PUBLIC HEALTH - SEATTLE & KING COUNTY

FINAL REPORT

VASHON/MAURY ISLAND CHILD-USE AREAS STUDY
2000-2001

prepared by

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VASHON/MAURY ISLAND
CHILD-USE AREAS STUDY
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GLOSSARY

As	chemical symbol for arsenic
ASARCO	registered name of the former American Smelting and Refining Company, recently acquired by Grupo Mexico
ATSDR	Agency for Toxic Substances and Disease Registry, an agency within the federal Centers for Disease Control
Box-and-Whisker Plot	a descriptive statistical graphing technique that summarizes the distribution of values in a data set. It is a graphical summary of the dot plot of results for that data set. The median, 25th percentile, and 75th percentile values for the data set are shown as a central box, with "whiskers" (lines) and on occasion individual results shown outside the box to represent values below the 25th percentile and above the 75th percentile. (See also the explanation in Attachment E).
CCA	copper chromated arsenic (a preservative treatment for wood)
dot plot	a data plot in which individual results are plotted according to magnitude along a scale (i.e., an axis) that represents one variable of measurement. For example, arsenic concentrations for a set of soil samples collected at 0-2 inches can be plotted to show the complete distribution of sample results.
DU	Decision Unit
FSP	Field Sampling Plan
GIS	Geographic Information System
GPS	Global Positioning System
HSP	Health and Safety Plan
MTCA	Model Toxics Control Act
p-value	in statistical hypothesis tests, the significance probability is given

	by the "p-value", or probability that results equal to or more extreme than the results actually observed would occur if the test hypothesis is true. For example, if the test hypothesis is that the regression slope is zero and the data result in a p-value of <0.01, the observed results (or more extreme results, in the direction of a stated alternate hypothesis) would occur less than one time in one hundred. Low significance probabilities lead to rejection of the test hypothesis in favor of the alternate hypothesis (i.e., a judgement that extremely rare events are unlikely to be observed). Thus, one would say that the regression slope is "statistically significantly different than zero at a significance level of 0.01".
Pb	chemical symbol for lead
PHSKC	Public Health - Seattle & King County
ppm	parts per million (unit of measurement for contaminant concentrations in soils)
PQL	practical quantitation limit
PSAPCA	Puget Sound Air Pollution Control Agency (now called Puget Sound Clean Air Agency)
QAPP	Quality Assurance Project Plan
QA/QC	Quality Assurance/Quality Control
R^2	"R-squared", where R is the correlation coefficient between two variables. In statistical regression analyses, R-squared (a value between 0 and 1, but often expressed as a percentage between 0% and 100%) is a measure of the percentage of the total variance in the dependent variable that is explained by its relationship with the independent variable.
scatterplot	a data plot in which individual results are plotted in a coordinate system with two or more axes, where each axis represents one of a set of related measures. For example, the arsenic versus lead concentrations for a set of soil samples analyzed for both can be plotted in two dimensions (i.e., as an X-Y plot), with arsenic concentrations on one axis and lead concentrations on the other. Similarly, the arsenic concentrations for two sampled depths in a set of borings can be plotted with each axis representing concentrations at one of the two depths. A scatterplot is a generalization of a dot plot.

SDG	sample delivery group
SRM	standard reference material (also referred to as lab control sample, or LCS)
UW	University of Washington
VMI	Vashon-Maury Island

EXECUTIVE SUMMARY

A survey of Vashon-Maury Island forest soils in 1999-2000 (PHSKC and Glass 2000) showed significantly elevated arsenic and lead concentrations in near-surface soils. That initial survey focused on forested areas because the degree of soil disturbance was expected to be minimal, compared to developed properties, and as a result the soil contamination (due to deposition of airborne contaminants) was expected to be greatest. Based on the initial survey findings, the Vashon-Maury Island Child-Use Areas Study was conducted to address concerns about possible exposures in developed areas where numbers of children could have frequent contact with soils. The Child-Use Areas Study was funded by the Washington State Department of Ecology (Ecology), designed by Ecology and Public Health - Seattle & King County (PHSKC), and performed by PHSKC. A primary goal of the study was to collect enough data to decide whether early cleanup actions, called Interim Actions under Ecology's Model Toxics Control Act regulations, should be taken at any of the sampled child-use areas. Interim Action criteria development and data evaluations are reported separately.

A total of 1,503 soil samples from 34 child-use areas was collected and analyzed for arsenic and lead. Each child-use area had one or more designated Decision Units (DUs), with soil samples collected in each Decision Unit from multiple borings and at multiple depths in each boring. The Decision Units represent distinct areas within a property where children play and which could be considered separately for cleanup decisions. Child-use areas included public and private schools, public parks and beaches, daycare centers, preschools, and camps. The sampled child-use areas were located on all parts of Vashon-Maury Island and were assigned to one of three spatial Zones reflecting the general patterns and gradients in soil contamination levels from the initial survey. These spatial Zones provided a simple but useful way to evaluate large-scale spatial patterns.

Public Health staff collected soil samples between August 28 and November 8, 2000. Laboratory analyses were performed by OnSite Environmental, Inc. (Redmond, WA). Except for beach DUs (where samples from different borings were composited by depth interval), all samples were analyzed as discrete samples (each sample representing a single depth interval from a single boring). Data validation was performed by EcoChem, Inc. (Seattle, WA). Based on the data quality assessments, all results reported by OnSite were acceptable for evaluating the child-use areas.

Data evaluations support the following conclusions with respect to the patterns of arsenic and lead contamination at sampled child-use areas:

- ☐ Beach areas. The Child-Use Areas Study provides the first extensive survey of arsenic and lead on Vashon-Maury Island beaches. Samples at the same depth interval from all borings were composited for analysis at beach DUs. All 16 sampled beach DUs had low arsenic and lead concentrations, regardless of location. The maximum arsenic and lead values were only 2.8 ppm and 19 ppm, respectively. For comparison, Ecology's default soil cleanup standards are 20 ppm for arsenic and 250 ppm for lead.

☐ Magnitude of contamination. The 48 non-beach DUs had maximum arsenic concentrations from 8.9 to 130 ppm, and maximum lead concentrations from 12 to 900 ppm. The maximum values in this study were lower than in the initial survey of forested areas, and the total data set included relatively few high values. Nevertheless, more than 70 percent of the non-beach DUs had a maximum arsenic concentration exceeding Ecology's default 20 ppm cleanup standard. Sampling in child-use areas thus confirmed the initial survey finding of contamination, to one degree or another, over most of Vashon-Maury Island.

☐ Spatial Pattern. Maury Island, south Vashon Island, and the eastern part of mid-Vashon Island showed the highest arsenic and lead values. This spatial pattern closely matches the results of the initial survey of forest soils. Two anomalous high-lead DUs (one on north Vashon, the other on the western shoreline) both had low arsenic levels and likely represent a different source for lead.

☐ Relationship of Arsenic and Lead. Arsenic and lead concentrations were strongly correlated, with typical (modeled) lead-to-arsenic ratios of about 2:1 to 3:1. The lead-to-arsenic ratios for individual samples in the Child-Use Areas Study varied over a somewhat broader range. The overall correlation between arsenic and lead in this study is very similar to that in the initial survey. A small number of anomalous lead values was observed in child-use area samples, which probably reflect non-smelter sources of lead.

☐ Depth Profiles. For the study as a whole, arsenic and lead concentrations are generally higher in the top 6 inches than at greater depths. Exceptions to this general pattern occur - at about 30 percent of DUs, for example, the maximum values occur below 6 inches - which is likely the result of property development and soil-disturbing actions. Arsenic exhibits greater downward mobility than lead within the top 6 inches at child-use areas, similar to the finding of the initial survey of forest soils.

☐ Variability in Concentrations. Arsenic and lead concentrations can vary substantially over quite small areas, such as within a single DU. As a result, average concentrations are much lower than maximum concentrations. Because of this local variability, a small number of soil samples may not adequately characterize contamination at a property. Arsenic and lead values can also vary significantly from one child-use area to another, even when those areas are located close together. The observed variability in contaminant concentrations at

> closely-spaced child-use areas is probably largely attributable to specific property development histories. Local variations in the original deposition of airborne contaminants may also be a factor.

The Child-Use Areas Study provides the first extensive characterization of soil arsenic and lead concentrations at developed as opposed to forested properties on Vashon-Maury Island. The results of the Child-Use Areas Study on Vashon-Maury Island confirm that contamination of near-surface soils by arsenic and lead (and, by inference, other smelter-related contaminants not measured in this study) extends to developed properties, with a large-scale spatial pattern that is strikingly similar to that found in the initial survey and with the highest contamination levels still generally found in the top 6 inches. Contaminant concentrations are reduced compared to nearby forest soils, with some samples at each child-use area showing background or low concentrations for arsenic and lead. This pattern is consistent with a conceptual model in which property development actions serve to dilute, mix, or remove original soil contamination to a degree that may vary from one location to another on the property, producing the small-scale variability often observed among borings within child-use areas in this study.

The reported results are specific to the properties sampled. There are good reasons not to generalize those results uncritically to other unsampled properties, whose development histories (e.g., the date of most recent significant soil disturbance), land uses, and topographic profiles may differ in important ways. Moreover, some portions of Vashon-Maury Island are under-represented by the group of child-use areas included in this study - for example, locations on south Vashon below Burton, and much of Maury Island.

1.0 PROJECT DESCRIPTION AND OBJECTIVES

Introduction. The former ASARCO Tacoma copper smelter operated in Ruston, Washington (a small municipality northwest of downtown Tacoma, WA) for almost 100 years before closing permanently in 1986. That smelter specialized in the toll smelting of complex ores, especially ores with high arsenic content. For many years it was the sole domestic supplier of arsenic for the U.S. market. Concerns over smelter emissions of arsenic and other contaminants, their transport downwind to nearby communities, and possible exposures and health effects from the deposition of contaminants from the smelter plume led to numerous studies starting in the early 1970s. (See PHSKC and Glass 2000 for a brief review of previous studies).

Vashon-Maury Island is located north-northeast of the former Tacoma Smelter, in the dominant downwind direction according to annual wind roses compiled by the Puget Sound Clean Air Agency (formerly Puget Sound Air Pollution Control Agency). Soil concentrations of arsenic and, occasionally, other smelter-related contaminants on parts of Vashon-Maury Island were measured in more than a dozen studies starting in the early 1970s. Other types of studies - for example, sampling and analysis of garden vegetables, urinary arsenic measurements, bee biomonitoring studies, air particulate monitoring, and sampling of sediments in Quartermaster Harbor and the East Channel - were also performed. The University of Washington School of Public Health, funded by the Centers for Disease Control, conducted an Exposure Pathways Study in the mid-1980s that included a small number of selected households on the southern half of Vashon-Maury Island. The UW study focused on the relationship between multiple environmental or behavioral measurements and arsenic exposures as measured by urinary arsenic levels. Through 1999, however, all of the data from all previous studies did not provide an adequate survey of island-wide contamination patterns.

In the early 1990s, under the federal Superfund program, the Environmental Protection Agency (EPA), Region 10 completed studies of the Ruston and North Tacoma areas near the former Tacoma Smelter. Properties in an area within approximately one mile of the smelter are being cleaned up by ASARCO in a multi-year program under a Consent Decree with the EPA. Current Superfund cleanup activities do not include any properties on Vashon-Maury Island.

In 1999 and 2000, Public Health - Seattle & King County (PHSKC) completed the first comprehensive survey of contamination by arsenic, lead, and cadmium in surficial[1] soils on Vashon-Maury Island (see PHSKC and Glass 2000). That survey was jointly funded by PHSKC

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[1] In the context of the initial soil survey, "surficial" refers to the top 6 inches of soil below the forest duff layer. This more general term does not define the relationship between "surface" soils and the frequency of contact or likelihood of exposure as a function of depth.

and the Washington State Department of Ecology (through a Site Hazard Assessment Grant). It was developed in response to community concerns following disclosure of substantially elevated concentrations of arsenic at a Maury Island gravel mine property, as well as from Ecology interests in better evaluations of "area-wide contamination problems" where the spatial extent of contamination is uncommonly large and response actions are correspondingly challenging. Soil samples were collected from second-growth forested areas in all parts of Vashon-Maury Island. The initial soil survey focused on forested areas because they were relatively undisturbed and were expected to provide upper-bound estimates of residual soil contamination (property development and soil disturbance are likely to decrease maximum contaminant concentrations). The depth profile of soil contamination was considered likely to be simpler, and therefore more cost-effectively sampled, in undisturbed areas. Data from sampling in forested areas was also deemed much less likely to be affected by artifacts or other sources for arsenic, lead, and cadmium, making data interpretations easier.

The initial soil survey confirmed the presence of substantially elevated concentrations of smelter-related contaminants on Vashon-Maury Island. The maximum arsenic, lead, and cadmium concentrations were 460 ppm[2], 1300 ppm, and 15 ppm, respectively. The results from 161 sampling locations on Vashon-Maury Island showed a distinct spatial gradient, generally from south to north, with the highest concentrations of contaminants on South Vashon Island, Maury Island, and the eastern part of central Vashon Island - consistent with the wind rose patterns and expected deposition from the smelter plume.

The Child-Use Areas Study was developed as a followup to the initial soil survey to assess soil contamination in areas where activities were more likely to result in soil contact and contaminant exposure. Children were identified as a population of special concern because of their play activities and frequent hand-to-mouth or object-to-mouth behaviors. The areas targeted for sampling included locations heavily used by children at schools (public and private), public parks and beaches, daycare centers, preschools, and camps. These targeted locations are all characterized by activities involving numbers of children rather than individual children, with repeated opportunities for contact rather than isolated, one-time contact. Resources were not available to sample the large number of private residential yards where individual children may have even more frequent soil contact.

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[2] In this report, unless otherwise noted, all soil contaminant concentrations are presented as parts per million, or ppm, measured on samples sieved to <2 mm and based on dry weight.

Objectives. The initial survey of forested areas generally characterized the highest expected soil concentrations of arsenic and lead over all of Vashon-Maury Island.[3] This characterization was achieved, however, at the "cost" of sampling only in forested areas where frequent soil contact is less likely. The initial survey data therefore have limitations for evaluating potential community exposures. The Child-Use Areas Study, in contrast to the initial survey, focused sampling in precisely those areas where soil contact is much more likely. Three specific objectives were defined to guide development of the sampling design.

The first objective of the study was to decide on the need for early cleanup actions at areas where a population of special concern, young children, could have frequent soil exposures. Ecology has informed the community that development and implementation of a final Cleanup Action Plan for Vashon-Maury Island under the Model Toxics Control Act (MTCA) will take many years. Under MTCA, earlier Interim Actions can be taken to reduce or minimize potential health risks before final cleanup actions are decided upon or completed. A primary objective for sampling at child-use areas was to decide whether such Interim Actions are advisable at any of these areas of high potential contact by children.

A second objective was to begin to evaluate the differences in soil contamination patterns between relatively undisturbed forested areas and a variety of developed land uses where soil disturbance has occurred to one degree or another. Experience at other sites has shown that the history of land development and soil disturbance is a very important factor affecting both the magnitude and depth profile of soil contamination originating from air deposition. Soil contamination data from the Child-Use Areas Study will improve the conceptual model for residual soil contamination on all of Vashon-Maury Island. The improved understanding of soil contamination patterns will support future Remedial Investigation studies under MTCA and the evaluation of cleanup alternatives.

A third objective of the study was to evaluate methods for confirming the likely source(s) of measured arsenic and lead in Vashon-Maury Island soils. Selected samples were analyzed for additional tracer elements, besides arsenic and lead, to help with source determinations.

The findings related to each of these three study objectives are being provided in separate reports. An Interim Action memo (Ecology 2001) describes the development of Interim Action Criteria (selected based on evaluations of a technical work group) and decisions reached on interim actions at the 34 sampled child-use areas, to address the first objective. The second objective is addressed in this report, which characterizes the patterns of soil contamination

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[3] The map of the initial survey results provides general rather than absolute upper-bound values. More intensive soil sampling is in fact likely to produce some even higher values than reported in the initial survey.

shown by the child-use area sampling results, in comparison to the initial survey in forested areas. Finally, the results of tracer element analyses for selected child-use area samples, as well as other information related to source identification, will be discussed in a report to be prepared after additional samples from the King County mainland are analyzed for tracer elements.

Project Description. The Child-Use Areas Study was funded by Ecology as one task within a larger scope of work for an extended Site Hazard Assessment of the Tacoma Smelter Plume Site under MTCA. The field sampling staff and day-to-day management of the study were provided by PHSKC. Frequent coordination team meetings were held throughout the study with PHSKC, Ecology, the Washington State Department of Health, and others participating. PHSKC arranged subcontracts with five groups to assist with the project. OnSite Environmental, Inc., of Redmond, WA performed all laboratory analyses for arsenic and lead. Battelle Marine Sciences Laboratories, in Sequim, WA performed tracer element analyses. EcoChem, Inc., of Seattle, WA provided data validation reviews of the arsenic and lead results. Best Consulting, Inc., of Kirkland, WA provided computer database software designers. PHSKC also retained Gregory L. Glass, an independent environmental consultant in Seattle, WA, to facilitate a study design work group, perform data evaluations, and help prepare project reports.

The detailed study design, sampling results, and data evaluations are discussed in subsequent sections of this report. In brief, soil samples were collected at 34 child-use areas located in all parts of Vashon-Maury Island. Multiple soil borings were completed at each child-use area; the sampling density for each area was greater than for the initial soil survey in forested areas. A total of 1,503 sample results was compiled to characterize the 34 child-use areas. Of these, 1,455 represent (discrete) results for "uplands" areas and 48 represent (composite) results for beach areas. Sampling depths extended to 22 inches in most cases, with five depth intervals analyzed separately in each soil boring; beach areas and some areas in north Vashon Island included analyses of only three depth intervals to 12 inches. Laboratory analyses of child-use area samples included (unspeciated) arsenic and lead.

The Child-Use Areas Study also included a small number of additional soil samples and analyses to meet the second and third objectives discussed above. A total of 36 samples was collected from four forested locations originally sampled in the initial soil survey. Selected samples from these 36 were included among the total of 166 samples analyzed in the tracer element study for Vashon-Maury Island (see Attachment C for a description of sampling locations and arsenic, but not other tracer element, results). At four of the child-use areas, a total of 80 additional "forest fringe" samples was collected in adjacent forested areas to help evaluate local differences in contamination patterns at undisturbed versus developed properties (see Attachment D for a description of sampling locations and arsenic and lead results).

Data Release. PHSKC and Ecology recognized the desire of many Vashon-Maury Island community members to be informed of study results as soon as final, validated data were available. Through close coordination and discussions with the Vashon Community Council, an approach was developed for data release before this final, peer-reviewed report was completed. Each owner of a sampled child-use area was first provided with a property report letter including all sampling results and a copy of the field notebook sketches showing sampling locations. PHSKC and Ecology then held two informal meetings on Vashon-Maury Island, on June 6th and 7th, at which the property owners could discuss their results and ask questions in person. On June 11, 2001 a Community Update meeting was held at McMurray Middle School. As part of a presentation on the overall status of Tacoma Smelter Plume activities on Vashon-Maury Island, Ecology and PHSKC presented a summary of the results of the Child-Use Areas Study. Handout materials available to community members at the meeting included a set of maps showing general sampling locations and maximum and average arsenic and lead results (see Figures 1 through 5) and a one-page written summary of preliminary data evaluations (discussed in more detail in Section 6.0, below), as well as other relevant information. PHSKC also made study information available through its website (see PHSKC 2001).

Report Organization. Section 2.0 provides a discussion of the study design. Sample collection and sample preparation are described in Section 3.0, which also notes how the initial study design was modified during field activities. The laboratory analyses are discussed in Section 4.0, and data validation reviews are summarized in Section 5.0. The results of various data evaluations to characterize the soil contamination patterns at sampled child-use areas are presented in Section 6.0. In Section 7.0, the results of this study are discussed in the context of previous studies. The main conclusions of the Vashon-Maury Island Child-Use Areas Study are summarized in Section 8.0, and references are provided in Section 9.0. The Attachments provide supporting information, including the results for resamples collected at initial soil survey locations and in "forest fringe" areas near four sampled child-use areas.

2.0 STUDY DESIGN

2.1 STUDY DESIGN PROCESS

A Sampling Design Work Group was convened to develop the study design. The work group included representatives of PHSKC, Ecology, the Washington State Department of Health, and the Agency for Toxic Substances and Disease Registry (ATSDR, a component of the federal Centers for Disease Control). PHSKC's consultant, Gregory Glass, facilitated work group discussions, provided technical analyses on various topics, and documented the adopted study design (see Glass 2000b). One member of the Vashon-Maury Island community also provided review comments on the draft design report; responses to those comments improved the presentation of the proposed study design.

The Sampling Design Work Group met four times in July and August, 2000 for discussions of study design issues, in a process similar to the one used for the initial soil survey. Before the start of work group meetings, PHSKC had begun to compile information on candidate child-use areas on Vashon-Maury Island. The initial list of candidate areas was developed through contacts with community organizations such as Vashon Youth and Family Services, the Vashon School District, and the Vashon Park District, among others. On May 24, 2000 PHSKC held a meeting with Vashon agencies and community members at the Vashon Park District headquarters at Ober Park. The preliminary list of candidate areas was reviewed and attendees were asked if there were other areas that should be considered for sampling. The best approaches for obtaining access agreements for sampling, and for determining specific sampling locations at each child-use area, were also discussed with community members. Based on their recommendations, a letter requesting access for sampling and information on child activity areas was prepared and mailed to each candidate area owner. Community residents expressed a strong desire for PHSKC to move quickly to sample collection without additional community meetings.

As the study design work progressed, PHSKC visited the candidate child-use areas for familiarization and to enhance the responses to the information request letter. The familiarization visits and letter responses provided information from which preliminary sample counts were developed. Some areas were removed from further consideration because they did not meet the criteria defining child-use areas (e.g., a daycare center no longer operated) or because property owners chose not to participate. (A few child-use areas were later added to the study during field sampling activities; see Section 3.0).

A series of design issues was addressed during work group meetings, such as the following: 1) defining study objectives; 2) identifying child-use areas for inclusion in the study; 3) developing the study design while Interim Action Criteria were still being developed; 4) deciding on the number of soil borings and sampling depth intervals at each child-use area; 5) selecting specific sampling locations at each area; 6) allocating sampling effort among child-use areas to satisfy study resource constraints; 7) incorporating tracer element analyses for source identification analyses; and 8) incorporating "forest fringe" sampling for assessing differences in contamination between undisturbed and developed properties. The candidate child-use areas were located and mapped by PHSKC using Geographic Information System (GIS) software. Much of the work group effort in the latter stages of the design process focused on the sample allocation problem. The distinct spatial gradient in soil contamination shown in the initial soil survey was used by the work group as one principal factor driving allocation decisions.

The work group reviewed and approved a memorandum documenting the final study design (Glass 2000b). PHSKC then completed a series of steps necessary to implement the design and start field sampling activities, including: preparation of the Field Sampling Plan, Quality Assurance Project Plan, and Health and Safety Plan (see PHSKC 2000); setting up a field supply station on Vashon Island; obtaining and field-testing sampling equipment; training field sampling staff; coordinating and contracting with the analytical laboratory; obtaining standard reference materials for use in the lab QA program; and completing access agreements with property owners.

2.2 STUDY DESIGN PRINCIPLES

The Sampling Design Work Group developed a number of principles to be applied for the study design to meet its identified objectives. Those principles are discussed in the memorandum documenting the study design (see Glass 2000b) and are summarized here.

Study area. Even though the initial soil survey showed distinct spatial gradients in the degree of soil contamination, all parts of Vashon-Maury Island were included in the Child-Use Areas Study. Furthermore, the intent of the study was to provide information on all child-use areas meeting the defining criteria and whose owners were willing to participate - that is, to provide a survey rather than a statistical sampling of child-use areas - within the limits of available resources. At a given child-use area, all locations where children's activities could lead to soil contact might not be sampled, but owners would be involved in prioritizing the areas for sampling.

Sampling density. The density of sampling in the Child-Use Areas Study would greatly exceed the sampling density used in the initial soil survey in forested areas. That difference reflected the different objectives of the two studies - regional-scale characterization for the initial soil survey, versus making Interim Action decisions for specific child-use areas in this study. Relatively large variability in soil contaminant concentrations within a single child-use area was judged to be possible based on information from detailed sampling at other sites (e.g., the Everett Smelter site; see ASARCO, Inc. 1998, Ecology 1999, and SAIC 2001), supporting the principle of collecting information from multiple locations at each area to adequately characterize potential child exposures. Sampling densities did not have to provide information for final cleanup decisions, and provided no guarantee that all contamination at a sampled property had been identified.[4]

Sampling depths. The development of child-use areas and consequent soil disturbance are likely to affect the pattern of contaminant concentrations by depth. This has been observed in detailed soil sampling at other sites (e.g., the Everett Smelter site). The Child-Use Areas Study would therefore include sampling to depths greater than the 6 inches sampled in the initial soil survey of forested areas. Multiple soil depth intervals would be analyzed separately so that contaminant depth profiles could be characterized and potential exposures evaluated. The Interim Action criteria had not been determined when the study design was being developed, but the collection of information for multiple depth intervals would support both Interim Action decisions and the characterization of differences in contamination patterns between undisturbed and developed properties. As is the case for sampling density, the total depth of sampling incorporated in the Child-Use Areas Study provides no guarantee that all soil contamination at a property will be identified.[5]

Allocation of sampling effort. Staffing resources for sample collection and budget limitations for sample analyses set practical constraints on the overall scope of the study. The Sampling Design Work Group considered a number of principles for allocating sampling efforts among child-use areas (see Glass 2000b). Two of the primary principles involved compositing of beach samples before analysis and using a comparatively lesser sampling intensity (although still with multiple sampling locations per child-use area) in regions where the initial soil survey showed the range of soil contaminant concentrations to be more limited (i.e., lower maximum contaminant concentrations). An early decision by the Sampling Design Work Group was to analyze soil samples as discrete samples. This approach would provide information on maximum and average contaminant concentrations, as well as the spatial variability within a

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[4] The variation in contaminant concentrations from one location to another at a child-use area cannot be predicted or modeled in advance. All practical sampling schemes have some non-zero probability of missing contamination that is present. The tolerance for error from evaluations of sampling information depends on the objectives to be met.

[5] At a property where two feet or more of fill was emplaced, for example, sampling to less than two feet could show uniformly low levels of soil contamination even though soils below the fill (i.e., the near-surface soils of original contours) were significantly contaminated.

child-use area. The work group expected, however, that samples at beach areas would show lower contamination levels. Contaminant concentrations in beach samples were also expected to be more homogeneous because of the mixing that normally occurs in beach depositional processes. Therefore, compositing of samples from different boring locations at the same depth interval (i.e., compositing in horizontal layers) was adopted as a principle for initial analyses of beach samples to meet study resource constraints. Later discrete sample analyses could be performed if judged necessary based on the initial results.

One of the major objectives of the previous forest soil survey was to identify areas where future studies should focus. The contamination gradients documented in the initial survey were used to modify the intensity of sampling, both in terms of the number of sample borings at a child-use area and the number of depth intervals analyzed, based on location. The total Vashon-Maury Island land area was divided into three Zones (south, middle, and north for Zones 1 through 3, respectively) to reflect the spatial pattern of contamination shown in the initial soil survey. The general principle applied in making allocation decisions was to decrease the sampling intensity (number of borings as well as depth intervals analyzed) from south to north by Zones. Greater precision in sampling results was sought in those areas where higher maximum concentrations and greater variability in contamination levels were likely to occur.

Specific sampling locations. Information on the specific property development history (if known to the property owner), child activity patterns, and owner preferences for sampling was best collected by the field sampling teams at the time of sample collection. Therefore the selection of specific sampling locations was left to the field teams, subject to a set of principles established by the work group (see Glass 2000b). The general principles included making the sampling results representative of children's activities and potential exposures, avoiding artifacts from unrelated sources of contaminants[6], providing spatial coverage of activity areas (prior to sampling, physical observations generally do not reveal the pattern of contamination), and incorporating where possible owners' preferences for targeted sampling. A set of exclusion criteria would be developed to address issues of potential artifacts in the data. A set of general "templates" for selecting sampling locations at various types of child-use areas was discussed by the work group.

Sampling beyond child-use areas. To meet the second and third objectives of the study, additional soil sampling and analysis was incorporated into the design. To support comparisons between relatively undisturbed forested areas and developed areas, soil samples from adjacent

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[6] This study is focused on potential exposures from soil contamination resulting from Tacoma Smelter releases. From that perspective, exposures from leaded paint, treated wood, or other possible sources of arsenic or lead are considered artifacts (even though they may contribute to total exposures). Such artifacts are not limited to the study area, but occur in most areas. Cleanup actions for the Tacoma Smelter Plume site under MTCA will focus on actions to address smelter-related impacts.

forested areas (the "forest fringe") would be collected and analyzed at a number of child-use areas. This local sampling would provide more detailed information than would otherwise be available from the regional-scale initial soil survey. To address source identification issues, tracer element analyses would be performed on selected samples from child-use areas. Approximately 10 percent of the child-use areas samples were targeted for inclusion in the tracer element study.

Data comparability. The Child-Use Areas Study should be designed so that the data were comparable to data from the initial soil survey. Both studies therefore analyzed for total (unspeciated) arsenic and lead in soil samples. The same analytical methods were used, and both sample handling protocols included sieving samples to retain the fraction <2 mm for analysis (consistent with MTCA requirements). All laboratory results were reported on a dry weight basis. The first two depth intervals to be analyzed were the same, 0-2 inches and 2-6 inches; however, the decision to use a different sample collection method in this study may introduce some differences in depth intervals actually analyzed (see Section 3.0). Except for the composited beach samples described above, all soil samples were analyzed as discrete samples. These and other details of the study designs resulted in data sets with a high degree of comparability. The primary differences between studies, other than sample collection methods, are the inclusion of more sampling depths, greater sampling density, and (for selected samples) tracer element analyses in the Child-Use Areas Study, all of which provide additional data but do not affect data comparability.

2.3 PRELIMINARY STUDY DESIGN

Considering the study objectives, study design principles, resource constraints, and uncertainty over access agreements (not yet completed when the preliminary design was adopted), the Sampling Design Work group developed a preliminary study design for the Child-Use Areas Study. The work group expected that some modifications would be needed as the study progressed (and such modifications did in fact occur), but that those modifications could be made by the PHSKC study manager and field sampling teams within the overall design and principles already established. An interim sample allocation scheme was completed (see Glass 2000a) that provided for 1,570 sample analyses at 33 child use areas and 4 forest fringe areas (count not including added resamples of initial soil survey locations for the tracer element study, or field QA samples).

The sampling design can best be understood as a series of hierarchic levels (these same hierarchic levels being used later for sample coding):

> Zone: consistent with the regional scale gradients in contamination shown in the initial survey, Vashon-Maury Island was divided into three Zones - south (Zone 1), middle (Zone 2), and north (Zone 3).

Area: Within each Zone, individual child-use areas - for example, parks, daycare centers, and schools - were identified for sampling. Wherever access agreements could not be completed, child-use areas were dropped from the study. Some candidate areas (e.g., parks with beach access only) were dropped from the study because they did not meet the criteria for frequent use by young children.

Decision Unit: Within each area, one or more Decision Units (DUs) were identified for sampling. A daycare center operated at a residential property may have only one child play area in the back yard, for example, while a camp or large school property may have multiple activity areas. One child-use area could include both "uplands" and beach activity areas. Each Decision Unit represents an area of child activity where frequent soil contact and contaminant exposures could occur, and which could be considered separately for decisions on cleanup actions.

Boring: Within each Decision Unit, soil samples were collected at a number of different locations (borings). Many sampling locations were selected as random or grid locations to provide coverage and spatial representativeness in a Decision Unit; some targeted sampling locations were selected, however, to reflect children's behaviors, ground cover conditions (e.g., areas of bare soils), or owner preferences.

Depth Interval: Within each boring, soil samples were collected at multiple depth intervals. As many as five depth intervals were included: 0-2, 2-6, 6-12, 12-18, and 18-22 inches[7].

The final study design included detailed assumptions for each hierarchic element. The 3 sampling Zones were used primarily as a means of applying several of the general study design principles. Approximately one-third of the total number of child-use areas occurred in each sampling Zone. As noted above, 33 identified child-use areas were targeted for sampling. The number of DUs selected for sampling at each child-use area was based on PHSKC's familiarization visits and information provided by property owners on returned questionnaires, as well as allocation decisions to meet study resource constraints. In the preliminary study design, the majority of child-use areas (26 of 33) had either 1 or 2 DUs. Of the 7 remaining child-use areas, 5 had 3 DUs and 2 had 5 DUs.

The number of soil borings per DU varied generally by Zone, with 8, 6 , and 4 borings

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[7] The sampling design memorandum (Glass 2000b) refers to the final depth interval as 18-24 inches. With the GeoProbe™ sampling equipment used in the study, the nominal two-foot coring tube actually recovered soils to 22 inches. That actual depth interval sampled is used here for consistency.

planned for DUs in Zones 1, 2, and 3 (i.e., south to north), respectively. This reflected the adopted principle of decreasing sampling intensity in regions shown to have lesser degrees of contamination in the initial soil survey. Minor variations from this general scheme were made based on considerations at specific child-use areas.

The number of depth intervals to be analyzed was generally 3 in Zone 3 (north Vashon Island) and 5 in Zones 1 and 2. The depth profiles were thus to be determined to 12 inches on north Vashon Island and 22 inches on central/south Vashon Island and Maury Island. This study design reflected the work group's best judgment on the optimal way to meet study constraints - that is, for example, that it was better to reduce the number of depths analyzed than to further reduce the number of locations (borings) sampled at child-use areas in Zone 3. This approach took into consideration the limited overall range of arsenic and lead concentrations on north Vashon Island shown in the initial soil survey. Samples from the fourth and fifth depth intervals would still be collected and archived for possible later analysis. Minor variations from this scheme were made based on considerations at individual child-use areas. Those variations included analyzing samples from the fourth and fifth depth intervals at a few Zone 3 child-use areas based on the amount of potential child contact with soils. The work group also decided to only sample beach DUs at the first 3 depth intervals (i.e., to a total depth of 12 inches).

Analyses for total (unspeciated) arsenic and lead were planned for all soil samples collected at child-use areas, including both "uplands" and beach DUs.

The final sample design included collection of additional soil samples for characterizing "forest fringe" areas. A total of 80 forest fringe samples was included in the final study design: 20 samples, representing 5 depth intervals at 4 boring locations, from each of 4 selected child-use areas (all in Zone 1 and 2). All forest fringe samples were also analyzed for total arsenic and lead. (Forest fringe sampling is discussed in Attachment D).

The final study design assumed that samples to be submitted for additional tracer element analyses would all be selected from the child-use area samples or forest fringe samples. As field sample collection started, however, it was recognized that the tracer element study would benefit from having samples with arsenic and lead concentrations covering as broad a range as possible. Therefore, although not specified in the study design memorandum, resampling was added at a number of the initial soil survey sampling locations where substantially elevated contaminant concentrations had been documented. A total of 36 resamples was included: 3 boring locations and 3 depth intervals (to 12 inches total) at each of 4 initial soil survey locations. The multiple boring locations were included in recognition of the documented small-scale spatial variability in contaminant levels (see PHSKC and Glass 2000); multiple borings provided greater assurance that some samples with substantially elevated contaminant levels would be available for inclusion in the tracer element study. The resamples were analyzed only for arsenic, a sufficient indicator for selecting samples to include in the tracer element study. (Resampling at selected initial soil survey locations is discussed in Attachment C).

The study design included provisions for field QA samples, such as field duplicate samples and equipment rinsate samples, with details to be provided in the Field Sampling Plan (see PHSKC 2000).

Finally, the study design effort included evaluations of various methods for collecting soil samples. The greater depth planned for soil sampling in this study (22 inches) versus the initial soil survey in forested areas (limited to 6 inches) raised concerns over the continued use of hand-sampling techniques, both with respect to their practicability (including time requirements) and effectiveness. Different methods for soil coring used at the Everett Smelter site and in Ecology's recent University Place (Pierce County) study were researched for their applicability to the Child-Use Areas Study. A push-type coring device (GeoProbe^{TM}) similar to that used at the Everett Smelter site was tentatively selected for sampling in this study, pending field testing of its effectiveness. Alternate methods included using a series of constructed stainless steel core tubes of varying lengths, advanced using a hand-held sledgehammer (similar to the approach used in the University Place study), or sampling by hand methods as in the initial soil survey. Both of the alternate methods were considered to have significant disadvantages for sampling to the planned depth of 22 inches.

3.0 SAMPLE COLLECTION

Sample collection. Six PHSKC staff, operating as two to four person sampling teams, collected all soil samples. Two field teams were typically active on any given day. The field sampling personnel received training in the study design, project objectives, and detailed sampling and sample handling protocols before field work started. Training included practice soil sampling in the field. Sampling protocols are described in the Field Sampling Plan (PHSKC 2000).

Sample collection occurred between August 28 and November 8, 2000. Weather conditions during sampling ranged from warm and clear to cool with light to moderate rainfall. Weather conditions did not require suspension of field activities during the period of field work. PHSKC maintained a field supply station on Vashon Island where equipment was stored throughout field activities. The field staff stayed in contact with the PHSKC study manager, and with property owners as required, using mobile cellular phones. This communication link provided quick review of field judgments on implementing or modifying the study design, as well as for scheduling field activities with property owners.

Sample collection activities commenced just before school started for the year. Therefore, PHSKC scheduled initial sampling at the Vashon school campus so that many of the samples there, especially at the elementary and middle schools where younger children would be present, could be collected before classes began. After sampling at the Vashon schools, field activities generally proceeded from south to north Vashon-Maury Island locations. However, day-to-day schedules for field work depended on the status of access agreements. A few child-use areas were also added to the study during the course of field work and were fit into the schedule once identified.

Written access agreements were obtained for all sampling activities prior to sampling (see Attachment A). A project description and access agreement form were mailed to all property owners, with a request for signed forms to be returned to PHSKC. Follow-up telephone calls and personal contacts were made as needed to complete access agreements. Sample collection at all child-use areas was anticipated to require 8 to 10 weeks; PHSKC and Ecology deemed it advisable to start sample collection as soon as possible once the basic study design was completed, in late summer, to take advantage of good weather and start sampling at schools before students returned. The process of completing access agreements for all identified child-use areas was therefore carried out concurrently with field sampling activities. During this process, two additional day-camping or overnight-camping properties were identified that agreed to participate in the study. PHSKC and Ecology also added sampling at two public beach areas that, while not formally designated parks, were mentioned by community members as frequent play areas for young children.

From the total of 45[8] identified possible sampling areas (including those added during field activities, after the initial study design was completed), soil samples were collected at 34 areas. Sampled areas included 17 daycare centers, preschools, or schools and 17 parks, camps, or beaches. The 11 remaining areas were not sampled for various reasons. PHSKC discussions with Vashon Park District staff revealed that two of the initially identified shoreline park areas were very unlikely to have significant child use. Another shoreline area targeted for beach sampling only was found to have a rocky, armored beach where child exposures were also unlikely. The eight remaining areas not sampled were all preschools or daycare centers, some located in each sampling Zone. The reasons for not sampling at these areas included owners declining to participate in the study, active construction (disturbed properties), and changes in the use of the property (e.g., closure of a daycare center).

The primary technique for soil sampling used GeoProbe™ stainless steel coring devices with plastic insert core tubes, driven by a roto-hammer powered by a portable generator. Field testing and evaluation of this sampling technique led to several modifications of the equipment. Initial inefficiencies and problems with penetration were resolved by increasing the size of the portable generator to 3,000 watts and the weight of the roto-hammers to 42 and 70 pounds. These modifications brought the frequency of core penetration failures down to a relatively low level. The field sampling teams also found that it was preferable to bring with them each day multiple sets of those parts of the coring equipment that were in contact with sampled soil, so that equipment decontamination could be done only once at the end of the day.

The GeoProbe™ sampling method was found to be problematic for sandy beach materials; retention of the granular materials was typically poor. An alternate sampling method was therefore used to collect beach samples at a total of 16 beach DUs. That alternate method involved hand-driving a series of constructed stainless steel sampling tubes with flat drive plates attached on top, using sledgehammers. The set of sampling tubes included one for each depth interval to be sampled, with successively greater total lengths. They were advanced in sequence in the same boring location to obtain samples (see PHSKC 2000). At beach DUs, samples were collected only for depth intervals 0-2, 2-6, and 6-12 inches.

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[8] Child-use areas were numbered 1 through 46. Two of those numbered areas turned out to be the same location after a daycare center moved; thus, the total number of distinct identified child-use areas was 45.

Field sampling teams selected specific boring locations at each child-use area through consultation with property owners and in accordance with the sampling design principles. Certain areas were excluded for sampling - for example, there were setback requirements from roads, buildings[9], and CCA-treated wood. Inquiries were made to identify septic field areas, which were also excluded from sampling wherever possible. PHSKC staff contacted a utility locator service to mark underground utility locations at many properties; only beach areas and selected parks or camps where utilities were not a concern were omitted from this procedure. Marked utility corridors were also excluded from sampling. Selected boring locations were a combination of random and targeted locations (see Section 2.0), generally designed to represent potential child exposures to soils through typical activities. A number of boring locations was selected for each defined DU following general design principles for sample allocation; however, some modifications in the number of borings per DU and number of DUs in child-use areas were made in the field. A summary of the final study design showing the numbers of child-use areas, DUs, and samples analyzed in each depth interval by Zone is provided as Table 1.

At one child-use area, three additional borings at specific locations requested by the property owner were sampled; these three targeted borings (designated 2-6-5-1..., 2-6-5-2..., and 2-6-5-3..., with a "DU" number 5; see **sample codes**, below) are not close together and are not considered to represent a DU. Where appropriate in the rest of this report, the results for these three borings will be distinguished from DU results (e.g., maximum or average values at DUs).

Occasionally the core tube could not be advanced to the intended sampling depth at a selected boring location, often because it hit a rock or root. In those cases, another nearby boring location was selected and a new soil core was obtained. The recovery of soils in the plastic liner tube was at times less than the nominal 22-inch sampling depth, even when the core tube was driven to the complete sampling depth, because of soil compaction. An acceptance criterion of 14 inches of recovered soil in the core tube was established. Sampling was repeated at another nearby boring location if soil recovery was less than that criterion. At one boring in Zone 2, an underground structure was encountered that limited soil recovery to the first 3 depth

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[9] The setback distance from buildings was three feet. This was intended to reduce potential artifacts of high lead levels from lead-based paint. Building surfaces, roofs, and downspouts also are known to intercept and collect airborne contaminants, often resulting in increased contaminant concentrations in soils near the buildings. If children's play areas include soils close to buildings, this setback requirement could omit potential high-exposure areas that are related to smelter emissions.

intervals (to 12 inches); at all other locations, the coring depths matched intended sampling depths. All boreholes were backfilled to original grade using bentonite pellets after sampling was completed.

A few property owners observed field sampling activities. There were no requests for split samples.

The field sampling teams recorded information about each soil boring in a field notebook. All sampling locations were recorded using GPS receivers (Garmin eTrex). At a few locations, GPS readings could not be obtained because of poor coverage and lack of signal. Boring location drawings with paced distances from reference points were also entered into the field notebooks. The sample code for each collected sample was written in the field notebook and on chain-of-custody forms accompanying the samples.[10] Two "page-stamps" were developed and used by PHSKC field teams to insure that other required field information was recorded in the notebooks, such as sampling team members, weather conditions, date, soil descriptions, and slope conditions.

The complete soil cores, in their plastic core liner tubes, and any sample jars from beach sampling were stored with ice in coolers and delivered daily to OnSite Environmental, Inc. using agreed-upon transfer points. Chain-of-custody forms were sent with each cooler of soil cores and jars, designating required sample analyses or archiving of samples. Field equipment rinsate samples were included in deliveries to the lab with accompanying chain-of-custody forms.

Sample preparation. All delivered soil cores and sample jars were stored in a chilled cooler at the OnSite lab, sorted by child-use area and DU. PHSKC staff, working in a project-designated area at the OnSite laboratories, separated soil cores into samples (i.e., specific depth intervals) for analysis or archiving. PHSKC staff also prepared composite samples for beach DUs and field duplicate samples as part of the project QA/QC protocol. Once samples were prepared, they were again stored in chilled coolers at OnSite until they were analyzed in batches of up to 20 samples. PHSKC staff made new chain-of-custody forms for all prepared samples identifying analyses required or indicating samples were to be archived without analysis, with copies kept in a lab book.

Each GeoProbe™ soil core tube was capped in the field at both ends, with color-coded

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[10] Review of the field notebooks and chain-of-custody forms revealed a small number of miscodes - for example, an incorrect Zone designation in a sample ID code. A corrections memo was prepared and all such miscodes were identified and corrected in the project records and database.

caps to identify the top (red) and bottom (black) of the soil core. When the core length was less than the intended 22 inch sampling depth, the core tube was trimmed in the field to the length of the recovered soil core. This prevented shifting of soils within the core tube during shipment and prior to sample preparation. The study design identified five sampling depth intervals: 0-2, 2-6, 6-12, 12-18, and 18-22 inches. The length of the recovered soil core, in comparison to the intended sampling depth of 22 inches, was used to linearly interpolate cut points for the soil core tube. For example, for a recovered core length of 19 inches, instead of cut points at 2, 6, 12, and 18 inches, they would be marked at 1.73, 5.18, 10.36, and 15.55 inches. The use of linear interpolation to define depth intervals in soil cores introduces some imprecision in the sample depth identification. It is a practical means of addressing what is essentially unknowable, namely the specific locations where voids in the in-situ soils or compression of materials in the core tube during sampling occurred. The longer the recovered soil core, the less uncertainty exists regarding depth intervals. A sample preparation notebook was compiled with information on the recovered core length at each boring and linear adjustments to the cut points, as well as the dates of sample collection and sample preparation, sample codes, and sample disposition.

Each marked core tube was placed in a table-mounted vice grip and cut into samples using a specially designed cutting tool made by GeoProbe™. Soils representing each depth interval were placed into sample jars provided by OnSite and labeled with the appropriate sample code. To prevent the distribution of soils between depth intervals, the work area was covered by aluminum foil and disposable gloves were worn. These materials were changed for each new sample. The cutting tool was also cleaned after its use on each core tube, using deionized water and Alconox detergent provided by OnSite.

Field duplicate samples were prepared by selecting core tubes and preparing duplicate samples for each depth interval from that core tube. A total of 59 field duplicate samples was prepared for child-use area samples. Soils representing one depth interval were placed in a clean, resealable plastic bag and mixed by hand for 30 seconds to homogenize the sample. The total soil volume was then split evenly between two sampling jars provided by OnSite. The labels for the two sampling jars reflected the same sample codes except that one jar was marked as a primary sample and the other as a field duplicate sample (see **sample codes**, below).

Beach samples were prepared for analysis as composite samples for each sampled depth interval: 0-2, 2-6, and 6-12 inches. Soils from each boring in a beach DU and from one selected depth interval were combined into a larger volume sampling jar provided by OnSite. (No field duplicate samples were prepared for beach samples). The accumulated soils were mixed for 30 seconds as a preliminary homogenization step. Like all discrete samples, beach composite samples were sieved to < 2 mm size and homogenized by OnSite before analysis.

Sample codes. Unique sample codes were assigned to identify all soil samples. These sample codes were used on the chain-of-custody forms accompanying samples delivered to OnSite and in all subsequent data management activities. The general format for sampling codes was as follows:

Zone - Area - DU - Boring - Depth Interval - Sample Type

where designations used included

Zone: 1, 2, or 3
Area: 1 through 46 (not all values included, since only 34 child-use areas were ultimately sampled)
DU: 1 through 7 (number used varies by child-use area)
Boring: 1 through 8 (number used varies by DU) for samples analyzed as discrete samples; 0 for beach samples analyzed as composite samples
Depth Interval: 1 through 5 to represent 0-2, 2-6, 6-12, 12-18, and 18-22 inches, respectively
Sample Type: 1 for primary sample, 2 for field duplicate sample, and additional number codes for other special designations such as equipment rinsate or field blank, resample, etc.; for many samples where only a primary sample was collected, this field in the sample code was not used

For example, sample **2-6-3-4-3-1** represents the primary soil sample from Zone 2 (central Vashon-Maury Island), child-use area number 6, the 3rd DU at that child-use area, soil boring number 4, and depth interval 6-12 inches. Sample **1-44-1-0-2** represents the composite beach sample from Zone 1 (south Vashon-Maury Island), child-use area 44, the first (in this case, the only) DU, composited over all borings (number and location of borings recorded in the field notebooks), and the 2-6 inch depth interval.

General sampling locations are shown on Figure 1, with child-use area number codes given and sampling Zones identified. Symbols are used in Figure 1 to identify the general type of child-use area (daycare/school, park/camp, or beach area[11]), as well as the locations of other areas initially identified but not sampled (because access was not obtained or because the property did not meet the criteria for sampling). This map and comparable maps showing arsenic and lead results (see Section 6.0) were generated using GIS software and with the assistance of King County DDES. Detailed information on the locations of individual DUs and soil borings is not provided on these generalized spatial maps, which reflect only overall property (parcel) locations.

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[11] Note that only a few areas are shown on Figure 1 as beaches, while other types of child-use areas can include one or more beach DUs (among other sampling areas). There are a total of 16 beach DUs for the entire study (see Figures 2 and 3 for locations of beach DUs).

4.0 LABORATORY ANALYSES AND RESULTS

All laboratory analyses for arsenic and lead were performed by OnSite Environmental, Inc. of Redmond, Washington under contract with PHSKC.[12] A total of 1,705 soil samples was analyzed. Of that total, 1,503 represented the final database samples for the 34 sampled child-use areas, with an additional 59 field duplicate (QA) samples for that group. Requested reanalyses of possibly anomalous samples contributed another 16 analyses; miscellaneous resamples accounted for 6 analyses.[13] In addition to these 1,584 samples representing the 34 child-use area DUs, analyses were also performed for 80 "forest fringe" samples, plus 5 field duplicate samples at forest fringe areas, and 36 samples collected at locations from the initial soil survey of forested areas. The main body of this report will focus on the results for the 1,503 samples characterizing the 34 sampled child-use areas. The results for forest fringe samples and resamples at initial survey locations are discussed only in the attachments to this report. The field duplicate results and requested reanalyses were considered (see Section 5.0) as part of the data quality review process. For the 6 miscellaneous resamples, the analytical results of the resamples were used in the final data set instead of the initial results. Thus, the final study database included a single analytical result for each analyte (arsenic and lead) at each of the 1,503 soil samples analyzed.

OnSite reported the analytical results for all delivered samples (including field rinsate QA samples) in a series of 96 Sample Delivery Group (SDG) reports (OnSite Environmental, Inc. 2000-2001). Many of the samples from the 12-18 inch and 18-22 inch depth intervals at child-use areas in Zone 3 were originally archived without analysis, in accordance with the study design. After reviewing the preliminary analytical results (pre-validation), PHSKC, in consultation with other members of the sampling design work group, decided to have arsenic and lead analyses performed for some of these archived samples from the lowest depth intervals. The selected samples were primarily from borings where the contaminant concentrations in the first 3 depth intervals did not show a decrease with depth; the additional analyses provided more

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[12] The results of tracer element analyses of selected samples, by Battelle Marine Sciences Laboratories of Sequim, Washington are presented and discussed in a separate report.

[13] Resamples occurred to provide a complete depth profile at one boring where 2 samples were lost, and at one beach DU where the sample recoveries in initial samples submitted for analyses were suspect.

complete depth profile information at these locations and a check on the possible occurrence of higher contaminant concentrations at depth. The results for these additional samples are included within the 96 SDG reports from OnSite and the total count of 1,503 analyzed soil samples. As shown in Table 1, 20 of the 59 borings at child-use areas in Zone 3 (uplands DUs, excluding beach DUs) eventually had soils from 12-18 and 18-22 inches analyzed. Samples from those depths at the other 39 borings were archived without analysis.

After sample analyses for arsenic and lead were completed, OnSite archived remaining sample materials. Selected samples were sent at PHSKC request to a second laboratory, Battelle Marine Sciences Laboratory in Sequim, Washington for tracer element analyses. PHSKC completed a cooperative agreement with the University of Washington to provide archived sample materials when they were no longer needed for the Child-Use Areas Study. After completion of all data validation reviews, PHSKC instructed OnSite to release all remaining soil samples to the University of Washington.

All soil samples from the child-use areas were analyzed for arsenic and lead in accordance with the protocols included in the Quality Assurance Project Plan (PHSKC 2000). Arsenic analyses used Method 7060A (graphite furnace AA); lead analyses used Method 6010B (ICP). These are the same analytical methods used in the initial soil survey (PHSKC and Glass 2000).

Consistent with the requirements of Ecology's MTCA regulations, all soil samples were first sieved by OnSite and analyses were performed on the fraction < 2 mm in size. The percent moisture was also determined for all samples and results were reported on a dry weight basis. These are also identical to the procedures used in the initial soil survey of Vashon-Maury Island.

Laboratory analyses included a number of quality assurance/quality control (QA/QC) provisions for evaluation of the quality of reported results (see Section 5.0), as described in the Quality Assurance Project Plan. In addition to standard laboratory QA/QC procedures, and as part of the overall QA/QC program for this study, PHSKC obtained standard reference materials from Environmental Resource Associates, Arvada, Colorado to be analyzed with each Sample Delivery Group as "performance evaluation" samples. The certified values and performance acceptance limits for arsenic and lead in those standard reference materials were available only to PHSKC, not to OnSite Environmental, Inc. The laboratory protocol called for PHSKC to review the reported (single blind) results for these performance evaluation samples in each Sample Delivery Group and to confirm to OnSite that they were within the performance acceptance limits. Reanalysis of all samples in an SDG would be required whenever results did not meet the acceptance criteria. All performance evaluation results were within the acceptance limits.

A listing of analytical results for arsenic and lead for the 1,503 samples in the final data set is provided in Attachment B. The overall ranges in results were as follows:

arsenic	< 1.5 ppm (not detected) to 130 ppm
lead	< 5 ppm (not detected) to 900 ppm

5.0 DATA VALIDATION REVIEW

OnSite Environmental, Inc. performed the initial reviews of laboratory data quality before submitting sample analysis results to EcoChem, Inc. for data validation. Other than assigning a U flag to the numerous not detected results (i.e., those below the practical quantitation limit), OnSite assigned data quality flags to only 4 sample results based on matrix spike/matrix spike duplicate results outside of acceptable limits.

An independent data validation review was performed by EcoChem, Inc., based on the arsenic and lead analytical method protocols, the Quality Assurance Project Plan (PHSKC 2000), and the procedures established in EPA's *National Functional Guidelines for Inorganic Data Review* (1994). A full validation review was conducted for 10 percent of the data, with a summary validation conducted for the remaining 90 percent. All data packages delivered from OnSite were first evaluated using an automatic data screening software tool. A total of 96 Sample Delivery Group data packages was received from OnSite Environmental, Inc.[14]

Data validation reviews included evaluations of sample processing and documentation (e.g., hold times and chain-of-custody forms), laboratory QA/QC measures (included with each Sample Delivery Group data package), and field QA/QC measures (e.g., 64 field duplicate samples and 11 equipment rinsate samples). Analytical accuracy evaluations included reviews of matrix spike/matrix spike duplicate results, laboratory control samples, and serial dilutions. Analytical precision evaluations included reviews of laboratory duplicate samples and field duplicate samples. (As noted, acceptable results on a blind standard reference material [performance evaluation] sample with each Sample Delivery Group were also required before OnSite reported data to EcoChem for validation). Instrument calibration and method blank results were also evaluated. EcoChem assessed the results of multiple reanalyses requested by PHSKC for 5 possibly anomalous samples and selected results to be reported for the study. The data validation results are summarized in a written report (EcoChem 2001).

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[14] The 96 Sample Delivery Group data packages include the results for analyses of resamples from initial soil survey locations and samples from "forest fringe" locations, as well as field equipment rinsate samples.

Based on its data validation reviews, EcoChem assigned an "estimated" data quality flag (J, or UJ for not detected results) to almost 29 percent of the soil arsenic results (486 of 1,688 results) and 2.5 percent of the soil lead results (42 of 1,652 results). No analytical results were rejected; the "estimated" values were judged to still be usable for meeting the study objectives, although possibly having lesser accuracy or precision than unflagged sample results. Thus, the completeness for analytical results was 100 percent. Most of the flagged arsenic results were due to serial dilution outliers, with matrix spike/matrix spike duplicate, laboratory duplicate, and field duplicate outliers also contributing to a much lesser extent to the total of 486 flagged results. The arsenic serial dilution outliers did not indicate consistent trends toward high or low bias and would only represent a small degree of bias in the reported sample values.[15] All flagged lead results were due to laboratory duplicate outliers.

At several times during the study, PHSKC requested multiple lab reanalyses, from archived sample materials, for each of 5 samples whose initial reported results were viewed as possibly anomalous. Two samples had 2 reanalyses performed; the remaining 3 samples had 4 reanalyses performed. For 3 of the 5 selected samples, the reanalysis results diverged strongly from the initial results. All of the reanalyses for each selected sample were similar to each other (i.e., they formed an internally consistent set of 2 or 4 additional results). EcoChem evaluated the initial and reanalysis results for each of these 5 samples based on the field duplicate quality control criterion (relative percent difference less than 100 percent) and based on the results selected a result to be reported for inclusion in the study database. For 3 of 5 samples the first reanalysis result was selected to replace the unconfirmed original analysis result (see section 3.7 and Attachment 1 in EcoChem 2001).

As data validation reviews were completed on Sample Delivery Groups, EcoChem prepared and submitted electronic data deliverable packages to PHSKC. Those electronic data deliverable packages were then used as input to the database program developed by PHSKC (see Section 6.1).

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[15] In many cases where flags were added based on serial dilution results, the results for the lab control sample (standard reference materials) and matrix spike/matrix spike duplicate analyses were acceptable, indicating at most minor degrees of bias.

6.0 DATA EVALUATIONS

6.1 APPROACH

As part of the Vashon-Maury Island Child-Use Areas Study, PHSKC developed a set of new data management tools for processing, storing, and retrieving project information. Those data management tools[16] were designed so that they would easily support other Tacoma Smelter Plume projects as well, providing a single database platform that could be used by multiple agencies for multiple projects. PHSKC contracted with Best Consulting, Inc. of Kirkland, WA to provide database development staff for this task.

The structure for the database was developed in coordination with project technical staff and GIS analysts to assure that it would support intended uses. It is designed to compile extensive information on all important aspects of the project - field sampling activities, sample coding and sample handling, laboratory analysis results, and data validation reviews. The database supports a variety of standard and special-purpose reports as well as GIS data mapping and includes controlled editing capabilities. Access levels specifying permissible database functions can be assigned to individual database users to protect database integrity and data quality. The database therefore serves an important role in maintaining and documenting project quality control.

Data entry occurred through electronic file links and uploading programs (e.g., for reports on sample analytical results provided by the data validation contractor, EcoChem, Inc.) as well as through coding of hand-recorded information (e.g., from field notebooks and sample preparation log books). Entered data were reviewed by PHSKC staff and through software screening tools to detect missing information and errors. Additional software was developed to provide data transfers to Ecology in the standard format requested by that agency.

The new database tools supported data evaluations for the Child-Use Areas Study. All final database entries for arsenic and lead results, as well as sample codes, were independently checked and verified before any data evaluations were performed. Data downloads to a GIS program (King County DDES) were used to produce all data maps. The GIS software, in turn,

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[16] Technically, the data management tools include a Visual Basic client-server application for uploading information into a SQL Server database and a web-based application installed to a web server database hosted by King County ITS ADSS/Web Team and Distributed Systems Services (DSS).

was used to determine information for each property sampled on its distance and direction from the former Tacoma Smelter tall stack. The distance and direction data associated with sampled properties were used for some data evaluations. Selected data for the 1,503 child-use area samples - sample codes, arsenic and lead analytical results, and lab and data validation flags - were downloaded in spreadsheet format for use with the Statgraphics^{TM} statistical software program (see Attachment B, which presents the downloaded data in a more-readable "matrix" format with results shown for boring versus depth interval for each DU and child-use area). Each element of the standard sample code was made an independent variable in that download so that sample results could be sorted or selected in various ways (e.g., by Zone, or excluding all beach DU results). All arsenic and lead results are reported to two significant figures (e.g., 10 ppm or 9.5 ppm).

Many of the arsenic and lead results are reported as "not detected", or less than a defined value called the practical quantitation limit (PQL). Where necessary for data evaluations, those not detected results were assigned a value equal to the PQL. This simplistic approach is judged to be adequate for the limited types of data evaluations being performed, most of which are essentially descriptive in nature. More detailed statistical (hypothesis testing) analyses are not required in this report to describe the general characteristics and spatial patterns of contamination at the sampled child-use areas. (Note that to the extent that unique property development histories influence soil contamination, combining data from multiple properties may involve combining disparate statistical populations). The only discussion of statistical significance occurs with respect to regression results, as a means of looking at the strength of association between two variables (e.g., arsenic versus lead concentrations). This report also evaluates individual sample results and sets of those results (e.g., results for one depth interval at a time) directly, without consideration of statistical confidence (or tolerance) limits; for discussion of upper confidence limits on mean values, see the Interim Action memo (Ecology 2001).

The results for individual samples were evaluated to derive Maximum and Average arsenic and lead concentrations for each DU. These summary values were coded as additional variables[17] and used, rather than individual sample results, for some data evaluations. These summary values can reduce variability in the results from individual samples (for example, caused by natural differences in fate processes affecting different contaminants or by property development actions that disturb soils affected by air deposition of contaminants). The reduced variability, in turn, can illuminate spatial patterns and relationships among contaminants. The Maximum and Average contaminant concentrations are also useful summary statistics for evaluating potential human exposures. The Maximum concentration in a DU is simply the largest value occurring in any single sample, at any depth. Average concentrations were calculated for each depth interval in a DU (that is, if surface topography is ignored for the

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[17] The terms Maximum and Average are capitalized to emphasize their use as coded variables with specific definitions as described in the text.

moment, in "horizontal" layers). Each Average concentration was the simple arithmetic average of the results for all borings in a DU with analyses for the specified depth interval.[18] Interim Action decisions were based on contaminant levels to depths of 6 inches (see Ecology 2001); therefore, a summary value was assigned using the larger Average concentration, comparing only the 0-2 and 2-6 inch depth intervals. Where the largest average concentration in a DU occurred at depths below 6 inches, that information was also noted. All Average values referenced in this report will refer to the larger Average concentration in the top 6 inches, unless otherwise specified.

The design for the Child-Use Areas Study is, as noted previously, hierarchic - arsenic and lead results exist for samples at depth intervals within borings within DUs within child-use areas within spatial Zones. As a result, data evaluations can be performed at various levels of analysis with respect to the design. For example, depth profiles or lead:arsenic relationships can be evaluated for all samples, by spatial Zone, or by DU. The Interim Action decisions focus on data evaluations at the level of DUs and individual child-use areas (see Ecology 2001). The data evaluations reported here to describe characteristic patterns in soil contamination are, for the most part, performed at the higher levels of the design. Detailed discussions of the results for each child-use area or each DU are not provided; comparisons among child-use areas are provided mainly to illustrate the variability in soil contamination. The focus here is instead on what the Child-Use Areas Study data tell us about general patterns of soil contamination on Vashon-Maury Island, and about soil contamination at developed/disturbed areas versus

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[18] Note that for one DU in Zone 2 and selected DUs in Zone 3, missing samples or samples archived without analysis mean that some but not all borings in the DU had analyses at depth intervals 4 and 5. In those cases, an average concentration was developed using available analytical results, which therefore do not represent the same set of borings as averages for depth intervals 1, 2, and 3 in those DUs.

relatively undisturbed forested areas.[19] Zone classifications are used in many data evaluations as a simplistic way of starting to look at large-scale spatial patterns in soil contamination. The specific Zone boundaries are not, in and of themselves, particularly meaningful; Zone designations merely reflect the general gradient in contamination shown by the results of the initial soil survey on Vashon-Maury Island.

Early in the data evaluation process, it was recognized that arsenic and lead concentrations for (composite) beach samples at all 16 sampled beach DUs were uniformly low. The maximum arsenic and lead results for any beach samples were only 2.8 ppm and 19 ppm, respectively - far below Ecology's MTCA Method A cleanup levels of 20 ppm and 250 ppm for arsenic and lead. Therefore, all further data evaluations focused on the 1,455 (discrete) sample results for the 48 "uplands" DUs (and including the 15 sample results from three targeted borings at child-use area number 6, which do not constitute a DU). Only the results for evaluations of those uplands (non-beach) DUs are discussed in the rest of Section 6.0.

Finally, the study design includes certain features that should be recognized as possible confounders when data evaluations are performed. Fewer than half of the samples collected in Zone 3 from the 12-18 and 18-22 inch depth intervals were analyzed. As a result, the Zone 3 data set is biased toward more surficial samples compared to data for the other two Zones. The density of sampling within DUs varies among Zones, which likely affects the precision of soil contaminant characterizations by spatial area. The frequency of not detected results is not equal across Zones and by depth intervals; the assignment rule to use the PQL value for not detected results may therefore have unequal effects by Zone and depth. These possible confounding factors are judged not to significantly affect any of the major conclusions of the data evaluations.

6.2 MAGNITUDE OF SOIL ARSENIC AND LEAD

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[19] PHSKC repeats its earlier caution that soil sampling results should not generally be assumed to be representative of unsampled areas at that property or other properties located nearby. Property-specific sampling is generally 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.

Both arsenic and lead results occurred over ranges spanning two orders of magnitude. The lowest concentrations (i.e., not detected results) reflect background soil values. The highest arsenic and lead concentrations for individual samples were 130 ppm and 900 ppm, respectively. The highest Average concentrations for the 48 uplands DUs were 49 ppm and 176 ppm for arsenic and lead. For comparison, Ecology's default soil cleanup levels (MTCA Method A standards) are 20 ppm for arsenic and 250 ppm for lead.[20]

A partitioning of the 1,455 uplands DU sample results by depth intervals within Zones provides useful summary information on the statistical distributions of arsenic and lead results. Table 2 summarizes the minimum and maximum values and selected percentile values (median = 50th, 75th, 90th, and 95th percentiles) by depth interval and zone. All depth intervals in all three Zones are seen to have similar minimum concentrations for arsenic and lead. Maximum values, however, show significant differences, indicating how the ranges in soil contamination vary over sampled child-use areas across Vashon-Maury Island. The median values are notably low, in comparison to upper percentile and maximum values.

The statistical distributions of both arsenic and lead results are of a type known as "right skewed" - that is, with frequent low values and infrequent high values. A simple way to visualize these skewed distributions is by constructing a table showing the frequency of values in specified concentration ranges. Table 3 provides this data summary for the Child-Use Areas Study. Table 3 includes sample counts and percentages, for a few specified arsenic and lead concentration ranges, for three data sets: 1) all samples at all depths (1,455 samples), 2) samples within the top 6 inches (614 samples), and 3) samples within the top 2 inches (307 samples). Information is provided for each sampling Zone (also discussed in Section 6.3 below) and for all sampling areas combined. (Since samples at many borings in Zone 3, where concentrations were lowest, were not analyzed at the two deepest depths, the summary at the top of Table 3 for all data probably understates the percentage of samples in the lowest concentration ranges that would have resulted from a "balanced" sampling design with equal numbers of sample analyses at all depths).

Table 3 (at the top) shows that most of the results are in the lowest concentration range, for both arsenic and lead. Only about 15 percent of the individual arsenic results and 1 percent

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[20] It should be noted that compliance with the cited MTCA Method A cleanup standards for soils is generally based on statistical evaluations of average concentrations for defined exposure units (i.e., Decision Units), not on individual sample results. MTCA compliance rules also include provisions for the maximum allowable magnitude and frequency of exceedance of the cited cleanup levels.

of the lead values numerically exceed Ecology's default cleanup standards of 20 and 250 ppm, respectively.

Since multiple soil samples were collected at each child-use area, most often to depths of 22 inches, the total set of results could include some "dilution" effects. The occurrence of higher concentrations could be diluted, or masked, by considering too large a data set - that is, by including numerous samples that are not actually in areas or at depths affected by contamination. Alternative ways of looking at the data show the effects of considering different data sets. The middle portion of Table 3 summarizes the results for only those samples in the top 6 inches. A focus on near-surface samples is motivated by considering soils to which children are most frequently exposed, absent significant soil disturbance, and the likely origin of the contamination as deposition of airborne particulate matter. The distributions of arsenic and lead are modestly shifted upwards towards higher concentrations. For example, about 23 percent of arsenic results exceed 20 ppm, versus 15 percent for the total data set; about 16 percent of lead results exceed 50 ppm, versus 9 percent. The results for only the top 2 inches (see bottom of Table 3) are similar to the results for the top 6 inches. Contaminant depth profiles are discussed further in Section 6.5 below.

A set of bar charts, or histograms, that show the statistical distributions for arsenic and lead concentrations in the top 6 inches is included in Attachment E. Those histograms provide comparative information for the three sampling Zones based on a larger number of concentration ranges than are used in Table 3.

A second alternative data summary shows more significant differences from the initial evaluation of all 1,455 results. If the higher arsenic and lead values are relatively infrequent, are they also limited to just a few locations or are they more widespread? Evaluation of the statistical distributions of the Maximum arsenic and lead concentrations at each DU provides insight into the spatial frequency of higher values. Information on the Maximum and Average arsenic and lead values by DU, as derived from the total data set (see Attachment B), is provided in Table 4. Table 5 summarizes the maximum results from each of the 48 uplands DUs in a manner similar to Table 3. The distributions in Table 5 are substantially shifted upwards toward higher concentrations. More than 70 percent of DUs have a maximum arsenic concentration above 20 ppm, and almost 60 percent of DUs have a maximum lead concentration above 50 ppm. This means that elevated concentrations of arsenic and lead are widespread rather than localized to small regions of Vashon-Maury Island. Sampling in child-use areas confirms the initial soil survey finding of contamination, to one degree or another, over most of Vashon-Maury Island. The large difference between the contaminant distributions in Table 3 and Table 5 is an indication of significant variability in results within child-use areas (see Section 6.6 below).

It should be noted that all of these data distributions reflect the specific areas and locations sampled. The locations of the sampled child-use areas are not uniformly distributed, and they are not necessarily representative of the sampling Zones as a whole. The results from one, or several, sampled areas are not necessarily predictive of what would be found at other, unsampled locations. The soil contamination results for each of the sampled child-use areas, and comparisons across the three sampling Zones, are summarized in Section 6.6 and Attachment E in a series of Box-and-Whisker plots.

6.3 SPATIAL PATTERNS

The large-scale spatial resolution of contaminant patterns is less detailed in the Child-Use Areas Study than in the initial soil survey, since the number of sampling areas is limited. For example, the Child-Use Areas Study includes only 4 areas on Maury Island and only 1 area on Vashon Island south of Burton. Nevertheless, the correspondence in the spatial patterns of arsenic and lead contamination between the two studies is striking.

Using GIS software, the Maximum and Average arsenic and lead concentrations for each DU were mapped. The results are provided in Figures 2 through 5. (Locations shown on Figures 1 through 5 are accurate to the level of the property or parcel sampled). Multiple values are shown for a child-use area when more than one DU was sampled; beach DU results are identified by a "[b]" code after the numerical value. Color shading of the location symbols is used to indicate the contaminant concentration range occurring at each location. The shading corresponds to the highest value when more than one result is shown for a child-use area. The color shading in the GIS maps makes spatial patterns easier to see.

The spatial gradient in contaminant concentrations shown by Figures 2 through 5 matches the pattern observed in the initial soil survey. The highest concentrations occur in Zone 1 and the eastern part of Zone 2 - that is, on South Vashon Island, Maury Island, and the eastern part of central Vashon Island. This pattern is consistent with the expected transport and deposition of Tacoma Smelter emissions. The data for Maximum arsenic and lead concentrations across DUs (excluding beach DUs) by Zone are summarized in Box-and-Whisker plots[21] in Figures 6 and 7, respectively. Maximum arsenic concentrations up to 130 ppm occur in both Zone 1 and Zone 2 (in the eastern part; see Figure 2); by contrast, the maximum arsenic result is only 33 ppm in Zone 3 (and 37 ppm in the western half of Zone 2; see Figure 2). Figure 6 shows that the distributions for Maximum arsenic concentrations decrease from Zone 1 to Zone 3 (i.e., south to north); note, for example, the differences in 75th percentile and median values. There is also considerable variation in Maximum concentrations within Zone 1 and within Zone 2 (with similar overall ranges between Zones), indicating that there is significant local variability across child-use areas within a sampling Zone (see the discussion of variability in Section 6.6).

Inspection of Figure 3, the map of Maximum lead results, suggests that there are two

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[21] For an explanation of Box-and-Whisker Plots, see Attachment E.

Maximum values that appear to be anomalous by location. Those two Maximum lead values, at child-use areas 30 (Zone 3) and 35 (Zone 2, western part), are also anomalous by virtue of having extremely high lead:arsenic ratios; this suggests a primary source for lead other than the smelter.[22] The statistical distributions of Maximum lead results (excluding beach DUs) by Zone are shown in the Box-and-Whisker plot in Figure 7. Similar to the Maximum arsenic results, the Maximum lead distributions are shifted toward lower values from Zone 1 to Zone 3 (i.e., south to north), and local variability is notable in Zone 1 and Zone 2. Maximum lead concentrations occur up to 580 ppm in Zone 1, 440 ppm in Zone 2 (in the eastern part; see Figure 3), only 65 ppm (apart from the anomalous results[23] at area 30) in Zone 3, and only 73 ppm in the western part of Zone 2 (see Figure 3).

The spatial patterns based on Average concentrations are very similar (see Attachment E). At 11 DUs for arsenic and 7 DUs for lead, slightly higher average concentrations occur at a depth interval below 6 inches (see Table 4), compared to the Average results within the top 6 inches shown on Figures 4 and 5, but the mapped spatial patterns are not affected.

The data summaries by Zone presented in Table 2, Table 3, and Table 5 also confirm a general spatial gradient of decreasing contamination levels from Zone 1 to Zone 3. Low concentrations of arsenic and lead occur frequently in all sampling Zones. Median values are shown in Table 2 to be similar in all parts of Vashon-Maury Island (at least in part because deeper soil samples were often relatively uncontaminated at most sampled child-use areas). Spatial gradients and Zone-to-Zone differences are most apparent in the upper-tails of the data distributions, such as the 90th and 95th percentiles (see Table 2). The shifts in statistical distributions from Zone 1 to Zone 3 are shown rather clearly in the percentages by concentration ranges for all uplands DU samples (Table 3) and for Maximum values (Table 5). For example, in Table 5 the percentage of (non-beach) DUs with a Maximum arsenic concentration greater than 50 ppm is 57 percent in Zone 1, 23 percent in Zone 2, and 0 percent in Zone 3.

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[22] Two additional DUs, at child-use areas 7 (Zone 2, eastern part) and 27 (Zone 1), have Maximum lead results that are not notably anomalous by location but have extremely high lead:arsenic ratios. They are discussed further in Section 6.4, but do not substantially affect the evaluation of spatial patterns here.

[23] Formal statistical testing for outliers was not performed. Extreme values (by inspection) are termed anomalous in this report.

The highest arsenic and lead concentrations in the Child-Use Areas Study are lower than those in the initial soil survey, although in some areas, such as the eastern portion of Zone 2, they approach the maximum values in the initial survey. Two factors are very likely to account for this finding: 1) fewer areas were sampled in the Child-Use Areas Study; and, more importantly 2) property development and the associated soil disturbances are expected to reduce maximum contaminant concentrations (through mixing and dilution and removing or replacing contaminated soils). Despite generally lower contaminant concentrations, however, the spatial patterns in the Child-Use Areas Study reproduce those from the initial soil survey very closely. The few anomalous lead results suggest a slightly higher risk for artifacts with sampling in developed areas versus forested areas, but do not significantly affect the interpretation of spatial patterns.

6.4 CONTAMINANT CORRELATIONS

The very similar spatial patterns for arsenic and lead results (see Figures 2 through 5) suggest that these two soil contaminants are highly correlated. A series of correlation/regression analyses was performed to statistically evaluate the relationship between arsenic and lead. The results confirm a strong association between these contaminants in child-use area soils on Vashon-Maury Island.

Various types of scatterplots are used in this section to illustrate the relationship between arsenic and lead for samples from the uplands DUs (n=1,455 samples). In performing regression analyses, a number of factors were identified that affect the manner in which the analyses were conducted. These factors and the approaches used for regression analyses are briefly described. Results are then summarized for three types of evaluations: 1) arsenic versus lead relationships for individual samples (n=1,455); 2) arsenic versus lead relationships for Maximum values in each DU (n=48); and 3) the relationship of the lead:arsenic ratio for Maximum values in DUs versus distance from the former Tacoma Smelter main stack (n=48).

Approach. All regression analyses were performed using Statgraphics^{TM} statistical software. Consideration of five factors that could affect the regression analysis results led to numerous regression analyses being performed. Each of these five factors is briefly discussed below.

> Regression model. Two types of regression models were evaluated: linear and multiplicative models. The general equations for these models are $y = mx + b$ and $y = ax^b$, respectively.[24] In general, the goodness-of-fit of the models was based on R^2 values;

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[24] Note that the multiplicative model, which plots as a curved line using raw data values whenever the exponent of x is not equal to 1, will always plot as a straight line with log-transformed values. Thus, it can be shown as a "linear model" on log-scaled axes. In the text, this is referred to as a "log-log linear" model, which is identical to a multiplicative model for the

however, given the highly skewed data sets, with many more low contaminant concentrations than high concentrations, the comparative performance of the models at significantly elevated concentrations was also independently considered. (Many of the low arsenic-low lead results probably reflect a different population of samples that are relatively uncontaminated - for example, many of the samples from the deepest soil intervals analyzed). Multiplicative models are less influenced by the infrequent high values in the data sets than linear models are.

Extreme Values. A few anomalous[25] values are evident in the child-use areas data set. For example, a small number of samples has substantially elevated lead concentrations and an extremely high lead:arsenic ratio, which is suggestive of another primary source than Tacoma Smelter emissions for lead. Including extreme (anomalous) values can mask the statistical association between arsenic and lead; excluding a small number of such extreme values can reveal that relationship. In general, regression analyses were first performed on full data sets, and only then on data sets with one or more extreme values excluded.

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original, untransformed data.

[25] Extreme values, as discussed in relation to regression analyses, were identified by inspection. Formal statistical evaluations for outliers were not performed.

Not detected results and background (uncontaminated) samples. As noted previously, all not detected results were assigned their PQL values before statistical analyses were performed. This simple assignment rule and the relatively high frequency of not detected results complicates regression analyses. Data censoring at the detection limit can introduce artifacts into the statistical evaluations (in visual terms, the censored values, assigned their PQL values, may be significantly mis-located on a scatterplot of the data).[26] Moreover, as noted above, the data sets that include many samples with low results for both arsenic and lead (often doubly censored, with both results not detected) may reflect a mixed population of uncontaminated and contaminated samples with different characteristic lead:arsenic relationships. To investigate such issues, regression analyses were performed first on full data sets, followed by evaluations of reduced data sets where samples with arsenic concentrations below 10 ppm (a cutoff point selected to be slightly above typical Puget Sound soil background levels and below the default MTCA cleanup level of 20 ppm) were excluded. The primary motivation for analyses of reduced data sets was to focus on the statistical population of contaminated soils and remove much of the possibly confounding background population. Some regression analyses were also performed on data sets limited to the first two depth intervals sampled, which generally showed higher contamination impacts (see the discussion of depth profiles in Section 6.5).

Individual sample results versus Maximum results in DUs. Once airborne contaminants are deposited to soils, different mobilities and fate processes can affect their vertical distribution in the soil column. As a result, analyses based on individual sample results do not take into account the possible separation of co-deposited contaminants, and they may underestimate the degree of association between the contaminants. The inclusion of relatively uncontaminated sample results (i.e., a mixed population data set) and the effects of property development and soil disturbance can further reduce the apparent correlation between contaminants. One simple approach to evaluating these effects is to perform regression analyses using only the Maximum arsenic and lead values for each DU, instead of all individual sample results. Regression analyses for both types of data sets were performed.

Analyses by Zone. Regression analyses were performed for results from each of the three spatial sampling Zones (see Figure 1) separately. This partitioning of the total data set provides an opportunity to investigate how the relationship between arsenic and lead

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[26] Note, however, that it is still important to initially consider all data including censored, or "not detected", results. It is quite a different circumstance when a set of samples with not detected results on the first variable also has not detected results for the second variable, versus having relatively high values on the second variable. Scatterplots in these two cases would look very different, and just eliminating all samples with one or both variables reported as not detected could result in a loss of important information.

changes spatially. It also minimizes the chance that a significant relationship in areas closer to the former Tacoma Smelter would be masked by evaluating only an extended data set including areas much less affected by smelter emissions.

Results. A substantial number of exploratory regression analyses was performed to address the factors described above. Rather than presenting the detailed results for all of these analyses, a simple summary of the primary results is provided, with comments where appropriate on how the results changed in alternate analyses. (Statistical terms such as R^2 and p-value are defined in the glossary).

Results for individual samples. Figures 8 through 10 provide arsenic versus lead scatterplots of the individual sample results from Zones 1, 2, and 3, respectively. Note that the horizontal and vertical axes on these scatterplots are log-scaled.

In Zone 1, the scatterplot of the data (see Figure 8) shows an obvious association between arsenic and lead concentrations, with a few results that appear to be high-lead anomalies. Alternate regression analyses all show statistically highly significant results. Linear regression for all Zone 1 results (n=540) shows R^2 = 58.2%, p<0.0001, and a regression model of Pb = 2.18(As) - 5.36. For arsenic between 20 ppm and 100 ppm, that model results in lead:arsenic ratios of 1.91 to 2.13. (All regression model lead:arsenic ratios discussed in this section will be based on the range of 20 ppm to 100 ppm arsenic). Linear regression results excluding samples with arsenic less than 10 ppm are very similar, with a slightly broader range of lead:arsenic ratios (n=250; R^2 = 53.5%; p<0.0001; Pb = 2.48(As) - 17.58; lead:arsenic ratios of 1.60 to 2.30). Multiplicative models have marginally higher R^2 values than linear models. The multiplicative model including all sample results, however, provides a relatively poor fit for higher arsenic results; at arsenic equal to 100 ppm, for example, the lead:arsenic ratio of the regression model is only 0.92. Inspection of Figure 8 shows that sample lead:arsenic ratios substantially exceed 1 (most data points fall above the lead equals arsenic line, y = x). Excluding samples with arsenic less than 10 ppm, the multiplicative model results in modestly lower lead:arsenic ratios ($Pb = 0.65(As)^{1.23}$; lead:arsenic ratios of 1.29 to 1.87) than the linear model. The characterization of lead versus arsenic correlations will focus on linear regression results.

Analysis of Zone 1 results restricted to samples within the top 6 inches (top two depth intervals) shows slightly better fit and modestly higher lead:arsenic ratios (n=216; R^2 = 64.6%; p<0.0001; Pb = 2.72(As) -12.63; lead:arsenic ratios of 2.09 to 2.59). Given the highly statistically significant results for Zone 1, extreme values were not considered further for individual sample evaluations; see the Maximum value regression results below.

Zone 2 samples also show a strong association between arsenic and lead concentrations. Comparison of the data scatterplots in Figure 8 (Zone 1) and Figure 9 (Zone 2) shows the similarity in patterns, except for an increased number of anomalous high-lead, low-arsenic results in Zone 2. Most of those extreme value results occur at arsenic concentrations below 10 ppm, and are therefore eliminated in regression analyses that exclude those low arsenic results. (The frequency of anomalous high-lead results in any Zone is probably a property associated with the specific child-use areas sampled rather than a characteristic of the Zone itself). As in Zone 1, alternate regression analyses all show statistically highly significant results whether extreme values are included or excluded, although the specific regression models differ.

Linear regression for all Zone 2 results (n=698) shows R^2 = 51.6%, p<0.0001, and a regression model of Pb = 2.14(As) - 1.58; the lead:arsenic ratios for this model are 2.06 to 2.12. Analyses excluding all samples from child-use area 35, where anomalous high lead concentrations occur, or excluding all samples with arsenic less than 10 ppm both improve the model fit; the latter approach provides the best results, with a broader range of lead:arsenic ratios (n=254; R^2 = 70.5%; p<0.0001; Pb = 2.62(As) - 18.45; lead:arsenic ratios from 1.70 to 2.44). These results are very similar to those for Zone 1. Regression analyses limited to samples from the top 6 inches in Zone 2 produce comparable results.

In Zone 3 the range of arsenic concentrations is smaller than in Zone 1 or Zone 2, but within that restricted range the data scatterplot appears to reflect a measure of association between arsenic and lead (see Figure 10). One anomalous high-lead sample occurs in Zone 3 (lead at 900 ppm, arsenic at 17 ppm in child-use area 30; therefore excluding samples with arsenic less than 10 ppm does not eliminate this sample), and there is a small group (occurring at four different child-use areas) of low-lead, elevated-arsenic results that appears to deviate from the general trend. Linear regression for all Zone 3 samples (n=217), including extreme values, shows a comparatively poor model fit, although still marginally statistically significant (R^2 = 2.3%; p<0.025; Pb = 1.54(As) + 3.44; lead:arsenic ratios from 1.71 to 1.57, declining as arsenic increases and projected well above the range of reported Zone 3 arsenic results).

Excluding the single extreme value at area 30, or all samples at area 30 (which includes additional anomalous results), both improve the Zone 3 results markedly. Omitting the area 30 results, the linear regression shows highly statistically significant results with lead:arsenic ratios lower than in Zone 1 or Zone 2 (n=199; R^2 = 23.8%; p<0.0001; Pb = 0.82(As) + 5.30; lead:arsenic ratios from 1.09 to 0.87). The regression model and resulting ratios are affected to some degree by the group of anomalous low-lead results, which were not excluded for the analysis. To the extent that all samples in the Child-Use Areas Study reflect a mixture of contaminant deposition and background conditions, the Zone 3 samples are more heavily weighted by background conditions.

Finally, Zone 3 regression analyses were performed restricted to samples within the top 6 inches. With samples from area 30 omitted and samples with arsenic less than 10 ppm also excluded, the analysis of samples from the top 6 inches showed additional improvement in model fit and a somewhat higher range of lead:arsenic ratios, although still lower than in Zone 1 or Zone 2 (n=51; R^2 = 35.2%; p<0.0001; Pb = 1.56(As) - 2.08; lead:arsenic ratios from 1.46 to 1.54). All but one of the anomalous low-lead, elevated-arsenic results occur below 6 inches and are therefore excluded from the data set for this analysis, which probably accounts for some of the improvement in model results.

The regression analysis results based on individual samples can be summarized as follows: 1) arsenic and lead are shown to be statistically highly significantly correlated in all three sampling Zones; 2) model fits are generally better for samples from the top 6 inches than for all samples in a Zone; 3) the regression model fits are stronger in Zone 1 and Zone 2 than in Zone 3; 4) while different regression modeling approaches produce varying results, the typical modeled lead:arsenic ratios (which vary by arsenic concentration because the modeled y-intercept is not zero) are somewhat greater than 2 in Zone 1 and Zone 2, but less than 2 in Zone 3; and 5) individual samples exhibit significant variability around the modeled lead:arsenic ratios, with a relatively small number of apparently anomalous results (high-lead and low-lead anomalies) detectable based on lead:arsenic ratios (or inspection of the data scatterplots). These results are similar to those found in studies of other soils near the former Tacoma Smelter.

Results for Maximum values in DUs. Regression analyses were also performed for the Maximum arsenic and Maximum lead values in each uplands DU. Figure 11 shows a scatterplot for these data (n=48), with four points that are anomalous (based on high Maximum lead: Maximum arsenic ratios) labeled with DU identification.[27] Note that the scatterplot axes in Figure 11 are scaled linearly, instead of the log-scaling used in the scatterplots for individual sample data sets. The Maximum lead values for child-use area 30 (900 ppm) and area 35 (310 ppm) are anomalous both in magnitude and in spatial location (see Figure 3). The other two labeled points are anomalous based on their ratios, which result either from apparent high Maximum lead or low Maximum arsenic values for the DUs. Note that for child-use areas 7 and 27 only one among several DUs for the child-use area includes such extreme values.

Except for the four labeled extreme values, there is an apparent positive correlation between Maximum lead and Maximum arsenic values in Figure 11. Linear and multiplicative regression analyses both have statistically significant results even if no results are excluded. Omitting the result at DU 3-30-1, the most extreme value, produces statistically highly significant results. The two regression models (n=47) have comparable fits and similar results, with somewhat higher modeled lead:arsenic ratios in the linear model: linear (R^2 = 48.6%; $p<0.0001$; Pb = 2.81(As) - 0.76; ratios from 2.77 to 2.80), and multiplicative (R^2 = 50.2%; $p<0.0001$; $Pb = 2.00As^{1.02}$; ratios from 2.12 to 2.19). If the three additional labeled results are omitted (n=44), the results are even stronger, with some broadening of the modeled lead:arsenic ratios: linear (R^2 = 70.8%; $p<0.0001$; Pb = 3.08(As) - 30.08; ratios from 1.58 to 2.78), and multiplicative (R^2 = 71.6%; $p<0.0001$; $Pb = 1.22As^{1.12}$; ratios from 1.75 to 2.12).

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[27] The results for DU 1-13-1, with Maximum arsenic and Maximum lead values of 110 ppm and 69 ppm, respectively, are not labeled but could be considered anomalous based on a low Maximum lead: Maximum arsenic ratio. However, that DU deviates less from the general trend than the four labeled DUs with high ratios in Figure 11.

The results of regression analyses for Maximum values, including DUs from all three spatial Zones, thus show a strong relationship between arsenic and lead concentrations over all of the sampled child-use areas. The lead:arsenic ratios for this approach are comparable to those for analyses of individual samples restricted to values at or above 10 ppm arsenic.

Figure 12 shows the relationship between Average arsenic and Average lead results for the uplands DUs. Two extreme values, based on lead:arsenic ratios, are labeled in Figure 12. The regression results based on Average values are similar to those for Maximum values, with typical lead:arsenic ratios of about 2.

<u>Maximum lead: Maximum arsenic ratio versus distance</u>. A regression analysis of the ratios for Maximum lead: Maximum arsenic versus distance from the former Tacoma Smelter stack in Ruston was also performed to examine spatial trends in the lead:arsenic relationship. Figure 13a shows a scatterplot of the data. Four extreme values with high lead:arsenic ratios (compare with Figure 11) are labeled. Figure 13b shows the same data with the extreme values omitted and a rescaling of the Y-axis. One DU is labeled in Figure 13b; that DU at area 40 is transitional between beach sands and true uplands soils, and can be distinguished from the other DUs on that basis.

Regression analyses were performed excluding the four extreme values with lead:arsenic ratios exceeding 10. Linear regression models produced better results than multiplicative models. For the 44 remaining DUs, linear regression resulted in an $R^2 = 16.0\%$, $p<0.01$, and a model of $Pb/As = -0.22(\text{miles}) + 4.06$. Thus, a statistically significant decrease in ratios with increasing distance is shown. The modeled ratios for distances of 6 to 12 miles are from 2.73 to 1.40. Omitting the data for DU 2-40-1 (see Figure 13b) produces an almost identical model (n=43) with slightly improved fit ($R^2 = 20.0\%$).

The possible influence of wind direction from the Tacoma Smelter stack to child-use areas was considered by partitioning the data into groups reflecting N and NE wind vectors (each covering 45 degrees centered on bearings of 0 and 45 degrees). Only 8 DUs are in the NE data set, and the regression results for this small data set are not statistically significant. An analysis of the 36 results for the N data set, excluding the four extreme values with lead:arsenic ratios greater than 10, produced an almost identical model as the analysis of the full data set (n=44) not considering direction, with modestly improved fit ($R^2 = 23.5\%$).

Although the regression models result in a statistically significant decrease in lead:arsenic ratios with distance, the relatively low R^2 values (even after removal of anomalous data points) reflect substantial remaining variability around the best-fit regression model (see Figure 13b). Similar evaluations of the lead:arsenic ratios from sampling of forested areas in the initial Vashon-Maury Island survey (unpublished results), which include many more data points, do not show statistically significant spatial trends. The relatively undisturbed forest soils might be expected to reflect such spatial trends, if they exist, more clearly than the developed properties sampled in this study. The lack of consistent results between the two studies indicates that spatial trends, if any, are likely to be relatively small.

The spatial trends in lead:arsenic ratios shown in this study are suggestive of minor differences in deposition efficiencies for arsenic and lead as emissions were transported downwind, reflecting differences in particle size distributions for these contaminants in the smelter plume. On the other hand, considering the non-confirmation of these spatial trends in the initial survey results, they may be nothing more than a random statistical occurrence reflecting sampling variability and the relatively small number of sampled child-use areas.

6.5 DEPTH PROFILES

Where soil arsenic and lead contamination result from deposition of airborne particulates, the expected depth profile in soils is for most of the contamination to remain near the surface; concentrations typically decrease rapidly with increasing depth, especially below about 12 inches. Physical disturbance of soils can alter this normal depth profile. In the Child-Use Areas Study, a larger number of depth intervals and greater total depth of soils (to 22 inches) were sampled than in most previous VMI studies to better define depth profiles at developed as opposed to undisturbed areas.

Samples were collected and analyzed from a total of 307 borings at the 48 uplands DUs at child-use areas (108 in Zone 1, 140 in Zone 2, and 59 in Zone 3). The distributions of arsenic and lead in individual samples are summarized, by Zone and depth interval, in a series of Box-and-Whisker plots (see Figures 14 through 16 for arsenic, Figures 17 through 19 for lead). Table 2 provides selected percentile values matching these Box-and-Whisker plots. For arsenic, Zone 1 and Zone 2 show somewhat higher values at shallower depth intervals, especially within the top 6 inches. Zone 3, by contrast, shows no noteworthy pattern with depth. For lead, all three Zones show somewhat higher values within the top 6 inches. Thus, despite the history of property development and soil disturbance that has occurred at the sampled child-use areas, the data in aggregate still reflect near-surface enrichment with arsenic and lead.

The patterns of depth profiles for individual borings, comparing concentrations at 0-2 inches and 2-6 inches, were examined.[28] For arsenic, the concentration at 0-2 inches was equal to or greater than the concentration at 2-6 inches (i.e., a non-increasing profile with depth) 51 percent of the time (157 of 307 borings); for lead, this occurred more frequently, 66 percent of the time (204 of 307 borings). Thus, lead appears to be retained in surface soils to a greater

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[28] The depth profiles for each individual boring are provided numerically in the data listing in Attachment B. Dot plots of selected child-use area arsenic results are provided in Attachment E, allowing the pattern in arsenic concentrations by depth interval to be visualized.

degree than arsenic. These results could be confounded by the relatively frequent occurrence of borings with low (nearly background) concentrations for both arsenic and lead in the top 6 inches. Therefore, the evaluation was repeated for the restricted data set in which at least one of the arsenic results in the top 6 inches was equal to or greater than 10 ppm. The results were almost identical (n=204 borings; 53 percent for arsenic, 69 percent for lead).

Figure 20 is a scatterplot of the depth profile ratios (0-2 inch divided by 2-6 inch results) for lead versus arsenic, for all 307 borings at uplands DUs. This "comparison of ratios" plot shows whether lead or arsenic exhibits comparatively greater downward mobility; each data point matches the data for lead versus arsenic for a single boring. For reference, the y=x line of equal mobility for lead and arsenic is drawn on Figure 20. Points above the line indicate higher lead ratios than arsenic ratios - and the higher the ratio, the greater the tendency of the contaminant to stay in surface soils rather than move downward. Thus, even if the lead ratio shown is less than 1, if it is above the y=x line this means lead is <u>comparatively</u> less mobile than arsenic despite the fact that lead at 2-6 inches exceeds lead at 0-2 inches in that boring. A total of 197 out of 307 borings, or 64 percent, are on or above the equal mobility line, indicating lower mobility for lead than for arsenic. (This result is again not affected by considering only borings where arsenic equals or exceeds 10 ppm within the top 6 inches; 129 of 204 such borings, or 63 percent, show comparatively lower mobility for lead). Interpreting these results as reflecting only natural mobility (e.g., leaching) is, of course, too simple: the possible effects of physical disturbance of soils have not been accounted for. It is noteworthy that the frequency of higher lead than arsenic ratios in Figure 20 is less than was observed in the initial soil survey of forested (relatively undisturbed) areas on Vashon-Maury Island (see Figure 26 in PHSKC and Glass 2000). Property development actions, and physical disturbance of soils, may therefore have made less dominant the apparent pattern of lower lead mobility observed in the initial soil survey. However, the pattern shown in Figure 20 and the general pattern of elevated contaminant concentrations within the top 6 inches suggest that the effects of property development actions at many of the sampled child-use areas have been limited and have not completely altered the characteristic patterns observed in forested areas. (The variability among child-use areas is discussed in Section 6.6 below). The general finding that arsenic and lead concentrations tended to be higher within the top 6 inches suggests that at many areas soil disturbance was limited in extent or depth, that it occurred well before contaminant deposition stopped, or that some degree of recontamination has occurred.

Low arsenic and lead concentrations occur frequently at all depth intervals in all sampling Zones; median arsenic values, for example, are less than 20 ppm for all depth/Zone combinations (see Table 2). Elevated arsenic and lead values occur disproportionately within the top 6 inches. Samples in the top 6 inches represent 42% of the total data set (614 of 1,455 values), but 75% of all arsenic results over 50 ppm and 66% of values over 20 ppm. For lead, 84% of all results over 100 ppm and 73% of values over 50 ppm occur in the top 6 inches. If average concentrations are calculated for each depth interval sampled in a DU, the depth interval with the highest average concentration can be determined. For the 48 uplands DUs, the highest arsenic and lead averages occur within the top 6 inches at 37 DUs (77 percent) and 41 DUs (85 percent), respectively (see Table 4). Many of the arsenic and lead results at depths below 12 inches approach background levels. There are, however, notable if infrequent exceptions.

At approximately 30 percent of uplands DUs, the maximum arsenic and lead concentrations in individual samples are at a depth below 6 inches. Even the deepest sampling interval, 18-22", occasionally had the highest arsenic or lead concentration. This pattern is likely the result of parcel development actions and soil disturbance that altered the typical depth profiles for undisturbed locations, on a property-specific basis. The Maximum arsenic and lead values by DU are plotted versus the sampling depth interval at which they occurred in Figures 21 and 22. Among all the Maximum concentrations, the largest ones tend to occur within the top 6 inches, with only a few exceptions. These largest Maximum concentrations, occurring near the surface, may reflect minimal dilution effects from soil disturbance compared to the lesser Maximum values that occur at greater depths.

6.6 VARIABILITY

The consistency or variability[29] in arsenic and lead concentrations can be examined at several different spatial scales, reflecting the hierarchic sampling design. Variability at multiple spatial scales, including within and between child-use areas, is for the most part greatest in those areas where arsenic and lead concentrations are highest. The child-use areas sampled in Zone 3, where maximum contaminant levels were smallest (except for one anomalous high-lead area) and all results were therefore constrained to a narrower range, in general showed the smallest variability. This pattern reflects the fact that low arsenic and lead concentrations occur in samples from every child-use area in the study. The spread of values, and the (absolute) variability, therefore closely follow the Maximum concentrations reported for the sampled areas.

The variability at the largest spatial scale - across sampling Zones, for example - has

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[29] The difference between absolute and relative measures of variability is discussed in the report on initial Vashon-Maury Island survey results (see PHSKC and Glass 2000). In this section, only absolute measures of variability (e.g., the range in values and the standard deviation of a group of values) are discussed. The primary use of the child-use areas data is to support interim action decisions, where the focus is on evaluating possible exposures in comparison to numerical criteria (i.e., to exposures and risks considered on an absolute rather than a comparative scale).

already been described (see Section 6.3 above). The large-scale pattern in soil contamination is among the clearest results in the study. Other than a few anomalous results for lead, the Maximum and Average concentrations show a spatial gradient over Vashon-Maury Island, one that is consistent with transport and deposition of arsenic and lead released by the Tacoma Smelter.

At a somewhat smaller spatial scale, the variability in results among child-use areas can be visualized using a Box-and-Whisker plot to summarize the data for each area. For this evaluation, all beach samples are excluded, results from multiple uplands DUs in one child-use area are combined, and only the results for the top 6 inches are used. Figures 23 through 28 show comparative Box-and-Whisker plots for child-use areas in each sampling Zone and for arsenic and lead. (Attachment E includes Box-and-Whisker plots comparing all child-use areas for 0-6 inch results and, separately, all results below 6 inches). These data visualizations show that significant differences occur among areas within Zone 1 and within Zone 2; the variations from area to area in Zone 3, on the other hand, are muted in comparison. The ranges for Maximum arsenic concentrations across child-use areas are 17 ppm to 130 ppm in Zone 1, 11 ppm to 130 ppm in Zone 2, but only 8.9 ppm to 33 ppm in Zone 3. The patterns for Average results and for lead (omitting the high-lead anomaly at area 30) are similar.

The calculated standard deviation for all sampling results at a child-use area (regardless of depth interval sampled) can be used as one simple measure of variability in results. Comparisons of standard deviations for arsenic and lead from all 32 child-use areas with uplands DUs confirm that, omitting the lead results for area 30, the highest standard deviations all occur in Zones 1 and 2 and the areas with highest standard deviations are precisely those with the highest Maximum results.

These observed differences across child-use areas within Zones reflect more than the fact that there are contaminant gradients across a Zone, with airborne deposition of contaminants being affected by distance and wind direction. Even areas that are located very close to one another sometimes show substantial differences in Maximum or Average contamination levels. Property-specific development histories may be contributing to these differences.

At 10 of the 32 child-use areas with uplands DUs, more than one DU was sampled. Most of these 10 areas show fairly consistent Maximum and Average contaminant levels (within a factor of x2) across DUs; a few show more substantial differences. The relative consistency across DUs within a child-use area may reflect similar development actions and histories at the different DUs on a property (for example, the development of the Vashon schools campus at one time).

The borings within one DU represent relatively closely-spaced sampling locations (often with separation of less than a few hundred feet, and at times measured in tens of feet). Arsenic and lead concentrations often show considerable variability even at this small spatial scale.[30] Attachment E includes "dot plots" of the individual sample arsenic results for 16 of the 32 areas with uplands DUs (results from multiple DUs combined where an area has more than one DU), occurring in all three Zones. These dot-plot figures show the individual results from each boring at each depth interval (note: identical values at one depth from different borings are overprinted and are not distinguishable on the dot-plots). The 16 areas represented by dot-plots were selected to reflect the range in variabilities exhibited by different child-use areas. Arsenic concentrations are seen to be most consistent where all of the results are relatively low. At depth intervals where moderate to significantly elevated arsenic concentrations occur, the ranges in results often reflect a factor of x10 or more variation. The occurrence of higher concentrations is therefore often uneven rather than consistent across a DU. Property-specific histories could, in some cases, help explain the patterns of contamination across borings, but reasonable explanations are often lacking. Note that even with as many as 8 borings in a DU, all locations with substantially elevated concentrations may not be identified.

The child-use area sampling results support an expectation of significant variability at even small spatial scales over much of VMI. This has important implications for how much sampling is required to adequately characterize contamination on a property; one, or a few, samples may not be adequate.

Mixing of soils by animals (e.g., moles or worms) and other biological processes, in addition to human actions disturbing soils, may contribute to the observed variability in contaminant concentrations; these processes may be of even greater significance in relatively undisturbed (forested) areas than in developed properties.

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[30] One simple measure of variability is the difference between Maximum and Average values for a DU; see Table 4. These differences are also generally smaller for areas in Zone 3 than in Zones 1 and 2.

7.0 CONSISTENCY WITH PRIOR STUDIES

The Child-Use Areas Study provides the first extensive characterization of arsenic and lead levels at developed child-use areas on Vashon-Maury Island.[31] It extends the results of PHSKC's 1999-2000 initial survey, which sampled exclusively in forested areas, to different types of land uses at properties that have all experienced some degree of development and soil disturbance. The Child-Use Areas Study incorporates some design differences from the initial survey - for example, in using much higher sampling densities, sampling to greater depths, and including sampling at beaches as well as uplands areas. Comparison of the results from this study and the forest soils survey reveals both similarities and differences.

A key finding is that the large-scale spatial pattern of elevated arsenic and lead levels is consistent with spatial patterns shown in the initial survey and previous smaller studies, differences in land use notwithstanding. The most affected locations continue to be south Vashon Island, Maury Island, and the eastern part of mid-Vashon Island. This large-scale spatial pattern is consistent with transport of Tacoma Smelter emissions, trending to the NNE, in accordance with annual wind rose data.

The maximum reported arsenic and lead concentrations are somewhat smaller than in the initial survey. The statistical distributions for arsenic and lead for the entire data set are also heavily skewed towards lower values - that is, significantly elevated values are relatively infrequent. On the other hand, elevated arsenic and lead results are found to be spatially widespread across the sampled child-use areas, indicating impacts to one degree or another over much of Vashon-Maury Island. The consistency with previous results is greater when Maximum values for sampled DUs are considered rather than the entire data set. The occurrence of low values at all sampled child-use areas suggests the impacts of property development actions that dilute, mix, or remove pre-development soil contamination. The infrequent but widespread elevated values suggests that at most properties the effects of soil-disturbing actions can vary from one location to another on the property. If this interpretation is correct, then the range in soil arsenic and lead concentrations at developed properties would depend on property-specific histories, with maximum concentrations possibly approaching the levels in nearby undisturbed soils if dilution, mixing, and removal effects are limited or absent at some specific locations on the property.

A few samples in the Child-Use Areas Study have elevated lead concentrations, with very atypical lead:arsenic ratios. In a few cases, these high-lead results are also spatially

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[31] A small number of residential yards was sampled in the UW's Exposure Pathways Study in 1985-1986.

anomalous. This finding met the expectation that control of artifacts, defined as non-smelter sources of arsenic and lead, might be somewhat more difficult in developed as opposed to undisturbed forest areas. Nevertheless, the number of anomalous results was very small and has an insignificant effect on the interpretation of arsenic and lead patterns in this study.

The Child-Use Areas Study provides the first extensive survey of arsenic and lead on Vashon Island beaches; the initial survey offers no comparable data for beaches. The (composite analysis) results for all 16 sampled beach DUs, located on all parts of the Island, were universally low. Beach areas have little organic matter in the surface soil profile, and particle sizes are dominated by larger sand fractions. Tidal actions also continually wash and mix sands and soils at the beach areas. These characteristics limit the potential accumulation of arsenic and lead.

The correlations between arsenic and lead are statistically highly significant, especially when a few anomalous results are excluded. These correlations tend to be even stronger for results from the top 6 inches, where arsenic and lead concentrations are generally higher. Typical modeled lead:arsenic ratios, and the scatter of individual sample results around the regression model results, are highly consistent with the findings of the initial survey and other previous studies in areas affected by the Tacoma Smelter.

Contaminant depth profiles were defined to significantly greater depths in this study compared to the initial survey of forest soils. Despite property development actions at the child-use areas, the overall contaminant distributions still were highest within the top 6 inches. Consistent with the initial survey, arsenic still appears to show greater downward mobility than lead within the top 6 inches - that is, arsenic and lead appear to separate in the soil column to some degree once deposited from air emissions, with lead being retained more than arsenic in surface soils. At a significant fraction of the sampled DUs, the highest arsenic or lead concentration occurs at a depth below 6 inches. This likely indicates that depth profiles at developed properties can be more complex than in forest areas, although the initial survey lacks data at depths below 6 inches to support a direct comparison. The occurrence of higher concentrations below 6 inches is interpreted as more probably the result of physical soil disturbances as part of property development than a result of mobilization/leaching of arsenic and lead absent physical disturbance. It is notable that higher arsenic and lead levels typically occur together at depths below 6 inches, a finding more consistent with disturbance than leaching.

Finally, the Child-Use Areas Study continues to show relatively high variability even at small spatial scales. The most contaminated DUs are characterized by uneven rather than consistently elevated contaminant concentrations; average values are therefore well below maximum values. The variability at individual child-use areas appears itself to vary depending on property development histories. Variability in soil arsenic and lead levels probably reflects both natural and human factors. Based on the results at child-use areas with significantly elevated contaminant levels, human activities can at times increase the variability otherwise observed in forest soils because of the inconstant effects of dilution, mixing, and soil removal over a property.

8.0 CONCLUSIONS

The Child-Use Areas Study provides the first extensive characterization of soil arsenic and lead concentrations at developed as opposed to forested properties on Vashon-Maury Island. The results of the Child-Use Areas Study on Vashon-Maury Island confirm that contamination of near-surface soils by arsenic and lead (and, by inference, other smelter-related contaminants not measured in this study) extends to developed properties, with a large-scale spatial pattern that is strikingly similar to that found in the initial survey and with the highest contamination levels still generally found in the top 6 inches. Contaminant concentrations are reduced compared to nearby forest soils, with some samples at each child-use area showing background or low concentrations for arsenic and lead. This pattern is consistent with a conceptual model in which property development actions serve to dilute, mix, or remove original soil contamination to a degree that may vary from one location to another on the property, producing the small-scale variability often observed among borings within child-use areas in this study.

The reported results are specific to the properties sampled. There are good reasons not to generalize those results uncritically to other unsampled properties, whose development histories (e.g., the date of most recent significant soil disturbance), land uses, and topographic profiles may differ in important ways. Moreover, some portions of Vashon-Maury Island are under-represented by the group of child-use areas included in this study - for example, locations on south Vashon below Burton and much of Maury Island.

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Table 1

STUDY DESIGN SUMMARY

	Areas	**Decision Units**			**Number of Samples**									
		Non-Beach	**Beach**		**Non-Beach (discrete)**						**Beach**	**(composite)**		**Total**
					0-2"	**2-6"**	**6-12"**	**12-18"**	**18-22"**	**subtotal**	**0-2"**	**2-6"**	**6-12"**	
Zone 1	11	14	9		108	108	108	108	108	540	9	9	9	567
Zone 2	13	21	4	[see note]	140	140	140	139	139	698	4	4	4	710
Zone 3	10	13	3		59	59	59	20	20	217	3	3	3	226
total	34	48	16		307	307	307	267	267	1455	16	16	16	1503

Note: At one site in Zone 2 15 samples were collected and analyzed from 3 targeted borings.
Those 3 borings are not included in the DU count, but the 15 samples are included in the sample counts.

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Table 2

STATISTICAL DATA SUMMARY
by Zone and Depth Interval

ARSENIC

(all concentrations in ppm, DW)

Zone	Depth	samples	minimum	maximum	average	median	75 %-ile	90 %-ile	95 %-ile
Zone 1	all	540	1.5	130	14.4	8.95	17.5	33	44.5
	1	108	1.5	130	23.0	17	27.5	47	71
	2	108	1.5	97	18.6	13	24.5	41	56
	3	108	1.6	67	13.3	9.85	16	32	41
	4	108	1.6	50	9.2	5.95	11	24	29
	5	108	1.5	110	8.0	3.95	8.9	16	17
Zone 2	all	698	1.5	130	10.7	7.3	13	22	35
	1	140	1.5	130	14.8	10	18.5	33	44
	2	140	1.5	66	14.4	10	18	37.5	42
	3	140	1.5	120	9.9	6.95	12.5	20	25.5
	4	139	1.5	52	8.2	5.8	11	20	26
	5	139	1.5	31	6.3	4.8	8.8	12	15
Zone 3	all	217	1.6	33	10.8	9.9	15	19	24
	1	59	1.6	33	10.3	9	14	17	26
	2	59	2.3	24	11.7	11	16	20	24
	3	59	1.7	26	11.1	10	15	20	24
	4	20	1.8	24	9.2	8.5	12	15.5	20
	5	20	1.7	28	10.7	9.55	13.5	18.5	23.5
All Zones and depths		1455	1.5	130	12.1	8.3	15	26	37

Table 2 (continued)

LEAD

(all concentrations in ppm, DW)

Zone	**Depth**	**samples**	**minimum**	**maximum**	**average**	**median**	**75 %-ile**	**90 %-ile**	**95 %-ile**
Zone 1	all	540	5.1	580	26.1	11	26	55.5	84.5
	1	108	5.1	580	52.1	22.5	49.5	130	200
	2	108	5.1	300	35.9	20	37	81	130
	3	108	5.1	110	18.1	11	25	40	53
	4	108	5.1	79	12.7	6.1	13.5	32	45
	5	108	5.1	120	11.8	5.7	9.75	19	42
Zone 2	all	698	5	440	21.4	8.5	22	48	70
	1	140	5.1	440	33.9	19	34.5	69.5	110.5
	2	140	5	270	28.8	16.5	33	61.5	78
	3	140	5.1	320	18.4	8.3	16	31	51
	4	139	5.2	100	12.7	5.7	12	31	54
	5	139	5.1	290	12.9	5.7	8.4	28	41
Zone 3	all	217	5.2	900	20.2	11	23	31	39
	1	59	5.2	110	22.1	16	29	40	65
	2	59	5.3	900	32.5	15	29	32	38
	3	59	5.3	95	13.9	8.6	18	29	32
	4	20	5.3	23	9.0	7.1	11	14	19.5
	5	20	5.4	28	7.6	5.85	6.2	12.3	23
All Zones and depths		1455	5	900	23.0	10	23	46	70

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Table 3

MAGNITUDE OF CONTAMINATION
Sample Counts by Concentration Ranges

All Data [n=1455]

Concentration	Sample Counts					Percentages			
Range	**Zone 1**	**Zone 2**	**Zone 3**	**total**		**Zone 1**	**Zone 2**	**Zone 3**	**total**
(in ppm)	[n=540]	[n=698]	[n=217]	[n=1455]		[n=540]	[n=698]	[n=217]	[n=1455]
Arsenic									
>100	3	3	0	6		0.6	0.4	0.0	0.4
51-100	18	8	0	26		3.3	1.2	0.0	1.8
21-50	95	71	16	182		17.6	10.2	7.4	12.5
0-20	424	616	201	1241		78.5	88.3	92.6	85.3
Lead									
>250	7	5	1	13		1.3	0.7	0.5	0.9
101-250	14	10	1	25		2.6	1.4	0.5	1.7
51-100	42	48	4	94		7.8	6.9	1.8	6.5
0-50	477	635	211	1323		88.3	91.0	97.2	90.9

Top 6 inches only [n=614]

Concentration	Sample Counts					Percentages			
Range	**Zone 1**	**Zone 2**	**Zone 3**	**total**		**Zone 1**	**Zone 2**	**Zone 3**	**total**
(in ppm)	[n=216]	[n=280]	[n=118]	[n=614]		[n=216]	[n=280]	[n=118]	[n=614]
Arsenic									
>100	2	2	0	4		0.9	0.7	0.0	0.7
51-100	14	6	0	20		6.5	2.1	0.0	3.3
21-50	61	47	10	118		28.2	16.8	8.5	19.2
0-20	139	225	108	472		64.4	80.4	91.5	76.9
Lead									
>250	7	2	1	10		3.2	0.7	0.9	1.6
101-250	12	9	1	22		5.6	3.2	0.9	3.6
51-100	28	34	3	65		13.0	12.1	2.5	10.6
0-50	169	235	113	517		78.2	83.9	95.8	84.2

Top 2 inches only [n=307]

Concentration	Sample Counts					Percentages			
Range	**Zone 1**	**Zone 2**	**Zone 3**	**total**		**Zone 1**	**Zone 2**	**Zone 3**	**total**
(in ppm)	[n=108]	[n=140]	[n=59]	[n=307]		[n=108]	[n=140]	[n=59]	[n=307]
Arsenic									
>100	2	2	0	4		1.9	1.4	0.0	1.3
51-100	8	3	0	11		7.4	2.1	0.0	3.6
21-50	31	22	5	58		28.7	15.7	8.5	18.9
0-20	67	113	54	234		62.0	80.7	91.5	76.2
Lead									
>250	5	1	0	6		4.6	0.7	0.0	2.0
101-250	8	6	1	15		7.4	4.3	1.7	4.9
51-100	13	15	3	31		12.0	10.7	5.1	10.1
0-50	82	118	55	255		75.9	84.3	93.2	83.1

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Table 4

MAXIMUM AND AVERAGE CONCENTRATIONS
by Decision Unit (DU)

			number of	Maximum concentration				Average concentration				higher average at > 6"		Ratios:	
Zone	**Area**	**DU**	**borings**	**As**	**depth**	**Pb**	**depth**	**As**	**depth**	**Pb**	**depth**	**As**	**Pb**	**Max Pb/As**	**Avg Pb/As**
															(< 6")
1	2	1	8	23	4	61	5	16.24	1	19.83	1			2.65	1.22
1	11	1	8	56	2	79	1	16.86	2	30.69	1			1.41	1.82
1	13	1	8	110	5	69	5	17.39	1	26.39	1	29.21	29.88	0.63	1.52
1	27	1	8	69	1	300	1	29.96	1	99.83	1			4.35	3.33
1	27	2	8	37	1	380	1	10.75	1	60.91	1			10.27	5.67
1	27	3	8	74	1	300	1	27.21	1	73.90	1			4.05	2.72
1	27	7	6	17	1	37	4	7.13	2	12.12	1		13.67	2.18	1.70
1	28	1	8	71	1	130	1	45.88	1	68.58	1			1.83	1.49
1	28	2	8	130	1	580	1	49.00	1	134.38	1			4.46	2.74
1	37	1	8	18	1	32	4	7.51	1	10.50	1			1.78	1.40
1	38	1	8	41	2	51	2	11.99	2	20.19	2	14.43	22.44	1.24	1.68
1	39	1	8	86	1	360	1	29.75	1	78.10	2			4.19	2.63
1	42	2	8	36	3	72	2	15.08	1	24.89	2			2.00	1.65
1	45	1	6	110	1	200	1	40.50	1	73.00	1			1.82	1.80
2	4	1	6	13	1	45	1	5.93	1	14.18	1			3.46	2.39
2	5	1	4	26	1	49	2	13.50	1	27.58	2			1.88	2.04
2	6	1	8	43	1	100	4	23.89	1	48.48	1			2.33	2.03
2	6	2	8	64	2	95	5	16.95	2	31.63	1			1.48	1.87
2	6	3	8	59	1	150	1	15.24	1	49.93	1			2.54	3.28
2	7	1	4	30	5	42	4	13.68	1	23.75	1			1.40	1.74
2	7	2	8	18	5	290	5	5.48	2	14.78	2	7.31	60.01	16.11	2.70
2	8	1	8	15	1	47	5	6.31	2	11.28	1	7.08	16.08	3.13	1.79
2	8	2	8	25	2	30	2	14.51	2	16.18	1			1.20	1.12
2	8	3	6	24	1	33	2	17.83	2	20.83	1			1.38	1.17
2	8	4	8	21	3	64	5	13.58	2	22.75	2			3.05	1.68
2	9	1	4	41	2	82	2	30.50	1	60.25	2			2.00	1.98
2	20	1	6	27	3	54	4	12.07	2	16.50	2	19.40	30.38	2.00	1.37
2	21	1	8	130	1	440	1	38.69	1	107.28	2			3.38	2.77
2	22	1	6	110	1	240	1	43.52	1	83.17	1			2.18	1.91
2	34	1	6	15	5	15	1	8.97	2	9.67	2			1.00	1.08
2	34	2	6	11	1	13	2	5.17	1	8.02	2			1.18	1.55

Table 4 (continued)

			number of	Maximum concentration				Average concentration				higher average at > 6"		Ratios:	
Zone	**Area**	**DU**	**borings**	**As**	**depth**	**Pb**	**depth**	**As**	**depth**	**Pb**	**depth**	**As**	**Pb**	**Max Pb/As**	**Avg Pb/As**
2	34	3	7	18	2	35	1	8.81	1	16.40	1			1.94	1.86
2	35	2	6	17	1	310	3	5.67	1	70.17	2			18.24	12.38
2	40	1	8	11	1	53	1	3.45	2	15.45	2			4.82	4.48
2	43	1	4	37	2	73	2	15.43	2	25.93	2			1.97	1.68
3	19	1	5	33	1	54	1	16.80	2	28.18	1			1.64	1.68
3	19	2	4	23	3	28	5	10.73	2	15.25	1	15.00	16.80	1.22	1.42
3	23	1	3	25	3	30	2	21.33	2	26.67	2			1.20	1.25
3	24	1	5	17	1	29	1	10.62	2	16.18	1	15.00		1.71	1.52
3	25	1	4	20	3	38	2	10.78	1	31.00	1	13.43		1.90	2.88
3	26	1	4	21	2	35	1	13.33	2	22.00	2			1.67	1.65
3	26	2	6	27	1	65	1	11.15	1	25.68	1			2.41	2.30
3	30	1	6	26	1	900	2	13.63	1	176.00	2			34.62	12.91
3	32	1	4	22	1	32	3	15.00	1	18.50	1			1.45	1.23
3	32	2	4	8.9	2	20	1	6.85	1	12.08	1			2.25	1.76
3	33	1	4	17	3	13	1	8.30	2	8.70	1	9.73		0.76	1.05
3	33	2	4	26	3	12	1	13.83	2	10.60	1	15.48		0.46	0.77
3	46	1	6	28	5	31	3	10.92	2	16.83	2	11.00		1.11	1.54

NOTES
All beach DUs excluded
All concentrations in ppm, DW
Maximum concentration is for any depth; Average concentration is larger of 0-2 inch and 2-6 inch averages
Where Maximum concentration occurs at more than one depth, shallower depth shown
Values shown under "higher average" where Average (top 6") is exceeded at greater depth interval
Number of sample results for a depth may be less than number of borings (e.g., in Zone 3)
For all ND results, the PQL value is used for calculations

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Table 5

MAGNITUDE OF CONTAMINATION
MAXIMUM VALUES IN DUs
Sample Counts by Concentration Ranges

Concentration Range	**Sample Counts** Zone 1	Zone 2	Zone 3	total		**Percentages** Zone 1	Zone 2	Zone 3	total
(in ppm)	[n=14]	[n=21]	[n=13]	[n=48]	[see note]	[n=14]	[n=21]	[n=13]	[n=48]
Arsenic									
>100	3	2	0	5		21.4	9.1	0.0	10.2
51-100	5	2	0	7		35.7	13.6	0.0	16.3
21-50	4	9	9	22		28.6	40.9	69.2	44.9
0-20	2	8	4	14		14.3	36.4	30.8	28.6
Lead									
>250	5	3	1	9		35.7	13.6	7.7	18.4
101-250	2	2	0	4		14.3	13.6	0.0	10.2
51-100	5	7	2	14		35.7	31.8	15.4	28.6
0-50	2	9	10	21		14.3	40.9	76.9	42.9

Note: The maximum single sample values for each DU are included. At one site in Zone 2, 15 samples were collected and analyzed from 3 targeted borings. Those data are not included in this summary of maximum values by DU.

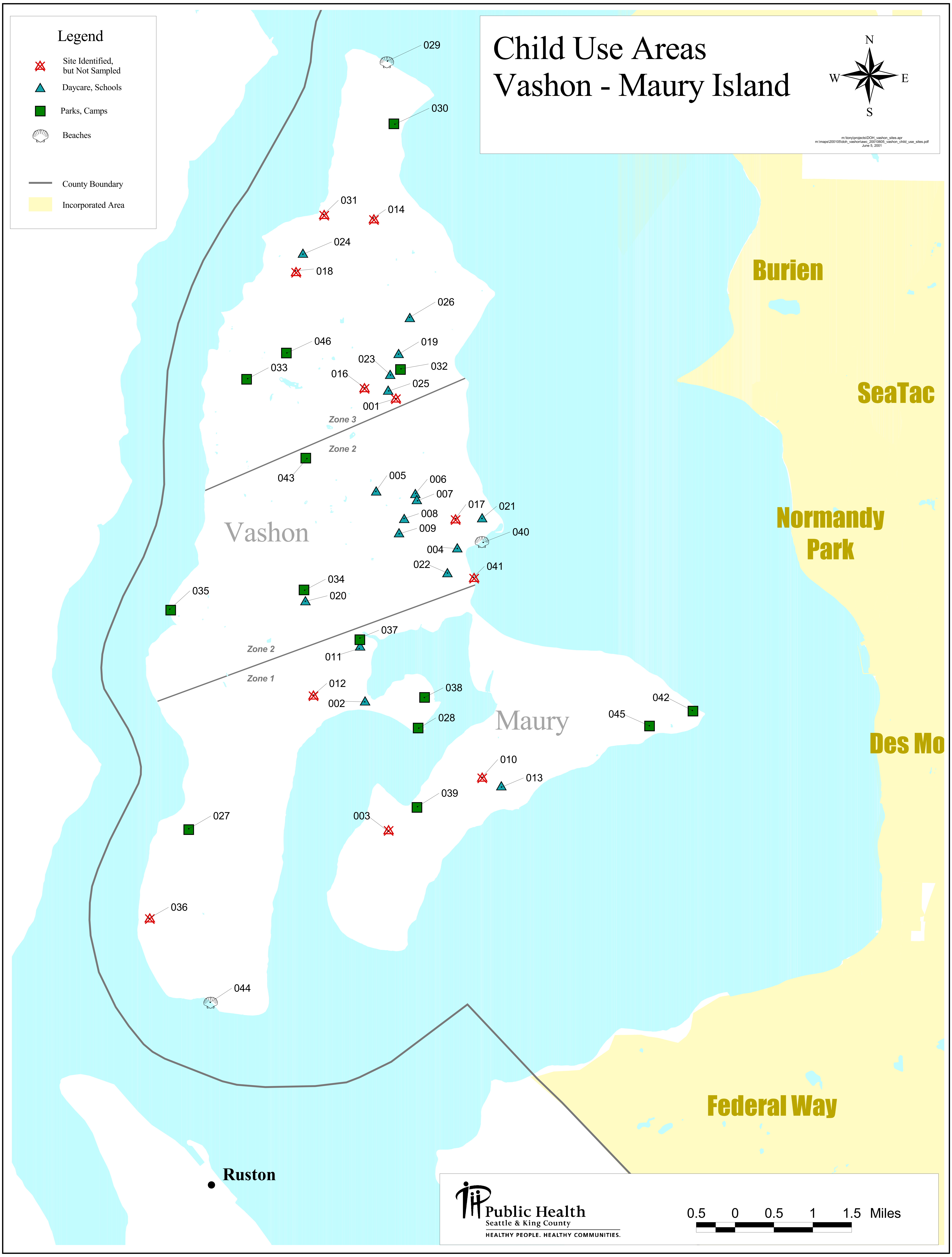

Child Use Areas
Vashon - Maury Island
N
W
E
S
Legend
Site Identified, but Not Sampled
Daycare, Schools
Parks, Camps
Beaches
County Boundary
Incorporated Area
029
030
031
014
024
018
026
046
019
033
023
032
016
025
001
Zone 3
Zone 2
043
005
006
007
017
021
008
009
040
004
022
041
Vashon
035
034
020
037
Zone 2
011
Zone 1
012
038
002
042
028
045
Maury
010
013
039
027
003
036
044
Burien
SeaTac
Normandy Park
Des Mo
Federal Way
Ruston
Public Health
Seattle & King County
HEALTHY PEOPLE. HEALTHY COMMUNITIES.
0.5
0
0.5
1
1.5
Miles

Figure 1

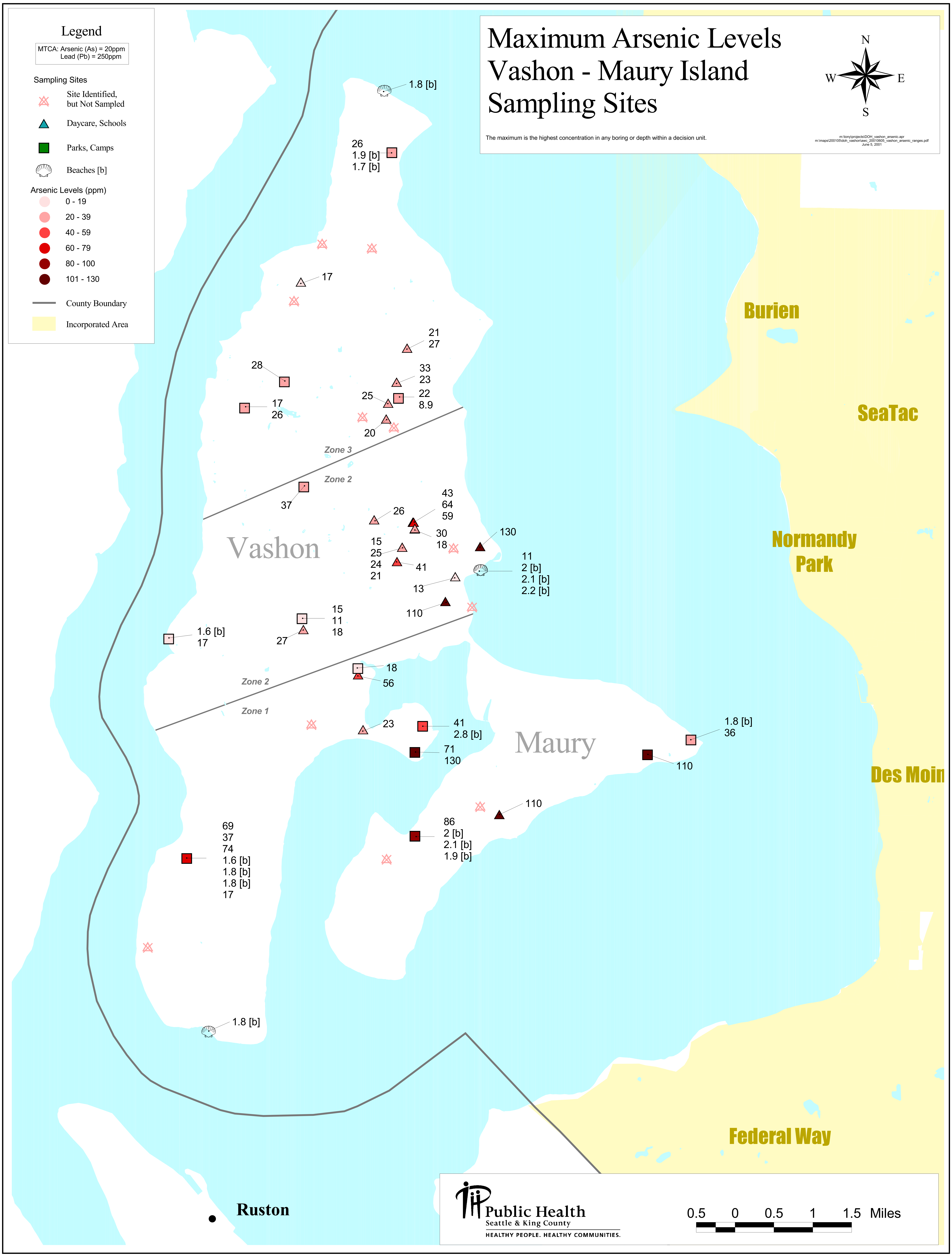

Maximum Arsenic Levels
Vashon - Maury Island
Sampling Sites
The maximum is the highest concentration in any boring or depth within a decision unit.
m:\tony\projects\DOH_vashon_arsenic.apr
m:\maps\200105\doh_vashon\awc_20010605_vashon_arsenic_ranges.pdf
June 5, 2001
N
W
E
S
Legend
MTCA: Arsenic (As) = 20ppm
Lead (Pb) = 250ppm
Sampling Sites
Site Identified, but Not Sampled
Daycare, Schools
Parks, Camps
Beaches [b]
Arsenic Levels (ppm)
0 - 19
20 - 39
40 - 59
60 - 79
80 - 100
101 - 130
County Boundary
Incorporated Area
Burien
SeaTac
Normandy Park
Des Moin
Federal Way
Ruston
Vashon
Maury
Zone 3
Zone 2
Zone 2
Zone 1
1.8 [b]
26
1.9 [b]
1.7 [b]
17
21
27
28
33
23
25
22
8.9
17
26
20
37
43
64
59
26
30
18
130
15
25
24
21
41
11
2 [b]
2.1 [b]
2.2 [b]
13
110
15
11
18
1.6 [b]
17
27
18
56
23
41
2.8 [b]
71
130
1.8 [b]
36
110
110
86
2 [b]
2.1 [b]
1.9 [b]
69
37
74
1.6 [b]
1.8 [b]
1.8 [b]
17
1.8 [b]
Public Health
Seattle & King County
HEALTHY PEOPLE. HEALTHY COMMUNITIES.
0.5
0
0.5
1
1.5
Miles

Figure 2

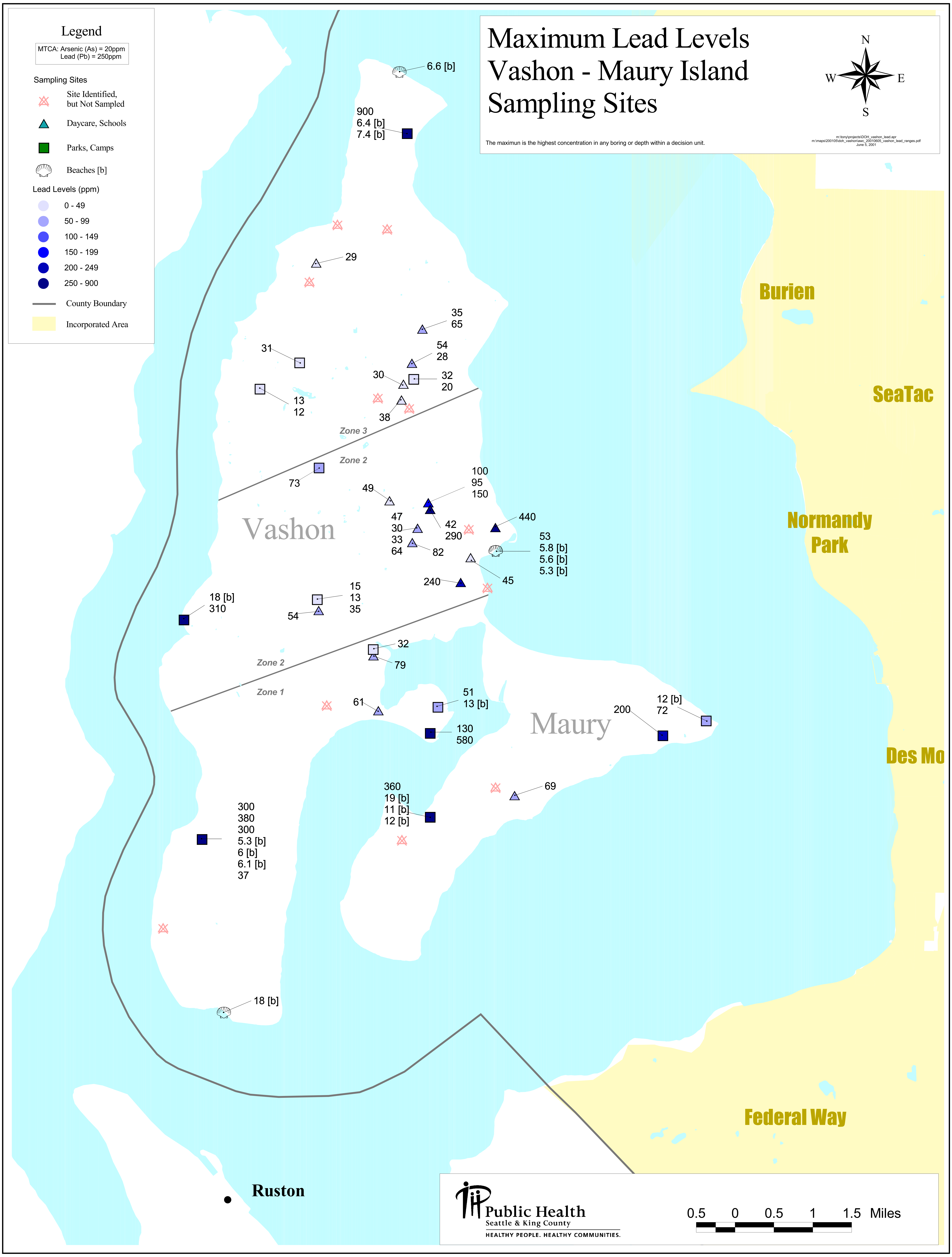
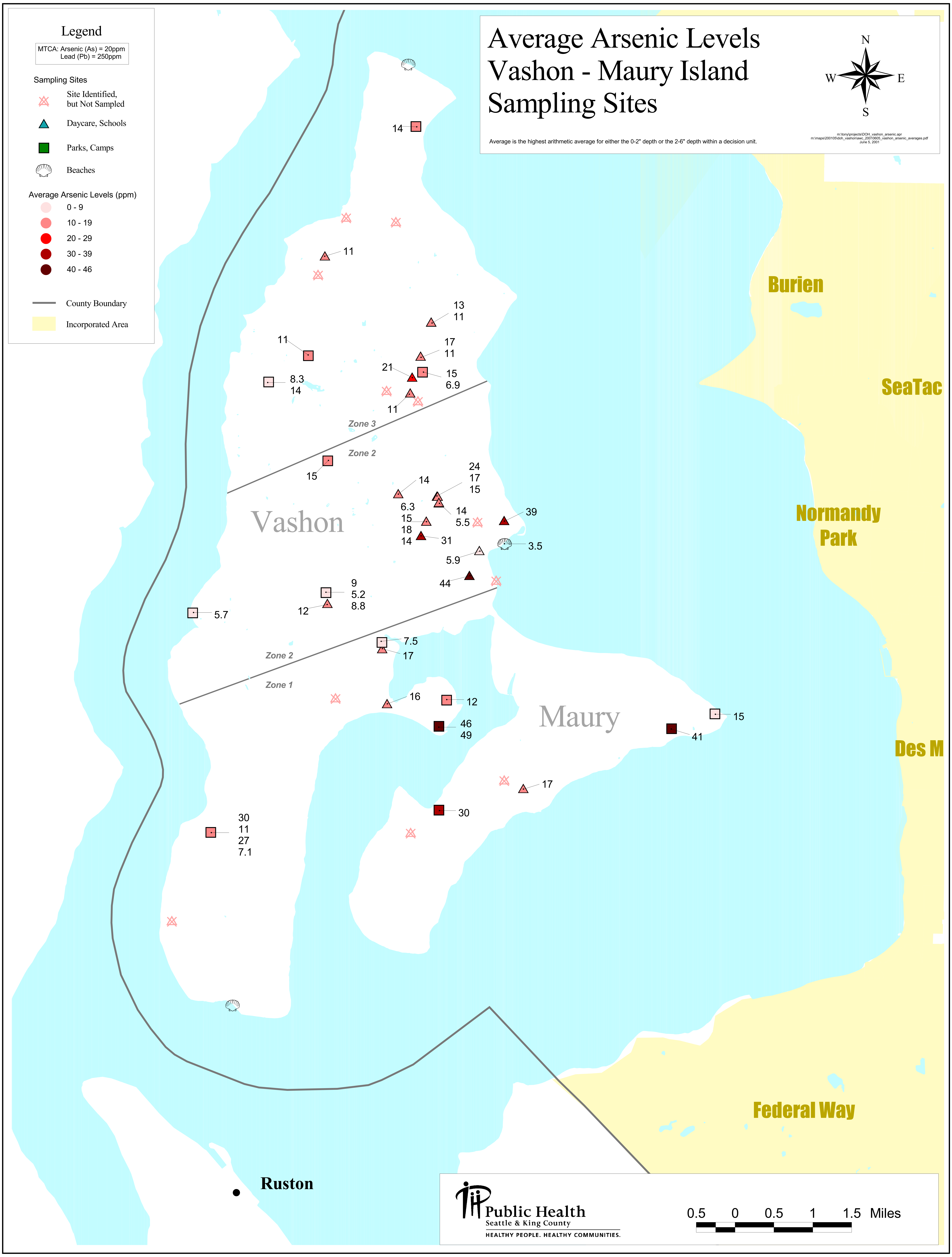

Maximum Lead Levels
Vashon - Maury Island
Sampling Sites
The maximun is the highest concentration in any boring or depth within a decision unit.
m:\tony\projects\DOH_vashon_lead.apr
m:\maps\200105\doh_vashon\awc_20010605_vashon_lead_ranges.pdf
June 5, 2001
N
W
E
S
Legend
MTCA: Arsenic (As) = 20ppm
Lead (Pb) = 250ppm
Sampling Sites
Site Identified, but Not Sampled
Daycare, Schools
Parks, Camps
Beaches [b]
Lead Levels (ppm)
0 - 49
50 - 99
100 - 149
150 - 199
200 - 249
250 - 900
County Boundary
Incorporated Area
6.6 [b]
900
6.4 [b]
7.4 [b]
29
35
65
54
28
31
30
32
20
13
12
38
Zone 3
Zone 2
73
100
95
150
49
Vashon
47
30
33
64
42
290
82
440
53
5.8 [b]
5.6 [b]
5.3 [b]
45
240
15
13
35
54
18 [b]
310
32
79
Zone 2
Zone 1
51
13 [b]
61
130
580
Maury
200
12 [b]
72
360
19 [b]
11 [b]
12 [b]
69
300
380
300
5.3 [b]
6 [b]
6.1 [b]
37
18 [b]
Burien
SeaTac
Normandy Park
Des Mo
Federal Way
Ruston
Public Health
Seattle & King County
HEALTHY PEOPLE. HEALTHY COMMUNITIES.
0.5
0
0.5
1
1.5
Miles

Figure 3



Average Arsenic Levels
Vashon - Maury Island
Sampling Sites

Average is the highest arithmetic average for either the 0-2" depth or the 2-6" depth within a decision unit.

m:\tony\projects\DOH_vashon_arsenic.apr
m:\maps\200105\doh_vashon\awc_20010605_vashon_arsenic_averages.pdf
June 5, 2001

Figure 4

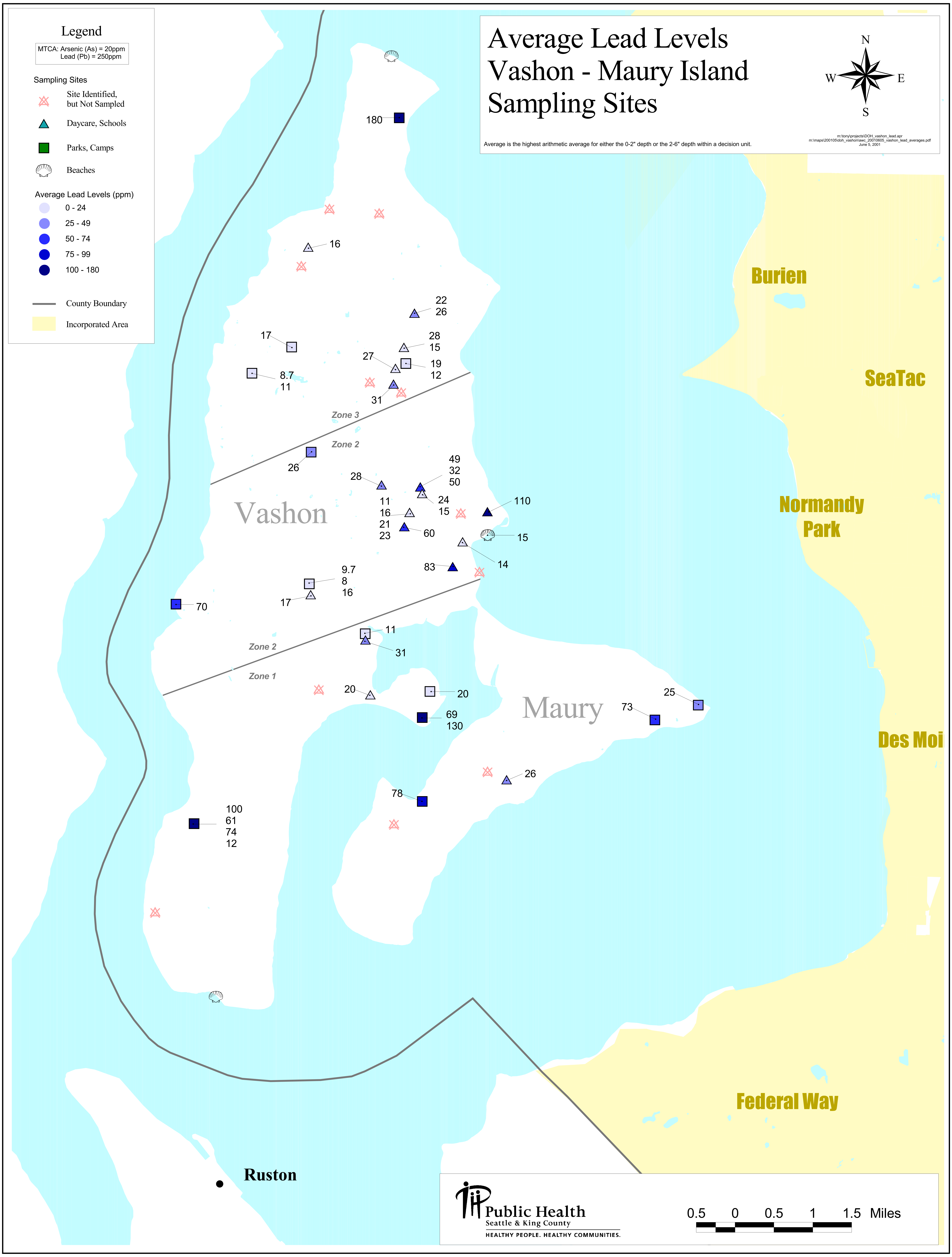

Average Lead Levels
Vashon - Maury Island
Sampling Sites
Average is the highest arithmetic average for either the 0-2" depth or the 2-6" depth within a decision unit.
m:\tony\projects\DOH_vashon_lead.apr
m:\maps\200105\doh_vashon\awc_20010605_vashon_lead_averages.pdf
June 5, 2001
N
W
E
S
Legend
MTCA: Arsenic (As) = 20ppm
Lead (Pb) = 250ppm
Sampling Sites
Site Identified, but Not Sampled
Daycare, Schools
Parks, Camps
Beaches
Average Lead Levels (ppm)
0 - 24
25 - 49
50 - 74
75 - 99
100 - 180
County Boundary
Incorporated Area
180
16
22
26
17
28
15
27
19
12
8.7
11
31
Zone 3
Zone 2
26
49
32
50
28
11
16
21
23
24
15
110
60
15
14
83
9.7
8
16
17
70
11
31
Zone 2
Zone 1
20
20
69
130
25
73
26
78
100
61
74
12
Vashon
Maury
Burien
SeaTac
Normandy Park
Des Moi
Federal Way
Ruston
Public Health
Seattle & King County
HEALTHY PEOPLE. HEALTHY COMMUNITIES.
0.5
0
0.5
1
1.5
Miles

Figure 5

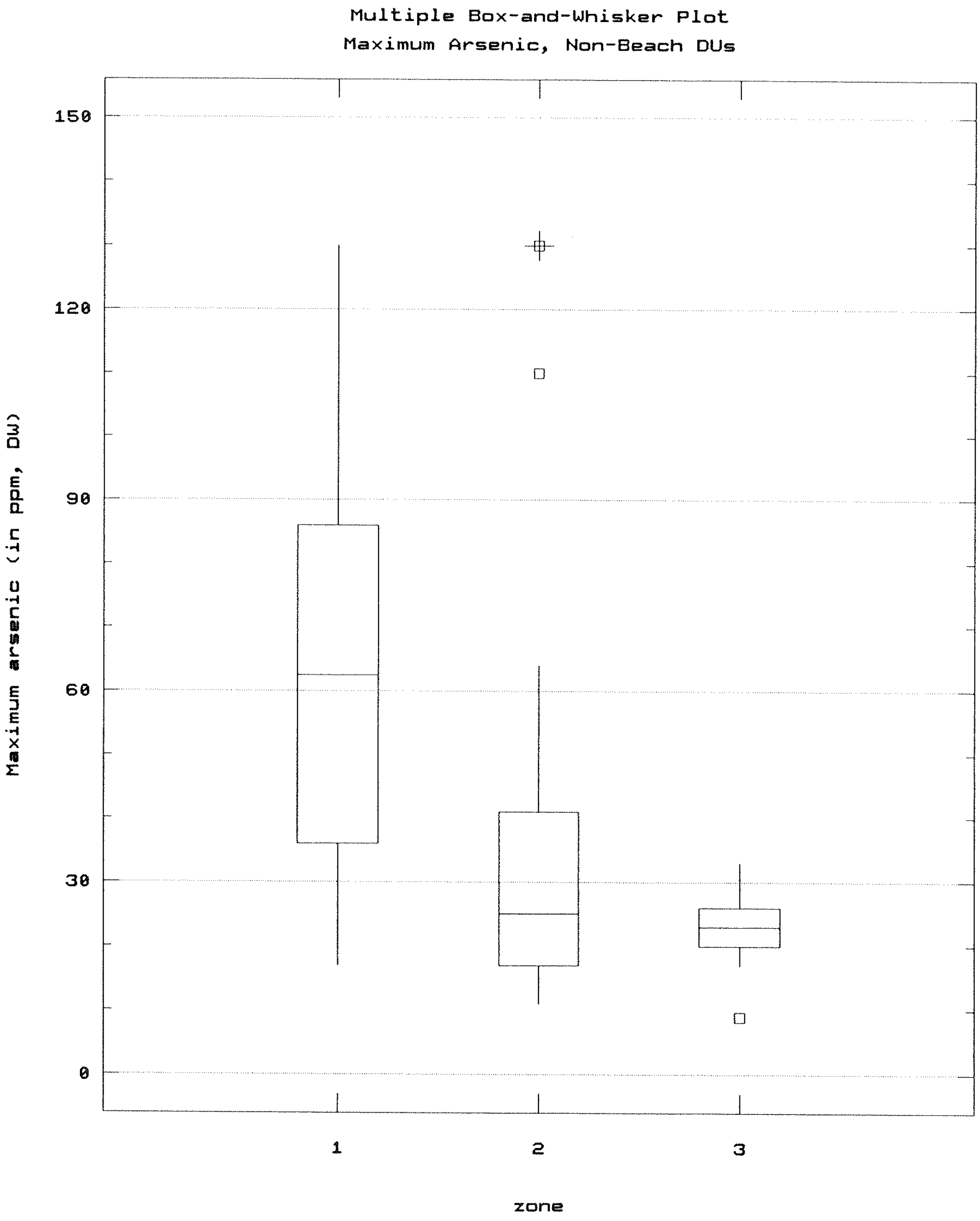


Figure 6
Box-and-Whisker Plot: Maximum Arsenic Results by Zone

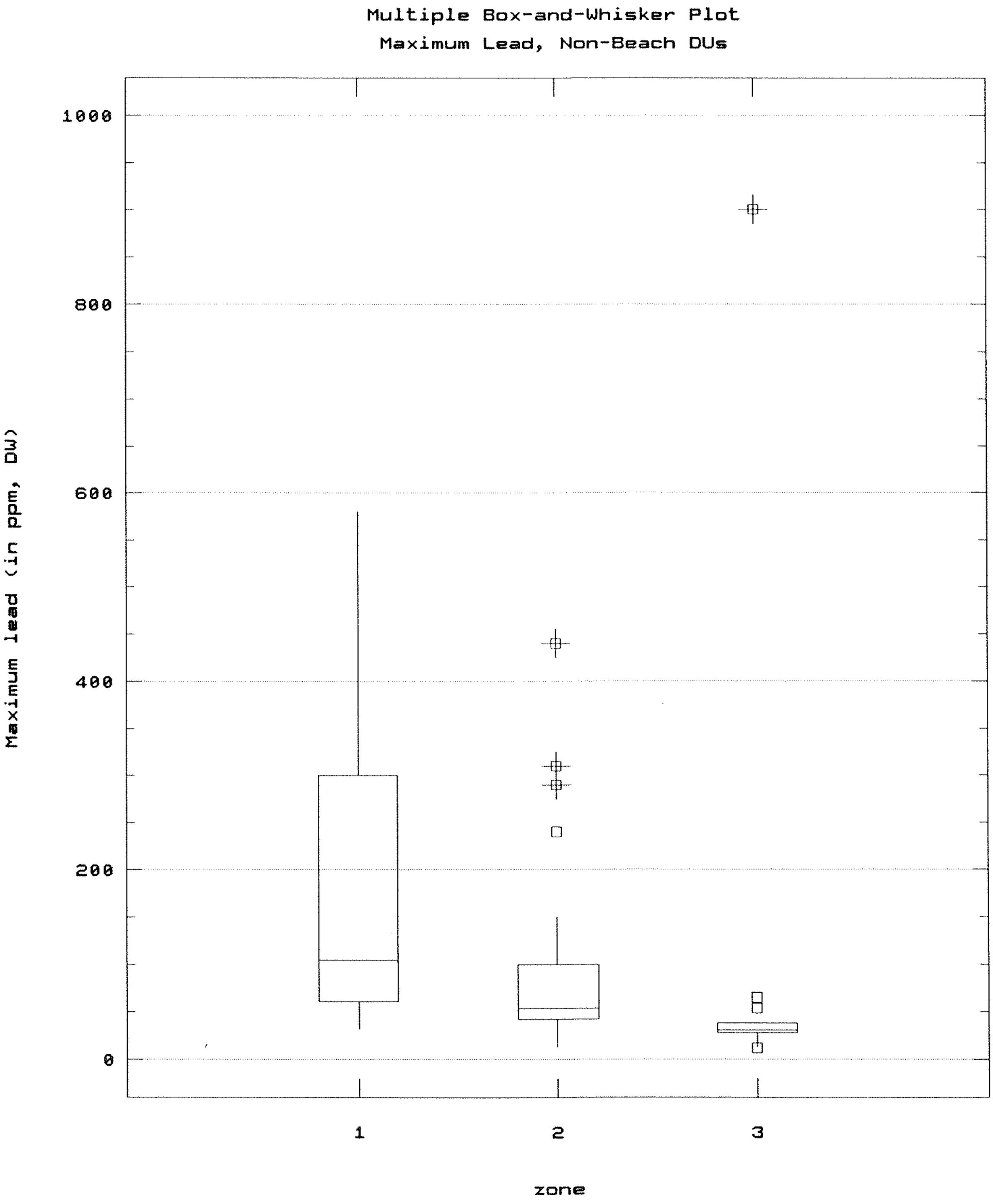


Figure 7
Box-and-Whisker Plot: Maximum Lead Results by Zone

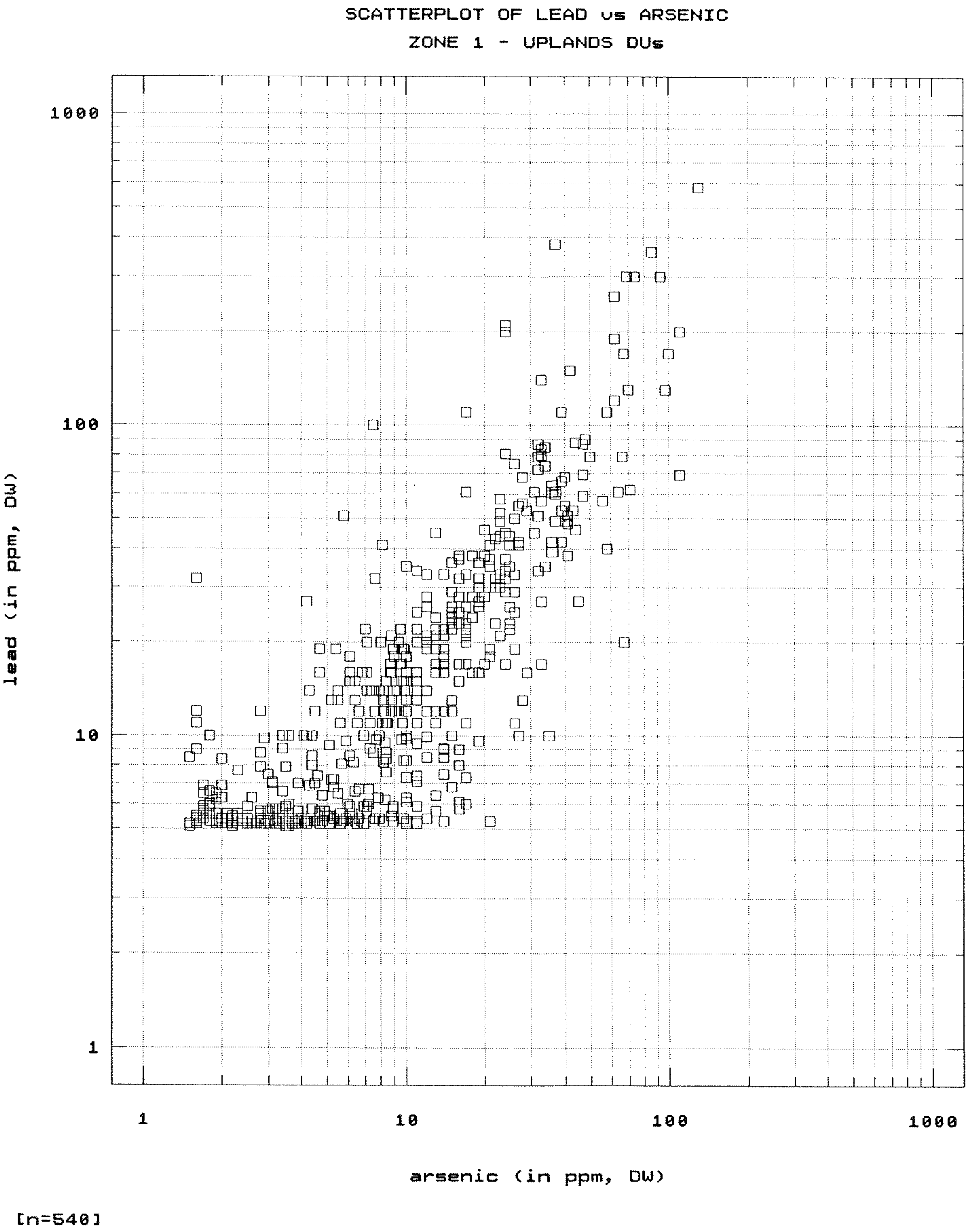


Figure 8
Scatterplot: Lead versus Arsenic Results, Zone 1

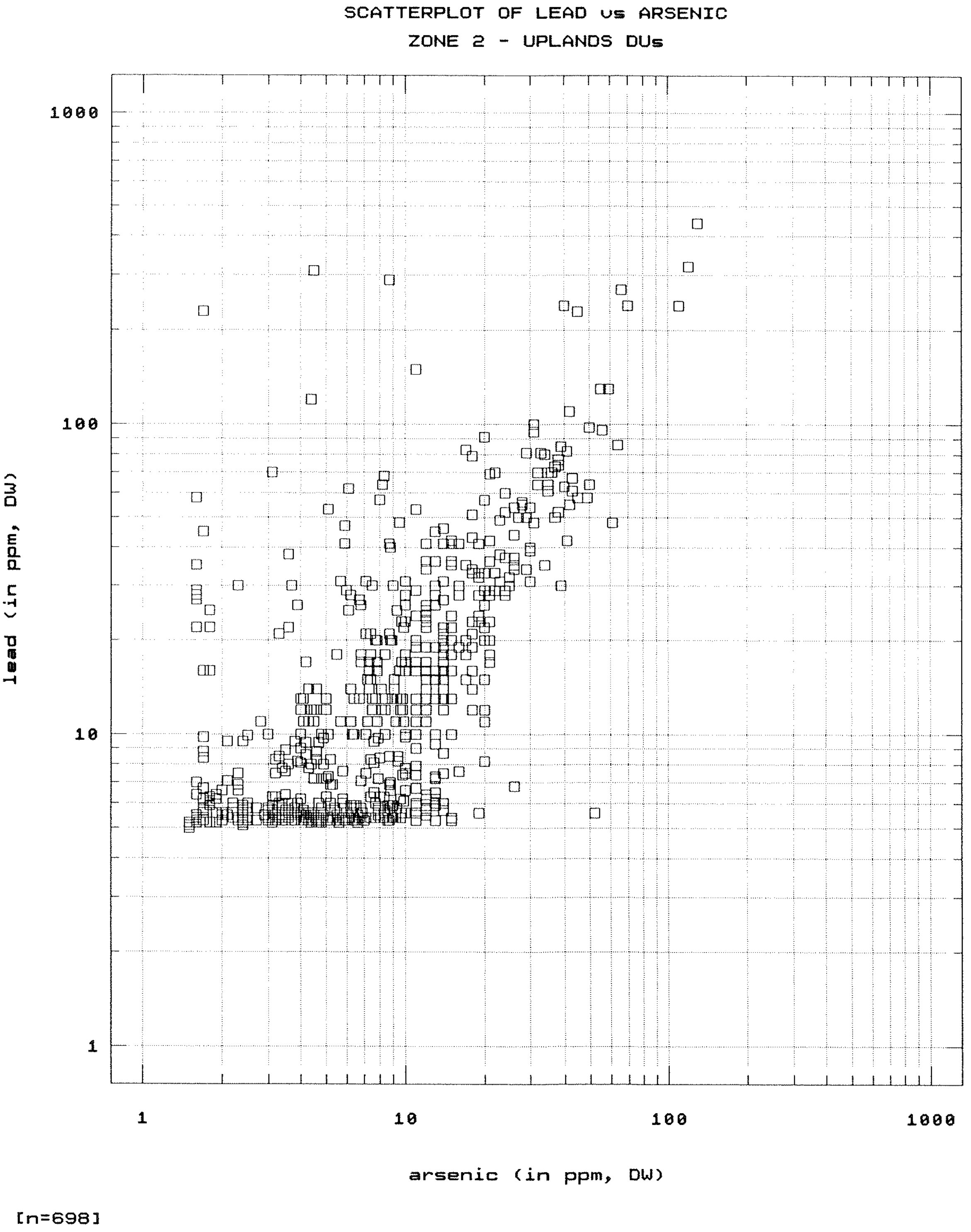


Figure 9
Scatterplot: Lead versus Arsenic Results, Zone 2

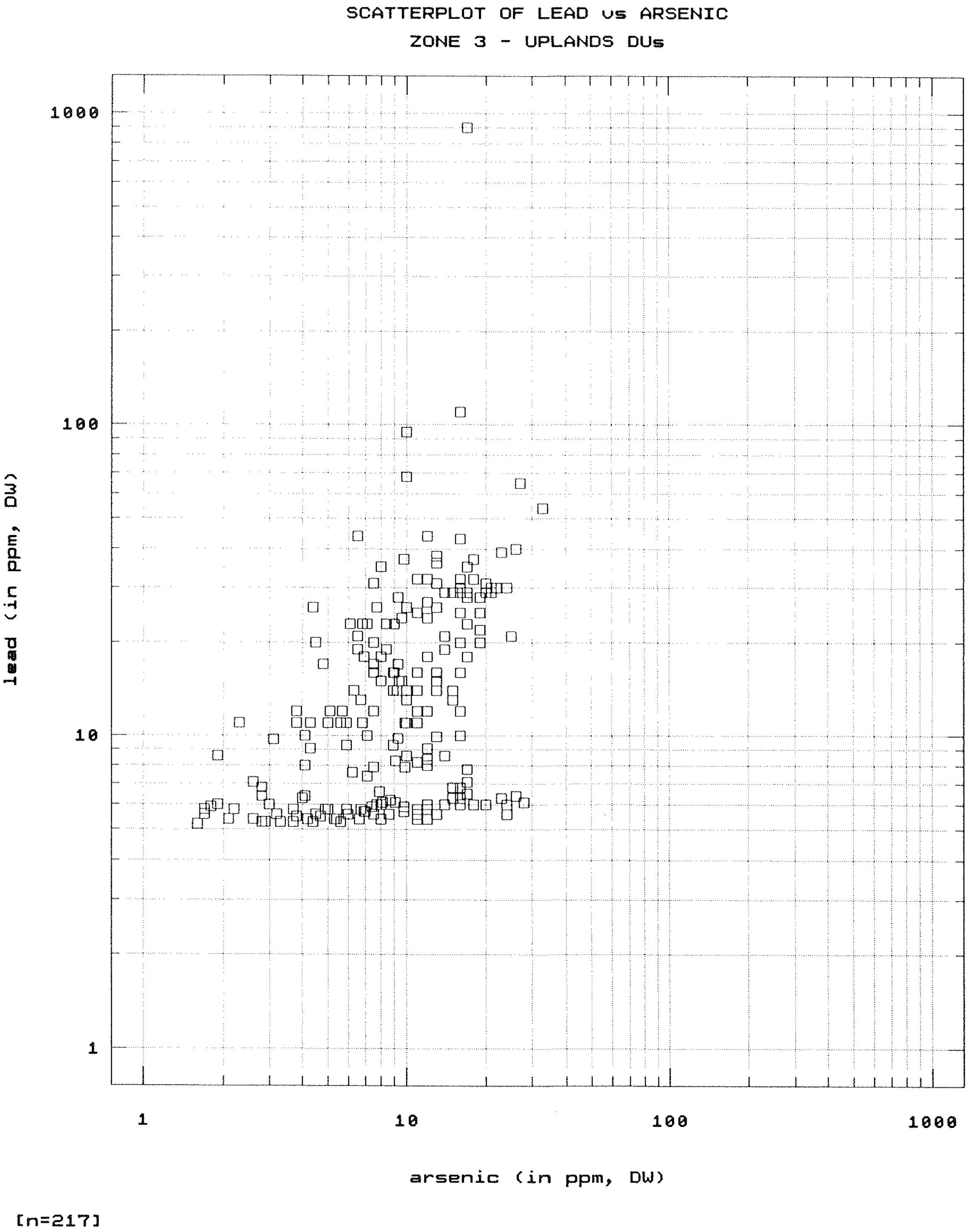


Figure 10
Scatterplot: Lead versus Arsenic Results, Zone 3

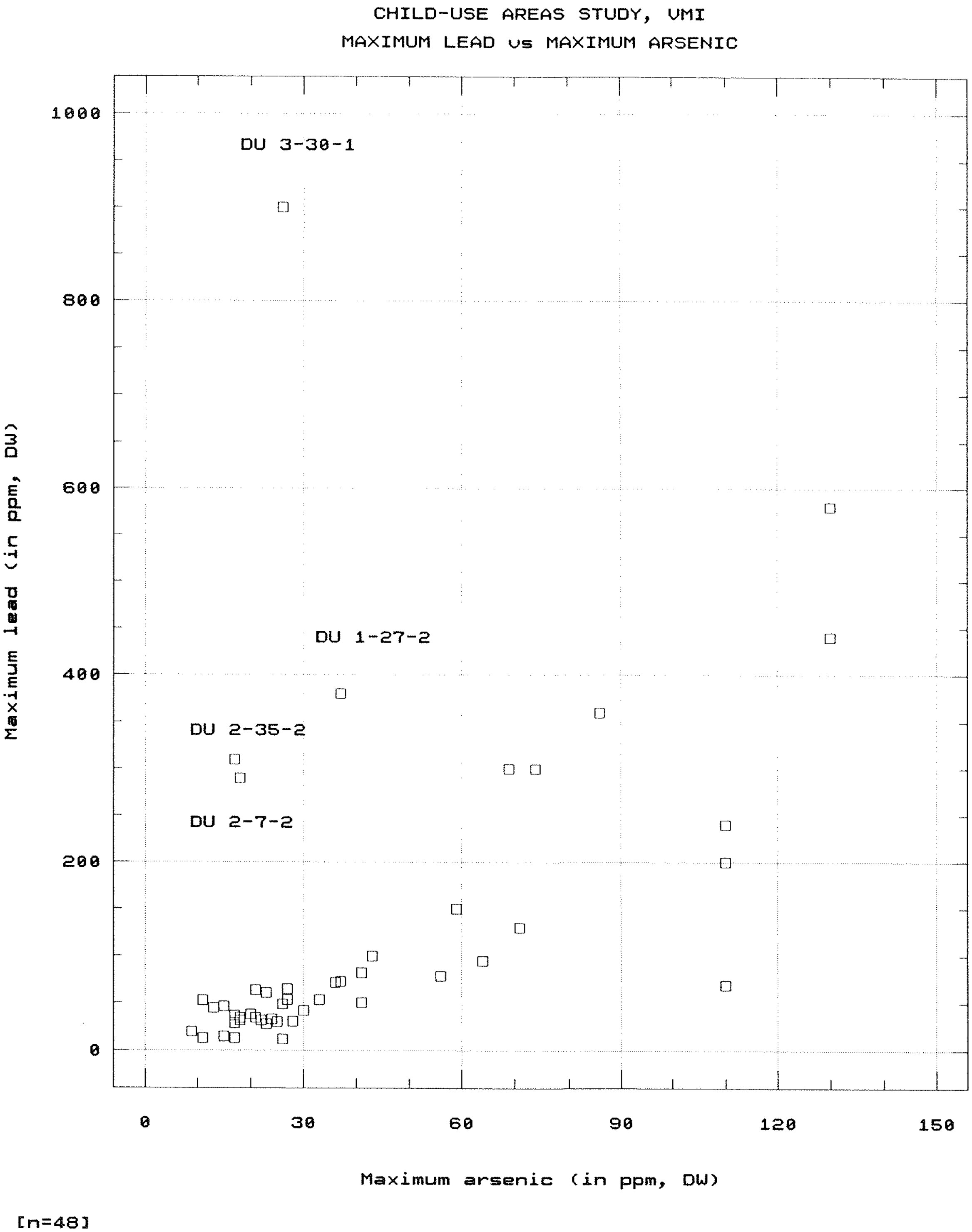


Figure 11
Scatterplot: Maximum Lead versus Maximum Arsenic Results

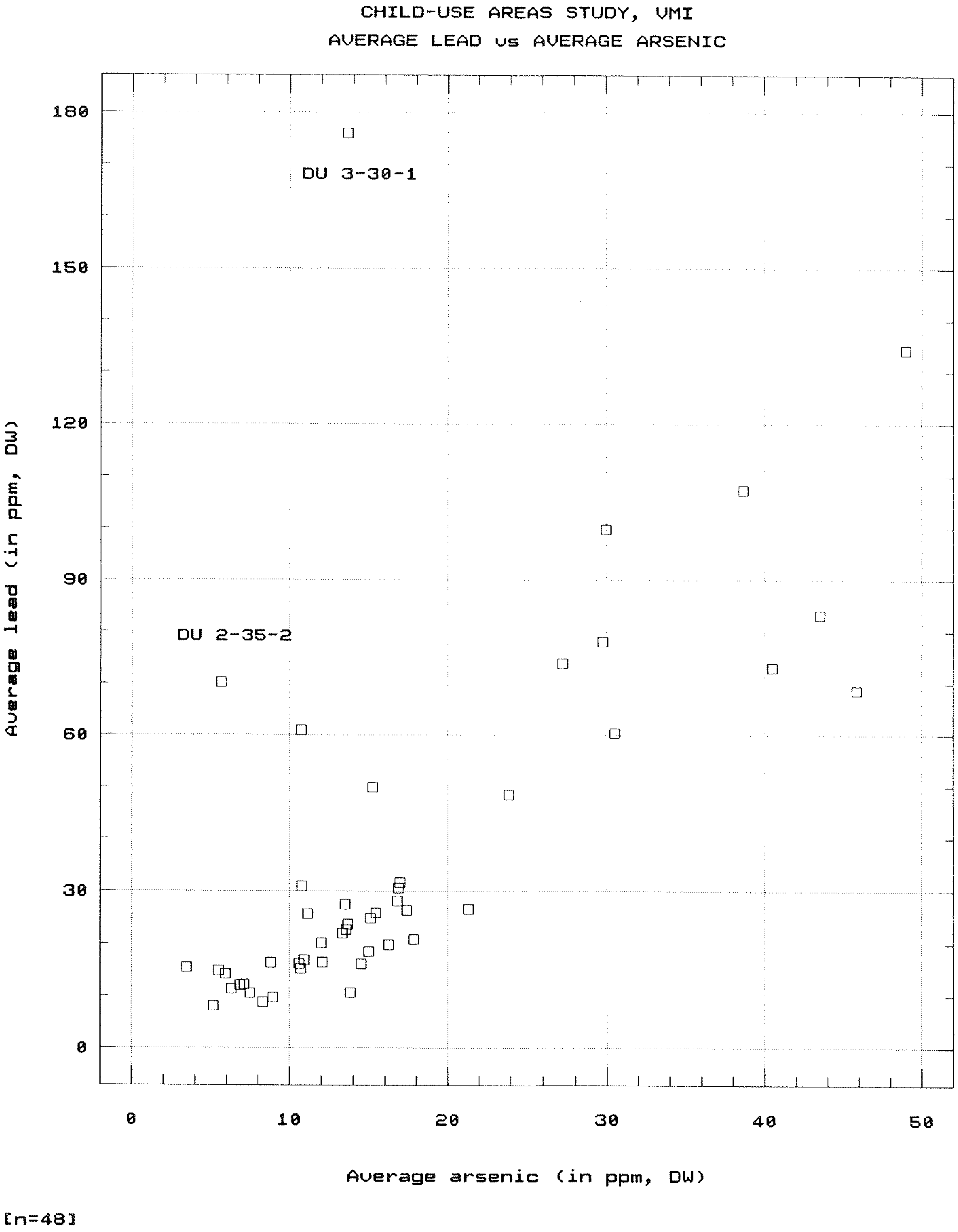


Figure 12
Scatterplot: Average Lead versus Average Arsenic Results

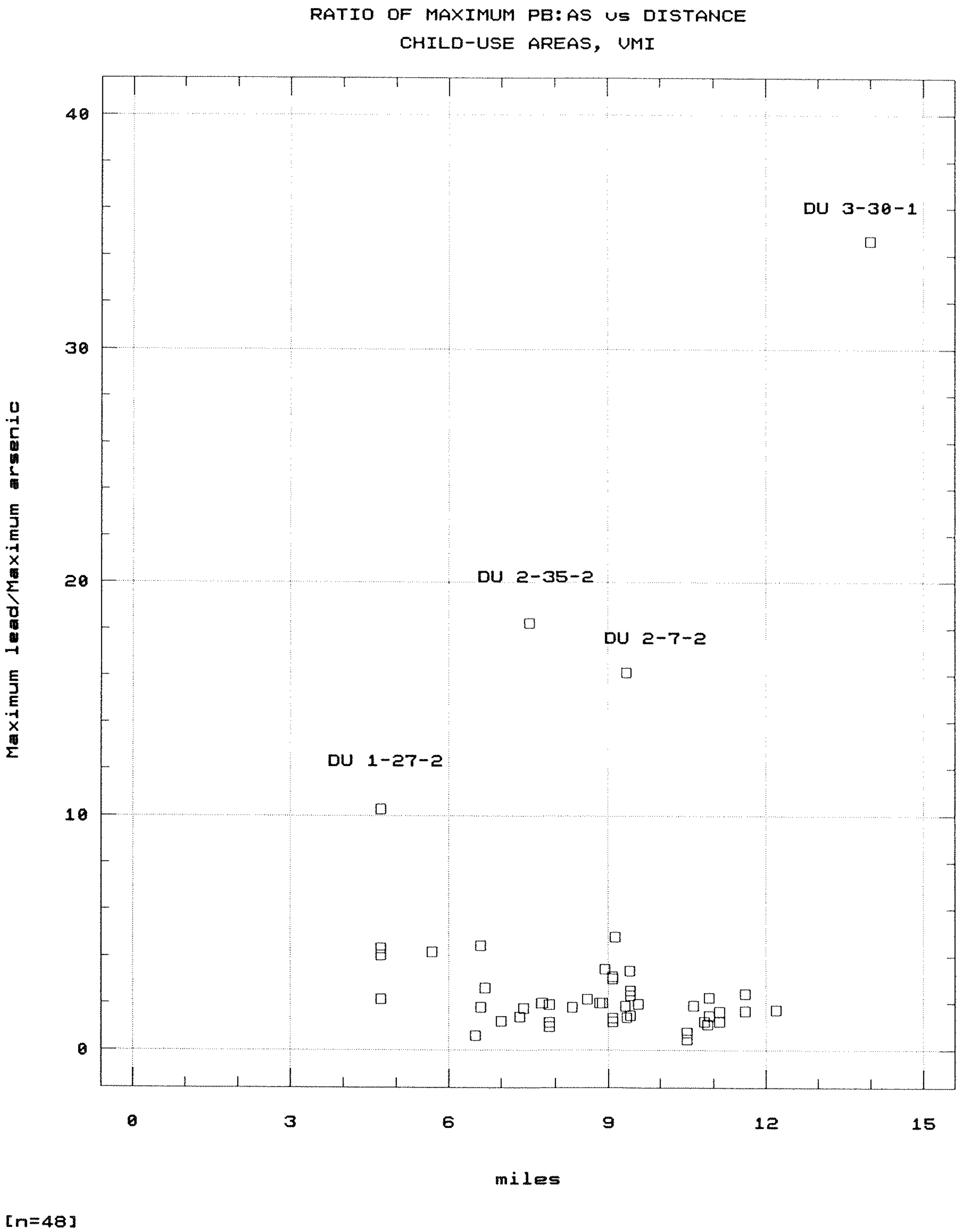


Figure 13a
Scatterplot: Maximum Lead:Maximum Arsenic Ratio versus Distance

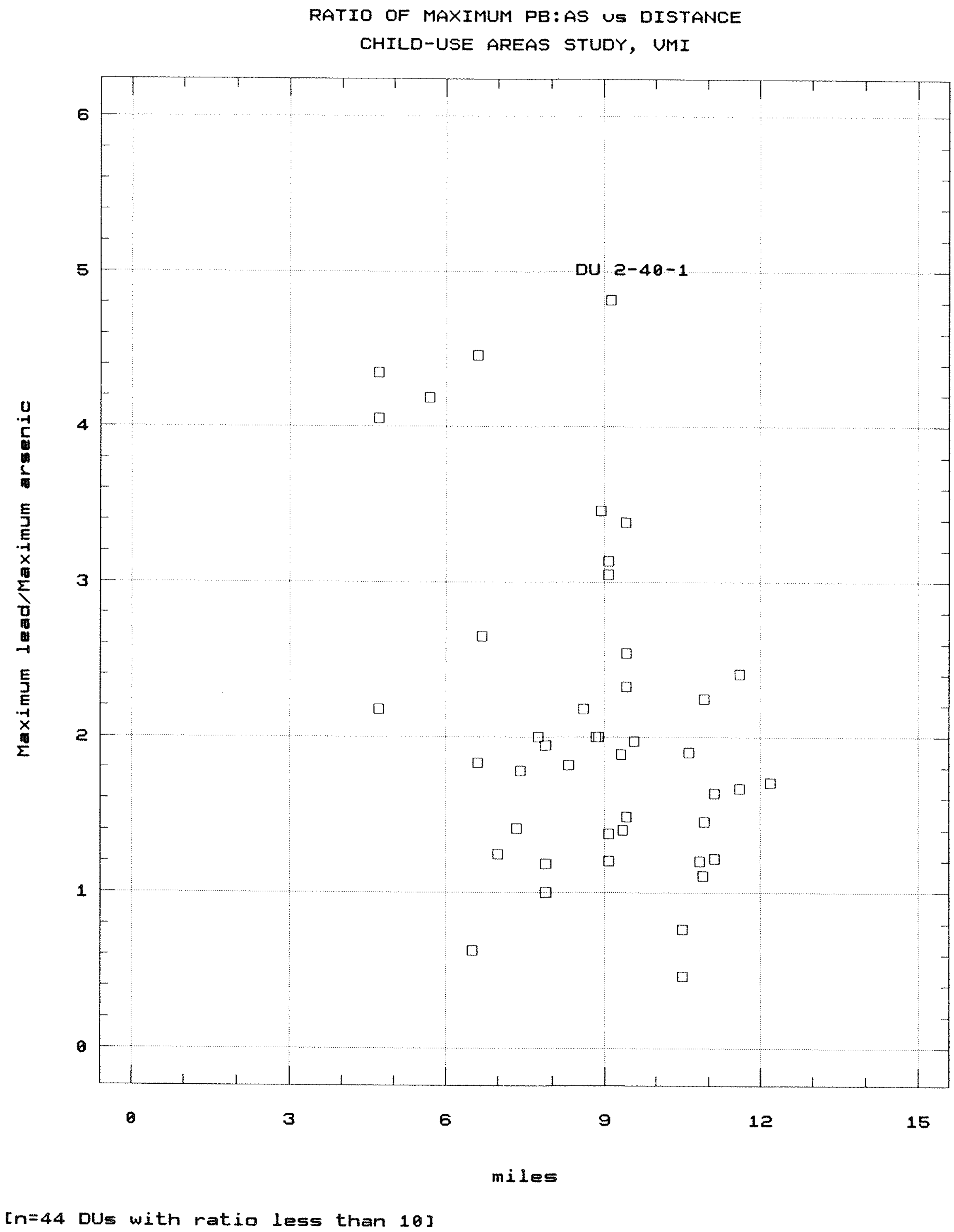


Figure 13b
Scatterplot: Maximum Lead:Maximum Arsenic Ratio versus Distance
Ratios Less Than 6

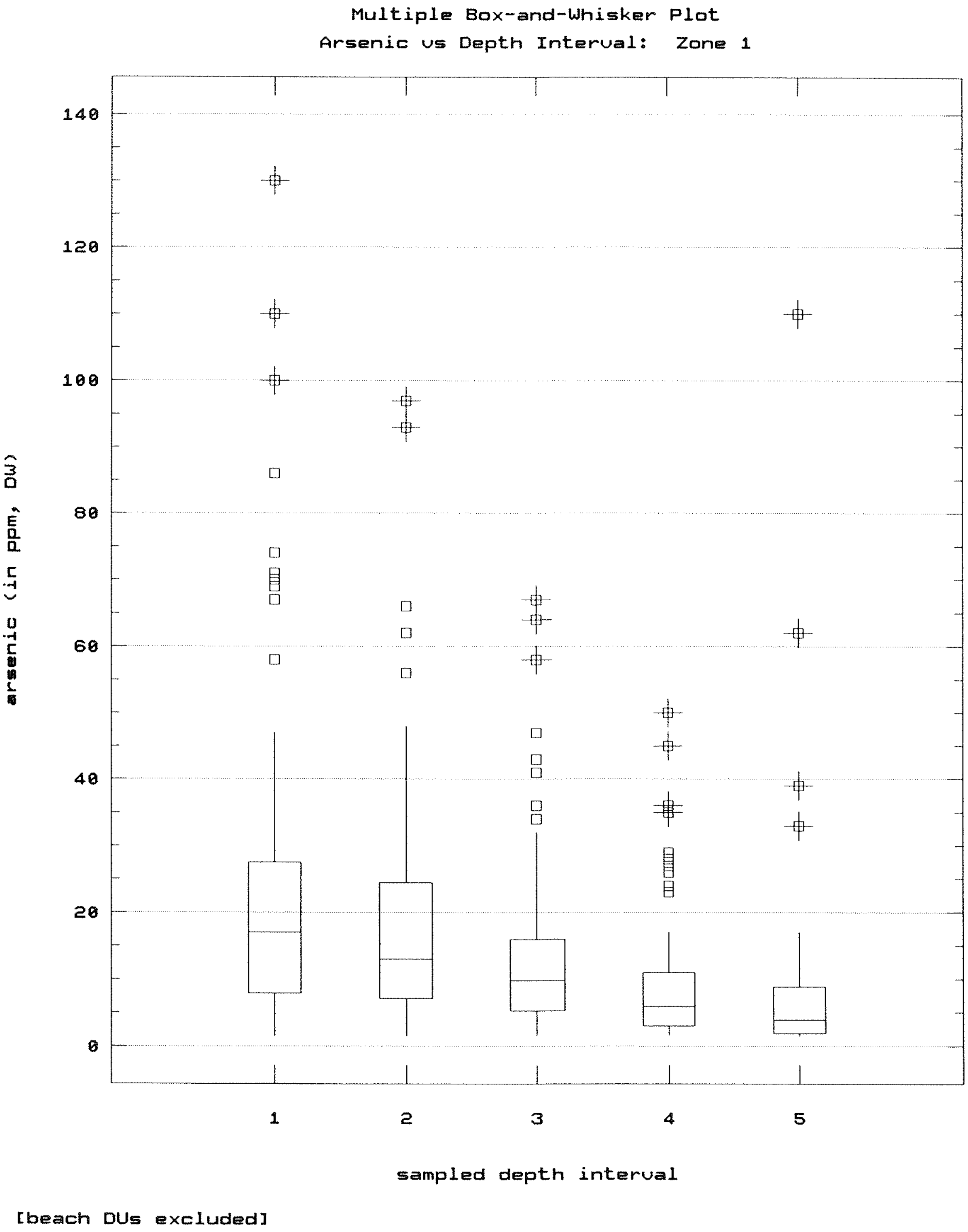


Figure 14
Box-and-Whisker Plot: Arsenic versus Depth Interval, Zone 1

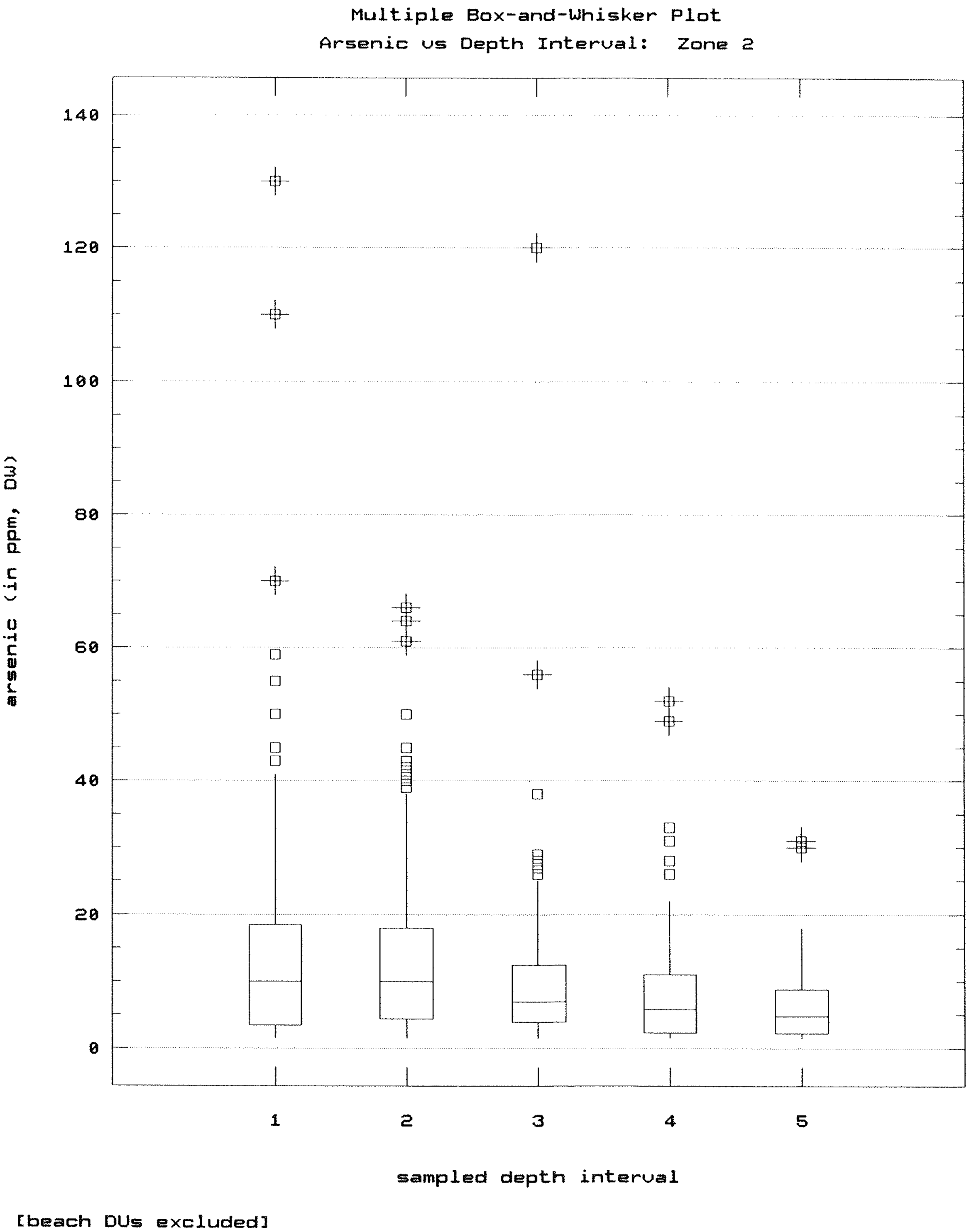


Figure 15
Box-and-Whisker Plot: Arsenic versus Depth Interval, Zone 2

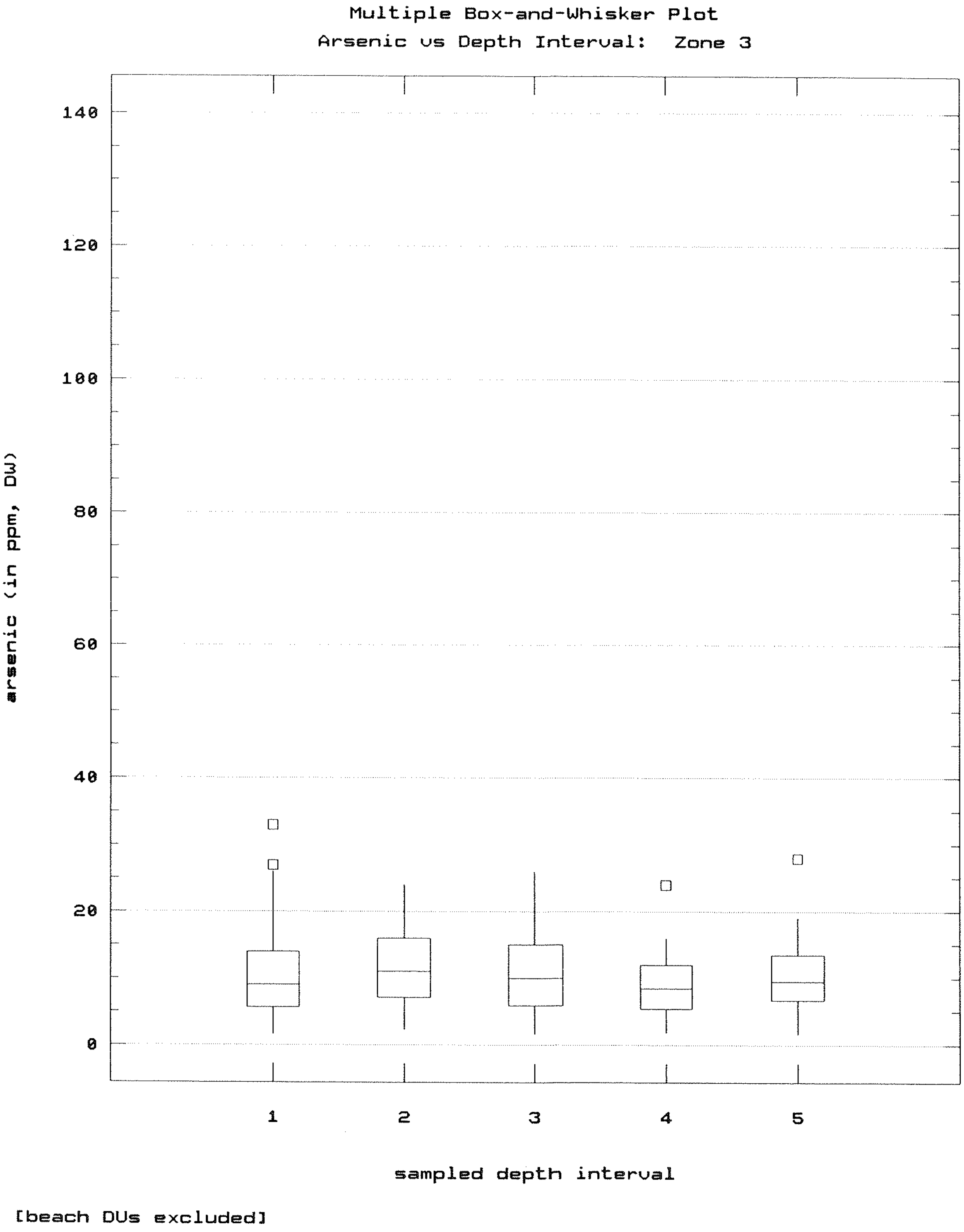


Figure 16
Box-and-Whisker Plot: Arsenic versus Depth Interval, Zone 3

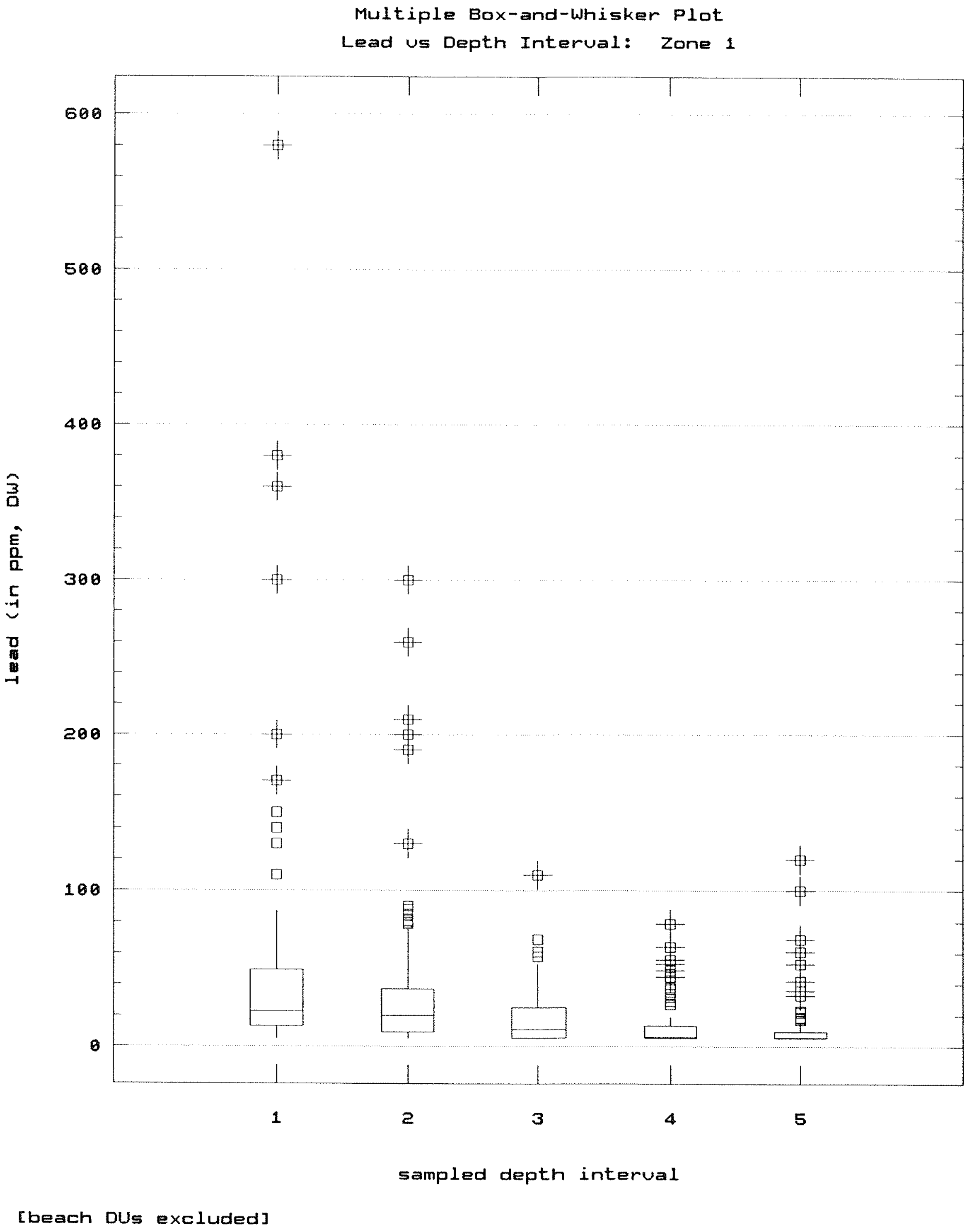


Figure 17
Box-and-Whisker Plot: Lead versus Depth Interval, Zone 1

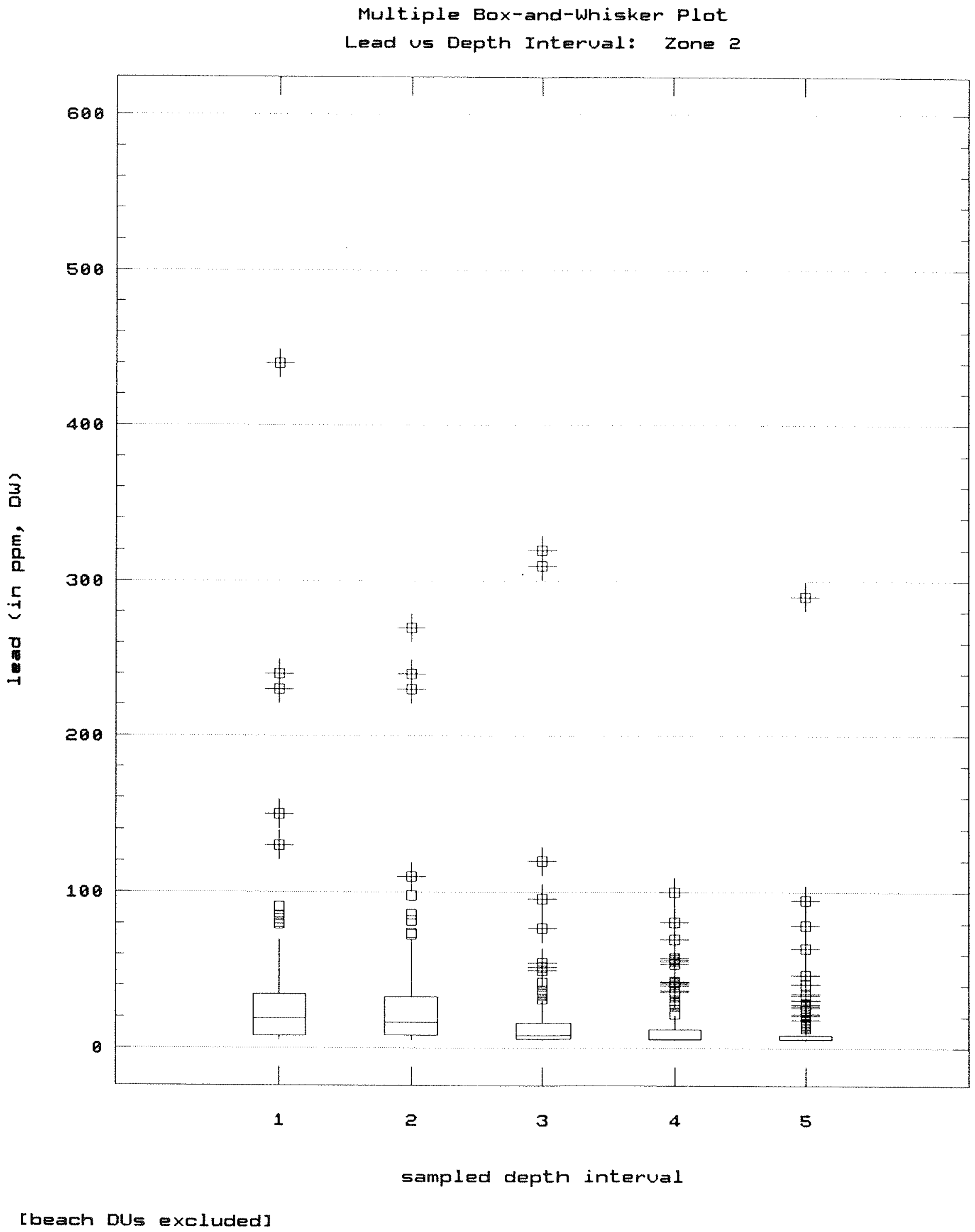


Figure 18
Box-and-Whisker Plot: Lead versus Depth Interval, Zone 2

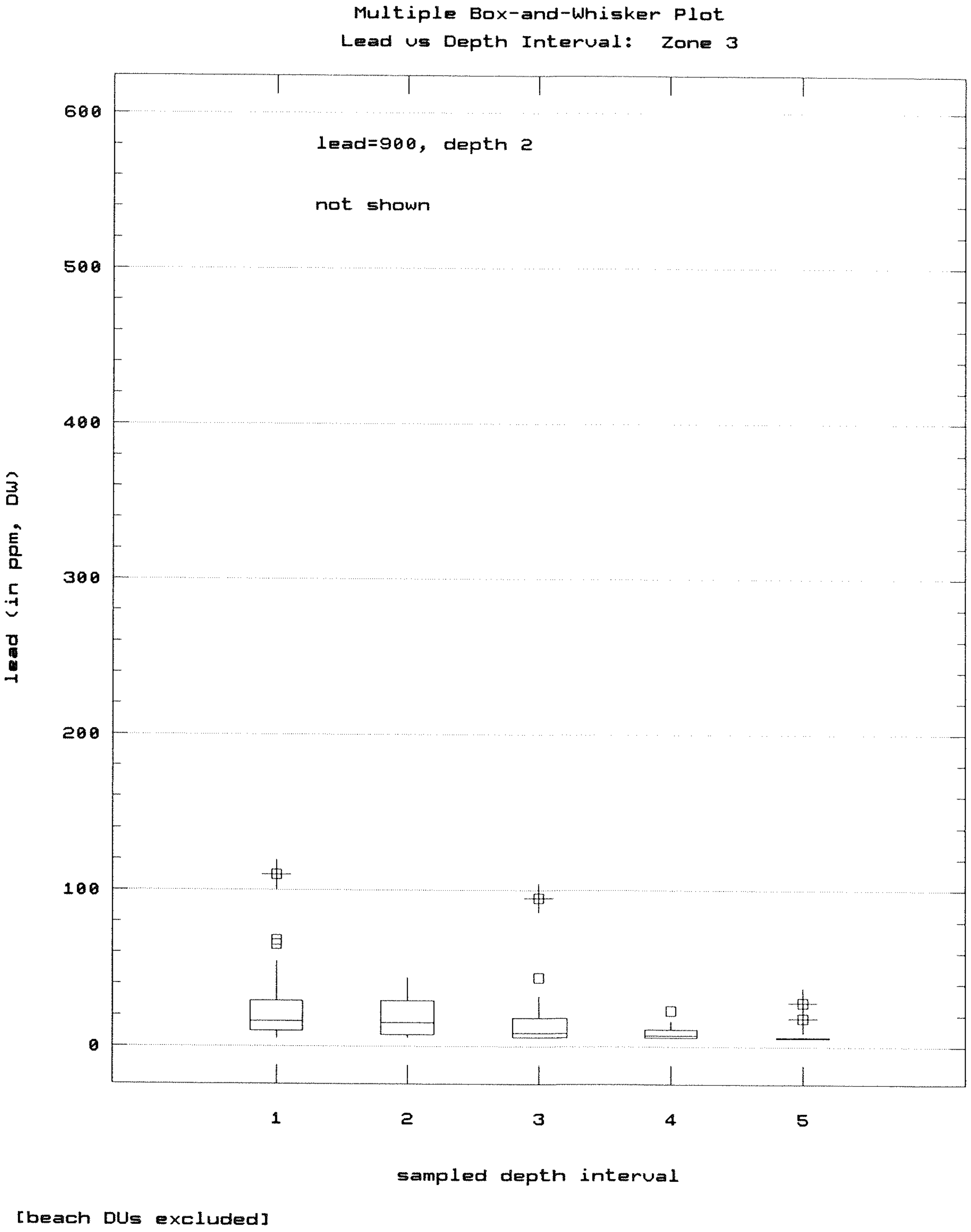


Figure 19
Box-and-Whisker Plot: Lead versus Depth Interval, Zone 3

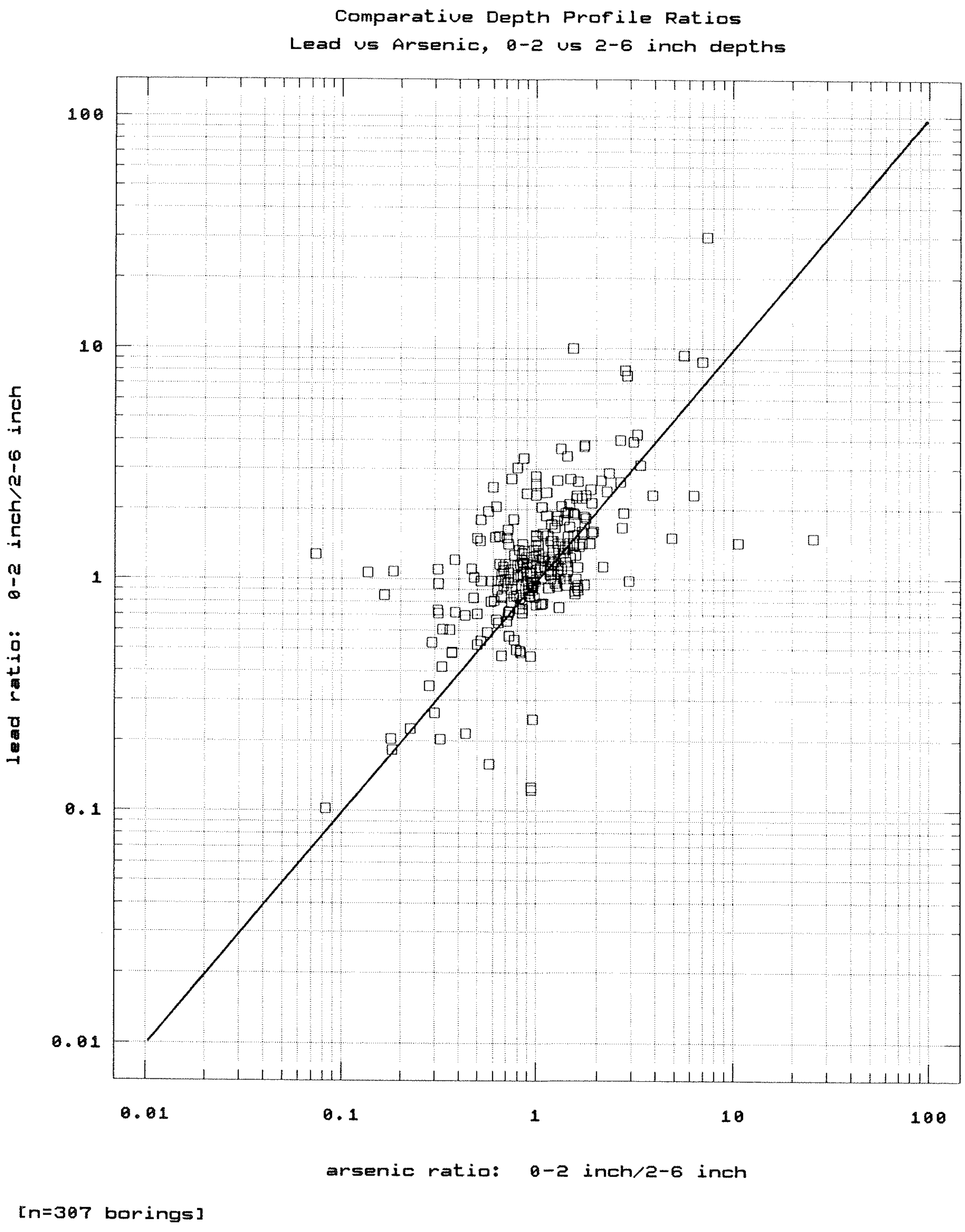


Figure 20
Scatterplot: Comparative Depth Profiles, Arsenic versus Lead

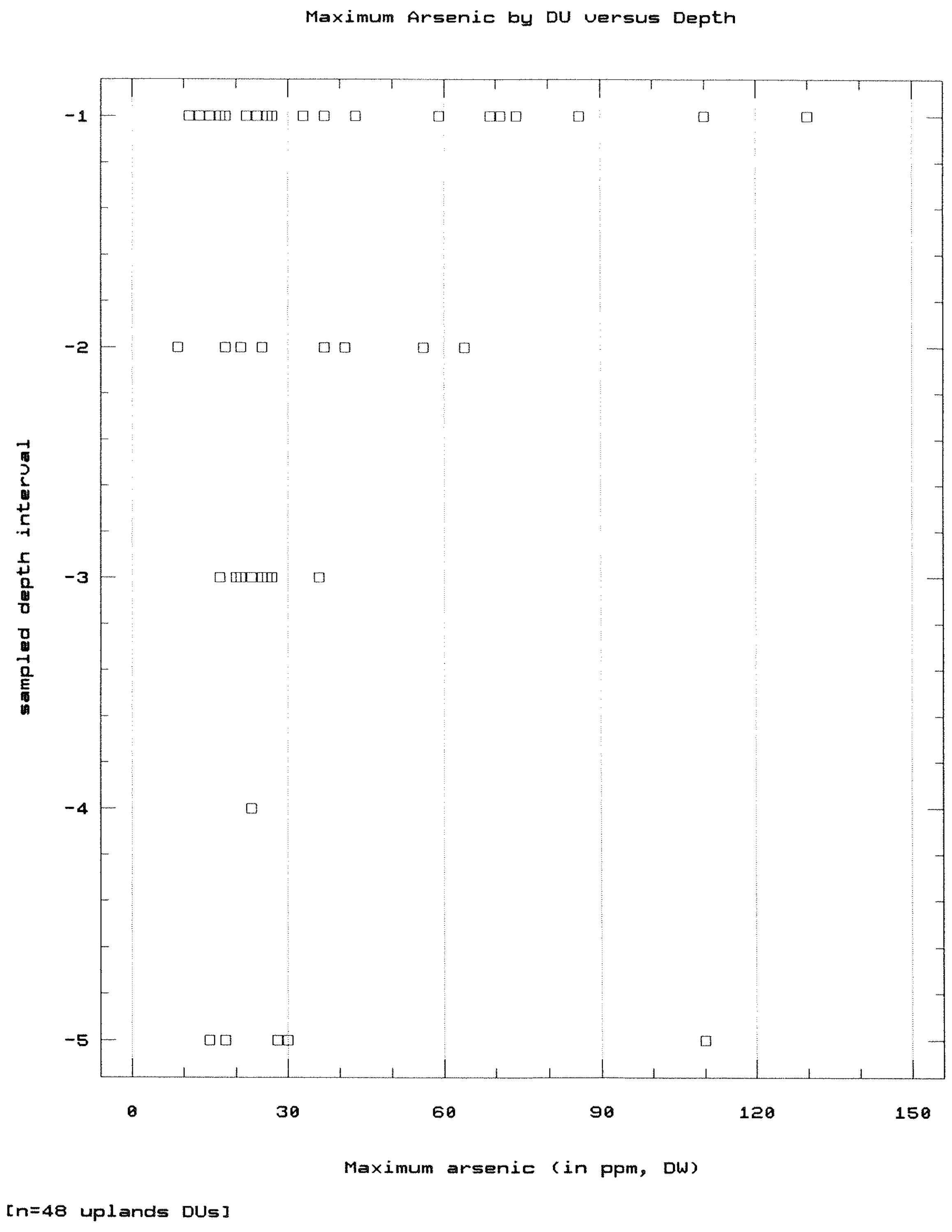


Figure 21
Scatterplot: Maximum Arsenic by Depth Interval

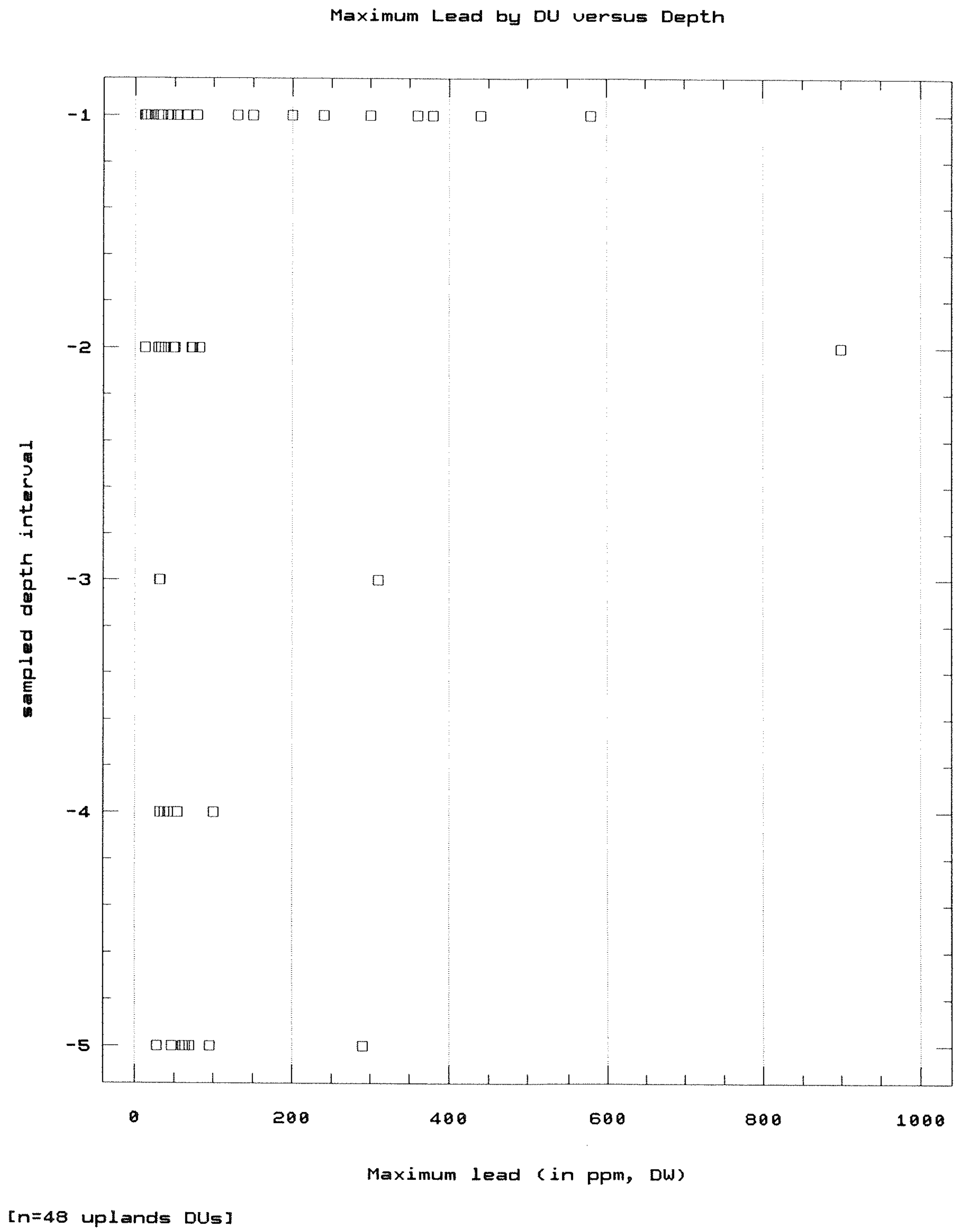


Figure 22
Scatterplot: Maximum Lead by Depth Interval

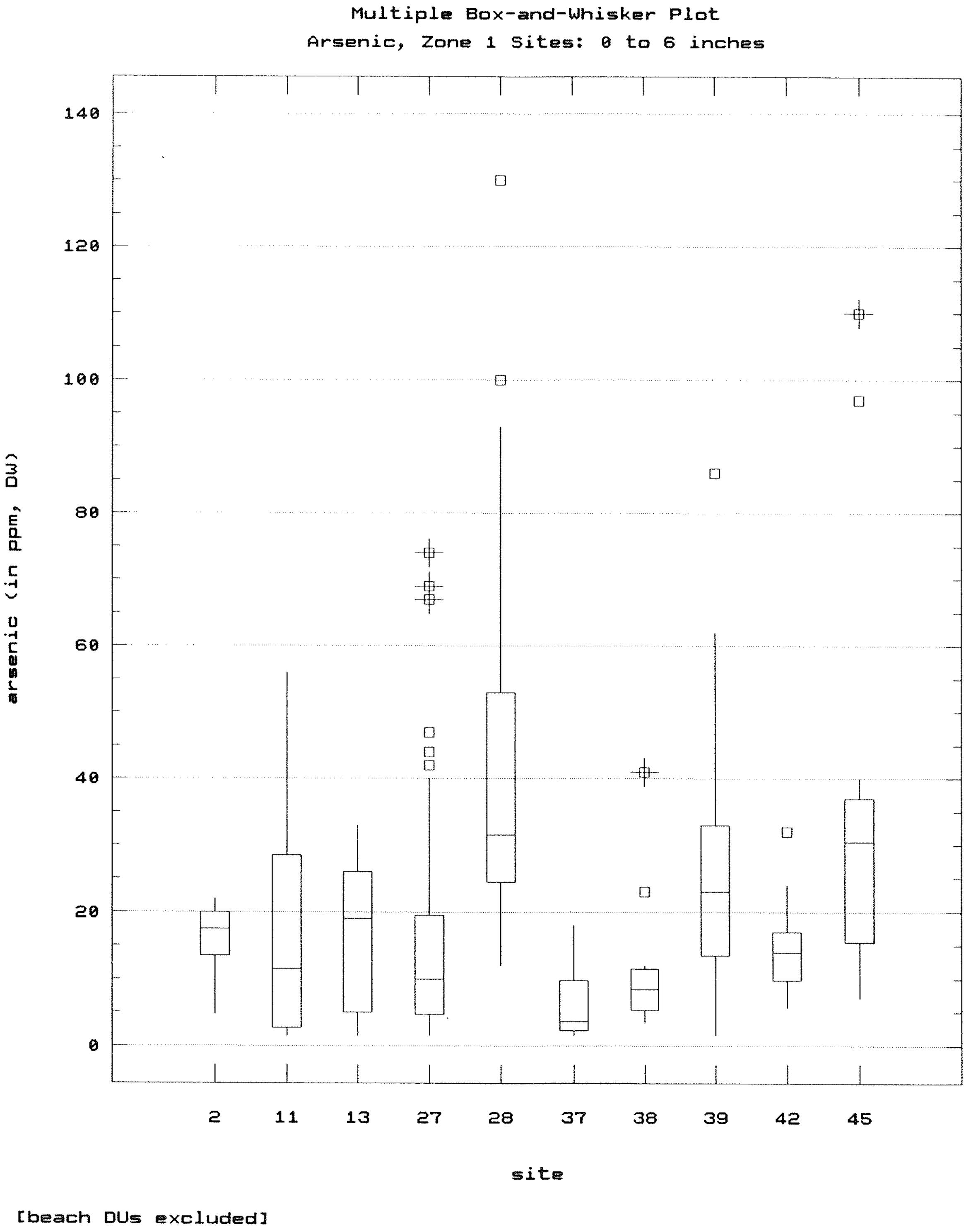


Figure 23
Box-and-Whisker Plot: Arsenic by Child-Use Area, Zone 1

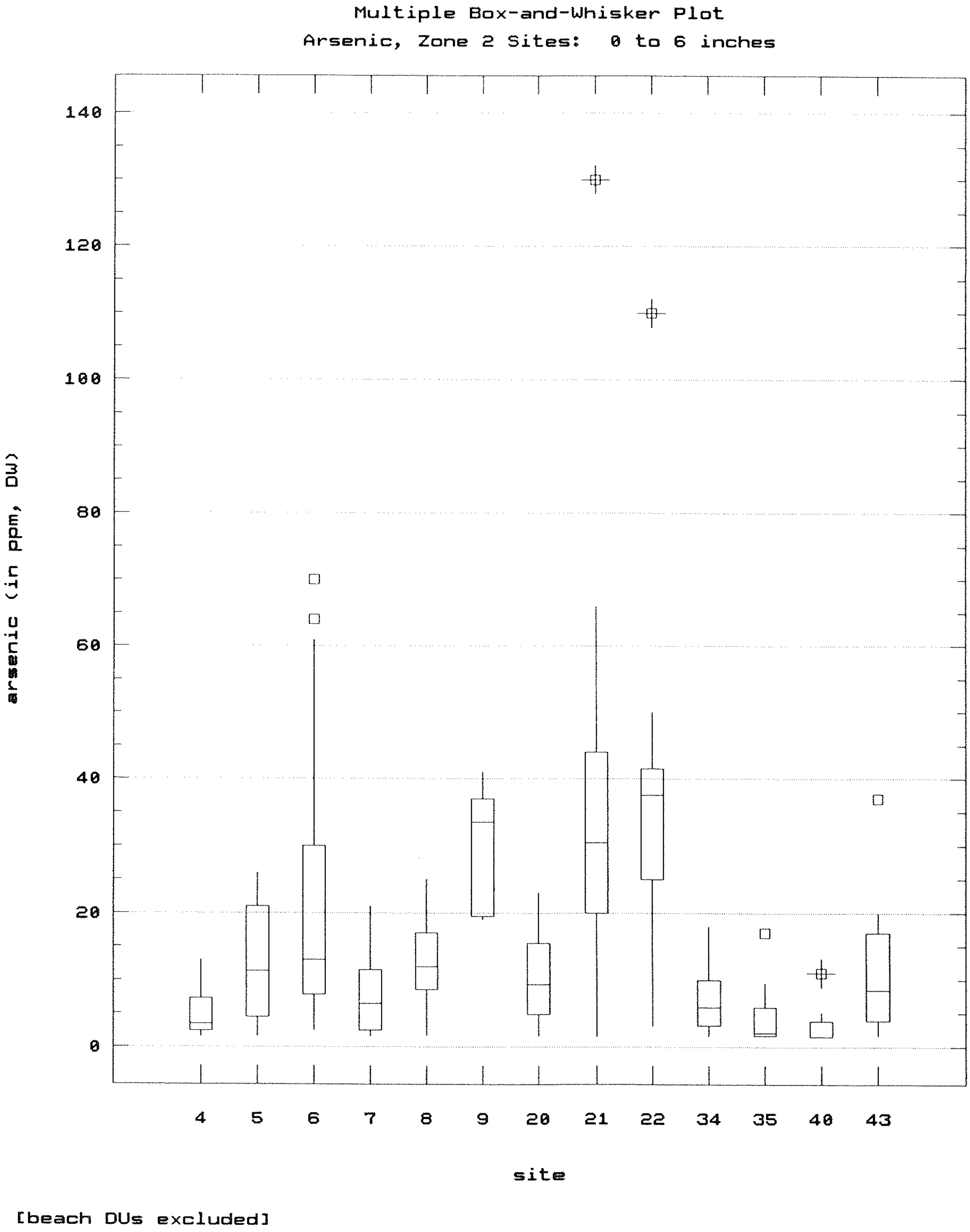


Figure 24
Box-and-Whisker Plot: Arsenic by Child-Use Area, Zone 2

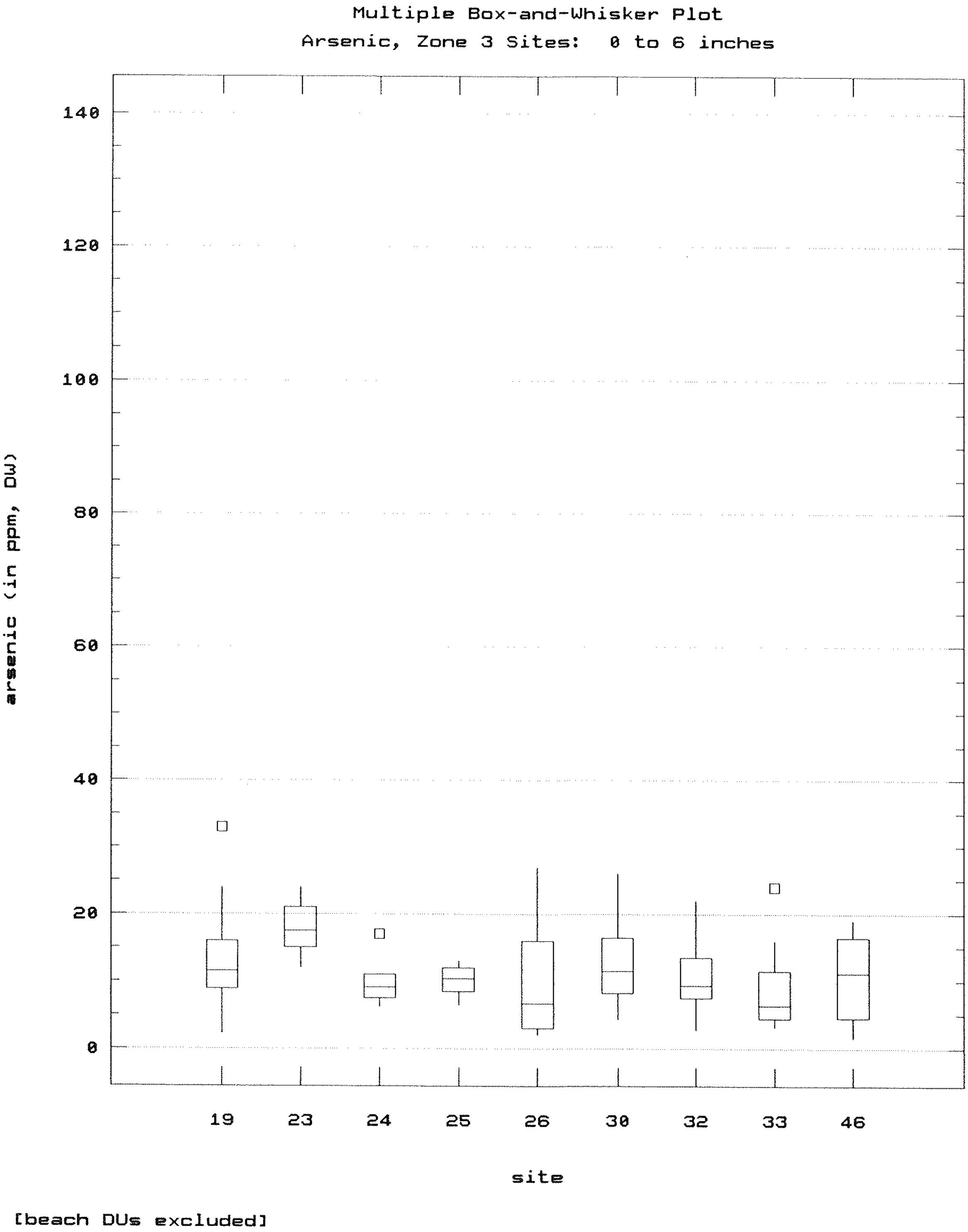


Figure 25
Box-and-Whisker Plot: Arsenic by Child-Use Area, Zone 3

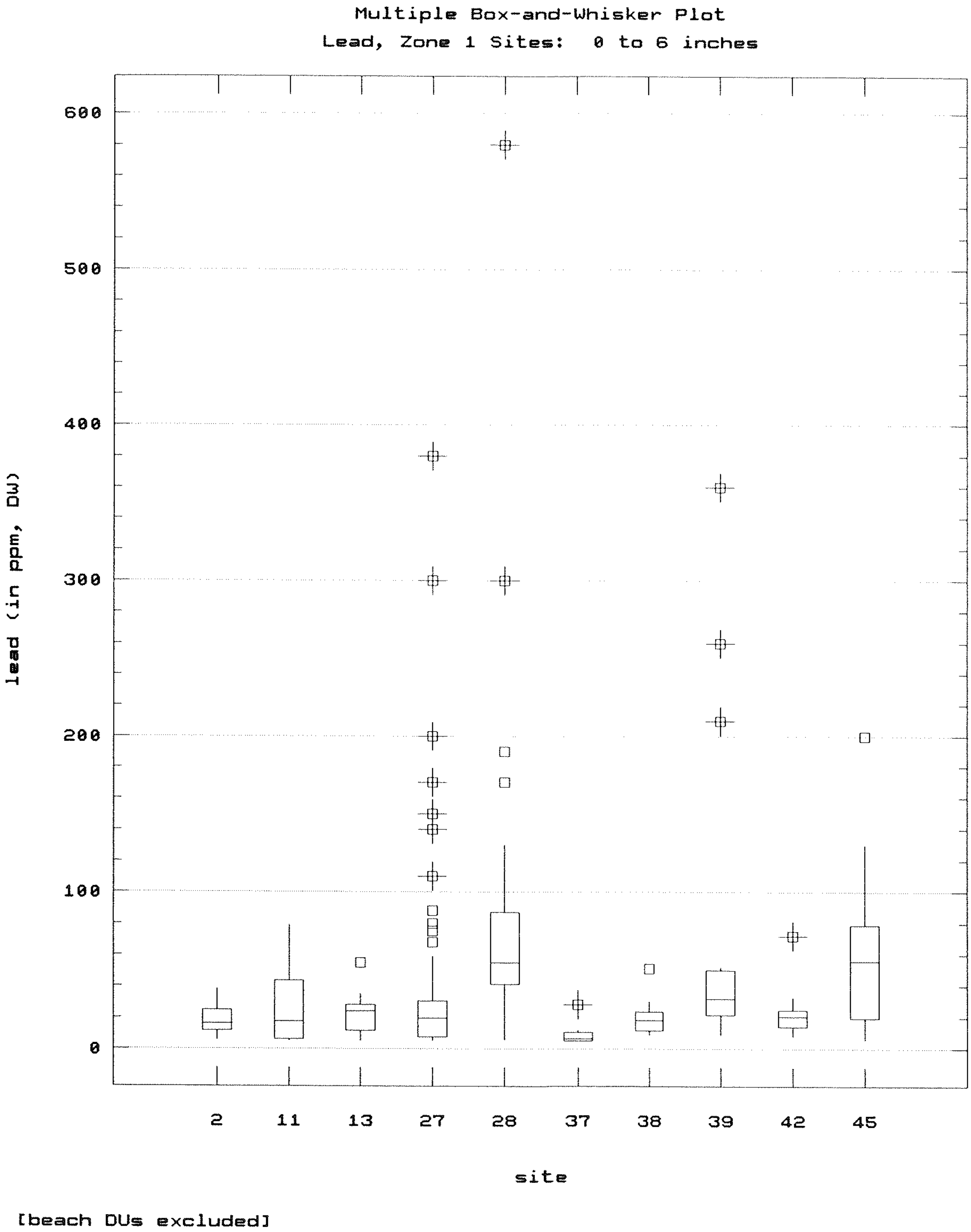


Figure 26
Box-and-Whisker Plot: Lead by Child-Use Area, Zone 1

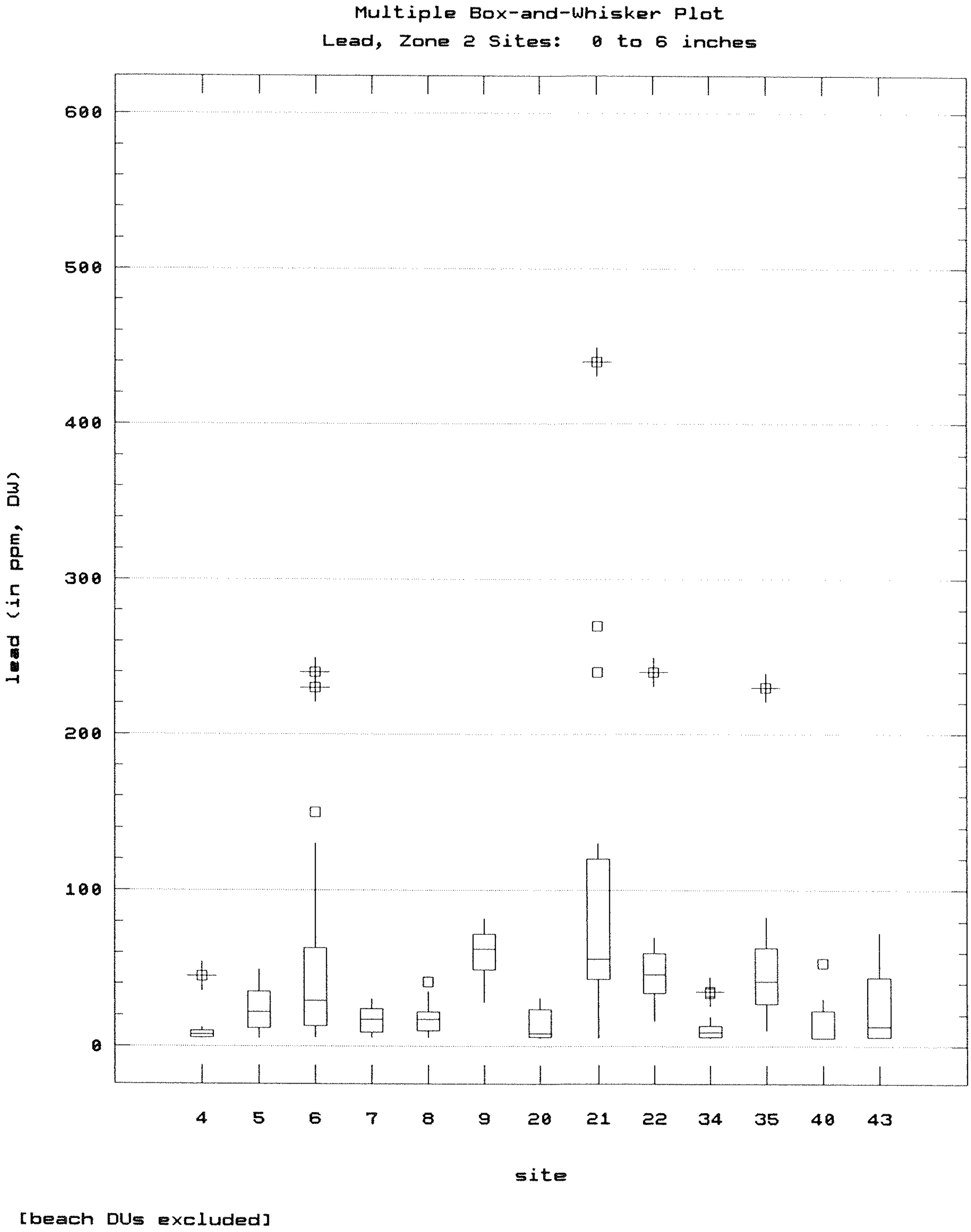


Figure 27
Box-and-Whisker Plot: Lead by Child-Use Area, Zone 2

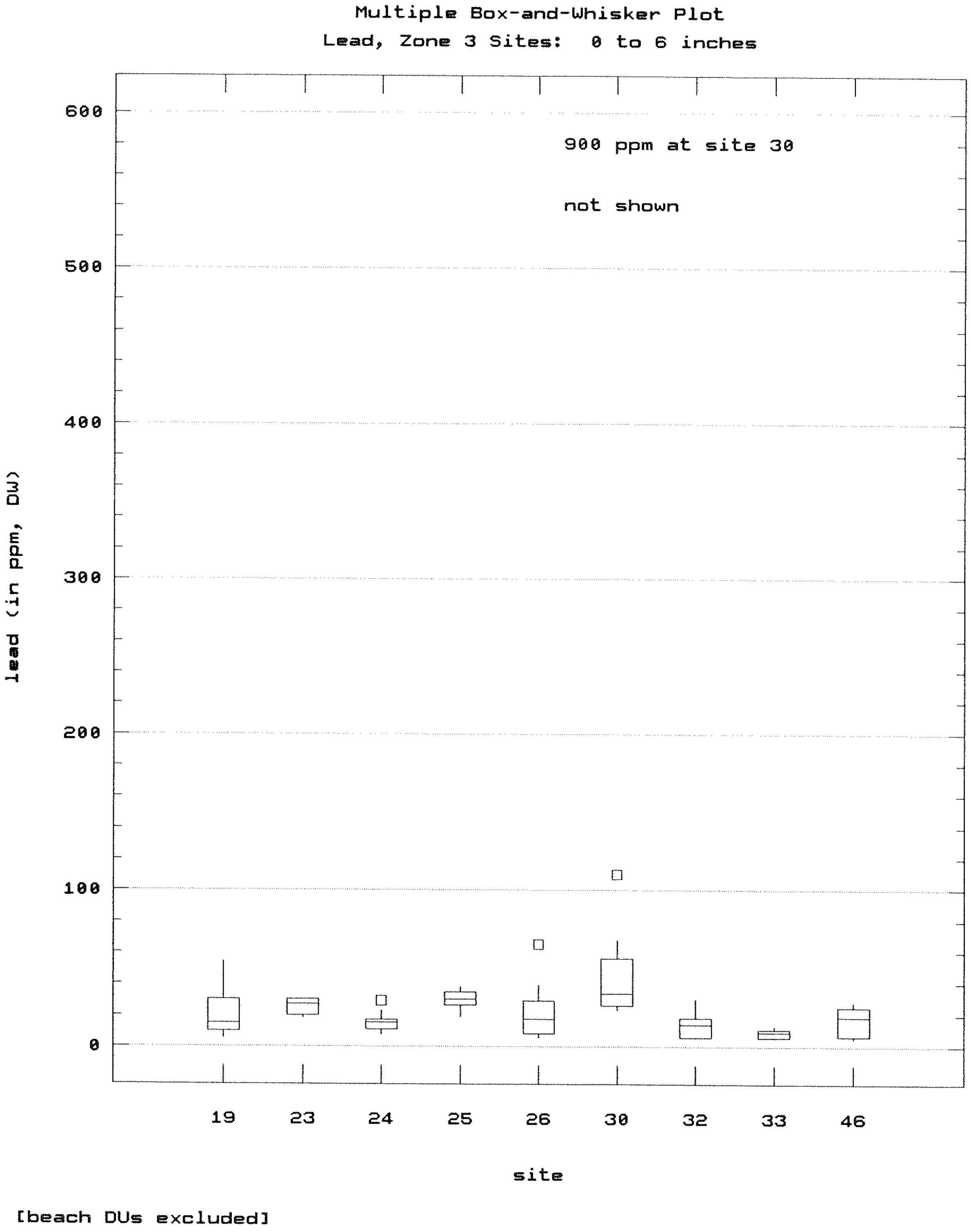


Figure 28
Box-and-Whisker Plot: Lead by Child-Use Area, Zone 3

Attachment B Vashon-Maury Island Child Use Area Study

Vashon-Maury Island
Child-Use Areas Study
Public Health - Seattle & King County
2001

Table B-1

Soil Arsenic and Lead Results
by DUs and Child-Use Areas
(in ppm, DW)

Note: Q1 shows data qualifiers (flags) by analytical lab
Q2 shows data qualifiers (flags) by data validators

			ARSENIC															**LEAD**														
		Boring	**0-2"**	**Q1**	**Q2**	**2-6"**	**Q1**	**Q2**	**6-12"**	**Q1**	**Q2**	**12-18"**	**Q1**	**Q2**	**18-22"**	**Q1**	**Q2**	**0-2"**	**Q1**	**Q2**	**2-6"**	**Q1**	**Q2**	**6-12"**	**Q1**	**Q2**	**12-18"**	**Q1**	**Q2**	**18-22"**	**Q1**	**Q2**
Zone:	1																															
Site:	2																															
DU:	1																															
		1	5.9			10			15			16			8.4			9.6			9.8			24			38			8.4		
		2	18			15			6.9			7.5			6.6			16			12			5.2	U		5.3	U		5.4	U	
		3	21			20			12			8.9			7.9			19			17			8.5			5.3	U		5.4	U	
		4	17			18			11			5.1			5.6			17			16			5.2	U		5.2	U		5.3	U	
		5	13			4.7			5.1			5.6			4.3			11			5.7			5.5	U		5.6	U		6.9		
		6	16			22			21			10			3.4			32			30			37			15			5.3	U	
		7	20			22			20			23			17			38			32			28			49			61		
		8	19			14			10			7.6			5.3			16			12			5.2	U		5.4	U		5.4	U	
Zone:	1																															
Site:	11																															
DU:	1																															
		1	1.6	U		2.3			1.6	U		1.6	U		1.6	U		5.4	U		5.4	U		5.4	U		5.3	U		5.3	U	
		2	5.5			3.1			1.6	U		1.6	U		1.6	U		13			7.1			5.2	U		5.2	U		5.2	U	
		3	1.5	U		1.5	U		3.5			45			3.2			5.1	U		5.1	U		5.1	U		27			5.3	U	
		4	9.8			10			23			3.6			1.6	U		15			18			32			5.3	U		5.3	U	
		5	19			13			6.5			2.2			2.2			36			17			5.3	U		5.3	U		5.3	U	
		6	39			56			24			2			1.6	U		66			57			17			5.2	U		5.2	U	
		7	32			32			6.2			4			3.7			79			51			5.3	U		5.2	U		5.2	U	
		8	25			17			8.2			4.7			2.9			26			21			5.3	U		5.2	U		5.2	U	
Zone:	1																															
Site:	13																															
DU:	1																															
		1	1.6	U		1.6	U		11			7.3			39			12			5.2	U		13			9.1			53		
		2	19			22			6.8			9.6			13			27			23			16			15			19		
		3	27			25			11			29			39			55			35			13			53			42		
		4	19			13			10			7.6			14			30			21			35			12			18		
		5	26			26			24			28			110			29			25			29			56			69		
		6	33			26			36			35			6.4			27			19			42			10			6.6		
		7	1.5	U		1.6	U		41			8.8			7.1			5.1	U		11			38			5.5	U		5.7		
		8	12			8.4			43			17			5.2		J	26			7.6			53			11			7.2		
Zone:	1																															
Site:	27																															
DU:	1																															
		1	69		J	26		J	5.3		J	3.7		J	1.5	U	UJ	300			75			6.8			5.4	U		5.2	U	
		2	42		J	33		J	67		J	14		J	2.5		J	150			80			20			5.3	U		5.3	U	

				ARSENIC																LEAD														
			Boring	**0-2"**	**Q1**	**Q2**	**2-6"**	**Q1**	**Q2**	**6-12"**	**Q1**	**Q2**	**12-18"**	**Q1**	**Q2**	**18-22"**	**Q1**	**Q2**		**0-2"**	**Q1**	**Q2**	**2-6"**	**Q1**	**Q2**	**6-12"**	**Q1**	**Q2**	**12-18"**	**Q1**	**Q2**	**18-22"**	**Q1**	**Q2**
				Note:	Q1 shows data qualifiers (flags) by analytical lab																													
					Q2 shows data qualifiers (flags) by data validators																													
			3	40		J	47		J	14		J	6.5		J	3.9		J		68			59			7.5			5.2	U		5.2	U	
			4	39		J	12		J	11		J	2.8		J	1.6	U	UJ		110			26			7.4			5.4	U		5.3	U	
			5	33		J	4.7			1.6	U		1.6	U		1.6	U			140			16			5.3	U		5.3	U		5.2	U	
			6	7.9			11			7.1			4.4			3.4				14			20			14			10			6.6		
			7	4.4			3.1			7.4			2			1.6	U			8			7			14			5.4	U		5.5	U	
			8	4.4			14		J	6.5		J	4.6		J	3.8		J		8.6			9			5.3	U		5.3	U		5.2	U	
	Zone:	1																																
	Site:	27																																
	DU:	2																																
			1	37		J	24		J	17		J	3.5		J	1.7		J		380			200			110			7.9			5.9		
			2	14		J	12		J	11		J	6.6		J	2.8		J		21			20			16			12			5.6	U	
			3	2		J	7.1		J	9.8		J	4.2		J	2.6		J		6.9			20			19			5.2	U		5.2	U	
			4	9.9		J	7.1			12			8.7			3.9				19			16			21			16			7		
			5	4.7			6.1			7.6			2.8			1.7	U			19			15			32			8.8			5.7	U	
			6	1.6	U		1.6	U		1.6	U		1.6	U		1.6	U			5.4	U		5.3	U		5.2	U		5.3	U		5.3	U	
			7	8			8.8			8.1			4.2			1.7				20			21			41			27			6.9		
			8	8.8			11			2.6			1.8	U		2.9	U			16			14			6.3	U		6	U		9.8	U	
	Zone:	1																																
	Site:	27																																
	DU:	3																																
			1	67			44			9.8			3.4			3.5				170			88			5.4	U		5.4	U		5.3	U	
			2	74			10			5.8			4.9			1.6	U			300			10			51			5.5	U		5.3	U	
			3	19			15			2.8			3.6			4.4				26			24			5.3	U		5.3	U		5.8	U	
			4	17			20		J	8.1		J	10		J	2.7		J		33			28			11			7.3			5.2	U	
			5	9.5		J	12		J	12		J	10		J	9.7		J		17			20			19			13			11		
			6	2.1		J	3.3		J	2.5		J	2		J	3.5		J		5.2	U		5.3	U		5.9	U		6.3	U		5.9	U	
			7	20		J	19		J	6.9		J	3.1		J	3		J		28			36			10			5.8	U		5.7	U	
			8	9.1		J	16		J	16		J	17		J	8.9		J		12			6.1			9			6	U		5.9	U	
	Zone:	1																																
	Site:	27																																
	DU:	4																																
			0	1.6	U	UJ	1.6	U	UJ	1.6	U	UJ								5.3	U		5.3	U		5.3	U							
	Zone:	1																																
	Site:	27																																
	DU:	5																																
			0	1.7	U	UJ	1.8	U	UJ	1.7	U	UJ								5.7	U		6	U		5.8	U							
	Zone:	1																																
	Site:	27																																
	DU:	6																																
			0	1.8	U	UJ	1.8	U	UJ	1.8	U	UJ								6	U		6	U		6.1	U							
	Zone:	1																																
	Site:	27																																
	DU:	7																																
			1	4.8		J	10		J	6.2		J	11			9.6		J		6.4	U		6.3			5.6	U		14			9.7		
			2	1.9	U	UJ	6.1		J	6.6		J	16		J	7.2		J		6.3	U		8.6			6.7			37			6.7		
			3	1.9	U	UJ	1.8	U	UJ	3.3		J	8.2		J	8.9		J		6.5	U		5.9	U		5.8	U		14			19		

			ARSENIC															LEAD														
		Boring	0-2"	Q1	Q2	2-6"	Q1	Q2	6-12"	Q1	Q2	12-18"	Q1	Q2	18-22"	Q1	Q2	0-2"	Q1	Q2	2-6"	Q1	Q2	6-12"	Q1	Q2	12-18"	Q1	Q2	18-22"	Q1	Q2
			Note:	Q1 shows data qualifiers (flags) by analytical lab																												
				Q2 shows data qualifiers (flags) by data validators																												
		4	1.6	U	UJ	1.7	U	UJ	1.6	U	UJ	3.4		J	3.6		J	5.5	U		5.6	U		5.5	U		5.8	U		6	U	
		5	9.5		J	7.2		J	3.2		J	2.3		J	2.3	U	UJ	22			6	U		5.8	U		5.6	U		7.7	U	
		6	17		J	16		J	9.9		J	1.8		J	1.6	U	UJ	26			23			14			5.6	U		5.3	U	
Zone:	1																															
Site:	28																															
DU:	1																															
		1	70			37			14			12			12			130			61			9.1			5.4	U		5.4	U	
		2	25			24			24			28			33			41			34			37			13			17		
		3	40			37			26			9.8			62			49			49			33			8.3			120		
		4	58			31			17			15			17			110			45			11			10			7.3		
		5	47			48			16			3.9			6.1			87			90			28			5.7			5.6	U	
		6	71			66			34			29			16			62			79			35			16			8		
		7	19			13			21			27			16			9.6			5.7			5.3	U		10			5.8	U	
		8	37			25			11			10			5.8			60			22			5.3	U		5.3	U		5.3	U	
Zone:	1																															
Site:	28																															
DU:	2																															
		1	27			34			47			8.8			15			42			85			69			12			36		
		2	25			27			36			36			11			44			41			39			64			11		
		3	31			24			32			5.9			4.5			61			81			34			5.4	U		7		
		4	26			22			4.5			3.9			1.6	U		50			43			5.3	U		5.3	U		5.3	U	
		5	130			93			12			13			16			580			300			26			19			17		
		6	100			62			21			1.6	U		1.6	U		170			190			18			5.3	U		5.3	U	
		7	32			12			1.6	U		1.7	U		1.9	U		87			33			5.5	U		5.8	U		6.2	U	
		8	21			18			5.4			26			15		J	41			38			19			11			13		
Zone:	1																															
Site:	37																															
DU:	1																															
		1	1.5	U		2.1			1.6	U		1.9			1.6			8.5			5.2	U		5.2	U		5.2	U		9		
		2	12			1.9			2.4			2.8			2.5			12			5.2	U		5.3	U		5.2	U		5.3	U	
		3	3.2			2.6			3.5			3.3			3			5.2	U		5.3	U		5.3	U		5.4	U		5.3	U	
		4	5.6			1.9			2.4			1.6	U		1.6	U		5.2	U		5.3	U		5.3	U		5.2	U		5.2	U	
		5	2.8			7.3			8.2			16			9.5			7.9			11			12			32			17		
		6	4			3.3			4.1			4.2			4.8			5.2	U		5.2	U		5.3	U		5.3	U		5.3	U	
		7	13			12			5.3			5.7			3.7			12			9.9			7.2			5.3	U		5.3	U	
		8	18			7.7			2.9			1.6	U		4			28			9.7			5.2	U		5.2	U		5.3	U	
Zone:	1																															
Site:	38																															
DU:	1																															
		1	6.1			5.5			3.4			5.6			6.4			16			14			10			11			13		
		2	11			12			21			6.1			11			25			28			35			18			22		
		3	12			9.4			11			8.8			8.4			21			20			25			13			15		
		4	7			9.4			20			12			4.5			22			20			46			19			12		
		5	4.3			4.2			11			3			2			14			10			20			7.5			8.4		
		6	5.2			3.4			14			14			11			13			9.1			17			16			5.9	U	
		7	7.5			11			21			9.6			5.9			8.8			9.4			18			17			5.3	U	
		8	23			41			14			2.2			3.6			30			51			8.5			5.1	U		5.1	U	

			ARSENIC															LEAD														
		Boring	**0-2"**	**Q1**	**Q2**	**2-6"**	**Q1**	**Q2**	**6-12"**	**Q1**	**Q2**	**12-18"**	**Q1**	**Q2**	**18-22"**	**Q1**	**Q2**	**0-2"**	**Q1**	**Q2**	**2-6"**	**Q1**	**Q2**	**6-12"**	**Q1**	**Q2**	**12-18"**	**Q1**	**Q2**	**18-22"**	**Q1**	**Q2**
			Note:	Q1 shows data qualifiers (flags) by analytical lab																												
				Q2 shows data qualifiers (flags) by data validators																												
Zone:	1																															
Site:	38																															
DU:	2																															
		0	2.8			2.7			1.9									8.7			13			11								
Zone:	1																															
Site:	39																															
DU:	1																															
		1	9			8.4			13			10			9.2			18			8.8			22			12			14		
		2	23			25			8.7			6			1.8	U		21			23			17			6	U		6.6		
		3	19			44			58			11			1.6	U		32			46			40			15			5.3	U	
		4	86			62			64			50			8.2			360			260			61			79			13		
		5	23			13			4.1			13			7.5			44			19			10			45			100		
		6	14			15			8.5			1.7	U		1.8			22			26			11			6.5			10		
		7	41			1.6	U		2.8			6.4			1.7	U		48			32			12			15			5.6	U	
		8	23			24			23			11			14			52			210			58			34			33		
Zone:	1																															
Site:	39																															
DU:	2																															
		0	1.7	U	UJ	2		J	1.7	U	UJ							8.4			18			19								
Zone:	1																															
Site:	39																															
DU:	4																															
		0	1.9	U		1.8	U		2.1									11			9.9			10								
Zone:	1																															
Site:	39																															
DU:	5																															
		0	1.9	U		1.8	U		1.9									12			11			12								
Zone:	1																															
Site:	42																															
DU:	1																															
		0	1.8	U		1.8	U		1.8	U								5.9	U		11			12								
Zone:	1																															
Site:	42																															
DU:	2																															
		1	15			13			8.2			24			8.9			22			24			8.2			45			5.8	U	
		2	16			10			3.6			4.6			4.7			15			16			10			7.4			5.6	U	
		3	23			24			12			6.9			4.9			33			32			14			5.9			5.7	U	
		4	9.6		J	32		J	6.3		J	2.5		J	2.2		J	19			72			8.2			5.4	U		5.5	U	
		5	15		J	16		J	36		J	5.1		J	1.9		J	23			25			61			9.3			5.6	U	
		6	13		J	9.4		J	8.4		J	15		J	17			16			12			11			29			23		
		7	11		J	5.7		J	13		J	5.5		J	6.5		J	13			8.1			6.4			6.5			11		
		8	18			7.9			2.2			2			2.1			24			10			5.2	U		5.4	U		5.6	U	
Zone:	1																															
Site:	44																															
DU:	1																															

			ARSENIC															LEAD														
		Boring	**0-2"**	**Q1**	**Q2**	**2-6"**	**Q1**	**Q2**	**6-12"**	**Q1**	**Q2**	**12-18"**	**Q1**	**Q2**	**18-22"**	**Q1**	**Q2**	**0-2"**	**Q1**	**Q2**	**2-6"**	**Q1**	**Q2**	**6-12"**	**Q1**	**Q2**	**12-18"**	**Q1**	**Q2**	**18-22"**	**Q1**	**Q2**
			Note:	Q1 shows data qualifiers (flags) by analytical lab																												
				Q2 shows data qualifiers (flags) by data validators																												
		0	1.7	U		1.7	U		1.8	U								12			11			18								
Zone:	1																															
Site:	45																															
DU:	1																															
		1	14		J	11		J	10		J	8.3		J	15		J	19			7.1			6.1			6.2	U		6.8		
		2	28		J	33		J	8.3		J	7.8		J	1.7	U	UJ	68			84			9.5			6.3			5.6	U	
		3	34		J	33		J	15		J	5.9		J	1.8		J	74			57			25			5.4	U		5.3	U	
		4	40		J	7.1		J	4		J	1.6	U	UJ	2.5		J	55			5.9			5.4	U		5.2	U		5.2	U	
		5	17		J	17		J	6.1		J	2.2		J	5		J	22			20			5.9			5.4	U		5.5	U	
		6	110		J	97		J	10		J	2.8		J	1.7		J	200			130			8.3			5.7	U		5.4	U	
Zone:	2																															
Site:	4																															
DU:	1																															
		1	1.5	U		1.5	U		1.6	U		1.7	U		1.6	U		5.1	U		5.1	U		5.3	U		5.7	U		5.2	U	
		2	3.6			3.7			2.5			1.6	U		1.5	U		8			6			5.3	U		5.2	U		5.2	U	
		3	3.2			2.5			1.6	U		1.6	U		1.5	U		7.5			5.4	U		5.4	U		5.3	U		5.1	U	
		4	13			7.5			7.6			1.6	U		1.5	U		45			12			8.1			5.3	U		5.2	U	
		5	2.3			2.7			3.4			3.1			1.5	U		7.5			5.3	U		5.4	U		5.2	U		5.2	U	
		6	12			7.1			2.3			2.3			1.6	U		12			7.5			5.4	U		5.3	U		5.2	U	
Zone:	2																															
Site:	5																															
DU:	1																															
		1	26		J	15		J	17		J	11		J	9.2		J	34			36			15			5.6	U		5.4	U	
		2	19		J	23		J	13		J	8.3		J	12		J	24			49			10			5.6	U		34		
		3	7.4		J	7.7		J	2.4		J	1.6	U	UJ	1.6	U	UJ	18			20			5.6	U		5.3	U		5.3	U	
		4	1.6	U	UJ	1.6	U		2.3			1.7	U		15			5.2	U		5.3	U		6.6			5.7	U		18		
Zone:	2																															
Site:	6																															
DU:	1																															
		1	39			32			8.1			5.1			3.5			85			70			12			5.4	U		5.3	U	
		2	19			26			4.8			3.7			3.3			32			44			5.5	U		5.5	U		5.4	U	
		3	29			35			14			5.2			12			81			70			21			5.7	U		6.4	U	
		4	43			30			9.9			4.1			3.5			61			40			6.1			5.4	U		5.4	U	
		5	3.4			4			6.8			31			5.2			7.8			10			18			100			6.9	U	
		6	7.7			4.7			3			4.1			3.7			13			9.4			5.8	U		5.7	U		5.6	U	
		7	34			35			11			7.7			3.7			80			64			10			5.4	U		5.3	U	
		8	16			24			14			4			2.1			28			60			13			5.5	U		5.5	U	
Zone:	2																															
Site:	6																															
DU:	2																															
		1	8.7			10			3.9			3.6			2.1			41			31			6			5.5	U		5.5	U	
		2	21			13			7.6			8.9			1.6	U		69			26			9.5			13			5.2	U	
		3	6			7.8			7.5			22			31			29			16			13			70			95		
		4	13			11			6.3			4.1			3.8			19			13			5.3	U		5.3	U		5.3	U	
		5	12			12			14			6.2			6.5			26			17			16			5.6	U		5.8	U	
		6	21			64			21			14			6.5			36			86			17			7.5			5.9	U	
		7	6.2			9.7			15			18			7.8			11			17			24			43			11		

			ARSENIC															**LEAD**														
		Boring	**0-2"**	**Q1**	**Q2**	**2-6"**	**Q1**	**Q2**	**6-12"**	**Q1**	**Q2**	**12-18"**	**Q1**	**Q2**	**18-22"**	**Q1**	**Q2**	**0-2"**	**Q1**	**Q2**	**2-6"**	**Q1**	**Q2**	**6-12"**	**Q1**	**Q2**	**12-18"**	**Q1**	**Q2**	**18-22"**	**Q1**	**Q2**
			Note:	Q1 shows data qualifiers (flags) by analytical lab																												
				Q2 shows data qualifiers (flags) by data validators																												
		8	14			8.1			3.4			1.6	U		2.2			22			14			5.3	U		5.3	U		5.8		
Zone:	2																															
Site:	6																															
DU:	3																															
		1	16			4.1			3.2			4.2			2.4			30			13			8.3			17			5.8	U	
		2	11			7.2			4.3			1.9	U		5.8			150			15			14			6.2	U		6.2	U	
		3	59			19			5.3			1.7	U		1.7	U		130			33			6.9			5.7	U		8.4		
		4	5			4.4			1.9	U		1.8	U		2.2			13			12			6.4	U		5.9	U		6	U	
		5	9.4			13			2.5			1.8	U		3.3			8.5			6	U		6	U		5.9	U		6	U	
		6	14			8.8			21			8.9			6.2			46			20			42			20			5.6	U	
		7	5			10			7.3			11			5			12			17			16			20			6.3	U	
		8	2.5			4.8			4.5			7			9.6			9.9			5.5	U		5.5	U		5.3	U		5.4	U	
Zone:	2																															
Site:	6																															
DU:	5																															
		1	70		J	40		J	7.9		J	7.9		J	5.4		J	240			63			7.2			5.8	U		5.8	U	
		2	22		J	61		J	13		J	8.7			12			29			48			5.9	U		5.9	U		5.8	U	
		3	45			50			20			4.8			3.1			230			98			8.2			5.3	U		5.2	U	
Zone:	2																															
Site:	7																															
DU:	1																															
		1	21			19			20			21			30			23			23			29			28			31		
		2	9.7			6.1			4.9			1.8			6.7			23		J	25		J	9.7			6.3			13		
		3	12			15			13			15			10			25			24			28			42			28		
		4	12			7.8			4			9.1			1.7	U		24		J	17			9			14			5.7	U	
Zone:	2																															
Site:	7																															
DU:	2																															
		1	1.7	U		4.6			4.5			7.1			3.6			5.8	U		12			11			31			22		
		2	2.8			3.3			2.3			1.6	U		8.7			11			8.5			6.9			5.5	U		290		
		3	1.6	U		1.6	U		12			13			14			5.4	U		7			36			36			41		
		4	6.8			4			8.4			2.4			4.1			17			12			18			9.5			11		
		5	2.1			1.7	U		3.6			1.6	U		1.6	U		9.5			5.7	U		5.4	U		5.5	U		5.5	U	
		6	10			11			7.5			8.8			18			26			29			30			40			79		
		7	11			13			3.5			1.7	U		1.7	U		24			30			8.9			5.8	U		5.6	U	
		8	1.7	U		4.6			5.5			7.4			6.8			6.7			14			18			21			26		
Zone:	2																															
Site:	8																															
DU:	1																															
		1	2.5			4			6.3			5.1			5.7			5.4	U		8.1			10			10			11		
		2	3.1			2			4			4.2			3.3			5.7	U		6.6			13			9.4			5.9	U	
		3	1.7	U		2.1			4.6			6.2			4.8			5.6	U		5.5	U		8.3			5.9	U		5.8	U	
		4	5.2			4.4			7.2			10			5.9			8.3			8			11			17			47		
		5	15			11			9.8			5.9			15			22			17			12			41			41		
		6	9			12			7.4			8.6			8.8			30			11			8.3			5.3	U		7		
		7	5.2			10			8			12			4.1			5.4	U		10			8.4			16			5.6	U	
		8	4.3			5			9.1			4.6			3.2			7.8			7.2			15			5.4	U		5.3	U	

			ARSENIC																LEAD														
		Boring	0-2"	Q1	Q2	2-6"	Q1	Q2	6-12"	Q1	Q2	12-18"	Q1	Q2	18-22"	Q1	Q2		0-2"	Q1	Q2	2-6"	Q1	Q2	6-12"	Q1	Q2	12-18"	Q1	Q2	18-22"	Q1	Q2
			Note:	Q1 shows data qualifiers (flags) by analytical lab																													
				Q2 shows data qualifiers (flags) by data validators																													
Zone:	2																																
Site:	8																																
DU:	2																																
		1	9.6			8.4			4.6			6.5			4.7				12			10			5.3	U		5.3	U		5.2	U	
		2	14			10			6.6			8.3			7.3				16			17			5.5	U		5.4	U		14		
		3	18			19			14			14			10				23			24			17			13			5.6	U	
		4	9.8			8.7			6.4			4.9			4.2				13			6.9			5.4	U		5.5	U		5.4	U	
		5	1.9	U		14		J	12		J	3		J	7.9		J		6.4	U		6	U		5.7	U		5.7	U		5.8	U	
		6	12		J	14		J	14		J	20		J	14		J		13			12			13			12			5.7	U	
		7	21		J	17		J	18		J	15		J	12		J		18			15			12			5.4			6.2		
		8	24		J	25		J	13		J	13		J	15		J		28			30			7.3			5.3	U		5.3	U	
Zone:	2																																
Site:	8																																
DU:	3																																
		1	15		J	20		J	18		J	10		J	12		J		18			20			16			7.8			11		
		2	17		J	22		J	13		J	6.3		J	4.3		J		18			33			6.2			5.3	U		5.3	U	
		3	12		J	14		J	12		J	9.6		J	5.5		J		19			18			11			6.2			5.3	U	
		4	18		J	15		J	13		J	6.4		J	4.4		J		19			13			9.3			5.3	U		5.4	U	
		5	12		J	18		J	20		J	11		J	14		J		22			21			15			12			31		
		6	24		J	18		J	10		J	14		J	8.4		J		29			14			7.5			8.7			12		
Zone:	2																																
Site:	8																																
DU:	4																																
		1	15		J	13		J	11		J	11		J	12		J		20			16			13			20			41		
		2	18		J	18		J	12		J	8.7		J	5.9		J		19			19			16			5.3	U		5.3	U	
		3	15		J	14		J	13		J	11		J	9.9		J		16			13			16			9			11		
		4	12		J	17		J	21		J	21		J	6.6		J		23			35			23			20			5.2	U	
		5	7.8		J	9.9		J	8.1		J	9.5		J	10		J		20			22			14			16			18		
		6	9.3			10			7.3			7.1			6.2				25			23			17			21			14		
		7	7.4		J	8.7			1.6			1.5	U		4.4				15			21		J	6.4		J	5.2	U	UJ	5.2	U	UJ
		8	16			18			8.4			4.3			8.2				41		J	33		J	13		J	5.4		J	64		J
Zone:	2																																
Site:	9																																
DU:	1																																
		1	19			19		J	9.8		J	11		J	11		J		41			28			7.4			6	U		5.9	U	
		2	35		J	41		J	38		J	5.8		J	8.8		J		61			82			77			6			6.6		
		3	32		J	20		J	4.3		J	3.4		J	5.2		J		64			57			11			6	U		6	U	
		4	36		J	38		J	10		J	1.8	U	UJ	1.8	U	UJ		70			74			18			6.1	U		6	U	
Zone:	2																																
Site:	20																																
DU:	1																																
		1	2.4			4.6			25			20			12				5.1	U		5.2	U		32			11			5.8	U	
		2	7.4			23			24			19			12				6.3			31			37			5.6	U		5.5	U	
		3	11			8.7			11			13			8.3				7.9			8.5			5.6			6.5			6.3		
		4	10			17			27			26			14				16			20			50			54			17		
		5	20			14		J	24		J	21		J	7.6		J		29			27			52			29			6.5		
		6	1.6	U	UJ	5.1		J	5.4		J	8.7		J	8.4		J		5.2	U		7.3			5.7	U		5.8	U		5.7	U	

			ARSENIC															**LEAD**														
		Boring	**0-2"**	**Q1**	**Q2**	**2-6"**	**Q1**	**Q2**	**6-12"**	**Q1**	**Q2**	**12-18"**	**Q1**	**Q2**	**18-22"**	**Q1**	**Q2**	**0-2"**	**Q1**	**Q2**	**2-6"**	**Q1**	**Q2**	**6-12"**	**Q1**	**Q2**	**12-18"**	**Q1**	**Q2**	**18-22"**	**Q1**	**Q2**
			Note:	Q1 shows data qualifiers (flags) by analytical lab																												
				Q2 shows data qualifiers (flags) by data validators																												
Zone:	2																															
Site:	21																															
DU:	1																															
		1	130		J	45		J	6.7		J	11		J	9		J	440			58			5.4	U		6.7			5.4	U	
		2	20		J	42		J	120		J	49		J	13		J	91			110			320			58			15		
		3	1.5	U	UJ	18			19			26			6.9			5.2	U		51		J	23		J	37		J	5.6	U	UJ
		4	23			40			56			26			11			38		J	240		J	96		J	6.8		J	5.3	U	UJ
		5	20			9.4			7.4			5.2			6			22		J	8.2		J	5.4	U	UJ	5.3	U	UJ	5.4	U	UJ
		6	31			43			29			16			7.9			48		J	67		J	34		J	7.6		J	5.8	U	UJ
		7	29			30		J	28		J	33		J	14		J	50		J	54			55			81			21		
		8	55		J	66		J	13		J	5.8		J	4.7		J	130			270			7.2			5.4	U		5.3	U	
Zone:	2																															
Site:	22																															
DU:	1																															
		1	110		J	39		J	11		J	52		J	6.1			240			30			7.4			5.6	U		5.4	U	
		2	3.1			42			7.4			1.7			1.9			70			55			6.3			5.3	U		5.2	U	
		3	37			11			3			1.6	U		1.6	U		50			16			5.3	U		5.4	U		5.4	U	
		4	50			38			5.3			3.1			1.6	U		64			52			5.4	U		5.4	U		5.3	U	
		5	20			30		J	26		J	28		J	8.6		J	33			39			35			56			5.9		
		6	41		J	34		J	8.7		J	1.6	U	UJ	5.6		J	42			35			5.3	U		5.2	U		5.2	U	
Zone:	2																															
Site:	34																															
DU:	1																															
		1	14		J	14		J	4.8		J	6.4		J	15		J	15			14			5.2	U		5.3	U		10		
		2	3.5		J	12		J	9.7		J	8.6		J	3.9		J	6.4			12			5.6	U		5.6	U		5.6	U	
		3	3		J	3.2		J	2.9		J	2.2		J	2		J	5.4	U		5.5	U		5.5	U		5.4	U		5.5	U	
		4	3.1		J	4.7			6.8			3			3.2			5.9			6	U		5.8	U		5.4	U		5.3	U	
		5	11			12			6.2			6.4			4.1			13			15			5.8	U		5.9	U		5.7	U	
		6	10			7.9			10			11			12			9.8			5.5	U		6.6			11			14		
Zone:	2																															
Site:	34																															
DU:	2																															
		1	11			5.8			4.8			5.1			4.2			12			7.6			7.2			5.4	U		5.5	U	
		2	2.1	U		3.1			5.4			7.9			8.9			7.1	U		6.3	U		5.8	U		5.7	U		5.4	U	
		3	7.9			9.6			6.4			4.8			3.5			9.7			13			10			5.4			5.4	U	
		4	1.6	U		1.9			1.7	U		2			3.1			5.3	U		5.6	U		5.8	U		5.6	U		5.6	U	
		5	6			4.3			1.7	U		3.1			3.6			5.6	U		5.6	U		5.6	U		5.6	U		5.6	U	
		6	2.4			4.8			5.5			4.5			2			5.2	U		10			5.5	U		7.2			5.6	U	
Zone:	2																															
Site:	34																															
DU:	3																															
		1	3.2			2.4			2.4			6.3			6.7			6.3	U		5.7	U		5.7	U		5.6	U		5.4	U	
		2	3.8		J	3.2		J	3.5		J							9.5			5.5	U		5.5	U							
		3	7.3			4.2			4			3.6			2.5			16			8.6			6.2			5.7	U		5.8	U	
		4	15			18			7.1			4.4			4.7			35			34			10			5.5	U		5.4	U	
		5	16			9.2			3.7			3.7			4.1			19			11			5.6	U		5.6	U		5.6	U	
		6	10			9.3			4.9			3.5			2.7			16			13			8			5.7	U		5.8	U	

			ARSENIC															**LEAD**														
		Boring	**0-2"**	**Q1**	**Q2**	**2-6"**	**Q1**	**Q2**	**6-12"**	**Q1**	**Q2**	**12-18"**	**Q1**	**Q2**	**18-22"**	**Q1**	**Q2**	**0-2"**	**Q1**	**Q2**	**2-6"**	**Q1**	**Q2**	**6-12"**	**Q1**	**Q2**	**12-18"**	**Q1**	**Q2**	**18-22"**	**Q1**	**Q2**
			Note:	Q1 shows data qualifiers (flags) by analytical lab																												
				Q2 shows data qualifiers (flags) by data validators																												
		7	6.4			3.8			3.4			1.6	U		1.6	U		13			5.8	U		5.8	U		5.5	U		5.5	U	
Zone:	2																															
Site:	35																															
DU:	1																															
		0	1.6	U		1.6	U		1.6	U								14			7.9			18								
Zone:	2																															
Site:	35																															
DU:	2																															
		1	1.6	U	UJ	1.7			4.5			8			1.6	U		29			230			310			57			35		
		2	1.8			3			4.6			3.5			3.9			25			10			8.8			7.6			8.2		
		3	3.6			2.3			6.2			5.7			6.7			38			30			28			31			27		
		4	17			1.6	U		1.6	U		1.7	U		1.7	U		83			58			22			8.8			6.2		
		5	8.3			1.7	U		1.7	U		1.7	U		1.7	U		68			45			16			5.7	U		5.8	U	
		6	1.7	U		9.5			4.4			1.8	U		1.8	U		9.8			48			120			22			16		
Zone:	2																															
Site:	40																															
DU:	1																															
		1	1.5	U		1.5	U		1.5	U		1.5	U		1.5	U		5.1	U		5.1	U		5.1	U		5.2	U		5.2	U	
		2	1.5	U		1.5	U		1.6	U		1.6	U		1.6	U		5.1	U		5	U		5.2	U		5.3	U		5.2	U	
		3	1.5	U		1.5	U		1.5	U		1.6	U		1.6	U		5.1	U		5.1	U		5.1	U		5.3	U		5.3	U	
		4	11			11			4.5			2.4			2			53			19			12			5.9	U		5.6	U	
		5	3.7			5.1			2			1.6	U		1.8			30			53			5.3	U		5.3	U		5.2	U	
		6	1.5	U		1.5	U		1.5	U		1.6	U		1.6	U		5.1	U		5.1	U		5.1	U		27			28		
		7	1.5	U		1.6	U		1.6	U		1.6	U		1.6	U		5.1	U		5.3	U		5.3	U		5.3	U		5.3	U	
		8	1.7	U		3.9			3.3			2.3			1.6	U		5.6	U		26			21			5.3	U		5.3	U	
Zone:	2																															
Site:	40																															
DU:	2																															
		0	2			1.7	U		1.7	U								5.8	U		5.6	U		5.6	U							
Zone:	2																															
Site:	40																															
DU:	3																															
		0	1.6	U		2.1			2.1									5.4	U		5.6	U		5.5	U							
Zone:	2																															
Site:	40																															
DU:	4																															
		0	1.6	U		1.7			2.2									5.2	U		5.3	U		5.3	U							
Zone:	2																															
Site:	43																															
DU:	1																															
		1	1.8	U		1.7	U		1.7	U		1.7	U		1.7	U		5.9	U		5.8	U		5.6	U		5.8	U		5.6	U	
		2	6.1			37			6.8			9.3			8.8			62			73			7.1			5.8	U		5.8	U	
		3	20			14			14			4.8			4.8			26			19			20			5.6	U		5.6	U	
		4	8			9			8.9			13			7.7			6.3			5.9	U		5.9	U		13			6	U	

			ARSENIC															LEAD														
		Boring	0-2"	Q1	Q2	2-6"	Q1	Q2	6-12"	Q1	Q2	12-18"	Q1	Q2	18-22"	Q1	Q2	0-2"	Q1	Q2	2-6"	Q1	Q2	6-12"	Q1	Q2	12-18"	Q1	Q2	18-22"	Q1	Q2
			Note:	Q1 shows data qualifiers (flags) by analytical lab																												
				Q2 shows data qualifiers (flags) by data validators																												
Zone:	3																															
Site:	19																															
DU:	1																															
		1	2.2			12			9.2									5.8	U		5.4	U		14								
		2	4.3			13			14									9.1			15			21								
		3	33			24			15									54			30			13								
		4	14		J	17		J	12		J							29			35			18								
		5	16		J	18		J	9.1		J							43			37			8.3								
Zone:	3																															
Site:	19																															
DU:	2																															
		1	11		J	10		J	12		J							16			14			9.1								
		2	6.3			8.9			9.9									14			9.3			7.9								
		3	9			11			23			7.5		J	19		J	16			12			6.3			16			28		
		4	8			13			13			11		J	11		J	15			9.9			5.6	U		5.6	U		5.6	U	
Zone:	3																															
Site:	23																															
DU:	1																															
		1	15			21			15			8.7			7.4			29			30			14			6.2			5.9	U	
		2	16			24			19			7.7			6.9			25			30			22			6			5.7	U	
		3	12			19		J	25		J	16		J	18		J	18			20			21			6	U		6	U	
Zone:	3																															
Site:	24																															
DU:	1																															
		1	9			9.6			9.1									16			15			6.1	U							
		2	7.5			6.2			7									7.9			7.6			5.7	U							
		3	8.9			9.3			9.9			3.8		J	15		J	16			17			11			12			6.3	U	
		4	7.5			11			12									12			11			24								
		5	17			17			6.7									29			23			5.8	U							
Zone:	3																															
Site:	25																															
DU:	1																															
		1	9.3		J	7.7			16			8.4			6.6			28			26			32			23			5.4	U	
		2	12			6.5			6.7			3.8			8			27			19			13			11			18		
		3	9.8			11			11			10			4.9			37			32			25			11			5.8	U	
		4	12			13			20			7.1			8.1			32			38			29			7.4			6.1	U	
Zone:	3																															
Site:	26																															
DU:	1																															
		1	2.3			2.3			9									11			11			23								
		2	6.5			14		J	5.9		J							21			19			9.3								
		3	2.9		J	16		J	16		J							5.3	U		29			6.8								
		4	8		J	21		J	13		J							35			29			14								
Zone:	3																															
Site:	26																															
DU:	2																															

				ARSENIC																**LEAD**														
			Boring	**0-2"**	**Q1**	**Q2**	**2-6"**	**Q1**	**Q2**	**6-12"**	**Q1**	**Q2**	**12-18"**	**Q1**	**Q2**	**18-22"**	**Q1**	**Q2**		**0-2"**	**Q1**	**Q2**	**2-6"**	**Q1**	**Q2**	**6-12"**	**Q1**	**Q2**	**12-18"**	**Q1**	**Q2**	**18-22"**	**Q1**	**Q2**
				Note:	Q1 shows data qualifiers (flags) by analytical lab																													
					Q2 shows data qualifiers (flags) by data validators																													
			1	2.1			2.8			4.1										5.4	U		6.8			8								
			2	3.1			5.1			1.9	U									9.7			12			8.6								
			3	27			17		J	14		J								65			29			8.6								
			4	23		J	16		J	17		J								39			20			7.1								
			5	6.9		J	8		J	5.6		J								18			5.4	U		5.3	U							
			6	4.8		J	6		J	5		J								17			5.6	U		5.8	U							
	Zone:	3																																
	Site:	29																																
	DU:	1																																
			0	1.8	U		1.8	U		1.8	U									6.6		J	6	U	UJ	6.1	U	UJ						
	Zone:	3																																
	Site:	30																																
	DU:	1																																
			1	13		J	20		J	17		J								36			31			18								
			2	26		J	9.6		J	2.8		J								40			24			6.4								
			3	16		J	17		J	10		J								110			900			95								
			4	6.8		J	4.4		J	4.5		J								23			26			20								
			5	10		J	13		J	12		J								26			31			44								
			6	10		J	6.5		J	5.9		J								68			44			11								
	Zone:	3																																
	Site:	30																																
	DU:	2																																
			0	1.9	U		1.8	U		1.9	U									6.2	U	UJ	6	U	UJ	6.4	U	UJ						
	Zone:	3																																
	Site:	30																																
	DU:	3																																
			0	1.6	U		1.6	U		1.7	U									5.4	U	UJ	5.3	U	UJ	7.4		J						
	Zone:	3																																
	Site:	32																																
	DU:	1																																
			1	22			16			18			6.8		J	11		J		30			30			32			11			5.4	U	
			2	16			16			20			8.6		J	5.3		J		16			12			6	U		5.6	U		5.4	U	
			3	11			9.8			9.8										14			5.9	U		5.7	U							
			4	11			11		J	11		J								14			5.4	U		5.4	U							
	Zone:	3																																
	Site:	32																																
	DU:	2																																
			1	8		J	3.7		J	3.8		J								6	U		5.3	U		5.5	U							
			2	4.4		J	2.8		J	3.7		J								5.3	U		5.3	U		5.8	U							
			3	7.5		J	8.4		J	4.5		J								20			19			5.6								
			4	7.5			8.9			2.6										17			14			5.4	U							
	Zone:	3																																
	Site:	33																																
	DU:	1																																
			1	4.2		J	4.7		J	4		J								5.4	U		5.5	U		6.3	U							

			ARSENIC															LEAD														
		Boring	**0-2"**	**Q1**	**Q2**	**2-6"**	**Q1**	**Q2**	**6-12"**	**Q1**	**Q2**	**12-18"**	**Q1**	**Q2**	**18-22"**	**Q1**	**Q2**	**0-2"**	**Q1**	**Q2**	**2-6"**	**Q1**	**Q2**	**6-12"**	**Q1**	**Q2**	**12-18"**	**Q1**	**Q2**	**18-22"**	**Q1**	**Q2**
			Note:	Q1 shows data qualifiers (flags) by analytical lab																												
				Q2 shows data qualifiers (flags) by data validators																												
		2	4.1		J	3.2			5.9									6.4			5.6	U		5.8	U							
		3	7.1			9.3			17									10			9.8			6.5								
		4	10			16			12									13			6.3	U		5.8	U							
Zone:	3																															
Site:	33																															
DU:	2																															
		1	5.6			4.3			1.9									11			11			6	U							
		2	5.7			11			10									12			8.2			8.6								
		3	5			16			26			15		J	15		J	11			10			6.4	U		6.8			6.3	U	
		4	12			24			24			13		J	11		J	8.4			5.6	U		5.6	U		5.6	U		5.6	U	
Zone:	3																															
Site:	46																															
DU:	1																															
		1	2.6			3			1.7	U		1.8	U		1.7	U		7.1			6	U		5.8	U		5.9	U		5.6	U	
		2	1.6	U		7.1			7.5			4.1			7.9			5.2	U		23			31			10			6.6	U	
		3	6.1			9.4			7.5			3.3			5.4			23			15			5.6	U		5.3	U		5.4	U	
		4	17			19		J	13		J	12		J	12		J	28			25			16			8			6	U	
		5	16		J	13		J	11		J	24		J	28		J	25			26			14			6	U		6.1	U	
		6	17		J	14		J	19		J	12		J	11		J	7.8			6	U		20			12			5.8	U	

Note:

For beach DUs, where samples were composited across borings for analysis, the boring number is 0.

U = not detected

J = estimated

ATTACHMENT C

Initial Soil Survey Resamples Results

Attachment C

Initial Soil Survey Resamples
Results

Soil samples were collected from 4 of the locations included in the initial soil survey of Vashon-Maury Island to provide additional samples with high contaminant concentrations for the tracer element study. At each of those four locations, 9 soil samples were collected by sampling at 0-2, 2-6, and 6-12 inch depth intervals in three borings. Only arsenic analyses were performed for these 36 samples; arsenic was considered to be a sufficient indicator for selection of samples to include in the tracer element study.

The four sampling locations included three on Maury Island (original locations 84, 100, and 101) and one on south Vashon Island, near Tahlequah (original location 65) (see PHSKC and Glass 2000). The same analytical protocols were used as for arsenic analyses in the child-use area samples. The results of arsenic analyses are shown in Table C-1. Resampling at these selected initial survey locations was successful in providing soil samples exceeding 200 ppm arsenic for inclusion in the tracer element study, thus extending the range of concentrations beyond those available from only the child-use area samples. (Tracer element analytical results are being reported separately).

Comparing the results for the soil resamples to the results at the same locations in the initial survey provides additional information on local variability in near-surface arsenic concentrations. These comparisons are made for results in the top 6 inches only, since only two depth intervals were sampled in the initial survey. The ranges for arsenic concentrations in the top 6 inches in the two data sets, and the number of samples included, are as follows:

Location	Initial Survey	Resamples
065	79-130 ppm (n=6)	97-210 ppm (n=6)
084	23-140 ppm (n=2)	49-230 ppm (n=6)
100	78-150 ppm (n=2)	15-180 ppm (n=6)
101	120-180 ppm (n=2)	43-160 ppm (n=6)

For three of the four resampled locations, the Maximum arsenic concentration in the resamples was greater than in the initial survey. This reflects both an increased number of samples analyzed in the resamples (locations 084, 100) and inherent variations in the near-surface soil arsenic levels (all locations). One of the three borings at location 100 has notably low arsenic concentrations (possibly reflecting natural disturbance of the soils). The results at all four locations confirm that even closely-spaced soil borings often exhibit variations of several hundred percent in maximum arsenic concentrations. Increasing the number of soil samples collected and analyzed typically expands the range in observed concentrations where the sample sizes are small - that is, a very small number of samples is unlikely to fully represent the true variability in local soil arsenic levels.

The results for resamples at 6-12 inches also provide additional information on arsenic depth profiles compared to the initial survey (see also the discussion in Attachment D for forest fringe samples collected to a depth of 22 inches). At all four resampled locations, the maximum arsenic concentration in the top 6 inches exceeds the maximum concentration at 6-12 inches. For three of the four locations, the maximum arsenic value below 6 inches is less than 30 percent of the maximum value within the top 6 inches, indicating a significant dropoff in arsenic mobility. At location 100, however, the maximum arsenic value of 120 ppm at 6-12 inches is fully 75 percent of the maximum value within the top 6 inches. The resamples were collected using a series of stainless steel core tubes of increasing lengths, advanced in sequence within the same boring using a sledgehammer. This sampling method could conceivably have resulted in some surface soils sloughing into the open borehole with the advancement of successive core tubes, affecting depth profile results to some degree. The control of such artifacts may be less than with hand-sampling techniques.

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Table C-1

Soil Arsenic Results
Initial Soil Survey Resamples
(in ppm, DW)

			ARSENIC														
		Boring	**0-2"**	**Q1**	**Q2**	**2-6"**	**Q1**	**Q2**	**6-12"**	**Q1**	**Q2**	**12-18"**	**Q1**	**Q2**	**18-22"**	**Q1**	**Q2**
			Note:	Q1 shows data qualifiers (flags) by analytical lab													
				Q2 shows data qualifiers (flags) by data validators													
Zone:	1																
Site:	84																
DU:	1																
		1	210			230			27								
		2	49			180			56								
		3	68			120			36								
Zone:	1																
Site:	101																
DU:	1																
		1	120			98			46								
		2	69			160			120								
		3	43			44			37								
Zone:	1																
Site:	1065																
DU:	1																
		1	97			120			17								
		2	110			100			6.5								
		3	190			210			62								
Zone:	1																
Site:	1100																
DU:	1																
		1	180			46			33								
		2	20			15			46								
		3	160			120			11								

ATTACHMENT D

Forest Fringe Samples Results

Attachment D

Forest Fringe Samples
Results

Samples were collected from the "forest fringe" (forested areas adjacent to sampled child-use areas) at four selected child-use areas. Three of the selected areas were in Zone 1 (near Burton, Dockton, and Point Robinson); the fourth was in Zone 2 (at the elementary school). The objective in sampling at these forest fringe areas was to provide area-specific data allowing comparisons to be made for contaminant levels on relatively undisturbed versus developed properties (see Section 2.0).

The sampling protocols for forest fringe samples were identical to those used for the child-use area samples. All forest fringe samples were collected using GeoProbe^{TM} methods and included the same 5 depth intervals between 0 and 22 inches used for child-use area samples. Four borings were sampled at each forest fringe area, with sample codes assigned using the same sample coding system and a new DU designation. Thus, a total of 20 sample results are available for each forest fringe area samples.

All forest fringe samples were analyzed for arsenic and lead, using the same protocols as for child-use area samples. The results from OnSite Environmental, Inc. were included in the data validation reviews conducted by EcoChem, Inc. All results were found suitable for use in further data evaluations.

The arsenic and lead results for forest fringe samples are provided in Table D-1. The depth profiles, lead versus arsenic correlations, and variability in the forest fringe results are all comparable to those in the initial soil survey of forest soils on Vashon-Maury Island. Additional information is available for depth profiles in the forest fringe results. The depth profiles for three of the four forest fringe areas show a rapid decrease in arsenic concentrations below 6 inches. At those three areas, the maximum arsenic values below 6 inches are 7.9 percent, 10.7 percent, and 20.3 percent of maximum values within the top 6 inches. The fourth area (the elementary school) has a comparable value of 37.7 percent. One boring has a depth pattern different from the other three at this location. Lead results with respect to depth profiles are similar, except that lead in general shows even less downward mobility than arsenic (as expected). The pattern at the elementary school is even more anomalous for lead than for arsenic; the ratio of maximum values below versus above 6 inches is 58.1 percent. The anomalies at this location could reflect natural variability or a comparatively higher degree of actual soil disturbance in the forest fringe (a possibility supported by field observations).

The forest fringe results were compared to the results for samples from their matched child-use areas. A summary of the Maximum and Average (larger of 0-2 inch and 2-6 inch) concentrations for forest fringe versus child-use areas is provided in Table D-2. The depth intervals are shown for each reported Maximum or Average concentration in Table D-2. The ratio of forest fringe to child-use area results is also shown for each comparison.

Inspection of Table D-2 reveals several interesting patterns. The forest fringe results generally exceed those from their matched child-use areas (i.e., most ratios are greater than 1). Only one arsenic Maximum value and one lead Maximum value from forest fringe areas are less than the comparable values at child-use areas (and the differences are not large in either case). Thus, whether evaluated based on Maximum or Average concentrations, the developed child-use areas show less near-surface soil contamination by arsenic and lead than nearby forest fringe areas. The ratios for Average concentrations are larger than the matched ratios for Maximum concentrations in all 8 cases. Therefore, there is a greater difference between forest fringe and child-use areas for average concentrations. This is consistent with a conceptual model in which property development actions dilute, mix, or remove soil contamination to a degree that varies from one location to another at a property, so that Maximum results more closely approach forest fringe contamination levels. At three of the four sampled areas, the Maximum child-use area results for arsenic and lead were both within a factor of 1.79 or less of the Maximum forest fringe results (and actually exceeded the forest fringe values in two cases, as noted). The fourth area shows much higher ratios for all forest fringe versus child-use area results, which may reflect a greater effect of property development actions on original soil contaminant levels.

A third finding is that Average concentrations (within the top 6 inches) are always at 0-2 inches in the forest fringe areas, but are at the 2-6 inch depth interval about half the time in child-use areas. This suggests that original contaminant soil profiles in forest soils are being affected by property development actions, resulting in more complex depth profiles at the child-use areas.

Although only four forest fringe areas were sampled for this preliminary study of contamination patterns at developed versus nearby undisturbed areas, the results provide considerable insight into the comparative patterns of arsenic and lead in near-surface soils. The relationship at other child-use areas, or other developed properties on Vashon-Maury Island, may differ from these results. Property-specific development histories are likely to affect the patterns at individual locations. These preliminary findings should not be automatically assumed to apply to other unsampled locations.

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Table D-1

Soil Arsenic and Lead Results
Forest Fringe Samples
(in ppm, DW)

Note: Q1 shows data qualifiers (flags) by analytical lab
Q2 shows data qualifiers (flags) by data validators

			ARSENIC															**LEAD**														
		Boring	**0-2"**	**Q1**	**Q2**	**2-6"**	**Q1**	**Q2**	**6-12"**	**Q1**	**Q2**	**12-18"**	**Q1**	**Q2**	**18-22"**	**Q1**	**Q2**	**0-2"**	**Q1**	**Q2**	**2-6"**	**Q1**	**Q2**	**6-12"**	**Q1**	**Q2**	**12-18"**	**Q1**	**Q2**	**18-22"**	**Q1**	**Q2**
Zone:	1																															
Site:	38																															
DU:	3																															
		1	130			27			6.5			3.5			5.1			360			23			6	U		6.2	U		5.7	U	
		2	140			100			11			3			1.8	U		390			210			11			6	U		6	U	
		3	76			130			7			1.7	U		1.6	U		220			49			5.9	U		5.6	U		5.4	U	
		4	100			40			8.4			1.8	U		1.6	U		170			61			6.3			5.9	U		5.5	U	
Zone:	1																															
Site:	39																															
DU:	6																															
		1	73		J	8.8		J	3.3		J	1.9		J	1.6	U	UJ	110			11			5.6	U		5.5	U		5.3	U	
		2	100		J	150		J	13		J	1.9		J	2.1		J	220			200			16			5.6	U		5.5	U	
		3	100		J	89		J	16		J	2.9		J	3.2		J	240			150			6.9			5.6	U		5.6	U	
		4	94		J	31		J	4.1		J	3.6		J	1.7		J	100			25			5.8	U		5.6	U		5.4	U	
Zone:	1																															
Site:	42																															
DU:	3																															
		1	59		J	58		J	12		J	12		J	9.3		J	84			79			9.9			6	U		5.7	U	
		2	59		J	31			4.3			1.8			1.7	U		99			47			6	U		5.7	U		5.6	U	
		3	48			25			3.7			1.7	U		1.7	U		100			42			6.3	U		5.6	U		5.7	U	
		4	28			30			2.3			1.8	U		1.7	U		120			68			6.6	U		6	U		5.8	U	
Zone:	2																															
Site:	6																															
DU:	4																															
		1	61			19			9.3			9.9			15			430			32			6.7			5.3	U		5.3	U	
		2	55			12			12			5.5			4.5			170			9.9			5.3	U		5.2	U		5.3	U	
		3	38			30		J	3.3		J	6.3		J	6.3		J	100			48			5.9	U		5.5	U		5.3	U	
		4	15		J	21		J	16		J	17		J	23		J	26			220			250			88			53		

Note:
U = not detected
J = estimated

Vashon-Maury Island
Child-Use Areas Study
Public Health - Seattle & King County
2001

Table D-2

Comparison of Child-Use Area and Forest Fringe Results

(in ppm, DW)

		Maximum Concentrations				Average Concentrations			
Location	**Type**	**Arsenic**	**depth**	**Lead**	**depth**	**Arsenic**	**depth**	**Lead**	**depth**
1-38-1	CUA	41	2	51	2	11.99	2	20.19	2
1-38-3	FF	140	1	390	1	111.50	1	285.00	1
ratio	FF/CUA	3.41		7.65		9.30		14.12	
1-39-1	CUA	86	1	360	1	29.75	1	78.10	2
1-39-6	FF	150	2	240	1	91.75	1	167.50	1
ratio	FF/CUA	1.74		0.67		3.08		2.14	
1-42-2	CUA	36	3	72	2	15.08	1	24.89	2
1-42-3	FF	59	1	120	1	48.50	1	100.75	1
ratio	FF/CUA	1.64		1.67		3.22		4.05	
2-6-1	CUA	43	1	100	4	23.89	1	48.48	1
2-6-2	CUA	64	2	95	5	16.95	2	31.63	1
2-6-3	CUA	59	1	150	1	15.24	1	49.93	1
targeted	CUA	70	1	240	1				
2-6-4	FF	61	1	430	1	42.25	1	181.50	1
ratio	FF/CUA	0.87		1.79		1.77		3.64	

NOTE
CUA = child-use area
FF = forest fringe
At child-use area 6, ratios are based on the largest CUA result.

ATTACHMENT E

Statistical Evaluations and Plots
Supplemental Information

Vashon-Maury Island Child-Use Areas Study
Final Report
November 2001

Attachment E

Box-and-Whisker Plots
Definitions

Vashon-Maury Island Child-Use Areas Study
Final Report
November 2001

What is a "Box-and-Whisker Plot"?

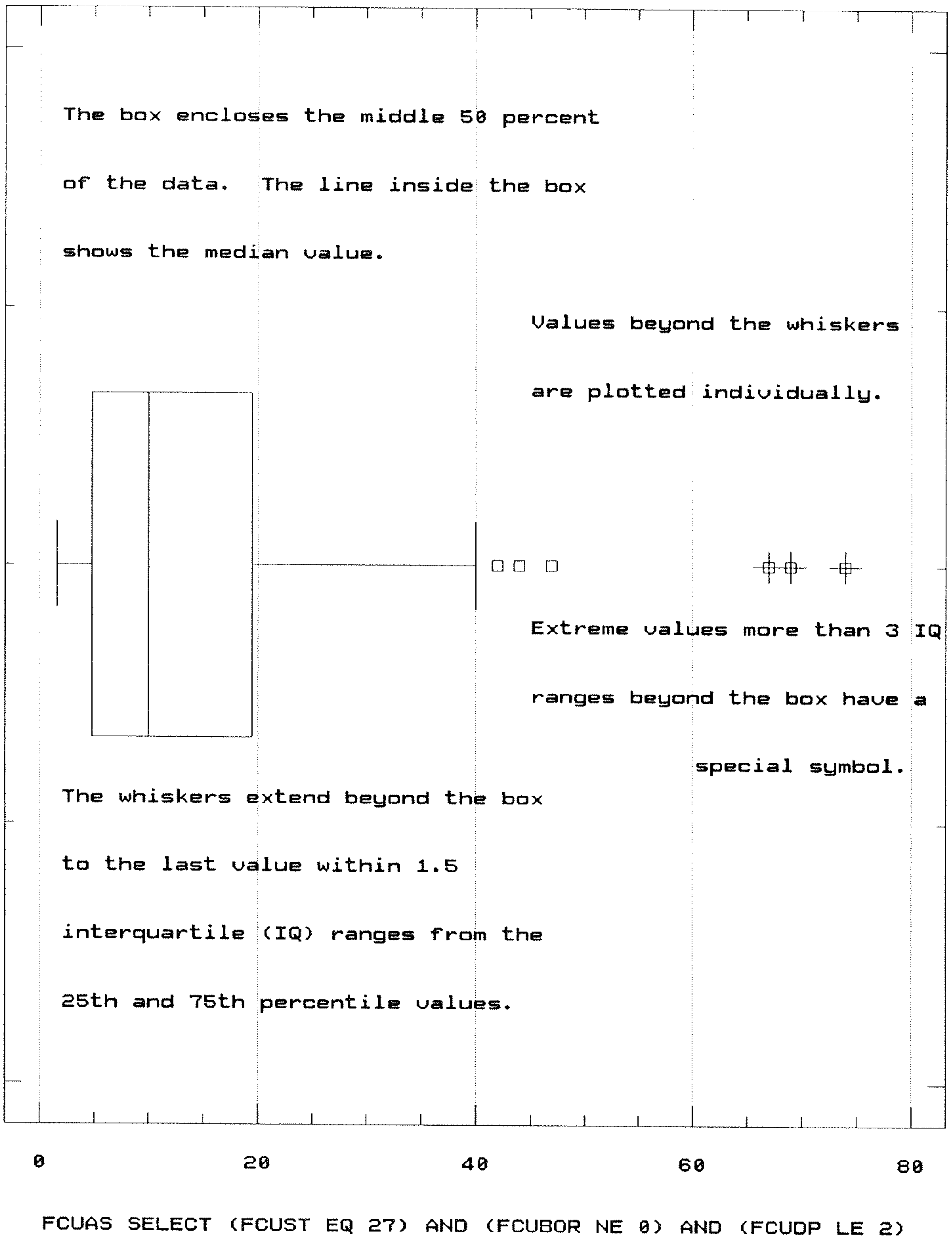
A Box-and-Whisker Plot is a method of visually presenting and summarizing a data set.

A Box-and-Whisker Plot visually summarizes some of the major properties of the data set - what the central (median) value is, how spread out the data are around that central value, whether the data are distributed symmetrically or asymmetrically around the central value, and whether any unusually large or small values ("outliers") occur in the data set.

To see what a Box-and-Whisker Plot does, consider first that all of the individual values in a data set can be plotted along a numerical scale, producing a simple "dot plot" of the data set. A Box-and-Whisker Plot concisely summarizes this "dot plot", eliminating many or all of the individual data points in favor of clearly identifying such summary values as the 25th, 50th, and 75th percentiles of the data set and showing the overall range of values. The numerical difference between the 25th and 75th percentiles is called the Interquartile Range and is shown by the length of the box in a Box-and-Whiskers Plot.

Box-and-Whisker Plots provide a quick and effective way of comparing multiple data sets. The individual Box-and-Whisker Plots for each data set are simply shown next to each other, using the same numerical scale for each one. For example, the arsenic values at different Child-Use Areas can be compared visually using side-by-side Box-and-Whisker Plots.

Box-and-Whisker Plot
Definitions

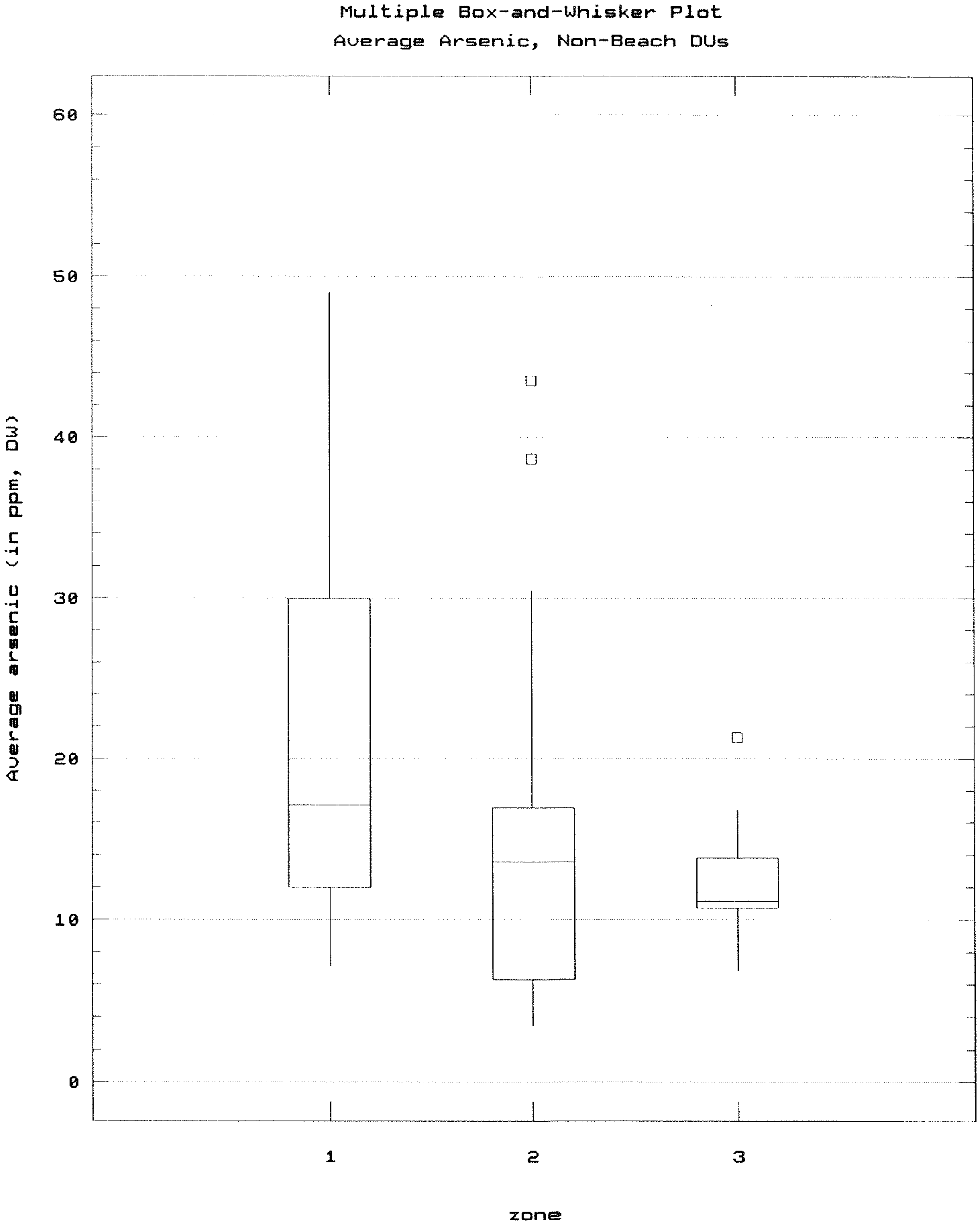


The box encloses the middle 50 percent of the data. The line inside the box shows the median value.

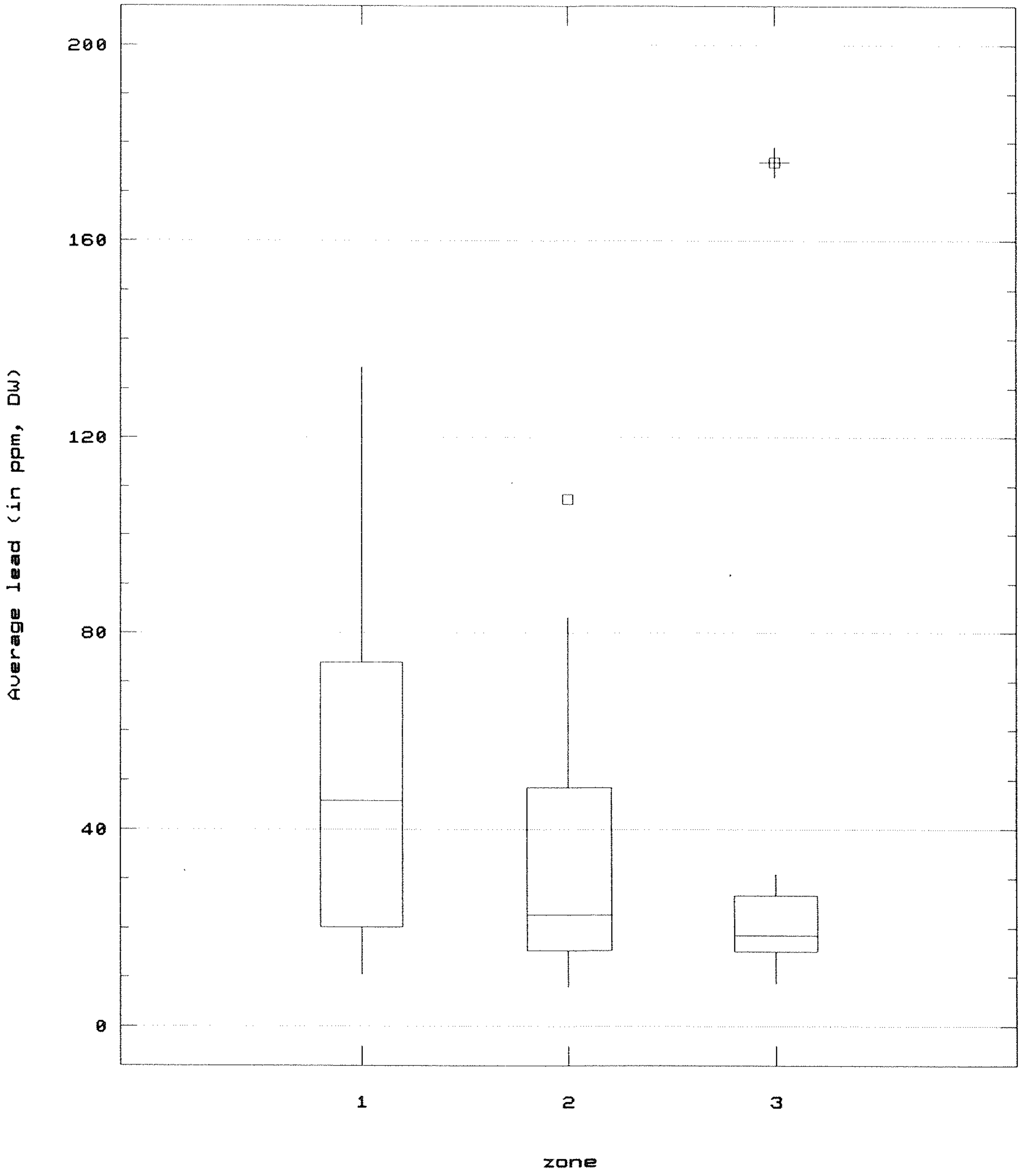
Values beyond the whiskers are plotted individually.

Extreme values more than 3 IQ ranges beyond the box have a special symbol.

The whiskers extend beyond the box to the last value within 1.5 interquartile (IQ) ranges from the 25th and 75th percentile values.

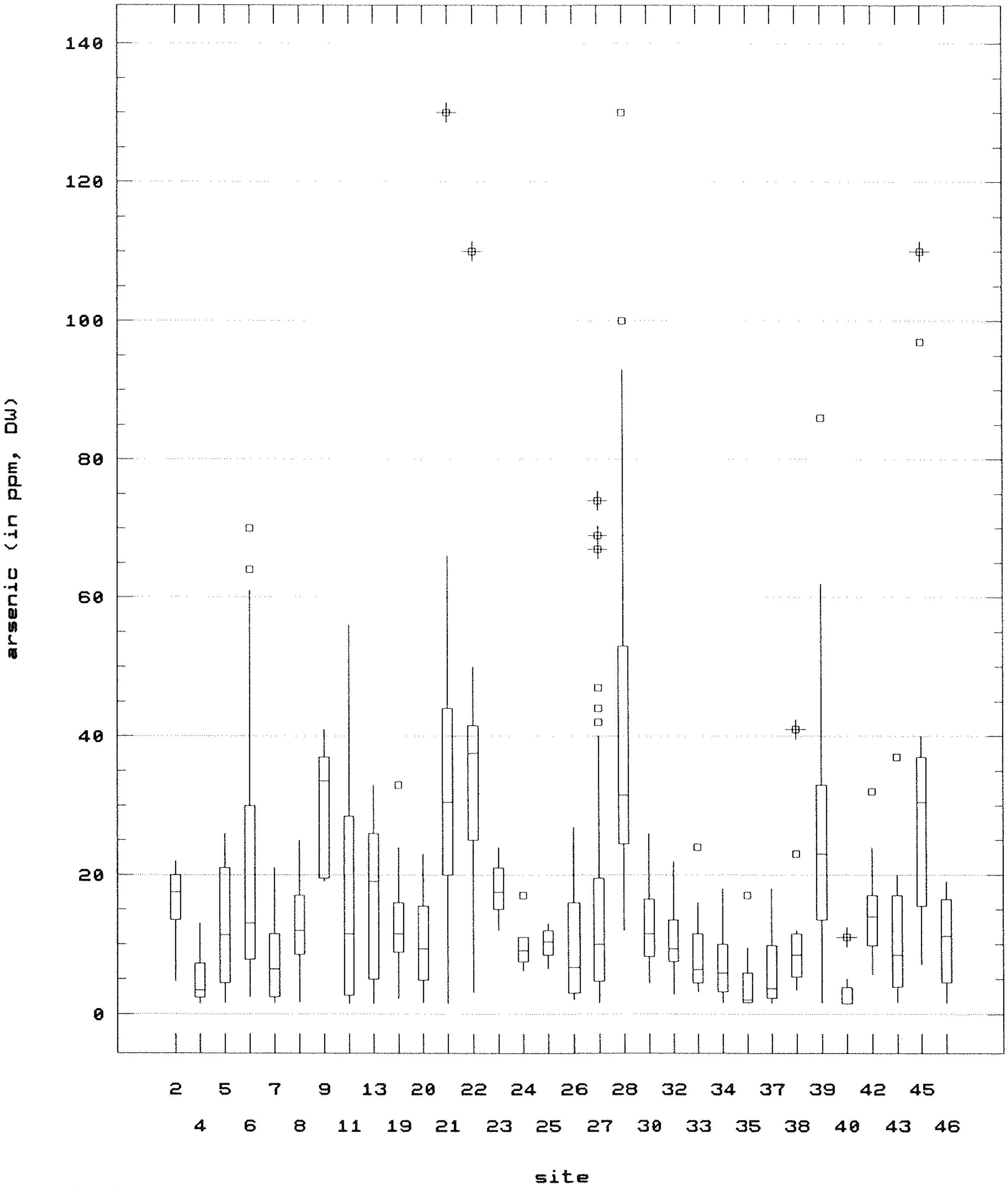

Multiple Box-and-Whisker Plot
Average Arsenic, Non-Beach DUs
Average arsenic (in ppm, DW)
0
10
20
30
40
50
60
1
2
3
zone

Multiple Box-and-Whisker Plot
Average Lead, Non-Beach DUs



ARSENIC CONCENTRATIONS

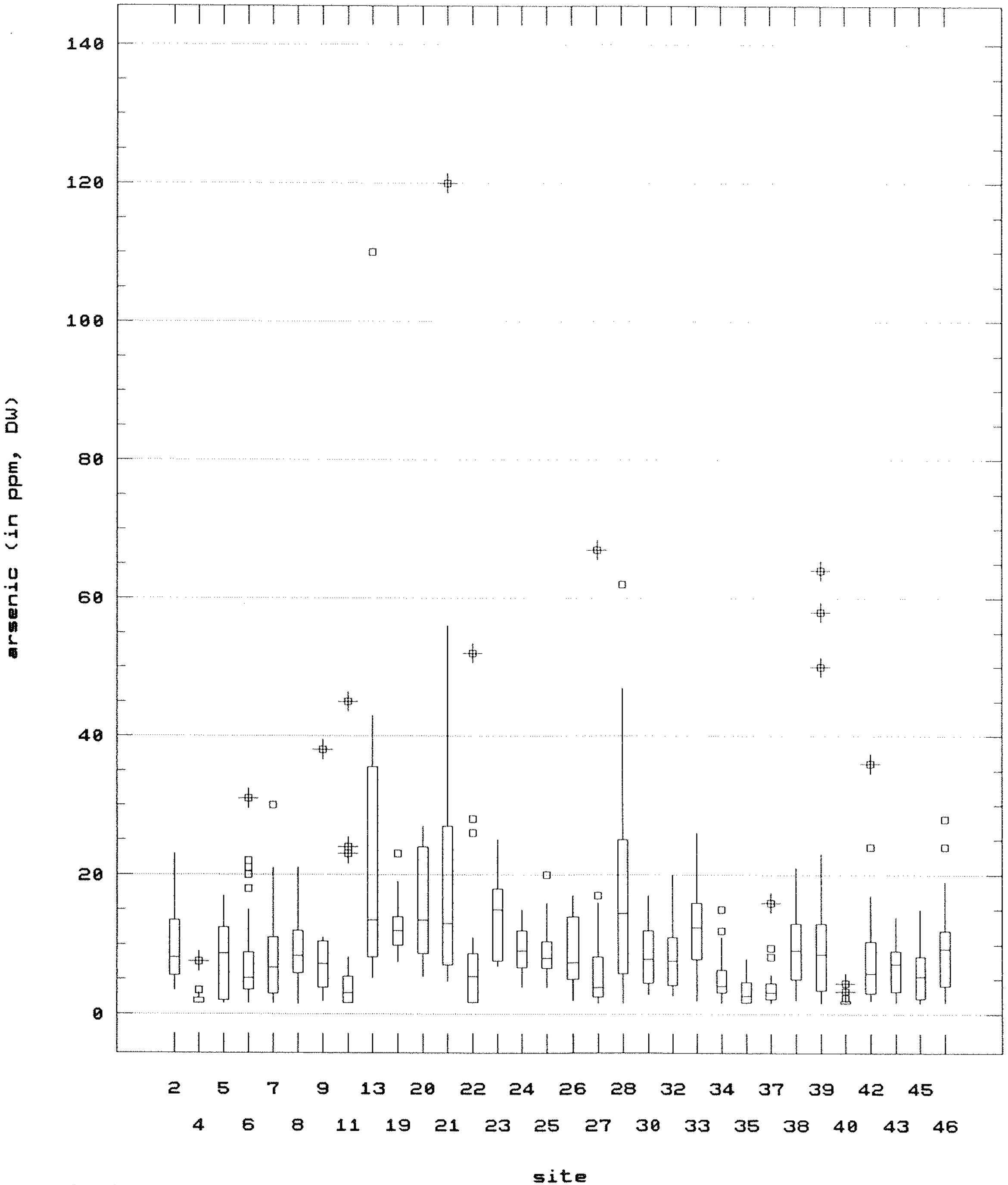
By Site, Soils from 0 to 6 inches



[excluding all beach DUs]

ARSENIC CONCENTRATIONS

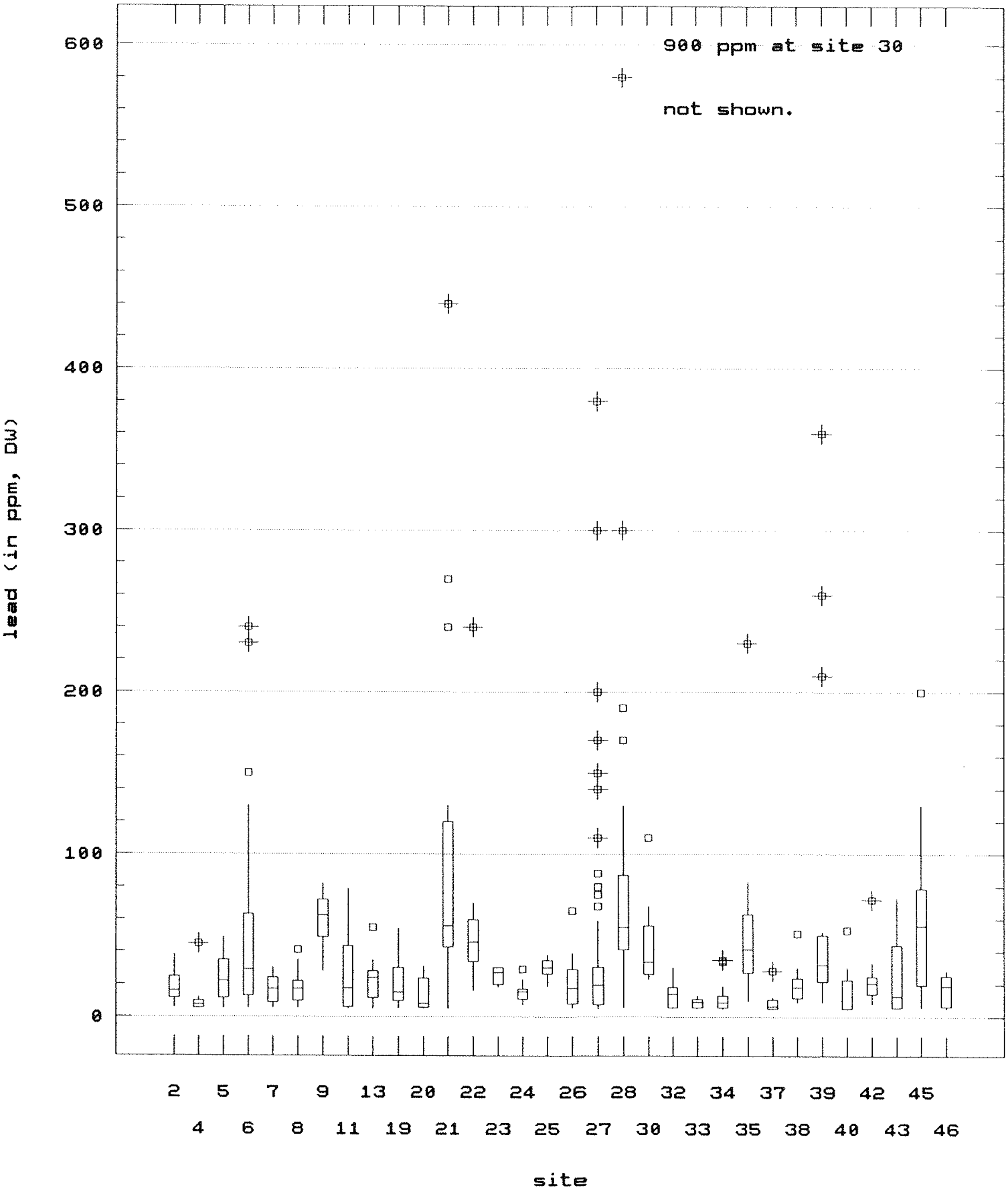
By Site, Soils below 6 inches



[excluding all beach DUs]

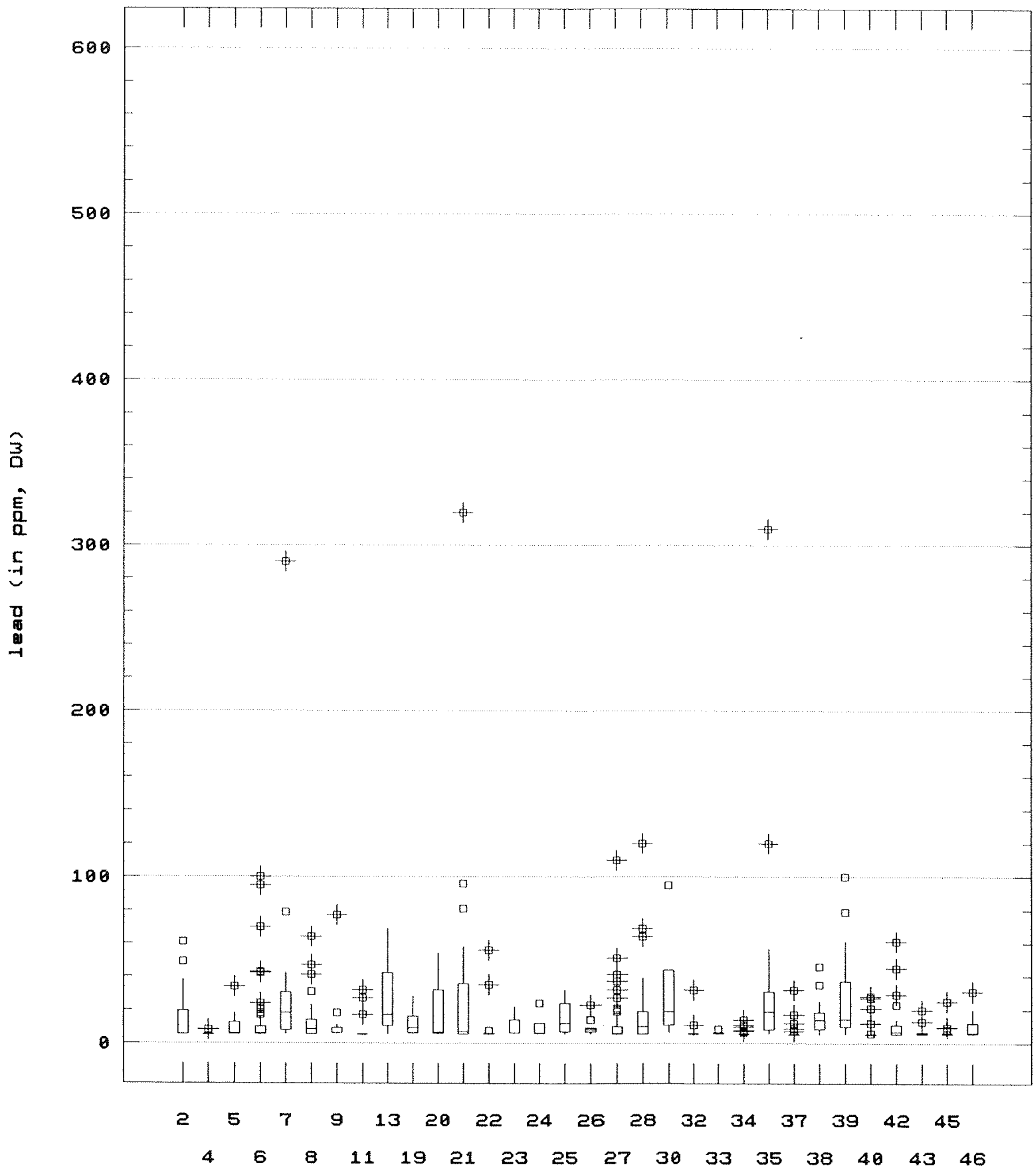
LEAD CONCENTRATIONS

By Site, Soils from 0 to 6 inches



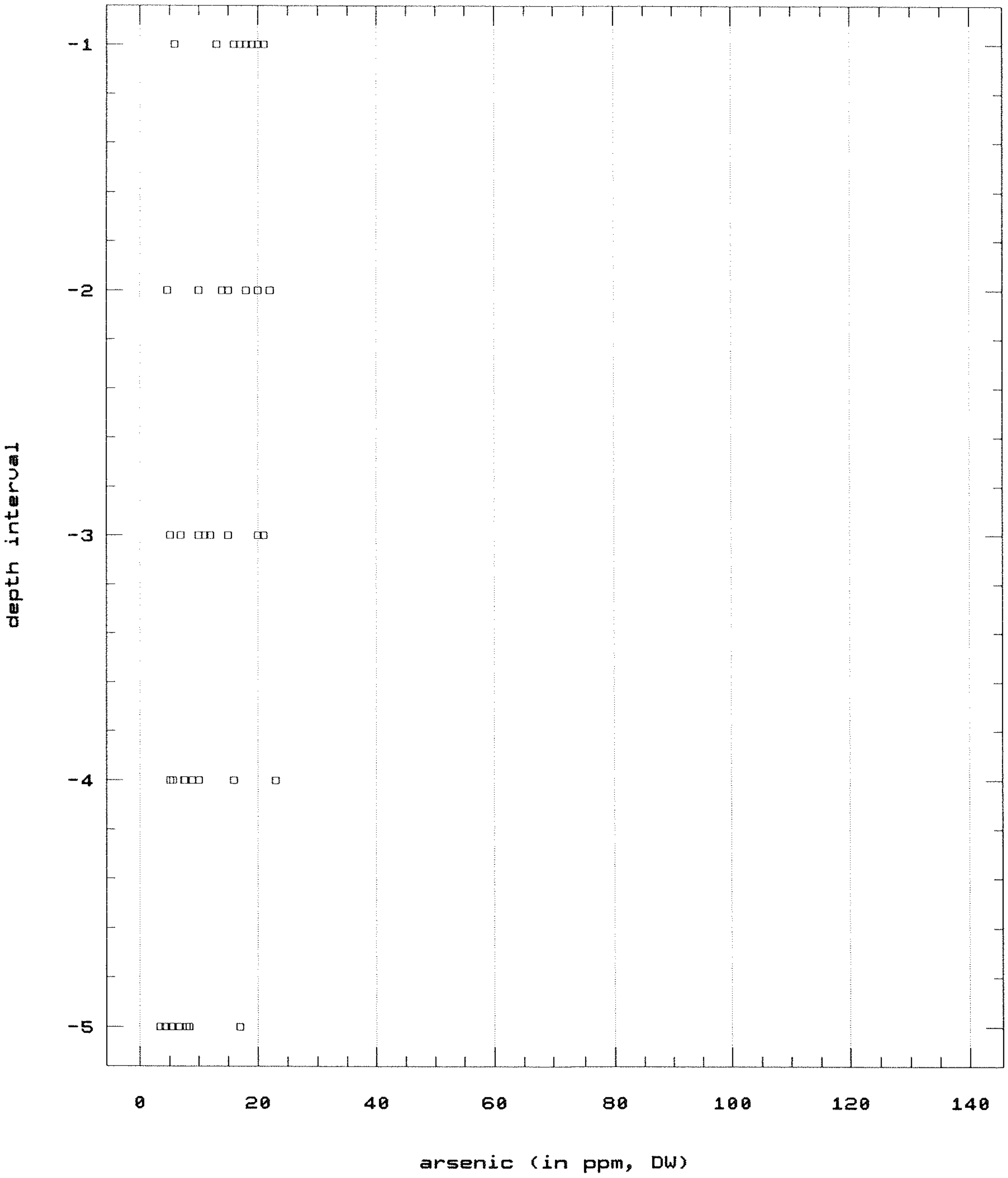
[excluding all beach DUs]

LEAD CONCENTRATIONS
By Site, Soils below 6 inches



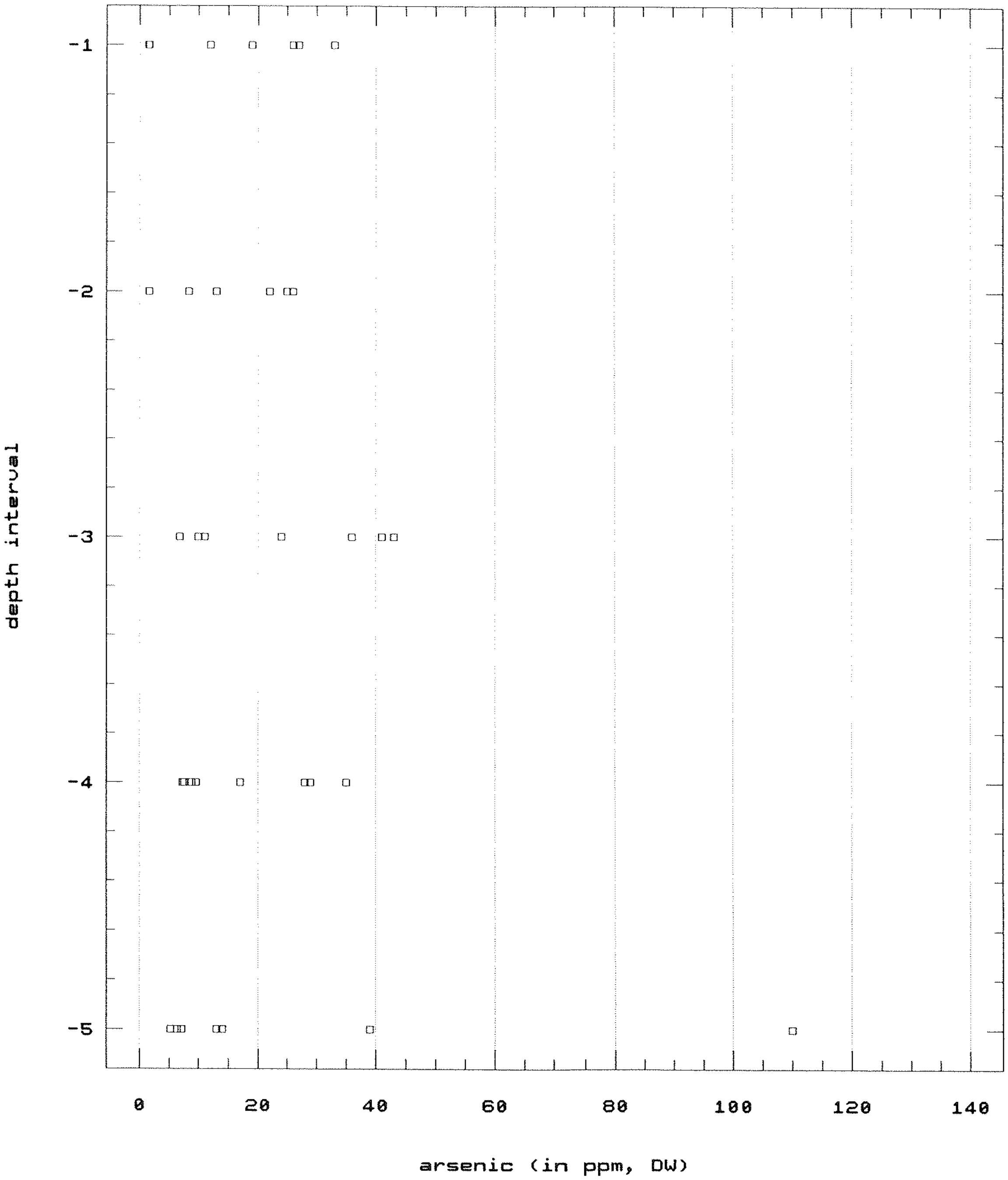
[excluding all beach DUs]

Child-Use Area 2 [Zone 1]
Arsenic Concentrations by Depth



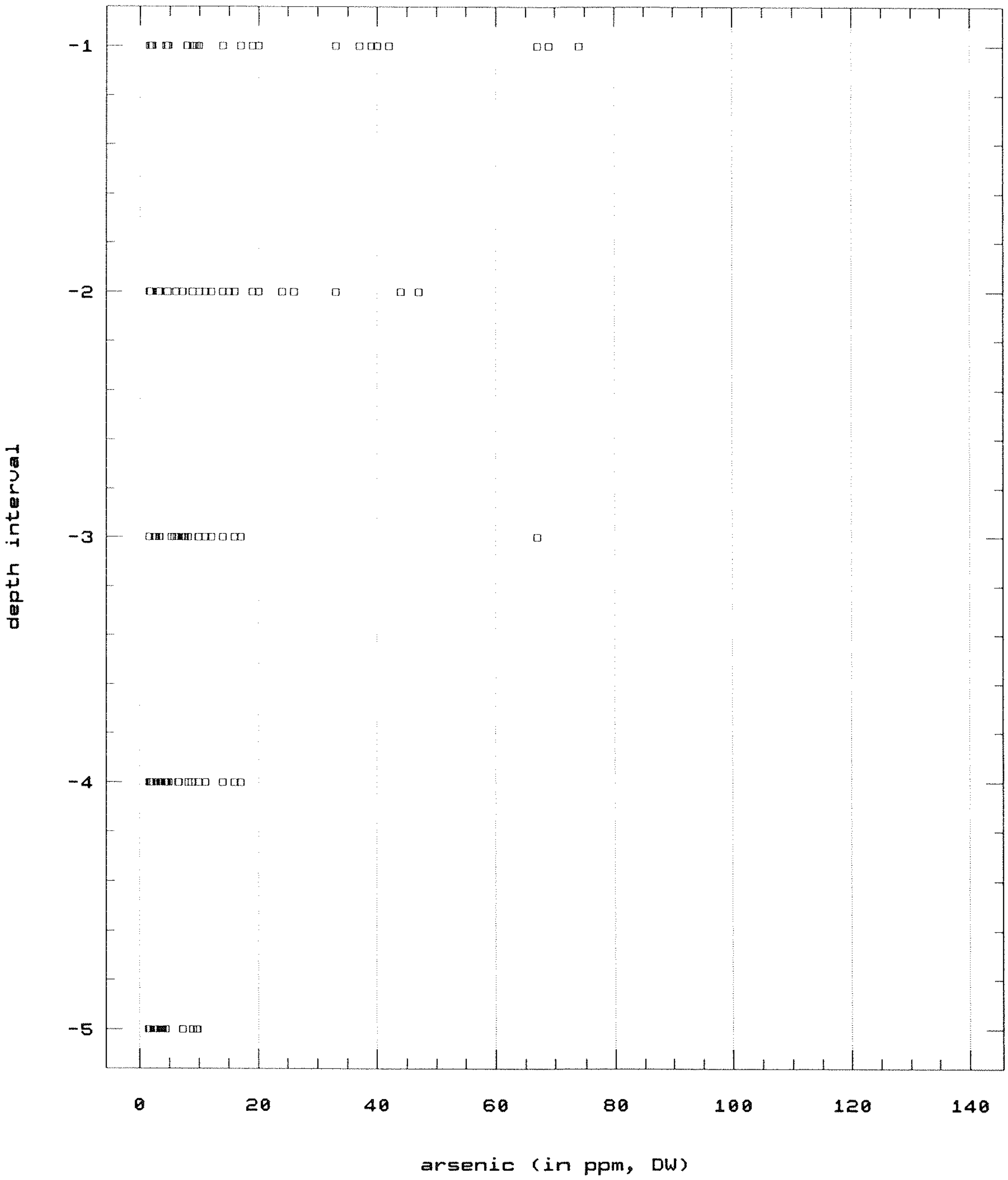
[beach samples, if any, excluded]

Child-Use Area 13 [Zone 1]
Arsenic Concentrations by Depth



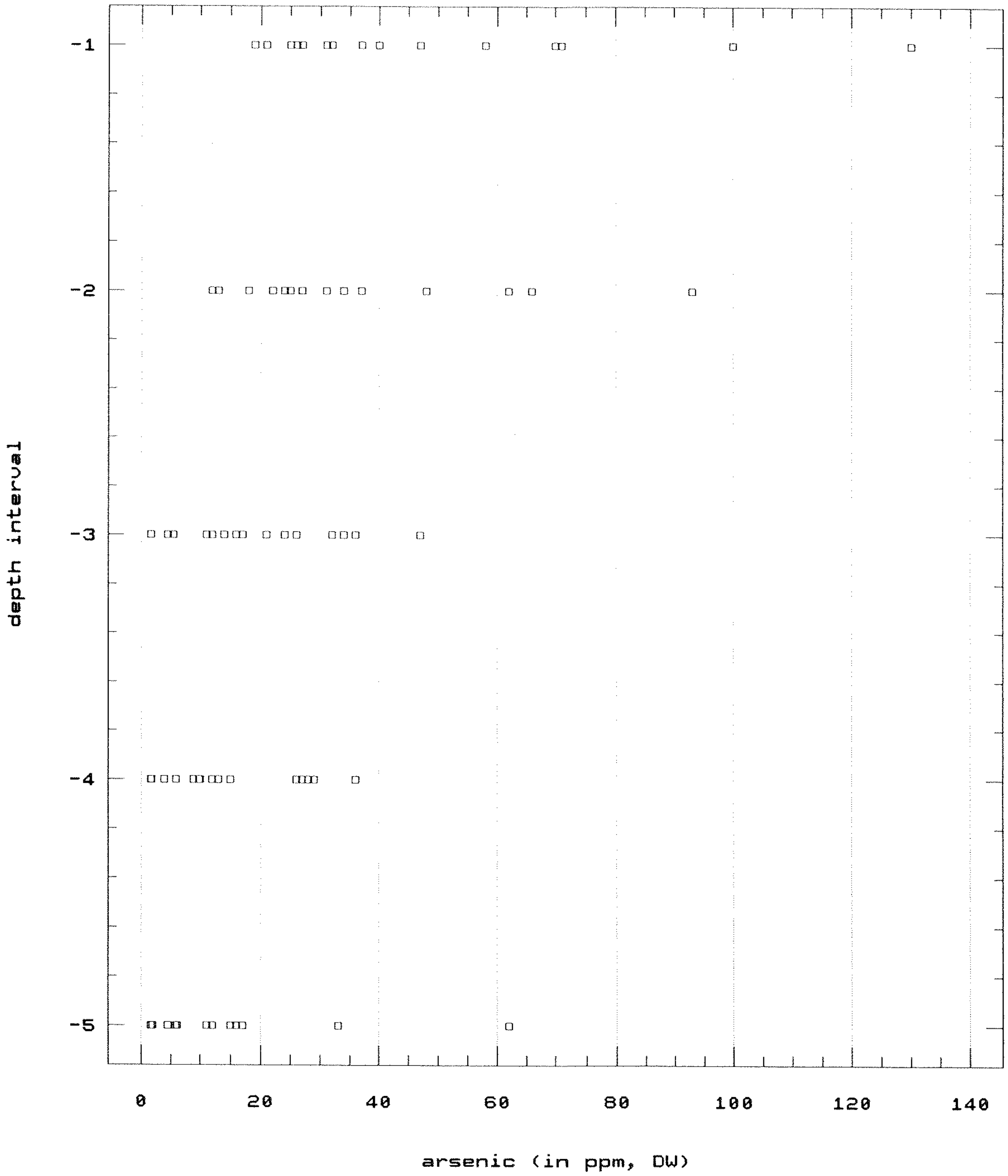
[beach samples, if any, excluded]

Child-Use Area 27 [Zone 1]
Arsenic Concentrations by Depth

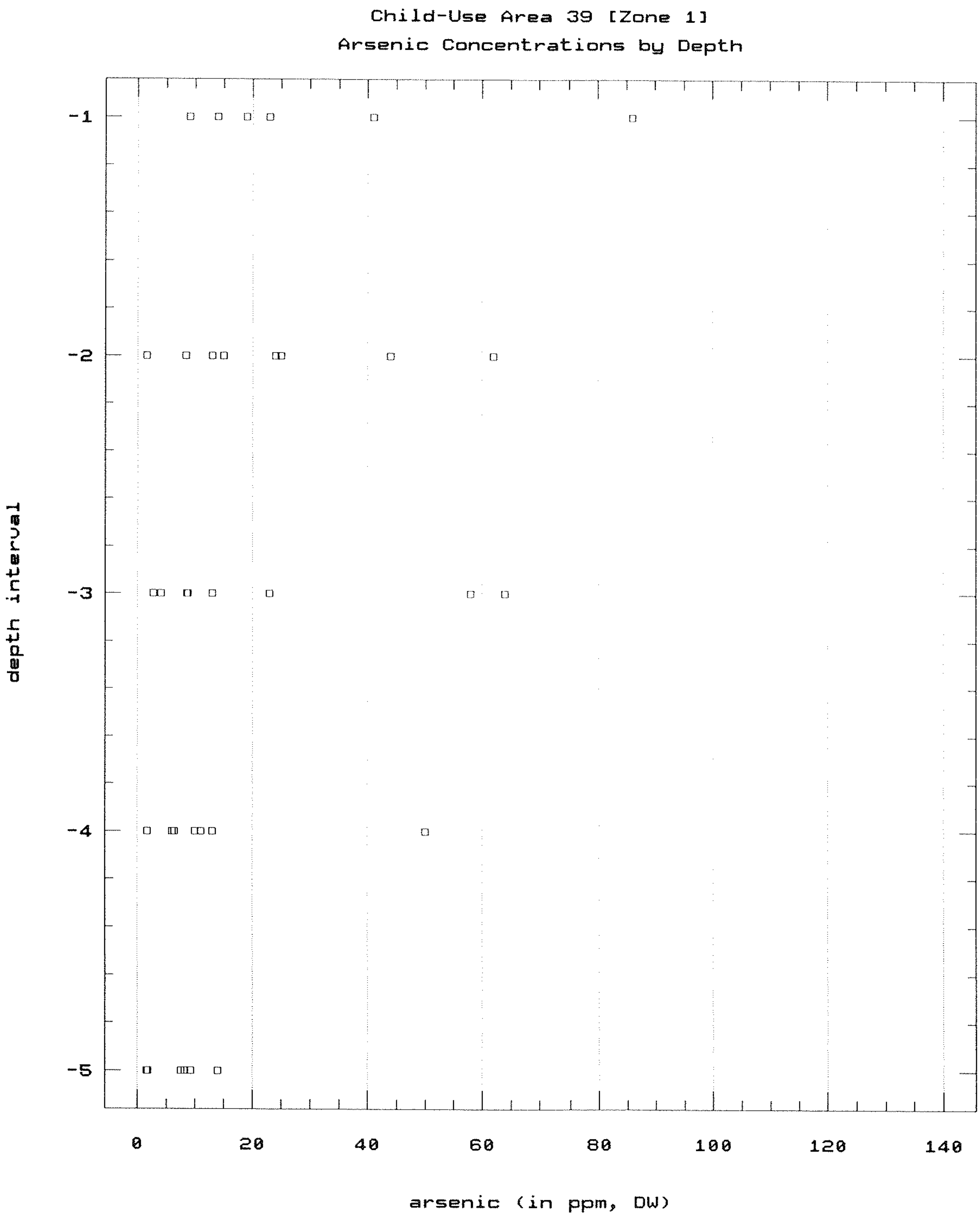


[beach samples, if any, excluded]

Child-Use Area 28 [Zone 1]
Arsenic Concentrations by Depth

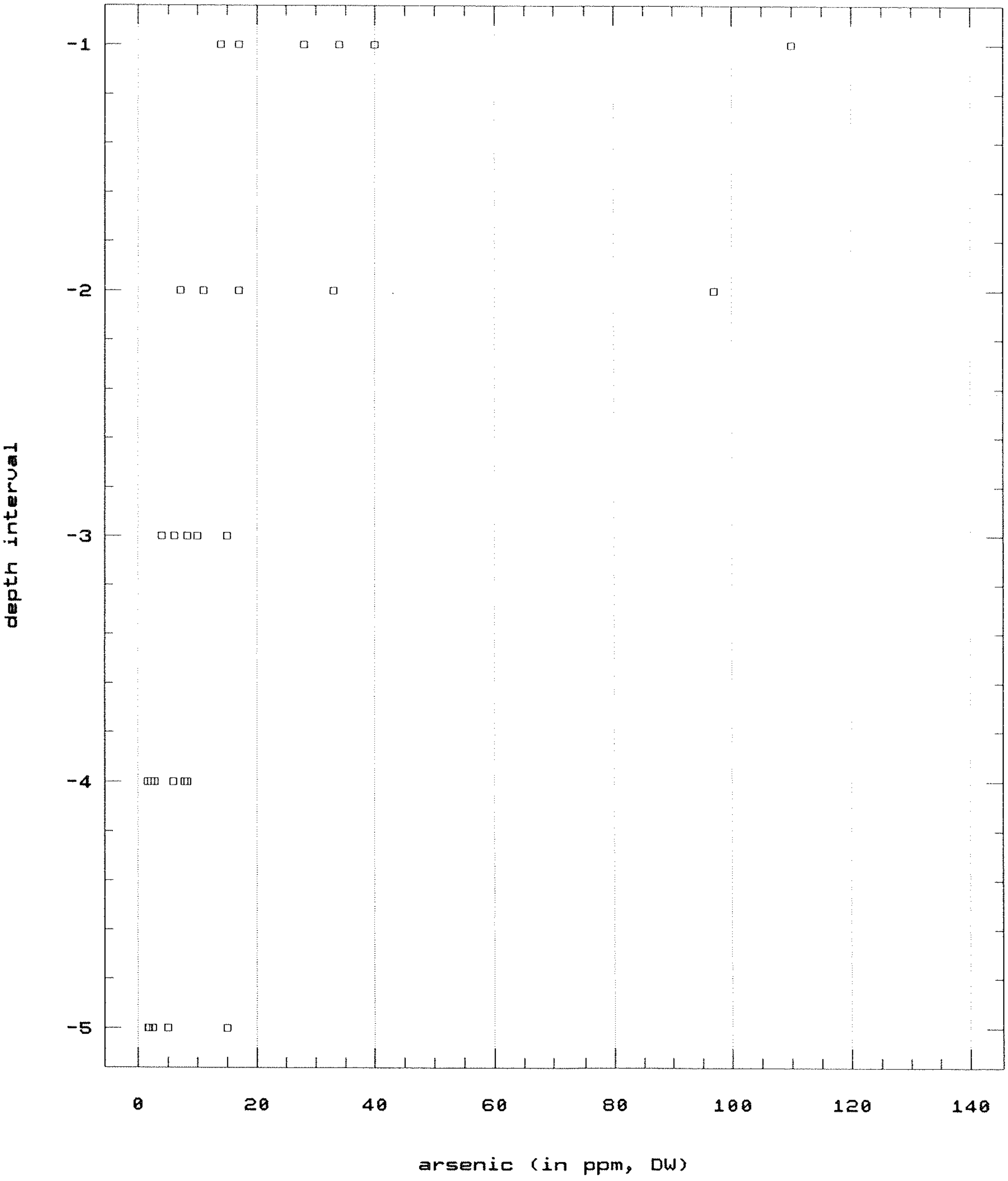


[beach samples, if any, excluded]



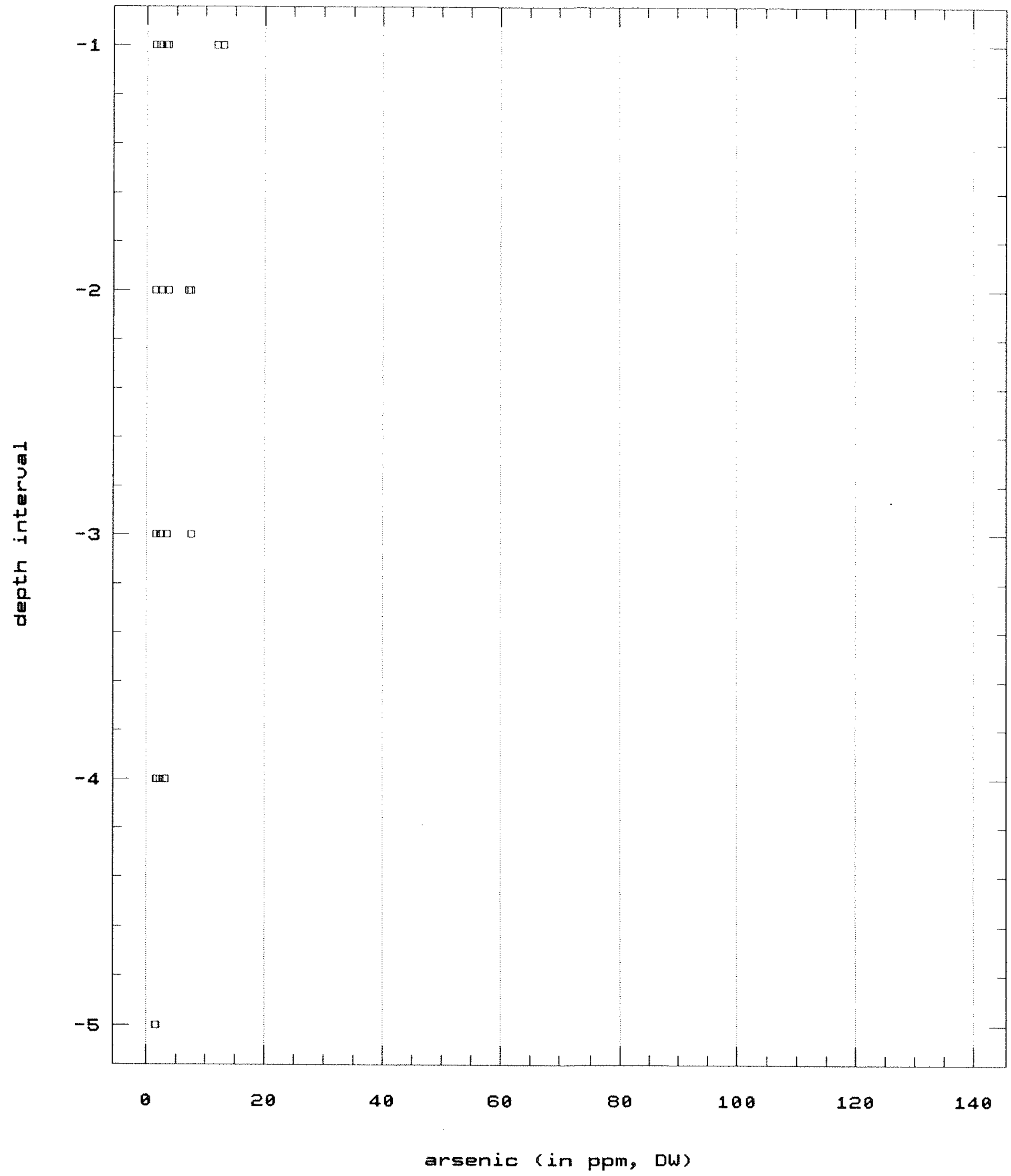
[beach samples, if any, excluded]

Child-Use Area 45 [Zone 1]
Arsenic Concentrations by Depth



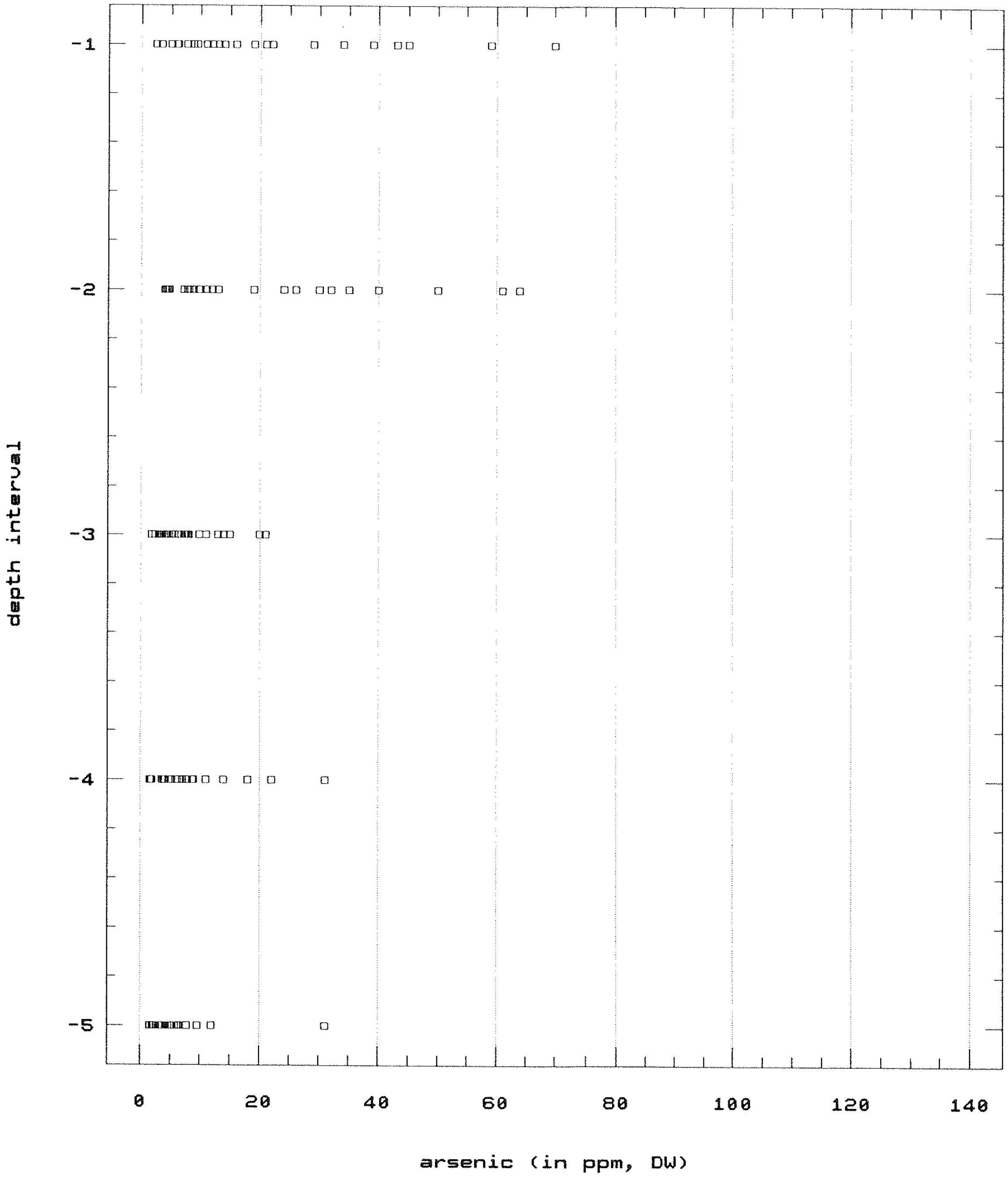
[beach samples, if any, excluded]

Child-Use Area 4 [Zone 2]
Arsenic Concentrations by Depth



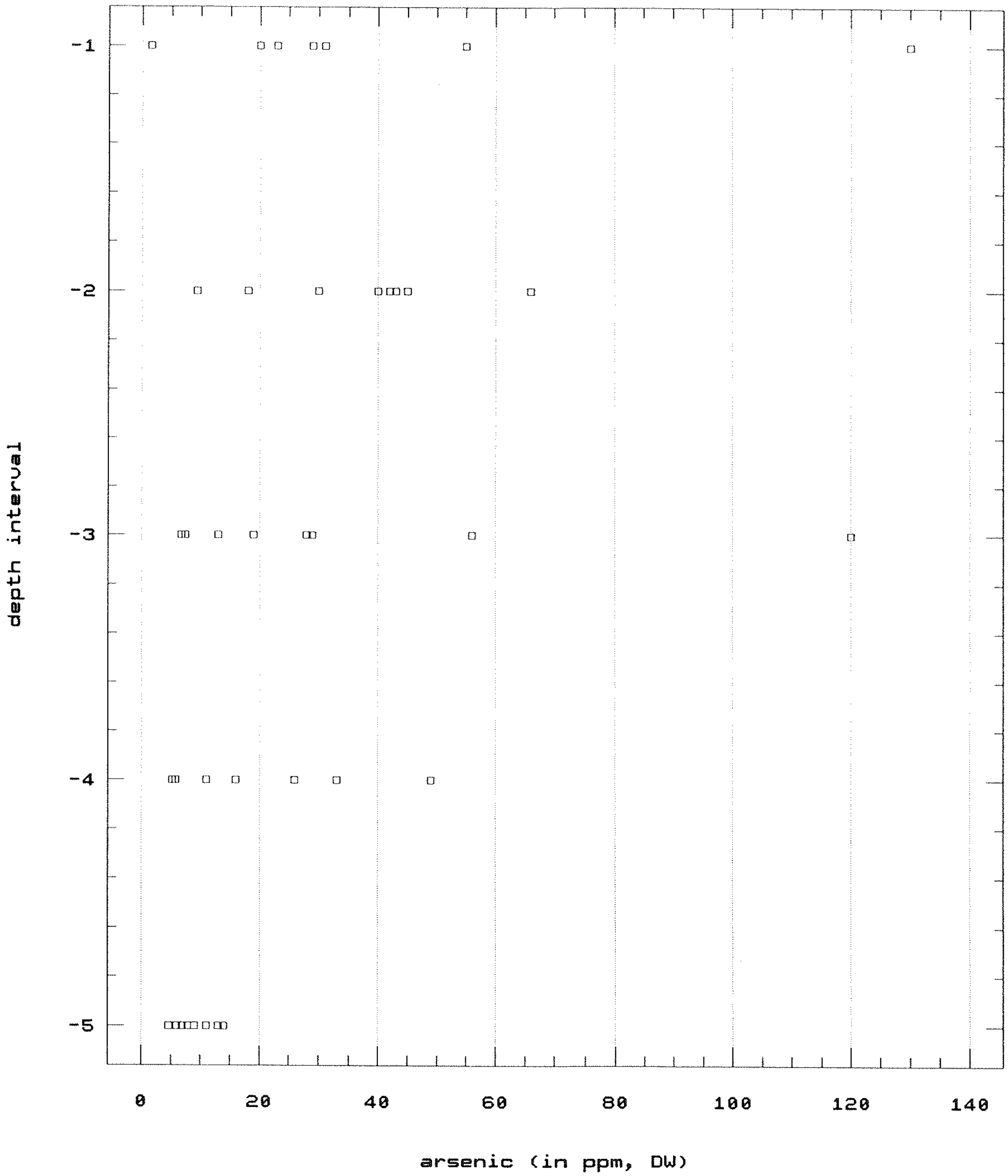
[beach samples, if any, excluded]

Child-Use Area 6 [Zone 2]
Arsenic Concentrations by Depth



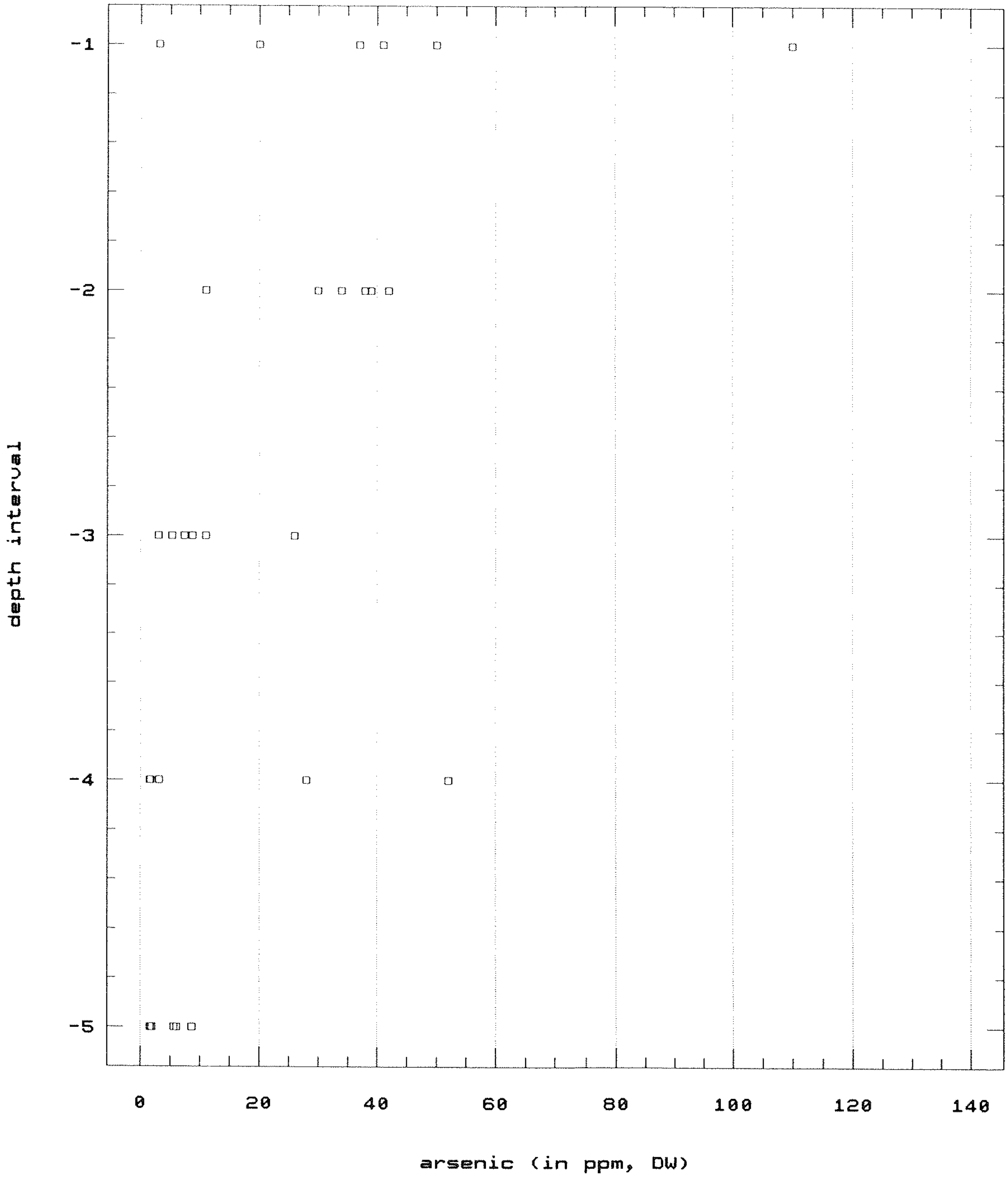
[beach samples, if any, excluded]

Child-Use Area 21 [Zone 2]
Arsenic Concentrations by Depth



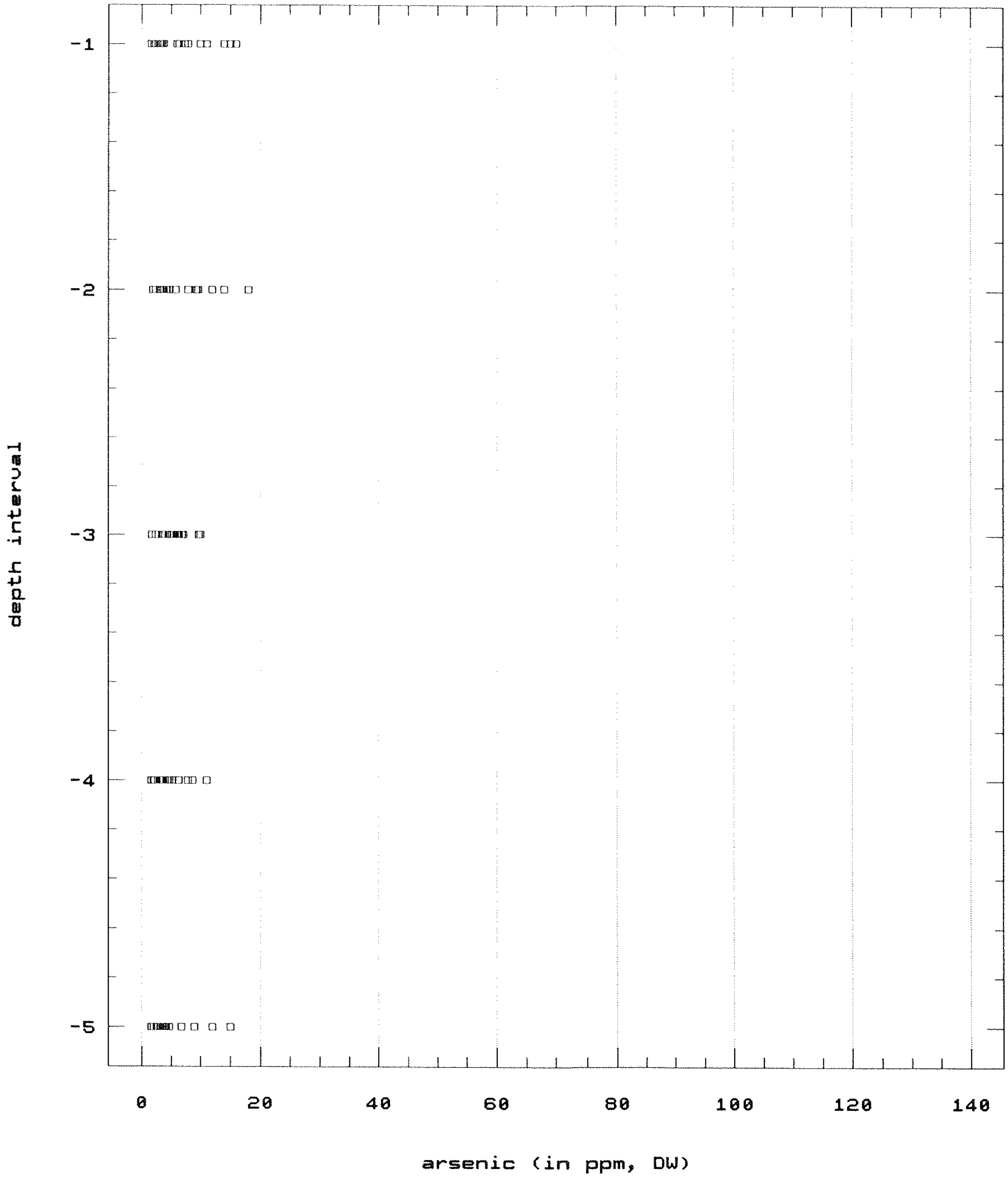
[beach samples, if any, excluded]

Child-Use Area 22 [Zone 2]
Arsenic Concentrations by Depth



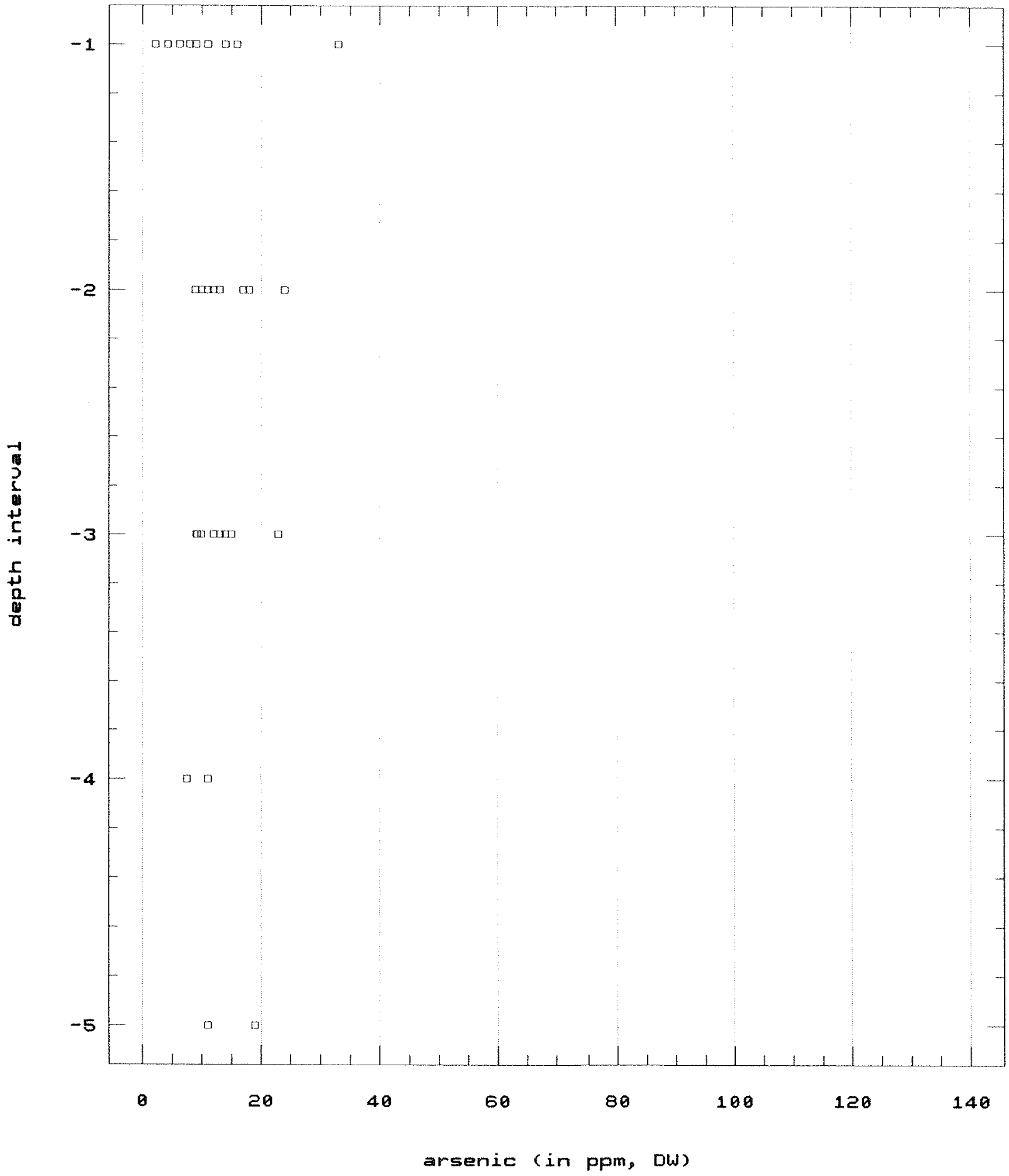
[beach samples, if any, excluded]

Child-Use Area 34 [Zone 2]
Arsenic Concentrations by Depth



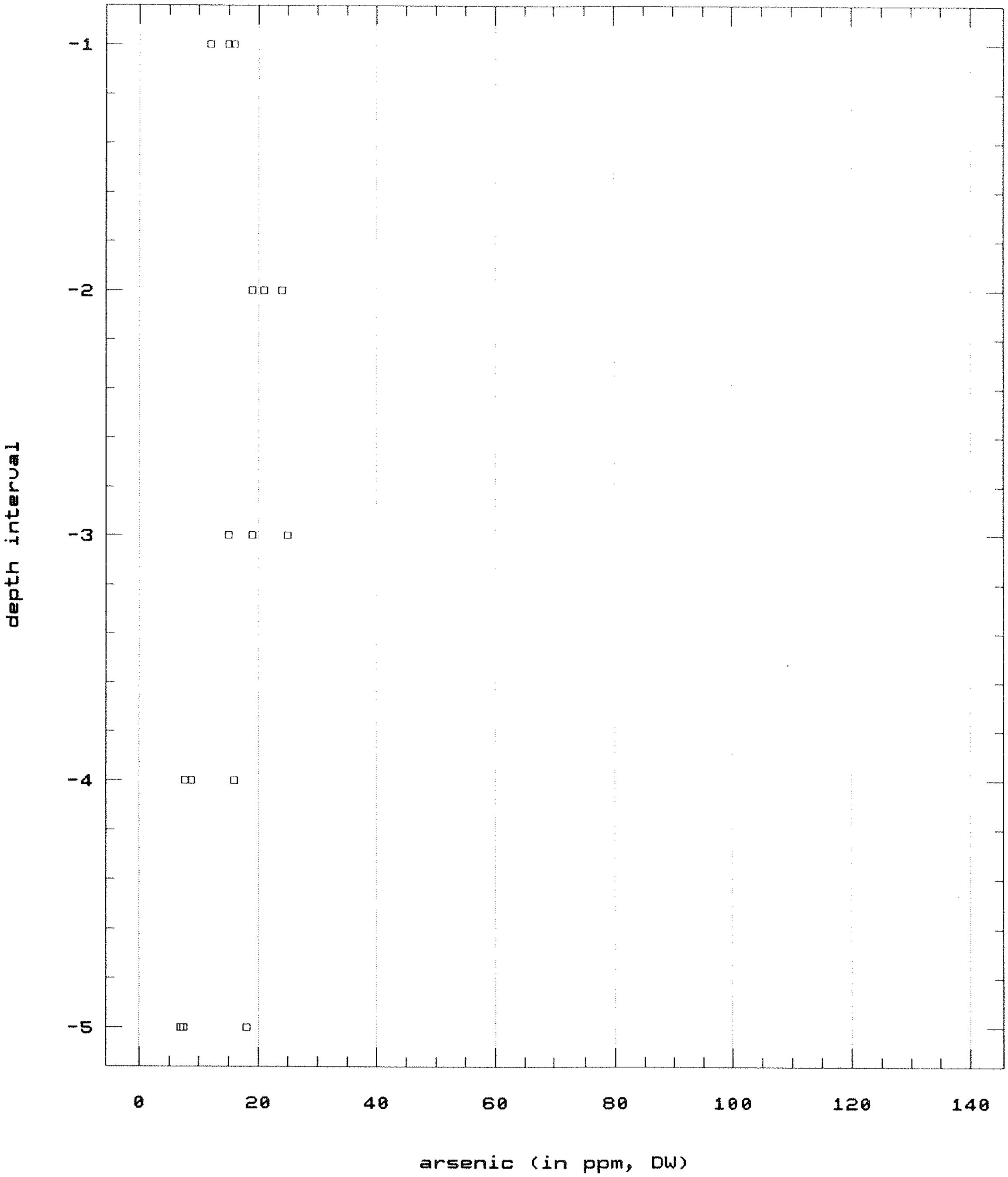
[beach samples, if any, excluded]

Child-Use Area 19 [Zone 3]
Arsenic Concentrations by Depth



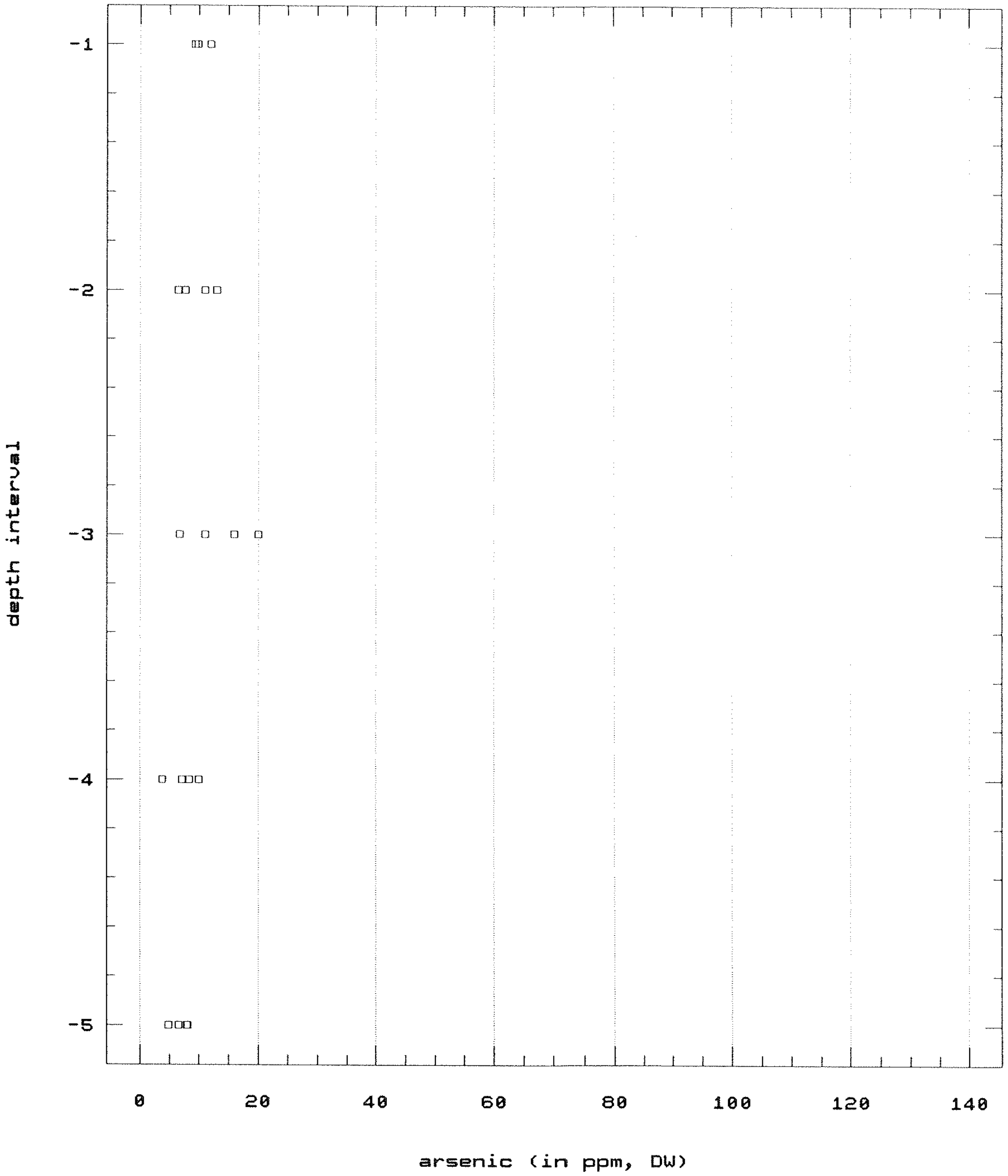
[beach samples, if any, excluded]

Child-Use Area 23 [Zone 3]
Arsenic Concentrations by Depth



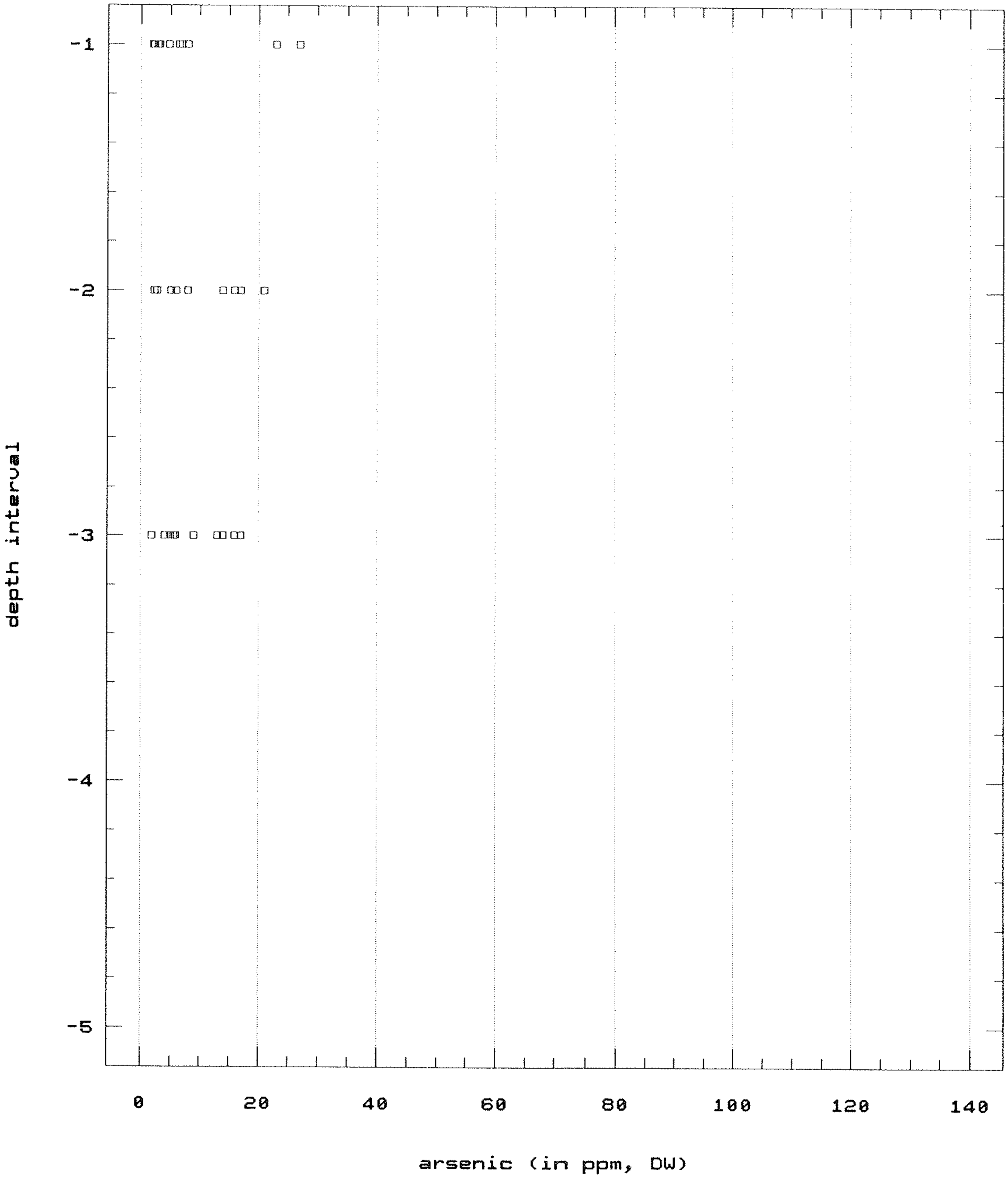
[beach samples, if any, excluded]

Child-Use Area 25 [Zone 3]
Arsenic Concentrations by Depth



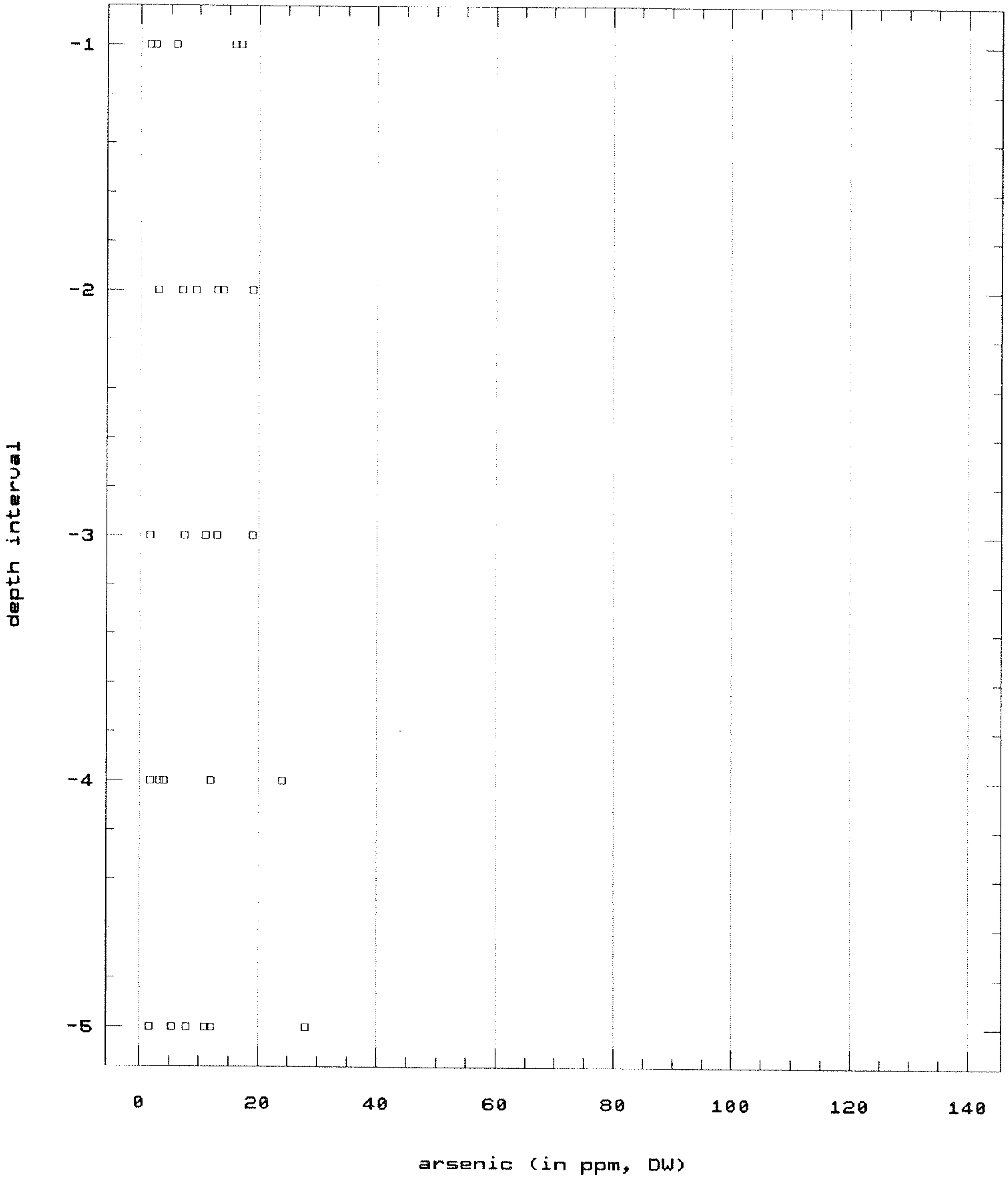
[beach samples, if any, excluded]

Child-Use Area 26 [Zone 3]
Arsenic Concentrations by Depth



[beach samples, if any, excluded]

Child-Use Area 46 [Zone 3]
Arsenic Concentrations by Depth



[beach samples, if any, excluded]