TACOMA SMELTER PLUME SITE

PIERCE COUNTY CHILD USE AREA STUDY

July, 2004

Prepared for:

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CLEAN WATER. HEALTHY ENVIRONMENT. FOR LIFE.

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EXECUTIVE SUMMARY

The Tacoma-Pierce County Health Department (TPCHD) conducted the Pierce County Child Use Area Study using funding provided through a grant from the Department of Ecology (Ecology). Ecology, TPCHD, Public Health – Seattle and King County, and the environmental consulting firm SAIC worked with consultant Greg Glass to design the study. TPCHD conducted the sampling in Pierce County. A similar study in King County was conducted by SAIC environmental consultants under contract with Ecology. The primary goals of the studies were to identify areas where soil contamination from smokestack deposits of the former ASARCO Smelter in Ruston Washington could pose a health risk to children, and to raise local awareness of arsenic and lead contamination.

Child use areas (CUA's) included elementary schools, public parks, and child care centers. The sampled CUAs were located in Tacoma, Fircrest, University Place, Lakewood, Steilacoom, Fox Island and Gig Harbor. The study zone was determined by calculating the geographic area predicted to have arsenic concentrations over 100 ppm, based on data from earlier studies. TPCHD identified a total of 194 CUAs within the study zone: 40 parks, 19 public elementary schools, 5 private elementary schools, and 130 child care facilities. Access was granted for sampling 72 properties: 22 parks, 19 public schools, and 32 child care facilities. Some of the facilities which granted access were not sampled after all because they did not have child use areas or because they were paved. Two additional sites (one child care facility and one state park) located outside of the study zone were also included at the request of the property owners. In all, TPCHD sampled 16 parks, 18 public elementary schools, and 30 child care facilities.

A total of 1211 soil samples were collected and analyzed between February 25 and July 14, 2003. Four to eight samples were collected from surface soils at distinct play areas (called 'decision units', or 'DU's in this study) within each CUA. Laboratory analyses were performed by Severn Trent Laboratory (STL) in Tacoma. Data validation was performed by EcoChem, Inc. in Seattle. Based on the data quality assessments, all results reported by STL were of acceptable analytical quality.

Sample results were evaluated for individual samples, as well as for averages of all samples in a Decision Unit. The Washington State Model Toxics Control Act (MTCA) sets cleanup levels of arsenic and lead in soil at 20 ppm and 250 ppm respectively. For the Tacoma Smelter Plume project, Ecology also established Interim Action Trigger Levels (IATL), the concentration of arsenic or lead at a property at which an interim action would be warranted. These are levels above which Ecology does not want to rely solely on the soil safety practices such as hand washing, and recommends more aggressive action to keep children from playing in the contaminated soil. Interim Action Trigger Levels are set at a concentration for the average for a decision unit, and also at a concentration for one individual sample within a decision unit, as shown in the table below:

	Arsenic		**Lead**	
	Average DU	Individual	Average DU	Individual
Child Care/School	100 ppm	200 ppm	700 ppm	1400 ppm
Parks/Camps	200 ppm	400 ppm	1000 ppm	2000 ppm

Arsenic Results

Thirty eight child use properties had at least one individual sample with arsenic concentrations above the MTCA cleanup level of 20 ppm. A total of 269 individual samples contained arsenic above the MTCA cleanup level. At twenty properties, one or more decision units contained average arsenic above the MTCA cleanup level. One school had decision units with average arsenic concentrations above the Interim Action Trigger Level of 100 ppm. That school, along with one child care facility, also had individual samples above the IATL of 200 ppm for individual samples.

The following properties contained at least one decision unit with average arsenic above the MTCA level of 20 ppm.. The school with average arsenic above the IATL is highlighted in bold.

Child care facilities	**Average As (ppm)**
108	31.6
112	96.18*
116	23.25
118	30.50
121	21.04
128	36.0
137	23.5
139	38.7
144	38.6
146	28.39
168	31.95
173	47.4
Schools	
307 – Pt. Defiance	**114.2***
308 – Downing	26.9
315 – Wainwright	63.17
317 – Whittier	26.11
Parks	
436 - Curran Park (University Place)	46.04
497 - Colgate Park (University Place	45.47
442 - Sunset Terrace Park (University Place)	25.04
433 - Masko Park (Fircrest)	34.66

*Individual samples on this site exceeded the IATL of 200 ppm for individual samples

Lead Results

Eight properties had at least one individual sample with lead concentrations above the MTCA cleanup level of 250 ppm, with a total of 11 samples containing lead above the level. No properties had decision units with average lead above the MTCA cleanup level. Also, no child use areas had average lead levels or individual samples above the IATL.

At the time of sampling, TPCHD field staff discussed project objectives with property owners and operators and presented literature listing “Healthy Actions”, steps people can take to reduce their exposure to arsenic and lead in the soil. These steps were reiterated in letters sent to property owners along with the results, and in meetings arranged between property owners and TPCHD staff.

1 INTRODUCTION

The former ASARCO copper smelter operated in Ruston, Washington (a small municipality northwest of downtown Tacoma, Washington) for almost 100 years before closing permanently in 1986. Concerns over the health effects of soil contamination from smelter emissions of arsenic and other pollutants led to numerous studies starting in the early 1970s, resulting in designation of the smelter site and surrounding area as a federal Superfund Cleanup Site in the early 1980's. More recent studies have characterized the extent and pattern of contamination surrounding the old smelter outside of the Superfund boundary. These studies concluded that the pollutants from the former smokestack have been deposited onto soils over a wide area of King and Pierce Counties and correlate with distance and wind direction from the smelter. Based on these findings, the Washington State Department of Ecology (Ecology) and the Tacoma-Pierce County Health Department (TPCHD) decided it would be prudent to evaluate Child Use Areas (CUAs) in Tacoma and western Pierce County to address concerns about possible exposures in areas where small children might come into frequent contact with soils.

1.1 CUA Purpose and Objectives

The Tacoma-Pierce County Health Department (TPCHD) collected and analyzed soil samples from 64 child use areas (CUAs) on mainland Pierce County and Gig Harbor between February and July of 2003. The primary objective for sampling soils at CUAs was to identify locations where smelter-related contamination poses the greatest exposure risks to young children. Young children (up to the age of 6) are considered to be at higher risk of exposure because they come into frequent contact with soil, exhibit more mouthing behaviors, and are more sensitive to contaminants. The study also continues TPCHD's outreach and education efforts to raise awareness of arsenic contamination in Pierce County.

The depth profiles of soil contamination where soils have been disturbed by development activities can be complex, with contamination extending well below depths affected in undisturbed soils. Sampling at child use areas was not intended to fully characterize soil contamination at each property, or to necessarily identify the maximum concentrations occurring at any depth. The emphasis on potential soil exposures under current conditions meant limiting sampling to near-surface soils where soil contact is most likely to occur. For this reason, this study is a "health screening level" study rather than a MTCA site characterization study or remedial investigation.

1.2 Organization and Personnel

The design of the study components (selecting the child use areas to be sampled, sample locations, sample depths, and analyses performed) was a collaborative effort between Washington State Department of Ecology (Ecology), TPCHD, Public Health-Seattle & King County, the consulting firm SAIC, and was led by Gregory L. Glass, an independent consultant. This group is referred to as the Study Design Group (Table 1). SAIC was contracted by Ecology to carry out the child use area sampling in King County.

Table 1: Sample Design Group Participants

Agency/Company	Name	Role
Washington Department of Ecology	Marian Abbett	Project Coordinator
	Joyce Mercuri	Site Manager, Pierce County CUA Study
	Guy Barrett	Site Manager, King County CUA Study
	Norm Peck	Ecology Northwest Region Representative
Pierce County Health Department	Glenn Rollins	TPCHD Project Lead
	Jennifer Olson	TPCHD Field Sampler
	Lindsay Spencer	TPCHD Field Sampler
Public Health – Seattle and King County	Nicole Fus/Charles Wu	Team Lead, Tacoma Smelter Plume Project
	Gary Irvine	Environmental Health Services Supervisor
SAIC	Doug Pearman	Contractor to Ecology for King County CUA sampling
Gregory Glass Environmental Consulting	Greg Glass	Study Design Consultant

2 HISTORIC STUDIES

Previous studies have characterized smelter emissions and documented environmental contamination in areas surrounding the former Tacoma Smelter. Historic studies have been compiled and placed in Tacoma Smelter Plume Site project files at the Ecology and local health departments. References for historic studies are available in previous study design documents (c.f. Glass 1999, 2000, 2001, 2002). Compact discs with copies of older historical studies are also available at the Ecology site files. The geographic areas sampled, the types of land uses at sampled properties, the sampling and analysis protocols, and the intensity of sampling varied greatly among studies.

2.1 Studies through smelter closure

The early studies sampled a variety of environmental media to document contamination in areas surrounding the Tacoma Smelter. Sampled media included airborne particulates, precipitation, soils, house dusts, vegetation, sediments, surface water, reservoir sludges, bees, cows, and fish tissue, as well as human urinary and blood samples. Soil sampling included forested properties, roadside soils, residential areas, vacant lots, playfields, and gardens. With the exception of extensive garden soil testing and regional-scale precipitation chemistry monitoring, the early studies were generally small in scale and limited in geographic coverage. Sampling and analytical protocols varied significantly among studies.

Taking advantage of the announced closure date for smelter operations, several studies performed comparative pre- and post-closure sampling at the time of smelter shutdown. A comprehensive multimedia study was also performed at that time by a University of Washington research team to investigate the environmental pathway(s) by which community residents, especially young children, were being exposed to arsenic (Polissar et al. 1987). That Arsenic Exposure Pathways Study, while compiling new sampling information for multiple census tracts on Vashon-Maury Island, Ruston, and North Tacoma, was not designed to define the geographic nature and extent of soil contamination.

2.2 Superfund studies

Between 1987 and 1992, Ecology and USEPA performed a series of studies to define the nature and extent of residual soil contamination in areas near the former smelter (Ruston and North Tacoma, within a distance of approximately one mile). Those studies included a dense grid of sampling locations within the restricted study area. Selected soil samples were also analyzed for an extended list of elements, documenting correlations among elements related to smelter operations and emissions. Once cleanup actions at residential properties began under a Superfund Record of Decision, property-by-property sampling results provided an extremely detailed data set for soil contamination patterns and magnitudes. Cleanup actions at Ruston/North Tacoma properties are continuing under EPA's Superfund program.

2.3 Tacoma Smelter Plume Studies

Ecology, in cooperation with local health departments, is investigating widespread contamination from smelter emissions extending beyond the designated EPA Superfund site. Discovery of elevated arsenic and lead levels in University Place in 1997, and at a gravel pit on Maury Island in 1999, prompted Ecology to begin regional soil studies referred to as Tacoma Smelter Plume (TSP) studies. Five soils investigations have been performed under the TSP program as of 2004. Samples were analyzed for arsenic and lead, and some for additional tracer elements. Those studies are:

1) Vashon-Maury Island Initial Footprint Study (1999). This study collected and analyzed samples from 177 forested locations covering all of Vashon-Maury Island and near-shore areas on the King County Mainland east of Vashon-Maury Island.

2) Vashon-Maury Island Child Use Areas Study (2000). A total of 34 child use areas (beaches, parks, camps, schools, preschools, and child care centers) and some nearby forested sites were sampled.

3) King County Mainland Initial Footprint Study (2002). Samples were collected from 59 relatively undisturbed forested sites over an area approaching 200 square miles.

4) Pierce County Initial Footprint Study (2002). This study covered approximately 200 locations, over an area approaching 200 square miles (those portions of Pierce County west and north of I-5), to evaluate the regional-scale pattern of smelter-related soil

contamination in western Pierce County. Sampling locations include both forested and residential properties.

5) King County Mainland Child Use Area Study (2003). The parallel study to this Pierce County Child Use Area Study report was completed in King County by SAIC. A total of 97 child use areas were sampled.

An additional study is currently underway (Summer, 2004) to evaluate the wider extent of the contamination "footprint" in Pierce, King, Thurston, and Kitsap Counties.

TSP studies differ from previous investigations in that they have an expanded, regional-scale area of coverage, a systematic approach to selecting the land use types being sampled, consistent sampling and analysis protocols for regional sampling coverage, and a large number of samples, with a comparatively high sampling intensity. The results of TSP investigations are generally consistent with information from the previous studies, but they increase the knowledge of the magnitude and extent of regional soil contamination. Statistical and spatial evaluations of the data support the following conclusions:

- Results demonstrate a broad range of contaminant concentrations, from less than 1 ppm to substantially elevated levels.
- Contaminant levels are affected by history of property development and soil disturbance
- There is a large-scale spatial pattern of contamination. The regional-scale pattern of environmental contamination shows a distance/direction versus concentration relationship consistent with airborne smelter emissions and local wind rose patterns.
- The study area exhibits small-scale variability. Even within a distance as small as 50 feet, concentrations can vary several-fold.
- Levels of arsenic, lead, cadmium and other heavy metals demonstrate a high degree of correlation.

3 CHILD USE AREA STUDY DESIGN

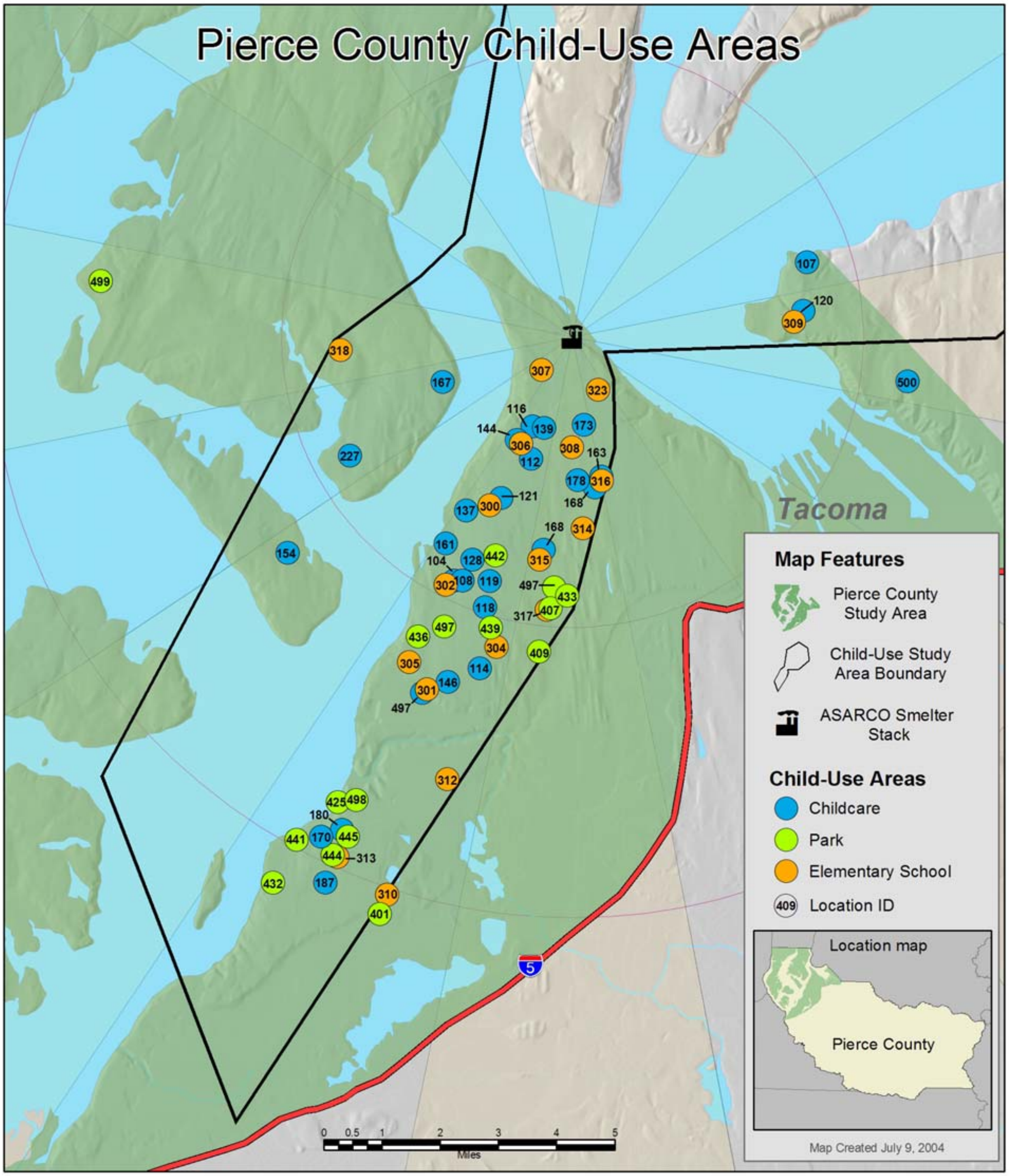
3.1 CUA Boundary

Based on sample results from relatively undisturbed properties (Glass 2004) which likely represent the upper limit of contaminant concentrations, and on prevailing wind directions from the smelter site, a boundary line was calculated to include all those sites where arsenic concentrations might exceed 100 ppm (the lowest interim action concentration identified by Ecology). A map of the study area and the sites sampled is shown on Figure 1. The general methodology for developing the boundary is detailed in Attachment A.

3.2 Identification of child use areas

Child use areas include any properties where young children are likely to be present with some frequency, and where their activities will put them in contact with potentially contaminated soils. Areas sampled for this study include elementary schools, preschools, child care facilities, parks, and playfields. Based on the results of sampling beaches on Vashon-Maury Island (PHSKC and Glass 2001), where arsenic and lead concentrations were uniformly low, beaches were excluded from this study.

Figure 1. Child Use Area Boundary And Facilities Sampled



TPCHD identified schools and parks from database lists provided through the Pierce County GIS system. A current list of licensed child care facilities in Pierce County was obtained from the Washington State Department of Social and Health Services (DSHS) and the Yellow Pages. Key contact people at local governments and neighborhood groups were also asked about other child use areas in their communities that were not listed in existing databases. TPCHD identified a total of 194 child use properties as potential sampling sites within the study area. The properties included 19 public and 5 private elementary schools, 40 parks, and 130 child care facilities. One child care facility and one state park outside of the project study zone were also included in the study at the request of the property owners.

3.2.1 Prioritization scheme

A system was developed by the study design team to prioritize sampling of the CUAs most likely to have high concentrations of lead and arsenic. Information on four factors was compiled for each CUA to derive a numerical score for establishing sampling priorities: distance and direction from the smelter site, number of young children using the facility, frequency of use, and the development history of the property. Data on facility development history and the number of children using the site were gathered from access agreements and interviews with owners and operators as well as the DSHS database. Properties that had no information about the year of last development were given a default year of 1940 for the City of Tacoma, 1970 on the Gig Harbor Peninsula and Fox Island, and 1960 for all other areas.

The individual scores on these four factors were combined to calculate a single overall score for each candidate child use area (see Attachment B for details). The child use areas were then prioritized by these scores, with higher scores indicating a higher priority for sampling. Priority was given to CUAs that were closer to the smelter site, that were downwind, which had larger numbers of young children using the facility, and that had not had major development or redevelopment since smelter closure. This system was developed to make the best use of limited agency resources, which would not permit sampling of every site; however, because so few child care facilities returned access agreements, all sites which allowed access could be sampled.

3.2.2 Access agreements

TPCHD made personal contact with the school districts to gain access to public schools and contacted local governments for permission to sample at parks. The personal contacts were followed up with a written access agreement form. Access from private schools and private child care operators was requested by mailing the written access agreement with a cover letter explaining the project to the property owners of child use areas selected for sampling (Attachment C). The access agreement addressed the legality of entering and sampling property and inquired about the number and age of children using the facility or property, property history, and specific areas used by the children. The access agreement also provided a check box where property owners could request a copy of the results of the samples collected from their property. No sampling was performed without a completed access agreement.

In all, TPCHD received permission to sample all 19 public elementary schools, 33 of 131 child care facilities (including one outside of the study boundary), and 22 of 41 parks (including one state park, Kopachuck, which was outside of the study boundary). Some of the sites for which we gained access were not sampled because they did not contain child use areas or exposed soils. A complete discussion of sites sampled and not sampled is included in Section 4.

3.3 Sampling strategy

3.3.1 Exclusion areas

Exclusion criteria were established to concentrate on areas most likely to contain contamination from the smelter and to avoid confounding results from non-smelter sources of contamination. Excluded areas include:

- Areas within ten feet from roads and twenty feet from railways
- Wetlands
- Steep slopes
- Flood plains
- Lakes
- Shorelines
- Areas with restricted access
- Areas with substantial soil disturbance
- Areas that have already had extensive sampling
- Inaccessible soils, such as those beneath buildings, paved driveways or patios
- Areas with cover one foot deep or more, such as gravel, wood chips or sand
- Areas with a barrier, such as a rubber mat or a liner covered with gravel, wood chips, or other non-soil material
- Three feet from possible treated wood structures such as play sets and fences
- Five feet from painted structures that may have lead-based paints

The Ruston/North Tacoma Superfund site was also excluded from the study. However, Point Defiance Elementary School was included in the study, even though part of the property lies within the Superfund site.

3.3.2 Decision units, borings, and depths

Child use properties were subdivided into multiple areas that reflected various activities, land uses, property histories, or other factors. These areas were called "decision units" (DU), since the decisions on appropriate response actions varied from one portion of the property to another. Small child use areas such as child cares usually contained a single decision unit. Elementary schools often contained two or three. The maximum number of decision units at any site was three.

Decision units were defined at the selected child use areas by the field sampling teams, based on observations and discussions with property owners. The set of defined decision units did not have to provide complete coverage of the entire property. For example, areas that were not used by children, play areas that already had a deep cover layer (such as sand or wood chips) that minimized contact with potentially contaminated soils, or landscaped areas, were not sampled.

Samples were collected from 4-10 borings at each decision unit. Field samplers selected boring locations at the time of sampling. Samples were collected from two depth intervals in each boring, 0-2 inches and 2-6 inches. The "zero" depth from which depth measurements were taken was defined as the bottom of the root mass for grass cover, just below other types of cover (e.g., wood chips), or just below the duff layer, if one existed. These two depth intervals provide information to characterize near-surface soils in areas where children may be exposed to them. The depth intervals are consistent with the near-surface intervals used throughout the set of Tacoma Smelter Plume investigations.

All samples collected and analyzed at child use areas represent discrete samples, collected from a single depth interval from a single boring. Soils from multiple borings, or multiple depth intervals within a boring, were not composited for lab analyses. Discrete samples provide the most detailed information on soil contamination in a decision unit; however, the sampling design was not intended to provide complete characterization of soil contamination at a DU.

3.3.3 Sample numbering scheme

The sample numbering scheme was designed to incorporate all the essential information about the property, DU, and the specific boring.
An example of a sample number is: 124-3-07-1-6, where fields are:

Property I.D. # - Decision Unit # - Boring # - Depth - Type of Sample

- The **property identification number** is a three-digit number that uniquely identifies the property. Properties 101-299 are child cares; properties 300-399 are schools; properties 400-499 are parks; and properties 500-599 do not fall in to one of the other categories. The properties are numbered in descending rank (i.e., the highest ranked child care is number 101, the highest ranked school is 300, etc).

- The **decision unit number** represents the specific decision unit on the property that was sampled.

- The **boring number** represents the boring in the sequence it was collected within one DU.

- The **depth number** represents whether the sample was taken from 0-2” or 2-6”.
  0-2” depth: **1**
  2-6” depth: **2**

- The **type of sample** category (see Quality control, below) represents the specific sample type as follows:
  - Regular soil sample: **4**
  - Duplicate sample: **5**
  - Rinsate sample: **6**

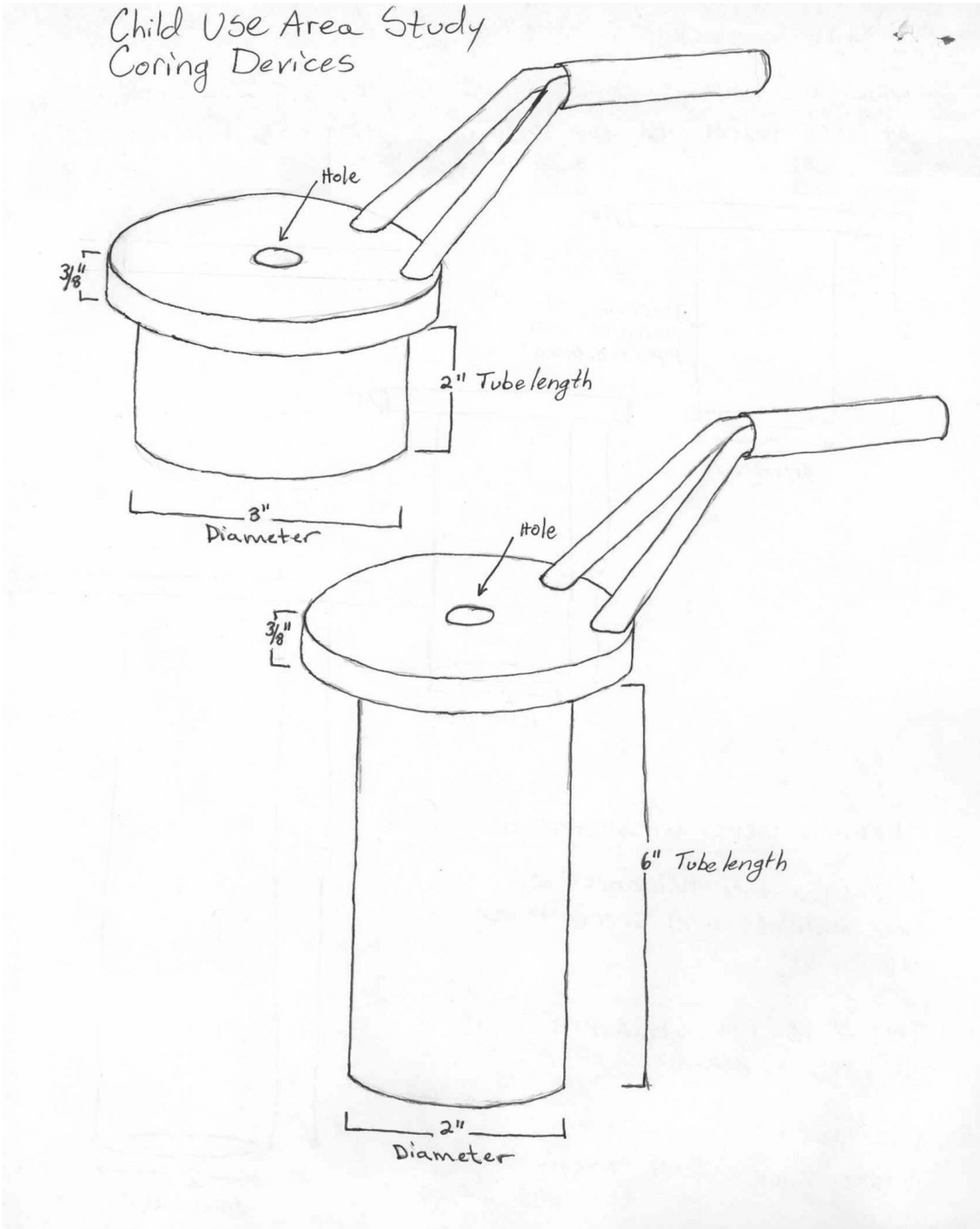
3.3.4 Equipment

The following equipment was used when collecting samples in the field:

- Backpack
- 2 stainless steel coring devices, lengths 2" and 6"
- Four pound mallet
- Latex gloves
- Earplugs
- Stainless steel bowls, spoons and trowel
- Crowbar
- Aluminum foil
- Rite-in-the-Rain field data sheets and pens
- Orthographic photos of the property
- Labels and stickers for the sample jars
- Gardening topsoil
- Liqui-Nox® detergent and deionized water
- Bottlebrushes
- 8 oz. Sampling jars (provided by STL)
- Pre-preserved (HNO_3) sample rinsate bottles (provided by lab)
- 2 gallon water sprayer
- De-ionized water (provided by STL)
- Kneeling pads
- Garbage bags
- Cooler and ice packs for sample storage in the field

The coring devices are 2- and 6-inch long stainless steel tubes with a diameter of 3" and 2" respectively. They are topped with 3/8" steel plates and handles (Figure 2). The devices were designed by Ecology and modified for this project. They were made at Zeigler's Welding in Olympia, Washington.

Figure 2. Coring Devices Used For Collecting Soil



3.3.5 Field protocol

A two-person team performed the soil sampling. Property owners were notified prior to sampling to arrange a time and date. While sampling, the residents/owners of the property were able to observe the sampling procedure outside the 10-foot radius of the sampling location. Below is the description of sample protocol while samplers are on site.

a. Samplers donned latex gloves prior to beginning work.
b. Any fallen leaves, pine needles, or other non-soil materials on the ground were removed (this does not include grass).
c. The 2” long coring device was driven into the ground using a four-pound mallet.
d. The coring device was removed from the ground, using a crowbar if necessary.
e. The soil was transferred from the pipe to aluminum foil or a stainless steel bowl by tapping lightly on the outside of the pipe with the mallet. The sample was kept out of the wind to prevent fine soil from blowing away. If the soil did not remain in the coring device when it was removed from the ground, the field staff dug the sample out using a clean stainless steel spoon.
f. If the coring device could not be driven into the ground due to an obstruction such as a large rock or root, the boring was either abandoned and a second adjacent hole created, or the obstruction was removed with the spoon or crowbar and sampling resumed. Any soil samples that were collected in an abandoned boring were discarded and the hole refilled.
g. Any tufts of grass and roots were removed from the sample. The soils were shaken from the roots onto the foil. Any large rocks or organic matter, such as sticks or roots, were removed (clay and soil particles were left in place, which the lab processed when sieving.) The soil was homogenized before being placed the sample jar.
h. The soil sample was transferred into sterile glass jars provided by STL Seattle Laboratory, using the stainless steel spoons. The jars were labeled with: the date and time, sampler name or initials, sample number and location, and a bright sticker to easily identify the sample as a TPCHD sample.
i. The 6” coring device was placed into the same hole to obtain the 2-6” sample, which was processed as described above.
j. Sample core equipment, spoons, and bowls were decontaminated by scrubbing with a brush and diluted Liqui-Nox® detergent, and rinsing with deionized water.
k. The site was returned to as close to the original conditions as possible, backfilling the borings with clean topsoil or sand and replacing the grass plug.
l. All information was collected and recorded on field data sheets, orthophotos, sample label, and chain of custody form.
m. Samples were delivered to STL Seattle where they were placed in a locked refrigerator and maintained at 4^{o}C until analyzed.

3.4 Quality control

A Quality Assurance Project Plan for the Child Use Area Project covering both Pierce and King Counties was developed by Ecology contractor SAIC (SAIC, 2002). A separate Field Sampling

Plan for the Child Use Area Project in Pierce County was developed by TPCHD (TPCHD, November, 2002).

3.4.1 Field duplicates

Field precision was assessed through the analysis of duplicate field samples collected from a particular sampling point. Approximately 5% of the total samples were collected as duplicates, spatially located throughout the study area. Duplicates were collected for the 0-2" and 2-6" depths from the same boring. A single sample was placed on a sheet of aluminum foil, any large rocks or sticks removed, homogenized using a stainless steel spoon, split in half, and analyzed as two separate samples. The location of field duplicate samples was not pre-selected because they were a test of field variability and sample collection competence. The locations were positioned throughout the study area and mapped to show where the duplicates were collected. All field duplicate samples fell well within the 50% relative percent difference acceptance limits specified in the QAPP.

3.4.2 Field rinsates

The equipment rinsates were obtained by rinsing the sampling equipment with deionized water after it was decontaminated, and collecting the water in an 8-oz plastic sample container provided by the lab. All containers used for the rinsate samples contained a small amount (~2 ml) of HNO_3 as a preservative. The container was labeled with the date and sample number using the sample numbering scheme described above, placed in a cooler with "blue ice" ice packs, and transported to STL Seattle as a rinsate sample. The sample number and type were noted on the field data sheets.

Equipment rinsate samples were collected for approximately 2.5% of the total samples, or every fortieth boring. The potential for cross contamination of samples from equipment is very low with proper washing. Rinsate results were not expected to be highly important to successful soil sample results, thus the low frequency of rinsates. The location of rinsate samples was not pre-selected because they are a test of field and sample collection competence. The locations were dispersed throughout the study area. Each rinsate spot was mapped to show which properties had rinsates collected. The rinsate samples were collected for each sampling depth in the boring. All rinsate sample results were below detection levels.

3.4.3 Decontamination and waste handling

To prevent the cross-contamination of samples, sampling devices were washed after each sample was collected to remove any adhering soil. The sampling devices were cleaned using Liqui-Nox® detergent, deionized water and a bottlebrush. Liqui-Nox® detergent is made by Alconox, Inc. and does not contain any phosphates that could affect sample results. The detergent was diluted, with one liter of water per10 ml Liqui-Nox®. The wastewater generated from washing and rinsing tools was discarded on the site.

3.4.4 Sample shipping and chain of custody

Samples were placed in a cooler with "blue ice" packs and kept in the field until transferred to STL Seattle. Samples were generally transported to STL Seattle the day they were collected, or sometimes held overnight at TPCHD in a secure refrigerated location. The Chain-of-Custody form was included in each sample shipment (Attachment D). The forms were printed from a STL Seattle template. The chain of custody forms indicate the date the samples were collected and the date they were delivered to STL Seattle. STL Seattle was responsible for filling out the chain of custodies and shipping all soil samples for further analysis.

3.5 Sample Analysis

3.5.1 Analytical methods

Prior to digestion, the entire soil sample was removed from its container, sieved through a 2mm sieve, then homogenized. This procedure is consistent with MTCA protocols [WAC 173-340-740(7)(d)]. The portion of the sieved homogenized material that was not needed for the primary analysis was returned to the original container. The samples were then prepared using a microwave digestion technique (USEPA SW 846 Method 3051A). Total arsenic and lead in the soil samples was analyzed by ICP-mass spectrometry (ICP-MS; USEPA method 6020). The reporting limits (RL) for this project are the practical quantitation limits (PQL). The PQL for the ICP-MS method is 1.0 mg/kg for arsenic and 0.5 mg/kg for lead. The laboratory method detection limits (MDL) for ICP-MS are 0.1537 mg/Kg for arsenic and 0.0232 mg/Kg for lead. Percent moisture was determined for each sample and sample results reported on a dry-weight basis.

The water samples from the field equipment rinsates were also analyzed for arsenic and lead. The samples were preserved in jars containing 2ml of nitric acid. The water was digested using Method 3015A and analyzed using ICP-MS.

3.5.2 Laboratory QA/QC

The laboratory was required to complete several QC elements; some were required by the EPA analytical method, others were project-imposed, in order for the data to be considered valid and accurate. These elements are as follows:

- Chain-of-custody and technical holding times: the sample chain-of-custody must show that, once the samples were received by the laboratory, they were under constant custody and control of the laboratory. The EPA analytical method requires that samples be digested and analyzed within 180 days of sample collection.
- Initial and continuing calibration verification
- Blanks (instrument, method, and field)
- Standard reference materials
- Matrix spike and matrix spike duplicate samples
- Laboratory duplicate samples
- ICP interference check samples

- ICP serial dilution

The frequency, acceptance criteria, and resulting laboratory action for each of these QC elements are explained in the quality assurance project plan (QAPP; SAIC 2002).

One hundred percent of the data were validated by EcoChem. The data were reviewed using guidance and quality control criteria documented in the analytical method, the QAPP (SAIC 2002) and National Functional Guidelines for Inorganic Data Review (USEPA 1994). Ten percent of the data packages received a full data review (commonly called a Level IV validation) and the rest received a compliance screening evaluation (commonly called Level III). Technical validation involves comparison of QC standards and instrument performance results to required control limits. In addition, the laboratory electronic data deliverable (EDD) was loaded into the data quality screening tool (EcoChem DQST). The following QC elements were reviewed for data packages undergoing summary validation:

- Analytical holding times (from summary forms).
- Chain of custody and sample handling
- Preparation Blank contamination (from summary forms)
- Initial and continuing calibration verification (from summary forms).
- Continuing calibration blanks (CCB) (from summary forms and raw data).
- Interference check samples results (from summary forms and raw data).
- Internal standards, ICP/MS only (from summary forms).
- Instrument tuning standards, ICP/MS only (from summary forms).
- Analytical accuracy (matrix spike compounds and standard reference materials [SRM]), expressed as percent recovery (%R; from summary forms).
- Analytical and field precision (comparison of duplicate sample results) expressed as relative percent difference (RPD; from summary forms).
- Reported detection limits (from sample result summaries).

Full validation included a review of all the items listed above for summary validation, plus the following QC elements:

- Compound identification (from raw data).
- Compound quantitation, transcription and calculation checks (from raw data).
- Transcription and calculation checks performed at a frequency of 10%. If an error was noted, 100% of the calculations and transcriptions for that data set were verified.

Full validation was performed on the initial data package and on approximately 10% of randomly selected data packages produced throughout the project. No significant deviations from required protocols and QC criteria were noticed; the remaining data (approximately 90%) received a summary validation.

No sample results were rejected during validation. No sample results were changed from detects or estimated detects to non-detects during the validation process.

4 RESULTS

As described in section 3.2.2, TPCHD received permission to sample all of the 19 public elementary schools, 33 of 131 child care facilities (including one outside of the study boundary), and 22 of 41 parks (including one state park, Kopachuck, which was outside of the study boundary). A final summary of properties actually sampled is shown on Table 2 and includes: 18 public elementary schools, 30 child care facilities, and 16 parks. An explanation of sites not sampled is shown below:

- Five private elementary schools did not return the access agreements.
- Fourteen facilities operated by Metro Parks Tacoma were not sampled because Metro Parks, Ecology, and TPCHD did not agree on conditions requested by Metro Parks for an access agreement to conduct the sampling.
- Five additional parks did not return access agreements: Chambers Creek Park (Department of Natural Resources), Fox Island Playfield, Dash Point and Fort Steilacoom Parks (Washington State Parks), and the Brown's Point Lighthouse Park (U.S. Lighthouse).
- Six of the parks that provided access were not sampled because they did not contain child use areas or exposed soils (for example, wetland or nature parks, paved areas). Those parks were: Emerson Park (Fircrest), Saltar and Farrell Marsh Parks (Steilacoom), City Park and Adriana Hess Park in University Place, and Alice Peers Park in Fircrest.
- Three of the child care facilities were not sampled because they did not have soils to sample – for example their play areas contained wood chips or gravel.
- Washington-Hoyt Elementary School in the Tacoma School District had paved play areas so was also not sampled.

Table 2. Child Use Facilities Sampled

SCHOOLS	
Clover Park School District	**Steilacoom School District**
Lake Louise Elementary School	Cherrydale Elementary School
Oakbrook Elementary School	
	Tacoma School District #10
Peninsula School District	Brown's Point Elementary School
Harbor Heights Elementary School	DeLong Elementary School
	Downing Elementary School
University Place School District	Geiger Elementary School
Chambers Primary School	Jefferson Elementary School
Evergreen Primary School	Point Defiance Elementary School
Sunset Primary School	Skyline Elementary School
University Place Primary School	Sherman Elementary School
	Wainwright Elementary School
	Whittier Elementary School
PARKS	
Fircrest	**University Place**
Fircrest Park	Curran Apple Orchard
Tot Lot	Homestead Park
Whittier Park	Sunset Terrace Park
Alameda Park	Curtis/Colgate Park
Masko Park	
	Lakewood
Steilacoom	Washington Park
Sunnyside Park	
Cormorant Park	**Washington State**
Webber Court Community Park	Kopachuck State Park
Cherrydale Park	
Manitoba Park	
CHILD CARE CENTERS (# of facilities in each municipality)	
Fircrest (1)	Steilacoom (2)
Fox Island (1)	Tacoma (16) (NE Tacoma -1)
Gig Harbor (2)	University Place (7)

4.1 Comparisons to MTCA cleanup levels

The Model Toxics Control Act (MTCA) is the Washington state law governing cleanup of contaminated soil, water, and air in Washington. MTCA cleanup levels are:

- 20 parts per million for arsenic
- 250 parts per million for lead

4.1.1 Individual samples

A total of 1211 samples were collected and analyzed during this study. Refer to Attachment E for a complete list of results for each property. Contaminant levels of individual samples exhibited a wide variation, ranging from 0.94 – 691 ppm for arsenic and 1.32 – 1040 ppm for lead. Two hundred and sixty nine individual samples (22%) contained arsenic above the MTCA cleanup level. Eleven individual samples (less than 1%) contained lead above he MTCA cleanup level.

Of the 64 properties sampled, 38 had at least one individual arsenic result above MTCA limits, including 20 child cares, 10 schools, and 8 parks (Table 3). Seven child use properties contained at least one individual lead result above MTCA limits, including 3 child cares, 2 schools, and 2 parks. One child care (#112) had particularly high arsenic and lead levels in an individual sample: 429 ppm arsenic and 502 ppm lead. Point Defiance Elementary also stood out, with individual samples containing 691 ppm arsenic and 1040 ppm lead.

4.1.2 Decision Unit Averages

Average lead and arsenic values were calculated from the 4-10 individual samples obtained at decision units at each property. Twenty facilities (31%) contained decision units in which average arsenic contamination exceeded 20 ppm in one or both depth profiles: 12 child cares, 4 schools, and 4 parks (Table 3). Again, child care #112 and Point Defiance Elementary had notably high averages. At Point Defiance, all three DUs had average arsenic levels over MTCA. Other public schools with elevated average average arsenic contaminant levels were Downing, Wainwright, and Whittier Elementary – all within the Tacoma School District. No child use area had average lead levels over the MTCA cleanup level. The highest average concentrations for a DU were 114.42 for arsenic and 170.30 for lead, both at Point Defiance Elementary School.

4.2 Comparisons to Interim Action Trigger Levels

Ecology also developed "interim action trigger levels" (IATL), contaminant levels above which Ecology does not want to rely solely on soil safety guidelines such as hand washing, and recommends more aggressive action to keep children from playing in the contaminated soil. Ecology refers to these as interim actions. IATL are based on risk assessment methods, a detailed description of which can be found at on the Department of Ecology Web Site at: http://www.ecy.wa.gov/programs/tcp/sites/tacoma_smelter/ts_q_and_a.pdf

The Interim Action Trigger Levels are:

	Arsenic		**Lead**	
	Average DU	Individual	Average DU	Individual
Child Care/School	100 ppm	200 ppm	700 ppm	1400 ppm
Parks/Camps	200 ppm	400 ppm	1000 ppm	2000 ppm

For child use areas with averages above these levels, Ecology plans to work with the property owner to determine ways to provide clean play areas for children.

4.2.1. Individual samples

Only two properties had individual samples that were above individual IATL level: child care #112, which had three samples with 257, 331, and 429 ppm arsenic; and Point Defiance Elementary (#307), which had arsenic levels of 557 and 691ppm. There were no individual lead samples above the IATL.

4.2.2 DU averages

Only one property, #307 (Point Defiance Elementary) contained an average in a DU that exceeded the IATL. The average level of arsenic at a decision unit on this site was 114.4 ppm. The maximum individual and average was in a vacant parcel adjacent to the school grounds that is not regularly used by children, but may be developed for school use in the future. This area had some soils removed in the past as a part of the Asarco Superfund cleanup (part of the site is in the Superfund Cleanup zone). Some individual samples on the main school grounds did contain levels of arsenic which were of concern to school officials, although not above the IATL. In response, officials in the Tacoma School District capped the playground with asphalt, and the top two feet of soil from the ballfield were removed and replaced with clean fill.

Table 3. Properties With Arsenic or Lead Above MTCA and IATL Limits*

Site #	Name	Decision Unit # 1 Average above MTCA				Decision Unit # 2 Average above MTCA				Decision Unit # 3 Average above MTCA				Highest Individual Result above MTCA		Exceeds IATL (average or individual)	
		0-2”		2-6”		0-2”		2-6”		0-2”		2-6”					
		As	Pb	As	Pb	As	Pb	As	Pb	As	Pb	As	Pb	As	Pb	As	Pb
Child Care Facilities																	
107														42.1	311		
108		24.2		31.6										43.5			
112		77.1		96.2		67		28.1						429	502	*	
114														29.9			
116		20.4		23.2										40.4			
118		30.5		29.7										68.1			
120														20.9			
121				21										63.5			
128		36.0		29.3										65.0			
137				23.5										31.2			
139		38.7		36										74.6			
143														25.0			
144		21.9		38.6										60.9			
146				28.4										74.3			
161														20.6			
168		32		29.5										51.5	272		
173		43.4		47.4										60.3			
178														25.5			
222														22.3			
500														32.9			

Site #	Name	Decision Unit # 1 Average above MTCA				Decision Unit # 2 Average above MTCA				Decision Unit # 3 Average above MTCA				Highest Individual Result above MTCA		Exceeds IATL (average or individual)	
		0-2”		2-6”		0-2”		2-6”		0-2”		2-6”					
		As	Pb	As	Pb	As	Pb	As	Pb	As	Pb	As	Pb	As	Pb	As	Pb
<u>Schools</u>																	
301	Chambers													37.1			
315	Wainwright									63.2		33.9		142.0	382		
317	Whittier					20.4		26.1						48.3			
307	Pt. Defiance			31.2		40.3		20		91.3		114.4		691	1040	*	
308	Downing	23.6		26.9										99			
309	Brown’s Point													27			
318	Harbor Heights													37.7			
310	Lake Louise													39.7			
305	Sunset													52.8			
313	Cherrydale													72.5			
<u>Parks</u>																	
409	Alameda													28.2			
433	Masko	34.7		25.3										78	250		
436	Curran	33.5		46.04										148			
439	Homestead													46.4			
442	Sunset Terrace			25										67.1			
497	Colgate	32		45.5										93.5			
498	Manitoba													25.9	595		

* Only exceedances are shown on this table. Blank squares in the table indicate that the property did not have this decision unit or that there were not exceedances. If a property is not listed on this table, there were not exceedances of the MTCA or IATL levels at that site.

<u>Table 3, continued</u>

4.3 Additional data analysis

The intent of the Child Use Area study was to determine if any properties where small children play present any health risks due to arsenic or lead contamination in soil. With this objective in mind, soil samples were collected, analyzed and compared to MTCA Cleanup Levels and Interim Action Trigger Levels (Sections 4.1 and 4.2 above).

In the following sections, an attempt was made to find global, or region-wide, trends in the resulting data. A caution must be noted: previous Tacoma Smelter Plume studies (and supported by this study) demonstrate that soil sampling results should not generally be assumed to be representative of unsampled areas at that property or other nearby properties based on the high variability of the results. Property-specific sampling is recommended for determining the degree of soil contamination at a property or area of interest. The larger spatial patterns are most useful in establishing a range within which property-specific results are expected to occur, rather than predicting actual levels of contamination, which are strongly affected by property development histories and local variations in the deposition of airborne contaminants.
The following data evaluations assume that the data are parametric, which may not be true. The variability within the data set indicates that there are factors affecting contaminant distribution that Ecology and the Tacoma-Pierce County Health Department do not understand and cannot draw meaningful conclusions about with the data currently available. These comparisons MAY provide some preliminary clues about potential sources of variability, and/or some preliminary suggestions of trends when viewed in combination with data from previous studies. Do not rely on the results of these evaluations as the basis for any regulatory or planning decisions at any higher level than the property-specific evaluations discussed in section 4.2 above.

4.3.1 By depth

Taking the child use area data set as a whole, the distribution of arsenic and lead in the 0-2” layer was compared to the distribution in the 2-6” layer in a pairwise comparison using the Student’s t-test. Total mean arsenic and lead concentrations by depth did not exhibit any statistical significance (paired t-test: $p = 0.135$ for As, $p = 0.114$ for Pb). That is - the amount of contamination appears to be the same in the 0-2” layer as it is in the 2-6” layer if the data set is looked at as a whole. Review of the data by depth for different wind directions is discussed in the next section. (See attachment G for the t-test results).

4.3.2 By wind vector

The wind rose from the smelter was divided into 16 different vectors of 22.5 degrees each, designated A through P (Figure 3). Wind vector A covered 11.25 degrees on either side of true north (348.75 to 11.25 degrees). Wind vector B included 11.25 through 33.75 degrees, and so on. Wind vectors covered in this study were D, E, H, I, J, K, L and M. Means and standard deviations of arsenic and lead concentrations for the 0-2” and 2-6” depths were calculated for samples in each wind vector to look at differences in arsenic and lead concentrations versus wind direction (Tables 4 and 5). In a number of cases, the standard deviation is higher than the mean, demonstrating the wide variation in the data. Distribution of all samples (without regard for depth) by wind vector is shown on Figures 4 and 5.

FIGURE 3: Wind Vectors and Child Use Area Boundary for Pierce and King Counties

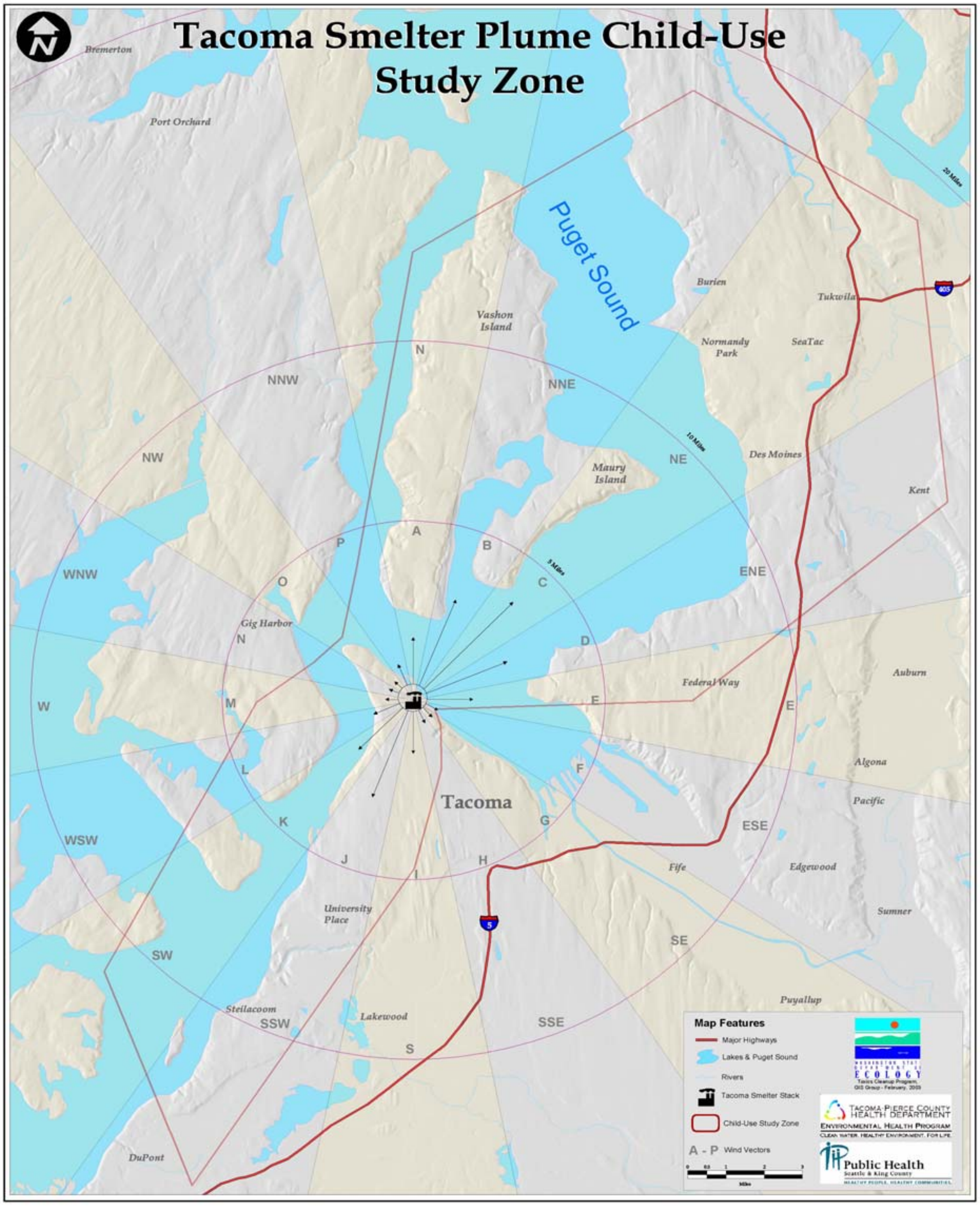


Table 4: Summary statistics for arsenic concentrations by wind vector.

Wind vector	Mean concentration 0-2 in	±SD	Min	Max	Mean concentration 2-6 in	±SD	Min	Max
D	16.36	8.63	8.82	42.10	11.80	5.66	3.09	42.10
E	11.31	8.18	1.08	25.80	12.25	9.36	1.08	32.90
H	4.55	4.74	0.94	17.50	4.90	3.86	0.94	17.50
I	15.01	20.01	0.95	142.00	15.04	16.21	0.95	142.00
J	18.30	39.59	0.96	557.00	20.70	46.04	0.96	691.00
K	3.29	2.87	1.01	8.61	3.02	2.59	1.01	8.92
L	4.83	2.19	2.58	10.30	4.31	1.69	2.46	10.30
M	3.67	0.98	2.05	5.16	3.23	1.03	2.02	5.16

Table 5: Summary statistics for lead concentrations by wind vector.

Wind vector	Mean concentration 0-2 in	±SD	Min	Max	Mean concentration 2-6 in	±SD	Min	Max
D	50.78	82.66	13.80	311.00	21.90	59.54	4.45	311.00
E	25.53	21.52	1.83	77.30	26.65	23.90	1.74	99.70
H	13.93	12.03	1.34	38.50	15.59	13.48	1.32	50.90
I	43.66	58.89	1.67	382.00	40.88	56.78	1.39	382.00
J	41.68	68.20	2.10	807.00	39.53	68.63	1.62	1040.00
K	5.93	5.40	1.39	16.90	5.08	5.36	1.38	19.50
L	9.65	6.46	3.79	24.90	7.20	5.53	2.75	24.90
M	11.47	2.86	2.86	16.00	9.05	3.21	4.52	16.00

An analysis of variance (ANOVA) of arsenic and lead results by depth layer, across each wind vector, showed significant difference between wind vectors (one-way ANOVA: $p=0.001$ for As; $p = 0.000$ for lead). (See attachment G for the statistical comparison). That is - the distribution of arsenic and lead in a depth layer differs across wind vectors. A multiple comparison of the distributions (e.g., Dunnett's) was not performed to determine which vectors are driving the difference. However, the relationships are illustrated graphically in figures 6 and 7. Arsenic and lead values in the 0-2" range in the prevailing wind directions (vectors D, I, and J) were higher than the results for the 0-2" range in the other vectors; the same holds true for the 2-6" range except for vector E. It should be noted that the sample sizes for wind vectors D, E, L, and M were fairly small (24 samples in vectors D and M, and 32 samples in vectors E and L).

Pairwise comparisons (t-tests) of arsenic and lead results between 0-2" layer to the 2-6" layer within each wind vector were not performed to evaluate significant differences between depth layers in each wind sector. However, this relationship can also be seen graphically in Figures 6 and 7. In vectors D, K, L, and M, arsenic levels appear to be higher in the 0-2" layer than the 2-6" layer, while the opposite is the case in vectors E, H, I, and J. Except for vectors E and H, lead levels appear to be higher in the 0-2" layer than the 2-6" layer. Reminder: with the high variability of the data set, these differences are not significant.

4.3.3 Arsenic/Lead correlation

Data from the Pierce County Footprint Study show evidence of a roughly 2:1 ratio of lead to arsenic. Regression analyses were performed for the CUA data to statistically evaluate the relationship between arsenic and lead. A series of scatterplots was prepared which graphed the $\log_{10}$ ratio of arsenic to lead for both depths combined in the different wind vectors (Attachment F). A $\log_{10}$-$\log_{10}$ plot of the data produced a nominal linear relationship. Wind vectors E and L show fairly high correlation between arsenic and lead: E ($R^2 = 0.9142$) and L ($R^2 = 0.9179$). The lead to arsenic ratio for these vectors is: E = 1.2:1, and L = 1.03:1; lower than what is seen in the Footprint Study. This probably reflects a high level of soil disturbance, and is certainly influenced by the high degree of variability.

Table 6: Linear Regression Analysis Results

Data Set (both depths combined)	Sample Size (n)	R^2
Vector D	24	76.4%
Vector E	32	91.4%
Vector H	40	86.8%
Vector I	283	69.6%
Vector J	723	78.0%
Vector K	48	72.4%
Vector L	32	91.8%
Vector M	24	39.5%

Figure 4. Arsenic distribution by wind vector

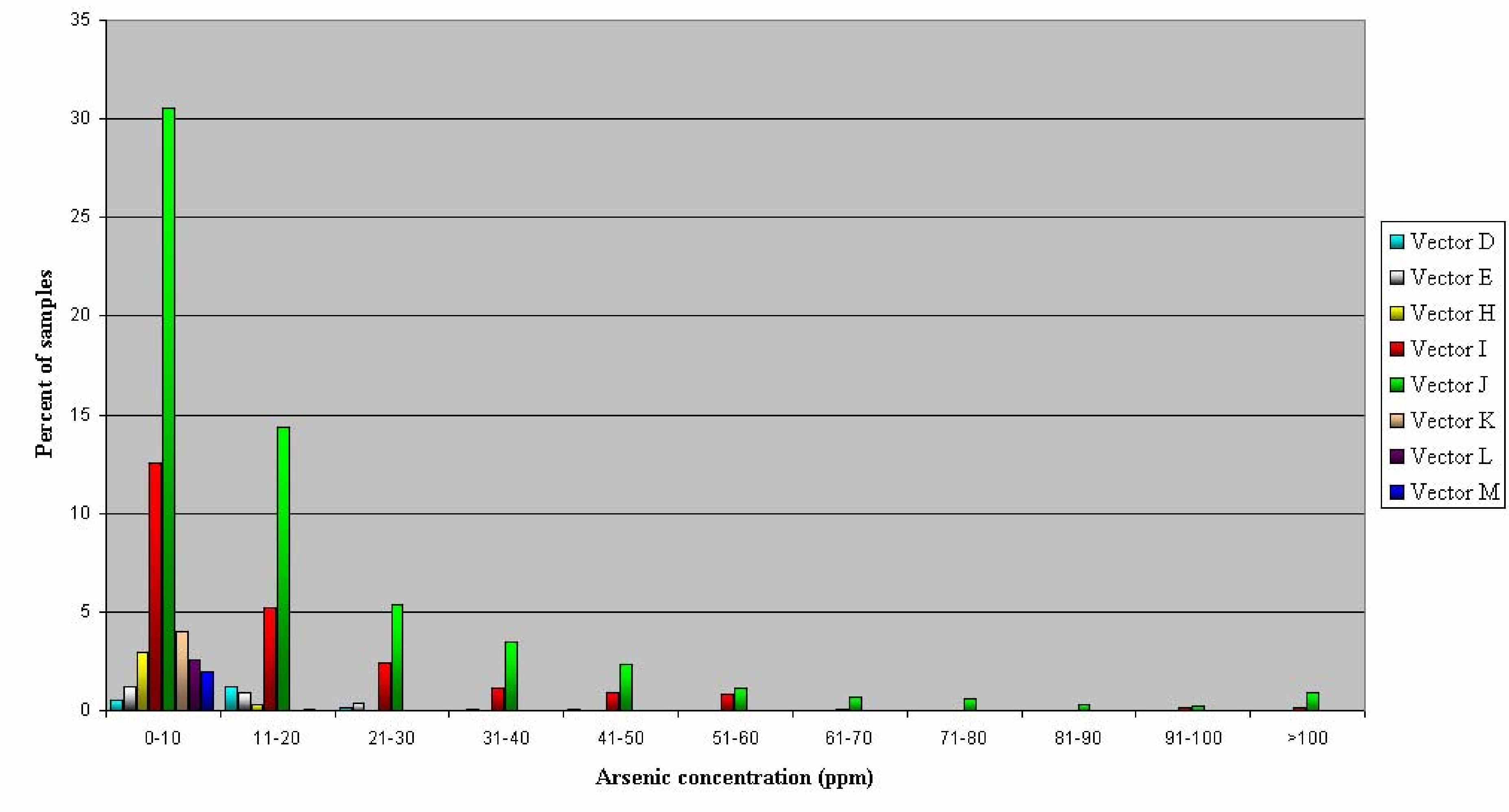


Figure 5. Lead distribution by wind vector

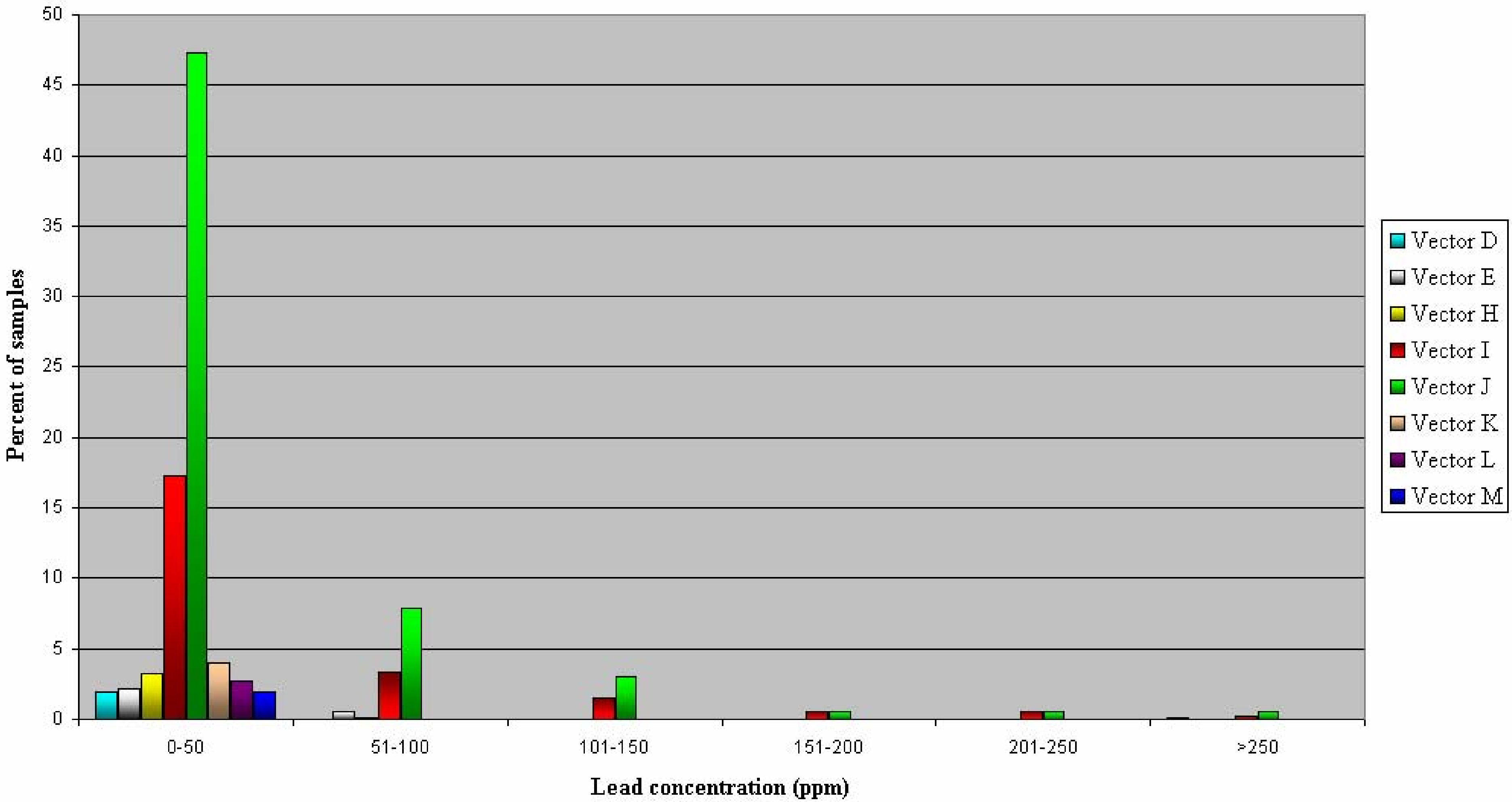


Figure 6. Mean arsenic concentration by wind vector and depth

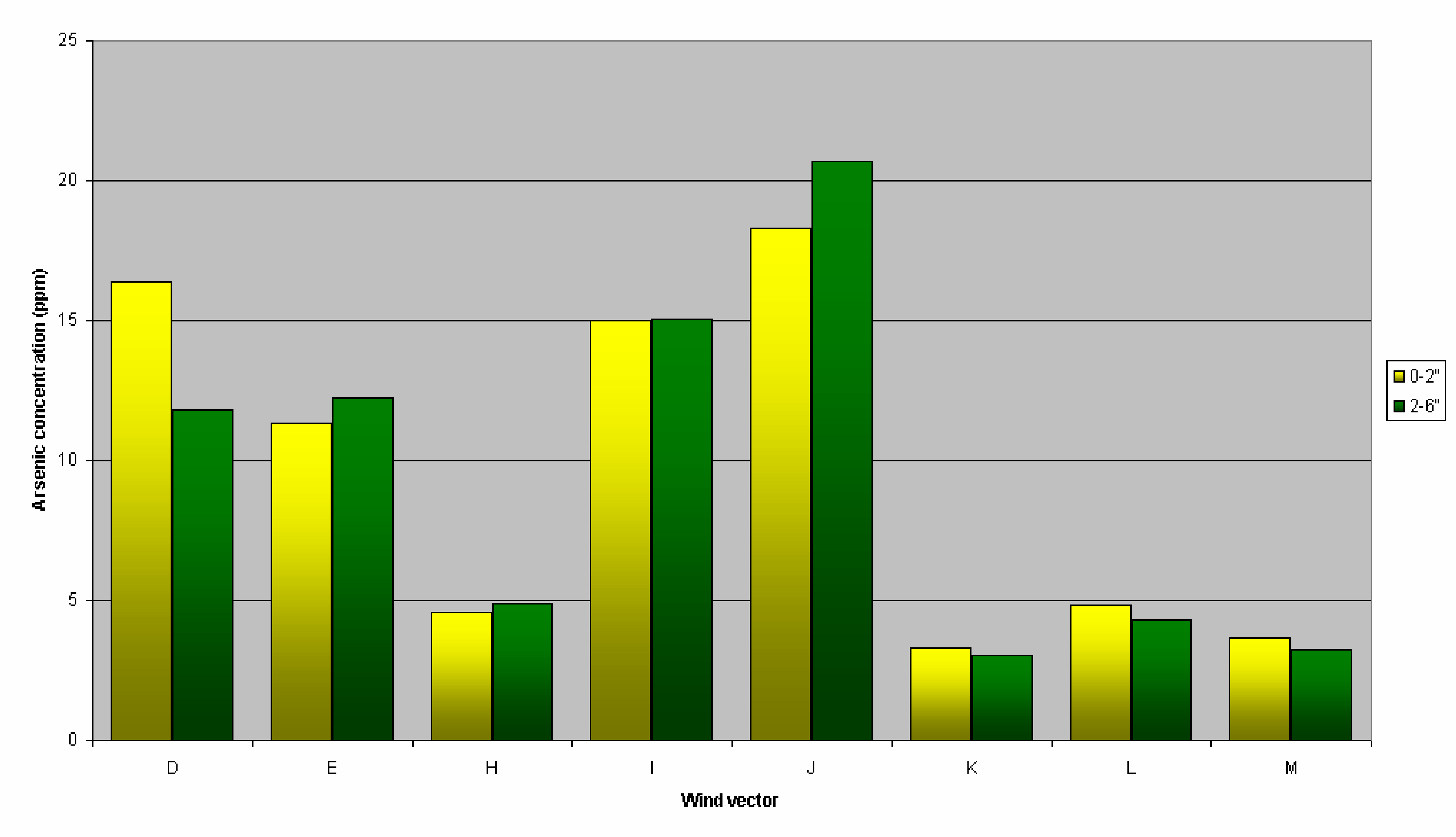
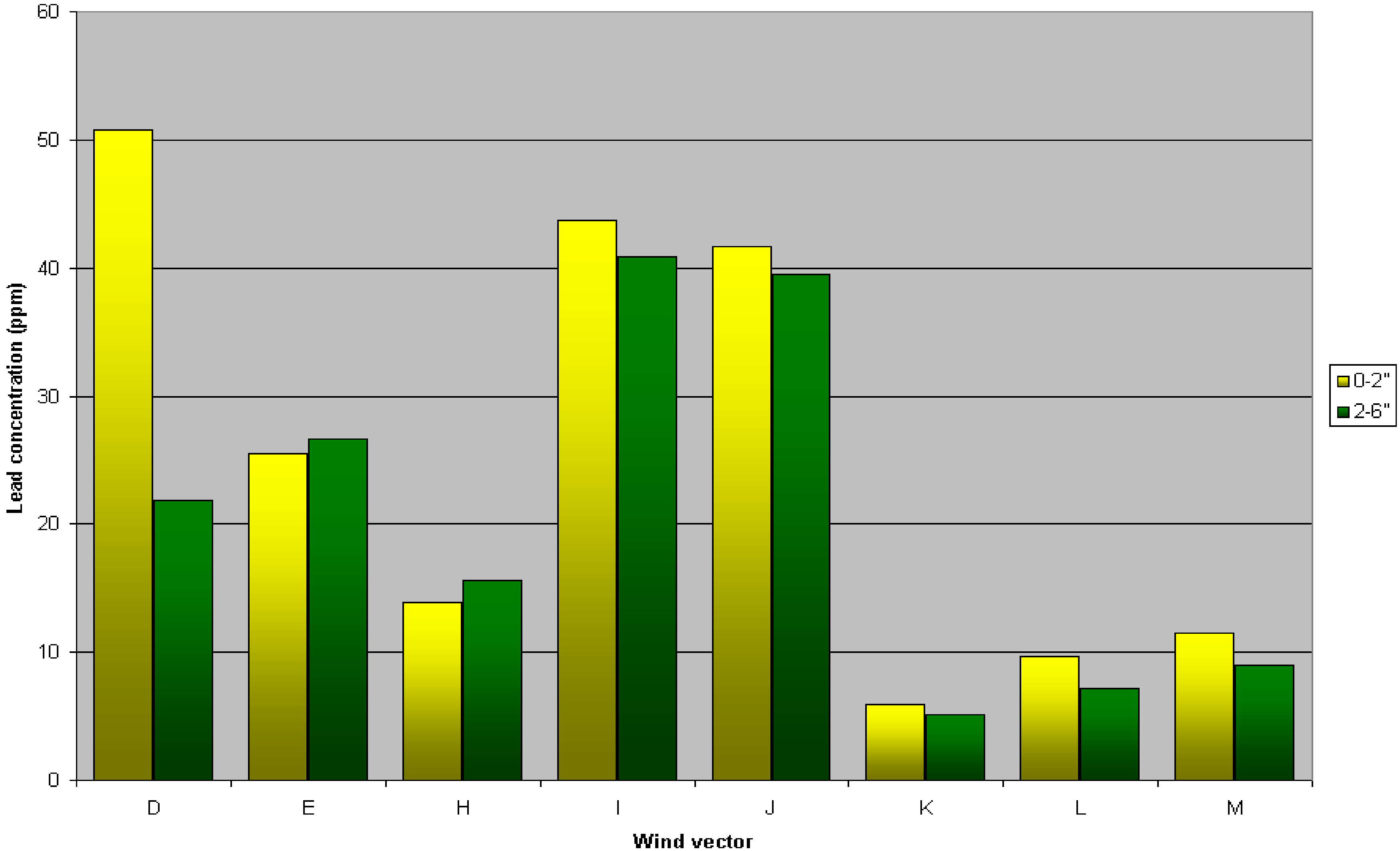


Figure 7. Mean lead concentration by wind vector and depth



5 CONCLUSIONS AND RECOMMENDATIONS

The lack of any clear pattern between wind vectors, and between depths reflects the high variability of the data likely due to the level of disturbance of the soil over time. Unlike the Pierce County Footprint Study, which attempted to sample the most undisturbed properties across an evenly-spaced grid, the CUA study included a random sampling of often highly disturbed properties, making statistical analysis of the data difficult.

What is clear from this study is that many Pierce County child use areas have elevated soil concentrations of lead and arsenic. Arsenic in soils at two properties exceeded the Interim Action Trigger Levels. At Pt. Defiance Elementary, the Tacoma School District voluntarily undertook cleanup of part of the property, replacing contaminated soil from a baseball field with clean fill, and covering part of the play area with asphalt. At child care #112, the child care opted to keep children from playing on the contaminated soils (this child care did not provide an outdoor play area anyway).

Within the Child Use Area study zone, access was granted to sample 19 of 24 elementary schools, 21 of of 40 parks, and only 32 of 130 child care facilities. Uncertainties about funding and requirements for cleanup were a major concern for Metro Parks and for private child care operators and prevented access being gained for sampling at many sites. Other facilities within the study zone may also contain elevated levels of arsenic and lead.

This study intended to serve short-term health screening needs. Ecology has published a *Dirt Alert - Arsenic and Lead in Soils* brochure (Ecology 2003) that offers property owners practical information about the Tacoma Smelter Plume project and assistance on what to do if the owner wants to know more about contamination on their property. These brochures were given to property owners at the time of sampling, and additional materials mailed out along with the results. TPCHD has also published information about how to minimize an individual's exposure to arsenic and lead in soils, listed below. Inside the home:

- Take off shoes before entering your home.
- Wash hands and face thoroughly after working or playing in the soil, especially before eating.
- Damp mop and wipe surfaces often to control dust.
- Wash toddler toys and pacifiers often.
- Scrub vegetables and fruits with soap and water.
- Wash clothes dirtied by contaminated soil separately from other clothes.
- Repair painted surfaces in homes. Homes built before 1980 may contain lead-based paint. Older paint flakes may be a source of lead.
- Eat a balanced diet. Iron and calcium help keep lead from becoming a problem in the body.
- Use water and soap to wash – avoid "waterless" soaps.

Outside the home:

- Keep children from playing in contaminated dirt.
- Cover bare patches of dirt with bark, sod or other material, or fence off area.
- Dampen dusty soils before gardening.
- Wear gardening gloves.
- Do not eat or drink in contaminated areas.
- Keep vegetable gardens away from old painted structures and treated wood.
- Do not plant food crops under the roof overhang of homes.
- Keep pets off of exposed dirt so they don't track it into the house.

Special considerations for adults doing construction or yard work:

- Avoid all unnecessary exposure to soil or dust.
- Dampen dusty soils before and during the work project.
- Wear full body protective clothing (coveralls, or long sleeve shirt and pants,) shoes, and gloves. For maximum protection wear a dust mask or respiratory protection.
- Avoid eating, drinking or smoking while working in dirt.

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Attachment A

Methodology for Determining Child Use Area Boundary

(From: Glass, Gregory L. 2002b. Sampling Design for Tacoma Smelter Plume Site; Soil Sampling and Analysis at Child Use Areas in King County and Pierce County, Washington. November.)

The Pierce County Footprint Study, completed in November 2002, provides soil arsenic results for 194 locations: 105 disturbed locations (residential property sampling) and 89 undisturbed locations. A Child-Use Areas Study Zone for Pierce County is defined to include those portions of Pierce County where soil arsenic concentrations could exceed 100 ppm. The data from the Footprint Study (supplemented by a few additional values from earlier studies, as described below) were evaluated, using the same methodology already described for the King County Mainland (see Attachment B- Glass, 2002b), to estimate bounding curves for each of 13 wind sectors included in the Pierce County Footprint Study. Each bounding curve equation can be used to calculate an estimated maximal distance, for one wind sector, at which soil arsenic concentrations at or above 100 ppm are likely to occur. The Child-Use Areas Study Zone is defined based on this set of maximal distances (across wind sectors) for 100 ppm soil arsenic. The bounding curve equations will also be used to assign maximum likely values to candidate child-use areas in Pierce County as part of a scoring and prioritization system (see Attachment A).

The evaluations for defining a Pierce County Child-Use Areas Study Zone were carried out using the same basic methodology used for King County. The soil arsenic results for the 194 sampling locations from the Footprint Study were the primary data used. Two types of supplemental data were reviewed and selectively used: 1) for the East-Northeast and East wind sectors, data from the King County Mainland study were added to the Pierce County Footprint Study results (providing an expanded view of spatial gradients for those wind sectors), and 2) historic studies from Pierce County were reviewed and a few results added to the evaluations where they resulted in an elevated bounding curve. There were also two new considerations compared to the King County child-use areas study zone evaluations: 1) the possibility that soil sampling results from areas extending well beyond smelter impacts could artificially raise the bounding curve, and 2) the possibility that a few results close to the former smelter could reflect contamination from smelter sources other than tall stack emissions (e.g., fugitive emissions). These methodology issues are briefly discussed below, followed by a summary of the results for each wind sector.

In brief, the bounding curve equations were developed as follows: 1) a database of maximum soil arsenic results by sampling location, together with distance and direction values from the tall stack, was compiled; 2) that database was partitioned according to wind sector (each 22.5 degrees wide, centered on one of 16 compass directions such as South-Southwest); 3) the maximum soil arsenic values were plotted (using log-scaled concentrations) versus distance for each wind sector, coded to distinguish undisturbed from disturbed sampling locations; 4) historic data and King County results were added to the scatterplots as appropriate; 5) a bounding line was drawn for each wind sector scatterplot; and 6) the intercept and slope of the bounding line were measured to establish the bounding line equation. The resulting bounding curve equations have the form of a decay function with the general equation

$$\text{maximum arsenic} = A\ 10^{(slope*D)}$$

where A is a constant and D is the distance (in miles) from the stack (see Attachment B for details).

Many of the Pierce County wind sector scatterplots included only a relatively small number of data points. In some cases, multiple options for how to draw a bounding line presented themselves. Judgment was used to select from among the options in such cases, considering which bounding lines gave the best overall fit to the available wind sector data as well as the spatial pattern for regional transport of tall stack emissions as reflected by the annual wind rose.

The chosen form for the decay equation asymptotes to a maximum arsenic value of zero; that is, as the distances increase, the calculated maximum arsenic concentration becomes closer and closer to zero. The regional background value for soil arsenic, in areas unaffected by smelter emissions, is of course somewhat greater than zero. Where sampling results include regions extending well beyond the area of smelter impacts - that is, where many background locations are included - fitting a bounding curve to a non-zero (background) value for one of the most distant sampling locations will artificially raise the bounding curve. The more distant the sampling locations included, the greater will be the degree of bias in the bounding curve. The Pierce County Footprint Study, by design, included areas (e.g. to the northwest) where smelter impacts were judged unlikely to be significant based on the annual wind rose patterns. (The King County Mainland study, by contrast, does not similarly extend into background regions). For several Pierce County wind sectors, the data appeared to represent sampling into the background region, beyond significant smelter impacts. In those cases, bounding curves were drawn using a sampling location judged to represent the approximate beginning of a background region, to avoid upward bias in the bounding curve.

The Pierce County Footprint Study includes sampling locations much closer to the smelter than either the Vashon-Maury Island or King County Mainland studies. Locations close to the smelter are more affected by low-level fugitive releases from smelter operations, and other accidental releases (e.g., from stack fires), than by typical tall stack releases. The distance at which tall stack releases dominate soil contamination impacts has not been accurately defined. A data set in which both regional tall stack effects and localized fugitive emissions effects are present would have a more complicated bounding curve, reflecting two different decay functions. Fitting a single decay curve to a data set containing both soil impact processes could bias the bounding curve and the estimated maximal distance to a 100 ppm soil arsenic concentration.

(Largely for that reason, the results from detailed property-by-property sampling within the Ruston/North Tacoma Superfund site and other historic soils data within about 1 mile of the smelter have not been considered for defining a child-use areas study zone). One high-outlier maximum arsenic result, from a sampling location close to the Ruston/North Tacoma Superfund boundary, was of particular concern with respect to the possibility of introducing bias (see the discussion of Southwest wind sector results below). After considering all results for that wind sector, a judgment was made to keep the high-outlier result in the analysis. Some even higher soil arsenic results from historic studies at locations a little closer to the smelter were not included in the evaluations (see the discussion of South-Southwest wind sector results below).

Soil arsenic data from various historic studies were considered as part of the study zone evaluations. The Pierce County Footprint Study represents the most extensive and current sampling of Pierce County soils outside of the Ruston/North Tacoma Superfund site. However, historic data provide additional valid results for defining the overall spatial patterns of soil arsenic contamination. In some cases, the sampling densities in historic studies are much greater than Footprint Study sampling densities in the same areas. Higher sampling densities are more likely to include significantly higher values (from among locally varying values). Historic studies have also included undisturbed sampling locations that were not, or could not be, resampled in the Footprint Study. Soil arsenic concentrations are not expected to have decreased naturally (e.g., by leaching or volatilization) in the years since sampling in historic studies; the reported results should therefore be representative of current spatial distributions. The collected historic studies with soil arsenic data for Pierce County were reviewed; the references list identifies those of most interest for the child-use areas study zone evaluations. In those few cases where historic data resulted in an elevated boundary curve, the sources for historic data are given in the discussions of wind sector results below.

Where appropriate, the results from both Pierce County and King County studies were combined to provide the most extensive data sets for evaluating concentration-by-distance patterns (East-Northeast and East wind sectors).

Results. The results of the evaluations for each wind sector are briefly described below. The number of Footprint Study sampling locations (out of the total of 194) is given after each heading (n = number of locations by wind sector), as well as the range of directions (bearing degrees clockwise from due north = 0 degrees) for each wind sector. In some cases, additional information is provided summarizing the results of alternate analyses.

North-Northwest. (n = 1) The North-Northwest wind sector (326.25 to 348.75 degrees) includes only a single undisturbed sampling location in the northern Gig Harbor peninsula, near the Kitsap County boundary line. The maximum arsenic concentration there is 17 ppm. Data are insufficient to estimate a bounding curve for this wind sector. (In this wind direction, no populated areas occur within almost four miles of the smelter tall stack). South Vashon Island sampling locations just east of the northern Gig Harbor peninsula, in the North wind sector, were found to have maximum soil arsenic levels exceeding 100 ppm. The annual wind rose (North 26th and Pearl Streets, Tacoma, WA) shows substantially less frequent winds to the North-Northwest than to the North (and somewhat more frequent winds than to the Northwest)*.(Note: this wind sector was later estimated to be 4.1 miles. See Attachment A-1 for explanation).*

Northwest. (n = 6) The Northwest wind sector (303.75 to 326.25 degrees) includes only undisturbed sampling locations. The highest soil arsenic result of 64.5 ppm occurs at the closest sampling location, along the Gig Harbor peninsula shoreline at almost four miles from the smelter stack. Without considering soil background issues, the bounding line would be defined by a 4.43 ppm arsenic result at a sampling location almost 13 miles from the smelter (with an equation of max arsenic = $210 \times 10^{-0.131\ \mathrm{Distance}}$). However, based on the annual wind rose and pattern of soil results, the selected bounding curve was based on the next most-constraining data point (10.3 ppm at almost 9.5 miles) to reduce the possible bias introduced by having results extending into the background region. The equation for the bounding curve is therefore

$$\text{max arsenic} = 240 \times 10^{-0.145\ \mathrm{Distance}}$$

with a calculated distance to 100 ppm of approximately 2.6 miles.

West-Northwest. (n = 11) The West-Northwest wind sector (281.25 to 303.75 degrees) includes only undisturbed sampling locations extending over 15 miles to the far northwest corner of Pierce County (near the Mason and Kitsap County lines). The highest soil arsenic result of 60.7 ppm occurs at a distance of almost four miles from the smelter stack. An adjustment in drawing the bounding line to account for sampling into the background region makes a greater difference here than in the Northwest wind sector. Excluding likely background region samples results in a greater calculated distance to 100 ppm maximum soil arsenic. The unconstrained bounding line (determined by the maximum result of 60.7 ppm and a 12.8 ppm value at almost 14 miles), with the estimated equation max arsenic = $115 \times 10^{-0.070\ \mathrm{Distance}}$, has a distance to 100 ppm of only 0.9 miles. The selected bounding curve, with four sampling results nearly on the line, has an equation of

$$\text{max arsenic} = 320 \times 10^{-0.184\ \mathrm{Distance}}$$

and a calculated distance to 100 ppm of approximately 2.7 miles. The slope for the chosen boundary curve is much more consistent with the annual wind rose (which shows a very low frequency in this direction) and the overall spatial pattern of soil contamination.

West. (n = 15) The West wind sector (258.75 to 281.25 degrees) includes only undisturbed sampling locations extending to almost 15 miles from the smelter (to the western side of the Key Peninsula). The highest soil arsenic result of 171 ppm occurs at the closest sampling location, along the eastern shore of the Gig Harbor peninsula. As is true of the Northwest and West-Northwest wind sectors, the annual wind rose shows a very low wind frequency for the West direction. An adjustment in drawing the bounding line to account for sampling into the background region makes a relatively small difference in the bounding curve. The unconstrained bounding line (determined by the highest result and a 7.18 ppm result at the most distant sampling location), with the estimated equation max arsenic = 300 x $10^{-0.109 \text{ Distance}}$, has a distance to 100 ppm of approximately 4.4 miles. The selected bounding curve, which provides a better fit to the results within 8 miles of the smelter, has an equation of

$$\text{max arsenic} = 360 \times 10^{-0.143 \text{ Distance}}$$

and a calculated distance to 100 ppm of approximately 3.9 miles. One historic value from a sampling location on the western end of Fox Island (Crecelius et al. 1974) falls almost exactly on the selected bounding line.

West-Southwest. (n = 22) The West-Southwest wind sector (236.25 to 258.75 degrees) includes one disturbed and 21 undisturbed locations, extending about 15 miles to the southern Key Peninsula. The undisturbed sampling location, less than one mile from the smelter stack, is closest to the smelter and has the highest arsenic result of 142 ppm. The bounding line, however, is determined by a value of 80.8 ppm on central Fox Island and an 11.8 ppm result from the Key Peninsula. A value of 31.4 ppm on McNeil Island is also nearly on this bounding line; thus, in contrast to the previous three wind sectors, an adjustment for sampling into the background region is not warranted. The bounding curve has an equation of

$$\text{max arsenic} = 380 \times 10^{-0.101 \text{ Distance}}$$

and a calculated distance to 100 ppm of approximately 5.7 miles.

Southwest. (n = 19) The Southwest wind sector (213.75 to 236.25 degrees) has three disturbed and 16 undisturbed sampling locations, extending over 14 miles to include portions of Fox and McNeil Islands and all of Anderson Island. The highest arsenic result of 1,050 ppm for this wind sector is the highest value for the entire Footprint Study and statistically is a high-outlier; the next highest value of 475 ppm (in the South-Southwest wind sector) is less than half as large. The third highest maximum arsenic result from the Footprint Study, 440 ppm, also occurs in this Southwest wind sector at a disturbed sampling location.

The 1,050 ppm result is from an undisturbed location about 1.3 miles from the smelter stack. One likely reason that the 1,050 ppm result appears to be a high outlier is that it represents one of the only undisturbed locations sampled in areas close to the former smelter; comparisons to other results therefore involve the difference between disturbed and undisturbed soil conditions. Including or excluding the 1,050 ppm result has only a small effect on the calculated distance to 100 ppm; the main difference between the bounding curves is in the arsenic concentrations calculated for locations within about 6 miles of the smelter. A judgment was made that the 1,050 ppm result should be retained for analysis. The bounding curve is then determined by that highest value and two results from Anderson Island (62.5 ppm and 43.1 ppm) and has the equation

$$\text{max arsenic} = 1{,}450 \times 10^{-0.106\ \text{Distance}}$$

and a calculated distance to 100 ppm of approximately 11.0 miles. Seven sampling locations in this wind sector, at distances up to 7 miles from the smelter, had actual maximum arsenic concentrations above 100 ppm. The Footprint Study results on eastern Fox Island, up to 182 ppm, confirmed the early result in Crecelius et al. (1974) of 166 ppm in that area.

South-Southwest. (n = 43) The South-Southwest wind sector (191.25 to 213.75 degrees) includes parts of the highly developed Pierce County mainland in Tacoma and University Place. Of the 43 sampling locations in this wind sector, the majority - 27 - are disturbed (residential) locations. Examination of the scatterplot of maximum arsenic results versus distance confirms that at similar distances the results from undisturbed locations are higher than those from disturbed locations. This supports the general approach of using undisturbed sampling results to estimate upper bounds on possible soil arsenic concentrations at disturbed properties.

The highest arsenic value for this wind sector is 475 ppm from an undisturbed location a little over two miles from the smelter stack. Nine sampling locations (four undisturbed, five disturbed) have maximum arsenic results over 100 ppm, at distances up to almost seven miles from the smelter. Values above 90 ppm occur to distances of about 15 miles. Annual wind roses show this wind direction to have the highest frequency for Pierce County.

Some of the undisturbed areas included in the Tacoma Water area background study in University Place (City of Tacoma and Glass 1999) were resampled in the Footprint Study. The original area background investigation, however, sampled more undisturbed locations and had a higher local density of sampling than the Footprint Study. A review of the Tacoma Water data resulted in adding maximum arsenic values for seven locations to the scatterplot. The addition of these data resulted in a very modest elevation of the bounding line, with the determining result being a maximum arsenic value of 281 ppm from the Tacoma Water study at a distance of about six and a half miles from the smelter. (The highest value from resampling this location in the Footprint Study was 204 ppm). The maximum value for this wind sector, 475 ppm, and a 91.6 ppm value from DuPont over 15 miles from the smelter would determine a very nearly identical bounding line. The equation for the bounding curve using the Tacoma Water results is

$$\text{max arsenic} = 650 \times 10^{-0.055\ \text{Distance}}$$

and a calculated distance to 100 ppm of approximately 14.8 miles.

Historic soil sampling results from several vacant lots in this wind sector, at distances of a little more than a mile from the smelter, show very high arsenic concentrations (see ASARCO 1978). Intensive sampling of these lots was initiated by a proposal to build low-cost housing (Mayer Built Homes project). They are located very close to the Footprint Study sampling location with 1,050 ppm maximum arsenic (discussed under Southwest wind sector above). Three sampled lots had maximum arsenic concentrations of 3,060 ppm, 2,160 ppm, and 2,040 ppm. These highest results were added to the scatterplot and a bounding equation, determined by the 3,060 ppm value and the 91.6 ppm result at over 15 miles from the smelter, was estimated. This alternate equation (max arsenic = $3{,}950 \times 10^{-0.109 \text{ Distance}}$) would have almost no effect on the calculated distance to 100 ppm (14.7 miles) but would produce much higher calculated maximum arsenic concentrations. For example, at 4 miles the calculated value would be about 1,450 ppm versus about 390 ppm for the selected bounding curve. Considering the poor fit of the alternate bounding curve to available data for this wind sector, and the possibility that the high soil arsenic values from the historic sampling reflect a different process for smelter impacts, the historic data were not used to estimate a bounding curve.

<u>South</u>. (n = 30) The South wind sector (168.75 to 191.25 degrees) includes only 2 undisturbed sampling locations; the remaining 28 locations are disturbed (residential). Sampling locations include Tacoma, Fircrest, and Lakewood areas to distances of almost 10 miles from the smelter. The lack of undisturbed sampling locations for this wind sector, and the limited number of disturbed locations sampled overall, means that the estimated bounding curve may be biased low to a degree greater than for other wind sectors (e.g., South-Southwest).

The highest soil arsenic result for this wind sector is 233 ppm, occurring for a disturbed property about one mile from the smelter stack. The bounding curve is determined by that result and a value of 30 ppm at a Lakewood sampling location at a distance approaching 10 miles. The bounding curve equation is

$$\text{max arsenic} = 300 \times 10^{-0.103 \text{ Distance}}$$

giving a calculated distance to 100 ppm of approximately 4.6 miles.

<u>South-Southeast</u>. (n = 21) The South-Southeast wind sector (146.25 to 168.75 degrees) includes only disturbed sampling locations. The estimated bounding curve may therefore be biased low, as in the case of the South wind sector. The highest soil arsenic result is 140 ppm from a sampling location about one and a half miles from the smelter. The bounding curve is determined by that result and a value of 10.3 ppm at the most distant sampling location about 5 miles from the smelter (near the Highway 16 and I-5 junction). It is possible that the Footprint Study extends marginally into a background region in this wind sector; the wind rose shows a low frequency of winds in this direction. Given the overall trend of the results by distance, however, any adjustments for background sampling would be of little consequence. Therefore, all of the data were included in the bounding curve evaluation. The bounding curve equation is

$$\text{max arsenic} = 440 \times 10^{-0.326\ \text{Distance}}$$

with a calculated distance to 100 ppm of approximately 2.0 miles.

Southeast. (n = 15) The Southeast wind sector (123.75 to 146.25 degrees) includes only disturbed sampling locations. The estimated bounding curve may therefore be biased low. A review of historic studies determined that one result from the Exposure Pathways Study (Polissar et al. 1987), also from a residential property, would elevate the bounding line. That result was therefore added to the scatterplot. The historic sampling result of 58 ppm at a distance of about one and a half miles from the smelter is the highest arsenic result for the Southeast wind sector. That highest value and a value of 20.7 ppm from the most distant sampling location, in the Hilltop area almost five miles from the smelter, determined the bounding line. The bounding curve equation is

$$\text{max arsenic} = 90 \times 10^{-0.130\ \text{Distance}}$$

which gives a calculated distance to 100 ppm of less than 0 miles. (Since sampling results from the Ruston/North Tacoma Superfund site have been excluded from these evaluations, a default of using the limit of that area in this wind sector for defining a child-use area study zone could be considered).

East-Southeast. (n = 3) The East-Southeast wind sector (101.25 to 123.75 degrees) includes only 3 disturbed sampling locations at distances of about 7 to 8 miles near Fife. These data are insufficient to estimate a bounding curve. However, since no populated areas occur within about five miles of the smelter in this direction, and the highest soil arsenic result from the Footprint Study is only 20.1 ppm, the consequences for defining a study zone are minimal.

East. (n = 6) The East wind sector (78.75 to 101.25 degrees) includes only disturbed sampling locations from the Footprint Study, extending to about 6 miles in Northeast Tacoma. An additional 10 undisturbed sampling locations have results from the King County Mainland study. Both sets of results were included in the initial data scatterplot. A review of historic studies determined that results from two previous investigations, both at relatively undisturbed sampling locations, would elevate the bounding line. An early study by Crecelius et al. (1974) included sampling at a park near Browns Point that could not be resampled in the Footprint Study. The soil arsenic value of 244 ppm, at a distance of about 3 miles, is the highest value for the East wind sector.[1] An academic study of forest soils impacted by smelter emissions (see Dempsey 1991) reported a soil arsenic value of about 110 ppm at a distance of about five miles in this

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[1] A reported soil arsenic value of over 900 ppm, at a Northeast Tacoma sampling location, from the EPA Urban Soil Monitoring Program appears highly anomalous and is not considered further. It may represent a local application of arsenical herbicides or pesticides.

wind sector (from among a set of sampled locations in the region). These historic data were added to the scatterplot. The bounding line is determined by the Crecelius et al. result of 244 ppm near Browns Point and a 41 ppm result from the King County Mainland Study at a distance of almost twelve miles. The Dempsey result approaches this bounding line. The bounding curve is identical to the one used for the King County study zone definition (see Attachment B), with an equation of

$$\text{max arsenic} = 450 \times 10^{-0.090\ \text{Distance}}$$

and a calculated distance to 100 ppm of approximately 7.3 miles.

East-Northeast. (n = 2) The East-Northeast wind sector (56.25 to 78.75 degrees) includes one disturbed and one undisturbed sampling location. Only a small area of Pierce County near Browns Point in Northeast Tacoma occurs within this wind sector. The King County Mainland Study provides another 27 results for the East-Northeast wind sector, which according to the annual wind rose is one of the dominant downwind directions for smelter emissions. The King County results include values over 100 ppm to distances of more than 11 miles from the smelter. The higher of the two Pierce County results is only 44.9 ppm at a distance of about 4 miles. A review of historic studies identified a soil arsenic value of 100 ppm in the Dempsey (1991) forest soils study, at a distance of about 6 miles. The low density of results within Pierce County for this direction makes evaluations difficult. Combining the Pierce County and King County results, the bounding line is entirely determined by King County results (180 ppm at a distance of about 11 miles and 51 ppm at a distance of about 19 miles). The equation is therefore identical to the one used for King County for the East-Northeast wind sector (see Attachment B), with an equation of

$$\text{max arsenic} = 1125 \times 10^{-0.071\ \text{Distance}}$$

and a calculated distance to 100 ppm of approximately 14.8 miles.

Inspection of the spatial pattern for the King County results suggests that the northern part of this wind sector has higher values than the southern part. The Pierce County areas within the East-Northeast wind sector fall within the southern half. The trend in annual wind rose frequencies by direction also seems consistent with more frequent winds in the northern part of this wind sector. An alternative analysis using only the Pierce County Footprint Study results, the historic Dempsey result, and those King County Mainland results in the sub-sector defined by Pierce County lands in the East-Northeast direction was carried out. The bounding line is determined by King County results of 62 ppm at about 11 miles and 30 ppm at a distance approaching 17 miles; the Dempsey result of 100 ppm approaches this bounding line, as do several other King County results. The alternative bounding curve equation is

max arsenic = 250 x 10 -0.054 Distance

which gives a calculated distance to 100 ppm of 7.4 miles, half the previous distance. This alternative evaluation would not alter the conclusion that all of the small Pierce County area in the East-Northeast wind sector should be included in the child-use areas study zone. For consistency in approach, the bounding curve matching the King County analysis may be used.

The set of bounding curves for Pierce County shows a strong concordance with a conceptual model for smelter tall stack emissions as influenced by annual wind rose frequencies. The calculated distances to 100 ppm soil arsenic correlate well with wind frequencies. The slopes by wind sector also show the expected pattern of faster decreases with distance when wind frequencies are low versus when they are high. Unlike the King County evaluations, which were based only on sampling results for undisturbed (forested) locations, the Pierce County evaluations included both disturbed and undisturbed locations. For some wind sectors, only disturbed location results are available. The lack of results from undisturbed locations in some wind sectors may bias the estimated bounding curves low. The number of results by wind sector in Pierce County is also much lower than for the primary downwind directions (North-Northeast and Northeast) in King County. That may also contribute to a somewhat larger degree of low bias for the Pierce County results. Nevertheless, the set of bounding curves appears to provide a reasonable basis for defining a child-use areas study zone for Pierce County and for prioritizing among candidate child-use areas for sampling.

East-Southeast. (n = 3) The East-Southeast wind sector (101.25 to 123.75 degrees) includes only 3 disturbed sampling locations at distances of about 7 to 8 miles near Fife. These data are insufficient to estimate a bounding curve. However, since no populated areas occur within about five miles of the smelter in this direction, and the highest soil arsenic result from the Footprint Study is only 20.1 ppm, the consequences for defining a study zone are minimal.

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[2]A reported soil arsenic value of over 900 ppm, at a Northeast Tacoma sampling location, from the EPA Urban Soil Monitoring Program appears highly anomalous and is not considered further. It may represent a local application of arsenical herbicides or pesticides.

wind sector (from among a set of sampled locations in the region). These historic data were added to the scatterplot. The bounding line is determined by the Crecelius et al. result of 244 ppm near Browns Point and a 41 ppm result from the King County Mainland Study at a distance of almost twelve miles. The Dempsey result approaches this bounding line. The bounding curve is identical to the one used for the King County study zone definition (see Attachment B), with an equation of

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and a calculated distance to 100 ppm of approximately 14.8 miles.

Inspection of the spatial pattern for the King County results suggests that the northern part of this wind sector has higher values than the southern part. The Pierce County areas within the East-Northeast wind sector fall within the southern half. The trend in annual wind rose frequencies by direction also seems consistent with more frequent winds in the northern part of this wind sector. An alternative analysis using only the Pierce County Footprint Study results, the historic Dempsey result, and those King County Mainland results in the sub-sector defined by Pierce County lands in the East-Northeast direction was carried out. The bounding line is determined by King County results of 62 ppm at about 11 miles and 30 ppm at a distance approaching 17 miles; the Dempsey result of 100 ppm approaches this bounding line, as do several other King County results. The alternative bounding curve equation is

max arsenic = 250 x 10 -0.054 Distance

which gives a calculated distance to 100 ppm of 7.4 miles, half the previous distance. This alternative evaluation would not alter the conclusion that all of the small Pierce County area in the East-Northeast wind sector should be included in the child-use areas study zone. For consistency in approach, the bounding curve matching the King County analysis may be used.

The set of bounding curves for Pierce County shows a strong concordance with a conceptual model for smelter tall stack emissions as influenced by annual wind rose frequencies. The calculated distances to 100 ppm soil arsenic correlate well with wind frequencies. The slopes by wind sector also show the expected pattern of faster decreases with distance when wind frequencies are low versus when they are high. Unlike the King County evaluations, which were based only on sampling results for undisturbed (forested) locations, the Pierce County evaluations included both disturbed and undisturbed locations. For some wind sectors, only disturbed location results are available. The lack of results from undisturbed locations in some wind sectors may bias the estimated bounding curves low. The number of results by wind sector in Pierce County is also much lower than for the primary downwind directions (North-Northeast and Northeast) in King County. That may also contribute to a somewhat larger degree of low bias for the Pierce County results. Nevertheless, the set of bounding curves appears to provide a reasonable basis for defining a child-use areas study zone for Pierce County and for prioritizing among candidate child-use areas for sampling.

Attachment A-1: Explanation of Child Use Area Boundary Determination in North-Northwest Wind Direction

-----Original Message-----
From: Greg Glass [mailto:glassec@attbi.com]
Sent: Tuesday, December 17, 2002 1:16 PM
To: Abbett, Marian L.
Subject: NNW Wind Sector

Marian,

Here is the procedure leading to an estimate of 4.1 miles for the distance to 100 ppm maximum soil arsenic for the NNW wind sector of the Tacoma Smelter Plume site.

Only one location in the NNW wind sector was sampled. That location (#710) is near the western limit of the NNW wind sector, Thus our data are insufficient to derive a bounding curve, as was done for other wind sectors.

Annual wind roses from PSAPCA are available for many years. There is great similarity in the frequencies by direction from one year to another. The wind frequencies for the NW, NNW, and N wind sectors are approximately 1 to 1.5 percent, 3 percent, and 6 to 7.5 percent, respectively. Thus the frequency for the NNW wind sector is intermediate between the frequencies for the N and NW wind sectors. Our regional spatial patterns for soil contaminant concentrations and the conceptual model for transport and deposition of tall stack emissions both indicate that the magnitude and spatial extent of soil arsenic concentrations should generally follow wind frequencies.

There are 88 sampling locations with soil arsenic data for the N wind sector, from the initial VMI study. While those 88 results were analyzed as one data set to develop a bounding curve for the N wind sector, inspection of the data and consideration of the 360-degree wind field pattern suggest that there are differences within the wind sector; the western half of the N wind sector likely has less contamination than the eastern half. (Refer to the discussions in Attachment C for a similar evaluation for another wind sector).

I produced a new scatterplot for the western half of the N wind sector (all data from location with direction from the tall stack of less than or equal to 0 degrees). Out of the 88 total locations for the N sector, 15 fall in the western half. I repeated the evaluation process previously applied to estimate a bounding equation for only those data. As expected the slope for the bounding curve was steeper than for all 88 data points for the N sector. The estimated distance to 100 ppm maximum soil arsenic using the 15 selected data points was 7.5 miles. (NOTE: a value of 260 ppm at a little less than 5 miles appears as a modest high-outlier value on the scatterplot. I kept that result in for the bounding curve evaluation. Without it, the distance to 100 ppm would be reduced to 5.6 miles).

The results for distances to 100 ppm for the NW wind sector and the western half of the N wind sector were used along with typical annual wind frequencies of 1.5% (NW), 3% (NNW), and 6.5% (N) to calculate a distance D for the NNW wind sector.

Thus,

(D-2.6 miles)/(7.5 miles-2.6 miles) = (3%-1.5%)/(6.5%-1.5%)

giving

D = 2.6 miles + (4.9)(0.3) = 4.07 miles, rounded to 4.1 miles

I recommend in the absence of sufficient sampling data for the NNW sector we use this distance of 4.1 miles as an estimate for mapping purposes.

Greg Glass
206 523 1858

Attachment B

Child Use Areas Ranking System

(From: Glass, Gregory L. 2002b. Sampling Design for Tacoma Smelter Plume Site; Soil Sampling and Analysis at Child Use Areas in King County and Pierce County, Washington. November.)

In a previous child use areas sampling program on Vashon-Maury Island, it was possible to sample all candidate child use properties where owners agreed to provide access. Given the populations and levels of development in the mainland King County and Pierce County study areas, the results of initial soil surveys (preliminary results for the Pierce County study, still in progress), and a decision to focus on those areas where maximum arsenic concentrations could exceed interim action criteria (see Attachment B), the Design Work Group readily concluded that all candidate child use properties could not be sampled within the available agency resources. Preliminary estimates of the number of candidate child use properties confirmed that resources would be available to sample only a relatively small percentage of all candidate properties.

A method for scoring and ranking candidate child use properties was developed to provide a basis for selecting those child use areas to be sampled. The Design Work Group decided that such a ranking system should be relatively simple to describe, use objective criteria (easily measured) to the extent possible, be able to be applied to a large number of candidate child use properties in a reasonable time with a reasonable level of resource commitments, be well documented, and provide overall ranking and scores related to comparative exposures and risks among properties so that selections would generally be based on a "worst first" principle. Other familiar ranking systems, such as the Washington Ranking Model (WARM) for ranking MTCA sites on a scale of 1 to 5, provided conceptual models for the approach.

The ranked list of child use areas is intended to guide selection of child use areas to be sampled. Other information and considerations may also be used, however, in making final selections (see main text). For example, a geographic allocation scheme may also be used to make sure that some child use areas are included in various parts of the study area. That goal can be met by disaggregating a single overall ranked list into several lists applying to the chosen geographic coverage areas, and then making selections from each list. Similar disaggregated lists can be used if allocations for different types of child use properties are desired. Discussions with local governments and community representatives may also identify priorities for child use area sampling, regardless of rankings, or identify additional child use properties not yet included on the lists (e.g., types of land uses hard to identify from databases, but well known locally, such as vacant lots favored as play areas).

This Attachment will focus on a description of the basic scoring and ranking system. Several examples are provided to illustrate how information on specific properties is used to develop a score for ranking purposes. Ecology has developed a simple Excel spreadsheet tool that allows information for candidate child use properties to be entered and then automatically calculates a ranking score for each property. Ranked lists of child use properties (single or disaggregated lists) are easily developed using this spreadsheet tool.

The basic structure of the ranking system includes the following elements:

> Identification of Factors: a set of characteristics, or factors, that relate to the potential for exposures at a child use property are identified.
>
> Scores: for each identified factor, a measurable variable is identified and a set of "factor scores" is related to the possible values for that variable.
>
> Weights: each factor is assigned a weight reflecting the relative contribution of that factor score to the overall property score.
>
> Total Score: the final score for a candidate child use property is the weighted sum of the individual factor scores. It therefore reflects the contributions of multiple unrelated factors, each of which contributes to the level of "total exposures".

Based on some initial discussions by the Design Work Group on the types of factors to be considered in a ranking system, a detailed preliminary proposal was developed by one participant (N. Peck, Ecology) for further consideration by the Work Group. That preliminary proposal used different ranges of scores for different factors rather than explicit weights for the summation of factor scores. Other participants used information from a number of real and hypothetical child use properties to investigate the performance of this preliminary model. Based on the results, the Design Work Group as a whole decided to modify the proposed system somewhat. Notably, the group chose to use an index scoring system in which the range of scores for every factor was identical, as well as an explicit set of factor weights for creating an overall total score. All factors are now scored in the range of 1 to 5. Most factors are now scored using only three discrete values: 1, 3, or 5 (comparable to low, moderate, or high values); one factor still uses a continuous measure, but it is now "rescaled" to also result in scores within the range of 1 to 5. Default weights of 1.0 are now used as a starting point for all factor scores, with adjustments made to reflect comparative weighting toward final scores (e.g., a weight of 2 would indicate a judgment that one factor was twice as important as others for ranking purposes). The resulting indexed scoring system is relatively simple to understand. The relative contributions of different property characteristics to ranking scores are obvious in this system, simply reflecting the assigned weights.[1] The use of

[1]All of the factors contribute to potential exposures in a straightforward manner; total exposures are the product of soil concentrations (adjusted appropriately from undisturbed to developed property conditions), frequencies/durations/intensities of soil contact, and the number of exposed children. Thus, none of the factors is (mathematically) more important than any of the others in estimating exposures. The

indexed scores reduces the importance of small differences in measured characteristics among properties and is appropriate to the quality of information now available to support ranking (e.g., estimated soil arsenic concentrations for unsampled locations).

Information on the scoring approach for factors used in the indexed ranking system is provided below for each of four factors.

Factor 1 (F1) - Population. The first factor considers the number of potentially exposed children at a child use property. Priority is given to those locations where a larger number of young children may be exposed to contaminated soils. The importance of age was considered by the Design Work Group. Incidental soil ingestion through mouthing behaviors, as well as purposeful soil ingestion (pica), are believed to be more characteristic of children at or below the age of 6 years. The urinary arsenic monitoring results from the University of Washington Exposure Pathways Study in communities near the former Tacoma Smelter were reviewed for information on exposures of somewhat older children, but relatively few children 7 or older were monitored and the results were therefore inconclusive with respect to the levels of exposure of these older children. The Work Group decided to use estimates of the population of children 6 years old or younger as a measure of the number of potentially exposed children for ranking purposes. That age range has often been used to focus on the most highly exposed group of children. It should be emphasized that this does not reflect a finding that soil exposures stop past the age of 6 years; on the contrary, some incidental exposures to soils, at reduced levels, may occur at ages through adulthood.

Indexed scores for the population factor (ages 0 to 6 years) were assigned as follows:

1 to 10 children	score = 1
10 to 50 children	score = 3
more than 50 children	score = 5

The population factor was assigned a factor weight of 1.0.

Factor 2 (F2) - Soil Arsenic Concentration. The second factor considers the level of soil arsenic to which children may be exposed. Priority was given to child use

---

weights instead reflect judgments about the best approach to selecting the small subset of candidate child use areas for sampling under substantial resource constraints. That is, they reflect judgments about how to balance what are roughly numerically equal "total exposures" where the number of children is small and the concentrations are high versus the number of children is large and the concentrations are lower (and other similar comparisons).

properties where greater levels of soil arsenic could occur. At a regional scale, the initial soil surveys demonstrate convincingly that levels of soil contamination reflect property locations with respect to the smelter; gradients with distance and corresponding to relative wind frequencies (i.e., direction) are shown by the data, as expected. However, substantial local variability in soil arsenic concentrations occurs, so that meaningful predictions of the concentrations at specific unsampled properties are not possible. The regional-scale patterns of soil contamination are therefore used to provide an estimate of the maximum likely arsenic concentrations in soils at child use properties, based on their locations. The equation for the appropriate bounding curve for maximum arsenic concentration versus distance, by wind sector, is used to calculate the maximum value used for ranking purposes. In many cases these bounding curves were estimated from data for relatively undisturbed, forested locations, and therefore may be conservative when applied to developed properties (see the discussion under Factor 3, below).

Indexed scores for the soil arsenic concentration factor were assigned as follows:

less than 150 ppm	score = 1
150 to 250 ppm	score = 3
greater than 250 ppm	score = 5

The soil concentration factor was assigned a factor weight of 1.5, reflecting the judgment of the Work Group that the selection of child use areas for sampling should be biased (more than proportionally among factors) toward the areas of greatest impact from smelter emissions.

Wind directions surrounding the smelter were divided into 16 vectors (A-P), each covering 22.5 degrees. Vectors in the Pierce County CUA Study are D, E, H, I, J, K, L, and M, which roughly correspond to compass directions ENE through SSW (refer to Figure 1).

Factor 3 (F3) - Property Development. The third factor considers the period since property development, or major redevelopment, for deposited smelter contaminants to accumulate. Priority is given to properties where a longer period for contaminant accumulation has occurred. Property development actions are considered likely to reduce, and can even eliminate, the near-surface soil contamination that accumulates in undisturbed soils from deposition of airborne smelter emissions. While the time since property development actions can be considered only an imperfect measure of this effect - the degree to which undisturbed soil contaminant concentrations are affected depends on the specific development actions disturbing soils - it is nonetheless considered a useful indicator. Ecology's study of University Place residential properties showed the age of residence was to be related to soil arsenic concentrations.

Smelter emissions were ongoing throughout the period of smelter operations (varying somewhat year-to-year as a result of copper production levels, labor strikes, pollution control equipment, and other variables). Thus, all else being equal, the period since major development actions should be an indicator for the degree to which soil contaminant levels approach those in nearby undisturbed soils. A property with major development activities after smelter shutdown in 1986 may not have all accumulated soil contamination eliminated, but it would have had no opportunity for further accumulations post-development. It is reasonable to characterize such a property as less contaminated, on average, than a similarly located property which has not had development activities for many decades, and which therefore probably reflects continued accumulation from contaminant deposition. The third factor can thus be thought of as addressing the possible degree of conservatism in the maximum arsenic concentration estimated from the bounding curve for undisturbed soils.

The Work Group determined that this factor should be scored on a continuous scale within the range of index scores, 1 to 5, based on the fraction of the smelter's total operating period (1890 to 1986, or 96 years) represented by the period since property development. Thus, the factor score is calculated by

$$\text{score} = 1 + ([1986 - \text{Year}]/[1986 - 1890])4$$

where "Year" is the year of property development, or major redevelopment, constrained to be between 1986 and 1890; that is, any development year after 1986 is assigned 1986 and any development year before 1890 is assigned 1890, so that the fraction in the equation is always between 0 and 1.

The property development factor was assigned a weight of 1.0.

Factor 4 (F4) - Soil Contact Frequency and Duration. The fourth factor considers the likely frequency (e.g., days per year) and duration (e.g., hours per day) of soil contact that could result in contaminant exposures. Priority was given to child use areas where a greater amount of soil contact may occur. Various types of child use areas - schools versus camps, for example - appear to have characteristic values for exposure frequencies and durations. For this factor, the Work Group adopted default assumptions (as originally developed in N. Peck's preliminary proposal for a ranking system) for different types of child use areas as a basis for assigning index scores. If property-specific information is available and well-supported that differs from the default assumptions, that information may be used to modify the default assigned score for the soil contact factor.

Indexed scores for the soil contact factor were assigned as follows:

camps	score = 1
parks, playfields, vacant lots,	score = 2

gardens

schools, score = 3
preschools,
daycare centers,
local playgrounds at housing complexes

with other types of child use areas, if any, assigned scores based on similarity to the identified property uses above.

The soil contact factor was assigned a weight of 1.0.

The overall ranking scores are calculated as the weighted sums of the four factor scores. With the assigned weight of 1.5 for the soil concentration factor (F2), and a range of 1 to 5 for raw scores for each factor, the overall range of total scores is 4.5 to 22.5. Several examples below illustrate how ranking scores for child use properties are developed. For these examples, the equations for the bounding curves derived for King County wind sectors (see Attachment B) are used to calculate factor scores for soil arsenic concentrations.

Example 1. A preschool, located in the northeast wind sector at a distance of 11.5 miles from the smelter, has 32 children ages 0 to 6 years in attendance. It was built in 1955.

F(1): a population of 32 children results in a score of 3 (10 to 50 children).

F(2): the bounding curve equation of max arsenic = $1{,}500 \times 10^{-0.063\ \text{Distance}}$ results in a value of 283 ppm at 11.5 miles. The factor score is 5 (greater than 250 ppm).

F(3): built in 1955, the post-development period is 31 years out of a total smelter operating period of 96 years. The factor score is therefore (1 + [31/96]4), or 2.29.

F(4): a preschool is assigned a factor score of 5 based on assumed exposure frequency and duration values.

Total score: 3 + (1.5)5 + 2.29 + 5 = 17.79

Example 2. A park, located in the north-northeast wind sector at a distance of 13.5 miles from the smelter, is used by an estimated 80 young children. It was developed in 1928.

F(1): a population of 80 children results in a score of 5 (more than 50 children).

F(2): the bounding curve equation of max arsenic = $700 \times 10^{-0.045 \text{ Distance}}$ results in a value of 173 ppm at 13.5 miles. The factor score is 3 (150 to 250 ppm).

F(3): built in 1928, the post-development period is 58 years out of a total smelter operating period of 96 years. The factor score is therefore (1 + [58/96]4), or 3.42.

F(4): a park is assigned a factor score of 3 based on assumed exposure frequency and duration values.

Total score: 5 + (1.5)3 + 3.42 + 3 = 15.92

Example 3. A daycare center, located in the east-northeast wind sector at a distance of 14 miles from the smelter, has 9 enrolled children younger than 6 years old. It is located in a private residence built in 1977.

F(1): a population of 9 children results in a score of 1 (1 to 10 children).

F(2): the bounding curve equation of max arsenic = $1{,}125 \times 10^{-0.071 \text{ Distance}}$ results in a value of 114 ppm at 14 miles. The factor score is 1 (less than 150 ppm).

F(3): built in 1977, the post-development period is 9 years out of a total smelter operating period of 96 years. The factor score is therefore (1 + [9/96]4), or 1.38.

F(4): a daycare center is assigned a factor score of 5 based on assumed exposure frequency and duration values.

Total score: 1 + (1.5)1 + 1.38 + 5 = 8.88

Example 4. An elementary school, located in the north-northeast wind sector at a distance of 16.5 miles from the smelter, has a total enrollment of 318 children. The estimated number of children aged 0 to 6 years is assumed to represent one-third of total enrollment (kindergarten plus first grade, out of K-5 classes), or 106 children. The school was built in 1962.

F(1): a population of 106 children results in a score of 5 (more than 50 children).

F(2): the bounding curve equation of max arsenic = $700 \times 10^{-0.045 \text{ Distance}}$ results in a value of 127 ppm at 16.5 miles. The factor score is 1 (less than 150 ppm).

F(3): built in 1962, the post-development period is 24 years out of a total smelter operating period of 96 years. The factor score is therefore (1 + [24/96]4), or 2.00.

F(4): an elementary school is assigned a factor score of 5 based on assumed exposure frequency and duration values.

Total score: 5 + (1.5)1 + 2.00 + 5 = 13.50

Attachment C. Child Use Area Study Access Agreement

TACOMA-PIERCE COUNTY HEALTH DEPARTMENT ENVIRONMENTAL HEALTH PROGRAM

The Tacoma-Pierce County Health Department (TPCHD) is seeking volunteers for **FREE soil sampling**. If you are a childcare provider and your property falls within the TPCHD's Child Use Area study boundary (please see enclosed map), you may be eligible for free soil sampling.

Please complete the information below, sign and return this form in the stamped, self-addressed envelope provided.

❑ Yes, please schedule me for **FREE soil sampling**

Name of Child Care Facility:____

Name of Contact Person: ____

Street Address:______________________City:_______State:_______Zip:________

Mailing Address______________________City:_______State:_______Zip:________

Phone: Daytime:____________________Evening: __________________________

Best time to call:____

Age of Childcare Facility / Home:

- ❑ Before 1900
- ❑ 1900-1920
- ❑ 1920-1950
- ❑ 1950-1970
- ❑ After 1970
- ❑ I don't know

Has the home or property had any major projects that disturbed surface soils in the past 30 years?

For example, landscaping, rototilling or grading?_________________________

If so, when?____

What type?____

Does the property have an underground sprinkler system?_______________________

If so, at what depth is it buried?____

❑ I would like a copy of the results from samples collected on my property.

I am the **operator** of the business identified above, and give my permission for representatives of the Tacoma-Pierce County Health Department to enter the property and take multiple soil samples for the purpose of analyzing the soil to determine whether it contains deposits of arsenic and lead. I understand that the data collected from my property are subject to requests for public disclosure.

I agree to hold harmless the Tacoma-Pierce County Health Department and its employees, agents and representatives from any and all liability arising directly or indirectly from the sampling, testing, evaluation, and disclosure related to the Project.

Signature:____Date:________

Attachment D. Chain of Custody Form

Severn Trent Laboratories, Inc.
5755 8th Street East
Tacoma, WA 98424

Phone: 253.922.2310 Fax: 253.922.5047

CHAIN OF CUSTODY
Request for Laboratory Services

SAS Lab No. ____________

Turnaround Request (business days)

10	5	3	1,2
x			

Client:	Tacoma Pierce County Health Department
Project:	Arsenic Project
Contact:	Glenn Rollins
Phone No.:	(253) 798-3503
Fax No.:	(253) 798-6498
Email:	grollins@tpchd.org

Analyses Requested

Lab #	Sample ID	Date	Time	Matrix	# of containers	Arsenic and Lead: ICP-MS											
1					1												
2					1												
3					1												
4					1												
5					1												
6					1												
7					1												
8					1												
9					1												
10					1												
11					1												
12					1												
13					1												
14					1												
15					1												
16					1												
17					1												
18					1												
19					1												
20					1												

	Printed Name	Signature		
Relinquished By				
Received By				
Relinquished By				
Received By				
Relinquished By				
Received By				

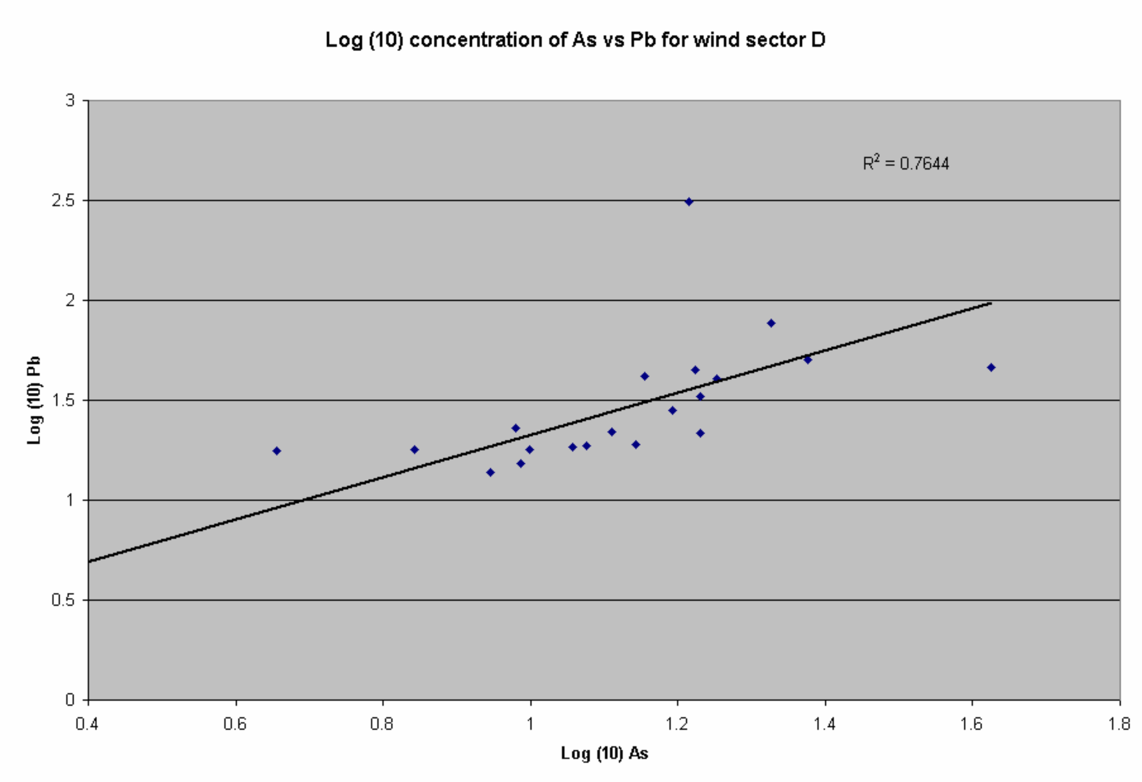
Cooler: 4 degrees C

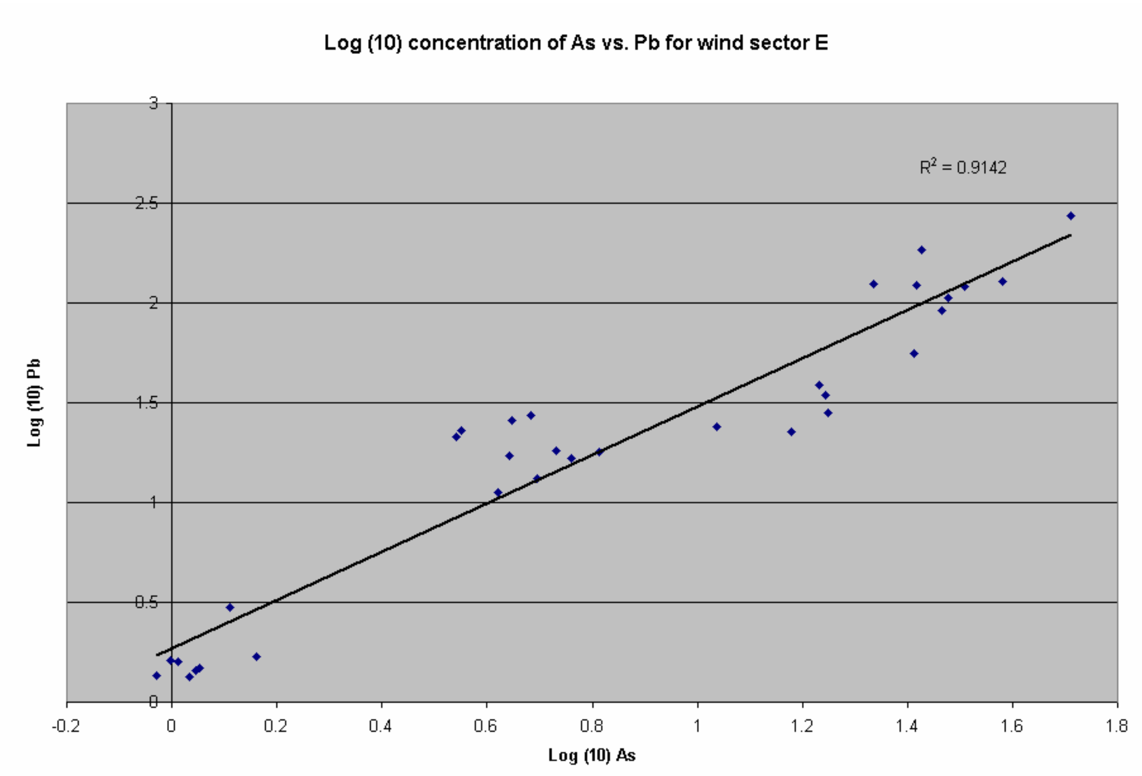
Back To
Client / Project Info
Samples Info
Analyses
Special Instructions

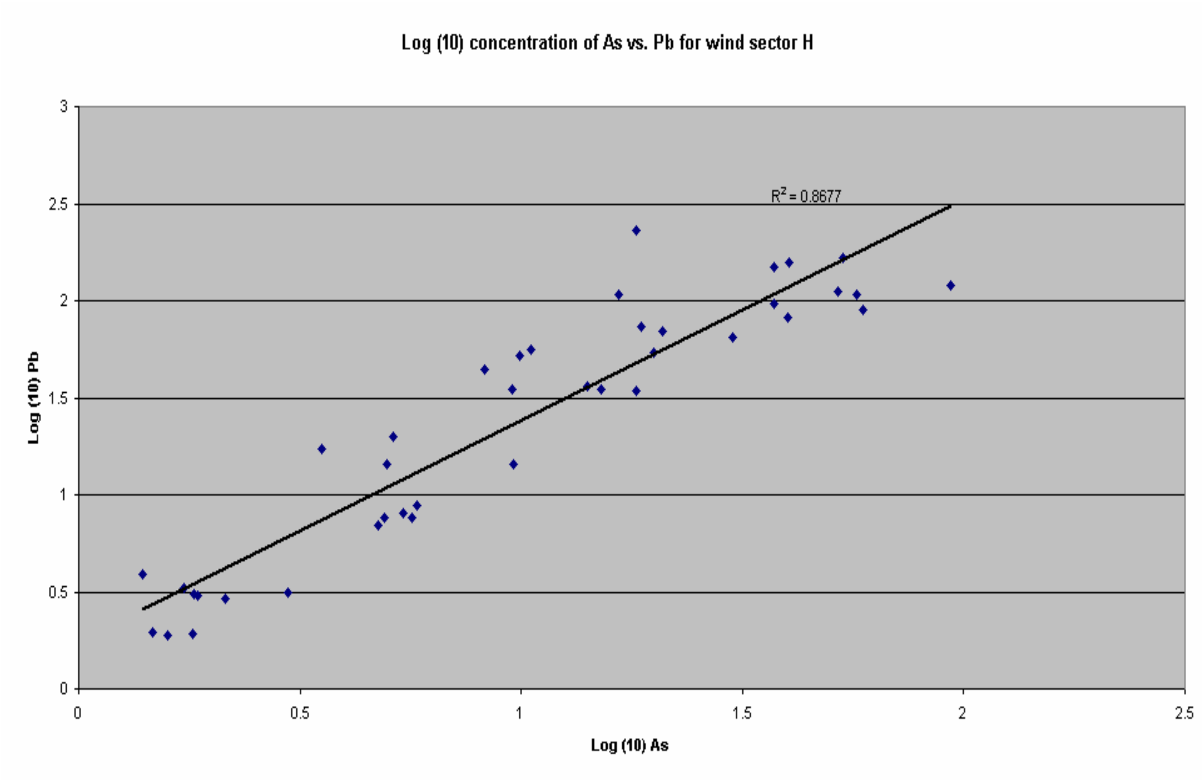
Print COC
Save

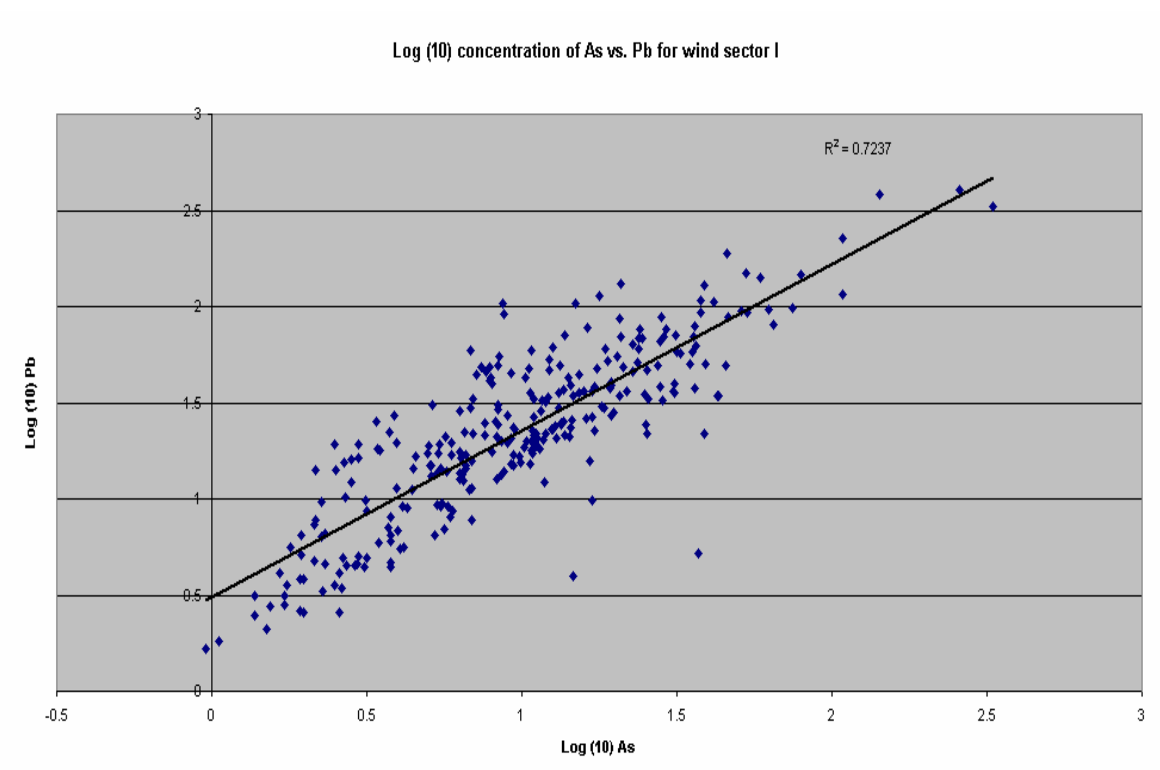
Clear
Sample Info
Clear All

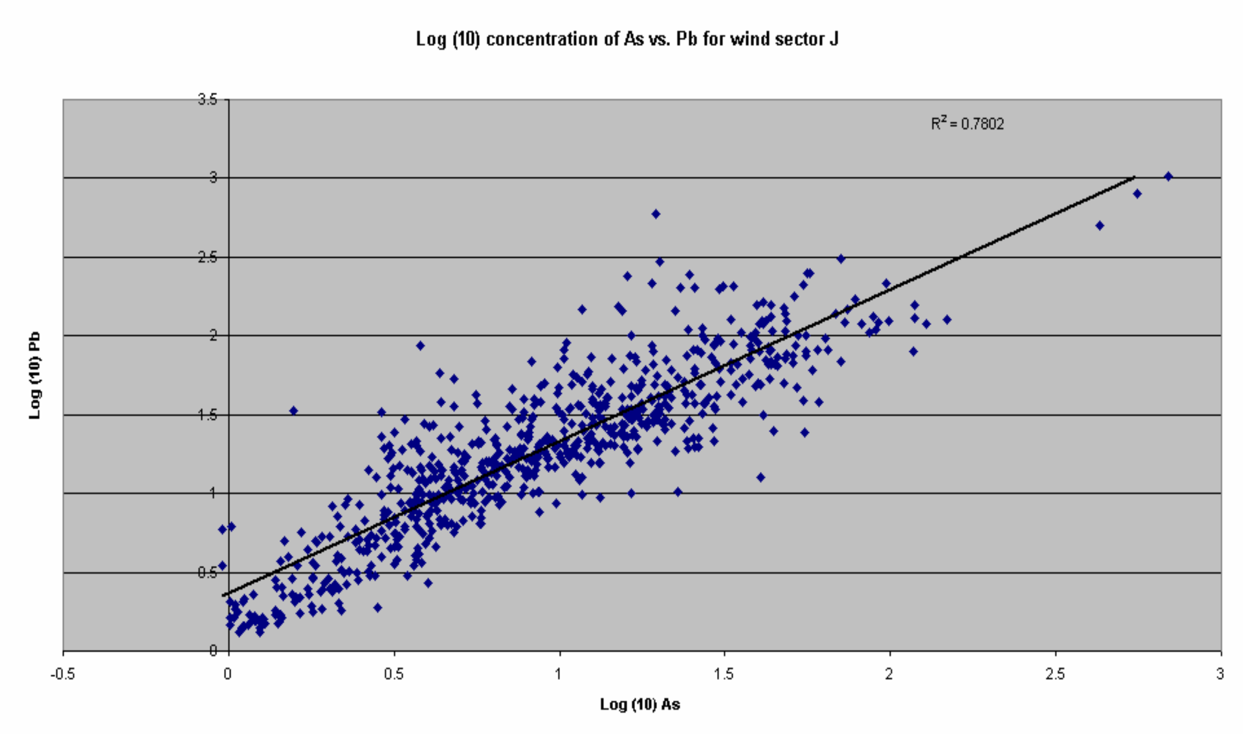
Attachment F. Log(10) Regression Plots Of Arsenic And Lead Concentrations

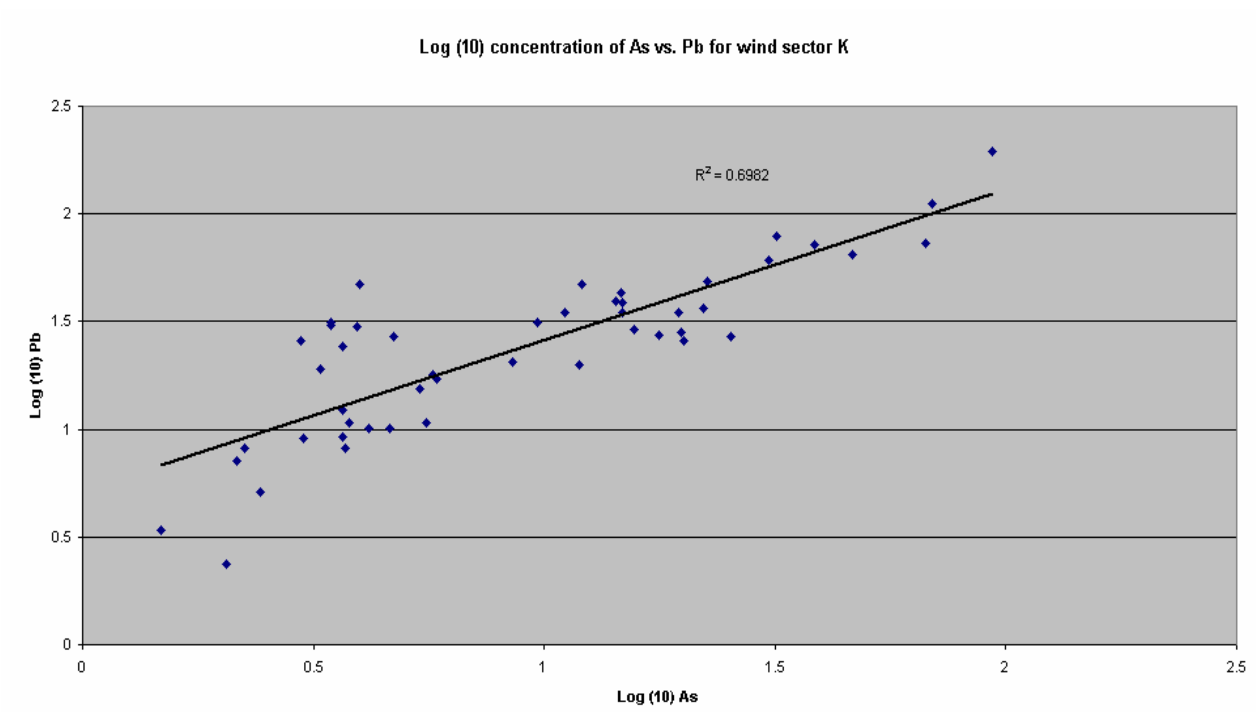


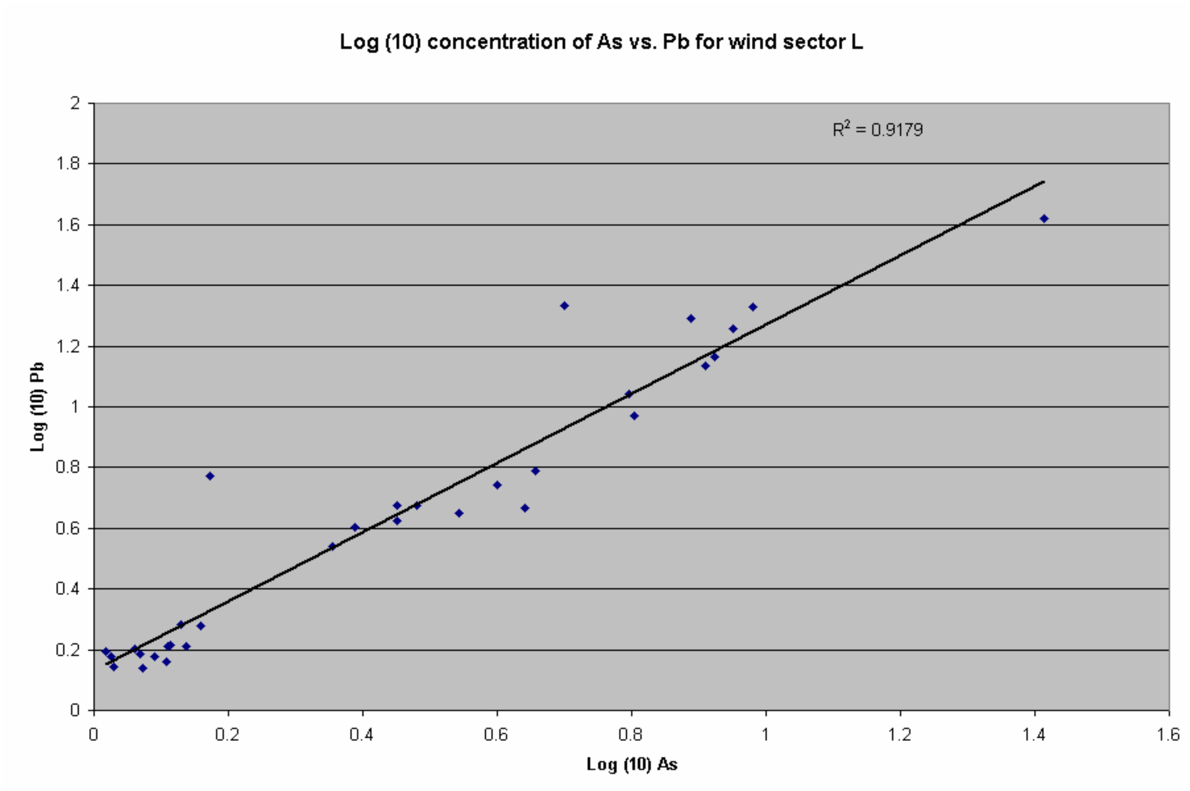


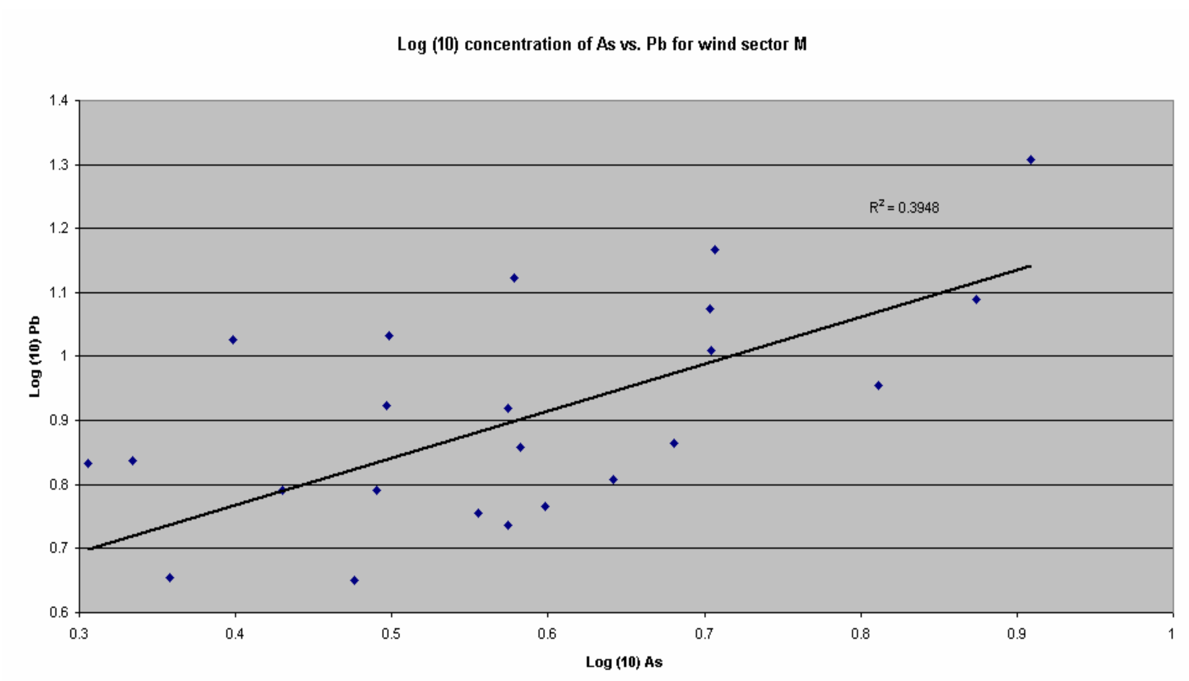

Log (10) concentration of As vs. Pb for wind sector H
$R^2 = 0.8677$
Log (10) Pb
Log (10) As
0
0.5
1
1.5
2
2.5
3


Log (10) concentration of As vs. Pb for wind sector I
$R^2 = 0.7237$
Log (10) Pb
Log (10) As
-0.5
0
0.5
1
1.5
2
2.5
3


Log (10) concentration of As vs. Pb for wind sector J
R^2 = 0.7802
Log (10) Pb
Log (10) As
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
0
0.5
1
1.5
2
2.5
3


Log (10) concentration of As vs. Pb for wind sector K
R^2 = 0.6982
Log (10) Pb
Log (10) As
2.5
2
1.5
1
0.5
0
0
0.5
1
1.5
2
2.5


Log (10) concentration of As vs. Pb for wind sector L
R^2 = 0.9179
Log (10) Pb
Log (10) As
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2


Log (10) concentration of As vs. Pb for wind sector M
R^2 = 0.3948
Log (10) Pb
Log (10) As
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4

Attachment G. Results of statistical tests.

T-Test

Arsenic – comparison of depths

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Value Depth 1	15.673	599	32.6353	1.3334
	Value Depth 2	16.910	599	37.0281	1.5129

Paired Samples Correlations

	N	Correlation	Sig.
Pair 1 Value Depth 1 & Value Depth 2	599	.839	.000

Paired Samples Test

	Paired Differences					t
				95% Confidence Interval of the Difference		
	Mean	Std. Deviation	Std. Error Mean	Upper	Lower	
Pair 1 Value Depth 1 - Value Depth 2	-1.237	20.2268	.8264	-2.860	.386	-1.497

Paired Samples Test

	df	Sig. (2-tailed)
Pair 1 Value Depth 1 - Value Depth 2	598	.135

Lead – comparison of depths

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Value Depth 1	38.228	601	62.2233	2.5381
	Value Depth 2	32.257	601	60.6141	2.4725

Paired Samples Correlations

	N	Correlation	Sig.
Pair 1 Value Depth 1 & Value Depth 2	601	.719	.000

Paired Samples Test

	Paired Differences					t
				95% Confidence Interval of the Difference		
	Mean	Std. Deviation	Std. Error Mean	Upper	Lower	

Pair 1 Value Depth 1 - Value Depth 2	2.971	46.0444	1.8782	-.718	6.659	1.582

Paired Samples Test

	df	Sig. (2-tailed)
Pair 1 Value Depth 1 - Value Depth 2	600	.114