
Standard Error	0.01	Standard Error	0.2458947	Standard Error	0.4355385
Median	0.08	Median	0.12	Median	1.24
Mode	0.10	Mode	0.08	Mode	#N/A
Standard Deviation	0.03	Standard Deviation	0.7376841	Standard Deviation	1.3066156
Variance	0.00	Variance	0.5441778	Variance	1.7072444
Kurtosis	-0.700187	Kurtosis	8.4023307	Kurtosis	0.0401937
Skewness	-0.260026	Skewness	2.8771807	Skewness	0.8097145
Range	0.08	Range	2.26	Range	4.06
Minimum	0.04	Minimum	0.08	Minimum	0.08
Maximum	0.12	Maximum	2.34	Maximum	4.14
Sum	0.74	Sum	3.56	Sum	14.96
Count	9	Count	9	Count	9
Confidence Level (95%)	0.0165851	Confidence Level (95%)	0.481944	Confidence Level (95%)	0.8536386
UCLM	0.0940436	UCLM	0.7390704	UCLM	2.2706696
P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	-2.547241	Mean	-1.727379	Mean	0.0826281
Standard Error	0.1152046	Standard Error	0.3656062	Standard Error	0.3955258
Median	-2.525729	Median	-2.120264	Median	0.2151114
Mode	-2.302585	Mode	-2.525729	Mode	#N/A
Standard Deviation	0.3456137	Standard Deviation	1.0968185	Standard Deviation	1.1865773
Variance	0.1194489	Variance	1.2030108	Variance	1.4079658
Kurtosis	0.2628473	Kurtosis	3.918617	Kurtosis	2.3560019
Skewness	-0.852126	Skewness	1.996947	Skewness	-1.362941
Range	1.0986123	Range	3.3758796	Range	3.9464244
Minimum	-3.218876	Minimum	-2.525729	Minimum	-2.525729
Maximum	-2.120264	Maximum	0.8501509	Maximum	1.4206958
Sum	-22.92517	Sum	-15.54641	Sum	0.7436528
Count	9	Count	9	Count	9
Confidence Level (95%)	0.2257965	Confidence Level (95%)	0.7165739	Confidence Level (95%)	0.7752151
UCLM	-2.386301	UCLM	-1.216628	UCLM	0.6351776
UCLM TRANS BACK	0.0919693	UCLM TRANS BACK	0.2962275	UCLM TRANS BACK	1.8873573

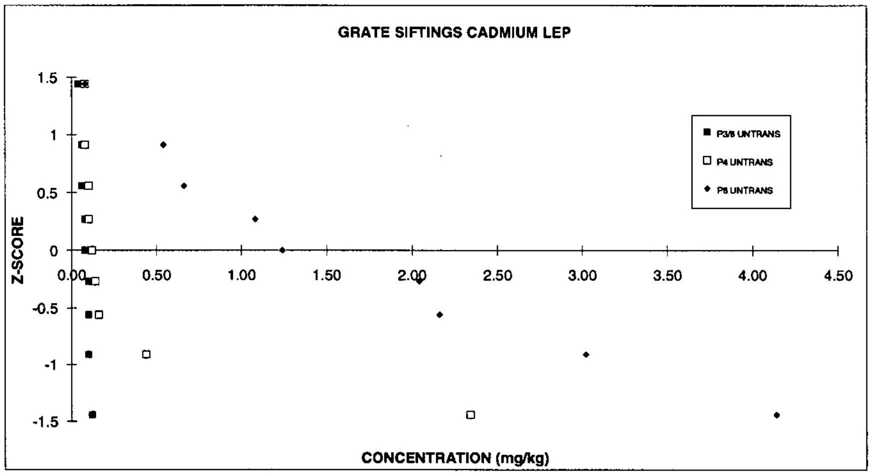

Figure D.1 GS LEP UNTRANSFORMED Z-SCORE Cd

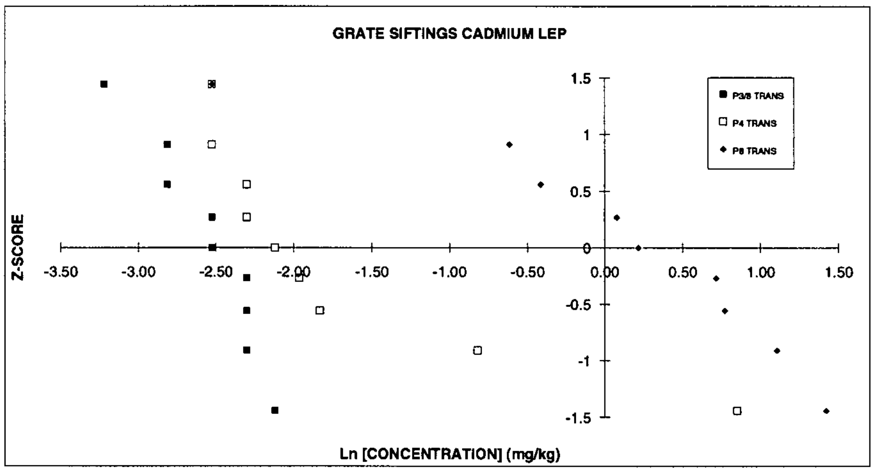

Figure D.2 GS LEP TRANSFORMED Z-SCORE Cd

Table D.3 GS LEP Cr RANKED CONCENTRATIONS (mg/kg)

GS LEP Cr RANKED CONCENTRATIONS (mg/kg)					
P3/8" UNTRAN	P3/8" TRANS	P4 UNTRAN	P4 TRANS	P8 UNTRAN	P8 TRANS
0.12	-2.12	0.12	-2.12	0.12	-2.12
0.12	-2.12	0.12	-2.12	0.12	-2.12
0.12	-2.12	0.12	-2.12	0.12	-2.12
0.12	-2.12	0.12	-2.12	0.12	-2.12
0.12	-2.12	0.12	-2.12	0.12	-2.12
0.12	-2.12	0.12	-2.12	0.12	-2.12
0.12	-2.12	0.12	-2.12	0.12	-2.12
0.12	-2.12	0.12	-2.12	0.12	-2.12
0.12	-2.12	0.12	-2.12	0.18	-1.71

Table D.4 DESCRIPTIVE STATISTICS FOR GS LEP Cr DATA

DESCRIPTIVE STATISTICS FOR GS LEP Cr DATA					
P3/8 UNTRANS		*P4 UNTRANS*		*P8 UNTRANS*	
Mean	0.12	Mean	0.12	Mean	0.1266667
Standard Error	0.00	Standard Error	0.00	Standard Error	0.0066667
Median	0.12	Median	0.12	Median	0.12
Mode	0.12	Mode	0.12	Mode	0.12
Standard Deviation	0.00	Standard Deviation	0.00	Standard Deviation	0.02
Variance	0	Variance	0	Variance	0.0004
Kurtosis	-2.666667	Kurtosis	-2.666667	Kurtosis	9
Skewness	-1.212183	Skewness	-1.212183	Skewness	3
Range	0	Range	0	Range	0.06
Minimum	0.12	Minimum	0.12	Minimum	0.12
Maximum	0.12	Maximum	0.12	Maximum	0.18
Sum	1.08	Sum	1.08	Sum	1.14
Count	9	Count	9	Count	9
Confidence Level (95%)	#NUM!	Confidence Level (95%)	#NUM!	Confidence Level (95%)	0.0130664
UCLM	0.12	UCLM	0.12	UCLM	0.13598
P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	-2.120264	Mean	-2.120264	Mean	-2.075212
Standard Error	0	Standard Error	0	Standard Error	0.0450517
Median	-2.120264	Median	-2.120264	Median	-2.120264
Mode	-2.120264	Mode	-2.120264	Mode	-2.120264
Standard Deviation	0	Standard Deviation	0	Standard Deviation	0.135155
Variance	0	Variance	0	Variance	0.0182669
Kurtosis	-2.666667	Kurtosis	-2.666667	Kurtosis	9
Skewness	1.2121831	Skewness	1.2121831	Skewness	3
Range	0	Range	0	Range	0.4054651
Minimum	-2.120264	Minimum	-2.120264	Minimum	-2.120264
Maximum	-2.120264	Maximum	-2.120264	Maximum	-1.714798
Sum	-19.08237	Sum	-19.08237	Sum	-18.67691
Count	9	Count	9	Count	9
Confidence Level (95%)	#NUM!	Confidence Level (95%)	#NUM!	Confidence Level (95%)	0.0882995
UCLM	-2.120264	UCLM	-2.120264	UCLM	-2.012275
UCLM TRANS BACK	0.12	UCLM TRANS BACK	0.12	UCLM TRANS BACK	0.1336842

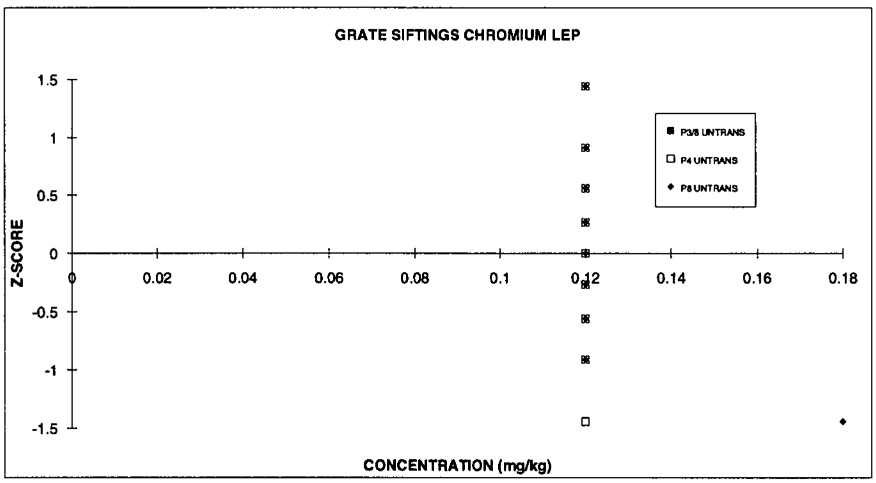

Figure D.3 GS LEP UNTRANSFORMED Z-SCORE Cr

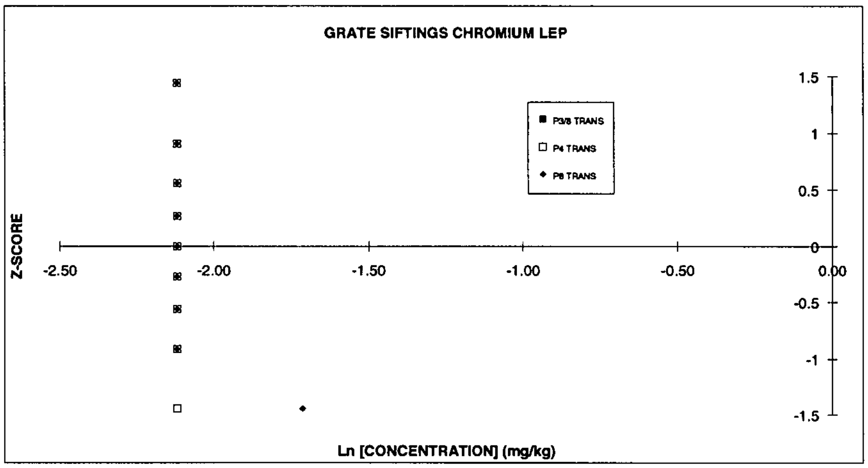

Figure D.4 GS LEP TRANSFORMED Z-SCORE Cr

Table D.5 GS LEP Cu RANKED CONCENTRATIONS (mg/kg)

GS LEP Cu RANKED CONCENTRATIONS (mg/kg)					
P3/8" UNTRAN	P3/8" TRANS	P4 UNTRAN	P4 TRANS	P8 UNTRAN	P8 TRANS
3.54	1.26	0.30	-1.20	0.16	-1.83
4.96	1.60	2.34	0.85	0.16	-1.83
5.40	1.69	3.54	1.26	0.16	-1.83
6.68	1.90	5.38	1.68	0.16	-1.83
11.60	2.45	6.98	1.94	0.16	-1.83
21.00	3.04	10.68	2.37	0.38	-0.97
21.80	3.08	12.02	2.49	0.44	-0.82
25.60	3.24	12.92	2.56	0.44	-0.82
29.60	3.39	14.12	2.65	2.22	0.80

Table D.6 DESCRIPTIVE STATISTICS FOR GS LEP Cu DATA

DESCRIPTIVE STATISTICS FOR GS LEP Cu DATA					
P3/8 UNTRANS		*P4 UNTRANS*		*P8 UNTRANS*	
Mean	14.46	Mean	7.59	Mean	0.4755556
Standard Error	3.35	Standard Error	1.68	Standard Error	0.2221305
Median	11.60	Median	6.98	Median	0.16
Mode	#N/A	Mode	#N/A	Mode	0.16
Standard Deviation	10.06	Standard Deviation	5.03	Standard Deviation	0.6663916
Variance	101.28178	Variance	25.3235	Variance	0.4440778
Kurtosis	-1.817403	Kurtosis	-1.656857	Kurtosis	8.0740885
Skewness	0.334219	Skewness	-0.077236	Skewness	2.7971065
Range	26.06	Range	13.82	Range	2.06
Minimum	3.54	Minimum	0.3	Minimum	0.16
Maximum	29.6	Maximum	14.12	Maximum	2.22
Sum	130.18	Sum	68.28	Sum	4.28
Count	9	Count	9	Count	9
Confidence Level (95%)	6.5749409	Confidence Level (95%)	3.2876688	Confidence Level (95%)	0.4353672
UCLM	19.15086	UCLM	9.9300159	UCLM	0.7858719
P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	2.4065393	Mean	1.6219284	Mean	-1.219438
Standard Error	0.2701943	Standard Error	0.4091089	Standard Error	0.2964784
Median	2.4510051	Median	1.9430489	Median	-1.832581
Mode	#N/A	Mode	#N/A	Mode	-1.832581
Standard Deviation	0.8105829	Standard Deviation	1.2273268	Standard Deviation	0.8894352
Variance	0.6570447	Variance	1.5063311	Variance	0.7910949
Kurtosis	-1.935662	Kurtosis	3.3260365	Kurtosis	2.8374173
Skewness	-0.126753	Skewness	-1.745176	Skewness	1.6434048
Range	2.1236476	Range	3.851565	Range	2.6300887
Minimum	1.2641267	Minimum	-1.203973	Minimum	-1.832581
Maximum	3.3877744	Maximum	2.6475922	Maximum	0.7975072
Sum	21.658854	Sum	14.597356	Sum	-10.97495
Count	9	Count	9	Count	9
Confidence Level (95%)	0.5295703	Confidence Level (95%)	0.8018376	Confidence Level (95%)	0.5810861
UCLM	2.7840007	UCLM	2.1934536	UCLM	-0.805258
UCLM TRANS BACK	16.183638	UCLM TRANS BACK	8.966125	UCLM TRANS BACK	0.4469726

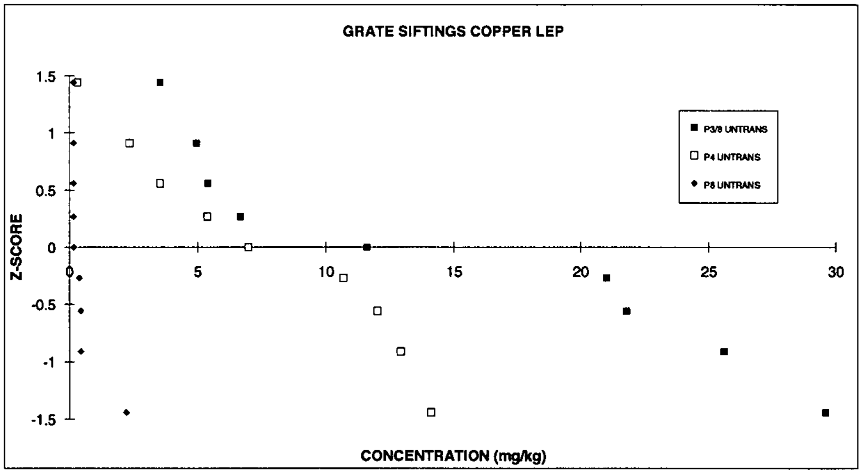

Figure D.5 GS LEP UNTRANSFORMED Z-SCORE Cu

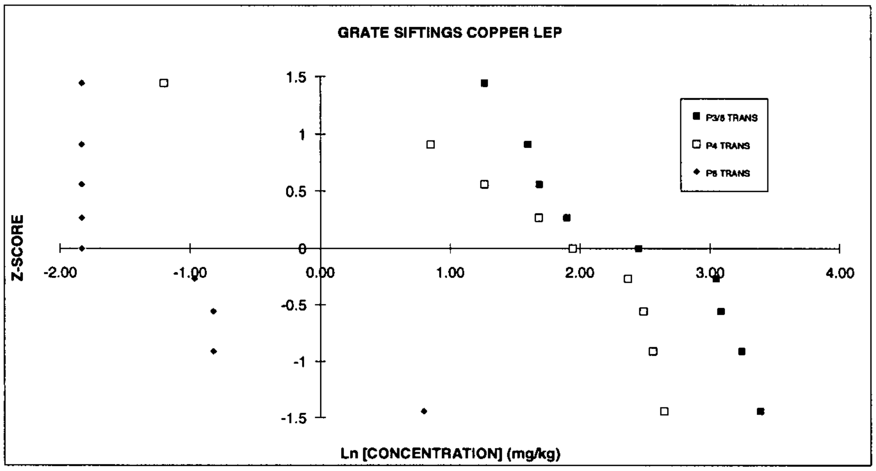

Figure D.6 GS LEP TRANSFORMED Z-SCORE Cu

Table D.7 GS LEP Fe RANKED CONCENTRATIONS (mg/kg)

GS LEP Fe RANKED CONCENTRATIONS (mg/kg)					
P3/8" UNTRAN	P3/8" TRANS	P4 UNTRAN	P4 TRANS	P8 UNTRAN	P8 TRANS
36.60	3.60	100.80	4.61	16.80	2.82
52.60	3.96	136.80	4.92	42.00	3.74
110.60	4.71	141.20	4.95	44.60	3.80
117.80	4.77	160.00	5.08	52.40	3.96
140.00	4.94	180.00	5.19	97.60	4.58
146.00	4.98	200.00	5.30	135.80	4.91
200.00	5.30	200.00	5.30	200.00	5.30
400.00	5.99	200.00	5.30	200.00	5.30
400.00	5.99	400.00	5.99	400.00	5.99

Table D.8 DESCRIPTIVE STATISTICS FOR GS LEP Fe DATA

DESCRIPTIVE STATISTICS FOR GS LEP Fe DATA					
P3/8 UNTRANS		*P4 UNTRANS*		*P8 UNTRANS*	
Mean	178.18	Mean	190.98	Mean	132.13333
Standard Error	44.94	Standard Error	28.52	Standard Error	40.417199
Median	140.00	Median	180.00	Median	97.6
Mode	400.00	Mode	200.00	Mode	200
Standard Deviation	134.82	Standard Deviation	85.56	Standard Deviation	121.2516
Variance	18175.704	Variance	7319.9644	Variance	14701.95
Kurtosis	-0.087381	Kurtosis	5.3800391	Kurtosis	2.2869146
Skewness	1.0758969	Skewness	2.0754684	Skewness	1.4749603
Range	363.4	Range	299.2	Range	383.2
Minimum	36.6	Minimum	100.8	Minimum	16.8
Maximum	400	Maximum	400	Maximum	400
Sum	1603.6	Sum	1718.8	Sum	1189.2
Count	9	Count	9	Count	9
Confidence Level (95%)	88.078887	Confidence Level (95%)	55.895993	Confidence Level (95%)	79.216138
UCLM	240.9577	UCLM	230.81872	UCLM	188.59616
P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	4.9160187	Mean	5.1818203	Mean	4.4884277
Standard Error	0.2679881	Standard Error	0.1266075	Standard Error	0.3303696
Median	4.9416424	Median	5.1929569	Median	4.5808775
Mode	5.9914645	Mode	5.2983174	Mode	5.2983174
Standard Deviation	0.8039642	Standard Deviation	0.3798224	Standard Deviation	0.9911087
Variance	0.6463585	Variance	0.1442651	Variance	0.9822964
Kurtosis	-0.388523	Kurtosis	2.4127165	Kurtosis	-0.58979
Skewness	-0.189859	Skewness	0.9376164	Skewness	-0.165014
Range	2.3914163	Range	1.3783262	Range	3.1700857
Minimum	3.6000482	Minimum	4.6131384	Minimum	2.8213789
Maximum	5.9914645	Maximum	5.9914645	Maximum	5.9914645
Sum	44.244168	Sum	46.636383	Sum	40.395849
Count	9	Count	9	Count	9
Confidence Level (95%)	0.5252462	Confidence Level (95%)	0.2481457	Confidence Level (95%)	0.6475115
UCLM	5.290398	UCLM	5.358691	UCLM	4.9499539
UCLM TRANS BACK	198.42239	UCLM TRANS BACK	212.44667	UCLM TRANS BACK	141.16846

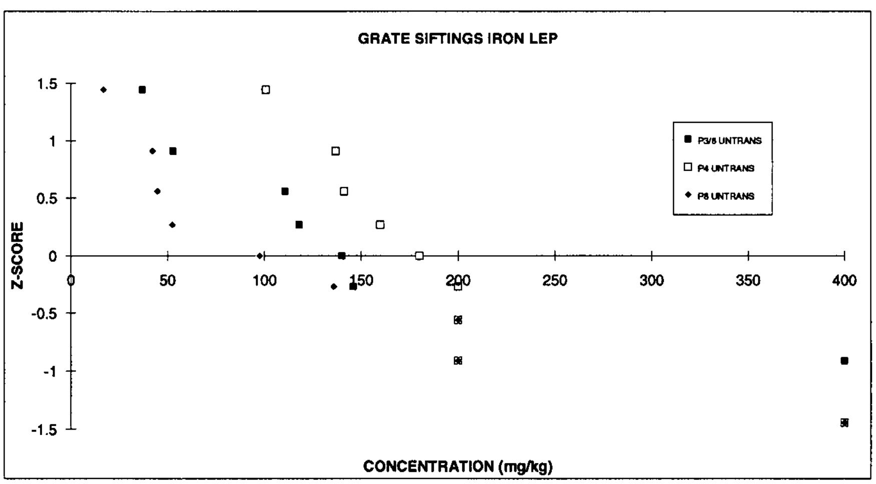

Figure D.7 GS LEP UNTRANSFORMED Z-SCORE Fe

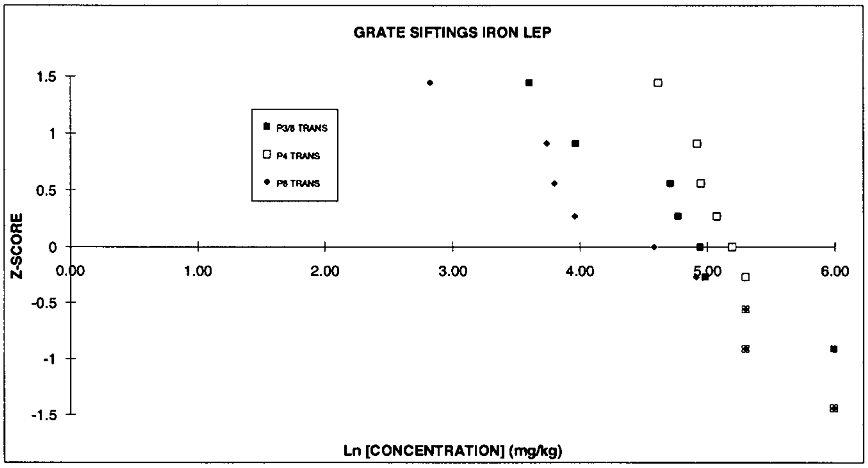

Figure D.8 GS LEP TRANSFORMED Z-SCORE Fe

Table D.9 GS LEP Mn RANKED CONCENTRATIONS (mg/kg)

GS LEP Mn RANKED CONCENTRATIONS (mg/kg)					
P3/8" UNTRAN	P3/8" TRANS	P4 UNTRAN	P4 TRANS	P8 UNTRAN	P8 TRANS
2.80	1.03	11.40	2.43	14.92	2.70
4.04	1.40	13.32	2.59	18.46	2.92
5.62	1.73	17.30	2.85	24.00	3.18
7.62	2.03	21.00	3.04	26.20	3.27
7.74	2.05	26.60	3.28	28.60	3.35
9.76	2.28	34.40	3.54	29.60	3.39
10.12	2.31	34.80	3.55	30.00	3.40
18.92	2.94	38.80	3.66	40.40	3.70
25.20	3.23	41.00	3.71	42.20	3.74

Table D.10 DESCRIPTIVE STATISTICS FOR GS LEP Mn DATA

DESCRIPTIVE STATISTICS FOR GS LEP Mn DATA					
P3/8 UNTRANS		*P4 UNTRANS*		*P8 UNTRANS*	
Mean	10.20	Mean	26.51	Mean	28.264444
Standard Error	2.44	Standard Error	3.74	Standard Error	2.98847
Median	7.74	Median	26.60	Median	28.6
Mode	#N/A	Mode	#N/A	Mode	#N/A
Standard Deviation	7.31	Standard Deviation	11.23	Standard Deviation	8.9654101
Variance	53.453544	Variance	126.1826	Variance	80.378578
Kurtosis	1.1786625	Kurtosis	-1.778524	Kurtosis	-0.395871
Skewness	1.3439219	Skewness	-0.084313	Skewness	0.2444364
Range	22.4	Range	29.6	Range	27.28
Minimum	2.8	Minimum	11.4	Minimum	14.92
Maximum	25.2	Maximum	41	Maximum	42.2
Sum	91.82	Sum	238.62	Sum	254.38
Count	9	Count	9	Count	9
Confidence Level (95%)	4.7765513	Confidence Level (95%)	7.3388148	Confidence Level (95%)	5.8572849
UCLM	13.606801	UCLM	31.744215	UCLM	32.439337
P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	2.1099159	Mean	3.1842985	Mean	3.2939723
Standard Error	0.2309685	Standard Error	0.1590454	Standard Error	0.1115445
Median	2.0464017	Median	3.2809112	Median	3.3534067
Mode	#N/A	Mode	#N/A	Mode	#N/A
Standard Deviation	0.6929055	Standard Deviation	0.4771361	Standard Deviation	0.3346336
Variance	0.4801181	Variance	0.2276588	Variance	0.1119797
Kurtosis	-0.298439	Kurtosis	-1.376206	Kurtosis	-0.076439
Skewness	0.1438266	Skewness	-0.480546	Skewness	-0.444508
Range	2.1972246	Range	1.2799587	Range	1.0397176
Minimum	1.0296194	Minimum	2.4336134	Minimum	2.7027026
Maximum	3.226844	Maximum	3.7135721	Maximum	3.7424202
Sum	18.989243	Sum	28.658686	Sum	29.645751
Count	9	Count	9	Count	9
Confidence Level (95%)	0.4526893	Confidence Level (95%)	0.3117227	Confidence Level (95%)	0.218623
UCLM	2.4325789	UCLM	3.4064849	UCLM	3.4498
UCLM TRANS BACK	11.388214	UCLM TRANS BACK	30.159044	UCLM TRANS BACK	31.494093

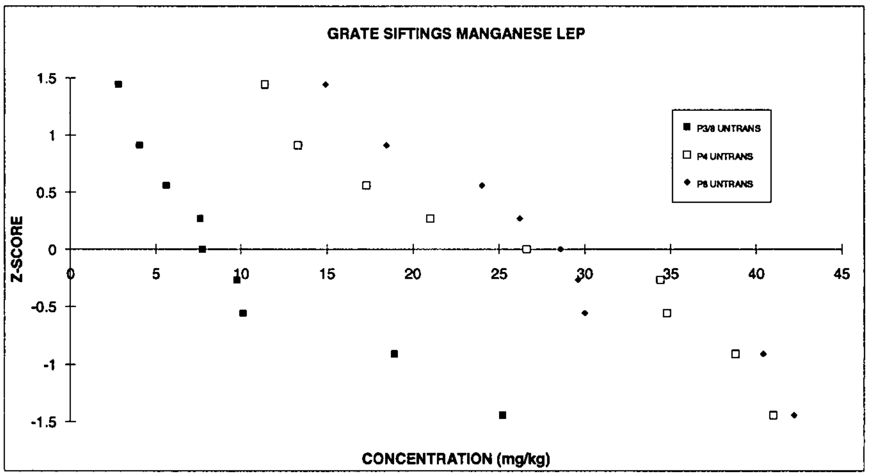

Figure D.9 GS LEP UNTRANSFORMED Z-SCORE Mn

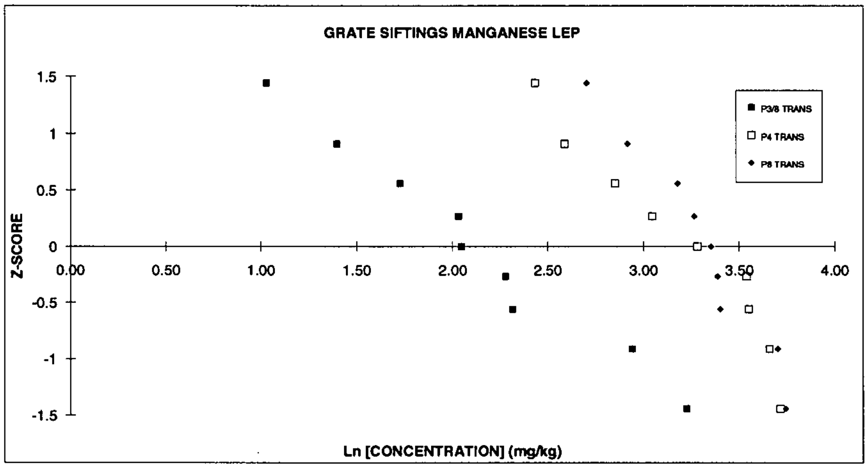

Figure D.10 GS LEP TRANSFORMED Z-SCORE Mn

Table D.11 GS LEP Ni RANKED CONCENTRATIONS (mg/kg)

GS LEP Ni RANKED CONCENTRATIONS (mg/kg)					
P3/8" UNTRAN	P3/8" TRANS	P4 UNTRAN	P4 TRANS	P8 UNTRAN	P8 TRANS
1.10	0.10	2.54	0.93	2.60	0.96
1.30	0.26	3.38	1.22	3.94	1.37
1.52	0.42	3.56	1.27	5.14	1.64
1.76	0.57	3.88	1.36	5.48	1.70
2.74	1.01	4.22	1.44	5.50	1.70
2.92	1.07	4.64	1.53	7.64	2.03
2.92	1.07	5.88	1.77	8.48	2.14
6.94	1.94	11.20	2.42	10.74	2.37
10.00	2.30	17.80	2.88	12.04	2.49

Table D.12 DESCRIPTIVE STATISTICS FOR GS LEP Ni DATA

DESCRIPTIVE STATISTICS FOR GS LEP Ni DATA					
P3/8 UNTRANS		*P4 UNTRANS*		*P8 UNTRANS*	
Mean	3.47	Mean	6.34	Mean	6.84
Standard Error	1.01	Standard Error	1.66	Standard Error	1.0441796
Median	2.74	Median	4.22	Median	5.5
Mode	2.92	Mode	#N/A	Mode	#N/A
Standard Deviation	3.02	Standard Deviation	4.99	Standard Deviation	3.1325389
Variance	9.109	Variance	24.941078	Variance	9.8128
Kurtosis	2.0277273	Kurtosis	3.2610205	Kurtosis	-0.735211
Skewness	1.6619109	Skewness	1.9166676	Skewness	0.4935638
Range	8.9	Range	15.26	Range	9.44
Minimum	1.1	Minimum	2.54	Minimum	2.6
Maximum	10	Maximum	17.8	Maximum	12.04
Sum	31.2	Sum	57.1	Sum	61.56
Count	9	Count	9	Count	9
Confidence Level (95%)	1.971794	Confidence Level (95%)	3.26275	Confidence Level (95%)	2.0465514
UCLM	4.8721008	UCLM	8.6700323	UCLM	8.298719
P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	0.9703012	Mean	1.6463171	Mean	1.8225462
Standard Error	0.2490832	Standard Error	0.2075921	Standard Error	0.1628528
Median	1.0079579	Median	1.4398351	Median	1.7047481
Mode	1.0715836	Mode	#N/A	Mode	#N/A
Standard Deviation	0.7472496	Standard Deviation	0.6227762	Standard Deviation	0.4885583
Variance	0.558382	Variance	0.3878502	Variance	0.2386892
Kurtosis	-0.291455	Kurtosis	0.7427698	Kurtosis	-0.298201
Skewness	0.7750455	Skewness	1.1981743	Skewness	-0.344834
Range	2.2072749	Range	1.9470344	Range	1.532723
Minimum	0.0953102	Minimum	0.9321641	Minimum	0.955114
Maximum	2.3025851	Maximum	2.8791985	Maximum	2.4882344
Sum	8.7327106	Sum	14.816854	Sum	16.402916
Count	9	Count	9	Count	9
Confidence Level (95%)	0.4881934	Confidence Level (95%)	0.4068724	Confidence Level (95%)	0.3191851
UCLM	1.3182704	UCLM	1.9363232	UCLM	2.0500515
UCLM TRANS BACK	3.7369524	UCLM TRANS BACK	6.9332122	UCLM TRANS BACK	7.7683014

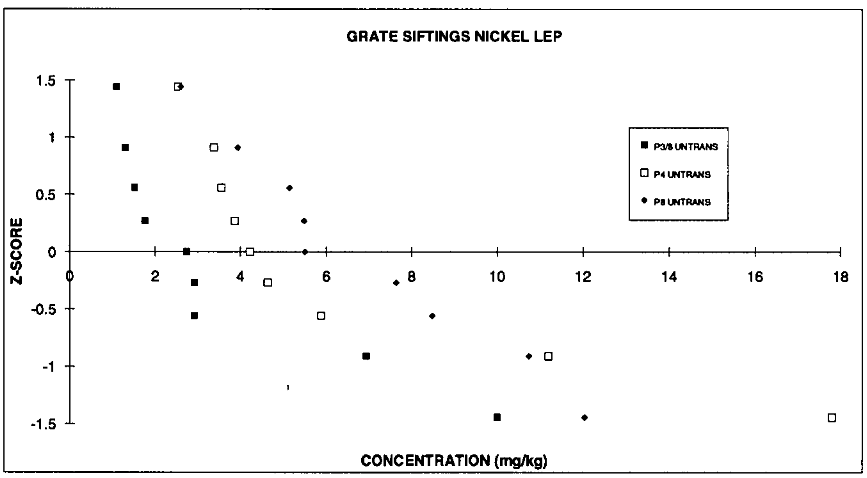

Figure D.11 GS LEP UNTRANSFORMED Z-SCORE Ni

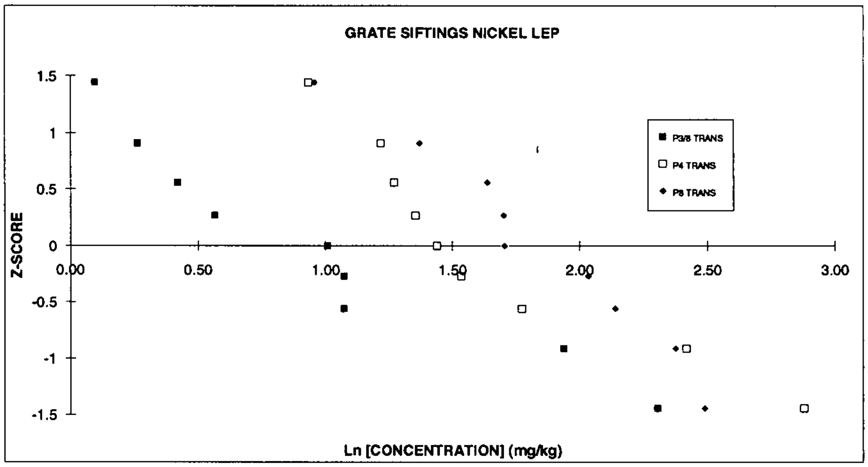

Figure D.12 GS LEP TRANSFORMED Z-SCORE Ni

Table D.13 GS LEP Pb RANKED CONCENTRATIONS (mg/kg)

GS LEP Pb RANKED CONCENTRATIONS (mg/kg)					
P3/8" UNTRAN	P3/8" TRANS	P4 UNTRAN	P4 TRANS	P8 UNTRAN	P8 TRANS
0.40	-0.92	2.00	0.69	0.40	-0.92
0.40	-0.92	33.80	3.52	3.00	1.10
0.80	-0.22	148.00	5.00	4.00	1.39
1.20	0.18	164.00	5.10	6.00	1.79
20.00	3.00	174.00	5.16	47.00	3.85
180.00	5.19	200.00	5.30	52.20	3.96
380.00	5.94	220.00	5.39	320.00	5.77
482.00	6.18	240.00	5.48	360.00	5.89
482.00	6.18	496.00	6.21	900.00	6.80

Table D.14 DESCRIPTIVE STATISTICS FOR GS LEP Pb DATA

DESCRIPTIVE STATISTICS FOR GS LEP Pb DATA					
P3/8 UNTRANS		*P4 UNTRANS*		*P8 UNTRANS*	
Mean	171.87	Mean	186.42	Mean	188.06667
Standard Error	72.27	Standard Error	47.06	Standard Error	100.60051
Median	20.00	Median	174.00	Median	47
Mode	0.40	Mode	#N/A	Mode	#N/A
Standard Deviation	216.80	Standard Deviation	141.18	Standard Deviation	301.80154
Variance	47000.88	Variance	19932.404	Variance	91084.17
Kurtosis	-1.619618	Kurtosis	2.7748249	Kurtosis	3.935016
Skewness	0.7115444	Skewness	1.1402707	Skewness	1.9742615
Range	481.6	Range	494	Range	899.6
Minimum	0.4	Minimum	2	Minimum	0.4
Maximum	482	Maximum	496	Maximum	900
Sum	1546.8	Sum	1677.8	Sum	1692.6
Count	9	Count	9	Count	9
Confidence Level (95%)	141.63781	Confidence Level (95%)	92.237185	Confidence Level (95%)	197.17309
UCLM	272.82174	UCLM	252.16605	UCLM	328.60558
P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	2.7345939	Mean	4.649878	Mean	3.2913806
Standard Error	1.0673241	Standard Error	0.5477327	Standard Error	0.8687372
Median	2.9957323	Median	5.1590553	Median	3.8501476
Mode	-0.916291	Mode	#N/A	Mode	#N/A
Standard Deviation	3.2019723	Standard Deviation	1.6431982	Standard Deviation	2.6062116
Variance	10.252626	Variance	2.7001004	Variance	6.7923391
Kurtosis	-2.28425	Kurtosis	4.7489741	Kurtosis	-1.145879
Skewness	-0.050707	Skewness	-2.104242	Skewness	-0.171688
Range	7.0942348	Range	5.5134287	Range	7.7186855
Minimum	-0.916291	Minimum	0.6931472	Minimum	-0.916291
Maximum	6.1779441	Maximum	6.2065759	Maximum	6.8023948
Sum	24.611345	Sum	41.848902	Sum	29.622425
Count	9	Count	9	Count	9
Confidence Level (95%)	2.0919137	Confidence Level (95%)	1.0735349	Confidence Level (95%)	1.7026911
UCLM	4.2256457	UCLM	5.4150606	UCLM	4.5050065
UCLM TRANS BACK	68.418664	UCLM TRANS BACK	224.76617	UCLM TRANS BACK	90.468929

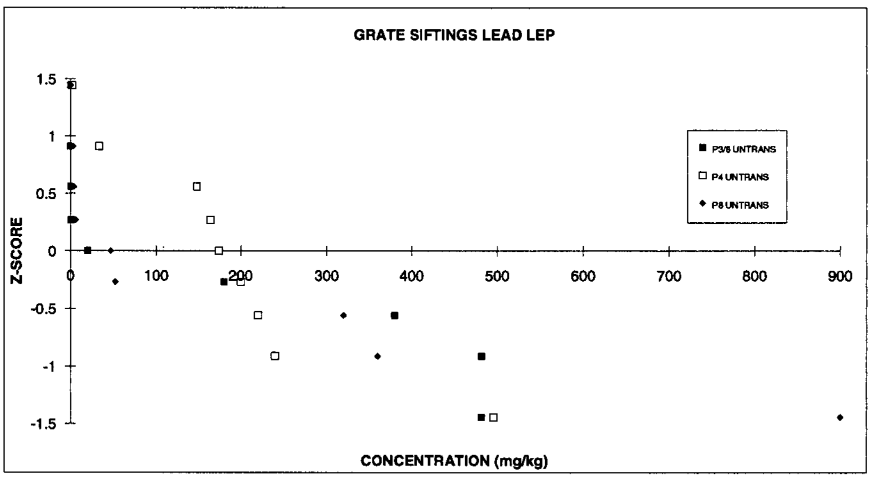

Figure D.13 GS LEP UNTRANSFORMED Z-SCORE Pb

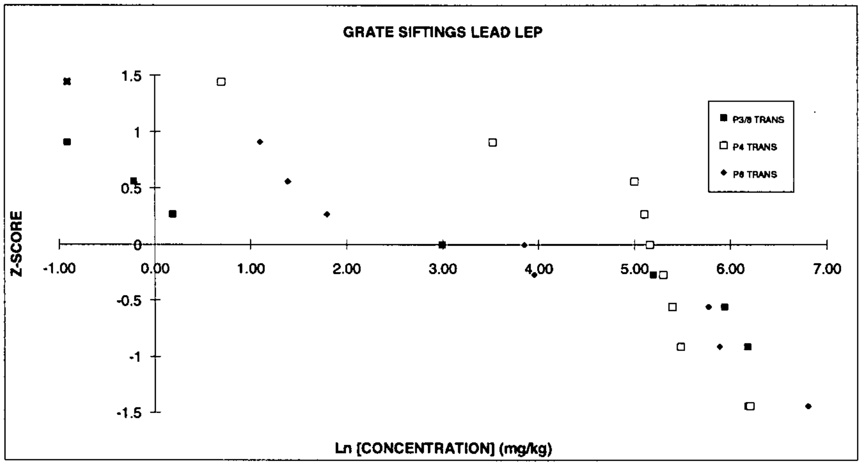

Figure D.14 GS LEP TRANSFORMED Z-SCORE Pb

Table D.15 GS LEP Zn RANKED CONCENTRATIONS (mg/kg)

GS LEP Zn RANKED CONCENTRATIONS (mg/kg)					
P3/8" UNTRAN	P3/8" TRANS	P4 UNTRAN	P4 TRANS	P8 UNTRAN	P8 TRANS
0.02	-3.91	310.00	5.74	252.00	5.53
376.00	5.93	394.00	5.98	430.00	6.06
430.00	6.06	668.00	6.50	460.00	6.13
500.00	6.21	768.00	6.64	694.00	6.54
508.00	6.23	772.00	6.65	744.00	6.61
670.00	6.51	784.00	6.66	826.00	6.72
1066.00	6.97	836.00	6.73	830.00	6.72
1568.00	7.36	1062.00	6.97	1188.00	7.08
1838.00	7.52	1572.00	7.36	2320.00	7.75

Table D.16 DESCRIPTIVE STATISTICS FOR GS LEP Zn DATA

DESCRIPTIVE STATISTICS FOR GS LEP Zn DATA					
P3/8 UNTRANS		*P4 UNTRANS*		*P8 UNTRANS*	
Mean	772.89	Mean	796.22	Mean	860.44444
Standard Error	200.01	Standard Error	123.05	Standard Error	204.01573
Median	508.00	Median	772.00	Median	744
Mode	#N/A	Mode	#N/A	Mode	#N/A
Standard Deviation	600.02	Standard Deviation	369.16	Standard Deviation	612.0472
Variance	360027.25	Variance	136277.44	Variance	374601.78
Kurtosis	-0.231665	Kurtosis	1.9121169	Kurtosis	4.4911397
Skewness	0.8419259	Skewness	0.969745	Skewness	1.9409617
Range	1837.98	Range	1262	Range	2068
Minimum	0.02	Minimum	310	Minimum	252
Maximum	1838	Maximum	1572	Maximum	2320
Sum	6956.02	Sum	7166	Sum	7744
Count	9	Count	9	Count	9
Confidence Level (95%)	392.00705	Confidence Level (95%)	241.17827	Confidence Level (95%)	399.8629
UCLM	1052.3017	UCLM	968.12668	UCLM	1145.4544
P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	5.4310419	Mean	6.5812263	Mean	6.5718137
Standard Error	1.1831396	Standard Error	0.1615274	Standard Error	0.211785
Median	6.2304814	Median	6.6489846	Median	6.612041
Mode	#N/A	Mode	#N/A	Mode	#N/A
Standard Deviation	3.5494187	Standard Deviation	0.4845823	Standard Deviation	0.635355
Variance	12.598373	Variance	0.23482	Variance	0.4036759
Kurtosis	8.3569348	Kurtosis	0.4506552	Kurtosis	0.8119203
Skewness	-2.8504	Skewness	-0.409188	Skewness	0.2638509
Range	11.428456	Range	1.6235317	Range	2.2198934
Minimum	-3.912023	Minimum	5.7365723	Minimum	5.5294291
Maximum	7.5164333	Maximum	7.360104	Maximum	7.7493225
Sum	48.879377	Sum	59.231036	Sum	59.146323
Count	9	Count	9	Count	9
Confidence Level (95%)	2.3189075	Confidence Level (95%)	0.3165875	Confidence Level (95%)	0.4150903
UCLM	7.0838878	UCLM	6.8068801	UCLM	6.8676773
UCLM TRANS BACK	1192.5961	UCLM TRANS BACK	904.04589	UCLM TRANS BACK	960.71454

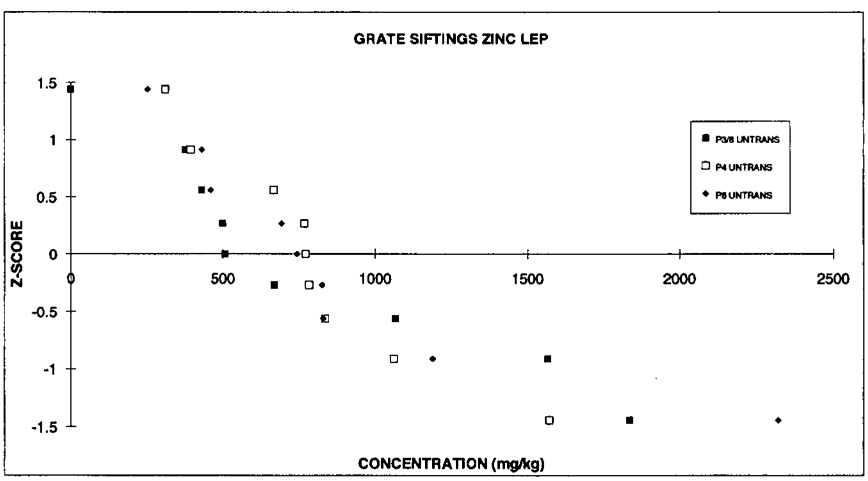

Figure D.15 GS LEP UNTRANSFORMED Z-SCORE Zn

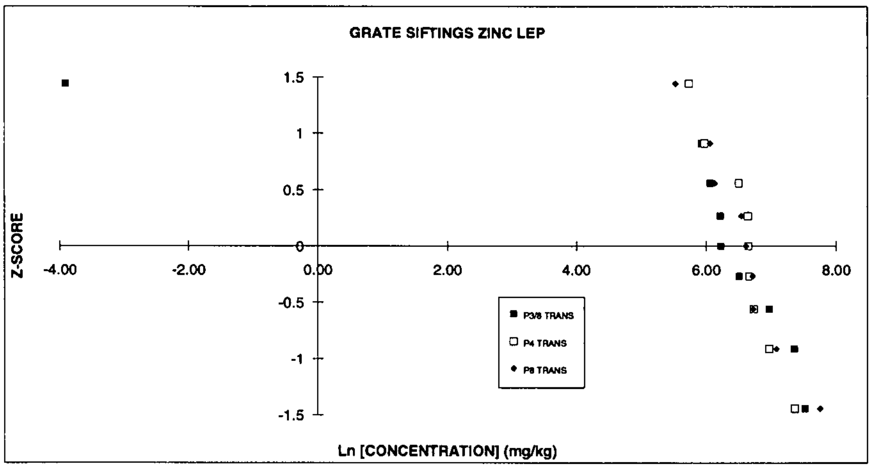

Figure D.16 GS LEP TRANSFORMED Z-SCORE Zn

Appendix E

ARD OF LEP GS SOLIDS

Table E.1 GS ARD OF LEP SOLIDS Cd RANKED CONCENTRATIONS (mg/kg)

GS ARD OF LEP SOLIDS Cd RANKED CONCENTRATIONS (mg/kg)					
P3/8" UNTRAN	P3/8" TRANS	P4 UNTRAN	P4 TRANS	P8 UNTRAN	P8 TRANS
1.20	0.18	1.60	0.47	3.60	1.28
1.30	0.26	2.00	0.69	3.70	1.31
1.30	0.26	2.30	0.83	4.10	1.41
1.70	0.53	2.80	1.03	4.30	1.46
1.80	0.59	3.20	1.16	4.30	1.46
1.80	0.59	3.30	1.19	5.20	1.65
1.80	0.59	3.80	1.34	7.80	2.05
2.70	0.99	4.00	1.39	8.80	2.17
4.40	1.48	4.80	1.57	20.10	3.00

Table E.2 DESCRIPTIVE STATISTICS FOR GS ARD OF LEP SOLIDS Cd DATA

DESCRIPTIVE STATISTICS FOR GS ARD OF LEP SOLIDS Cd DATA					
P3/8 UNTRANS		*P4 UNTRANS*		*P8 UNTRANS*	
Mean	2	Mean	3.0888889	Mean	6.8777778
Standard Error	0.3349959	Standard Error	0.3421519	Standard Error	1.7639742
Median	1.8	Median	3.2	Median	4.3
Mode	1.8	Mode	#N/A	Mode	4.3
Standard Deviation	1.0049876	Standard Deviation	1.0264556	Standard Deviation	5.2919226
Variance	1.01	Variance	1.0536111	Variance	28.004444
Kurtosis	4.440398	Kurtosis	-0.654338	Kurtosis	6.000136
Skewness	2.0453503	Skewness	0.1530597	Skewness	2.3768894
Range	3.2	Range	3.2	Range	16.5
Minimum	1.2	Minimum	1.6	Minimum	3.6
Maximum	4.4	Maximum	4.8	Maximum	20.1
Sum	18	Sum	27.8	Sum	61.9
Count	9	Count	9	Count	9
Confidence Level (95%)	0.6565788	Confidence Level (95%)	0.6706043	Confidence Level (95%)	3.4573208
UCLM	2.4679892	UCLM	3.566875	UCLM	9.3420497
P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	0.6084327	Mean	1.0747404	Mean	1.755082
Standard Error	0.1363688	Standard Error	0.1180027	Standard Error	0.1880852
Median	0.5877867	Median	1.1631508	Median	1.458615
Mode	0.5877867	Mode	#N/A	Mode	1.458615
Standard Deviation	0.4091064	Standard Deviation	0.354008	Standard Deviation	0.5642557
Variance	0.1673681	Variance	0.1253217	Variance	0.3183845
Kurtosis	1.7866632	Kurtosis	-0.612371	Kurtosis	2.2102904
Skewness	1.3190149	Skewness	-0.435574	Skewness	1.5598005
Range	1.299283	Range	1.0986123	Range	1.719786
Minimum	0.1823216	Minimum	0.4700036	Minimum	1.2809338
Maximum	1.4816045	Maximum	1.5686159	Maximum	3.0007198
Sum	5.4758946	Sum	9.672664	Sum	15.795738
Count	9	Count	9	Count	9
Confidence Level (95%)	0.2672776	Confidence Level (95%)	0.2312807	Confidence Level (95%)	0.3686398
UCLM	0.79894	UCLM	1.2395902	UCLM	2.017837
UCLM TRANS BACK	2.223183	UCLM TRANS BACK	3.4541976	UCLM TRANS BACK	7.5220374

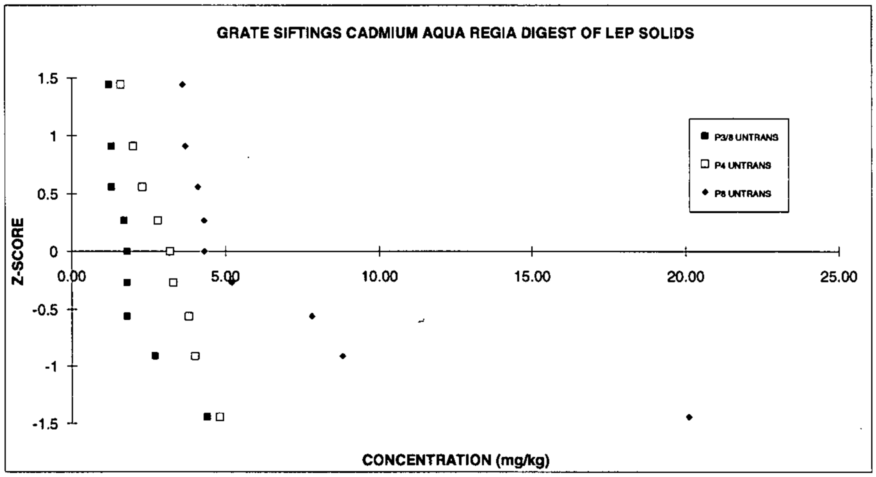

Figure E.1 GS LEP UNTRANSFORMED Z-SCORE Cd

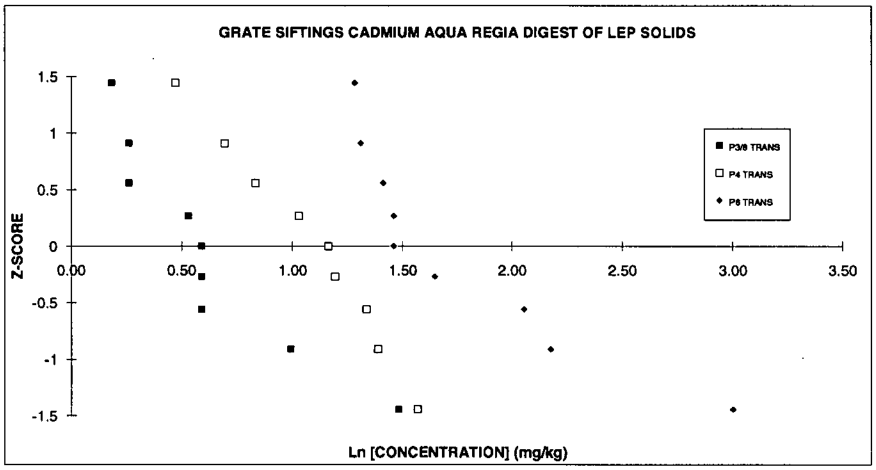

Figure E.2 GS LEP TRANSFORMED Z-SCORE Cd

Table E.3 GS ARD OF LEP SOLIDS Cr RANKED CONCENTRATIONS (mg/kg)

GS ARD OF LEP SOLIDS Cr RANKED CONCENTRATIONS (mg/kg)					
P3/8" UNTRAN	P3/8" TRANS	P4 UNTRAN	P4 TRANS	P8 UNTRAN	P8 TRANS
13.60	2.61	45.90	3.83	40.00	3.69
19.70	2.98	48.00	3.87	48.50	3.88
20.70	3.03	64.20	4.16	49.70	3.91
30.90	3.43	69.60	4.24	60.10	4.10
34.90	3.55	73.80	4.30	75.40	4.32
54.60	4.00	102.00	4.62	85.50	4.45
87.50	4.47	111.00	4.71	89.60	4.50
105.00	4.65	136.00	4.91	106.00	4.66
285.00	5.65	162.00	5.09	132.00	4.88

Table E.4 DESCRIPTIVE STATISTICS FOR GS ARD OF LEP SOLIDS Cr DATA

DESCRIPTIVE STATISTICS FOR GS ARD OF LEP SOLIDS Cr DATA					
P3/8 UNTRANS		*P4 UNTRANS*		*P8 UNTRANS*	
Mean	72.433333	Mean	90.277778	Mean	76.311111
Standard Error	28.587701	Standard Error	13.404682	Standard Error	10.074341
Median	34.9	Median	73.8	Median	75.4
Mode	#N/A	Mode	#N/A	Mode	#N/A
Standard Deviation	85.763104	Standard Deviation	40.214045	Standard Deviation	30.223023
Variance	7355.31	Variance	1617.1694	Variance	913.43111
Kurtosis	5.7009126	Kurtosis	-0.594657	Kurtosis	-0.28876
Skewness	2.2990095	Skewness	0.6944849	Skewness	0.6374865
Range	271.4	Range	116.1	Range	92
Minimum	13.6	Minimum	45.9	Minimum	40
Maximum	285	Maximum	162	Maximum	132
Sum	651.9	Sum	812.5	Sum	686.8
Count	9	Count	9	Count	9
Confidence Level (95%)	56.030782	Confidence Level (95%)	26.272655	Confidence Level (95%)	19.745316
UCLM	112.37035	UCLM	109.00412	UCLM	90.384965
P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	3.820243	Mean	4.4153941	Mean	4.265042
Standard Error	0.3233077	Standard Error	0.1481159	Standard Error	0.1326488
Median	3.5524868	Median	4.3013587	Median	4.3228073
Mode	#N/A	Mode	#N/A	Mode	#N/A
Standard Deviation	0.9699231	Standard Deviation	0.4443477	Standard Deviation	0.3979463
Variance	0.9407508	Variance	0.1974449	Variance	0.1583612
Kurtosis	-0.033296	Kurtosis	-1.219077	Kurtosis	-1.110322
Skewness	0.718104	Skewness	0.1337752	Skewness	0.0479547
Range	3.0424194	Range	1.2611312	Range	1.1939225
Minimum	2.6100698	Minimum	3.8264651	Minimum	3.6888795
Maximum	5.6524892	Maximum	5.0875963	Maximum	4.8828019
Sum	34.382187	Sum	39.738547	Sum	38.385378
Count	9	Count	9	Count	9
Confidence Level (95%)	0.6336705	Confidence Level (95%)	0.2903014	Confidence Level (95%)	0.2599864
UCLM	4.2719039	UCLM	4.622312	UCLM	4.4503523
UCLM TRANS BACK	71.657934	UCLM TRANS;BACK	101.72896	UCLM TRANS BACK	85.657116

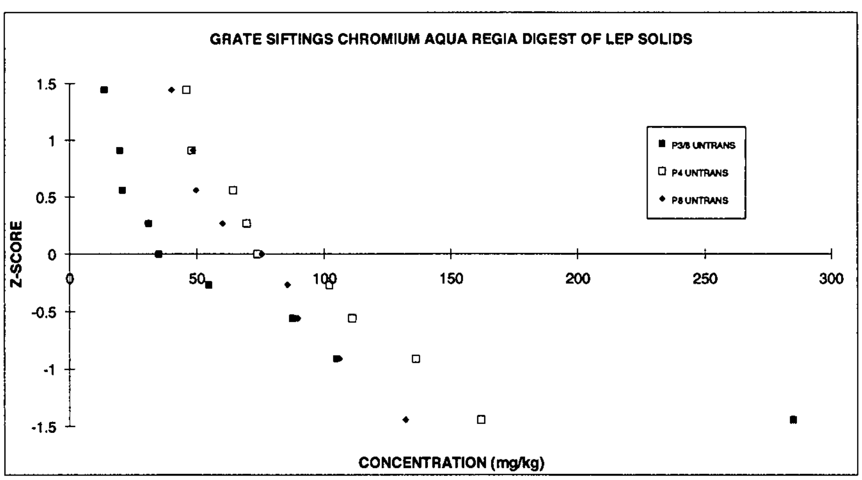

Figure E.3 GS LEP UNTRANSFORMED Z-SCORE Cr

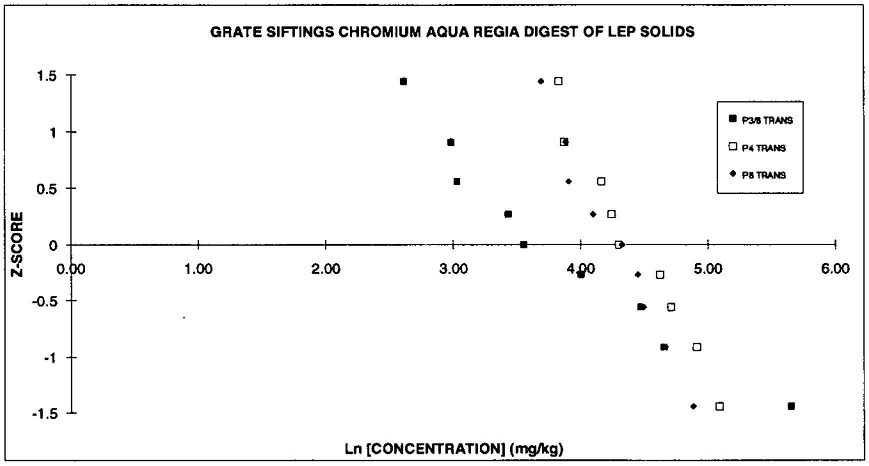

Figure E.4 GS LEP TRANSFORMED Z-SCORE Cr

Table E.5 GS ARD OF LEP SOLIDS Cu RANKED CONCENTRATIONS (mg/kg)

GS ARD OF LEP SOLIDS Cu RANKED CONCENTRATIONS (mg/kg)					
P3/8" UNTRAN	P3/8" TRANS	P4 UNTRAN	P4 TRANS	P8 UNTRAN	P8 TRANS
8150.00	9.01	8450.00	9.04	4750.00	8.47
16400.00	9.71	10400.00	9.25	4880.00	8.49
17900.00	9.79	11600.00	9.36	4920.00	8.50
18400.00	9.82	22100.00	10.00	6000.00	8.70
23800.00	10.08	23200.00	10.05	6670.00	8.81
24200.00	10.09	31000.00	10.34	7050.00	8.86
26500.00	10.18	35200.00	10.47	7080.00	8.87
28700.00	10.26	44400.00	10.70	8200.00	9.01
44900.00	10.71	63100.00	11.05	19600.00	9.88

Table E.6 DESCRIPTIVE STATISTICS FOR GS ARD OF LEP SOLIDS Cu DATA

DESCRIPTIVE STATISTICS FOR GS ARD OF LEP SOLIDS Cu DATA					
P3/8 UNTRANS		*P4 UNTRANS*		*P8 UNTRANS*	
Mean	23216.667	Mean	27716.667	Mean	7683.3333
Standard Error	3410.0749	Standard Error	5985.9326	Standard Error	1541.0972
Median	23800	Median	23200	Median	6670
Mode	#N/A	Mode	#N/A	Mode	#N/A
Standard Deviation	10230.225	Standard Deviation	17957.798	Standard Deviation	4623.2916
Variance	104657500	Variance	322482500	Variance	21374825
Kurtosis	2.2051112	Kurtosis	0.4376634	Kurtosis	7.3706243
Skewness	0.9602622	Skewness	0.9046361	Skewness	2.6309177
Range	36750	Range	54650	Range	14850
Minimum	8150	Minimum	8450	Minimum	4750
Maximum	44900	Maximum	63100	Maximum	19600
Sum	208950	Sum	249450	Sum	69150
Count	9	Count	9	Count	9
Confidence Level (95%)	6683.6142	Confidence Level (95%)	11732.195	Confidence Level (95%)	3020.4905
UCLM	27980.541	UCLM	36079.014	UCLM	9836.2461
P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	9.9618629	Mean	10.029944	Mean	8.8428601
Standard Error	0.156529	Standard Error	0.230415	Standard Error	0.1450678
Median	10.077441	Median	10.051908	Median	8.8053751
Mode	#N/A	Mode	#N/A	Mode	#N/A
Standard Deviation	0.4695871	Standard Deviation	0.6912451	Standard Deviation	0.4352034
Variance	0.2205121	Variance	0.4778198	Variance	0.189402
Kurtosis	1.8708216	Kurtosis	-1.205139	Kurtosis	4.5518861
Skewness	-0.672762	Skewness	-0.124552	Skewness	1.9336298
Range	1.7064199	Range	2.0105543	Range	1.4173849
Minimum	9.0057732	Minimum	9.0419217	Minimum	8.4658999
Maximum	10.712193	Maximum	11.052476	Maximum	9.8832848
Sum	89.656766	Sum	90.269498	Sum	79.58574
Count	9	Count	9	Count	9
Confidence Level (95%)	0.3067908	Confidence Level (95%)	0.4516045	Confidence Level (95%)	0.2843272
UCLM	10.180534	UCLM	10.351834	UCLM	9.0455197
UCLM TRANS BACK	26384.552	UCLM TRANS BACK	31314.423	UCLM TRANS BACK	8480.4581

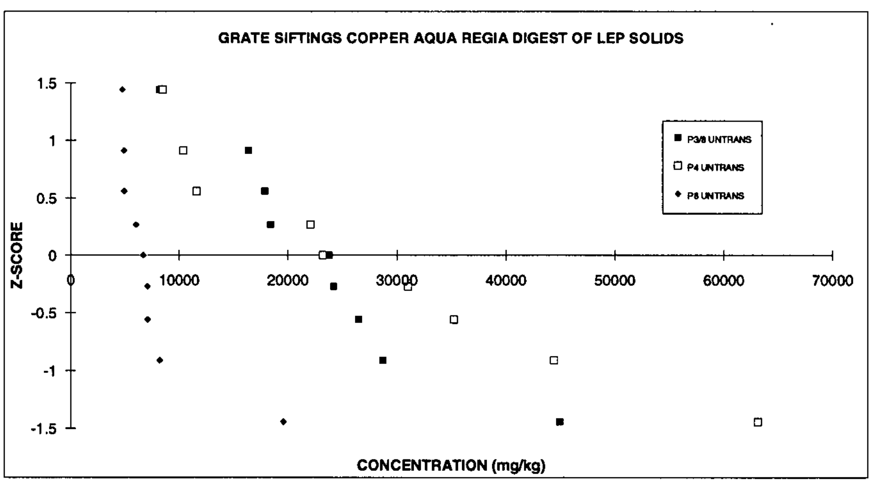

Figure E.5 GS LEP UNTRANSFORMED Z-SCORE Cu

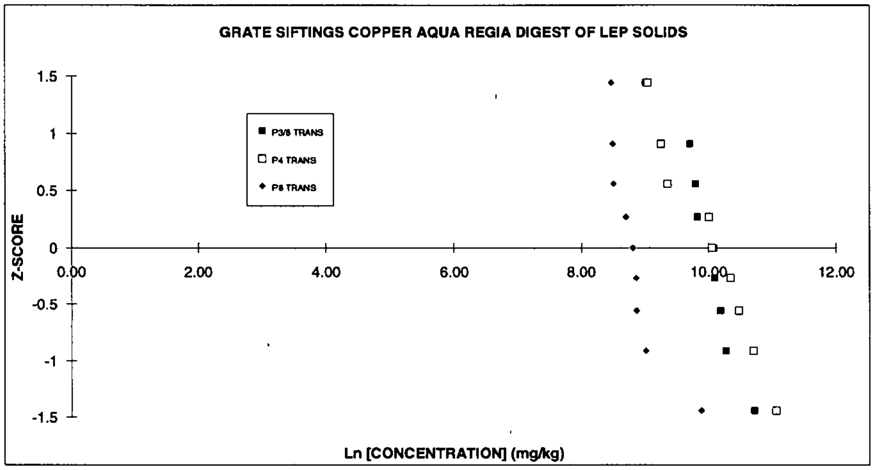

Figure E.6 GS LEP TRANSFORMED Z-SCORE Cu

Table E.7 GS ARD OF LEP SOLIDS Fe RANKED CONCENTRATIONS (mg/kg)

GS LEP Fe RANKED CONCENTRATIONS (mg/kg)					
P3/8" UNTRAN	P3/8" TRANS	P4 UNTRAN	P4 TRANS	P8 UNTRAN	P8 TRANS
15000.00	9.62	5810.00	8.67	2000.00	7.60
17000.00	9.74	6430.00	8.77	12900.00	9.46
29000.00	10.28	8400.00	9.04	19500.00	9.88
33000.00	10.40	32000.00	10.37	22900.00	10.04
50100.00	10.82	42400.00	10.65	24300.00	10.10
69000.00	11.14	43200.00	10.67	27000.00	10.20
72600.00	11.19	46600.00	10.75	29600.00	10.30
73400.00	11.20	52900.00	10.88	29600.00	10.30
109000.00	11.60	64000.00	11.07	31000.00	10.34

Table E.8 DESCRIPTIVE STATISTICS FOR GS ARD OF LEP SOLIDS Fe DATA

DESCRIPTIVE STATISTICS FOR GS ARD OF LEP SOLIDS Fe DATA					
P3/8 UNTRANS		*P4 UNTRANS*		*P8 UNTRANS*	
Mean	52011.111	Mean	33526.667	Mean	22088.889
Standard Error	10480.093	Standard Error	7248.8453	Standard Error	3154.8219
Median	50100	Median	42400	Median	24300
Mode	#N/A	Mode	#N/A	Mode	29600
Standard Deviation	31440.278	Standard Deviation	21746.536	Standard Deviation	9464.4657
Variance	988491111	Variance	472911825	Variance	89576111
Kurtosis	-0.511545	Kurtosis	-1.487111	Kurtosis	1.5480891
Skewness	0.4955281	Skewness	-0.275774	Skewness	-1.367822
Range	94000	Range	58190	Range	29000
Minimum	15000	Minimum	5810	Minimum	2000
Maximum	109000	Maximum	64000	Maximum	31000
Sum	468100	Sum	301740	Sum	198800
Count	9	Count	9	Count	9
Confidence Level (95%)	20540.574	Confidence Level (95%)	14207.455	Confidence Level (95%)	6183.3281
UCLM	66651.801	UCLM	43653.304	UCLM	26496.175
P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	10.666137	Mean	10.096244	Mean	9.8019525
Standard Error	0.2317765	Standard Error	0.3254699	Standard Error	0.2898233
Median	10.821776	Median	10.654904	Median	10.098232
Mode	#N/A	Mode	#N/A	Mode	10.29553
Standard Deviation	0.6953294	Standard Deviation	0.9764096	Standard Deviation	0.86947
Variance	0.483483	Variance	0.9533758	Variance	0.7559782
Kurtosis	-1.193828	Kurtosis	-1.568076	Kurtosis	6.5476365
Skewness	-0.384134	Skewness	-0.758605	Skewness	-2.493773
Range	1.9832977	Range	2.3993025	Range	2.74084
Minimum	9.6158055	Minimum	8.6673358	Minimum	7.6009025
Maximum	11.599103	Maximum	11.066638	Maximum	10.341742
Sum	95.995229	Sum	90.866196	Sum	88.217573
Count	9	Count	9	Count	9
Confidence Level (95%)	0.4542729	Confidence Level (95%)	0.6379083	Confidence Level (95%)	0.5680425
UCLM	10.989928	UCLM	10.550925	UCLM	10.206836
UCLM TRANS BACK	59274.131	UCLM TRANS BACK	38212.785	UCLM TRANS BACK	27087.719

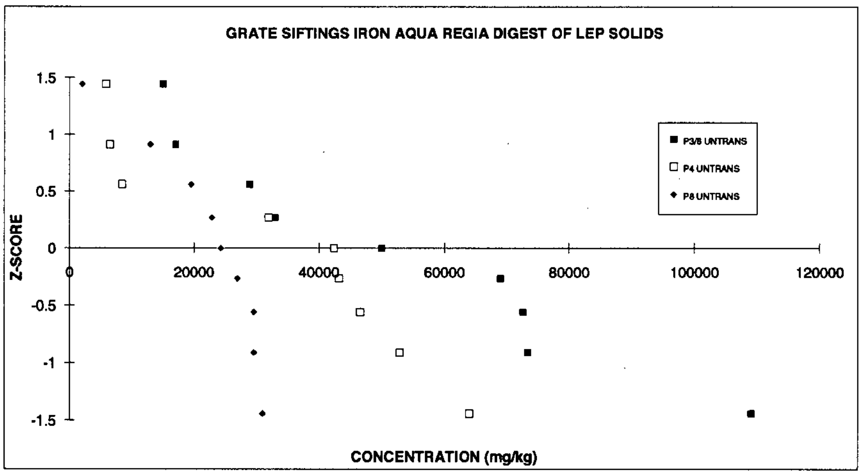

Figure E.7 GS LEP UNTRANSFORMED Z-SCORE Fe

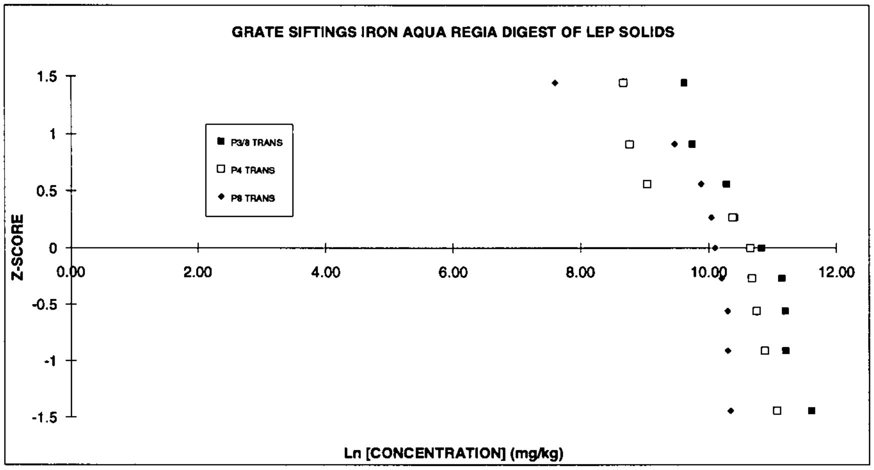

Figure E.8 GS LEP TRANSFORMED Z-SCORE Fe

Table E.9 GS ARD OF LEP SOLIDS Mn RANKED CONCENTRATIONS (mg/kg)

GS ARD OF LEP SOLIDS Mn RANKED CONCENTRATIONS (mg/kg)					
P3/8" UNTRAN	P3/8" TRANS	P4 UNTRAN	P4 TRANS	P8 UNTRAN	P8 TRANS
242.00	5.49	554.00	6.32	592.00	6.38
321.00	5.77	616.00	6.42	602.00	6.40
428.00	6.06	707.00	6.56	635.00	6.45
463.00	6.14	765.00	6.64	669.00	6.51
503.00	6.22	775.00	6.65	670.00	6.51
531.00	6.27	794.00	6.68	703.00	6.56
562.00	6.33	805.00	6.69	720.00	6.58
713.00	6.57	894.00	6.80	761.00	6.63
1220.00	7.11	900.00	6.80	794.00	6.68

Table E.10 DESCRIPTIVE STATISTICS FOR GS ARD OF LEP SOLIDS Mn DATA

DESCRIPTIVE STATISTICS FOR GS ARD OF LEP SOLIDS Mn DATA					
P3/8 UNTRANS		*P4 UNTRANS*		*P8 UNTRANS*	
Mean	553.66667	Mean	756.66667	Mean	682.88889
Standard Error	94.855153	Standard Error	38.526326	Standard Error	22.877964
Median	503	Median	775	Median	670
Mode	#N/A	Mode	#N/A	Mode	#N/A
Standard Deviation	284.56546	Standard Deviation	115.57898	Standard Deviation	68.633892
Variance	80977.5	Variance	13358.5	Variance	4710.6111
Kurtosis	4.0259364	Kurtosis	-0.26352	Kurtosis	-0.852566
Skewness	1.7725961	Skewness	-0.574967	Skewness	0.254936
Range	978	Range	346	Range	202
Minimum	242	Minimum	554	Minimum	592
Maximum	1220	Maximum	900	Maximum	794
Sum	4983	Sum	6810	Sum	6146
Count	9	Count	9	Count	9
Confidence Level (95%)	185.91241	Confidence Level (95%)	75.510099	Confidence Level (95%)	44.839919
UCLM	686.17932	UCLM	810.48794	UCLM	714.8494
P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	6.2177967	Mean	6.6178008	Mean	6.521864
Standard Error	0.1532927	Standard Error	0.0537157	Standard Error	0.0333924
Median	6.2205902	Median	6.652863	Median	6.5072777
Mode	#N/A	Mode	#N/A	Mode	#N/A
Standard Deviation	0.4598781	Standard Deviation	0.1611472	Standard Deviation	0.1001773
Variance	0.2114879	Variance	0.0259684	Variance	0.0100355
Kurtosis	1.190455	Kurtosis	0.1224809	Kurtosis	-0.951012
Skewness	0.4406445	Skewness	-0.850535	Skewness	0.1004683
Range	1.6176684	Range	0.4852301	Range	0.2935768
Minimum	5.4889377	Minimum	6.3171647	Minimum	6.3835066
Maximum	7.1066061	Maximum	6.8023948	Maximum	6.6770835
Sum	55.960171	Sum	59.560207	Sum	58.696776
Count	9	Count	9	Count	9
Confidence Level (95%)	0.3004478	Confidence Level (95%)	0.1052808	Confidence Level (95%)	0.0654478
UCLM	6.4319467	UCLM	6.6928417	UCLM	6.5685132
UCLM TRANS BACK	621.38239	UCLM TRANS BACK	806.61116	UCLM TRANS BACK	712.30998

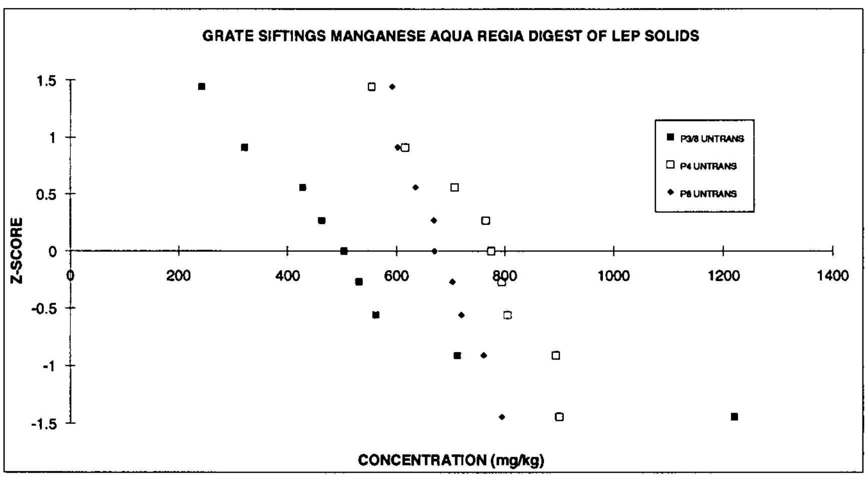

Figure E.9 GS LEP UNTRANSFORMED Z-SCORE Mn

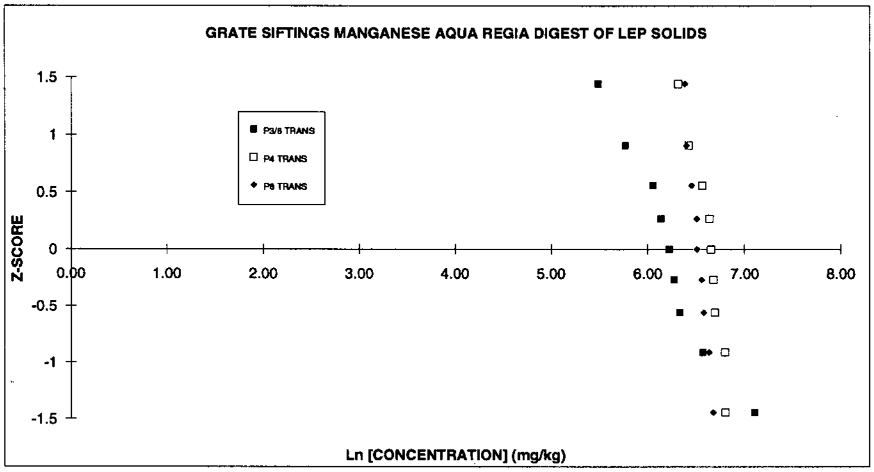

Figure E.10 GS LEP TRANSFORMED Z-SCORE Mn

Table E.11 GS ARD OF LEP SOLIDS Ni RANKED CONCENTRATIONS (mg/kg)

GS ARD OF LEP SOLIDS Ni RANKED CONCENTRATIONS (mg/kg)					
P3/8" UNTRAN	P3/8" TRANS	P4 UNTRAN	P4 TRANS	P8 UNTRAN	P8 TRANS
70.30	4.25	156.00	5.05	131.00	4.88
71.30	4.27	181.00	5.20	152.00	5.02
125.00	4.83	254.00	5.54	159.00	5.07
221.00	5.40	392.00	5.97	163.00	5.09
227.00	5.42	453.00	6.12	171.00	5.14
264.00	5.58	502.00	6.22	182.00	5.20
321.00	5.77	891.00	6.79	299.00	5.70
496.00	6.21	919.00	6.82	322.00	5.77
506.00	6.23	1090.00	6.99	483.00	6.18

Table E.12 DESCRIPTIVE STATISTICS FOR GS ARD OF LEP SOLIDS Ni DATA

DESCRIPTIVE STATISTICS FOR GS ARD OF LEP SOLIDS Ni DATA					
P3/8 UNTRANS		*P4 UNTRANS*		*P8 UNTRANS*	
Mean	255.73333	Mean	537.55556	Mean	229.11111
Standard Error	54.290108	Standard Error	115.37007	Standard Error	38.806301
Median	227	Median	453	Median	171
Mode	#N/A	Mode	#N/A	Mode	#N/A
Standard Deviation	162.87032	Standard Deviation	346.11021	Standard Deviation	116.4189
Variance	26526.743	Variance	119792.28	Variance	13553.361
Kurtosis	-0.800132	Kurtosis	-1.31904	Kurtosis	1.9042464
Skewness	0.5532912	Skewness	0.5459545	Skewness	1.5452604
Range	435.7	Range	934	Range	352
Minimum	70.3	Minimum	156	Minimum	131
Maximum	506	Maximum	1090	Maximum	483
Sum	2301.6	Sum	4838	Sum	2062
Count	9	Count	9	Count	9
Confidence Level (95%)	106.4065	Confidence Level (95%)	226.12085	Confidence Level (95%)	76.05884
UCLM	331.57661	UCLM	698.72754	UCLM	283.32351
P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	5.3279553	Mean	6.0778894	Mean	5.3402683
Standard Error	0.2467412	Standard Error	0.2374691	Standard Error	0.1458842
Median	5.42495	Median	6.1158921	Median	5.1416636
Mode	#N/A	Mode	#N/A	Mode	#N/A
Standard Deviation	0.7402236	Standard Deviation	0.7124074	Standard Deviation	0.4376526
Variance	0.547931	Variance	0.5075243	Variance	0.1915398
Kurtosis	-1.041324	Kurtosis	-1.374484	Kurtosis	-0.063082
Skewness	-0.417917	Skewness	-0.166834	Skewness	1.041445
Range	1.9737649	Range	1.944077	Range	1.3048193
Minimum	4.2527718	Minimum	5.049856	Minimum	4.8751973
Maximum	6.2265367	Maximum	6.993933	Maximum	6.1800167
Sum	47.951597	Sum	54.701005	Sum	48.062414
Count	9	Count	9	Count	9
Confidence Level (95%)	0.4836031	Confidence Level (95%)	0.4654303	Confidence Level (95%)	0.2859274
UCLM	5.6726527	UCLM	6.4096338	UCLM	5.5440685
UCLM TRANS BACK	290.80494	UCLM TRANS BACK	607.67113	UCLM TRANS BACK	255.71626

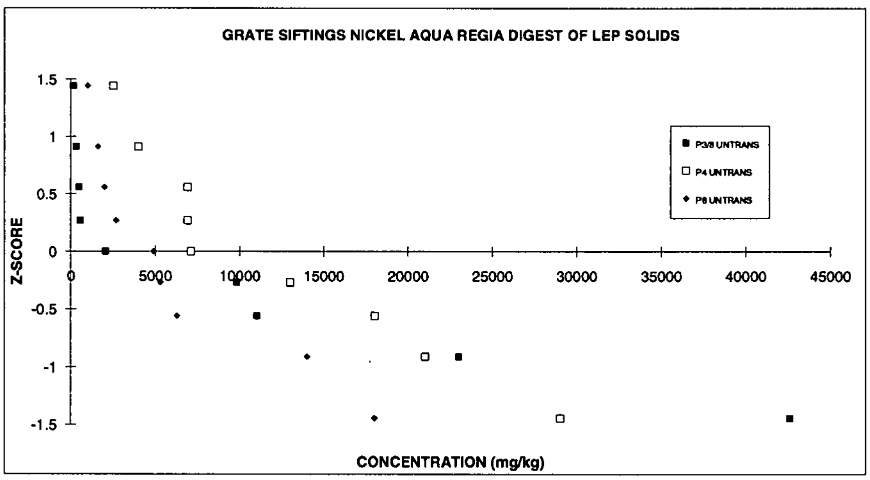

Figure E.11 GS LEP UNTRANSFORMED Z-SCORE Ni

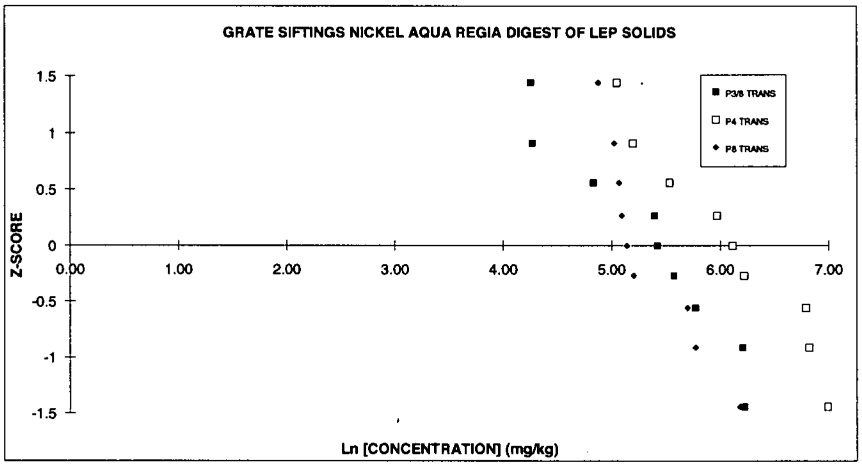

Figure E.12 GS LEP TRANSFORMED Z-SCORE Ni

Table E.13 GS ARD OF LEP SOLIDS Pb RANKED CONCENTRATIONS (mg/kg)

GS ARD OF LEP SOLIDS Pb RANKED CONCENTRATIONS (mg/kg)					
P3/8" UNTRAN	P3/8" TRANS	P4 UNTRAN	P4 TRANS	P8 UNTRAN	P8 TRANS
146.00	4.98	2500.00	7.82	1000.00	6.91
300.00	5.70	4000.00	8.29	1600.00	7.38
480.00	6.17	6900.00	8.84	1990.00	7.60
540.00	6.29	6900.00	8.84	2670.00	7.89
2040.00	7.62	7100.00	8.87	4900.00	8.50
9800.00	9.19	13000.00	9.47	5290.00	8.57
11000.00	9.31	18000.00	9.80	6260.00	8.74
23000.00	10.04	21000.00	9.95	14000.00	9.55
42600.00	10.66	29000.00	10.28	18000.00	9.80

Table E.14 DESCRIPTIVE STATISTICS FOR GS ARD OF LEP SOLIDS Pb DATA

DESCRIPTIVE STATISTICS FOR GS ARD OF LEP SOLIDS Pb DATA					
P3/8 UNTRANS		*P4 UNTRANS*		*P8 UNTRANS*	
Mean	9989.5556	Mean	12044.444	Mean	6190
Standard Error	4812.4173	Standard Error	2975.0402	Standard Error	1975.495
Median	2040	Median	7100	Median	4900
Mode	#N/A	Mode	6900	Mode	#N/A
Standard Deviation	14437.252	Standard Deviation	8925.1206	Standard Deviation	5926.485
Variance	208434242	Variance	79657778	Variance	35123225
Kurtosis	2.8142279	Kurtosis	-0.146357	Kurtosis	0.8158566
Skewness	1.7524524	Skewness	0.9091225	Skewness	1.3638919
Range	42454	Range	26500	Range	17000
Minimum	146	Minimum	2500	Minimum	1000
Maximum	42600	Maximum	29000	Maximum	18000
Sum	89906	Sum	108400	Sum	55710
Count	9	Count	9	Count	9
Confidence Level (95%)	9432.1506	Confidence Level (95%)	5830.963	Confidence Level (95%)	3871.8933
UCLM	16712.503	UCLM	16200.576	UCLM	8949.7665
P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	7.7746774	Mean	9.1291844	Mean	8.3254086
Standard Error	0.6940372	Standard Error	0.2685664	Standard Error	0.3239288
Median	7.6207051	Median	8.8678501	Median	8.4969905
Mode	#N/A	Mode	8.8392767	Mode	#N/A
Standard Deviation	2.0821117	Standard Deviation	0.8056991	Standard Deviation	0.9717865
Variance	4.335189	Variance	0.6491511	Variance	0.944369
Kurtosis	-1.781561	Kurtosis	-0.882233	Kurtosis	-0.928489
Skewness	0.0733121	Skewness	-0.144469	Skewness	0.1642427
Range	5.6760029	Range	2.4510051	Range	2.8903718
Minimum	4.9836066	Minimum	7.824046	Minimum	6.9077553
Maximum	10.65961	Maximum	10.275051	Maximum	9.798127
Sum	69.972097	Sum	82.16266	Sum	74.928677
Count	9	Count	9	Count	9
Confidence Level (95%)	1.3602859	Confidence Level (95%)	0.5263796	Confidence Level (95%)	0.6348879
UCLM	8.7442474	UCLM	9.5043716	UCLM	8.7779371
UCLM TRANS BACK	6274.4895	UCLM TRANS BACK	13418.258	UCLM TRANS BACK	6489.4764

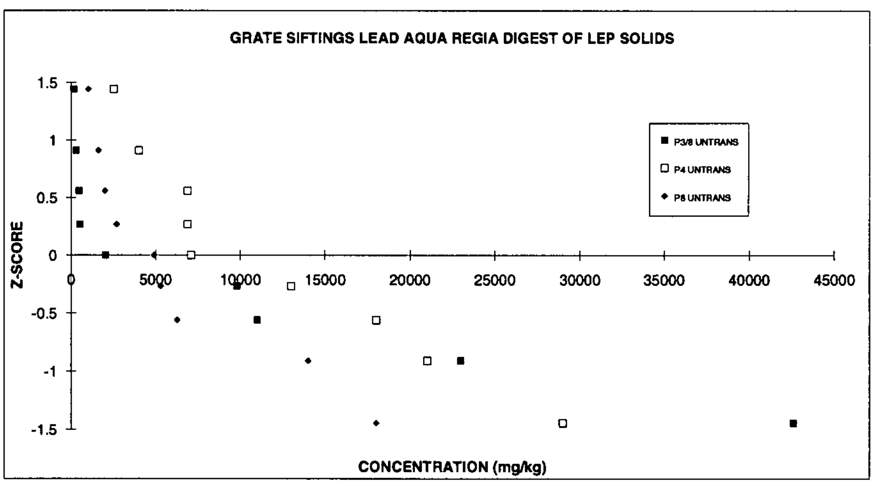

Figure E.13 GS LEP UNTRANSFORMED Z-SCORE Pb

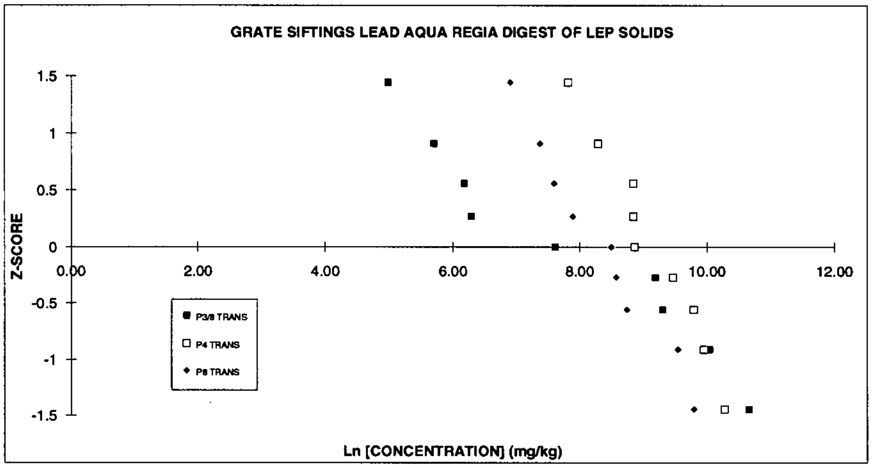

Figure E.14 GS LEP TRANSFORMED Z-SCORE Pb

Table E.15 GS ARD OF LEP SOLIDS Zn RANKED CONCENTRATIONS (mg/kg)

GS ARD OF LEP SOLIDS Zn RANKED CONCENTRATIONS (mg/kg)					
P3/8" UNTRAN	P3/8" TRANS	P4 UNTRAN	P4 TRANS	P8 UNTRAN	P8 TRANS
2710.00	7.90	4140.0	8.33	2060.00	7.63
3000.00	8.01	5430.0	8.60	2970.00	8.00
23700.00	10.07	8420.0	9.04	3910.00	8.27
24900.00	10.12	14000.0	9.55	4040.00	8.30
33900.00	10.43	14900.0	9.61	4040.00	8.30
35800.00	10.49	20400.0	9.92	4570.00	8.43
46000.00	10.74	21000.0	9.95	4950.00	8.51
70400.00	11.16	36700.0	10.51	5320.00	8.58
97100.00	11.48	117000.0	11.67	6520.00	8.78

Table E.16 DESCRIPTIVE STATISTICS FOR GS ARD OF LEP SOLIDS Zn DATA

DESCRIPTIVE STATISTICS FOR GS ARD OF LEP SOLIDS Zn DATA					
P3/8 UNTRANS		*P4 UNTRANS*		*P8 UNTRANS*	
Mean	37501.111	Mean	26887.778	Mean	4264.4444
Standard Error	10187.454	Standard Error	11739.066	Standard Error	433.43945
Median	33900	Median	14900	Median	4040
Mode	#N/A	Mode	#N/A	Mode	4040
Standard Deviation	30562.363	Standard Deviation	35217.197	Standard Deviation	1300.3183
Variance	934058011	Variance	1.24E+09	Variance	1690827.8
Kurtosis	0.5671062	Kurtosis	7.0249388	Kurtosis	0.4690301
Skewness	0.9010945	Skewness	2.5770744	Skewness	0.0038944
Range	94390	Range	112860	Range	4460
Minimum	2710	Minimum	4140	Minimum	2060
Maximum	97100	Maximum	117000	Maximum	6520
Sum	337510	Sum	241990	Sum	38380
Count	9	Count	9	Count	9
Confidence Level (95%)	19967.014	Confidence Level (95%)	23008.112	Confidence Level (95%)	849.52445
UCLM	51732.985	UCLM	43287.252	UCLM	4869.9594
P3/8 TRANS		*P4 TRANS*		*P8 TRANS*	
Mean	10.045071	Mean	9.6864965	Mean	8.3113712
Standard Error	0.4229843	Standard Error	0.3376954	Standard Error	0.1124354
Median	10.43117	Median	9.6091165	Median	8.304
Mode	#N/A	Mode	#N/A	Mode	8.304
Standard Deviation	1.268953	Standard Deviation	1.0130863	Standard Deviation	0.3373061
Variance	1.6102418	Variance	1.0263438	Variance	0.1137754
Kurtosis	0.0140217	Kurtosis	0.7479152	Kurtosis	1.2417132
Skewness	-1.056746	Skewness	0.6693796	Skewness	-0.896582
Range	3.5787927	Range	3.3414781	Range	1.1521684
Minimum	7.9047039	Minimum	8.3284511	Minimum	7.6304613
Maximum	11.483497	Maximum	11.669929	Maximum	8.7826297
Sum	90.40564	Sum	87.178469	Sum	74.802341
Count	9	Count	9	Count	9
Confidence Level (95%)	0.8290329	Confidence Level (95%)	0.6618699	Confidence Level (95%)	0.2203689
UCLM	10.63598	UCLM	10.158257	UCLM	8.4684434
UCLM TRANS BACK	41605.193	UCLM TRANS BACK	25803.284	UCLM TRANS BACK	4762.0969

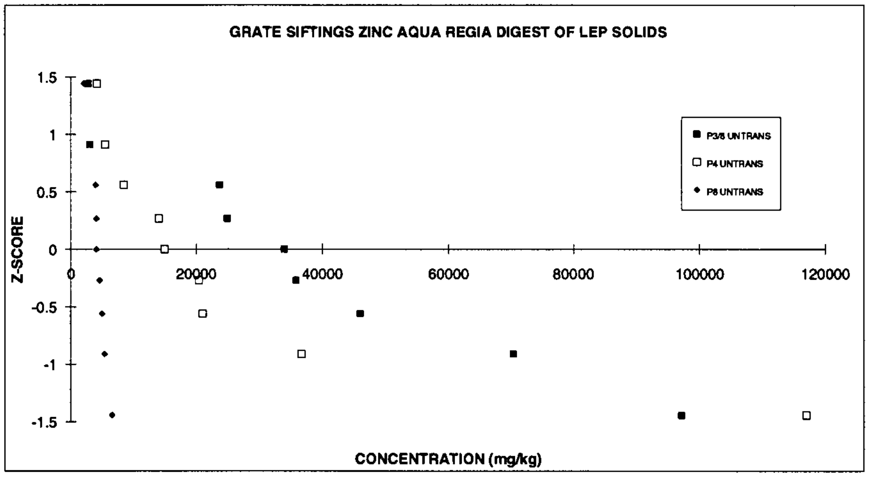

Figure E.15 GS LEP UNTRANSFORMED Z-SCORE Zn

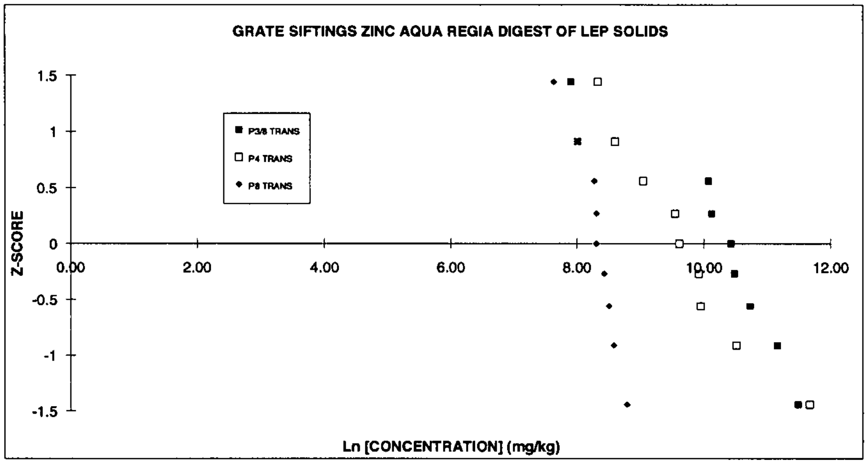

Figure E.16 GS LEP TRANSFORMED Z-SCORE Zn

Appendix F

GRAPHICAL COMPARISON OF LEP AND ARD OF LEP SOLIDS CONCENTRATIONS

Figures F1 through to F.13 are plots which compare the relative magnitude of the LEP concentrations and the ARD of the LEP solids concentrations for DBA. Some plots do not contain legends because there was insufficient space to do so but the legend used is the same for each of the plots.

The cadmium results in Figure F.6 shows that there is not a discernible difference between the ARD and LEP concentrations. Cadmium is LEP soluble.

Figure F.7 shows the chromium results for which there appears to beat least two orders of magnitude difference between the ARD and the LEP concentrations, meaning it is relatively insoluble, in terms of the LEP.

Excellent spatial agreement in the P8 fraction for copper for both the LEP and ARD concentrations is obvious in Figure F.8. Again, approximately two orders of magnitude separate the ARD and LEP concentrations, meaning copper is relatively LEP insoluble.

Good agreement between grabs is shown for all three iron fractions in Figure F.9. Iron is the least LEP soluble metal because upwards of three orders of magnitude separates the ARD and LEP concentrations.

The manganese P3/8" ARD and LEP, P4 ARD and P8 ARD concentrations show good spatial agreement in Figure F.10. The P3/8" fraction ARD and LEP are separated by approximately two orders of magnitude while the P4 and P8 fractions are separated by a maximum of one order of magnitude.

All three ARD and LEP nickel fractions plotted in Figure F.11 seem to be spatially well distributed and their concentrations are separated by about one order of magnitude.

The P3/8" and P4 ARD and LEP concentrations for lead are variable (Figure F.12). Excellent agreement between grabs is, however, observed between the three grabs in the P8 fraction. About one to one and a half orders of magnitude separates the ARD and LEP concentrations for lead.

Zinc is highly LEP and ARD soluble. Only fraction P8 shows good spatial agreement for zinc (Figure F.13).

Iron is present at the highest concentration. The total concentrations determined are P3/8" - 64,967, P4 - 69,194, and 64, 714 mg/kg. Copper, then zinc, then lead seem to be the metals next in concentration significance. Manganese and nickel are present at appreciable "total" levels. Cadmium and chromium are present at very low levels.

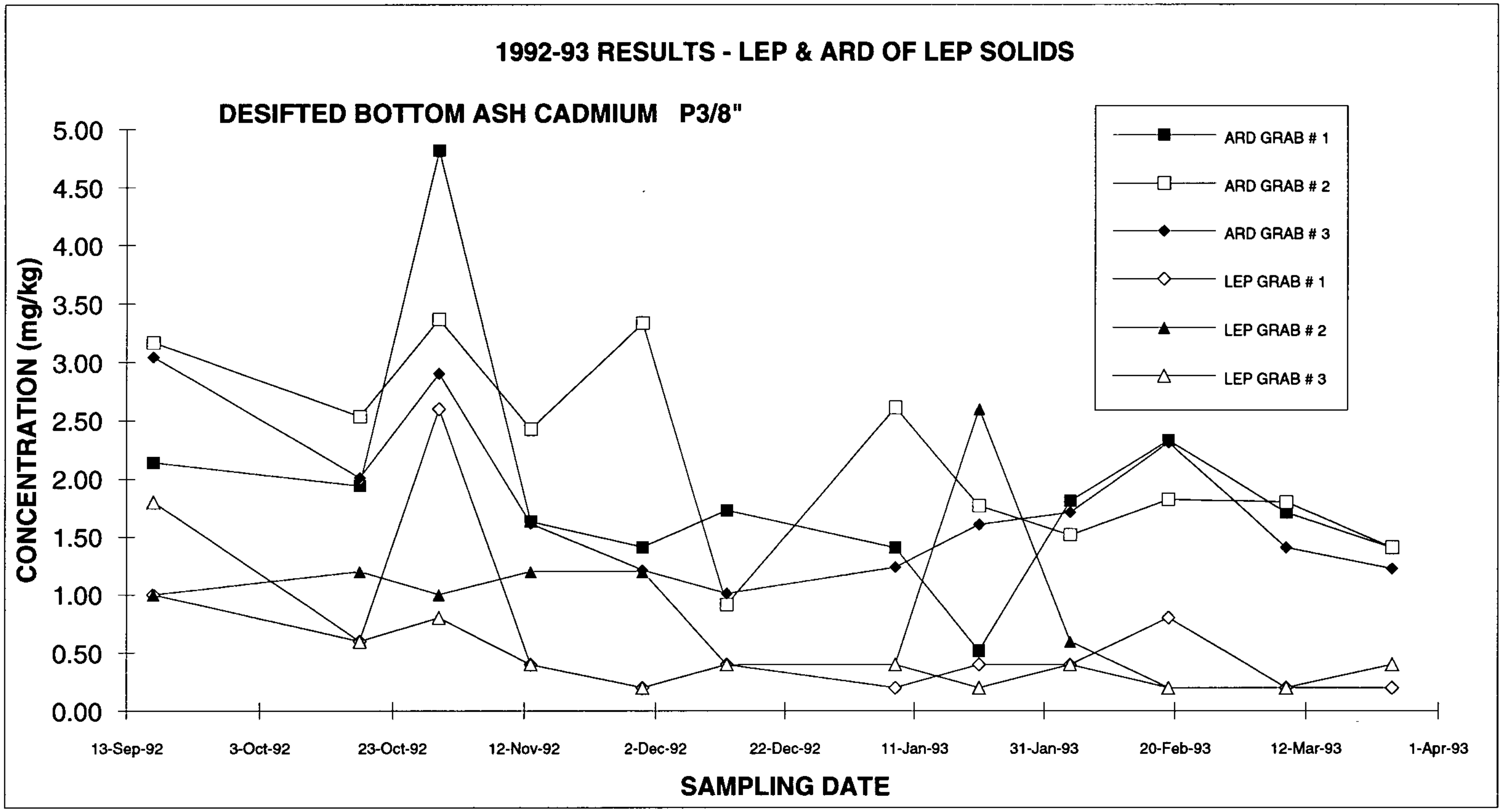

Figure F.1 DBA LEP AND ARD OF LEP SOLIDS - Cd P3/8"

334

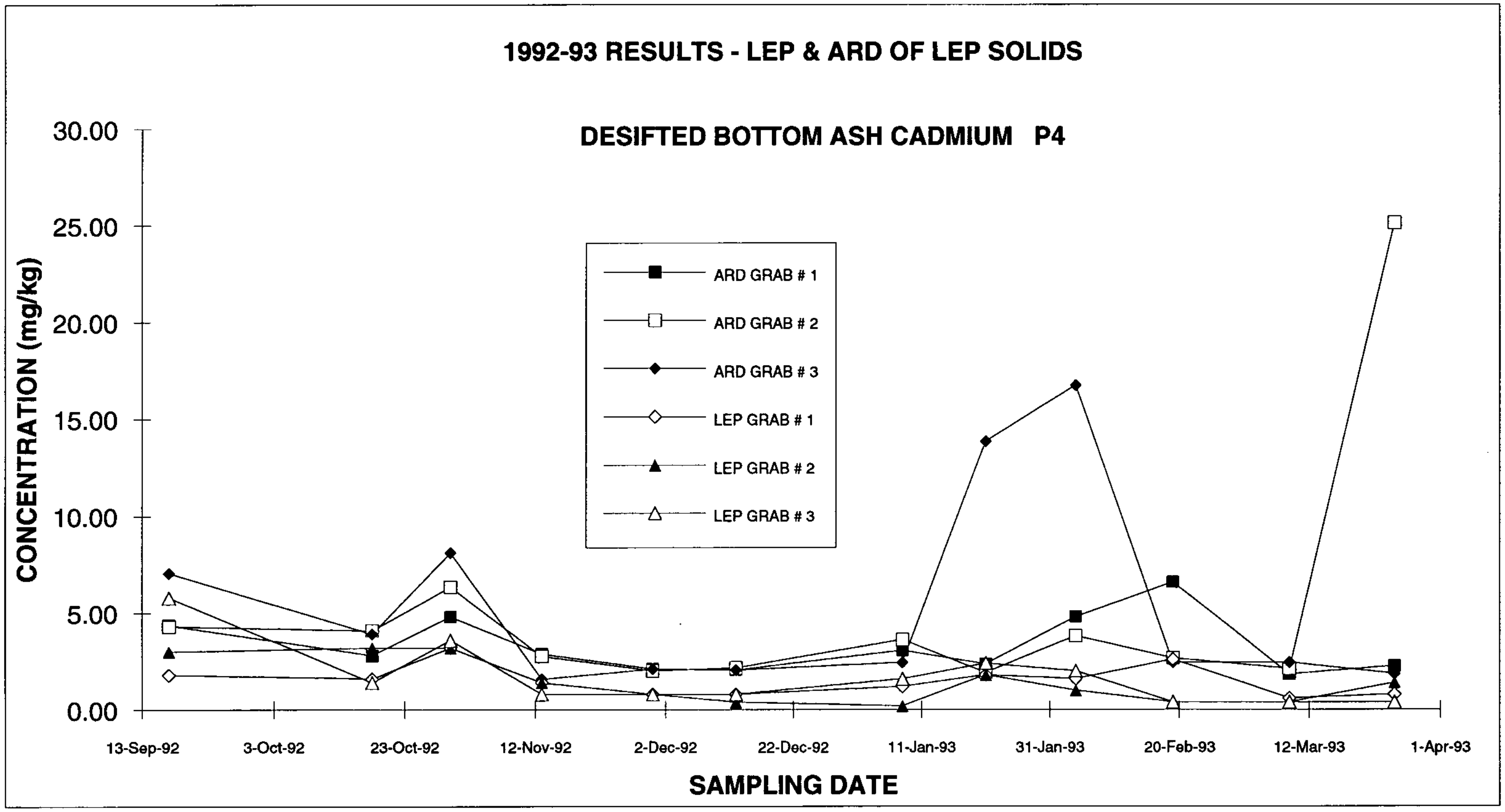

Figure F.2 DBA LEP AND ARD OF LEP SOLIDS - Cd P4

335

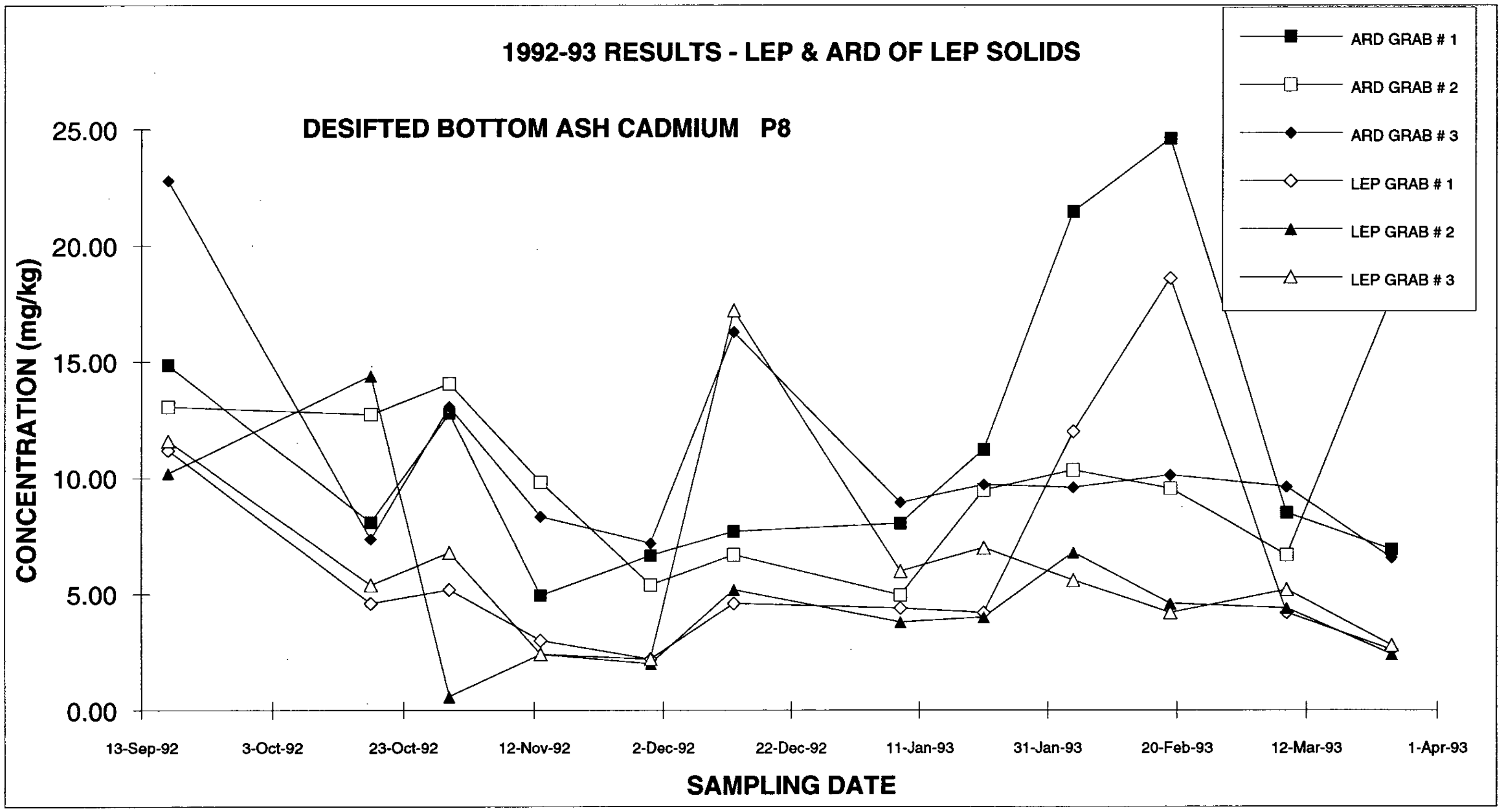

Figure F.3 DBA LEP AND ARD OF LEP SOLIDS - Cd P8

336

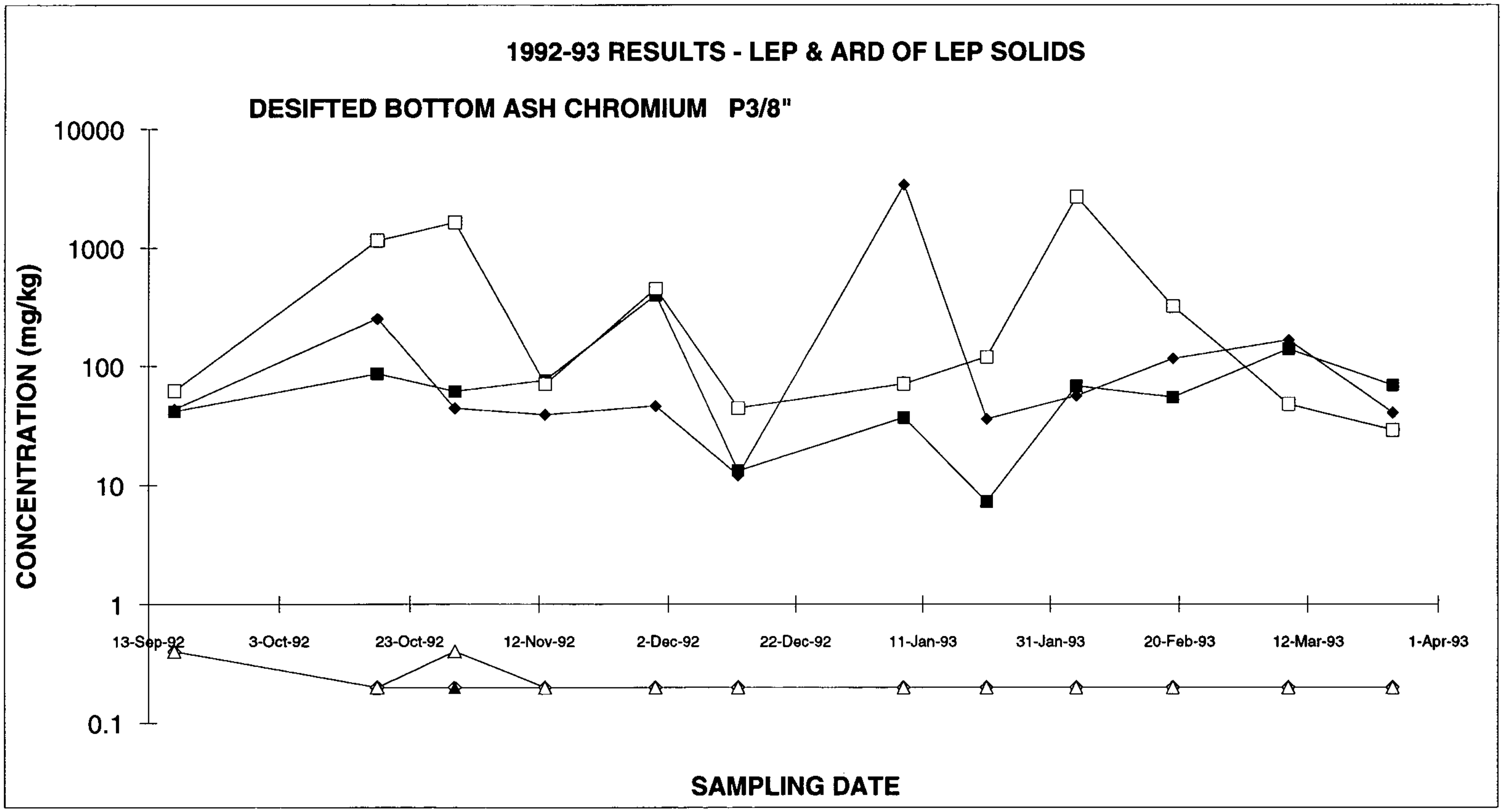

Figure F.4 DBA LEP AND ARD OF LEP SOLIDS - Cr P3/8"

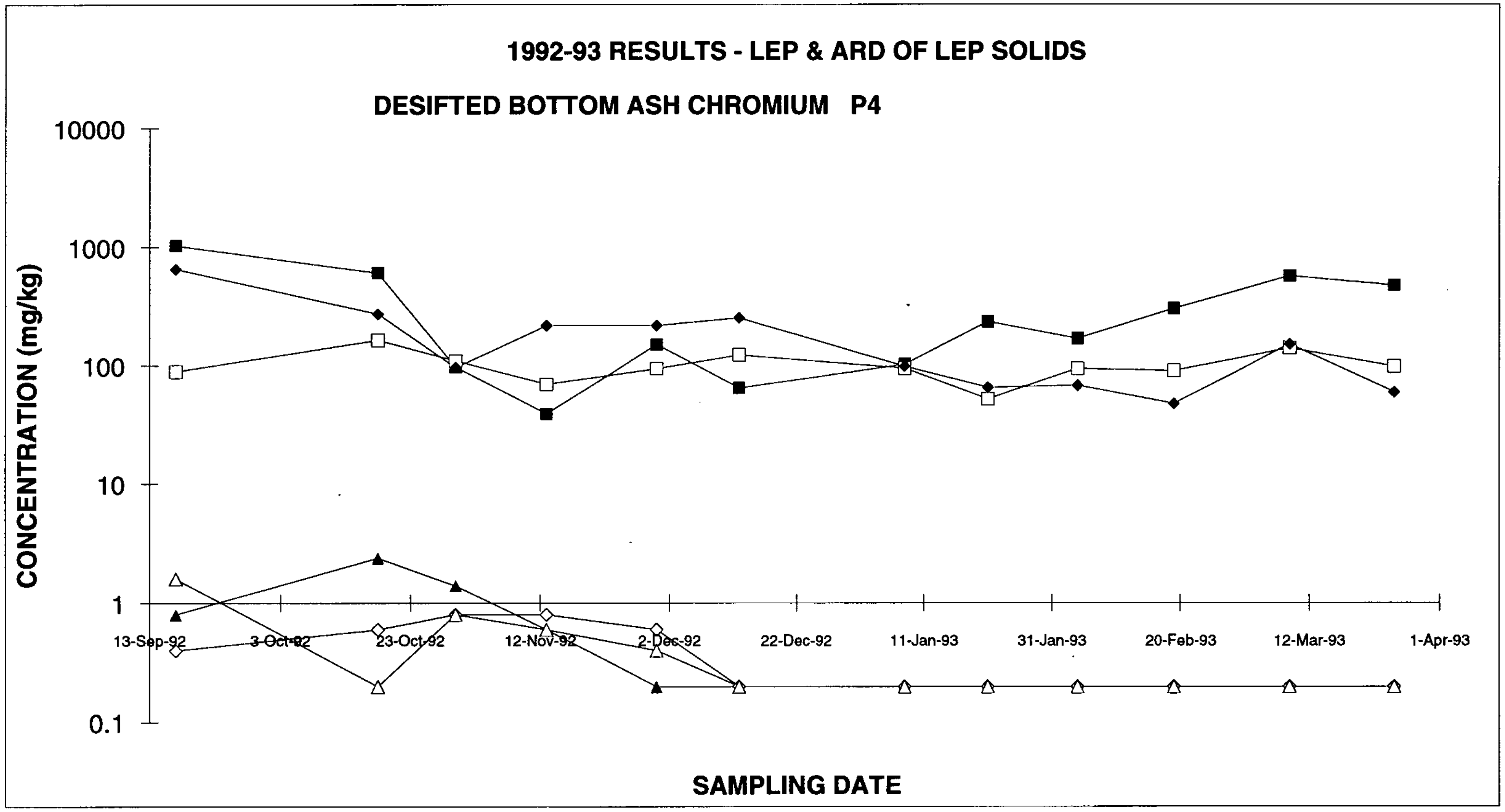

Figure F.5 DBA LEP AND ARD OF LEP SOLIDS - Cr P4

338

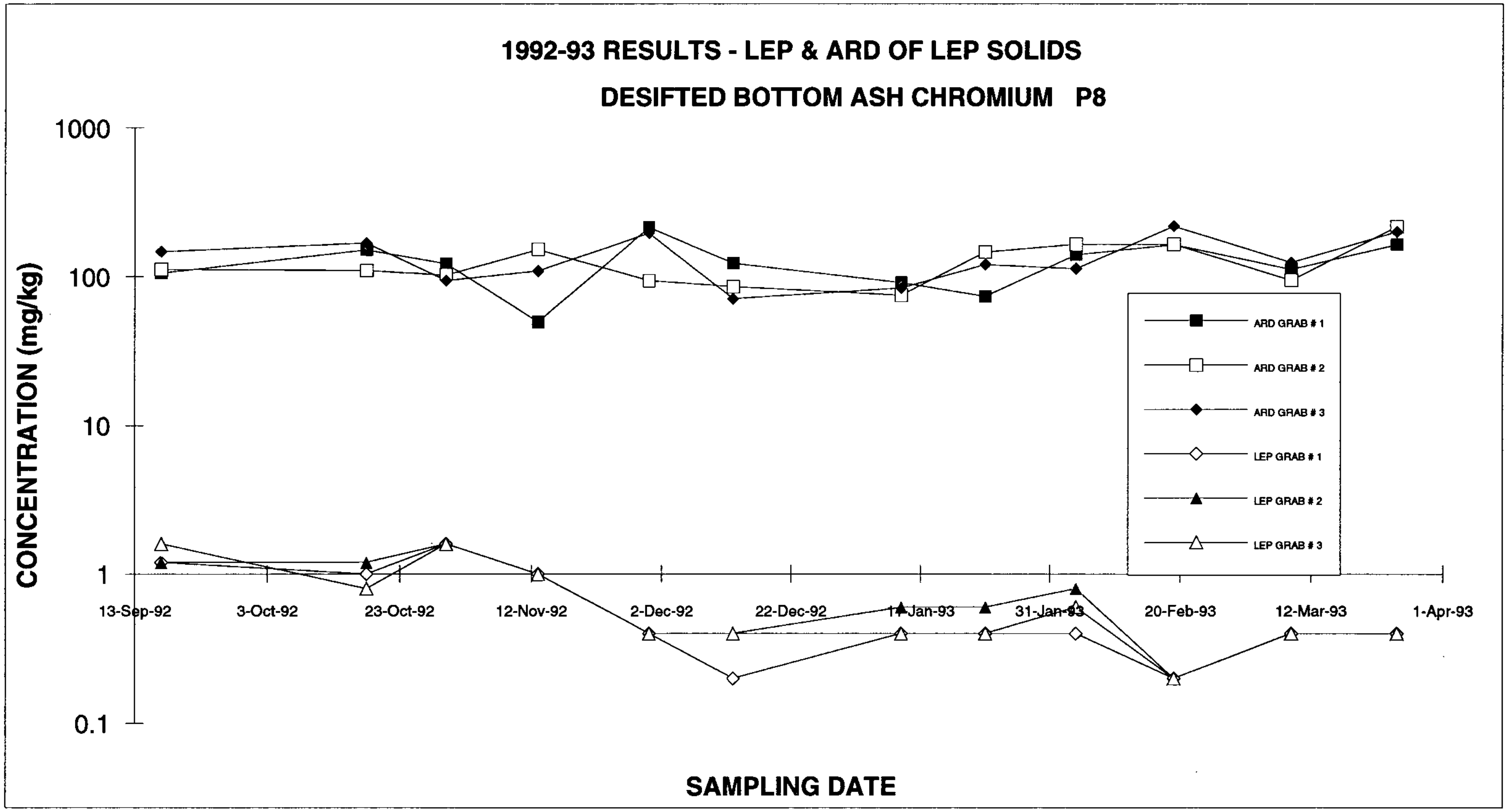

Figure F.6 DBA LEP AND ARD OF LEP SOLIDS - Cr P8

339

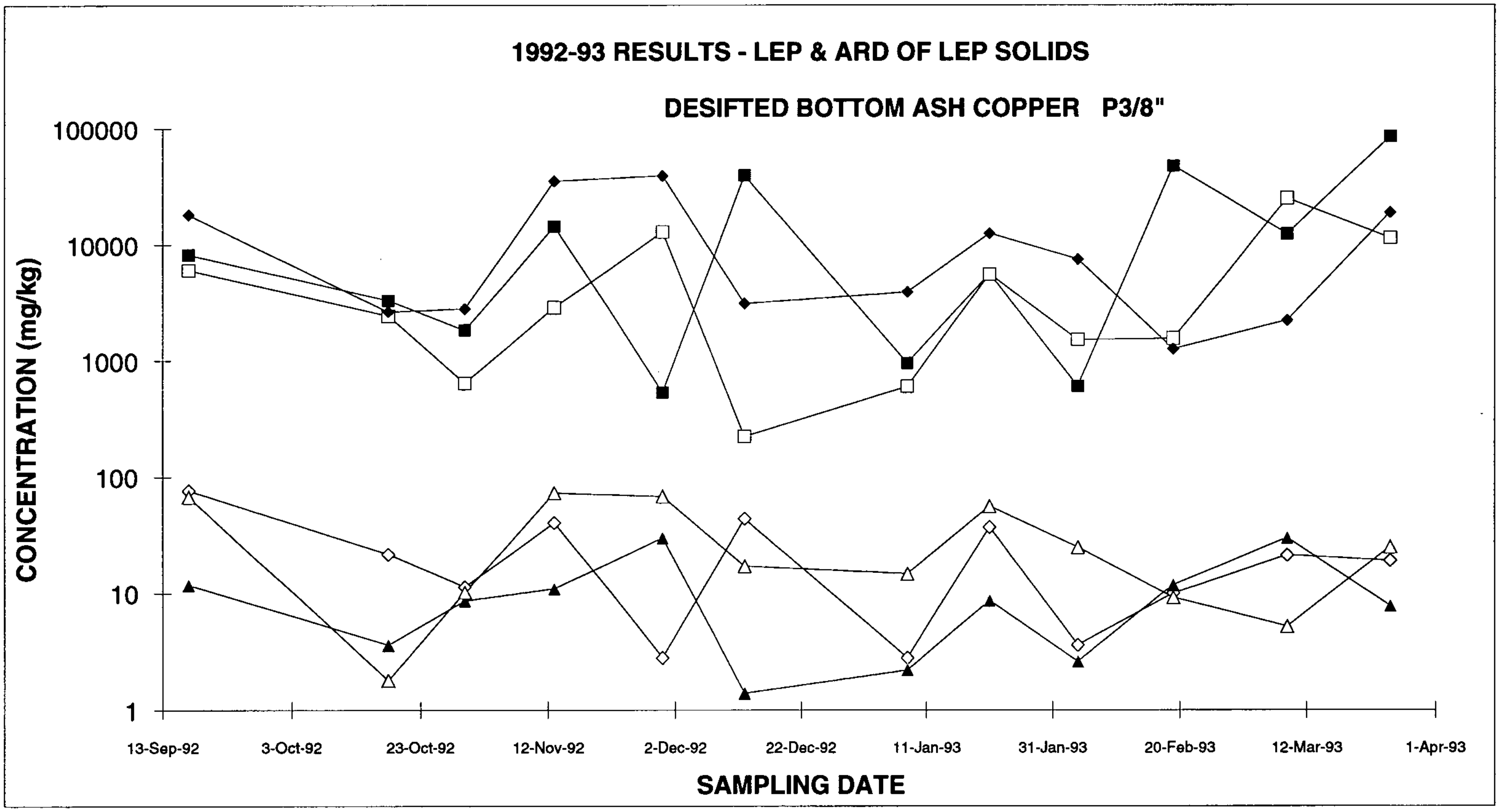

Figure F.7 DBA LEP AND ARD OF LEP SOLIDS - Cu P3/8"

340

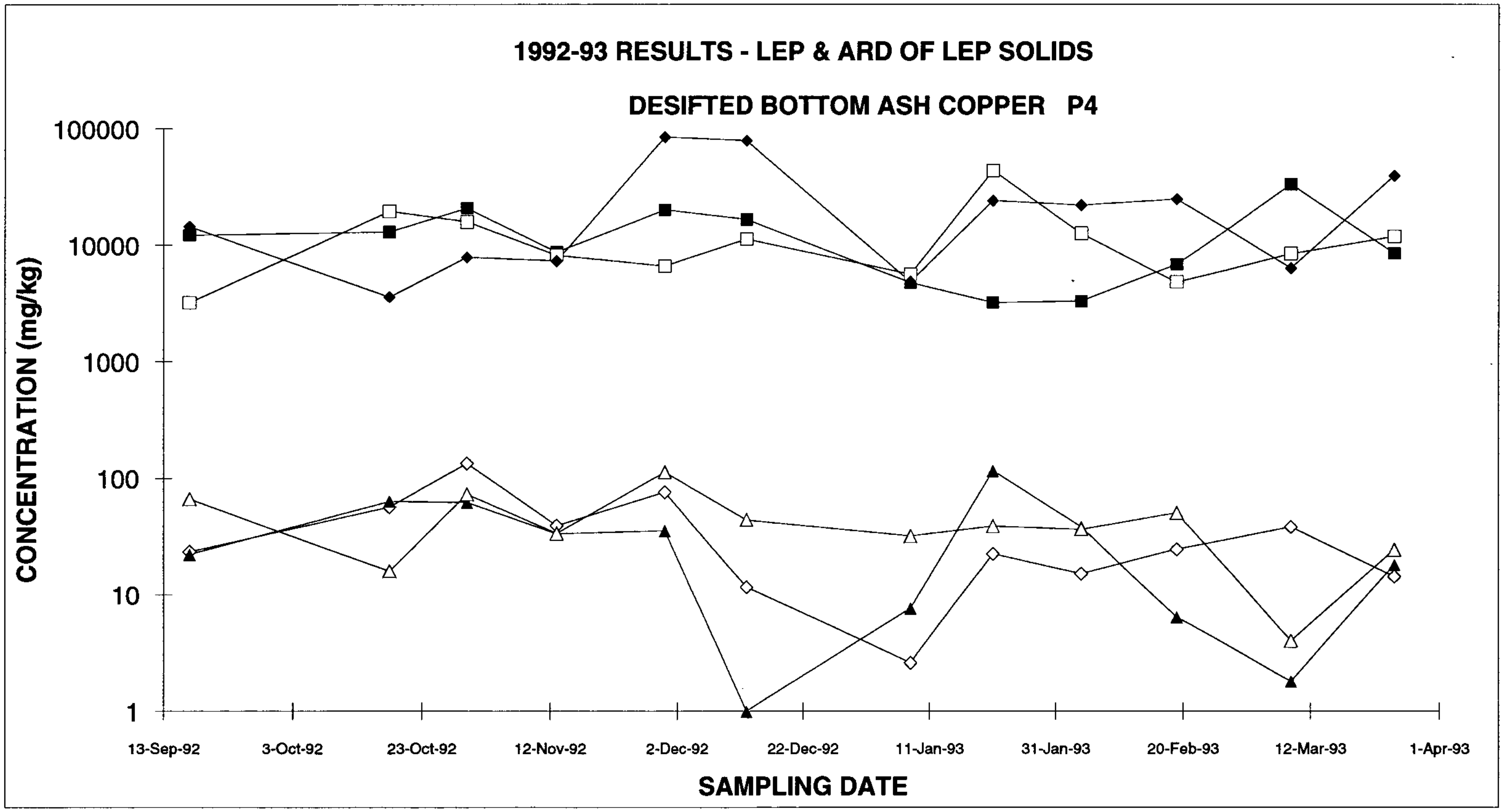

Figure F.8 DBA LEP AND ARD OF LEP SOLIDS - Cu P4

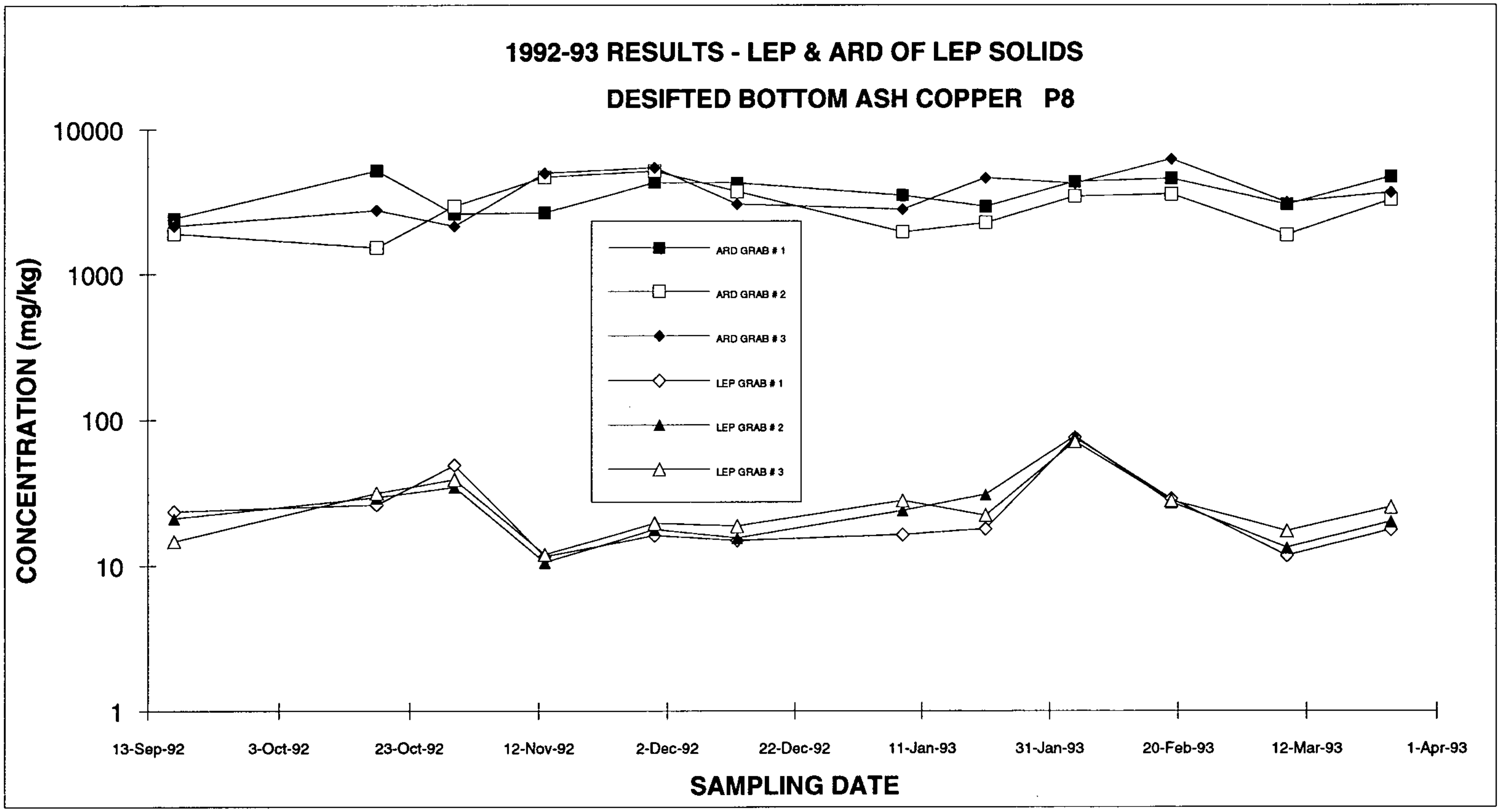

Figure F.9 DBA LEP AND ARD OF LEP SOLIDS - Cu P8

342

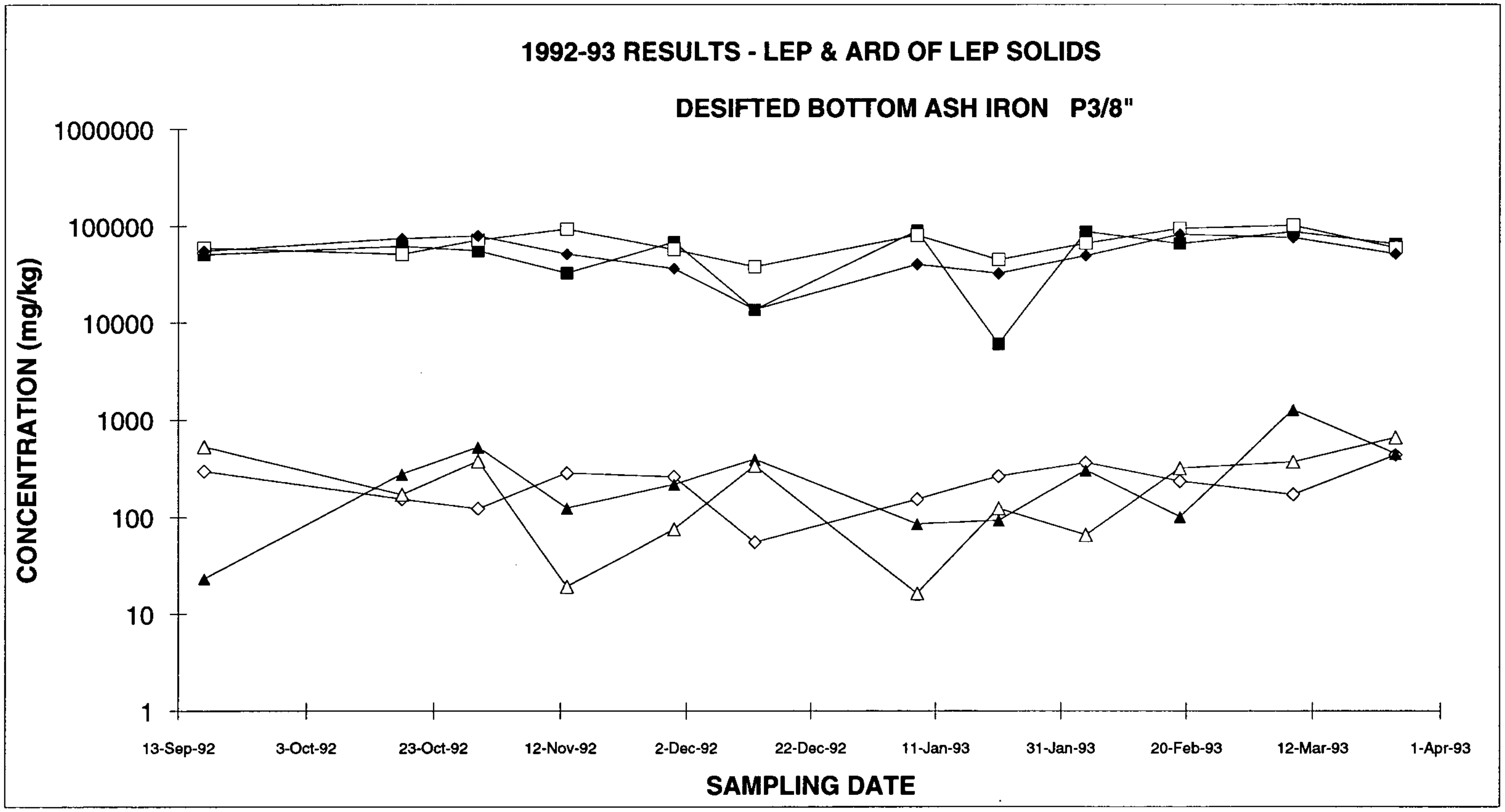

Figure F.10 DBA LEP AND ARD OF LEP SOLIDS - Fe P3/8"

343

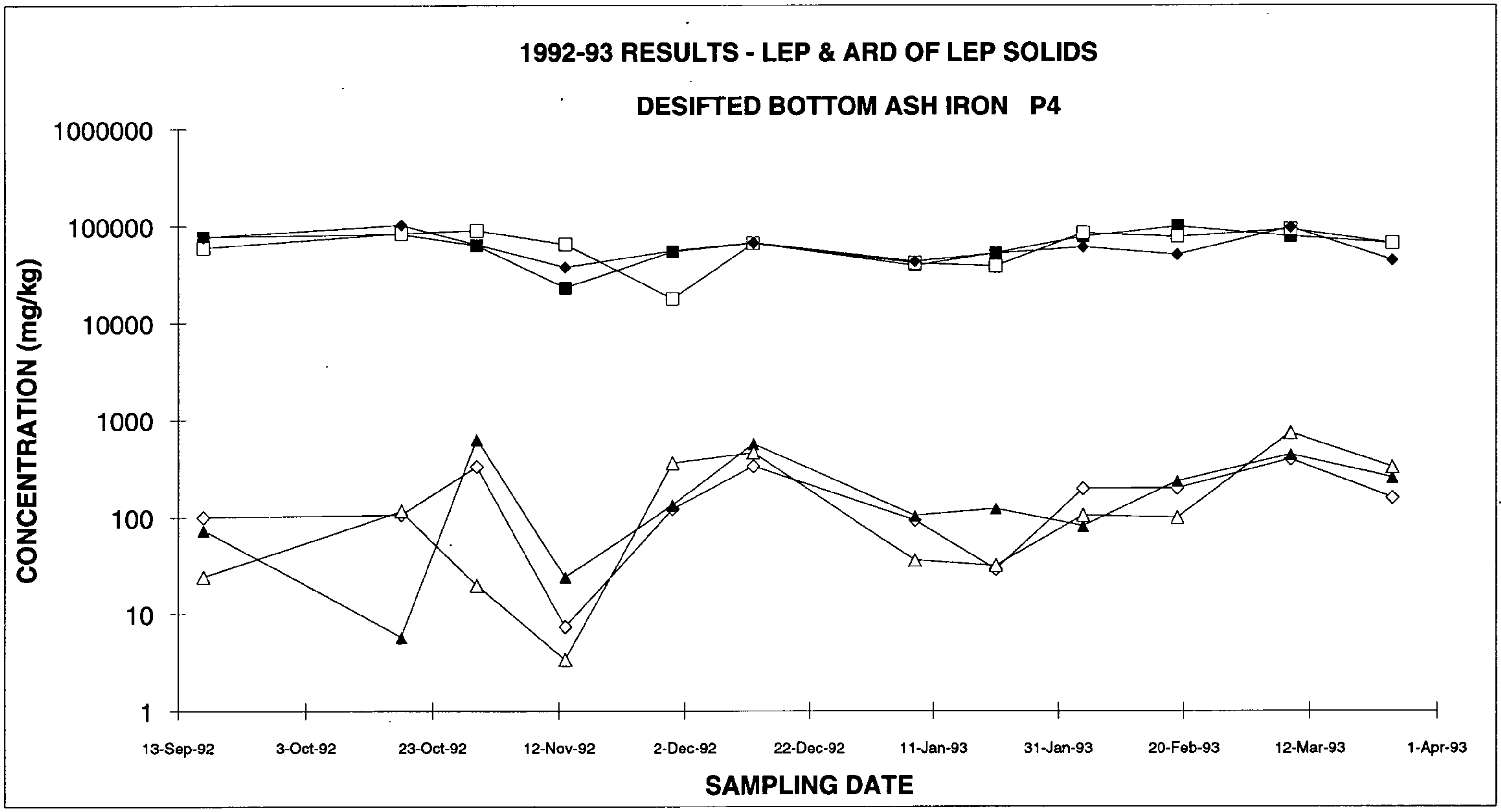

Figure F.11 DBA LEP AND ARD OF LEP SOLIDS - Fe P4

344

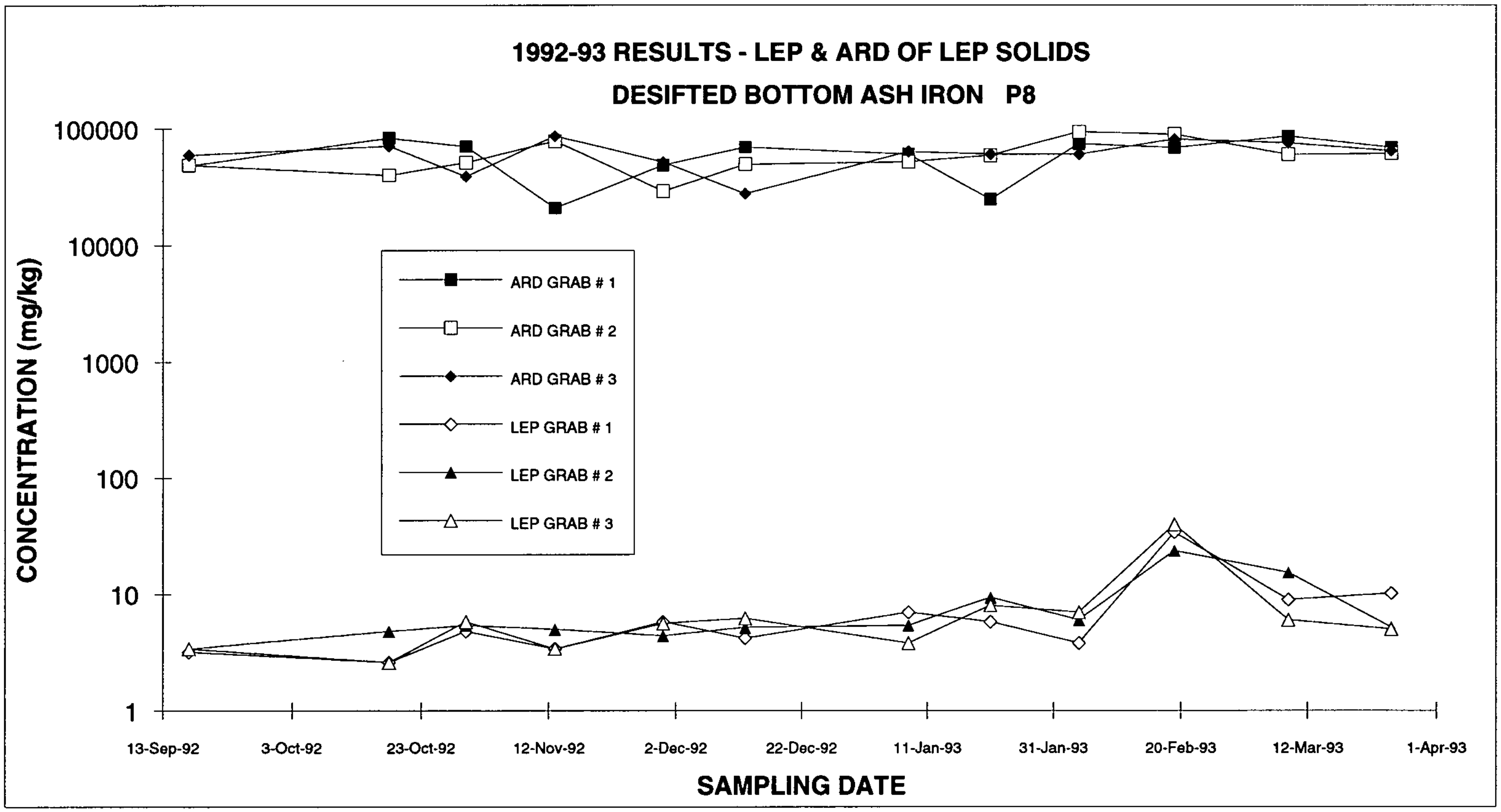

Figure F.12 DBA LEP AND ARD OF LEP SOLIDS - Fe P8

345

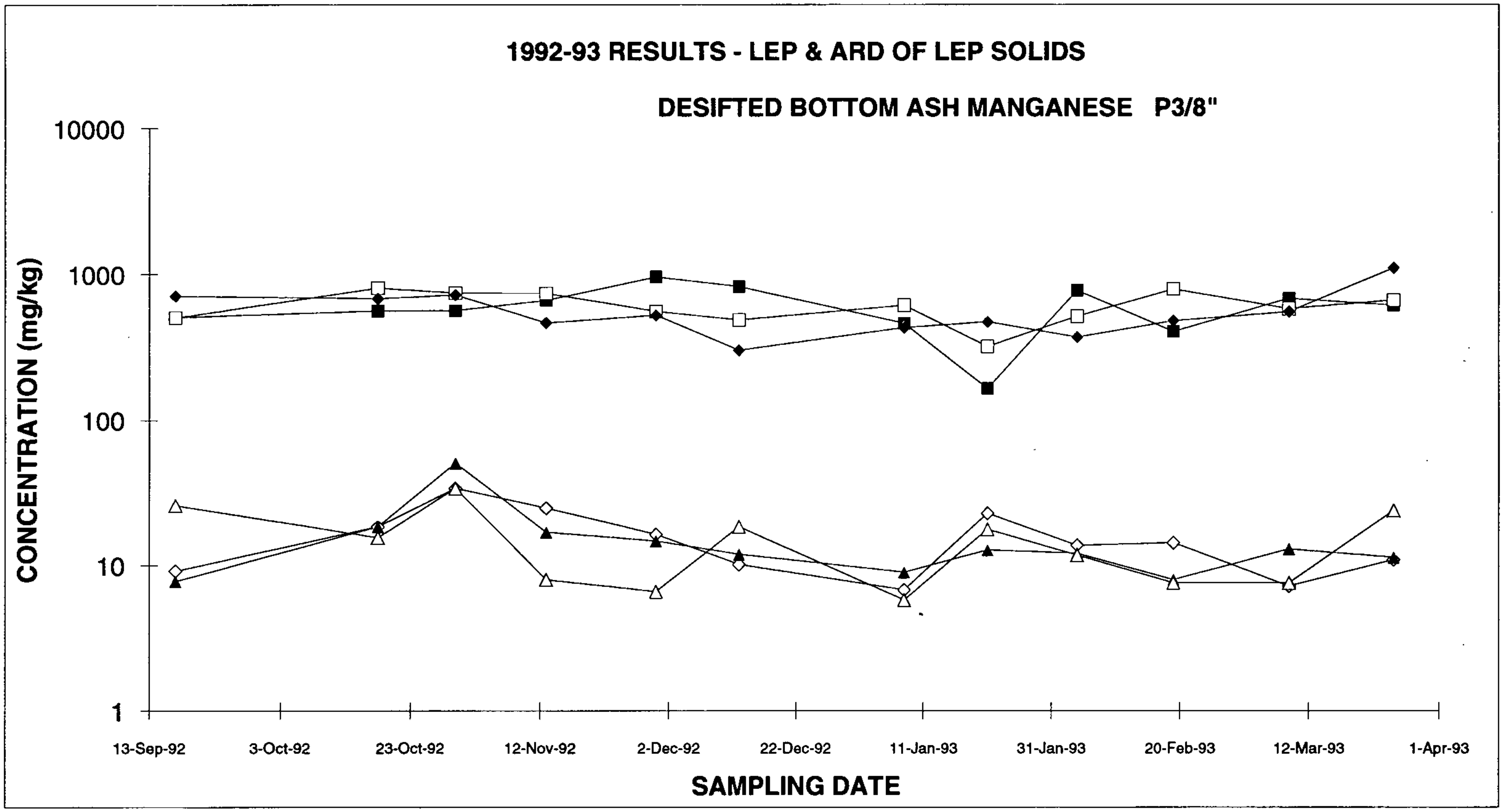

Figure F.13 DBA LEP AND ARD OF LEP SOLIDS - Mn P3/8"

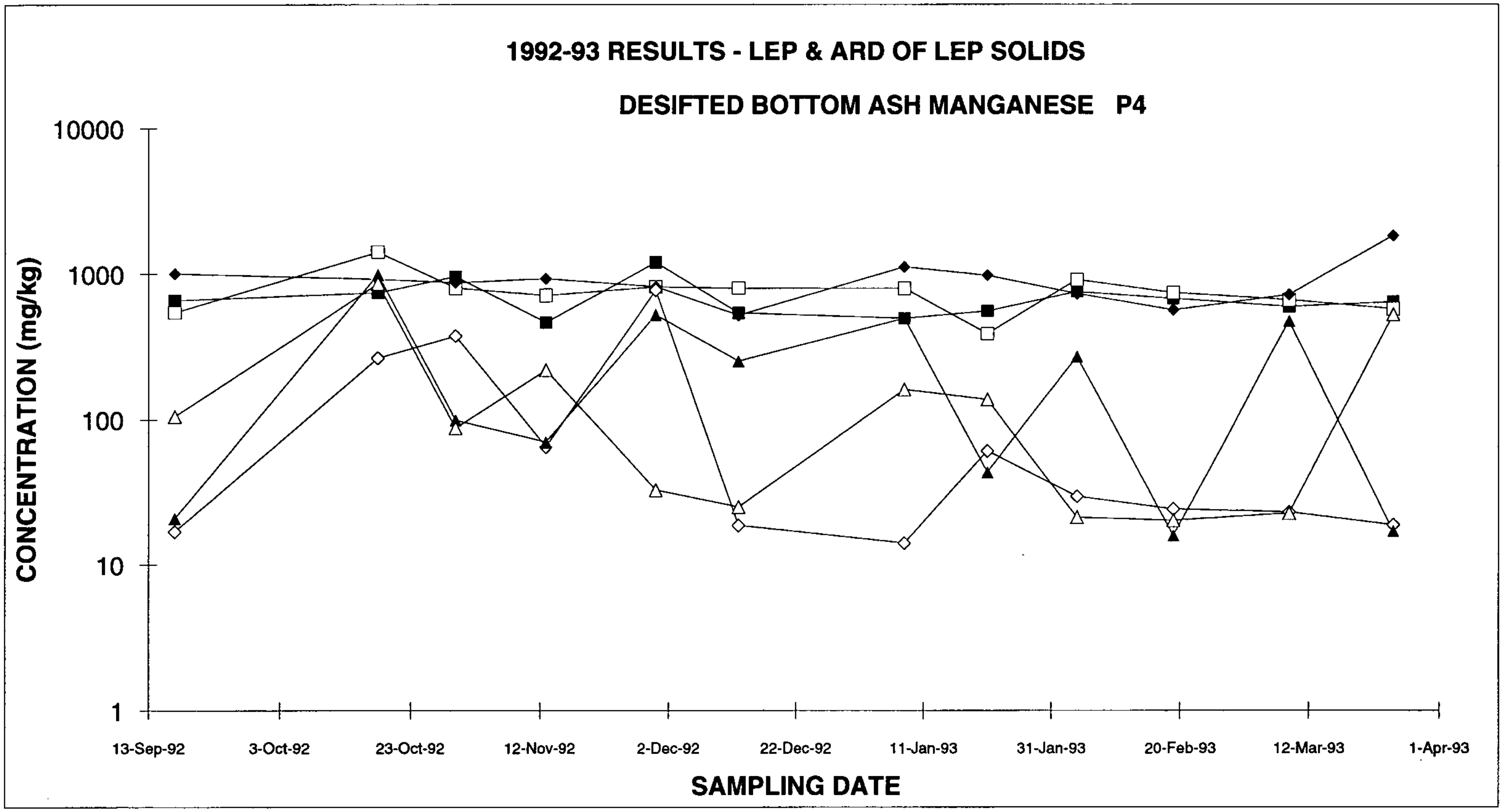

Figure F.14 DBA LEP AND ARD OF LEP SOLIDS - Mn P4

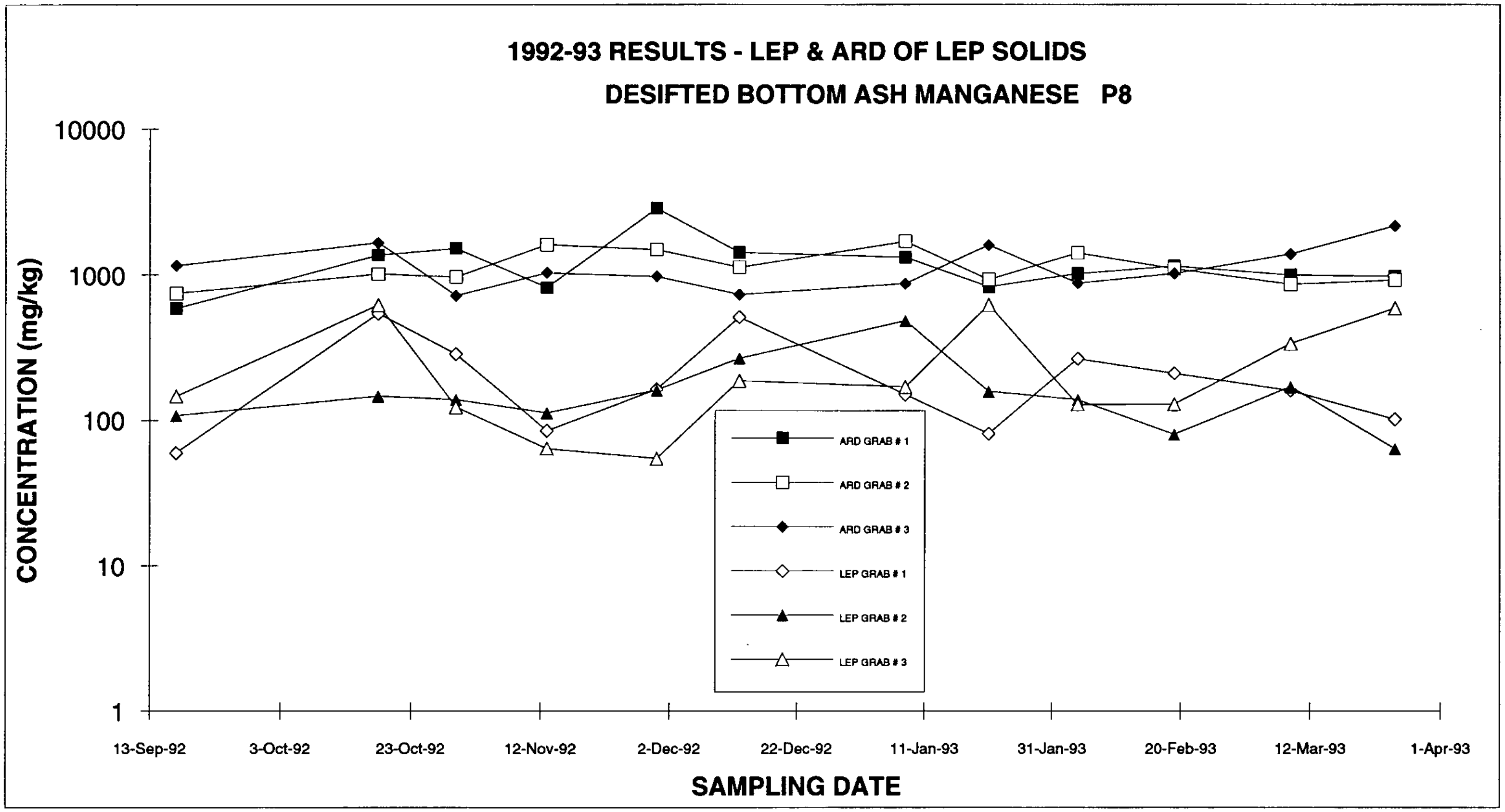

Figure F.15 DBA LEP AND ARD OF LEP SOLIDS - Mn P8

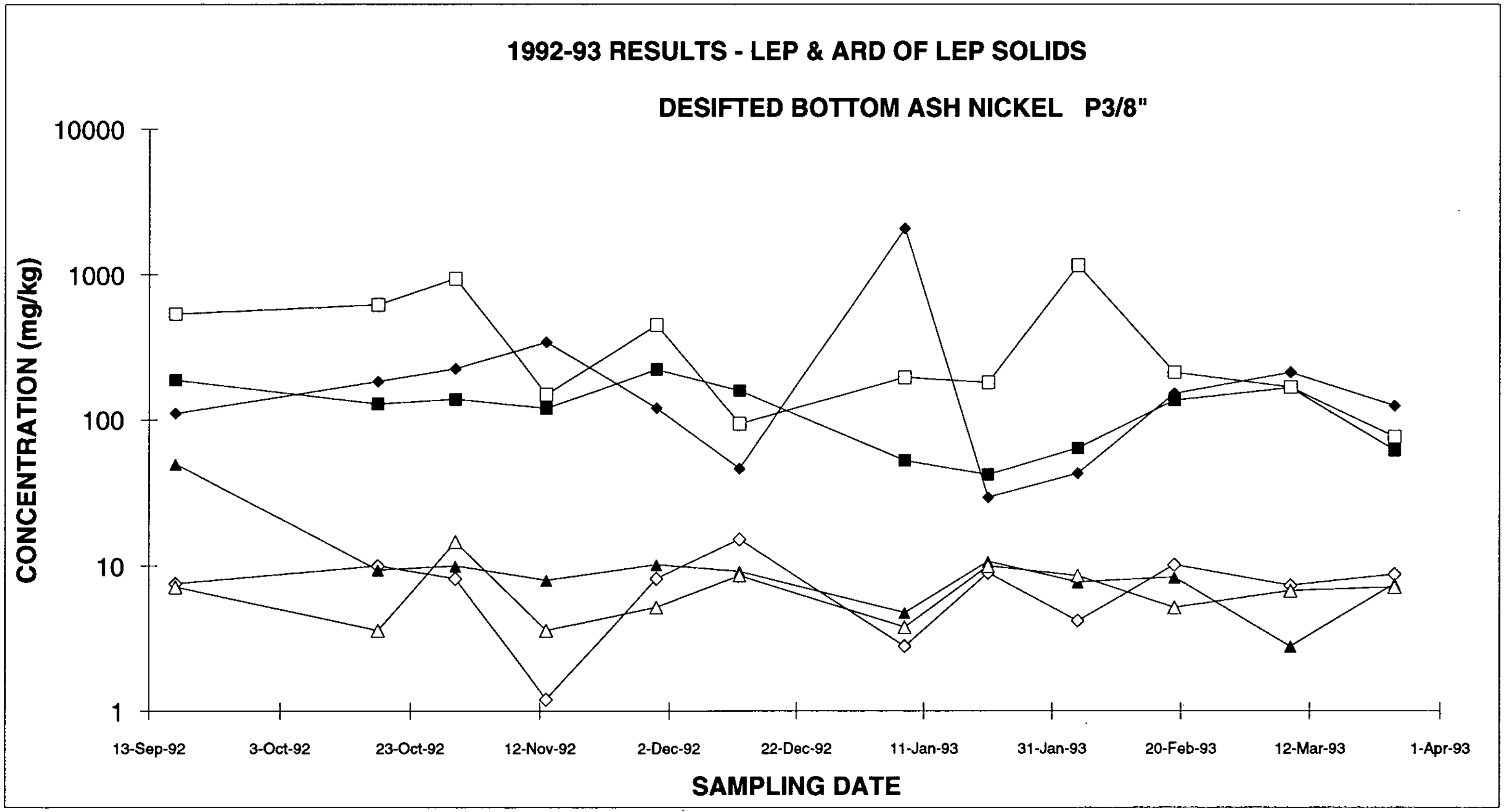

Figure F.16 DBA LEP AND ARD OF LEP SOLIDS - Mn P3/8"

349

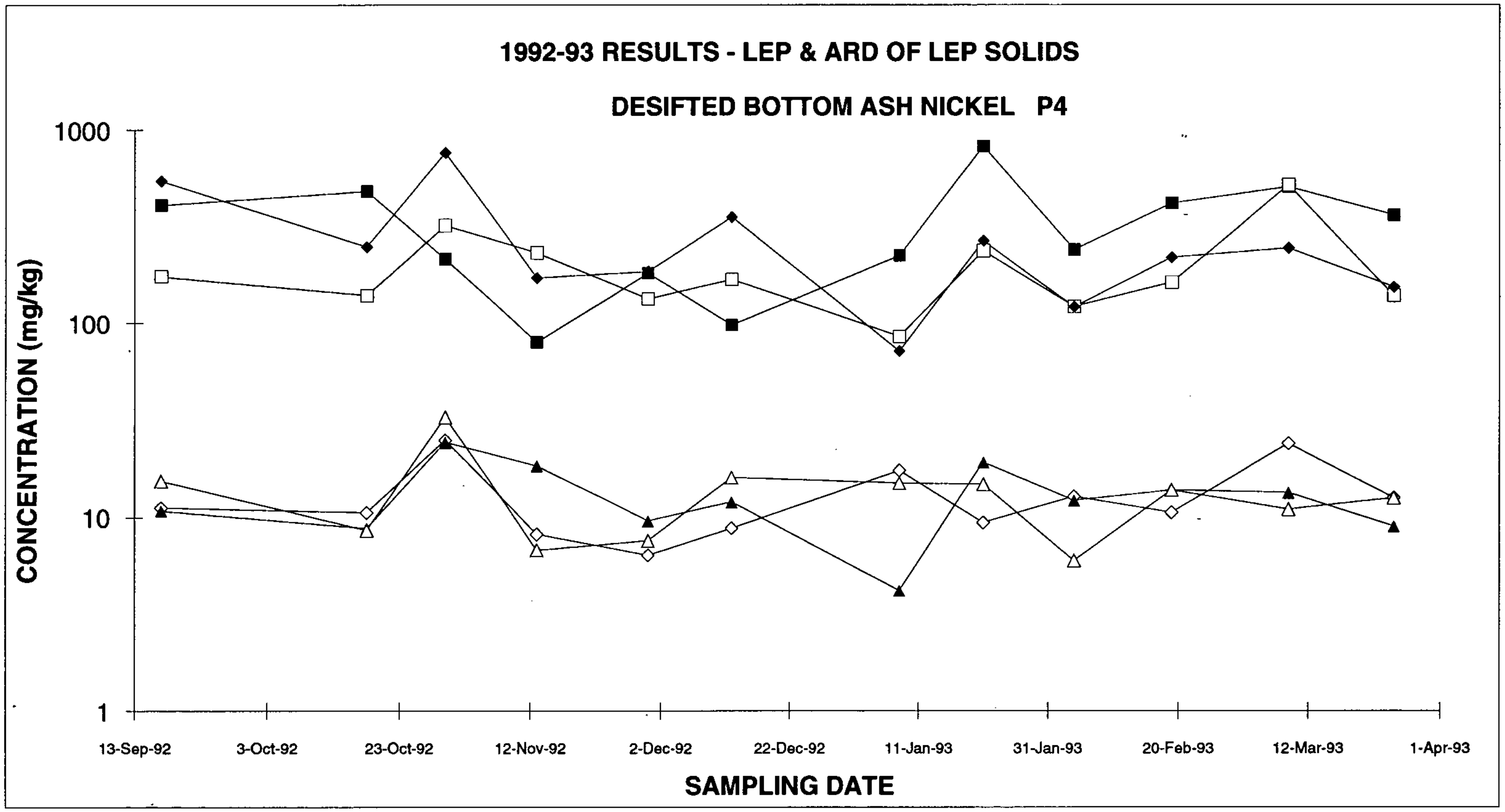

Figure F.17 DBA LEP AND ARD OF LEP SOLIDS - Mn P4

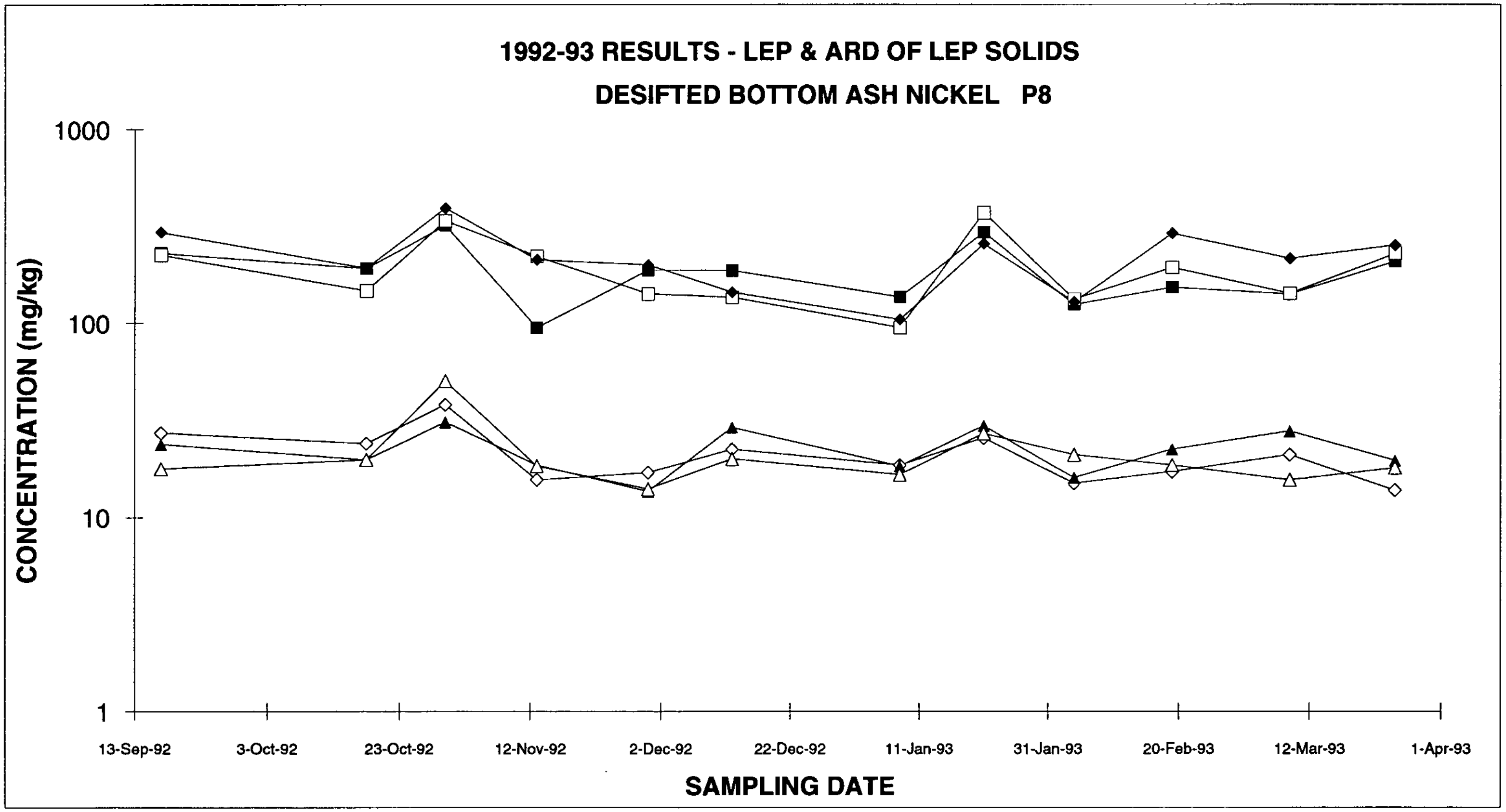

Figure F.18 DBA LEP AND ARD OF LEP SOLIDS - Mn P8

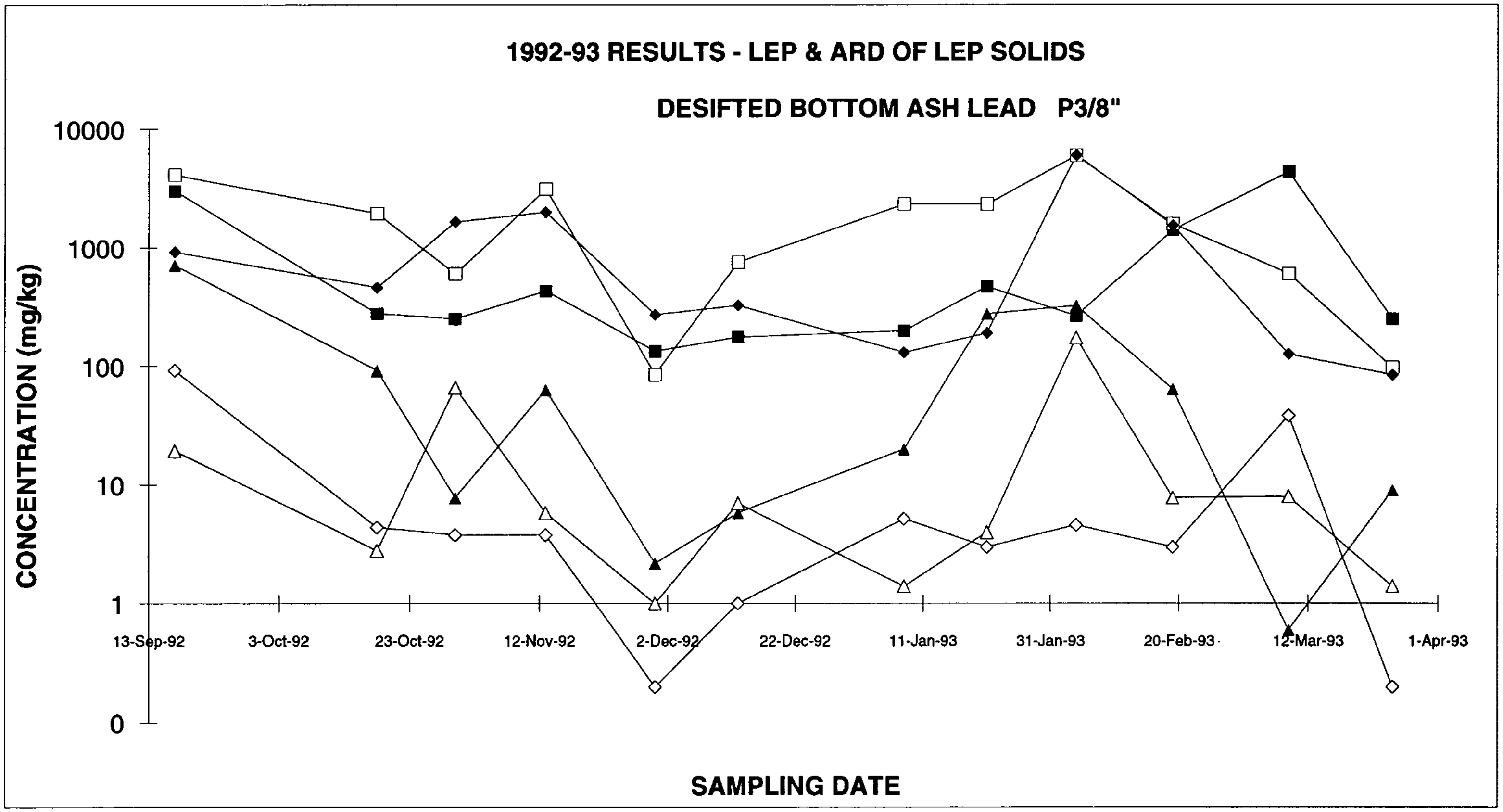

Figure F.19 DBA LEP AND ARD OF LEP SOLIDS - Pb P3/8"

352

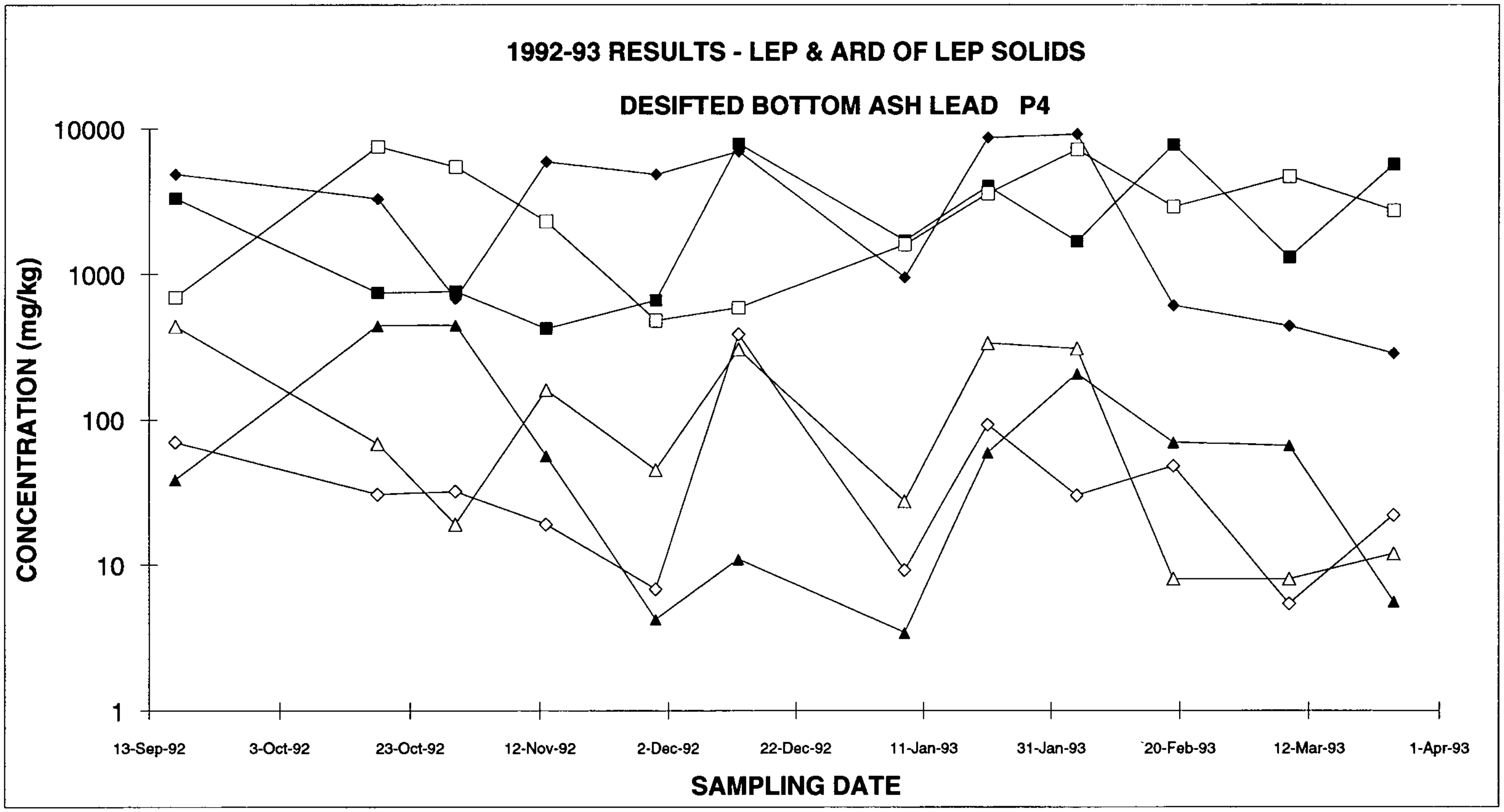

Figure F.20 DBA LEP AND ARD OF LEP SOLIDS - Pb P4

353

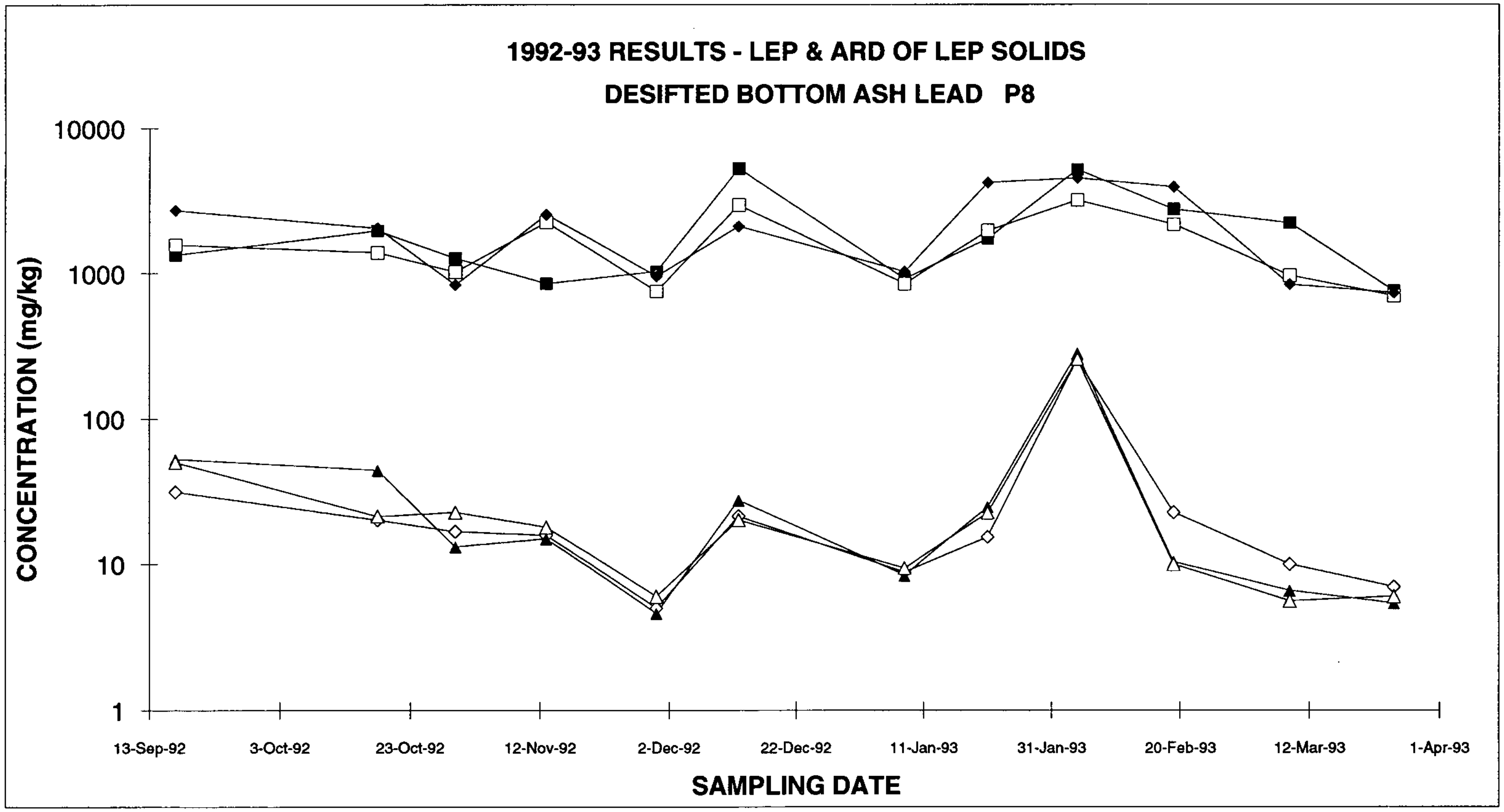

Figure F.21 DBA LEP AND ARD OF LEP SOLIDS - Pb P8

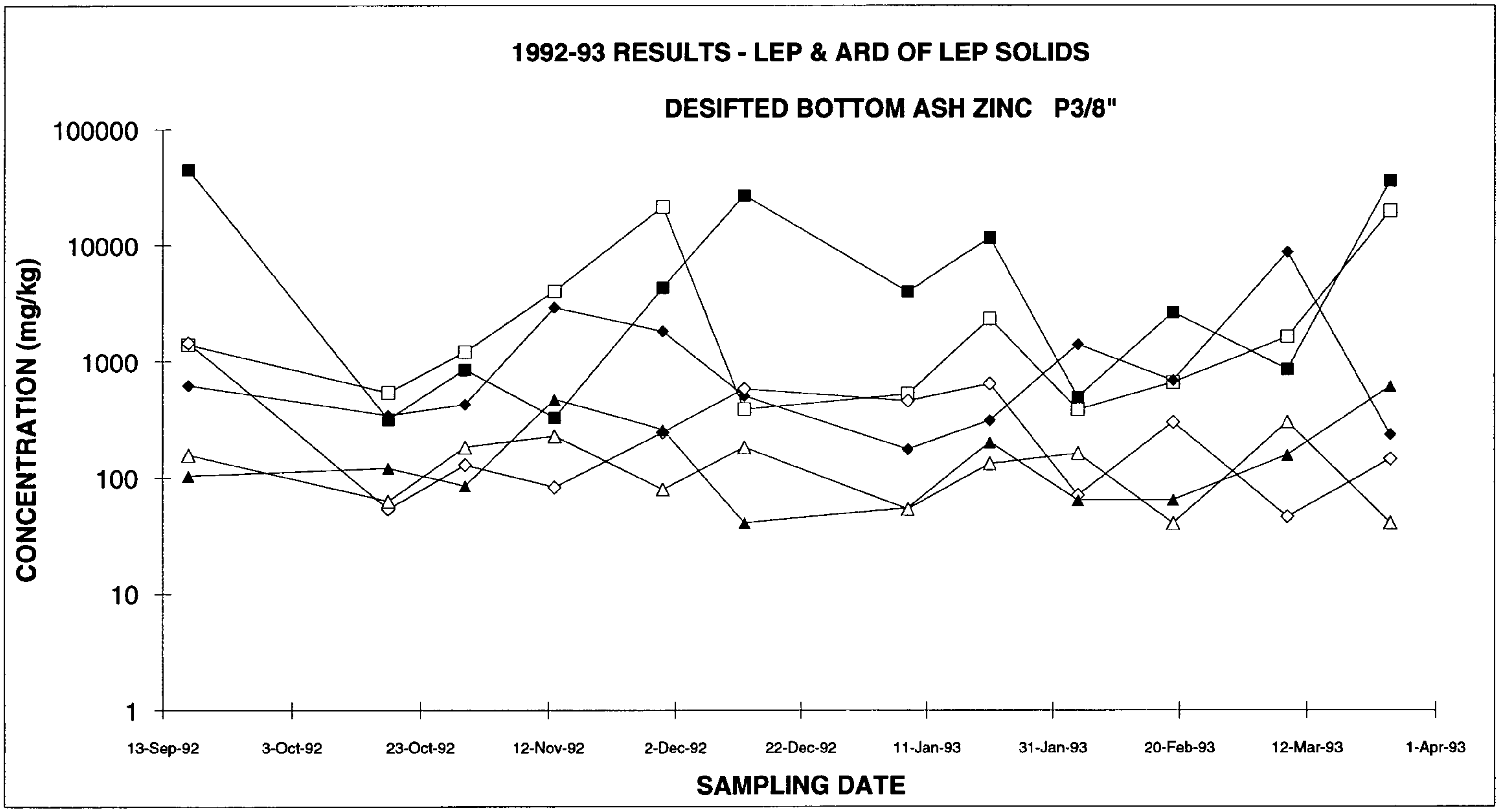

Figure F.22 DBA LEP AND ARD OF LEP SOLIDS - Zn P3/8"

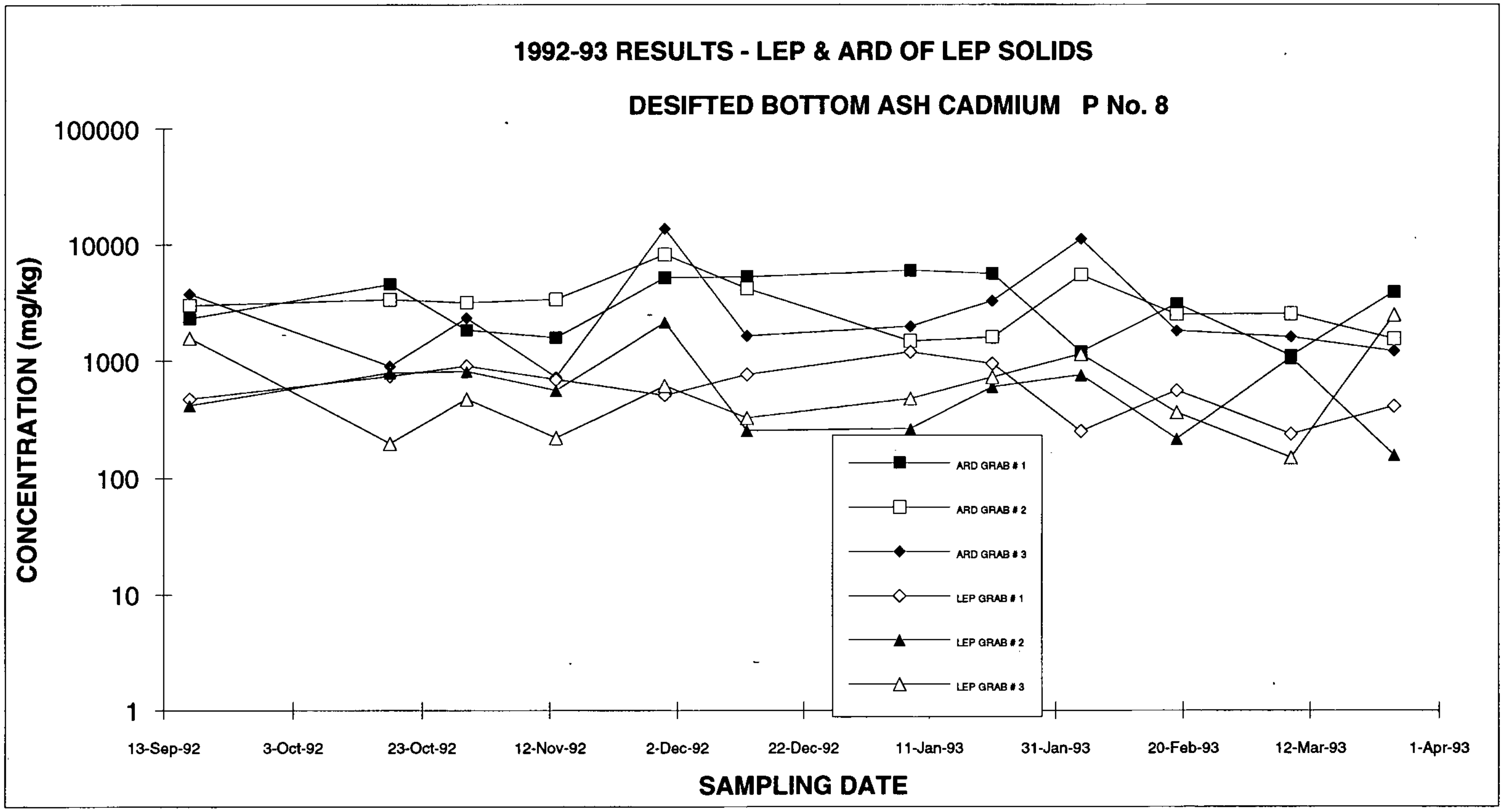

Figure F.23 DBA LEP AND ARD OF LEP SOLIDS - Zn P4

356

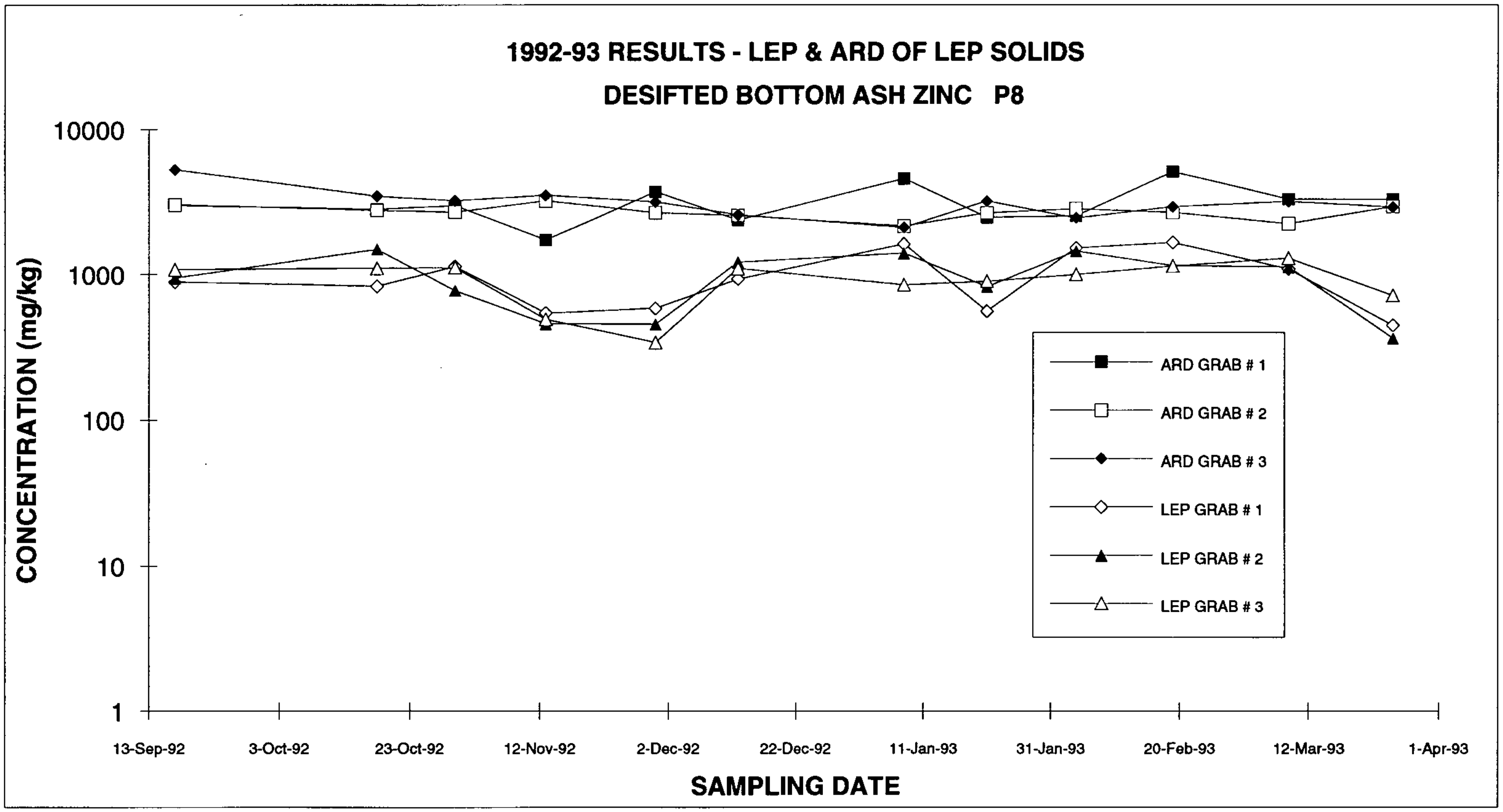

Figure F.24 DBA LEP AND ARD OF LEP SOLIDS - Zn P8

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Appendix G

DUPLICATES

Duplicate concentrations for both the LEP and the ARD of the LEP solids are listed in Tables G.1 to G.2. The original concentration for the same date is also listed for comparative purposes. The magnitude percent difference is calculated and shown for each metal. In each calculation the difference between the larger and smaller concentrations was divided by the larger of the two concentrations (used as the denominator). There are a number of large differences between the original and duplicate concentrations. The range went from a high of 98.66% for nickel on October 18, 1992 to a low of 0% for one cadmium measurement, March 25, 1993, and several chromium measurements. The 0% differences for cadmium and chromium occurred for the zero or non-detect values when a value of "0.2" mg/kg was used as a minimum value to facilitate log-normal statistical calculations.

Due to the heterogeneous nature of MSW differences in concentrations can be expected. Original and duplicate samples for the LEP test were taken from the same ziploc bag containing approximately one (1) kilogram of sample. The bagged samples were as well mixed as possible, therefore, the differences in concentration can be primarily attributed to the heterogeneous nature of the ash, and possibly experimental error. In some cases this is why other researchers have abdicated the use of larger masses of sample in larger volumes of extraction fluid for LEP's. More sample and larger volumes would reduce the variability of conducting the LEP on such a small and unrepresentative sample.

One point to be made about LEP sample selections is that each individual 50 gram sample is a discrete sample and is essentially a "grab" unto itself. This is most apparent with the P3/8" and P4 fractions where percentage differences in the range of 30% to 80% were common. Even though initial grabs were coned and quartered, variability in the coarser fractions existed. Low Percentage differences were observed in the P8 fraction duplicates; these have been bolded for added clarity.

The argument that the duplicates are essentially just another "grab" of the same heterogeneous desifted bottom ash sample can be tested by comparing the two remaining grabs for each day that a sample and a duplicate were listed. The result of comparing all three grabs with the duplicate shows that duplicates are well within the concentration range of the grabs. On several occasions there is better agreement between a duplicate and the two grabs that did not have a duplicate.

Table G.1 CADMIUM DUPLICATE AND ORIGINAL LEP CONCENTRATIONS

CADMIUM COMPARISON OF DUPLICATE AND ORIGINAL CONCENTRATION							
			LEP DBA		ARD OF LEP SOLIDS		
SAMPLE DATE	RANDOM SAMPLE	DUP (mg/Kg)	ORIG (mg/Kg)	% DIFF	DUP (mg/Kg)	ORIG (mg/Kg)	% DIFF
18-Oct-92	P3/8 R4 [1]	0.2	0.6	66.67%	2.33	1.94	16.62%
18-Oct-92	P4 R8 [3]	0.8	1.4	42.86%	2.98	3.92	23.95%
30-Oct-92	P4 R8 [1]	2.4	3.2	25.00%	5.50	4.82	12.33%
30-Nov-92	P4 R8 [3]	1.0	0.8	20.00%	2.86	2.10	26.64%
21-Jan-93	P8 [1]	4.0	4.2	**4.76%**	15.29	11.23	**26.55%**
4-Feb-93	P4 R3 [1]	1.2	1.6	25.00%	3.71	4.81	22.82%
4-Feb-93	P8 [3]	5.8	5.6	**3.45%**	9.55	9.59	**0.41%**
19-Feb-93	P3/8 R4 [2]	0.8	0.2	75.00%	3.44	1.82	47.15%
19-Feb-93	P8 [2]	4.8	4.6	**4.17%**	8.56	9.55	**10.40%**
9-Mar-93	P3/8 R4 [2]	0.4	0.2	50.00%	1.91	1.80	5.78%
25-Mar-93	P3/8 R4 [3]	0.4	0.4	0.00%	1.72	1.22	29.06%

Table G.2 CHROMIUM DUPLICATE AND ORIGINAL LEP CONCENTRATIONS

CHROMIUM COMPARISON OF DUPLICATE AND ORIGINAL CONCENTRATION							
			LEP DBA		ARD OF LEP SOLIDS		
SAMPLE DATE	RANDOM SAMPLE	DUP (mg/Kg)	ORIG (mg/Kg)	% DIFF	DUP (mg/Kg)	ORIG (mg/Kg)	% DIFF
18-Oct-92	P3/8 R4 [1]	0.2	0.2	0.00%	118	86.8	26.66%
18-Oct-92	P4 R8 [3]	0.2	0.2	0.00%	190	274.3	30.66%
30-Oct-92	P4 R8 [1]	0.4	0.8	50.00%	240	97.4	59.42%
30-Nov-92	P4 R8 [3]	0.2	0.4	50.00%	742	218.5	70.56%
21-Jan-93	P8 [1]	0.2	0.4	**50.00%**	153	73.7	**51.80%**
4-Feb-93	P4 R3 [1]	0.2	0.2	0.00%	324	169.9	47.53%
4-Feb-93	P8 [3]	0.6	0.6	**0.00%**	148	113.0	**23.55%**
19-Feb-93	P3/8 R4 [2]	0.2	0.2	0.00%	502	319.8	36.35%
19-Feb-93	P8 [2]	0.4	0.2	**50.00%**	155	164.8	**5.85%**
9-Mar-93	P3/8 R4 [2]	0.2	0.2	0.00%	70	48.0	31.80%
25-Mar-93	P3/8 R4 [3]	0.2	0.2	0.00%	23	40.8	42.97%

Table G.3 COPPER DUPLICATE AND ORIGINAL LEP CONCENTRATIONS

COPPER COMPARISON OF DUPLICATE AND ORIGINAL CONCENTRATION							
			LEP DBA		ARD OF LEP SOLIDS		
SAMPLE DATE	RANDOM SAMPLE	DUP (mg/Kg)	ORIG (mg/Kg)	% DIFF	DUP (mg/Kg)	ORIG (mg/Kg)	% DIFF
18-Oct-92	P3/8 R4 [1]	4.4	21.8	79.82%	2286	3300.0	30.72%
18-Oct-92	P4 R8 [3]	36.0	16.0	55.56%	12696	3547.0	72.06%
30-Oct-92	P4 R8 [1]	60.2	134.0	55.07%	3109	20748.0	85.02%
30-Nov-92	P4 R8 [3]	28.8	113.0	74.51%	9574	84561.0	88.68%
21-Jan-93	P8 [1]	17.8	18.0	**1.11%**	2858	2937.0	**2.69%**
4-Feb-93	P4 R3 [1]	33.2	15.2	54.22%	5868	3182.0	45.77%
4-Feb-93	P8 [3]	66.6	71.0	**6.20%**	3320	4248.0	**21.85%**
19-Feb-93	P3/8 R4 [2]	3.4	11.8	71.19%	739	1548.0	52.23%
19-Feb-93	P8 [2]	24.0	27.2	**11.76%**	2567	3581.0	**28.31%**
9-Mar-93	P3/8 R4 [2]	10.0	30.2	66.89%	11482	24997.0	54.06%
25-Mar-93	P3/8 R4 [3]	66.8	25.2	62.28%	29591	18955.0	35.94%

Table G.4 IRON DUPLICATE AND ORIGINAL LEP CONCENTRATIONS

IRON COMPARISON OF DUPLICATE AND ORIGINAL CONCENTRATIONS							
		LEP DBA			ARD OF LEP SOLIDS		
SAMPLE DATE	RANDOM SAMPLE	DUP (mg/Kg)	ORIG (mg/Kg)	% DIFF	DUP (mg/Kg)	ORIG (mg/Kg)	% DIFF
18-Oct-92	P3/8 R4 [1]	707.0	154.4	78.16%	113903.1	62171.0	45.42%
18-Oct-92	P4 R8 [3]	424.0	116.8	72.45%	125832.7	103123.0	18.05%
30-Oct-92	P4 R8 [1]	150.4	331.6	54.64%	96999.3	63175.0	34.87%
30-Nov-92	P4 R8 [3]	397.0	361.0	9.07%	72640.3	55547.0	23.53%
21-Jan-93	P8 [1]	5.6	5.8	**3.45%**	69671.2	24819.0	**64.38%**
4-Feb-93	P4 R3 [1]	131.8	198.4	33.57%	101142.6	78320.0	22.56%
4-Feb-93	P8 [3]	7.8	7.0	**10.26%**	69762.2	60342.0	**13.50%**
19-Feb-93	P3/8 R4 [2]	357.0	101.4	71.60%	61506.0	94720.0	35.07%
19-Feb-93	P8 [2]	6.4	23.8	**73.11%**	73144.9	90014.0	**18.74%**
9-Mar-93	P3/8 R4 [2]	1177.0	1275.0	7.69%	146195.3	101754.0	30.40%
25-Mar-93	P3/8 R4 [3]	468.0	659.0	28.98%	73385.4	51437.0	29.91%

Table G.5 MANGANESE DUPLICATE AND ORIGINAL LEP CONCENTRATIONS

MANGANESE COMPARISON OF DUPLICATE AND ORIGINAL CONCENTRATIONS							
		LEP DBA			ARD OF LEP SOLIDS		
SAMPLE DATE	RANDOM SAMPLE	DUP (mg/Kg)	ORIG (mg/Kg)	% DIFF	DUP (mg/Kg)	ORIG (mg/Kg)	% DIFF
18-Oct-92	P3/8 R4 [1]	24.4	18.6	23.77%	931	562.0	39.61%
18-Oct-92	P4 R8 [3]	1462.0	862.0	41.04%	1439	921.0	36.01%
30-Oct-92	P4 R8 [1]	149.6	378.0	60.42%	1734	963.0	44.46%
30-Nov-92	P4 R8 [3]	29.4	33.0	10.91%	753	820.0	8.19%
21-Jan-93	P8 [1]	91.0	81.2	**10.77%**	1400	828.0	**40.84%**
4-Feb-93	P4 R3 [1]	24.8	29.8	16.78%	877	757.0	13.64%
4-Feb-93	P8 [3]	110.8	128.6	**13.84%**	853	879.0	**2.99%**
19-Feb-93	P3/8 R4 [2]	8.2	8.0	2.44%	527	789.0	33.24%
19-Feb-93	P8 [2]	77.0	80.4	**4.23%**	901	1103.0	**18.28%**
9-Mar-93	P3/8 R4 [2]	23.0	13.0	43.48%	975	580.0	40.53%
25-Mar-93	P3/8 R4 [3]	12.6	24.0	47.50%	465	1102.0	57.77%

Table G.6 NICKEL DUPLICATE AND ORIGINAL LEP CONCENTRATIONS

NICKEL COMPARISON OF DUPLICATE AND ORIGINAL CONCENTRATIONS							
		LEP DBA			ARD OF LEP SOLIDS		
SAMPLE DATE	RANDOM SAMPLE	DUP (mg/Kg)	ORIG (mg/Kg)	% DIFF	DUP (mg/Kg)	ORIG (mg/Kg)	% DIFF
18-Oct-92	P3/8 R4 [1]	6.4	10.0	36.00%	101	127.9	20.67%
18-Oct-92	P4 R8 [3]	10.8	8.6	20.37%	148	249.5	40.67%
30-Oct-92	P4 R8 [1]	31.0	25.0	19.35%	287	216.0	24.70%
30-Nov-92	P4 R8 [3]	14.0	7.6	45.71%	338	185.9	45.05%
21-Jan-93	P8 [1]	23.4	25.6	**8.59%**	330	294.4	**10.76%**
4-Feb-93	P4 R3 [1]	15.4	12.8	16.88%	291	241.0	17.19%
4-Feb-93	P8 [3]	17.2	18.6	**7.53%**	132	128.6	**2.66%**
19-Feb-93	P3/8 R4 [2]	11.8	8.4	28.81%	578	211.0	63.52%
19-Feb-93	P8 [2]	18.2	22.4	**18.75%**	183	194.2	**5.94%**
9-Mar-93	P3/8 R4 [2]	7.4	2.8	62.16%	94	167.5	43.75%
25-Mar-93	P3/8 R4 [3]	6.6	7.2	8.33%	72	125.2	42.79%

Table G.7 LEAD DUPLICATE AND ORIGINAL LEP CONCENTRATIONS

LEAD COMPARISON OF DUPLICATE AND ORIGINAL CONCENTRATIONS							
		LEP DBA			ARD OF LEP SOLIDS		
SAMPLE DATE	RANDOM SAMPLE	DUP (mg/Kg)	ORIG (mg/Kg)	% DIFF	DUP (mg/Kg)	ORIG (mg/Kg)	% DIFF
18-Oct-92	P3/8 R4 [1]	4.6	4.4	4.35%	290	277.0	4.42%
18-Oct-92	P4 R8 [3]	3.6	68.4	94.74%	301	3294.0	90.87%
30-Oct-92	P4 R8 [1]	260.2	32.0	87.70%	6241	760.0	87.82%
30-Nov-92	P4 R8 [3]	2.0	45.0	95.56%	373	4824.0	92.26%
21-Jan-93	P8 [1]	14.8	15.4	**3.90%**	3178	1734.0	**45.43%**
4-Feb-93	P4 R3 [1]	279.0	30.0	89.25%	6499	1681.0	74.13%
4-Feb-93	P8 [3]	329.8	258.4	**21.65%**	4293	4532.0	**5.27%**
19-Feb-93	P3/8 R4 [2]	143.0	64.2	55.10%	4592	1592.0	65.33%
19-Feb-93	P8 [2]	11.4	10.4	**8.77%**	1412	2171.0	**34.94%**
9-Mar-93	P3/8 R4 [2]	0.8	0.6	25.00%	288	606.0	52.45%
25-Mar-93	P3/8 R4 [3]	2.8	1.4	50.00%	488	84.0	82.79%

Table G.8 ZINC DUPLICATE AND ORIGINAL LEP CONCENTRATIONS

ZINC COMPARISON OF DUPLICATE AND ORIGINAL CONCENTRATIONS							
		LEP DBA			ARD OF LEP SOLIDS		
SAMPLE DATE	RANDOM SAMPLE	DUP (mg/Kg)	ORIG (mg/Kg)	% DIFF	DUP (mg/Kg)	ORIG (mg/Kg)	% DIFF
18-Oct-92	P3/8 R4 [1]	98.8	53.6	45.75%	516	317.0	38.55%
18-Oct-92	P4 R8 [3]	962.0	197.6	79.46%	1758	897.0	48.97%
30-Oct-92	P4 R8 [1]	1314.0	904.0	31.20%	1998	1840.0	7.92%
30-Nov-92	P4 R8 [3]	586.0	612.0	4.25%	5673	13677.0	58.52%
21-Jan-93	P8 [1]	582.0	556.0	**4.47%**	3046	2469.0	**18.94%**
4-Feb-93	P4 R3 [1]	1290.0	251.0	80.54%	10539	1198.0	88.63%
4-Feb-93	P8 [3]	1034.0	996.0	**3.68%**	2251	2443.0	**7.85%**
19-Feb-93	P3/8 R4 [2]	102.8	64.6	37.16%	1195	358.0	70.05%
19-Feb-93	P8 [2]	952.0	1146.0	**16.93%**	2168	2660.0	**18.51%**
9-Mar-93	P3/8 R4 [2]	33.6	157.0	78.60%	513	1629.0	68.52%
25-Mar-93	P3/8 R4 [3]	788.0	40.8	94.82%	18898	235.0	98.76%

Appendix H

DATA COLLECTION FORMS USED

SAMPLE DATE	WEIGHT	MAGNET ATTRACTED	BRICKS	CONCRETE	GLASS	PAPER & WOOD	PORCELIN & TILE	ROCK	NON-FERROUS METALS	GLASS MIXTURES	OTHER
	CONTAINER										
	SAMP+CONT										
	CONTAINER										
	SAMP+CONT										
	CONTAINER										
	SAMP+CONT										
	CONTAINER										
	SAMP+CONT										
	CONTAINER										
	SAMP+CONT										
	CONTAINER										
	SAMP+CONT										
	CONTAINER										
	SAMP+CONT										
	CONTAINER										
	SAMP+CONT										
	CONTAINER										
	SAMP+CONT										

Figure H-1 FORM USED TO RECORD RAW MASS DATA FROM VISUAL 10 CATEGORY MATERIAL SORT

UNIVERSITY OF BRITISH COLUMBIA DEPT. OF CIVIL ENGINEERING

SOIL MECHANICS LABORATORY

MOISTURE-DENSITY RELATIONSHIP

TESTED BY: ______________________ DATE: ____________

SOIL DESCRIPTION: ______________________________

TYPE OF TEST: ______________________________

MOLD: DIA: ________ HEIGHT: ________ VOLUME: ________

RUN					
MASS OF SAMPLE + MOLD					
MASS OF MOLD					
MASS OF SAMPLE					
w (from below)					
DRY MASS OF SAMPLE					
DRY UNIT WEIGHT					

WATER CONTENT

CONTAINER No.					
MASS OF WET SAMPLE + DISH					
MASS OF DRY SAMPLE + DISH					
MASS OF WATER					
MASS OF DISH					
MASS OF DRY SOIL					
WATER CONTENT (w)					

REMARKS:

Figure H-2 SOILS LAB - COMPACTION-DENSITY TEST RESULTS

LEACHATE EXTRACTION PROCESS: DAY NUMBER ONE
SAMPLE DATE:

HOUR	TIME	#1 & #2	#3 & #4	#5 & #6	#7 & #8	#9 & #10
0	10:00	START				
	10:15	pH (15min)				
	10:30		START			
	10:45		pH (15min)			
1	11:00	pH (1 hr)		START		
	11:15			pH (15min)		
	11:30		pH (1 hr)		START	
	11:45				pH (15min)	
2	12:00			pH (1 hr)		START
	12:15					pH (15min)
	12:30				pH (1 hr)	
	12:45					
3	1:00	pH (3 hr)				pH (1 hr)
	1:15					
	1:30		pH (3 hr)			
	1:45					
4	2:00			pH (3 hr)		
	2:15					
	2:30				pH (3 hr)	
	2:45					
5	3:00					pH (3 hr)
	3:15					
	3:30					
	3:45					
6	4:00	pH (6 hr)				
	4:15					
	4:30		pH (6 hr)			
	4:45					
7	5:00			pH (6 hr)		
	5:15					
	5:30				pH (6 hr)	
	5:45					
8	6:00					pH (6 hr)
ACID	15 min					
ADDED	1 hour					
DAY	3 hours					
ONE	6 hours					
	TOTAL					

Figure H-3 LEP DAY ONE FORM

LEACHATE EXTRACTION PROCESS: DAY NUMBER TWO
SAMPLE DATE:

HOUR	TIME	#1 & #2	#3 & #4	#5 & #6	#7 & #8	#9 & #10
ACID ADDED DAY ONE						
22	8:00	pH (22 hr)				
	8:15					
	8:30		pH (22 hr)			
	8:45					
23	9:00			pH (22 hr)		
	9:15					
	9:30				pH (22 hr)	
	9:45					
24	10:00	STOP (24 hr)				pH (22 hr)
	10:15					
	10:30		STOP (24 hr)			
	10:45					
25	11:00			STOP (24 hr)		
	11:15					
	11:30				STOP (24 hr)	
	11:45					
26	12:00					STOP (24 hr)
TOTAL ACID ADDED						
DISTILLED WATER ADDED						

Figure H-4 LEP DAY TWO FORM

Note on above there is a time overlap at hour 3 for bottles #1 and #2 and hour 1 for bottles #9 and #10. To avoid interfering with the chemistry of the LEP the 1 hour pH check and adjustment for bottles #9 and # 10 took priority, and then bottles #1 and #2 were dealt with. It typically took no more than 5 minutes to record and adjust pH's, so it is felt that the 3 hour check and adjustment of bottles #1 and #2 were not affected by a slight delay. There is a similar overlap at hour 24 for bottles #1 and #2 and hour 22 for bottles #9 and #10.