PUBLIC HEALTH - SEATTLE & KING COUNTY

FINAL REPORT

VASHON/MAURY ISLAND SOIL STUDY
1999-2000

prepared by

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EXECUTIVE SUMMARY

Soil contamination with arsenic, lead, and other metals in the area downwind from the former Tacoma Copper Smelter has been documented on Vashon/Maury Island in a number of small-scale investigations since the early 1970s. The Tacoma Copper Smelter operated for more than 90 years, closing in 1986. This study provides the first comprehensive survey of near-surface soil contamination by arsenic, lead, and cadmium over all of Vashon/Maury Island. A pilot-scale investigation of soil contamination on mainland King County shoreline areas east of Vashon/Maury Island is included in the study. Little information is available from previous studies on the mainland. The Washington State Department of Ecology and Public Health - Seattle & King County funded this study.

All soil sampling occurred in forested areas assumed to represent the least disturbed soils available. Residual soil contamination is expected to be greatest in undisturbed soils; therefore, the results of this study likely reflect the upper range of soil contamination across all land uses. Soil samples were collected at 177 locations at depths of 0-2 inches and 2-6 inches; some 2-6 inch samples were archived without analysis. At 34 locations (approximately 20 percent), additional closely spaced samples were collected to characterize the variability in contamination over small distances. Laboratory analyses were performed by OnSite Environmental Inc. of Redmond, Washington. A total of 436 soil samples was analyzed for arsenic, lead, and cadmium. Arsenic analyses used graphite furnace AA methods; lead and cadmium were analyzed using ICP methods. Based on initial results, cadmium analyses were omitted for 98 of the final samples analyzed. Contaminant concentrations are reported on a dry weight basis and for the <2mm size fraction of the soil samples.

Data validation reviews were performed on approximately one-third of the data reported by the laboratory. The results supported the high quality of the data. Results for four samples were removed before data evaluation (one sample exceeded the hold time for analysis, and three samples represented repeated field sampling or laboratory analysis). After averaging fifteen field duplicate results, the final data evaluation data set included 417 soil samples.

The detailed study design was developed by a work group involving agency and community representatives. The primary objective of the study is to characterize the upper-bound magnitude and extent of soil contamination in the study area. Several specific data

evaluation objectives were identified by the work group; the study design reflects those concerns . Statistical and spatial evaluations of the data support the following conclusions:

- Magnitude of contamination. A broad range of contaminant concentrations is reported, from at or near background levels to substantially elevated levels (one to two orders of magnitude above background). The maximum arsenic, lead, and cadmium concentrations are 460 ppm, 1300 ppm, and 15 ppm, respectively. The statistical distributions of concentrations are right-skewed, meaning the higher values occur relatively infrequently.

- Large-scale spatial pattern. Contamination does not occur equally throughout the study area; instead, a distinct large-scale spatial pattern is observed. The highest levels generally occur on Maury Island, followed by South Vashon Island, portions of the mainland nearshore areas, and North Vashon Island. The extent of soil contamination inland from the mainland shoreline areas remains to be defined.

- Small-scale variability. Most sampling locations were spaced about 1500 to 2000 feet apart. Contaminant concentrations demonstrate considerable variability at this scale within localized regions of the study area. Variability was also explored at much smaller scales, with samples as close as 50 feet apart. Even over distances that small, contaminant concentrations can vary several-fold (i.e., several hundred percent). The possibility of significant small-scale variability should be recognized in future studies.

- Contaminant correlations. Arsenic, lead, and cadmium demonstrate a high degree of association. Statistical correlations among all pairs are highly significant. Thus, each of these contaminants shows a similar overall pattern of occurrence, although at different concentrations.

- Depth profiles. Contaminant concentrations well above background levels were observed for all three contaminants at both sampling depths. Comparison of the 0-2 inch and 2-6 inch results shows that the downward movement of arsenic is significantly greater than that of lead. Almost half of the depth profiles show higher arsenic concentrations in the 2-6 inch interval than at 0-2 inches. This has important implications for future soil sampling programs. Since sampling was limited to the top 6 inches in this study, the full depth of contamination was not defined.

The results of this study are generally consistent with information from previous, smaller studies, but they substantially increase our knowledge of the magnitude and extent of soil contamination in King County in the area downwind from the former Tacoma Smelter. Public Health -Seattle & King County and the Washington State Department of Ecology, together with other agencies and local governments, are working with the affected communities to formulate appropriate response actions given this information, and to design and perform followup studies to address remaining questions about contaminant occurrence and effects.

1.0 PROJECT DESCRIPTION AND OBJECTIVES

In 1999 and 2000, Public Health - Seattle & King County (PHSKC) performed the first comprehensive survey of contamination by arsenic, lead, and cadmium in surficial[1[1]] soils on Vashon/Maury Island, Washington. This study also included an initial "pilot scale" evaluation of surficial soils in shoreline areas of the King County mainland, east of Vashon/Maury Island. The results of soil sampling and analysis in both areas are presented and evaluated in this report.

Previous studies. Since the early 1970s, more than a dozen studies have determined arsenic concentrations in surficial soils in selected areas of Vashon/Maury Island (see Sections 2.2 and 7.0, and the references in Section 9.0). Analyses in some of the studies included lead, with analyses of additional metals (e.g., cadmium, selenium, or antimony) occasionally reported. Those studies were motivated by concerns over the magnitude, extent, and fate of contamination resulting from operation of the former ASARCO Tacoma Smelter, located at Ruston on the shoreline of Commencement Bay, a few miles south/southwest of Vashon/Maury Island (see PSAPCA 1981a and 1981b for a general review of Tacoma Smelter operations and emissions). The Tacoma Smelter operated for over 90 years, closing smelting operations in 1985 and arsenic processing operations in 1986. For many years, the Tacoma Smelter was the sole domestic supplier of arsenic for the United States. Arsenic has generally been considered the best tracer element for evaluating smelter impacts (see, for example, Crecelius et al. 1974 and PSAPCA 1981a and 1981b), and it has also been the focus of concerns for potential human health risks from smelter emissions. The smelter site and surrounding areas (within an approximate one-mile radius) are subject to ongoing cleanup actions under EPA's Superfund program.

[1[1]] In this study, soils were sampled to a depth of 6 inches below the forest duff layer. The term "surficial" rather than the simpler term "surface" soils is used to emphasize that there can be important differences in potential exposures (e.g., frequency of contact) between soils within the top inch or so versus soils at depths of, for example, 4 to 6 inches. "Surficial" is in this sense used to refer to true surface soils as well as near-surface soils.

Soil studies over the past 30 years, performed both during smelter operations and after closure, have documented elevated levels of arsenic, lead, and other metals in surficial soils on Vashon/Maury Island. However, the previous studies in aggregate do not provide a comprehensive portrait of current soil contamination levels. Separate studies used different protocols for collection and laboratory analysis of soil samples, making comparisons among studies more difficult. The studies also targeted different types of land uses, such as residential yards and garden areas, parks and playgrounds, and relatively undeveloped and undisturbed areas. The degree of soil disturbance has been shown to be an important factor affecting the residual concentrations of air-deposited contaminants in surficial soils; the marked differences in past soil-disturbing activities among sampled land types is expected to contribute significantly to variability in results. The representativeness of studies performed up to 30 years ago for characterizing current soil contamination levels can be questioned, especially with respect to current depth profiles for contamination. Finally, the number (density) and spatial pattern of prior sampling locations are both limited; most of the previous studies have focused on Maury Island and south Vashon Island, with relatively few samples collected on north Vashon Island. Evaluation of all of these factors supported the conclusion that previous studies, considered cumulatively, could not provide a comprehensive description of current soil contamination levels on Vashon/Maury Island. Previous study results were used in developing the study design for the current PHSKC study (see Section 2.2).

In addition to soil sampling and analysis studies, several other types of investigations help to characterize the likely extent of soil contamination in the area downwind of the former Tacoma Smelter. Those additional studies included deposition modeling, plume tracking (opacity) studies, an extended series of precipitation chemistry monitoring studies, sediment core chemistry monitoring, vegetation sampling, and bee biomonitoring (see references listed in Section 9.0). Several of these studies (e.g., deposition modeling, precipitation chemistry studies, and bee biomonitoring) have provided "contour" mapping of potential impact areas. The resulting predicted pattern of soil contamination levels on Vashon/Maury Island had not been fully validated by soil sampling and analysis data prior to this PHSKC study. The "contouring" study results also indicated that the spatial scale for measurable smelter impacts may be on the scale of tens of miles, extending onto the mainland areas of King County[2][2]. Very few soil

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[2][2] A recently discovered study by Environment Canada comparing periods before and after smelter closure showed significant decreases in sulfate and arsenic levels in precipitation along the Canadian border coinciding with smelter closure. See D.A. Faulkner, "The Effect of a Major Emitter on the Rain Chemistry of Southwestern British Columbia - a Second Look",

samples from such mainland areas are available from previous studies; nevertheless, some elevated soil arsenic results have been reported. The study of Vashon/Maury Island soils was extended to include an initial "pilot scale" evaluation of soils in mainland King County shoreline areas east of Vashon/Maury Island.

Project description and objectives. The ongoing Superfund cleanup of areas surrounding the Tacoma Smelter that were affected by air deposition from smelter emissions does not include any areas on Vashon/Maury Island (see USEPA, Region 10 1993). Residents of Vashon/Maury Island were active participants in several earlier processes involving Tacoma Smelter operations and impacts, including the PSAPCA Environmental Impact Statement process under SEPA and EPA's proposed rules for arsenic under the National Emissions Standards for Hazardous Air Pollutants (NESHAPS) provisions of the Clean Air Act. After EPA issued its Superfund Record of Decision for cleanup of residential areas in Ruston and North Tacoma, in 1993, soil contamination issues arose for a number of years primarily in connection with real estate transactions. In 1998 and 1999, a proposal to expand gravel mining operations at the Lone Star (now Glacier Northwest) Maury Island gravel mine (see King County DDES 1999) resulted in two independent soil studies on gravel mine property. Both studies showed significantly elevated soil arsenic concentrations, with maximum levels in relatively undisturbed areas exceeding 300 ppm. These findings resulted in heightened interest in soil contamination levels and impacts among some Vashon/Maury Island residents. In this same time frame, Ecology was also beginning to evaluate "area contamination" issues under the Model Toxics Control Act (MTCA), which represented areas of contamination far larger than the typical MTCA site. Widespread soil contamination by arsenic and other smelter-related metals was recognized by Ecology as one such "area contamination" problem.

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presented at the November 8-10, 1987 annual meeting of the Pacific Northwest International Section, Air Pollution Control Association, in Seattle, WA.

The current study was conceived in response to both community concerns specific to Vashon/Maury Island and Ecology interest in evaluating area contamination problems where threats to human health or the environment could occur over large areas. It is intended to provide a comprehensive survey of current surficial soil contamination over all areas of Vashon/Maury Island, as well as an initial evaluation of King County mainland areas to the east. Funding for the study was provided jointly by PHSKC and Ecology. PHSKC staff developed study plans (see PHSKC 1999), in collaboration with Ecology, and provided staff to perform all field sampling work. Laboratory analyses were performed by OnSite Environmental, Inc., Redmond, Washington under contract to PHSKC. The study design was developed through a multi-party Vashon/Maury Island Soils Work Group. PHSKC retained Gregory L. Glass as a consultant to work with the Soils Work Group in developing a study design; he also performed data evaluations and prepared the project report. PHSKC maintained the database of analytical results and performed data validation reviews. Ecology provided technical support and oversight of the study.

The primary objectives of the study are to document the current magnitude and large-scale spatial patterns in soil contamination in relatively undisturbed King County areas downwind from the former Tacoma Smelter, including a comprehensive survey of all of Vashon/Maury Island and an initial exploration of King County mainland shoreline areas to the east. This regional-scale study provides information useful for focusing additional investigation and response actions by the agencies and the public. Several detailed data evaluation objectives were also identified and reflected in the study design: 1) to evaluate the vertical pattern of soil contaminant concentrations at different depths (depth profiles); 2) to assess the relationship (correlations) among different soil contaminants; and 3) to evaluate how soil contaminant concentrations vary within relatively small areas (variability and spatial scale). Since all soil sampling occurred in relatively undisturbed areas, the results are believed to be biased toward upper-bound contaminant concentrations. All data interpretations should take this study design feature into account. This study does not provide any information on the comparative magnitudes or patterns of contamination between relatively undisturbed and developed/disturbed properties.

The detailed study design and data evaluations are discussed in subsequent sections of this report. In brief, the study involved collection of soil samples at 0-2 inch and 2-6 inch depth intervals; analyses for arsenic, lead, and cadmium - three primary smelter-related contaminants; targeted sampling in forested areas believed to represent least-disturbed soils where contaminant levels are likely to be highest; and collection of samples in an approximate grid pattern within forested areas, plus additional collection of closely-spaced samples (in comparison to grid spacing) to look at local variability. In all, 436 soil samples were analyzed for arsenic and lead, and 338 for cadmium.

Report organization. Section 2.0 provides a discussion of the study design. The sampling and analysis protocols and results are described in Sections 3.0 through 5.0. Statistical and spatial data evaluations are presented and discussed in Section 6.0, with "visualization" of the results in several summary figures. In Section 7.0, the results of this study are reviewed in comparison to the results of previous studies. The main conclusions from the study are given in Section 8.0, and a detailed references list is provided in Section 9.0. Additional technical details are provided in a series of attachments to the main report.

2.0 STUDY DESIGN

A brief discussion of the study design is provided in the following sections. More detailed information is provided in a sampling design report prepared for PHSKC (Glass 1999).

2.1 STUDY DESIGN PROCESS

From the inception of the study, the study design process was guided and reviewed by a multi-party Vashon/Maury Island Soils Work Group. A technical subcommittee of this Work Group was established to work on study design issues. The technical subcommittee included representatives of PHSKC, the Washington State Department of Health, Ecology, and, importantly, citizens representing the residents of Vashon/Maury Island. A staff member of King County Councilman Greg Nickels attended several meetings. A consultant, Gregory L. Glass, was also retained to assist the technical subcommittee and to document the adopted study design (see Glass 1999). The full Soils Work Group also included a student from the University of Washington and a staff person from the King County Department of Development and Environmental Services (DDES).

The Soils Work Group technical subcommittee held a series of working meetings from March through May, 1999. Topics addressed during those meetings included, among others: 1) defining the problem and study objectives; 2) reviewing information from previous studies; 3) developing a site conceptual model; 4) identifying study area boundaries; and 5) developing the technical study design. From their review of available data, including but not limited to the recent soil sampling results from the Lone Star Maury Island Gravel Mine (King County DDES 1999), the subcommittee members concluded there was already convincing evidence of elevated soil contaminant concentrations on Vashon/Maury Island (although the existing information was deemed insufficient to characterize the full magnitude and extent of such contamination). One result of this finding was that subcommittee members began to examine how information on soil contamination would be used, and what actions government agencies and community members would take in response to such information. The numerous identified issues were collectively referred to by the subcommittee as "response objectives". Evaluation of response objectives was passed from the technical subcommittee to the full Vashon/Maury Island Soils Work Group. The technical study design itself was not modified based on response objectives; rather, the design was developed based on the identified information needs and study objectives. Starting before release of the preliminary study results in April 1999, a series of actions coordinated with the community was begun to meet the identified response objectives (see PHSKC 2000). Response actions are expected to continue for an extended period of time. Ecology, as the lead agency, has designated the Tacoma Smelter Plume Site, including Vashon/Maury Island, as a site under MTCA. Ecology will work with PHSKC, local governments, and citizens of affected areas on continuing studies and response actions.

The subcommittee discussed whether the objectives for defining current soil contamination should be met by a phased study approach. Part of that discussion was recognition of practical constraints on the study, including staff resources for sample collection, budgets for lab analyses and other study costs, difficulties in securing a large number of access agreements for sampling, and other factors. The subcommittee chose to focus this study on a comprehensive, synoptic survey of current soil contamination levels over all of Vashon/Maury Island. Vashon/Maury Island is the landmass immediately downwind of the former Tacoma Smelter, and is therefore likely to have the highest levels of residual soil contamination, reflecting the greatest potential human exposures. In this approach, the information from previous studies was considered an adequate basis for detailed study design, avoiding the need for further preliminary or pilot-phase studies. This study was designed to reveal large-scale patterns in soil contamination for relatively undisturbed areas. Later phases of sampling will address such questions as how land use types and soil disturbance affect the soil contamination levels, or what the concentrations of contaminants are in specific identified areas of high potential human exposures. The technical subcommittee recognized a need for early guidance to individual residents on how they could determine contamination levels on their own properties, since this study focused exclusively on undisturbed (forested) areas as the best technical and practical approach to understanding island-wide large-scale patterns of contaminant deposition and consequent soil contamination. As a result, and separate from the main study design process, self-testing guidance was prepared with standardized soil collection and laboratory analysis protocols identified (see PHSKC 2000).

Once a preliminary study design had been developed, proposed sampling areas and sampling locations were identified and marked on overlays to a composite airphoto of Vashon/Maury Island (Walker & Associates 1999). The proposed sampling locations were reviewed with community representatives at a meeting on Vashon Island on May 10, 1999. After minor revisions based on comments received at that meeting, the final study design was presented to the full Vashon/Maury Island Soils Work Group on May 12, 1999. The Work

Group approved that study design and PHSKC completed the final actions necessary prior to field activities. Those implementation steps included preparation of a Field Sampling Plan, Health and Safety Plan, and Quality Assurance Project Plan; developing procedures for contacting property owners and securing access agreements; training the field sampling teams in the sample collection and sample handling protocols; contracting with the analytical laboratory and acquiring standard reference materials; and establishing a field office on Vashon Island for sampling activities.

2.2 REVIEW OF PREVIOUS STUDIES

No previous study provides a comprehensive survey of soil contamination on Vashon/Maury Island and other King County areas downwind of the former Tacoma Smelter. A substantial number of studies have been performed over the past 30 years, however, that provide information on soil contaminant levels for limited sampling areas, or that otherwise help characterize the likely spatial extent of contamination (see ASARCO 1983; Bromenshenk et al. 1985; Carpenter et al. 1978; City of Tacoma and Glass 1999; Crecelius et al. 1974; Dempsey 1991; Heilman 197[3?]; Heilman and Ekuan 1977; Hofer et al. 1972; Johnson and Lippman 1973; King County Department of Development and Environmental Services 1999; Knudson et al. 1977; Larson et al. 1975; Landau Associates 1999a and 1999b; Lefkovitz et al. 1997; Lowry 1983; Luecken et al. 1989; Lutrick 1971; Polissar et al. 1987; PSAPCA 1974, 1981a, and 1981b; Ratsch 1974; Riehl 1979; Simpson 1983; Terra Associates, Inc. 1999; Vong et al. 1988; Vong and Peterson 1988; and Wishik 1999).

Information from these previous studies was compiled and reviewed with the technical subcommittee. Soil arsenic concentrations reported in multiple studies were assembled and hand-plotted on a Vashon/Maury Island base map (at a scale of 1" = 2000'); the important differences in sampling and analysis protocols that affect data comparability among these studies were noted. This cumulative soil arsenic data plot provided a visualization of the spatial coverage and sampling density available from previous investigations.

In spite of limited spatial coverage and the variations in study protocols, the accumulated soil arsenic data appeared to be generally consistent with other information such as wind roses and "contouring" studies (e.g., deposition modeling, precipitation chemistry monitoring, and bee biomonitoring) in suggesting the large-scale pattern of contaminant distribution. The subcommittee adopted a conceptual model reflecting this suggested large-scale pattern of contaminant deposition as a basis for development of the detailed study design to evaluate current soil contamination (see discussion in Section 2.3 below).

The mapped arsenic concentrations from previous studies showed a large degree of variability within relatively small subareas of Vashon/Maury Island, with part of the observed variability undoubtedly due to differences in study protocols. Two recent sampling and analysis programs for surficial soils at the Lone Star Maury Island Gravel Mine site provided relatively dense local sampling well-suited for a preliminary evaluation of local variability in contamination levels. Analyses of these data sets (Landau Associates Inc. 1999 and Terra Associates, Inc. 1999; see also King County DDES 1999) were performed and confirmed that soil arsenic concentrations can vary substantially in undeveloped (forested) areas over even relatively small horizontal distances. Similar local variability had also been observed in a study of soil arsenic and lead concentrations in forested areas downwind of the Tacoma Smelter covering approximately 5 square miles in Pierce County (see City of Tacoma and Glass 1999). The technical subcommittee included sampling to evaluate small-scale variability in contamination levels in all parts of Vashon/Maury Island as part of the design for the current study based on these results.

The "contouring" studies noted previously and the limited soil arsenic results for mainland areas of King County east of Vashon/Maury Island indicated that some degree of soil contamination was likely on the mainland. A summary of all information from previous studies for mainland areas of King County was prepared for review by the subcommittee. The available information was judged sufficient to expand the study area beyond Vashon/Maury Island to include mainland areas to the east. The technical subcommittee decided to include preliminary, or "pilot-scale", sampling along near-shore locations from the Pierce/King County line north to approximately SeaTac airport in the current study. This was not intended to cover all areas of possible soil contamination; the available data are inconclusive with respect to establishing likely boundaries for such study areas. The pilot-scale sampling of near-shore areas will help define the main areas or directions of impact and provide an initial basis for designing further investigations of soil contamination on the mainland.

2.3 STUDY DESIGN PRINCIPLES

Careful consideration of the various factors that influence reported contaminant concentrations in soil samples - type of land use, degree and timing of soil disturbance, depth intervals sampled, soil size fractions tested, composited versus discrete sampling, laboratory analysis methods, and more - was required in deciding what study design and sampling and analysis protocols would best meet the objectives of this study. It was clear to the study design team that different approaches to sampling and analysis would produce different results for contaminant concentrations.

The primary study objective of determining the magnitude and extent of soil contamination can be understood as essentially a mapping problem. The U.S. Geological Survey has developed a statistical approach to such mapping problems (see Miesch 1967 and 1976b for theory, and Miesch 1976a, Crock et al. 1992, Erdman et al. 1976, Severson et al. 1990, and Tidball 1976 for example applications); a review of that literature was very useful to the study design team. In Miesch's approach, an understanding of the spatial scale of variability in geochemical data is necessary to design a sampling study for producing a useful map (see also Loftis et al. 1991 for a similar discussion of the importance of understanding scale issues). Knowing the important spatial scale for the matter under investigation determines what sampling resolution (roughly, the distance between sampling locations) is required to produce a map with the important property of stability: a stable map is not changed significantly by the collection of additional information, and therefore adequately represents the true state of the world. Miesch developed a specific phased sampling approach to do geochemical mapping, with the first phase (formally, a nested ANOVA design with varying inter-sample distances) designed to identify what spatial scale contributes most to the variability in the data. That determines the grid-spacing for the second phase of sampling, which is used to produce the desired map.

For the Vashon/Maury Island soil study, a review of available data and some practical considerations (available sampling areas, budget constraints) were used instead of Miesch's Phase I study to define sampling densities. Additional sample collection to explore the variability in contaminant levels over small distances, however, was included in the study design (see spatial scale sampling discussion below). It was recognized that the map produced in this investigation would not necessarily support extrapolation of contaminant concentrations to unsampled areas, particularly if those areas represented different land cover and land use types. Instead, by focusing on relatively undisturbed areas where surficial soil contamination is expected to be highest (disturbance should only decrease, not increase, contaminant concentrations), this study is intended to provide a large-scale map of the general upper-bound pattern of soil contamination over all of Vashon/Maury Island. The degree of local variability in contaminant levels, especially for developed/disturbed properties, may well be so large that property-specific sampling should be recommended rather than extrapolation from even nearby samples to accurately determine the magnitude of soil contamination. By sampling only relatively undisturbed areas, the results are intentionally biased toward the higher concentrations occurring within the study area. All mapping of contaminant results should be interpreted with this likely bias in mind.

The major elements of the study design are briefly reviewed below.

Contaminants of concern. Various types of information have been used to characterize what contaminants occurred in Tacoma Smelter emissions. While arsenic has been the primary focus in many previous studies, smelter emissions are known to have contained a list of metals. Information is available from smelter feedstock analyses, emissions testing, stack fallout testing, air particulates and precipitation analyses, and soil analyses to identify smelter-related contaminants. Air quality studies comparing strike and nonstrike periods (i.e., periods of smelter shutdown versus smelter operations) have clearly shown marked increases in ambient air concentrations of a number of elements during smelter operations. Analyses for 13 metals in soil samples from areas close to the smelter have shown 8 to have consistent high pairwise correlations indicative of a common source (Black & Veatch 1988); those 8 elements are arsenic, selenium, lead, mercury, silver, cadmium, antimony, and copper. (Note: this may not be a complete list of smelter-related contaminants). Screening-level exposure and risk analyses have generally shown arsenic, lead, and cadmium to be the principal concerns for possible human health threats. Given the high documented correlations among smelter-related contaminants, these three analytes can also serve as indicators for other contaminants. For this study, soil samples were analyzed for total (unspeciated) arsenic, lead, and cadmium. Percent moisture in soil samples was also determined so that results could be reported on a dry weight basis.

Study area. This PHSKC study is limited to areas within King County and does not address all potential smelter impact areas. Ecology and other local health jurisdictions will separately evaluate the need for studies in additional areas (e.g., Pierce County outside of EPA's current Superfund cleanup area).

As already noted, the study area includes all of Vashon/Maury Island, as well as the nearshore mainland areas to the east, from the Pierce/King County Line north to the vicinity of SeaTac Airport.

Sampling areas. Deposition of any air-transported contaminants released from the Tacoma Smelter may have occurred over a period of more than 90 years, with accumulation over that time period in surficial soils. Activities that disturb soils, especially nonhomogeneous or spatially limited activities, introduce additional complexity to the pattern of soil contamination, both horizontally and vertically. More intensive sampling is needed to characterize disturbed soils versus relatively undisturbed soils. Moreover, soil disturbance may remove or dilute contamination, or make it less likely to be detected under typical sampling protocols (e.g., those limited to uppermost soils when disturbance has moved contamination deeper in the soil profile). As a result, data from limited sampling in disturbed areas may significantly underestimate the highest local contaminant levels.

In this study, all sampling was targeted to relatively undisturbed areas. This provided a consistent land use/land cover pattern for all sampling locations, making data interpretation easier. The resulting data represent better estimates of the upper ranges of soil contamination present in island soils, due to the minimal disturbance of soils; this approach results in more information for regional-scale mapping than the same number of samples taken from disturbed soils with a more complicated contamination pattern. Focusing sample collection in relatively undisturbed areas also minimized potential confounding with other sources of contamination.

The original old growth forests of Vashon/Maury Island have essentially all been logged, meaning some degree of disturbance has occurred everywhere. However, all parts of the island have areas of naturally regenerated forests whose tree maturity indicates a lengthy period without substantial development activities. A recent composite airphoto (Walker & Associates 1999) with a scale of 1"=1750' was used to identify wooded parcels of sufficient size to serve as candidate sampling areas. The coverage of these identified areas was adequate to provide the desired comprehensive survey of Vashon/Maury Island. In contrast, the mainland study area is intensively developed with very limited undisturbed areas. The best candidate sampling areas were identified as a series of shoreline parks and preserves that provide a north-south alignment for sample collection adequate for the preliminary pilot study of this region.

The overall study area was stratified into three zones based on information available from previous studies and the site conceptual model. The primary goal of this stratification of the study area was to provide a more efficient study design by varying the intensity of sampling according to the expected magnitude and variability in contamination levels. The three defined strata were south Vashon and Maury Island (zone 1), the mainland areas (zone 2), and north Vashon Island (zone 3). The dividing line between zones 1 and 3 was a roughly northeast-southwest line located somewhat north of Portage, where Maury Island connects to Vashon Island. This orientation for the zone boundary was chosen based on the estimated contour patterns of smelter deposition.

Sampling locations and exclusion criteria. Sampling locations were selected within the candidate (forested) sampling areas identified from airphoto review using a systematic sampling grid approach, with a random grid starting point. Grid spacings of 1500' and 2000' were chosen for zones 1 and 3, respectively; this results in approximately 80 percent greater sampling density in zone 3 versus zone 1. Adjustments of up to a few hundred feet from grid locations were allowed to maximize the number of sampling locations within candidate areas. All soil samples reflect discrete locations, not broader horizontal composites.

The candidate areas on the mainland were few in number and relatively small in size individually. An "opportunistic" approach was used to identify a minimum of three well-spaced sampling locations (1500' spacing if possible) within individual sampling areas, with up to 8 areas targeted for sampling in a roughly north-south alignment along the shoreline.

General exclusion criteria were identified and applied to avoid sampling close to major roads, in wetland areas, or on steep slopes. Additional site-specific exclusion criteria were considered by the field sampling teams to avoid sampling in areas with evidence of soil disturbance or at locations otherwise deemed unrepresentative.

A total of 213 sampling locations was identified: 120 in zone 1 (with 73 on south Vashon Island and 47 on Maury Island), 24 in zone 2, and 69 in zone 3.

Depth intervals. Soil samples were collected from two near-surface depth intervals, 0 to 2 inches and 2 to 6 inches, at each sampling location. The vegetative duff layer of decaying leaves, branches, and needles was removed before starting sampling. All of the 0 to 2 inch samples were analyzed. Initially, only 20 percent of the 2 to 6 inch samples (reflecting broad spatial coverage in all three zones) was targeted for contaminant analyses; the remaining samples from this second depth interval were archived at the laboratory. A review of the comparative 0-2" versus 2-6" results at that 20 percent of sampling locations ultimately led to a decision to analyze all of the remaining archived 2-6" samples from zones 1 and 2.

Based on previous soil studies (e.g., Dempsey 1991) and evaluations of the likely fate and mobility of smelter-related contaminants, vertical movement of the air-deposited contaminants down the soil profile was expected to be quite limited. The two depth intervals used in this study provide a first look at contaminant mobility. Some information exists (e.g., Terra Associates, Inc. 1999) to suggest that higher concentrations may occasionally be found below 6 inches. This study does not attempt to define the maximum depth to which contaminants could have moved.

Assuming that maximum residual soil concentrations of smelter-related contaminants could occur at varying depth intervals of near-surface soils (all within the top foot or so) from one sampling location to another, analyzing multiple depth intervals increases information on the maximum current concentrations and thereby improves the mapping of contamination patterns within the study area. Note in this regard that since fewer 2-6" depth interval samples were analyzed for zone 3 (north Vashon Island), there is a relative increase in uncertainty in that portion of the study area. The overall ranges of contaminant concentrations in zone 3 are, however, narrower than in the rest of the study area.

The selected depth intervals for sampling provide a consistent protocol and uniformity in information over the entire study area. Those intervals have also been used in several other soil studies, enhancing data comparability. They are, however, an obvious simplification of the true, detailed depth profiles for contaminants; for example, if at a given sampling location the 0-2" result is greater than the 2-6" result, it may nevertheless be the case that the maximum contaminant concentration occurs between 3 and 4 inches. Depth intervals for sampling have traditionally been selected based on consideration of potential human exposures (greatest for surface soils), soil remediation approaches (equipment tolerances for scraping), and study costs and other practical constraints. This study chose depth intervals to 6 inches for sampling primarily to allow an initial analysis of contaminant depth profile patterns and to avoid missing maximum contaminant concentrations (e.g., by focusing only on 0-2 inch samples). It was not intended to determine maximum depths of contamination or to provide complete data for exposure assessment or remediation planning. Practical constraints of costs and staff resources also contributed to limiting samplinmg to only the top 6 inches.

Spatial scale sampling. At approximately 20 percent of the targeted grid sampling locations, additional "spatial scale" samples were collected to investigate and document scale-dependent variability. At selected locations, a second sample was collected at a distance of 300 feet in a random direction from the grid sample. A third sample was then collected at a distance of 50 feet from the second, in a random left-right direction perpendicular to the line between the first and second samples. These spatial scale triplets were spaced to provide broad coverage over all three sampling zones. Both 0-2" and 2-6" depth intervals were sampled at all spatial scale sampling locations.

The general grid sampling approach was expected to provide suitable information for determining the regional scale map of soil contamination patterns. Local variability was assumed to occur, based on previous studies, to a degree that made it impractical to address by a decreased grid spacing. The spatial scale sampling was therefore included in the study design to evaluate how contaminant concentrations vary at scales substantially smaller than the grid spacings of 1500 to 2000 feet.

Sample preparation. Contaminant concentrations in soil have been shown to be affected by particle sizes. In this study, all samples were sieved at the laboratory to separate particles less than or equal to 2 mm, and laboratory analyses were performed on that smaller size fraction of the bulk samples collected in the field. Ecology's Model Toxics Control Act cleanup regulation (Chapter 173-340 WAC) specifies that this size fraction should be tested to determine compliance with state cleanup standards. Any data evaluations related to compliance with MTCA regulations or exposure/risk assessments should be based on analytical results for sieved samples.

Given the large number of property owners from whom access agreements had to be obtained within a relatively short time period, it was expected that some reduction from the number of sampling locations designated in the study design would occur. Provisions were made for developing alternate sampling locations if required. However, the study design included a tolerance for a modest degree of loss of sampling locations.

3.0 SAMPLE COLLECTION

All field sampling activities were performed by five PHSKC staff, operating as two-person sampling teams. 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 1999).

Sample collection took place between August 17, 1999 and December 6, 1999. 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. A community meeting was held on August 5, 1999 on Vashon Island to introduce the field sampling teams, and to respond to any citizen questions about the program, before sampling started. Throughout the period of field work, PHSKC maintained a field office on Vashon Island where community members could contact the sampling teams.

Sample collection generally proceeded from North Vashon Island (zone 3) to South Vashon and Maury Islands (zone 1); sampling at mainland locations (zone 2) occurred at the end of field work. Written access agreements were obtained for all sampling activities. The designated sampling locations were matched against parcel maps to determine parcel ownership; a large number of owners, including both public and private entities, was identified. A description of the project and a written access agreement form (see Attachment A) were mailed to all identified parcel owners. Followup telephone calls and, in some cases, personal contacts were made as needed. Only a few owners refused access; in a small number of cases, contact with non-resident owners was not established. Alternate sampling locations were usually identified to replace those lost to the study for these reasons. The timing of the study dictated a rapid start to field work. The process of securing written access agreements was therefore carried out concurrently with field sampling activities, consistent with the general north-to-south progression of sample collection.

Given the shallow depth for soil collection and the designation of undisturbed, forested areas for sampling, no utility locator services were contacted. No utilities or other structures were encountered during sampling activities.

Sampling locations as marked on parcel maps were located in the field by taping or pacing from roads or other reference points. No physical barriers to access at intended sampling locations were encountered. All sampling locations were recorded in the field using GPS receivers (Garmin 45 and Garmin 12 XL units). At a few sampling locations, GPS readings were not available due to poor coverage and lack of signal. The detailed sampling protocols as described in the Field Sampling Plan were followed throughout the field program; no modifications or major deviations from the sampling protocols occurred. A few property owners accompanied the field sampling teams in the field to observe site access and sampling activities. There were no requests for split samples.

Field notebooks were used to record information for each sampling location. In addition to site location and sample identification information, the sampling team members, weather conditions, date, soil description, slope conditions, vegetation, and other site observations were recorded. No markers were left at sampling locations, which were restored to as close to original conditions as possible.

Clean sampling jars were provided by PHSKC's contract laboratory, OnSite Environmental Inc. Soil samples were stored in iced coolers in the field during the day and then transferred to a locked refrigerated storage unit maintained by PHSKC staff. When a number of samples had been accumulated, one of the sampling team members delivered a batch of samples to the laboratory in Redmond, WA; the typical delivery frequency was once a week to once every two weeks. Chain-of-custody forms accompanied all sample deliveries. The chain-of-custody forms included instructions to the laboratory for which samples to analyze and which samples to archive without analysis.

Field quality assurance measures included collection of field duplicate samples and equipment decontamination rinsate blanks. Field duplicates were prepared by collecting twice the normal volume of soils (i.e., collecting samples from a larger area), placing the collected soils in a sealed ZipLoc bag, and mixing the soils by hand within the bag by kneading, turning, and shaking the bag. The sample was then divided into two regular sampling jars which were appropriately labeled. Rinsate samples were collected after field decontamination washes of the sampling equipment. A total of 15 field duplicate samples and 16 equipment rinsate samples were collected. The results for these field QA measures are discussed further in Section 5.0.

Except for hand removal of large rocks, twigs, or roots, the samples were collected in the field as bulk samples. No additional sample preparation (e.g., sieving) was performed in the field.

The field sampling team assigned locations for an initial 20 percent of 2-6" samples to be analyzed, and for spatial scale samples to be collected, based on the success in acquiring access agreements and to meet the objective of distributing those locations over the entire study area to provide broad spatial coverage. A listing of random compass headings and right-left headings was used by the sampling teams to determine the locations for spatial scale samples. In some cases, the next listed value in sequence led to an unacceptable location; in that case, it was discarded and the following value was used, until representative and acceptable locations were identified.

A total of 177 of the 213 sampling locations designated in the study design were ultimately included in field sampling activities. The primary reason additional locations were not sampled was the constraint on available PHSKC staff time, rather than any problems in securing access agreements or in finding sites that passed the exclusion criteria for sampling. The overall completeness for sampling compared to the study design (which had a built-in tolerance for loss of samples) was 83 percent; the values by sampling zone were 78 percent in zone 1 (55 of 73 locations for South Vashon Island, 39 of 47 locations for Maury Island), 67 percent in zone 2 (16 of 24 locations on the mainland), and 97 percent in zone 3 (67 of 69 locations for North Vashon Island). At termination of the field program, PHSKC judged the coverage and spatial representativeness of the 177 sampled locations to be sufficient to meet the study objectives.

The sampling teams adjusted sampling locations in the field when site observations indicated possible localized disturbance, steep slopes, or other conditions that could affect sample representativeness. Alternate sampling locations were required when the scale of disturbance was greater (e.g., a substantial area had been logged recently) or access agreements were not completed. Those alternate locations were selected to still meet the overall grid sampling approach. Approximately 30 percent of the locations in zones 1 and 3 ended up as alternate sampling locations; no alternate locations were required in zone 2 where, by definition, an opportunistic rather than grid sampling approach was used.

Unique sample codes were assigned to identify all soil samples. Those sample codes were used on the chain-of-custody forms delivering soil samples to the laboratory and in all subsequent data management activities. The format for the sample codes was as follows:

sampling team and zone - location - sample identification

where designations used are

sampling team: **A,B,C**
zone: **1,2,3**
location: **001** through **114**; **A** if alternate location
sample identifiers: **S,T** for 0-2", 2-6" depth intervals, respectively
Y,Z for 300' and 50' spatial scale spacing, respectively
K for field duplicate
ER for equipment rinsate

For example, sample **B1-052A-TZ** represents sampling by team B, location 052 in zone 1 (South Vashon/Maury Island), an alternate location, and the 2-6" depth at the third of the spatial scale triplicate of samples, at a spacing of 50 feet from the **Y** sample.

General sampling locations and zone-location codes (e.g., **1052** for location **B1-052A**), with location identified only to the level of parcels sampled, are shown on Figure 1. Sampling locations are color-coded in Figure 1 according to sampling zone; the NE-SW dividing line between zones 1 and 3 (South Vashon and North Vashon) is clearly denoted. This Figure, and comparable figures (see Section 6) providing spatial mapping of arsenic and lead results, were generated using PHSKC's GIS software. On these GIS figures, details of spatial scale (triplicate) sampling locations and sample depths are not shown.

4.0 LABORATORY ANALYSES AND RESULTS

All laboratory analyses were performed by OnSite Environmental Inc. of Redmond, WA under contract with PHSKC. Groups of soil samples and associated equipment rinsate samples were delivered to the OnSite laboratory by the PHSKC sampling teams on 12 dates between August 18, 1999 and December 7, 1999. OnSite reported analysis results in a series of 25 reports between August 30, 1999 and May 4, 2000 (see OnSite Environmental Inc. 1999-2000). The first 13 of those OnSite reports provide results for 314 sample analyses under Phase I of the laboratory program. After review of the Phase I results, PHSKC determined that additional analyses of archived 2-6" samples in zones 1 and 2 should be performed. The last 12 OnSite reports provide those Phase II results for an additional 122 samples. In total, 436 soil samples (including 15 field duplicate samples) and 16 equipment rinsate water samples were analyzed for this study. All remaining archived sample materials were released from laboratory storage by PHSKC at the end of the Phase II analyses and have been discarded by OnSite in accordance with established lab protocols.

Analyses were performed for total arsenic, lead, and cadmium in the soil samples. All Phase I samples were analyzed for all three contaminants; in Phase II, all samples were analyzed for arsenic and lead, and 24 of 122 samples (20 percent) were analyzed for cadmium. This produced a total of 436 analyses for arsenic and lead and 338 analyses for cadmium. PHSKC's decision to reduce the number of cadmium analyses in Phase II was based on the observed maximum magnitude and the relatively high frequency of not detected values (approximately half of all analyses) for cadmium in Phase I. The analytical methods differed among the three contaminants: lead and cadmium were analyzed using Method 6010B (ICP), while arsenic analyses used Method 7060A (graphite furnace AA). The graphite furnace AA method for arsenic provided a lower detection limit than ICP. Ecology has also previously noted a potential for ICP arsenic analyses to show high bias for relatively low concentrations (see Washington State Department of Ecology 1994); this potential bias in reported levels was avoided by using GFAA methods.

The percent moisture was also determined for all analyzed soil samples, and sample results were calculated and reported on a dry weight (rather than as-received, or wet weight) basis. Dry weight values are more appropriate for exposure and risk evaluations and comparisons to regulatory standards (such as those in Ecology's Model Toxics Control Act

[MTCA] cleanup regulation) derived from exposure/risk calculations. [It should be noted, however, that QA/QC values included in OnSite reports are reported on a wet weight rather than dry weight basis].

Before performing total metals analyses, OnSite sieved the bulk soil samples delivered from the field by PHSKC to separate the <2mm size fraction. Smaller particle sizes are typically deemed more relevant to human exposures, and Ecology's MTCA cleanup regulation specifies that compliance evaluations should be based on analyses of the <2mm size fraction. All sample analyses and reported results reflect sieving and sample homogenization as sample preparation steps.

Laboratory analyses included a number of quality assurance/quality control (QA/QC) provisions for evaluation of the quality of reported results, consistent with the requirements of the Quality Assurance Project Plan (see PHSKC 1999). Method blanks, duplicate samples, and matrix spike/matrix spike duplicates were analyzed for each sample delivery group (batch) reported by the laboratory. Initial and ongoing equipment calibrations were also performed by OnSite. As part of the overall QA/QC program for this study, PHSKC procured standard reference materials to be analyzed with each sample batch as lab control samples (see Environmental Resource Associates 1999). The certified values and performance acceptance limits for arsenic, lead, and cadmium in those standard reference materials were not conveyed to the laboratory. The laboratory protocol called for PHSKC to review the reported results for lab control samples for each sample batch and to notify OnSite if any values did not meet the designated performance acceptance limits, in which case re-analyses would be required. All reported results for the lab control samples were within the performance acceptance limits.

Based on its internal reviews of laboratory results, OnSite did not assign any qualifiers to the reported data. A complete listing of laboratory results, ordered by sample codes (zones and locations), is provided as Attachment B. The overall ranges for reported results (dry weight basis, <2mm size fraction) are as follows:

arsenic	<2.3 (not detected) to 460 ppm
lead	<5.3 (not detected) to 1300 ppm
cadmium	<0.50 (not detected) to 15 ppm

Preliminary study results were released by the office of the King County Executive and PHSKC on April 18, 2000 (see PHSKC 2000). A number of public education measures and initial response activities preceded or accompanied release of the preliminary study findings.

5.0 DATA VALIDATION REVIEW

The initial reviews of laboratory data quality were performed by OnSite Environmental Inc. before data reports were issued to PHSKC. As noted previously, Onsite did not assign any data qualifiers based on its reviews.

An independent data validation review was performed by PHSKC (Mayfield 2000). That data validation review followed the procedures established in EPA's *Contract Laboratory Program National Functional Guidelines for Inorganic Data Review*. The program Data Quality Objectives are defined in the Quality Assurance Project Plan (QAPP; see PHSKC 1999). A summary of PHSKC's independent data validation findings is provided as Attachment C. Following completion of the data validation review, several specific questions on data quality issues were raised and addressed, leading to decisions on the final project database for evaluations of soil contamination patterns.

PHSKC's data validation reviewed 5 sample delivery groups and OnSite data reports; cumulatively, those 5 sample groups accounted for approximately one-third of all soil samples and 44 percent of the equipment rinsate samples analyzed in this study.

The precision and accuracy of laboratory results reported by OnSite were evaluated through technical review of laboratory QA/QC results and laboratory procedures. PHSKC evaluated, among other elements, the laboratory calibration procedures, method blanks, laboratory duplicate analyses, matrix spike/matrix spike duplicate results, and sample handling (sample storage, hold times). The results for OnSite analyses of standard reference materials (SRMs) supplied by PHSKC, whose true values and acceptable performance limits were not known to the laboratory, were also evaluated. All lab control sample results for the standard reference materials (two different lots were used in the course of the study) were within acceptable performance limits established by the supplier of the SRMs. The data validation review noted a few minor discrepancies in protocols, as well as cases where laboratory performance and procedures exceeded requirements. No significant deviations that affected data quality were identified in the data validation review, and no data qualifiers were assigned. One transcription error for a GFAA analysis was noted and corrected; further reviews for transcription errors found no additional cases.

Field QC information, consisting of field duplicate samples and equipment rinsate blanks, was also reviewed. There were 15 pairs of field duplicate samples collected and analyzed in the study; the field duplicate results, including calculated relative percent differences (RPDs), are extracted from the full project database (Attachment B) and provided in Table 1. The QAPP established a criterion of +/- 50 percent RPD for each contaminant analysis in field duplicate samples; the reported field duplicate data are evaluated against this criterion. The 15 pairs of field duplicate samples represent an approximate 1:20 frequency for the planned Phase I laboratory analyses. No additional field duplicate samples were submitted for archived soil samples later analyzed in the Phase II analytical program.

Field duplicate samples were analyzed for arsenic, lead, and cadmium, resulting in a total of 45 possible RPD comparisons. RPDs were not calculated for 7 cadmium pairs because both results were not detected. A total of 9 of 38 calculated RPDs (24 percent) exceeded the +/- 50 percent criterion: 4 of 15 for arsenic (exceedances from 55 to 127 percent), 3 of 15 for lead (from 75 to 124 percent), and 2 of 8 for cadmium (from 76 to 86 percent). The RPD values for different analytes at a single field duplicate location showed a high degree of covariation. At least one of the three analytes had an RPD greater than 50 percent in 5 of the 15 field duplicate sampling locations. On the other hand, almost 45 percent (17 of 38) of the calculated RPDs were less than 10 percent, illustrating the heterogeneity in results, from highly similar to significantly variable, among field duplicate samples.

The field notebooks were reviewed for observations possibly related to these findings. There was a suggestion, but not a firm demonstration, that the soils at sampling locations with high RPDs may have been characterized by higher organic content and extensive root structures. Such characteristics could have made selected soil samples more refractory in the field homogenization procedures used. The high RPD results for one-third of the field duplicate sampling locations indicates that the field sample homogenization procedures may not have been adequate. It should be noted, however, that all soil samples other than the field duplicate samples were submitted as unhomogenized bulk samples (i.e., with no field subsampling) to the laboratory; sample homogenization as a preparation step prior to selection of a sample aliquot for analysis occurred at the OnSite laboratory, not in the field. The field duplicate results therefore were not judged to significantly affect data quality.

A total of 16 field equipment rinsate blanks were submitted for laboratory analysis. No detected results for arsenic or cadmium were reported; however, 4 of the 16 lead values exceeded detection limits, ranging from 1.2 to 7.8 ug/L. No lead hits were reported in associated method blanks analyzed by OnSite, and laboratory staff reported that lead detections in water blanks at the lab were rare. A summary of the lead data for equipment rinsate samples, together with soil lead information for the sample immediately preceding collection of the rinsate blanks in the field, is provided in Table 2. A comparison of soil and associated rinsate blank results shows that soil lead concentrations were not notably higher in cases where the rinsates showed detectable lead levels. The field QC results for decontamination samples suggests that rinsate water may have contained low levels of lead, or that the decontamination procedures may have been marginally incomplete. The low levels reported for lead hits, while a minor possible source of bias in successive samples, are judged too small (e.g., from a mass balance perspective and recognizing that soil lead concentrations are many orders of magnitude higher than the ppb rinsate hits) to significantly affect soils data quality.

Specific issues were raised for review of 4 soil samples. Data reviews resulted in their removal from the data set used for evaluations of study area contamination. In the Phase II laboratory program, 2 samples already analyzed in the Phase I program were inadvertently reanalyzed. The second analyses for those two samples (AB1-010A-S and AB1-104A-S) were eliminated from the data evaluation database. At one sampling grid location, two field samples were collected and submitted for analysis by separate field sampling teams. The second sample for this location was reported by the field teams as being more representative for undisturbed soils; the results for B3-021-S were therefore retained in the data evaluation database, and results for A3-021-S were removed. Finally, laboratory analyses for sample B1-018-T occurred after an archiving period slightly exceeding the recommended 6 months for inorganic analyses. Those results were also conservatively removed from the data evaluation database. None of the reported contaminant concentrations for these 4 samples were remarkable. After elimination of the results for these 4 samples, the data set was reduced from 436 to 432 samples, representing excellent data completeness.

PHSKC compiled an electronic database for arsenic, lead, and cadmium results for soil samples using an Excel spreadsheet format. All data were hand-entered from OnSite reports; 100 percent of all data entries were validated by an independent review from original laboratory report sheets. A final validated database spreadsheet (see data listing in Attachment B) was used as the reference data set for all further data evaluations.

The completeness, comparability, and representativeness characteristics of the final data set meet the objectives for evaluations of contamination patterns in the defined study area. The field QC results suggest some deficiencies in field protocols, and minor possible effects on data precision and accuracy, but they are judged not to have significant effects on the overall quality of the reported laboratory soils data. No data were rejected for use in data evaluations based on the field QC results.

6.0 DATA EVALUATIONS

As described in Section 1.0, a set of data evaluation objectives was identified for this study. Each of the identified data evaluation objectives is discussed in its own subsection below, preceded by a brief discussion of the approach taken to data evaluations. The discussions that follow emphasize the primary data evaluation results; references are provided to more detailed statistical results and data plots that are included as Attachment D, for readers interested in such details.

6.1 APPROACH

The initial data set accepted after data validation reviews includes laboratory analyses of 432 physical samples (see Section 5.0 and Attachment B). There are 15 pairs of field duplicate samples (see Table 1) in that initial data set. Before performing any data evaluations, the results for each pair of field duplicate samples were averaged and rounded to two significant figures, a precision in agreement with all other reported results. This produced a final data evaluation data set with results for 417 samples.

Coding variables were added to the data file to identify results reported as not detected (below the limit of quantification). This allowed not detected results to be included or excluded from analysis, as desired. Only one arsenic and two lead results are reported as not detected; evaluations for those contaminants are relatively unaffected by not detected results. However, more than half of the cadmium results (175 of 322 values) are not detected. The reported detection limits (reported as dry weight values) varied from sample to sample because of different percent moisture results. Values equal to one-half the reported detection limits were entered into the data file for all not detected results. For cadmium, the detection limits for not detected results overlapped the quantified values. The smallest quantified value was at 0.57 ppm (dry weight), while the detection limits varied from 0.50 to 1.6 ppm. Of the 175 not detected results, 122 had a detection limit greater than the 0.57 minimum concentration. Using one-half the detection limit as a concentration in the data file, however, minimized the overlap; only 3 not-detected samples exceeded 0.57 ppm using that approach. Assigning one-half the detection limit to not detected values is a simplistic approach for a highly censored data set such as the cadmium results for this study. The primary concern for evaluations of the censored cadmium data was to check whether the not detected results could significantly change evaluations based on only the quantified cadmium values. This simple assignment rule was judged to be adequate for that limited purpose.

Table 3 enumerates the components of the final data evaluation data set - that is, the number of samples by sampling zone and sample type (grid or spatial scale location; depth interval sampled). For simplicity, the term "grid locations" as used in this section will include the primary Zone 2 (mainland) sampling locations, which were chosen in more of an opportunistic manner than by a formal grid. Grid locations refer to the primary sampling locations and are in contrast to the spatial scale samples added at selected sites. Table 3 provides an easy reference point for identifying the number of samples available for various types of data evaluations, as well as their allocation among sampling zones. The numbers of arsenic/lead and cadmium analyses performed for each component of the final data set are provided. As shown in Table 3, arsenic and lead results are available for all 417 samples, while there are only 322 cadmium analyses. There are 177 grid locations, at 34 of which spatial scale samples were collected and analyzed (but not all of the deeper 2-6 inch depth interval samples were analyzed at spatial scale sites). Depth profiles, with arsenic and lead analyses at both 0-2 inch and 2-6 inch intervals of the same site, are available for 172 physical sampling locations (grid or spatial scale).

The final verified data set was compiled as an Excel spreadsheet. That file was then used to generate all subsequent data sets used for specific data evaluations. Statistical evaluations and data plots were prepared using the Statgraphics^{TM} software package. Data maps were prepared by PHSKC using an in-house Geographic Information System (GIS). Preliminary data mapping was used for exploratory analyses and data visualization.

A convenient way to start to look at the larger-scale spatial patterns in the results over the entire study area is to use the sampling zones from the study design to partition the overall data set. Readers are cautioned that there is no expectation or finding that the zone boundaries are in and of themselves representative of any marked differences; the distribution of contaminants shows a gradational rather than a sharply differentiated pattern. Sampling zones are used for more detailed analysis of several data evaluation questions in the following sections. (As a result, aspects of the discussion of spatial patterns are to be found in most of the specific data evaluation subsections). In recognition of the natural division of Zone 1 into South Vashon Island versus Maury Island, the designations Zone 1A and Zone 1B are used for those two areas, respectively. The simplest data analyses use the entire data set without partitioning; those results are generally discussed first.

The maximum contaminant concentrations occurring at a grid location (at any depth interval analyzed, and at any location within a spatial scale cluster) were determined and recoded as additional variables for analysis. Once deposited from transported air emissions, different contaminants may have different fates (e.g., vertical movement) in soils. Using the maximum location values instead of the original data reduces variability caused by such fate processes. It can help illuminate relationships among contaminants, and it also clarifies the mapping of horizontal spatial patterns.

Finally, the study design includes certain features that should be recognized as possible confounders when data evaluations are performed. Not every 0-2 inch analysis has a matching 2-6 inch analysis. Not every arsenic and lead result has a corresponding cadmium result. The density and number of results (both grid locations and spatial scale locations) vary in different parts of the study area, or sampling zones. It is also worth noting the highly censored cadmium results. However, after considering all of the results discussed below and performing additional evaluations to eliminate possible artifacts from the unbalanced study design, confounding issues are judged to be of only minor importance. The major conclusions of the data evaluations are not significantly affected.

6.2 MAGNITUDE OF SOIL ARSENIC, LEAD, AND CADMIUM

Arsenic, lead, and cadmium were found to occur over a broad range of concentrations. At the low end, reported contaminant concentrations are at or near background values (Washington State Department of Ecology 1994). The upper end of the range includes substantially elevated concentrations, approximately one to two orders of magnitude greater than typical background values. The maximum arsenic, lead, and cadmium concentrations are 460 ppm, 1300 ppm, and 15 ppm, respectively.

As already noted, only one arsenic and two lead values were reported as not detected, while more than half the cadmium analyses produced not detected values.

The statistical distributions for contaminant concentrations are all significantly right-skewed; that is, they have longer right tails reflecting more lognormal than normal distribution shapes. This lognormal distribution type is illustrated in Figures 2 and 3, which provide normal probability plots for log-transformed arsenic and lead data sets (all 417 individual samples). In both cases, the data show good fit to the lognormal distribution represented by the straight line. Lognormal distributions also characterize partitioned components of the complete data set, for example the data from only the 0-2 inch or 2-6 inch depth intervals or the data from only sampling Zone 1, Zone 2, or Zone 3 (see Attachment D for arsenic probability plots for these data subsets).

The statistical distributions of arsenic, lead, and cadmium values are shown in Figures 4 through 6, which present bar charts showing the number of samples in successive concentration increments. (All not detected [ND] values are included at one-half the detection limit; note that especially for cadmium, there is a range of dry weight basis not-detected values because of different percent moistures in the soil samples). The extended right tails of the distributions, reflecting relatively infrequent higher concentrations, are apparent in these Figures. (Similar plots of the distributions for arsenic and lead in Zones 1A, 1B, 2, and 3 are provided in Attachment D).

Percentiles of the contaminant distributions are easily read off from cumulative frequency plots; examples for arsenic and lead, for the complete data set of 417 individual samples, are provided in Attachment D. Tables 4a, 4b, and 4c provide a summary of selected percentile values and sample counts for arsenic, lead, and cadmium results for the full data set as well as for separate sampling zones. The median or 50th percentile values for arsenic and lead are 53 ppm and 110 ppm, respectively; since more than half the cadmium results are not detected, the median cadmium value is not detected. Tables 4a, 4b, and 4c show how the median and other percentiles vary by sampling zone. Arsenic medians, for example, vary from 120 ppm on Maury Island (Zone 1B) to 28 ppm on North Vashon Island (Zone 3). Lead median concentrations vary from 200 ppm on Maury Island to 62 ppm on North Vashon Island.

A similar summary of selected percentile concentrations based on maximum location values (N=177) rather than individual samples (N=417 for lead and arsenic, N=322 for cadmium) is provided in Table 5. This alternate data evaluation approach focuses on how high concentrations could be at any location, rather than what the average might be (including variability from multiple samples). Arsenic and lead median values are, of course, higher than in the previous analysis. For all grid locations, the arsenic and lead median values are 67 ppm and 170 ppm, respectively; in individual sampling zones they range up to 170 ppm and 370 ppm, respectively, on Maury Island.

6.3 SPATIAL PATTERNS

Arsenic and lead results were mapped using GIS software. Figures 7 and 8 show the resulting maps; spatial sampling locations are identified only at the level of the parcel sampled. Not all results (see Attachment B for a complete listing) are plotted on Figures 7 and 8; only the maximum concentration at any depth is plotted for a given sampling location. Where only one grid location at a parcel was sampled, only a single result is shown. Multiple results are shown when spatial scale sampling occurred or when more than one grid cell location within a single parcel was sampled. For example, at sampling location 113 in Zone 1, at the southern end of Maury Island, the three values of 250 ppm, 210 ppm, and 130 ppm represent the maximum arsenic concentrations regardless of depth at the three spatial scale sampling locations (i.e., B1-113-T, B1-113-TY, and B1-113-SZ). The sampling grid locations are color coded on Figures 7 and 8 to reflect ranges of maximum contaminant concentrations, making it easier to see spatial patterns in the results.

Inspection of Figures 7 and 8 reveals that substantial differences in contamination levels can occur within localized areas. This small-scale spatial variability is discussed further in Section 6.6. A large-scale spatial pattern is also visible; that large-scale pattern is similar for arsenic, lead, and cadmium, indicating a high degree of co-occurrence and correlation among the three contaminants (discussed further in Section 6.4). The highest contaminant levels are generally found on Maury Island (Zone 1B), followed by South Vashon Island (Zone 1A) and the Mainland (Zone 2). The lowest concentrations are found on North Vashon Island (Zone 3). The degree of variability in results within zones is large enough that the distributions in these subareas are broadly overlapping rather than entirely dissimilar. Nevertheless, there is a clear and meaningful large-scale spatial pattern evident in the data. (This large-scale pattern would be particularly evident if, for example, the results were averaged over blocks of significant size, such as 1 to 2 square miles). As noted in Section 2.3, all mapped results are representative of relatively undisturbed areas and are very likely not generalizable to developed/disturbed areas. Land use and the history of site disturbance are emphasized again as very important factors afffecting the current pattern (including depth of contamination) and magnitude of residual soil contamination. The best use of the maps of contamination magnitudes from this study is as likely upper-bounds (or near upper bounds, because the number of samples is limited) for soil contamination across various types of land uses.

The dominant spatial pattern can be illustrated using the sampling zones to partition the data set (while recalling that the actual pattern is gradational rather than clearly associated with the chosen zone boundaries). Tables 4a, 4b, and 4c provide detailed comparisons of selected percentile values across all sampling zones, based on individual samples; Table 5 provides similar information for maximum location values. The ranking of subareas is shown clearly in these Tables.

Bar charts showing the distributions for arsenic and lead in each sampling zone are included in Attachment D. Comparison of these bar charts across zones also reveals the large-scale spatial pattern in the results.

Figures 9 through 11 show multiple box and whisker plots[3[3]] of arsenic, lead, and cadmium results (with not detected results assigned values of one-half the detection limit) for individual samples by sampling zone. These visual summaries of the statistical distributions by zones show that the median and extreme high values follow the ranking of Zones 1, 2, and 3, from highest to lowest levels; more detailed examination supports the finding that Zone 1B (Maury Island) shows generally higher contaminant levels than Zone 1A (South Vashon Island). [Note: the lead box and whisker plot for Zone 3 (see Figure 10) is likely biased high because there are comparatively fewer 2-6 inch analyses in Zone 3, and lead depth profiles typically show higher concentrations in the 0-2 inch interval. Thus, the actual differences between Zones 1 and 2 versus 3 for lead are probably understated. Additional box and whisker plots for arsenic and lead in the 0-2 inch samples only are provided in Attachment D, showing similar results.]

[3[3]] Box and whisker plots provide a visual summary of statistical data distributions. The box encloses the 25th to 75 percentiles of the data (i.e., the middle 50 percent), defining the size of the interquartile range. The median is shown as a line within this box. The straight line whiskers above and below the box extend to the values in the data set closest to, but not exceeding, 1.5 times the interquartile range above and below the 75th and 25th percentiles. Outlier values beyond the whiskers are plotted individually, with a special symbol if they are more than 3 times the interquartile range above or below the ends of the box. Multiple box and whisker plots allow data sets to be rapidly compared visually.

6.4 CONTAMINANT CORRELATIONS

Arsenic, lead, and cadmium contamination in soil samples show strong and statistically highly significant correlations for all contaminant pairs. Spearman rank correlations (a nonparametric approach to correlation analysis, applicable to any data distributions) are all significant at $p < 0.0001$; the rank correlations are 0.86 for arsenic and lead, 0.74 for arsenic and cadmium, and 0.74 for lead and cadmium. (The results involving cadmium are, of course, affected by the substitution of one-half the detection limit for all not detected results).

The correlation in arsenic versus lead concentrations is notable. Figure 12 shows a scatterplot of the individual sample results for lead versus arsenic. (Separate scatterplots for each sampling zone and for the two depth intervals sampled are provided in Attachment D, with identical scaling of the X and Y axes across scatterplots. Zone 1, which has the highest concentrations, is also seen to show the largest degree of scatter in the data. The differences between the 0-2 inch and 2-6 inch scatterplots indicate differences in the depth profiles for arsenic and lead; this is discussed in Section 6.5). Despite the scatter in Figure 12, a positive relationship between arsenic and lead concentrations is obvious. This is easier to see by using log scaling of the X and Y axes to plot the same data shown in Figure 12, as is done in Figure 13 which provides the results of a regression analysis for lead versus arsenic. The pattern of lead versus arsenic results in this study is similar to the pattern previously reported for soil samples in relatively undisturbed areas in University Place, Pierce County, to the south of the Tacoma Smelter (City of Tacoma and Gregory L. Glass 1999), as well as for remedial action sampling of individual residential properties in Ruston and North Tacoma.

Regression models were determined to predict lead concentrations as a function of arsenic values (see Attachment D). A multiplicative model (equivalent to linear regression on log-transformed values) provided the best fit (see Figure 13); in this model, the ratio of lead to arsenic changes for different arsenic concentrations, although in this case the differences are not too large. The correlation coefficient for log-transformed values is 0.77; the regression model accounts for approximately 60 percent of the variance in the data (see the statistical summary attached to Figure 13). This regression model predicts average lead to arsenic ratios ranging from 2.12 down to 1.62 as arsenic concentrations go from 20 ppm to 500 ppm.[4[4]] For the

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[4[4]] The regression equation uses the intercept and slope values in the following equation:

$$Y = aX^{slope}$$

individual soil sample results, about 71 percent of all lead to arsenic ratios are between 1 and 4. (Additional regression results for the data partitioned by sampling zone and depth interval sampled are provided in Attachment D).

The relationship between arsenic and lead using maximum location values is even stronger. Arsenic and lead show different patterns of mobility in the soil column, as discussed in Section 6.5. This means that over time contaminants deposited together have tended to separate in the soil column, reducing somewhat their observed correlations. Evaluations based on maximum location values remove some of this additional post-deposition variability in the data. (Another approach would be to calculate a weighted average concentration over the 0-6 inch depth interval, or a total mass for arsenic and lead, and then assess correlations). Figures 14 and 15 provide a scatterplot and regression analysis for lead versus arsenic based on maximum location values. Compared to Figures 12 and 13 for individual sample results, these Figures show less scatter. The correlation coefficient for log-transformed values is increased to 0.85, and the regression model accounts for 72 percent of the variance in the data. The regression model predicts average ratios of maximum lead to maximum arsenic ranging from 2.77 down to 1.96 for arsenic concentrations of 20 ppm to 500 ppm. About 76 percent of all maximum location data show ratios between 1 and 4.

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where Y is the lead concentration, X is the arsenic concentration, and $a = e^{\text{intercept}}$. From this equation, the average predicted lead value can be calculated for any arsenic concentration. On the regression plots, the inner pair of dashed lines shows the 95 percent confidence interval for the average lead values or regression line, while the outer pair of dashed lines shows the 95 percent prediction limits for individual lead values.

Cadmium correlations with arsenic and lead are also statistically highly significant, but not as strong as the correlation of arsenic and lead. Cadmium (omitting not detected results) versus arsenic scatterplots are shown on Figures 16 and 17 for individual sample results and maximum location values; the amount of scatter is reduced using maximum location values, as before. Cadmium versus lead scatterplots are shown on Figures 18 and 19, with similar results. Using maximum location values and log-transformed data, the correlation coefficients for cadmium versus arsenic and cadmium versus lead are 0.66 and 0.67, respectively. Regression analysis results for cadmium versus arsenic and lead are provided in Attachment D.

6.5 DEPTH PROFILES

Analyses of both 0-2 inch and 2-6 inch depth intervals at a large number of sampling locations provide a data set for evaluating contaminant depth profiles in near-surface soils. Since sampling was limited to the top 6 inches in this study, and the deeper sampling interval exhibited substantial contamination, the full depth of contamination was not determined. It should also be recognized that the results reported in this study are associated with the specific depth intervals sampled. These results do not define to a greater precision where exactly the maximum contaminant concentrations occur. For example, if the 0-2 inch result is larger than the 2-6 inch sample, it is still possible that a higher concentration would have been reported for a sample at 2-3 inches or 2-4 inches.

Consistent with the original study design, approximately 20 percent of the 2-6 inch samples were initially analyzed for arsenic, lead, and cadmium. All remaining 2-6 inch samples were archived at the laboratory. After reviewing these Phase I analytical results, and observing frequent "inverted" profiles (2-6 inch value larger than 0-2 inch value), a decision was made to analyze all remaining archived 2-6 inch samples from Zone 1 and Zone 2. Contaminant concentrations were generally lower in Zone 3; with available resources for this study, deeper samples in that zone were not analyzed. All samples in this Phase II laboratory program were analyzed for arsenic and lead. Approximately 20 percent were analyzed for cadmium, which did not appear to be as significant as arsenic and lead based on the Phase I results.

A total of 172 depth profiles (including both primary grid locations and additional spatial scale locations) is available for arsenic and lead evaluations, for the combined Phase I and Phase II analytical programs. For cadmium, 77 depth profile locations are available. Only 25 of those 77 locations for cadmium reported quantified, detected concentrations for both the 0-2 inch (**S**) and 2-6 inch (**T**) depths.[5] Concentrations at both depths are reported as not detected for 34 locations, and at the remaining 18 locations only 1 of the 2 depth results is quantified. Information on cadmium depth profiles is thus more limited because of fewer analyses and a high degree of data censoring.

The depth profile results for all locations can be summarized in a single scatterplot showing the matched **S** and **T** concentrations for a selected contaminant. Figures 20 through 22 provide such scatterplots for arsenic, lead, and cadmium (for both **S** and **T** results detected), respectively. The data points on these plots are number-coded to show which sampling zone they represent. (Separate scatterplots for each sampling zone, for arsenic and lead depth profiles, are provided in Attachment D). The X and Y axes on the scatterplots are LOG-scaled reflecting the lognormally-distributed concentration data at both depths.

Two lines are drawn in on each of Figures 20 through 22 to provide useful visual references for data evaluations. The lower line shows where **S** and **T** concentrations are equal; areas above this line have "inverted" profiles with higher **T** concentrations. The second line shows where **T** concentrations are twice the **S** values; data points above that line are more than 100 percent higher than the **S** values.

Table 6 provides a summary of the depth profile patterns for arsenic and lead (compare to Figures 20 and 21). The frequency of "inverted" profiles is shown, as well as the frequencies with which **T** exceeds **S** by 50 percent or 100 percent. Arsenic and lead exhibit somewhat different depth profile patterns. The frequency of "inverted" profiles is greater for arsenic (45 percent) than for lead (30 percent), and higher **T/S** ratios (i.e., more downward movement of contamination) occur more frequently for arsenic. Table 6 also provides information by sampling zone. Interestingly, the frequencies by zone closely follow the ranking of contaminant concentrations by sampling zone (see Section 6.3). Thus, the greater the level of soil contamination, the more movement down the soil column there appears to be. This is particularly true for the highest **T/S** ratios, as shown in Figure 23 with box-and-whisker summaries of the distribution of ratios by sampling zone; 9 of the 10 highest ratios occur in Zone 1.

Figures 24 and 25 present frequency histograms for the **T/S** ratios for arsenic and lead,

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[5] For convenience, depth intervals are simply designated as **S** and **T** in the remainder of this section and in accompanying figures and tables.

respectively. A shift upwards in these distributions for arsenic is discernible.

For cadmium, 10 of the 25 depth profiles where both values are quantified show concentrations at **T** greater than **S** (see Figure 22). All but one of the 18 cases where one of two values is quantified can also be classified as to which depth interval is higher. Overall, 15 of 42 profiles, or 36 percent, show an "inverted" profile. Cadmium thus appears to be intermediate between arsenic and lead with respect to patterns.

Examination of Figures 20 through 22 shows that "inverted" depth profiles occur broadly over the range of concentrations present at 0-2 inches, rather than in only a restricted portion of that range. Depth profile patterns for closely spaced spatial scale (triplicate) locations exhibit large variability even in such localized areas. It therefore appears that factors influencing downward movement of contaminants in relatively undisturbed areas are highly localized.

The relatively greater downward mobility of arsenic versus lead can be effectively illustrated by comparing the depth profile ratios of these two contaminants for each depth profile sampling location. Figure 26 provides a scatterplot of the **S/T** ratios; a line representing equal ratios (i.e., equal mobility) is drawn in on Figure 26. Data points above the line have a larger **S/T** ratio for lead versus arsenic; thus, for that sampling location, lead is retained at **S** comparatively more than arsenic is. For the great majority of samples, the data points fall above the line. (Note that this does not mean that lead is immobile or that for lead the **S** concentration is necessarily larger than the **T** concentration; recall that for lead **T** exceeds **S** 30 percent of the time [see Table 6]. The point here is that lead is *comparatively* less mobile than arsenic). Figure 27 provides a frequency histogram of the "ratio of depth profile ratios" for lead versus arsenic; this distribution characterizes the difference in mobility between lead and arsenic. As in the scatterplot of Figure 26, it is readily seen that for the great majority of samples lead shows lower mobility.

Figures 28 and 29 provide scatterplots of the comparative mobility of cadmium versus arsenic and cadmium versus lead, respectively, in the same way that Figure 26 illustrates lead versus arsenic mobility. From the patterns revealed in Figures 28 and 29, cadmium appears to be somewhat less mobile than arsenic and slightly more mobile than lead. The smaller data sets for cadmium depth profiles suggests that these be considered provisional findings.

6.6 VARIABILITY AND SPATIAL SCALE

The typical distance between grid sampling locations is on the order of 1500 to 2000 feet. The arsenic and lead data are mapped at this scale on Figures 7 and 8. Considerable variability in contaminant concentrations can be seen at this scale, especially in those portions of the study area where concentrations are highest. A number of sampling locations with atypically low concentrations within Zone 1 were identified, and the field logs were reviewed with the field sampling staff for any notable characteristics at those locations. There are suggestions within the field notes, but certainly no proof, that soil characteristics, slopes, or other features could be associated with these atypically low concentration sites. All sampling locations met the criteria established for targeting minimally disturbed soils in this study. It is possible that degrees of disturbance not readily observable (especially if disturbance happened some years ago, which could still significantly affect cumulative soil contamination from air deposition) have occurred at some sampling sites. Another possibility is that contaminant deposition is itself quite heterogeneous on a spatial scale of a few thousand feet. Whatever the reasons, the primary grid sampling results document variability at that scale.

The study design included additional spatial scale samples to investigate variability in contamination on much smaller scales. At 34 of the 177 grid locations (almost 20 percent), spatial scale samples were collected at a spacing of 300 feet and (at a right angle to the first pair) 50 feet. These 34 locations are widely distributed over the study area (see Table 3); Zone 1B (Maury Island) is somewhat under-represented because only 3 suitable locations for spatial scale sampling were identified there. Each triplicate of spatial scale samples provides one pair of locations 50 feet apart. Simple geometry reveals that each of those locations separated by 50 feet is about 300 feet away from the primary grid sampling location, providing two pairs at a distance of 300 feet. Thus, there are twice as many pairs at a distance of 300 feet versus 50 feet.

Fewer spatial scale samples were analyzed for cadmium, and many of the analyses for those that were reported are not detected. This results in too little cadmium data to warrant detailed evaluation. Evaluations are therefore limited to arsenic and lead, which are quantified in all analyzed spatial scale samples.

Two different measures of variability are used in the spatial scale data evaluations. The first measure simply reflects the ratio of the higher to the lower contaminant concentration in each data pair (e.g., two samples separated by 50 feet). This is referred to as a "K-Factor", representing the factor by which the larger value exceeds the smaller one. Thus, for concentrations of 250 ppm and 125 ppm, the K-Factor is 250/125, or 2.0. The K-Factor is very similar to the more familiar "relative percent difference" or RPD measure commonly used in laboratory QA reviews, with a nonlinear scaling factor relating the two measures. The K-Factor is more intuitively appealing, however. The K-Factor, like an RPD measurement, is scale-invariant; that is, it remains unchanged if the data are multiplied by a constant. It is useful for assessing relative differences, and is dimensionless. The minimum K-Factor, for two equal concentrations, is 1.0; there is no theoretical upper bound.

The second measure is the familiar standard deviation of two concentrations. A standard deviation is scale-dependent; that is, it changes if the data are multiplied by a constant. Standard deviations are useful for assessing absolute differences. The unit of measurement for standard deviations is the same as the contaminant concentration data themselves, namely ppm. The minimum standard deviation, for two equal concentrations, is zero; there is no theoretical upper bound.

The results of evaluations of small-scale variability in arsenic and lead concentrations, using these two measures, are summarized in Figures 30 through 33. These Figures show box-and-whisker plots summarizing the distributions of K-Factors and standard deviations, comparing those results for sampling pair distances of 50 and 300 feet. The distributions for 50 feet versus 300 feet within each Figure are seen to be quite similar. This indicates that collecting samples as close as 50 feet apart does not significantly improve the consistency in results, compared to 300 feet apart. The general magnitude of variability is also shown (for example, refer to the line within each box that shows the median value). Frequency histograms for each of the 8 distributions included in Figures 30 through 33 are provided in Attachment D, providing a more complete picture of the distributions. A summary of these results, including selected percentile values for each measure, are presented in Tables 7a and 7b. These tables also provide a breakdown of results by sampling zone.

K-Factors equal to or greater than 2 are relatively common in the spatial scale data. For arsenic, 30 percent and 35 percent of the 50 foot and 300 foot data pairs, respectively exceed a K-Factor of 2. For lead, those values are higher, at 50 percent and 59 percent for 50 foot and 300 foot data pairs, respectively.[6[6]] These results reflect discrete sample analyses; any protocol with

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[6[6]] One technical reviewer noted that the results of field duplicate samples (see Table 1) indicate that substantial variability in arsenic and lead concentrations can occur at a scale as substantial compositing of samples (horizontally or vertically) would be expected to show comparatively reduced variability.

The standard deviation values shown on Table 7b can be put in perspective by noting some values for the overall concentrations at sampling sites used for spatial scale evaluations. For arsenic, the median concentration is 56 ppm, and the 25th and 75th percentiles are 33 ppm and 120 ppm, respectively. For lead, the median concentration is 110 ppm, and the 25th and 75th percentiles are 55 ppm and 220 ppm, respectively.

Examination of Tables 7a and 7b shows that for both variability measures lead shows somewhat higher variability than arsenic. (Scatterplots providing direct comparison of matched lead versus arsenic variability measurements are included in Attachment D). Since lead concentrations are generally higher than arsenic concentrations, this finding seems reasonable with respect to standard deviations (which are scale-dependent), but the observed differences in K-Factors (scale-invariant) seem less obvious and predictable. Those K-Factor differences may be associated with the differences shown in contaminant mobility in the soil column.

Figures 34 and 35 compare the arsenic variability results to the maximum arsenic concentration for each data pair used in the evaluations. K-Factors are seen to be fairly unrelated to the magnitude of contamination, while standard deviations show quite a clear relationship (i.e., they show scale-dependence, as expected). (Similar figures for lead, with the same patterns evident, are provided in Attachment D). Variability measures that show an association with the magnitude of contamination should also show differences by sampling zones in this study, since there is a clear large-scale spatial pattern in the levels of contamination. Tables 7a and 7b provide summary information by sampling zone. Indeed, K-Factors are quite similar across all zones (except for possibly higher values in Zone 2, which may be an artifact of a small number of samples). Standard deviations, however, are markedly lower in zone 3 versus zones 1 and 2.

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small as several inches (i.e., within a single soil sample). For both arsenic and lead, 3 of 15 pairs (20 percent) of field duplicate results had K-Factors exceeding 2.

The two measures of variability thus provide somewhat different patterns of results. One is not more correct than the other; they simply represent answers to different ways of asking about variability.

In summary, spatial variability in contaminant concentrations at distances of as little as 50 feet has been documented in this study. K-Factors and standard deviations provide two ways of measuring this variability as a function of spatial scale. The results of spatial scale evaluations indicate that local variability in arsenic and lead concentrations can at times be significant enough to warrant caution in interpreting levels from only one or a few local samples.

7.0 CONSISTENCY WITH PRIOR STUDIES

As noted previously (see Section 2.2), information on numerous prior studies was compiled and reviewed as part of the study design process for the current investigation. This study represents a considerable expansion over all previous soil sampling and analysis studies on Vashon/Maury Island. It is the first such study with large-scale coverage of any part of the mainland areas of King County. It also has another important difference from the assemblage of previous smaller-scale studies, namely the application of consistent sampling and analysis protocols throughout the study area. The findings from this study are more powerful than earlier results because of the larger sample size, better spatial coverage, and unvarying protocols used, as well as the focus on relatively undisturbed soils where the contamination pattern is least complicated or disrupted. Accepting that the current study is more powerful and detailed, are the findings generally consistent or inconsistent with previous information?

The large-scale spatial pattern revealed by the extensive sampling in this study is highly consistent with older estimates of Tacoma Smelter plume effects. Wind rose information and deposition modeling based in part on wind rose measurements show impact contours with approximately the same shape as the mapped soils data from this study (see PSAPCA 1981a and 1981b). Regional-scale precipitation chemistry measurements performed at the University of Washington mapped downwind plume impacts extending onto the mainland and with similar spatial patterns for arsenic, sulfates, and other smelter-related contaminants (see, for example, Larson et al. 1975, Knudson et al. 1977, Carpenter et al. 1978, and Vong et al. 1988). A regional-scale bee biomonitoring investigation (Bromenshenk et al. 1985) produced contaminant contours that are highly consistent with the pattern shown by soil analyses in the current study.

All previous soil studies analyzed for arsenic. Analyses for other contaminants such as lead, cadmium, or antimony were inconsistent across studies. Nevertheless, where measured these other contaminants documented in smelter emissions showed an association with arsenic. The current study confirms and documents the strong correlations among arsenic, lead, and cadmium in surficial soils

Soil depth profiles for arsenic were measured in a number of previous studies (see, for example, Dempsey 1991, Heilman undated [1973?], King County DDES 1999). Some findings of increased arsenic concentrations with depth are reported in these earlier studies. Most samples were found to have a steadily decreasing arsenic concentration with increasing depth. In the current study, a greater frequency of "inverted" depth profiles (increasing concentration with depth) for arsenic was measured. The full depth profile was not determined, since sampling was limited to the top 6 inches of soil. These results suggest a somewhat greater mobility for arsenic than earlier studies indicated.

The upper range in the magnitude of soil contamination is much better defined based on this study, with many more sampling locations and a focus on areas where soil contamination is expected to be highest. Very little information was previously available on the mainland. This study confirms the occurrence, suggested in a handful of earlier results, of substantially elevated contamination levels in some mainland areas. The range of concentrations found on North Vashon Island is generally consistent with the limited results from previous studies. Maximum concentrations are constrained to approximately 20 or 30 percent of the highest values for Vashon/Maury Island as a whole. About 90 percent of all previous soil sampling occurred on South Vashon and Maury Island. The magnitude of contamination shown in the current study for these areas is somewhat greater than previous results. Especially on South Vashon and Maury Island, significant localized differences are observed between this study and earlier studies. In part, this reflects the localized heterogeneity in contamination documented through spatial scale sampling in this study, as well as the larger size of the current study compared to earlier ones. The differences in sampling and analysis protocols among studies are probably more significant. The land use and degree of disturbance in sampled areas is expected to strongly affect measured contaminant levels, and various studies on Vashon/Maury Island have sampled in widely divergent types of land uses. Compositing versus discrete sampling, depth intervals sampled (i.e., vertical compositing), sieving or not sieving soils before analysis, and laboratory analytical methods all can be expected to introduce variability among studies. These findings reinforce the conclusion that using different sampling approaches within the same area is likely to produce different results. Great care is therefore needed to correctly interpret results in light of study objectives and the sampling and analysis approaches chosen for the study. The representativeness and generalizability of study results should be carefully examined, not assumed.

8.0 CONCLUSIONS

The Vashon/Maury Island Soil Study was successful in defining the large-scale magnitude and extent of near-surface soil contamination with arsenic, lead, and cadmium. The strategy of targeting relatively undisturbed areas to define contamination patterns (i.e., to provide a mapping of contamination levels) appears to have been well-chosen. The study design for sampling on Vashon and Maury Islands was supported by the results of a number of previous studies. With respect to the King County mainland areas included in this study, only very limited prior information informed study design, and the mainland portion of the study is recognized as a "pilot-scale" investigation in contrast to the more detailed study on Vashon and Maury Islands.

The detailed study design was developed by a work group involving agency and community representatives. The primary objective of the study was to characterize the magnitude and extent of soil contamination in relatively undisturbed areas within the study area. Several specific data evaluation objectives were identified by the work group; the study design reflects those concerns . Statistical and spatial evaluations of the data support the following conclusions:

- ☐ Magnitude of contamination. A broad range of contaminant concentrations is reported, from at or near background levels to substantially elevated levels (one to two orders of magnitude above background). The maximum arsenic, lead, and cadmium concentrations are 460 ppm, 1300 ppm, and 15 ppm, respectively. The statistical distributions of concentrations are right-skewed, meaning the higher values occur relatively infrequently.

- ☐ Large-scale spatial pattern. Contamination does not occur equally throughout the study area; instead, a distinct large-scale spatial pattern is observed. The highest levels generally occur on Maury Island, followed by South Vashon Island, portions of the mainland nearshore areas, and North Vashon Island.

- ☐ Small-scale variability. Most sampling locations were spaced about 1500 to 2000 feet apart. Contaminant concentrations demonstrate considerable variability at this scale within localized regions of the study area. Variability was also explored at much smaller scales, with samples as close as 50 feet apart. Even over distances that small, contaminant concentrations can vary several-fold (i.e., several hundred percent). The possibility of significant small-scale variability should be recognized in future studies.

- ☐ Contaminant correlations. Arsenic, lead, and cadmium demonstrate a high degree of association. Statistical correlations among all pairs are highly significant. Thus, each of these contaminants shows a similar overall pattern of occurrence, although at different concentrations.

- ☐ Depth profiles. Contaminant concentrations well above background levels were observed for all three contaminants at both sampling depths. Comparison of the 0-2 inch and 2-6 inch results shows that the downward movement of arsenic is significantly greater than that of lead. Cadmium appears to show an intermediate pattern of mobility between arsenic and lead. Almost half of the depth profiles show higher arsenic concentrations in the 2-6 inch interval than at 0-2 inches. This has important implications for future soil sampling programs.

This study was not intended to answer all questions about soil contamination with arsenic, lead, and cadmium. Several important issues remain to be investigated, for example: 1) the extent of soil contamination inland from the mainland shoreline areas remains to be defined; 2) since sampling was limited to the top 6 inches in this study, the full depth of contamination was not defined; and 3) the differences in contamination levels between disturbed and relatively undisturbed locations was not determined.

The results of this study are generally consistent with information from previous, smaller studies, but they substantially increase our knowledge of the magnitude and extent of soil contamination in King County in the area downwind from the Tacoma Smelter. These results provide an excellent conceptual model and framework within which additional studies can be designed to resolve remaining questions. Areas of comparatively higher contamination levels within the overall study area are identified where continuing activities can be focused.

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Table 1

Vashon/Maury Island Soil Study

Field Duplicate Results

Duplicate Sample ID		**Contaminant Concentrations (in ppm)**		
		arsenic	lead	cadmium
A1-030-SK		47	180	ND
A1-030-S		49	190	ND
	RPD (%)	4.17	5.41	-----
B1-033A-S		110	290	2.3
B1-033A-SK		160	370	3
	RPD (%)	37.04	24.24	26.42
A1-048-TY		260	420	ND
A1-048-TYK		290	450	ND
	RPD (%)	10.91	6.90	-----
A1-051-S		120	380	2.2
A1-051-SK		150	240	0.88
	RPD (%)	22.22	45.16	**85.71**
B1-059-S		130	820	9.4
B1-059-SK		110	570	6.7
	RPD (%)	16.67	35.97	33.54
AB1-085-S		310	670	6.2
AB1-085-SK		260	650	5.9
	RPD (%)	17.54	3.03	4.96
AB1-093A-S		210	490	4.2
AB1-093A-SK		120	490	4.9
	RPD (%)	**54.55**	0.00	15.38
AB1-112-S		110	1000	4.6
AB1-112-SK		100	1100	4.8
	RPD (%)	9.52	9.52	4.26
C2-006-S		52	180	ND
C2-006-SK		53	190	ND
	RPD (%)	1.90	5.41	-----
A3-006-SY		99	170	1.4
A3-006-SYK		22	71	0.63
	RPD (%)	**127.27**	**82.16**	**75.86**
A3-007A-SK		5.7	19	ND
A3-007A-S		14	42	ND
	RPD (%)	**84.26**	**75.41**	-----
A3-017-S		28	77	ND
A3-017-SK		27	80	ND
	RPD (%)	3.64	3.82	-----
AB3-048-SK		15	78	3.8
AB3-048-S		19	82	3.8
	RPD (%)	23.53	5.00	0
B3-051-SK		53	89	ND
B3-051-S		25	21	ND
	RPD (%)	**71.79**	**123.64**	-----
B3-063A-SK		77	130	ND
B3-063A-S		73	120	ND
	RPD (%)	5.33	8.00	-----

Table 2

Vashon/Maury Island Soil Study

Equipment Rinsate Samples: Lead Results

	Lead Concentrations		
Sample ID	**Rinsate Blank** (in ug/L)	**Preceding Soil Sample** (in ppm)	
AB3-057-TER	**7.8**	NA	[51 ppm at prior -S sample]
A3-017-TZER	**5.2**	NA	[220 ppm at prior -SZ sample]
B3-053A-SER	**4.5**	95	
C2-005-TER	**1.2**	47	
B1-029A-SER	ND	73	
B1-040-SER	ND	180	
A1-048-TZER	ND	18	
A1-051-TER	ND	140	
AB1-084-TER	ND	490	
AB1-085-SER	ND	670/650	[duplicate field sample]
AB1-089-SER	ND	79	
A3-004A-TER	ND	NA	[36 ppm at prior -S sample]
A3-006-TZER	ND	NA	[61 ppm at prior -SZ sample]
AB3-048-SER	ND	78/82	[duplicate field sample]
B3-051-SER	ND	21	
A3-070-TER	ND	74	

Legend:

ND	not detected
NA	not analyzed

Table 3
Vashon/Maury Island Soil Study
Components of Data Evaluation Data Set

Number of Results by Sampling Zone and Type

Sampling Zone		Number of Grid Locations	Total Number of Results	Number of Results by Type S	T	SY	SZ	TY	TZ
Zone 1		94	248	94	91	16	16	16	15
[S. Vashon/Maury]			(170)	(94)	(36)	(16)	(16)	(4)	(4)
	Zone 1A	55	158	55	52	13	13	13	12
	[S. Vashon]		(108)	(55)	(20)	(13)	(13)	(4)	(3)
	Zone 1B	39	90	39	39	3	3	3	3
	[Maury]		(62)	(39)	(16)	(3)	(3)	(0)	(1)
Zone 2		16	48	16	16	4	4	4	4
[Mainland]			(31)	(16)	(5)	(4)	(4)	(2)	(0)
Zone 3		67	121	67	22	14	14	1	3
[N. Vashon]			(121)	(67)	(22)	(14)	(14)	(1)	(3)
	Totals:	177	417	177	129	34	34	21	22
			(322)	(177)	(63)	(34)	(34)	(7)	(7)

Legend:

S	0-2 inch depth, main grid locations
T	2-6 inch depth, main grid locations
SY,SZ	0-2 inch depth, spatial scale locations
TY,TZ	2-6 inch depth, spatial scale l0cations
248	number of arsenic and lead analyses
(170)	number of cadmium analyses

Table 4a

Vashon/Maury Island Soil Study

Arsenic Concentration Percentiles by Sampling Zone

Based on Individual Results

			Arsenic Concentrations (in ppm)						
			Percentiles:						**Number of**
Sampling Zone		**Depth**	**10**	**25**	**50**	**75**	**90**	**maximum value**	**Values**
Zone 1		all	29	45.5	85	140	200	460	248
[S. Vashon/Maury]		0-2 inch	36	50	88.5	130	170	360	126
		2-6 inch	21	41	85	150	210	460	122
	Zone 1A	all	23	41	67	120	160	360	158
	[S. Vashon]	0-2 inch	37	48	80	120	150	360	81
		2-6 inch	15	35	54	99	160	280	77
	Zone 1B	all	36	65	120	180	260	460	90
	[Maury]	0-2 inch	34	63	110	150	190	340	45
		2-6 inch	39	94	150	200	280	460	45
Zone 2		all	18	29.5	43.5	74.5	160	260	48
[Mainland]		0-2 inch	18	29	42.5	71.5	160	200	24
		2-6 inch	21	29.5	44	74.5	150	260	24
Zone 3		all	9.3	18	28	40	63	140	121
[N. Vashon]		0-2 inch	10	18	29	43	63	140	95
		2-6 inch	5.6	9.3	24.5	29	68	79	26
All Zones		all	17	29	53	110	170	460	417
		0-2 inch	18	29	52	100	150	360	245
		2-6 inch	16	29.5	55.5	120	200	460	172

Table 4b

Vashon/Maury Island Soil Study

Lead Concentration Percentiles by Sampling Zone

Based on Individual Results

			Lead Concentrations (in ppm)						
			Percentiles:						**Number of Values**
Sampling Zone		**Depth**	**10**	**25**	**50**	**75**	**90**	**maximum value**	
Zone 1		all	28	68.5	150	315	570	1300	248
[S. Vashon/Maury]		0-2 inch	60	110	210	370	660	1300	126
		2-6 inch	22	45	97.5	220	430	920	122
	Zone 1A	all	22	57	130	270	440	1300	158
	[S. Vashon]	0-2 inch	60	99	190	330	540	1300	81
		2-6 inch	17	28	73	150	330	650	77
	Zone 1B	all	43.5	93	200	400	745	1100	90
	[Maury]	0-2 inch	79	130	220	460	860	1100	45
		2-6 inch	41	69	160	340	720	920	45
Zone 2		all	21	44	92.5	170	340	790	48
[Mainland]		0-2 inch	26	44.5	102	190	290	580	24
		2-6 inch	21	44	88	125	340	790	24
Zone 3		all	21	35	62	130	210	440	121
[N. Vashon]		0-2 inch	30	45	77	140	220	440	95
		2-6 inch	9.7	21	26.5	54	91	160	26
All Zones		all	23	49	110	220	430	1300	417
		0-2 inch	36	61	130	260	460	1300	245
		2-6 inch	19	34.5	77.5	160	370	920	172

Table 4c
Vashon/Maury Island Soil Study
Cadmium Concentration Percentiles by Sampling Zone
Based on Individual Results

			Cadmium Concentrations (in ppm)						
			Percentiles:						Number of
Sampling Zone		Depth	10	25	50	75	90	maximum value	Values
Zone 1		all	0.305	0.39	0.99	1.9	3.7	15	170
[S. Vashon/Maury]		0-2 inch	0.33	0.43	1	2	3.9	14	126
		2-6 inch	0.28	0.315	0.67	1.3	2.3	15	44
	Zone 1A	all	0.29	0.365	0.85	1.4	2.3	8.1	108
	[S. Vashon]	0-2 inch	0.32	0.41	0.91	1.6	2.5	8.1	81
		2-6 inch	0.28	0.31	0.6	1.2	1.7	3.1	27
	Zone 1B	all	0.33	0.42	1.45	3.3	6.9	15	62
	[Maury]	0-2 inch	0.38	0.5	1.8	3.8	6.9	14	45
		2-6 inch	0.3	0.32	1	1.7	12	15	17
Zone 2		all	0.35	0.39	0.47	1.1	1.7	3.6	31
[Mainland]		0-2 inch	0.35	0.4	0.5	1.12	1.9	3.6	24
		2-6 inch	0.35	0.37	0.41	1.1	1.7	1.7	7
Zone 3		all	0.27	0.29	0.32	0.48	0.86	3.8	121
[N. Vashon]		0-2 inch	0.28	0.29	0.34	0.63	1	3.8	95
		2-6 inch	0.26	0.27	0.28	0.29	0.71	1	26
All Zones		all	0.28	0.32	0.47	1.2	2.3	15	322
		0-2 inch	0.29	0.34	0.5	1.3	2.7	14	245
		2-6 inch	0.27	0.28	0.35	1.1	1.7	15	77

NOTE:

Not detected results are included at one-half the detection limit.

Using this approach, only 3 not-detected results exceed the smallest reported quantified value of 0.57 ppm.

Overall, 175 of 322 cadmium results are not detected.

Table 5
Vashon/Maury Island Soil Study
Arsenic, Lead, and Cadmium Concentration Percentiles by Sampling Zone
Based on Maximum Location Values

Arsenic Concentrations (in ppm)

Sampling Zone	Percentiles: 10	25	50	75	90	maximum value	Number of Values
Zone 1 [S. Vashon/Maury]	45	75	130	180	250	460	94
Zone 1A [S. Vashon]	39	58	100	130	180	360	55
Zone 1B [Maury]	65	130	170	230	340	460	39
Zone 2 [Mainland]	21	33.5	53	140	170	260	16
Zone 3 [N. Vashon]	9.9	20	32	53	69	140	67
All Zones	18	34	67	140	200	460	177

Lead Concentrations (in ppm)

Sampling Zone	Percentiles: 10	25	50	75	90	maximum value	Number of Values
Zone 1 [S. Vashon/Maury]	73	140	285	490	770	1300	94
Zone 1A [S. Vashon]	60	110	230	400	620	1300	55
Zone 1B [Maury]	100	200	370	710	920	1100	39
Zone 2 [Mainland]	21	54.5	140	260	580	790	16
Zone 3 [N. Vashon]	30	44	85	170	280	440	67
All Zones	41	75	170	330	650	1300	177

Cadmium Concentrations (in ppm)

Sampling Zone	Percentiles: 10	25	50	75	90	maximum value	Number of Values
Zone 1 [S. Vashon/Maury]	0.36	0.79	1.4	2.3	6.1	15	94
Zone 1A [S. Vashon]	0.35	0.69	1.2	1.7	3.1	8.1	55
Zone 1B [Maury]	0.37	1.1	1.9	4.6	9.4	15	39
Zone 2 [Mainland]	0.35	0.415	0.525	1.4	2.1	3.6	16
Zone 3 [N. Vashon]	0.28	0.31	0.37	0.73	1	3.8	67
All Zones	0.3	0.37	0.83	1.6	3.6	15	177

Table 6

Vashon/Maury Island Soil Study

Summary of Depth Profile Patterns for Arsenic and Lead by Sampling Zone

Arsenic Depth Profiles

Sampling Zone		Number by Pattern:					Percent by Pattern:	
		total	S>=T	T>S	T>1.5 S	T>2 S	T>S	T>2 S
Zone 1		122	67	55	31	20	45.1	16.4
[S. Vashon/Maury]								
	Zone 1A	77	49	28	11	5	36.4	6.5
	[S. Vashon]							
	Zone 1B	45	18	27	20	15	60.0	33.3
	[Maury]							
Zone 2		24	9	15	4	2	62.5	8.3
[Mainland]								
Zone 3		26	18	8	3	1	30.8	3.9
[N. Vashon]								
All Zones		172	94	78	38	23	45.4	13.4

Lead Depth Profiles

Sampling Zone		Number by Pattern:					Percent by Pattern:	
		total	S>=T	T>S	T>1.5 S	T>2 S	T>S	T>2 S
Zone 1		122	90	32	18	12	26.2	9.8
[S. Vashon/Maury]								
	Zone 1A	77	60	17	9	6	22.1	7.8
	[S. Vashon]							
	Zone 1B	45	30	15	9	6	33.3	13.3
	[Maury]							
Zone 2		24	10	14	2	1	58.3	4.2
[Mainland]								
Zone 3		26	21	5	3	0	19.2	0.0
[N. Vashon]								
All Zones		172	121	51	23	13	29.7	7.6

Table 7a
Vashon/Maury Island Soil Study
Summary of Spatial Scale Variability by Sampling Zone
K-Factors

Arsenic K-Factors

		Percentiles:			Number of Values
Sampling Zone	**Distance**	**50**	**75**	**maximum**	
Zone 1	50	1.36	1.8	9.33	31
[S. Vashon/Maury]	300	1.55	2.03	10.0	62
Zone 2	50	2.51	4.64	10.4	8
[Mainland]	300	2.39	3.51	7.88	16
Zone 3	50	1.52	2.33	7.18	15
[N. Vashon]	300	1.67	3.29	7.37	30
All Zones	50	1.52	2.33	10.4	54
	300	1.64	2.25	10.0	108

Lead K-Factors

		Percentiles:			Number of Values
Sampling Zone	**Distance**	**50**	**75**	**maximum**	
Zone 1	50	1.86	2.73	24.4	31
[S. Vashon/Maury]	300	2.21	3.50	31.7	62
Zone 2	50	4.30	6.41	8.85	8
[Mainland]	300	2.36	6.33	10.24	16
Zone 3	50	1.97	2.60	8.24	15
[N. Vashon]	300	2.21	2.88	12.42	30
All Zones	50	2.05	3.21	24.4	54
	300	2.21	3.53	31.7	108

Table 7b

Vashon/Maury Island Soil Study

Summary of Spatial Scale Variability by Sampling Zone

Standard Deviations

Arsenic Standard Deviations (in ppm)

Sampling Zone	Distance	Percentiles: 50	75	maximum	Number of Values
Zone 1	50	20	51	177	31
[S. Vashon/Maury]	300	24	40	115	62
Zone 2	50	34	99	166	8
[Mainland]	300	28	75	161	16
Zone 3	50	9	18	34	15
[N. Vashon]	300	12	25	86	30
All Zones	50	17	35	177	54
	300	22	39	161	108

Lead Standard Deviations (in ppm)

Sampling Zone	Distance	Percentiles: 50	75	maximum	Number of Values
Zone 1	50	49	170	658	31
[S. Vashon/Maury]	300	70	113	537	62
Zone 2	50	72	271	318	8
[Mainland]	300	54	136	489	16
Zone 3	50	38	87	127	15
[N. Vashon]	300	43	71	267	30
All Zones	50	53	121	658	54
	300	64	100	537	108

Phase I
Vashon/Maury Island
Sampling Sites

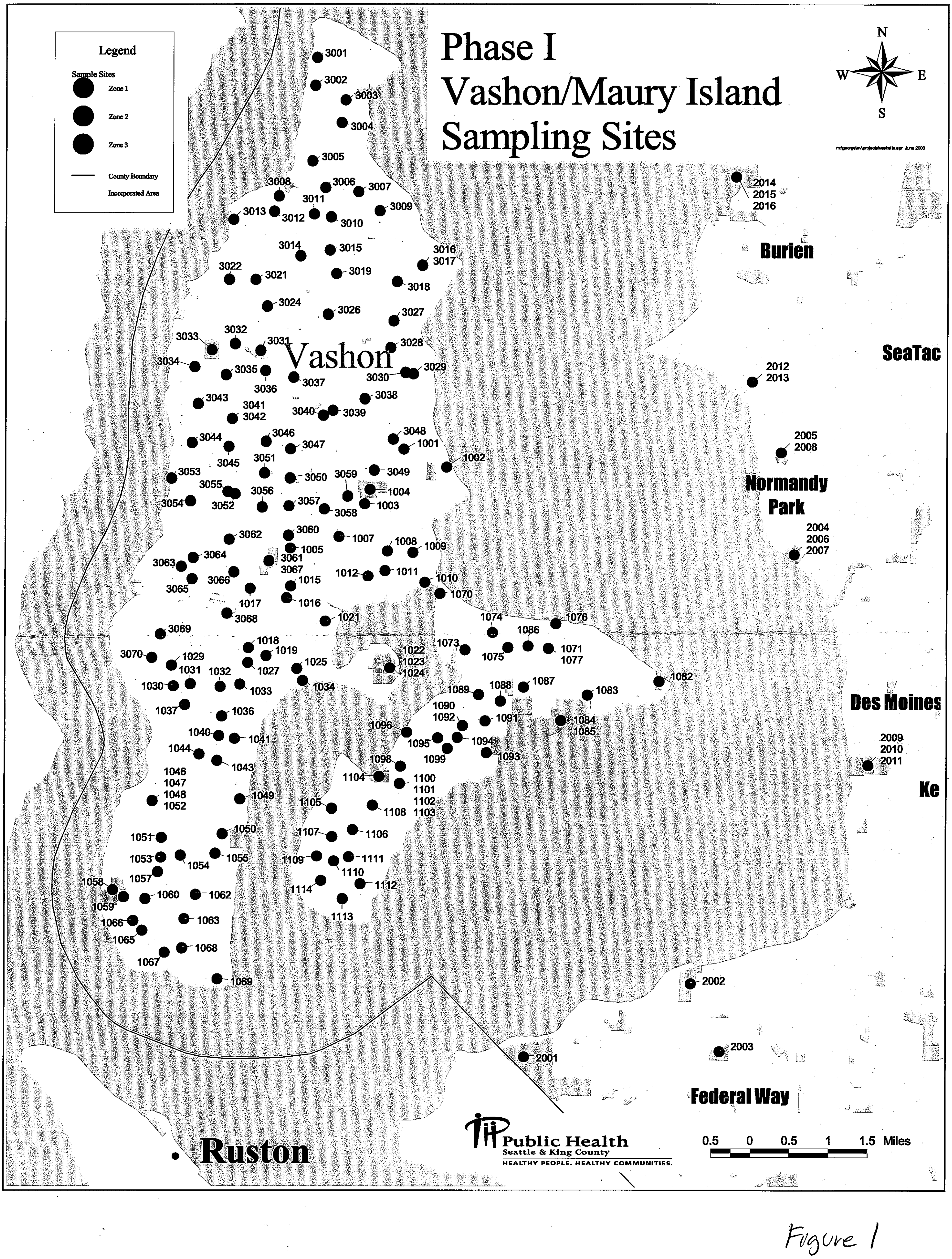


Figure 1

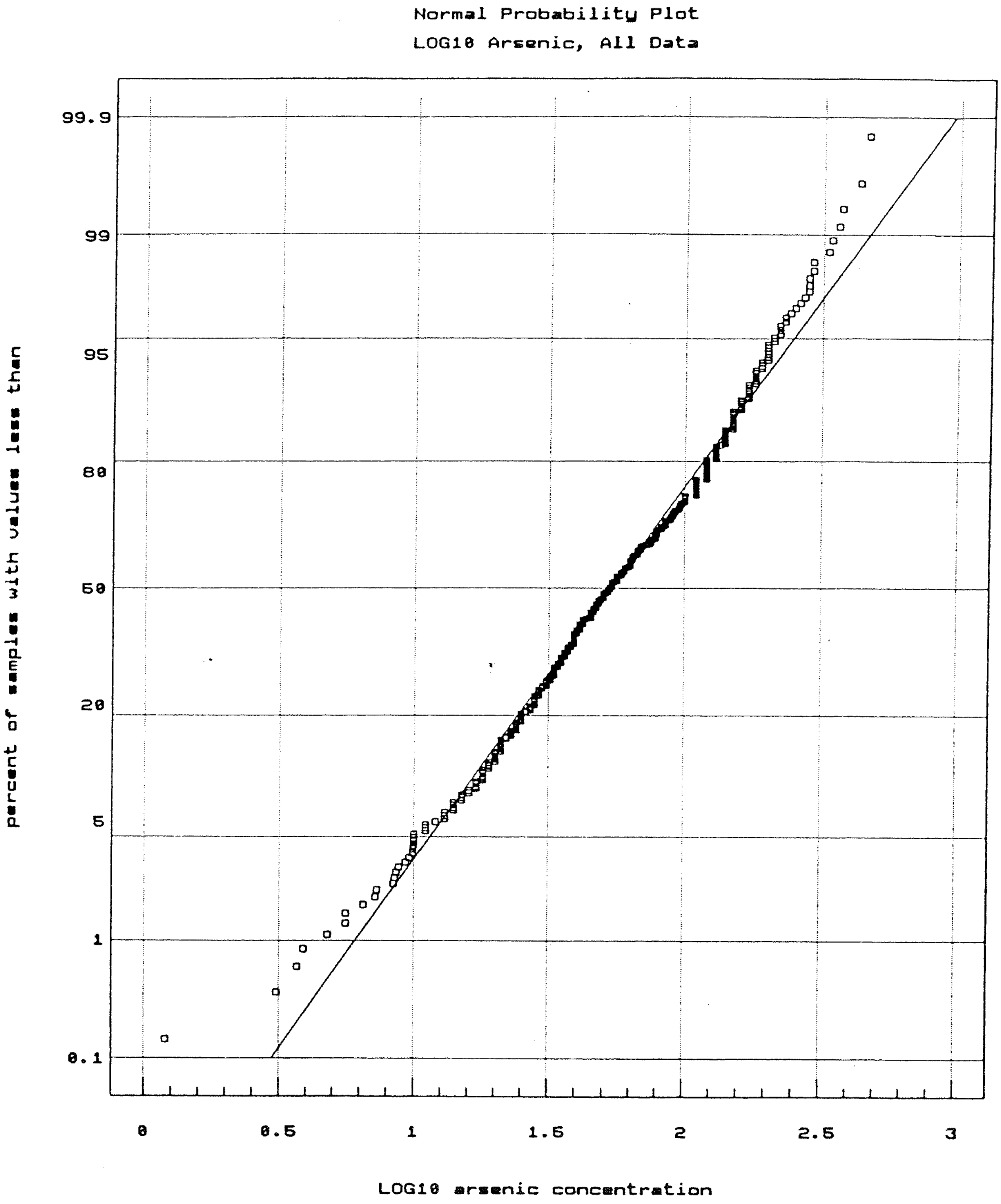


Figure 2
Lognormal Probability Plot: Arsenic (All Data)

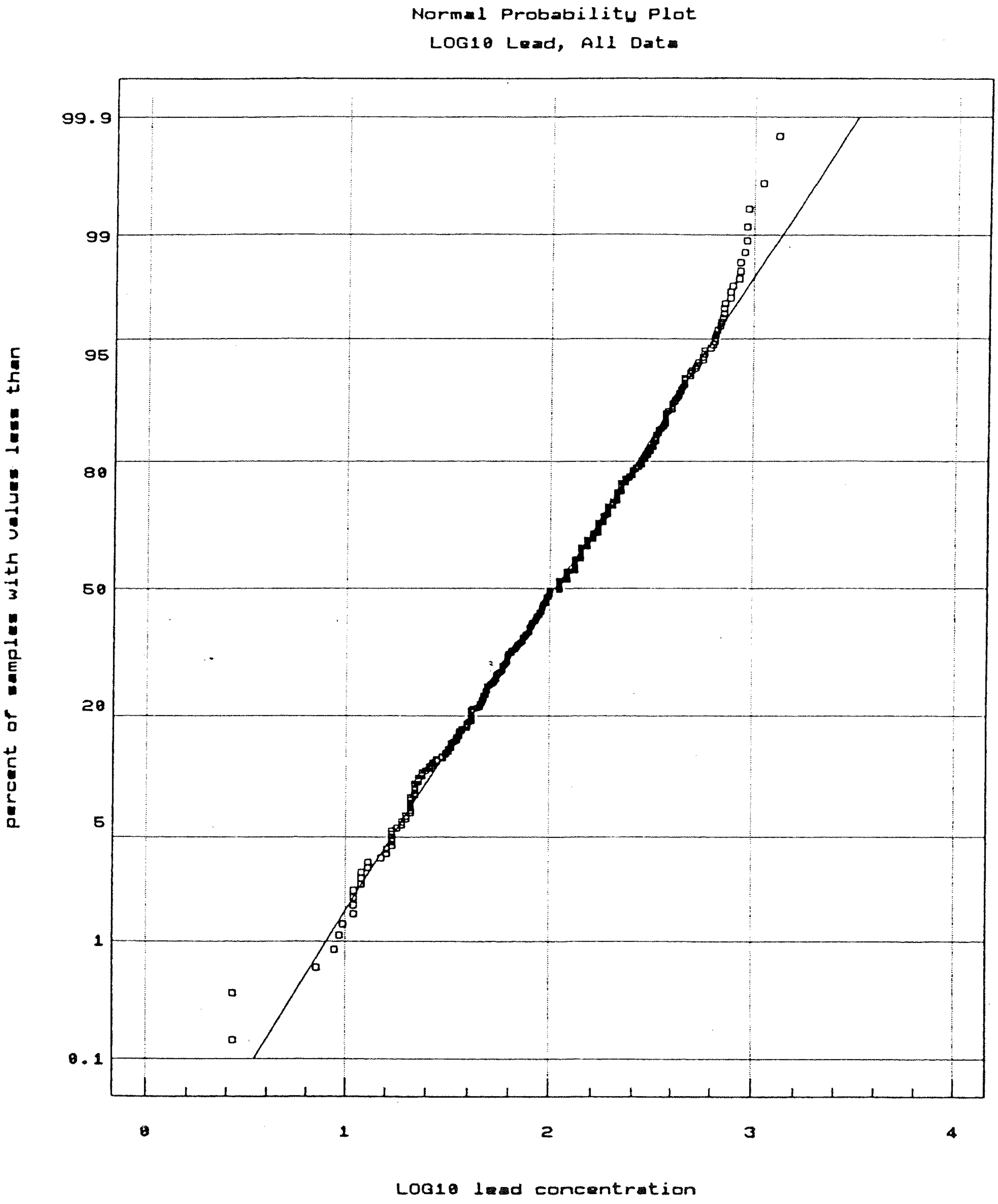


Figure 3
Lognormal Probability Plot: Lead (All Data)

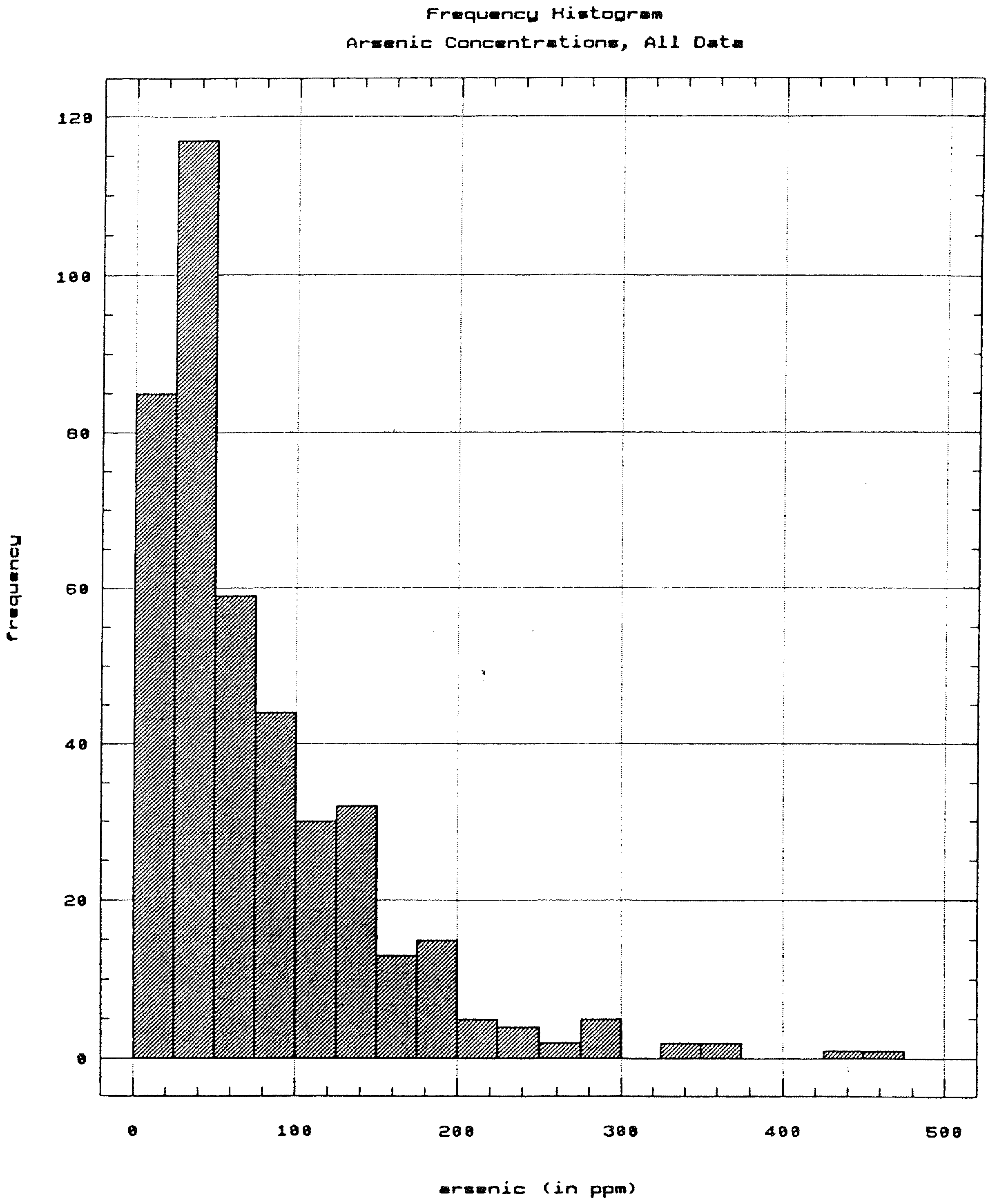


Figure 4
Frequency Histogram: Arsenic (All Data)

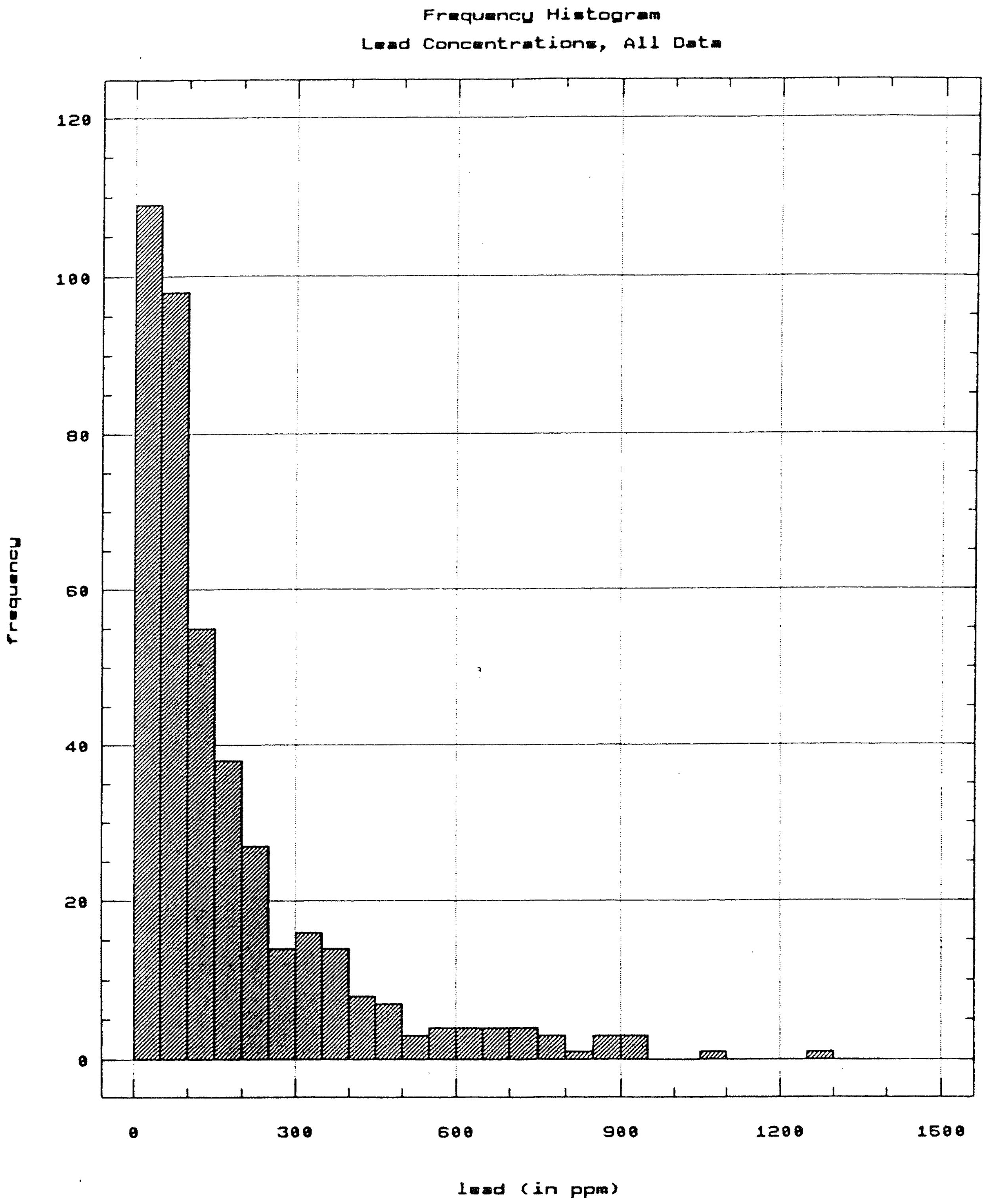
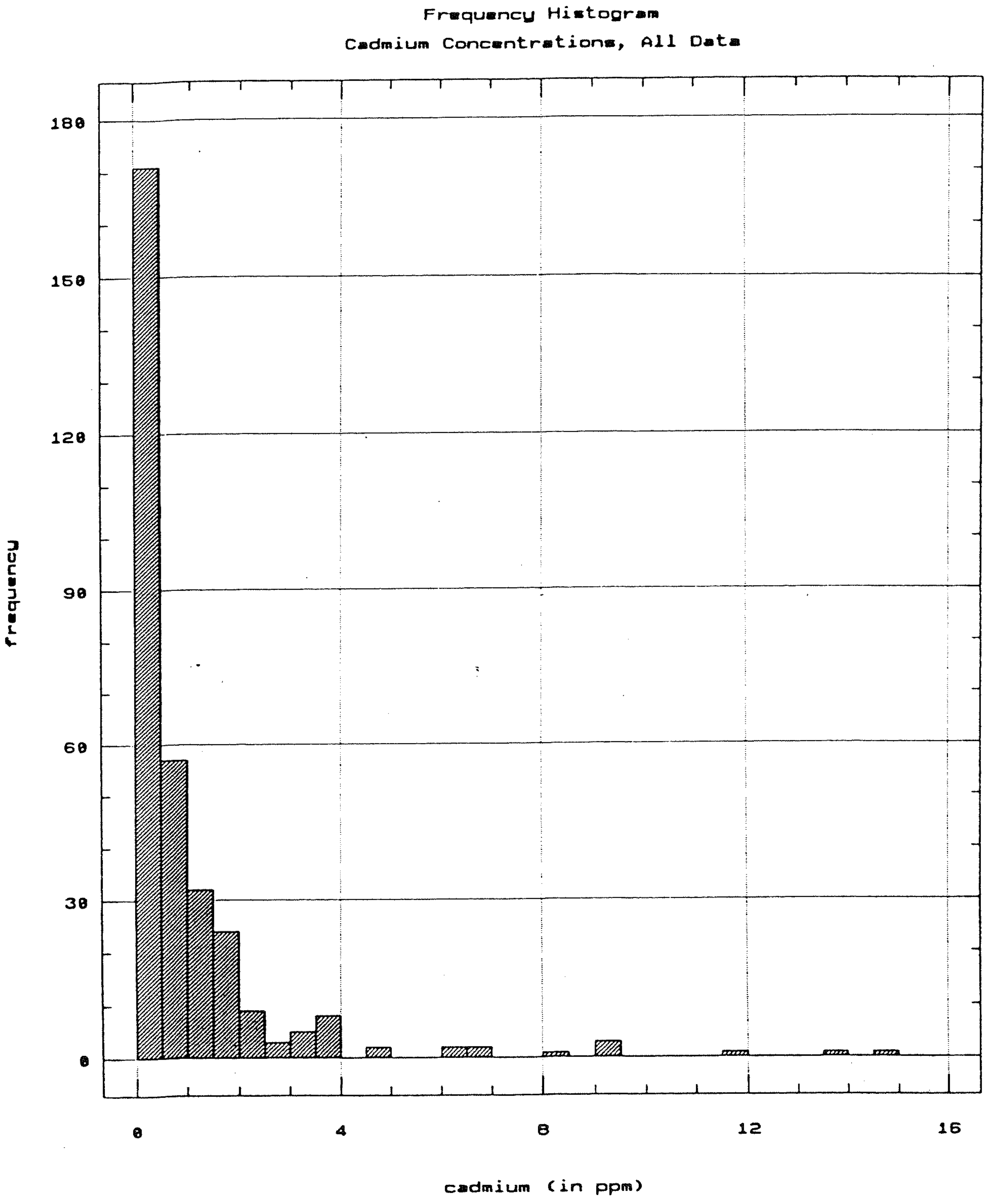


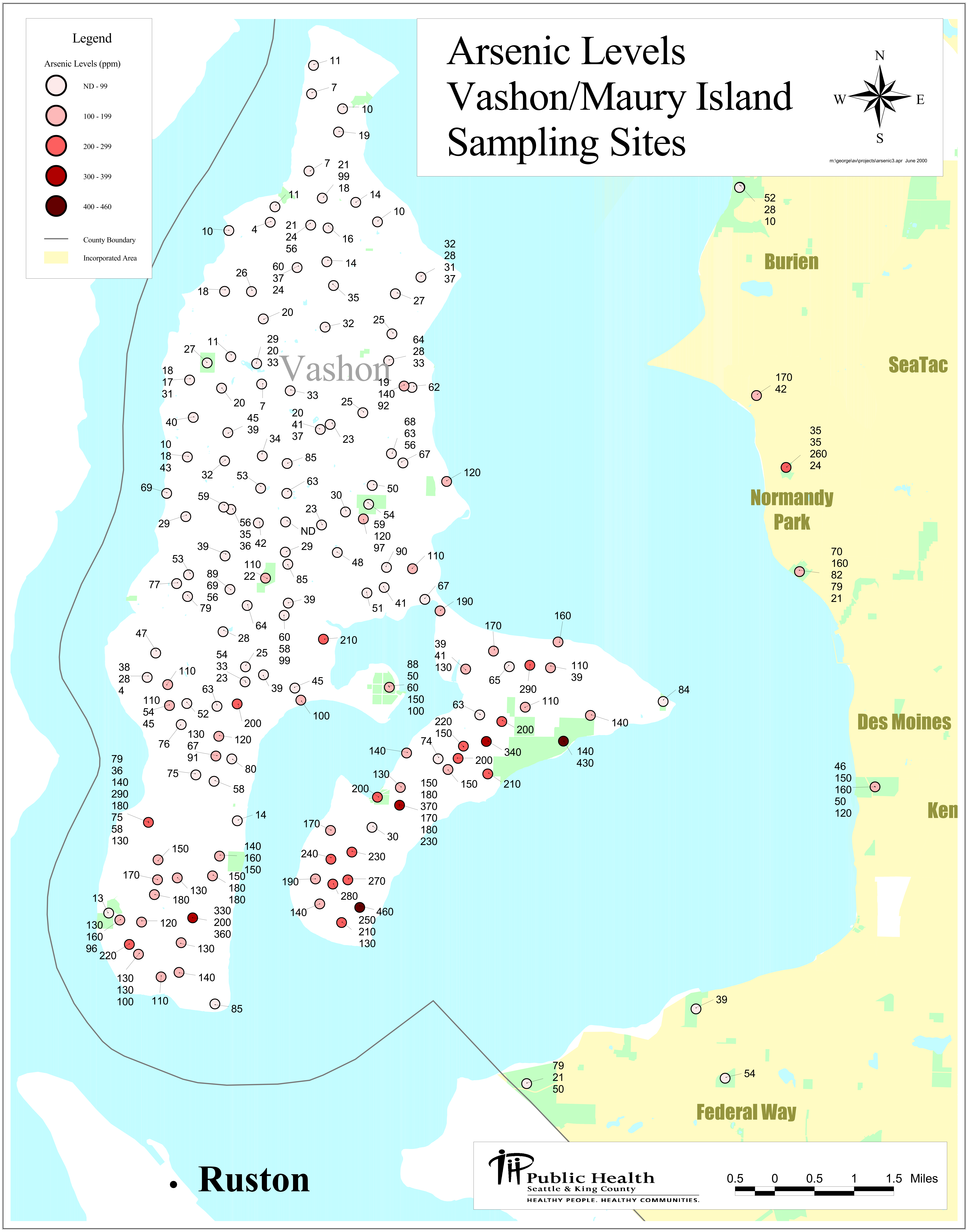
Figure 5
Frequency Histogram: Lead (All Data)



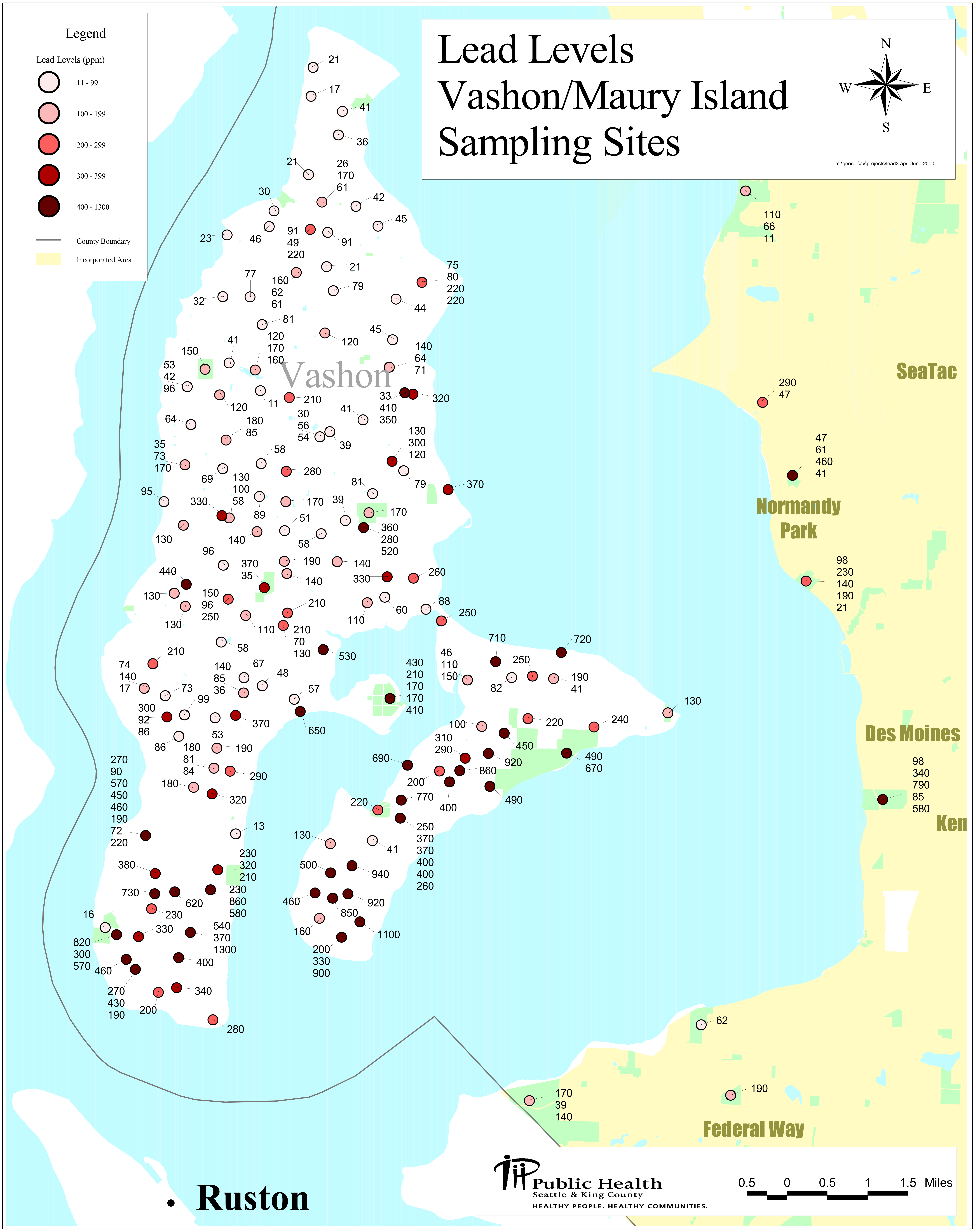
(Note: NDs at 1/2 detection limit)

Figure 6
Frequency Histogram: Cadmium (All Data)

Arsenic Levels Vashon/Maury Island Sampling Sites



Lead Levels Vashon/Maury Island Sampling Sites



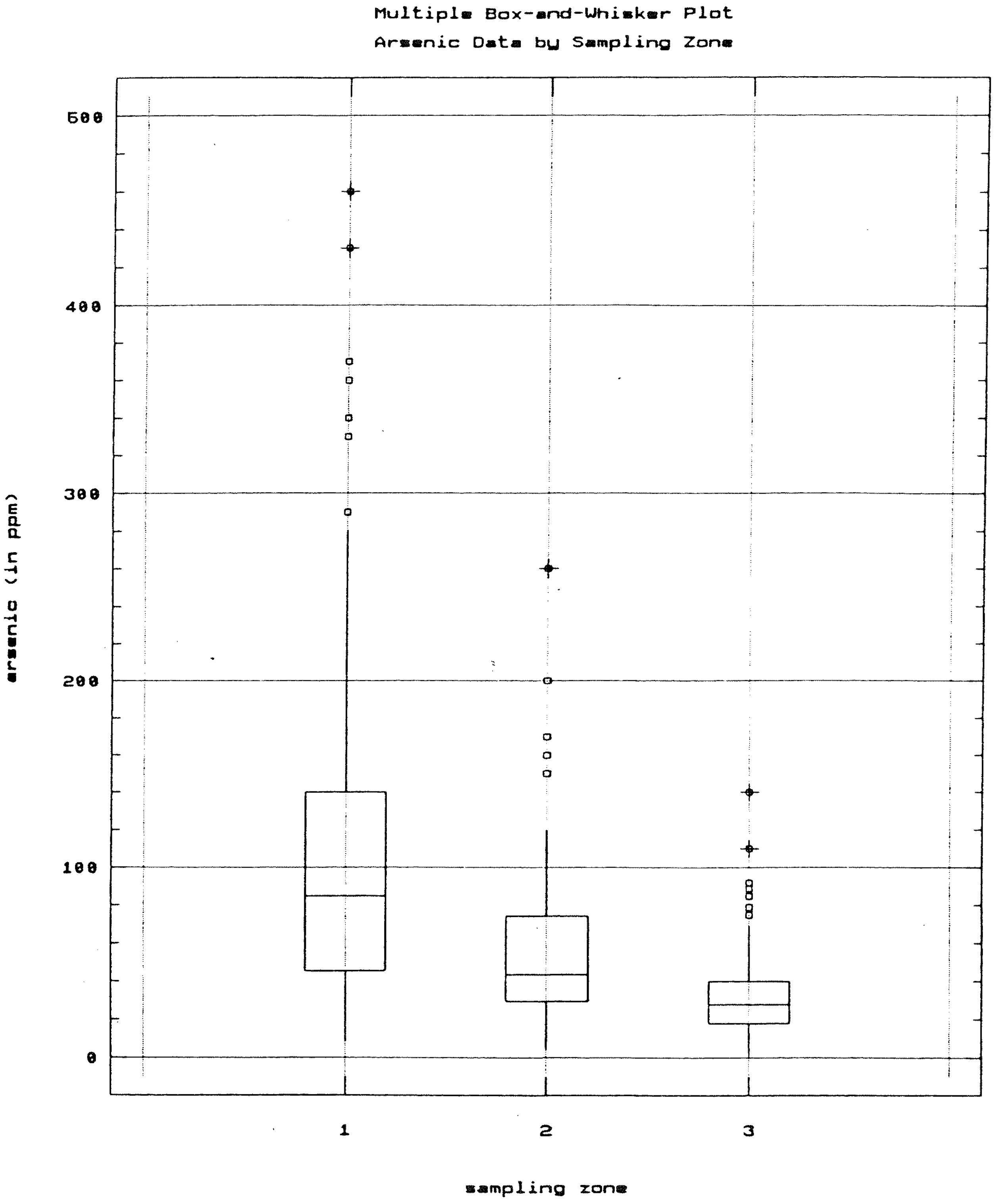


Figure 9
Box-and-Whisker Plot: Arsenic Data by Sampling Zone

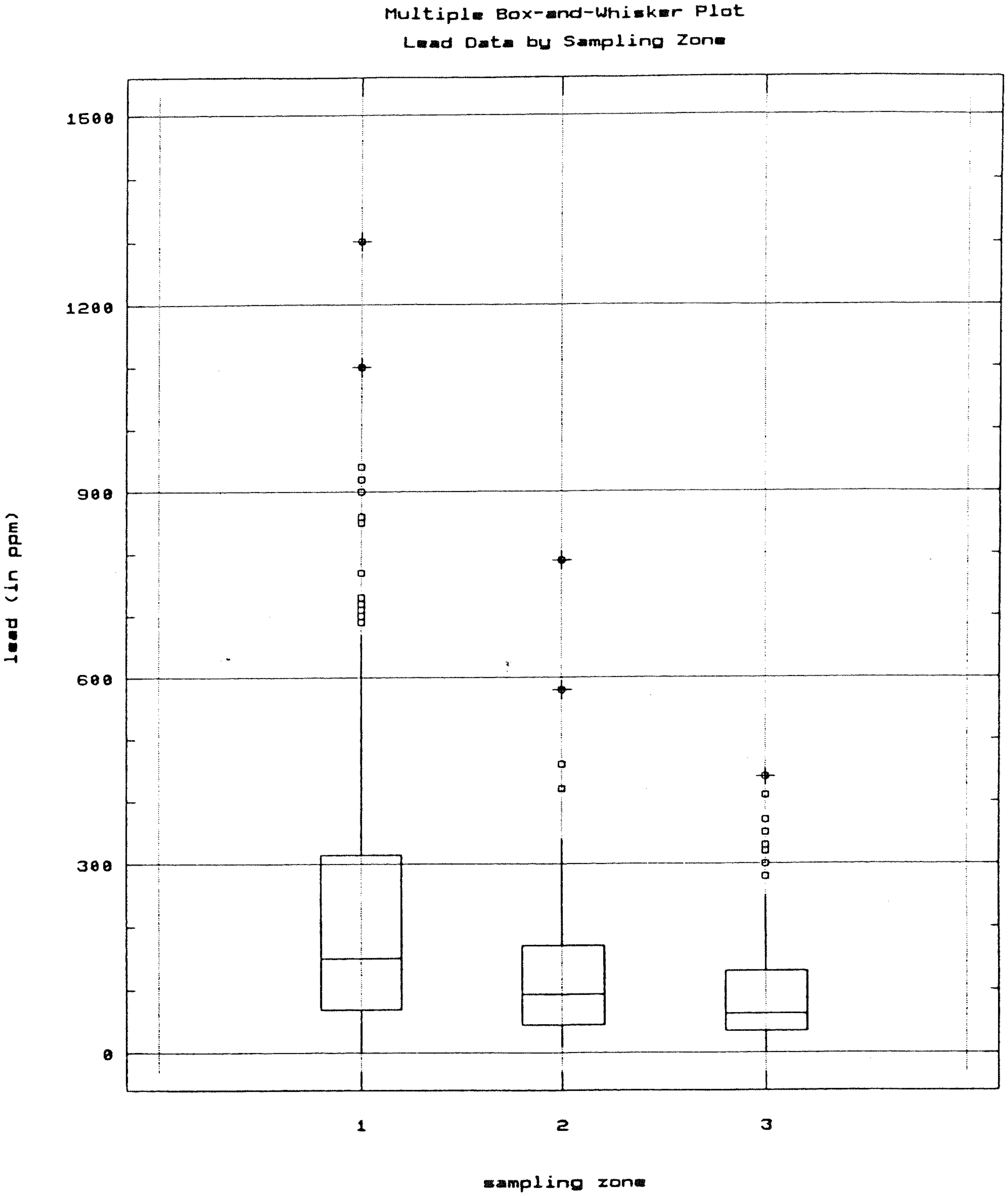


Figure 10
Box-and-Whisker Plot: Lead Data by Sampling Zone

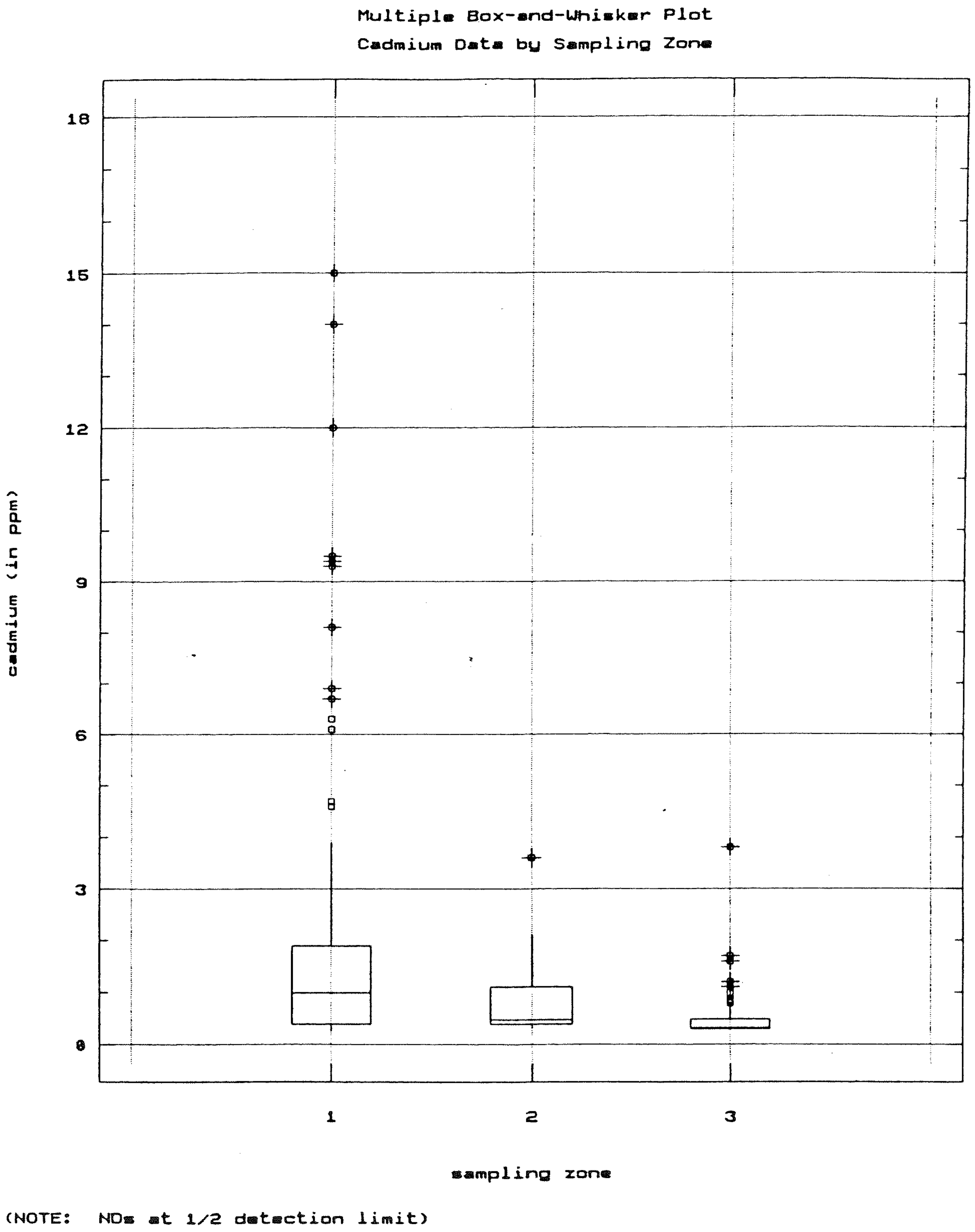


Figure 11
Box-and-Whisker Plot: Cadmium Data by Sampling Zone

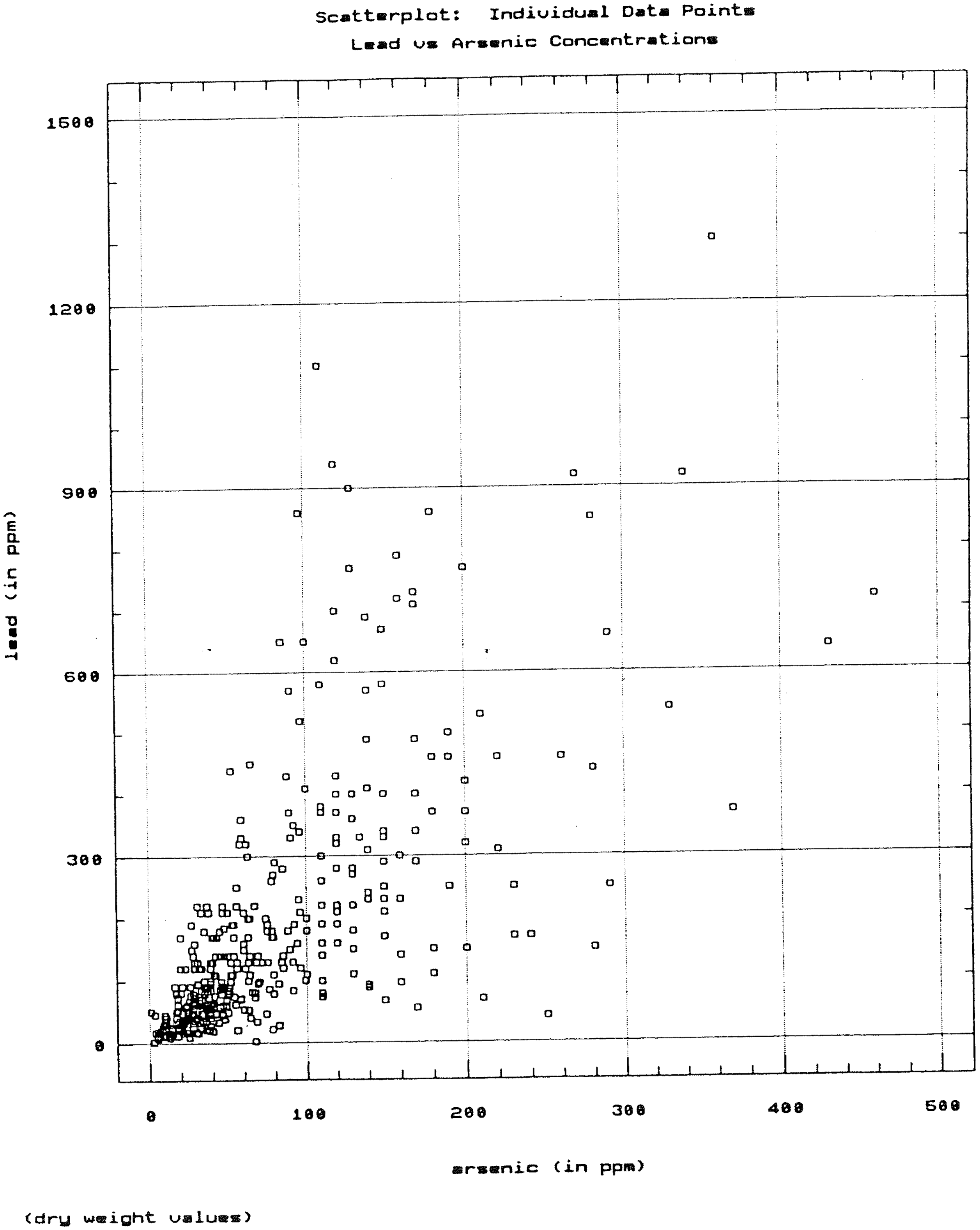
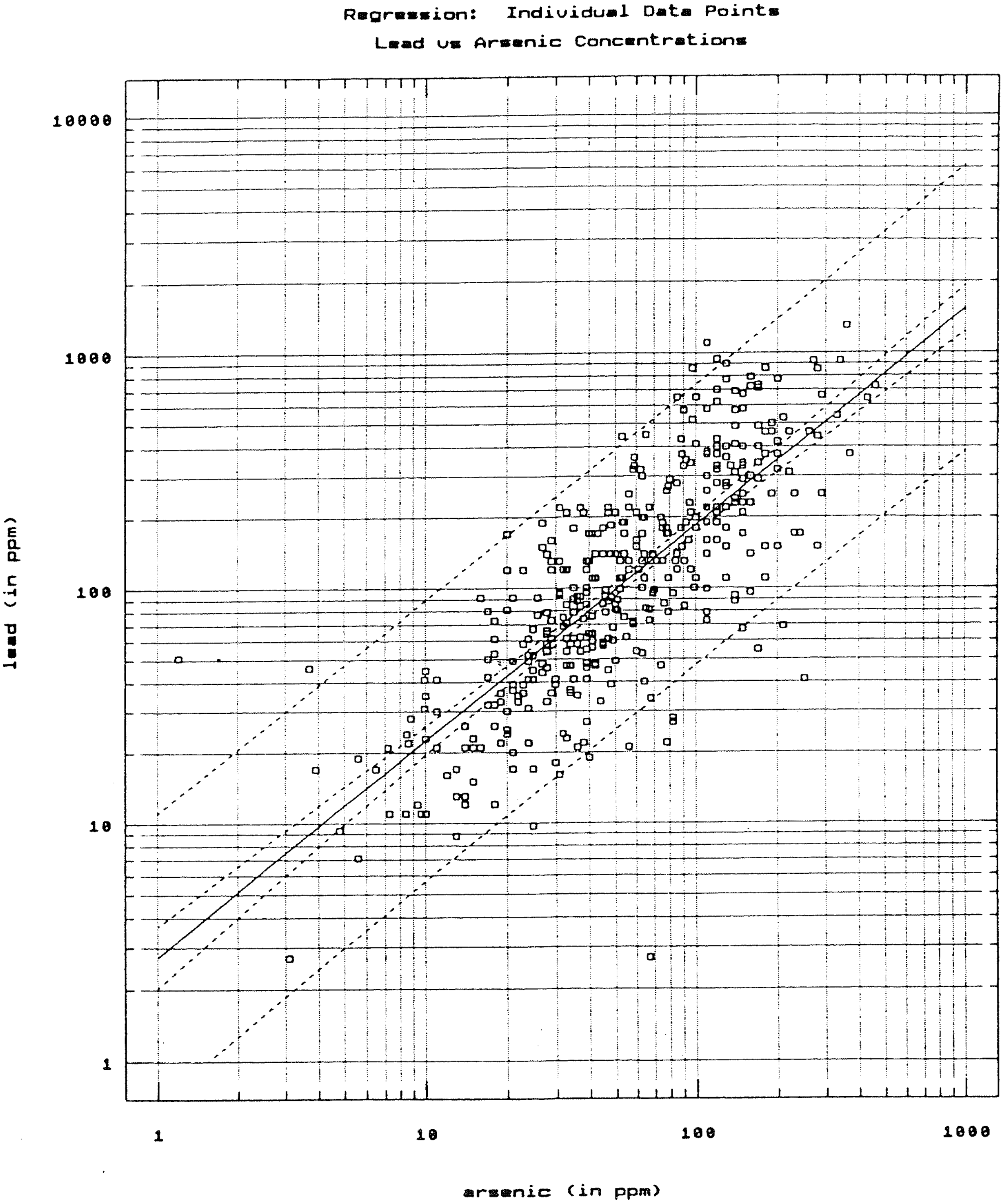


Figure 12
Scatterplot: Lead versus Arsenic Concentrations (All Data)



(LOG-LOG linear = multiplicative model)

Figure 13
Regression: Lead versus Arsenic Concentrations (LOG-LOG linear model, All Data)

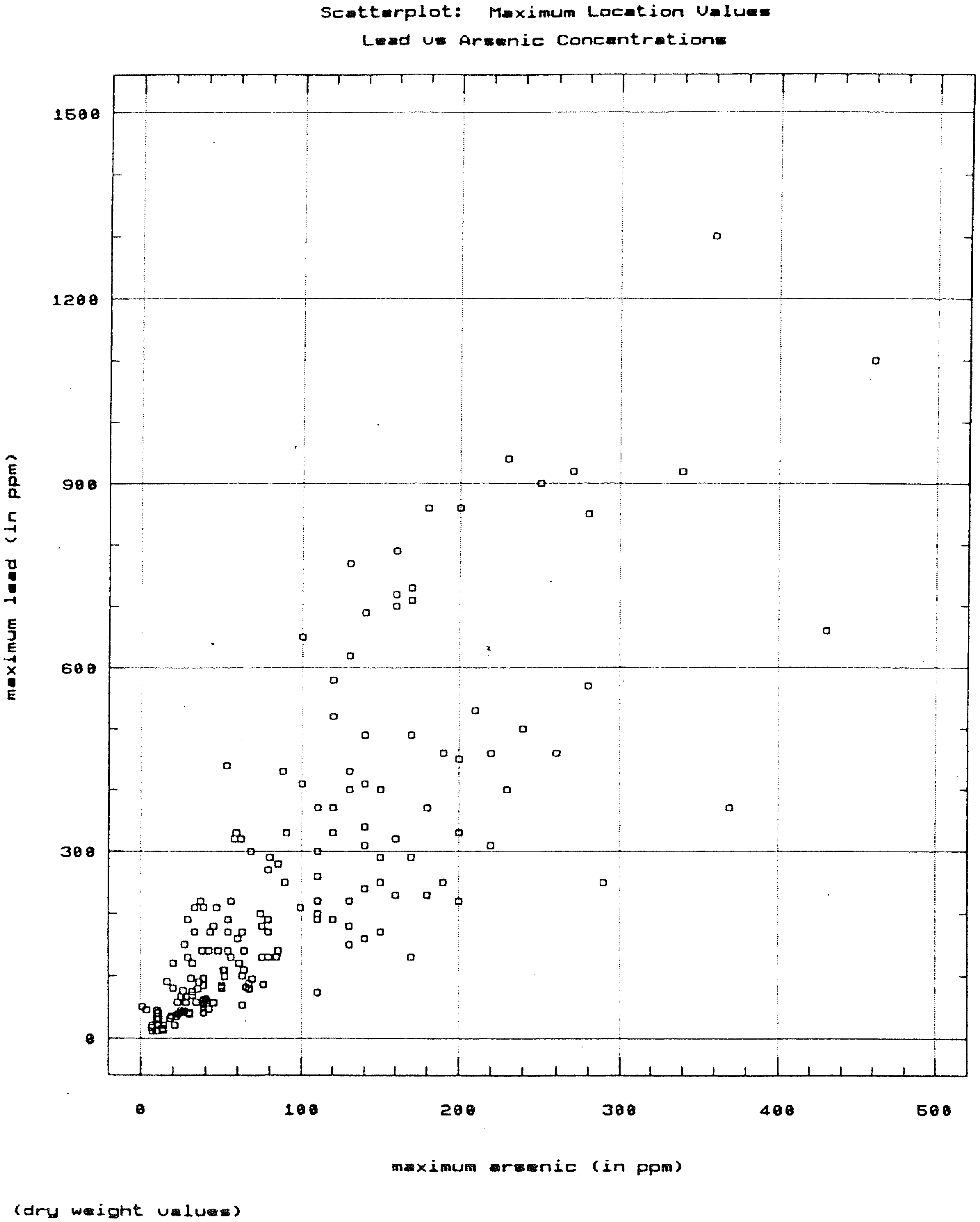


Figure 14
Scatterplot: Lead versus Arsenic Concentrations (Maximum Location Values)

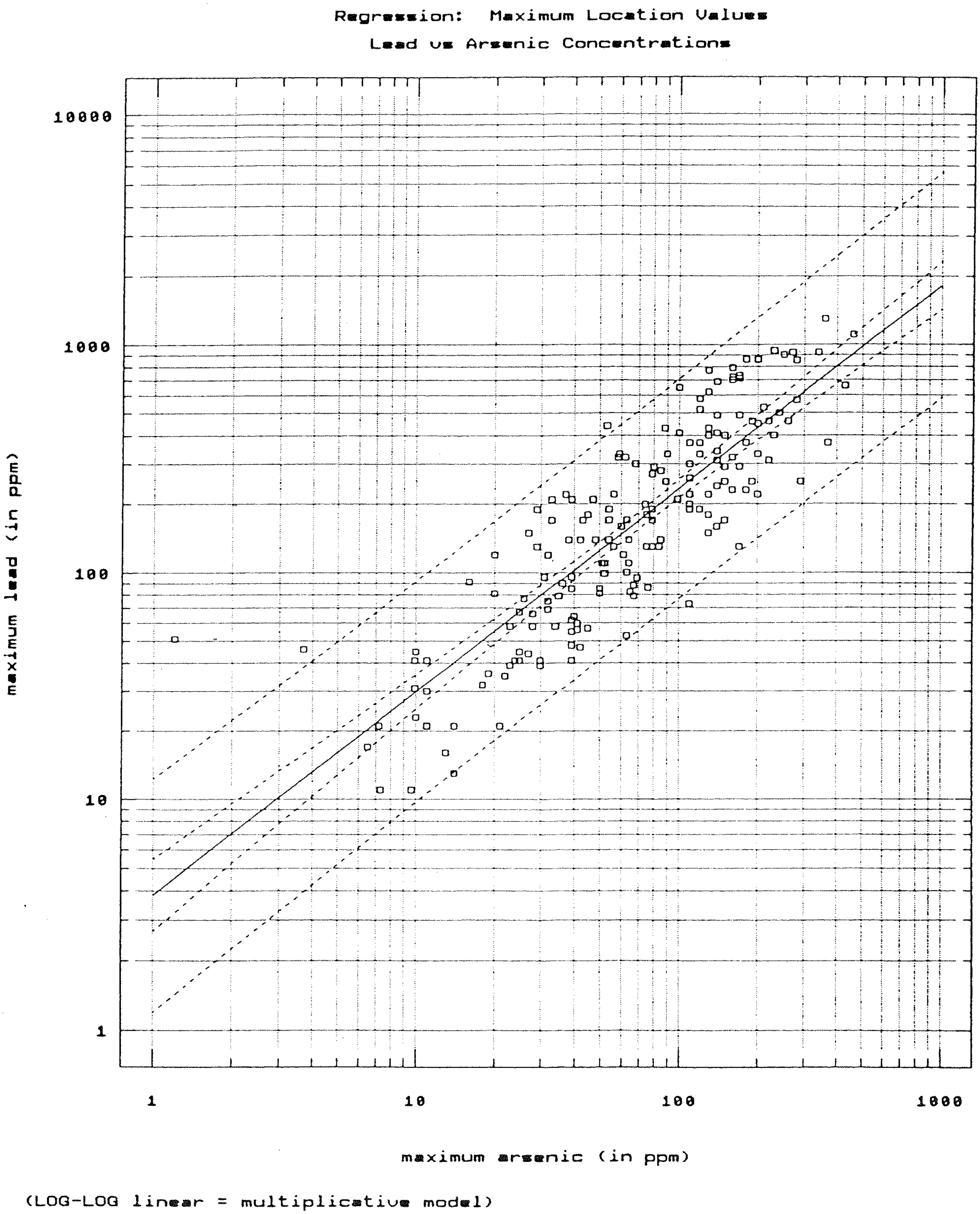
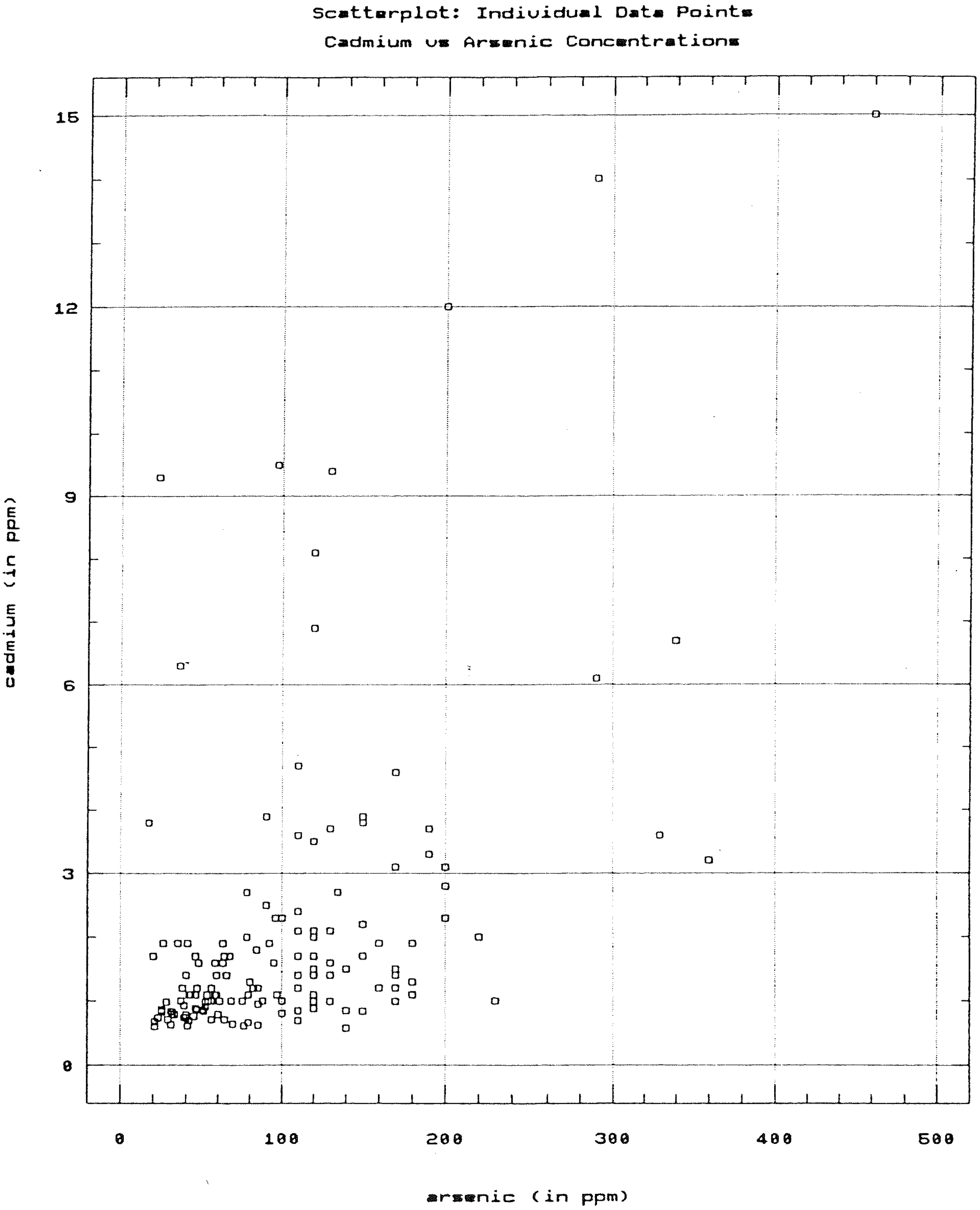


Figure 15
Regression: Lead versus Arsenic Concentrations (LOG-LOG linear model, Maximum Location Values)



(not detected cadmium results omitted)

Figure 16
Scatterplot: Cadmium versus Arsenic Concentrations (All Data)

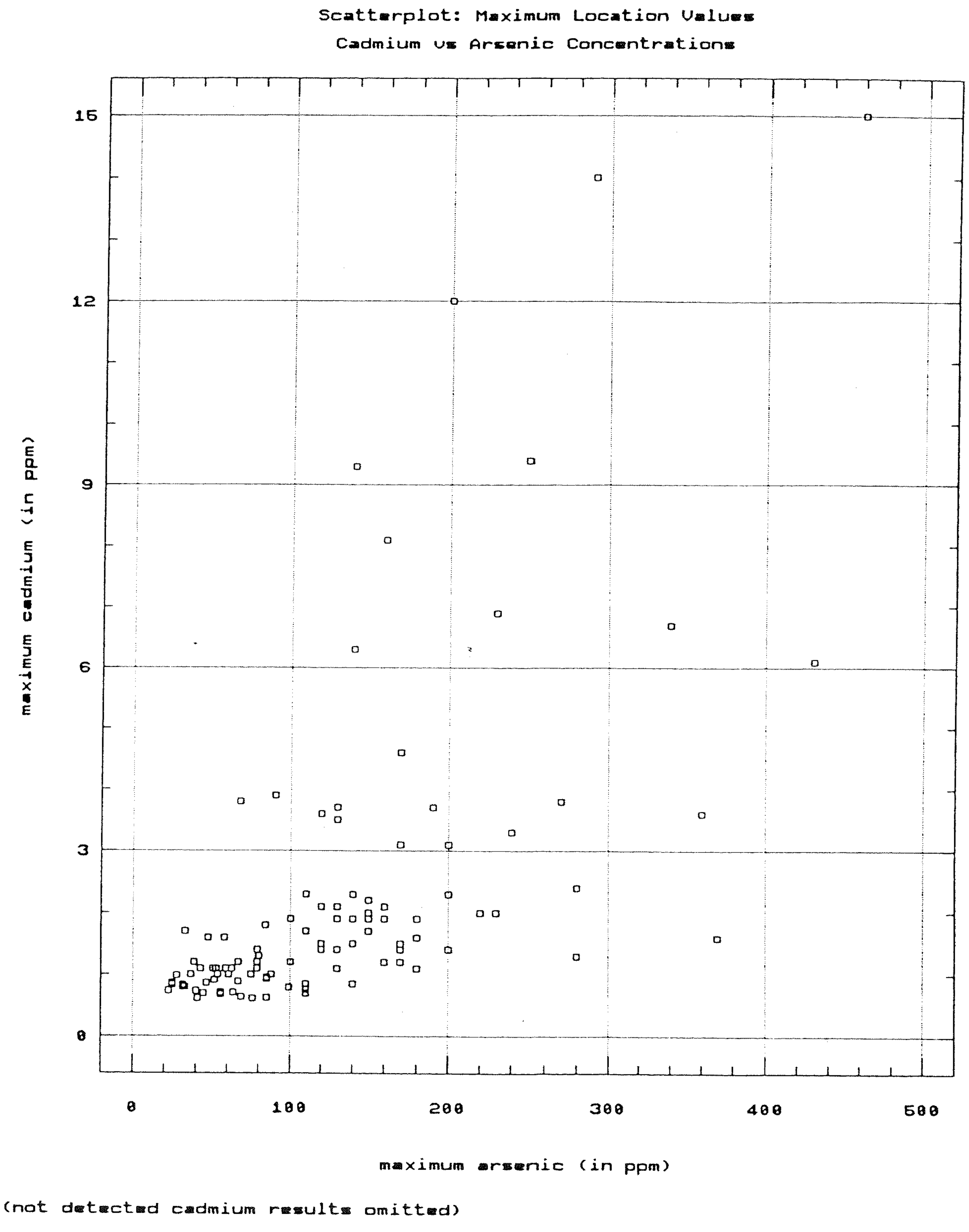


Figure 17
Scatterplot: Cadmium versus Arsenic Concentrations (Maximum Location Values)

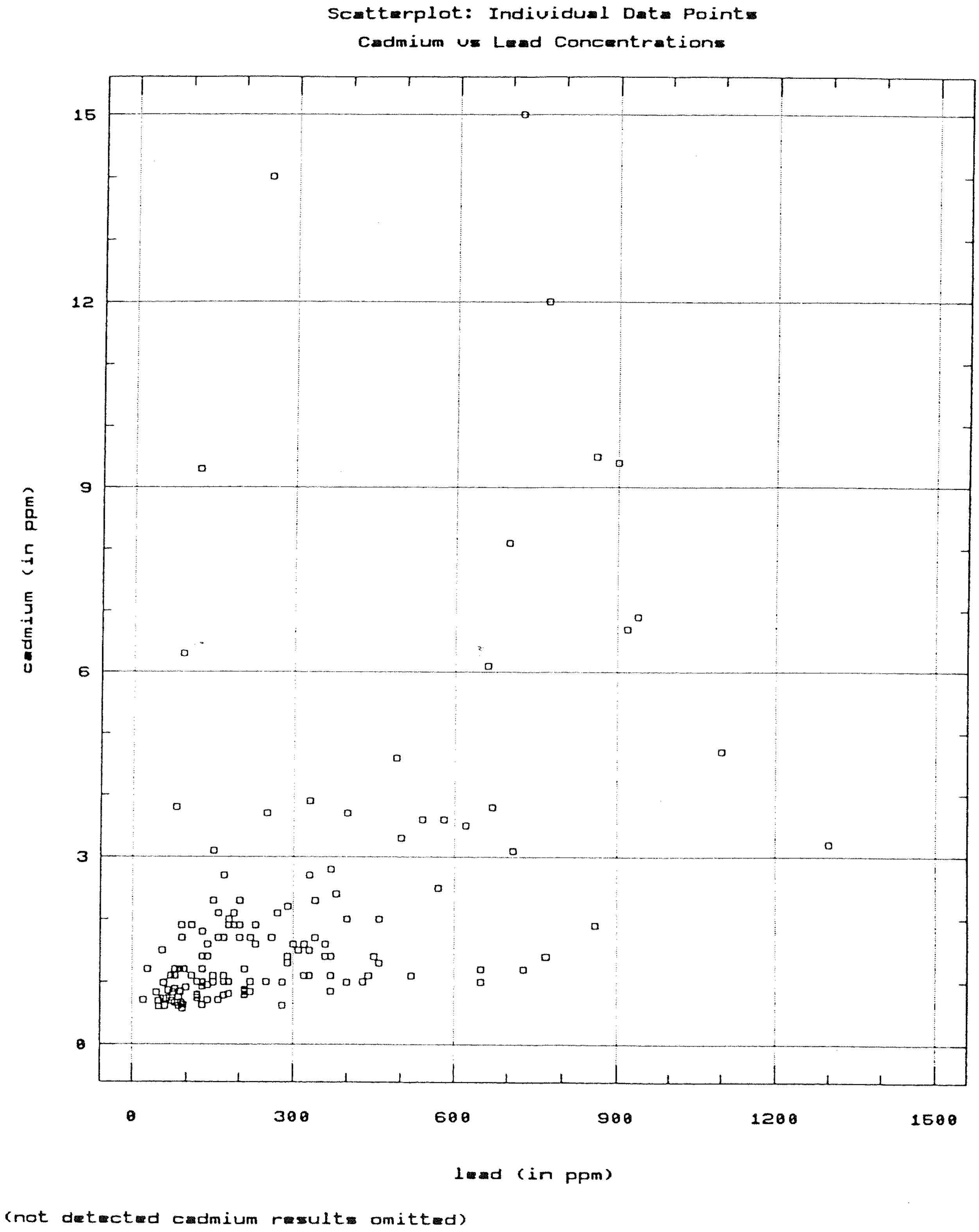


Figure 18
Scatterplot: Cadmium versus Lead Concentrations (All Data)

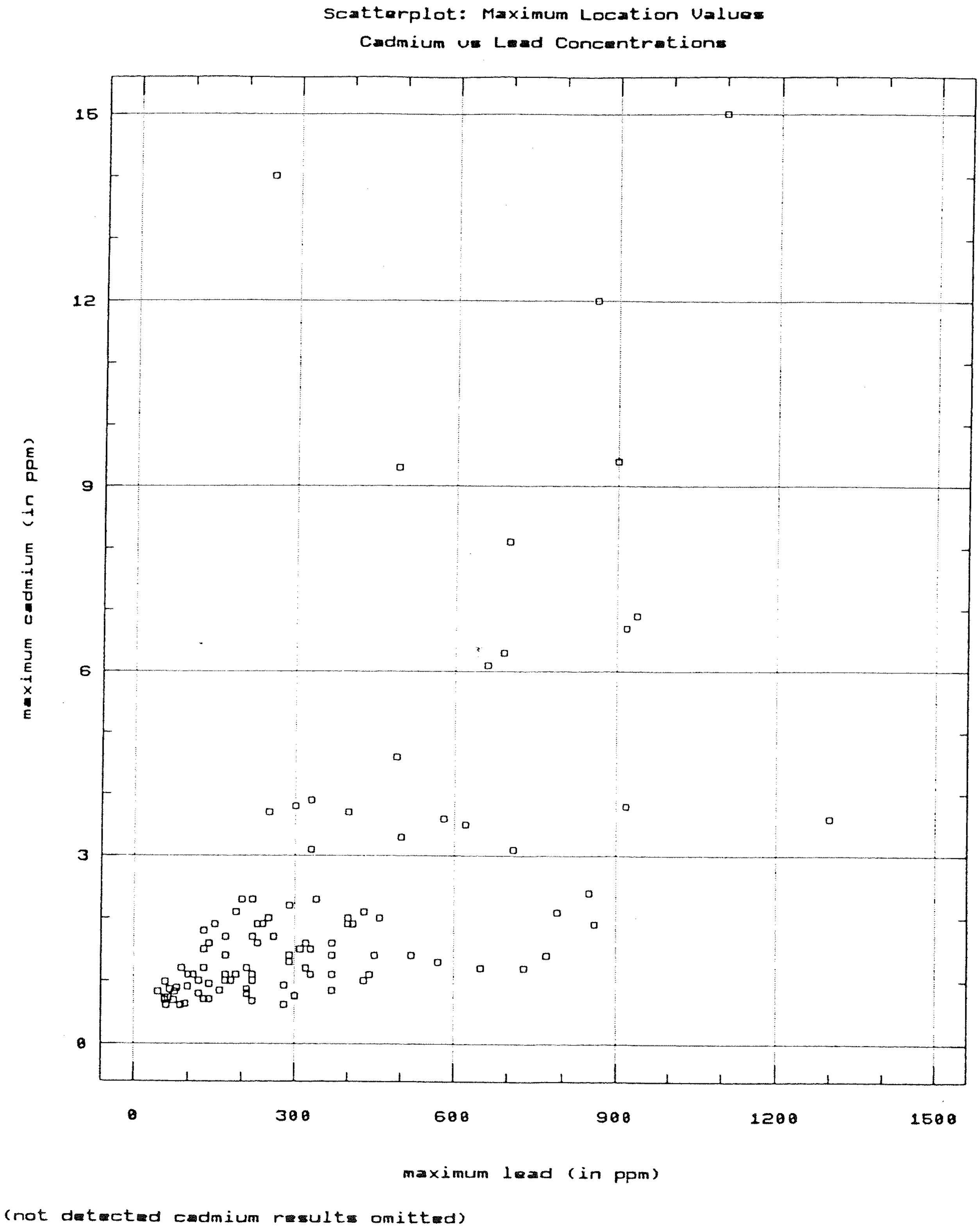


Figure 19
Scatterplot: Cadmium versus Lead Concentrations (Maximum Location Values)

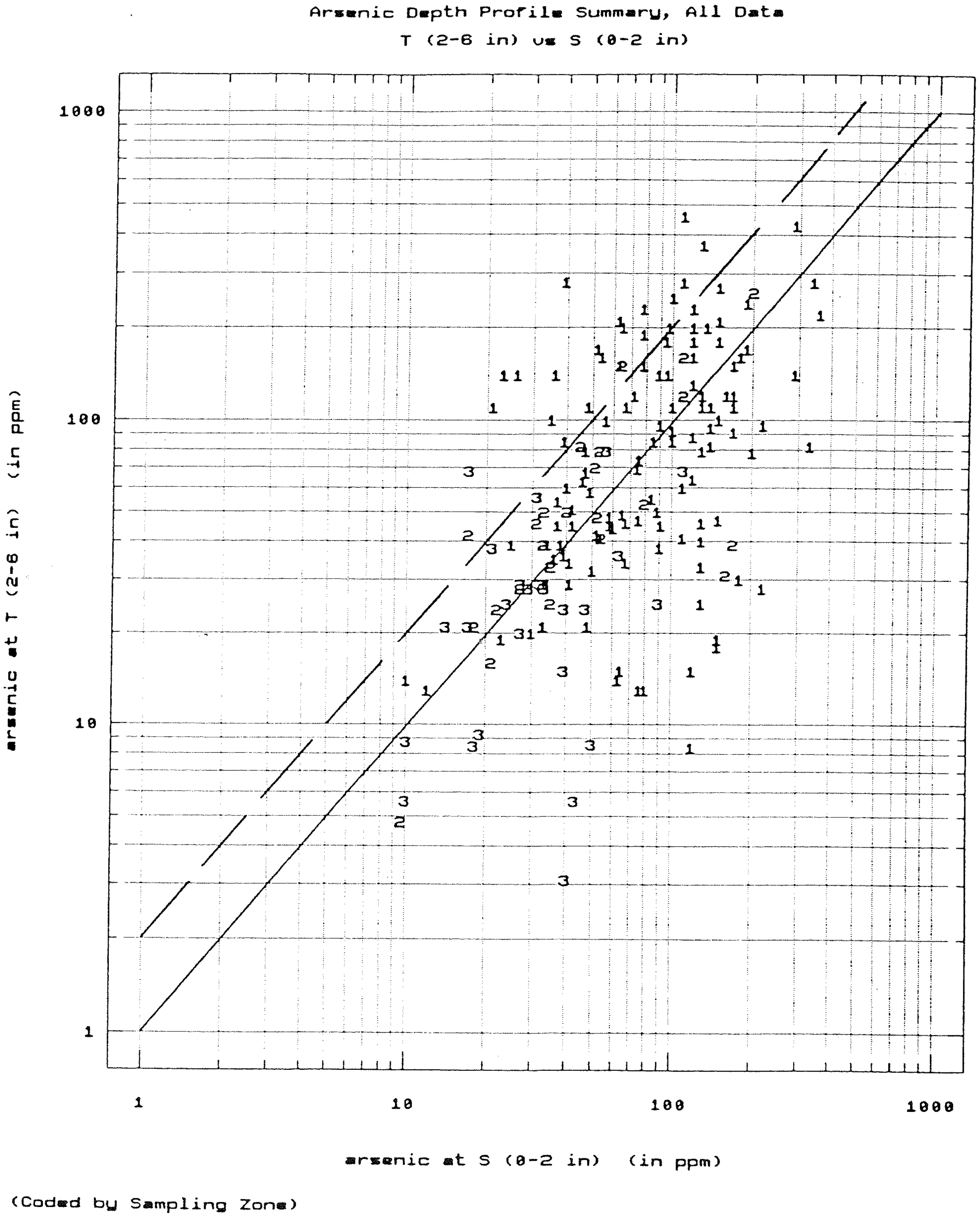


Figure 20
Arsenic Depth Profile Summary (All Data)

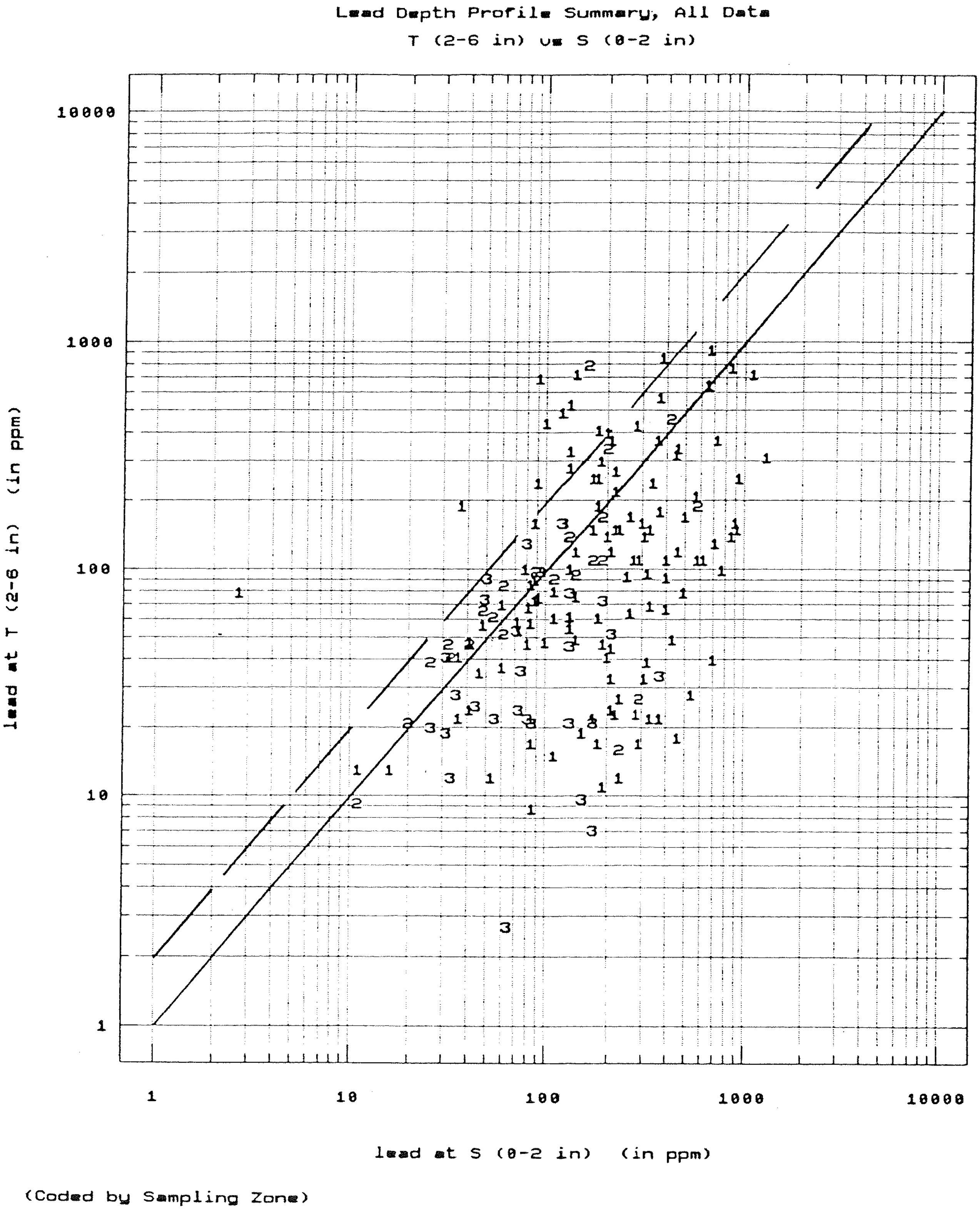
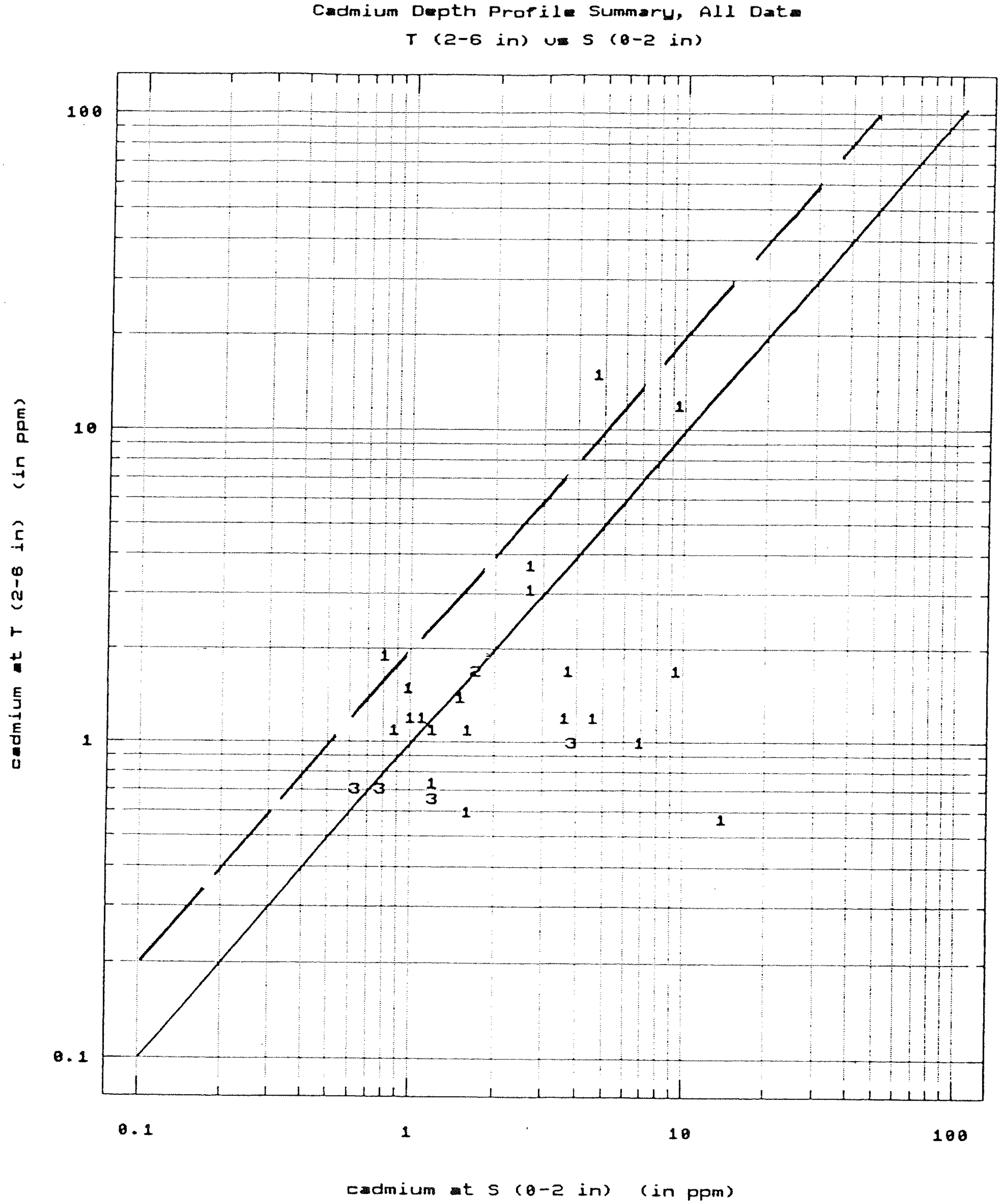


Figure 21
Lead Depth Profile Summary (All Data)



(Coded by Zone; detected values only)

Figure 22
Cadmium Depth Profile Summary (Detected Values Only)

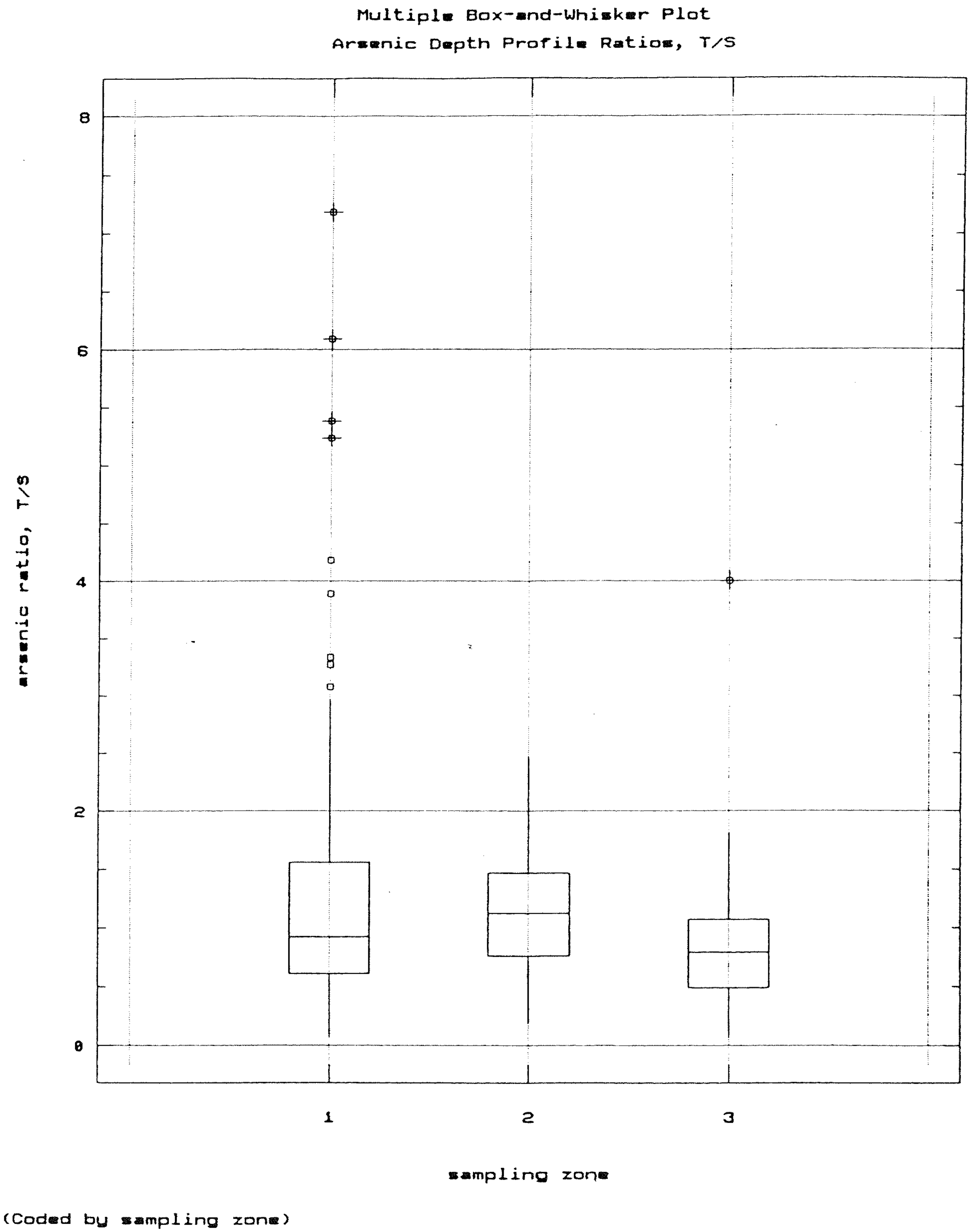


Figure 23
Box-and-Whisker Plot: Arsenic Depth Profile Ratios, T/S, by Sampling Zone

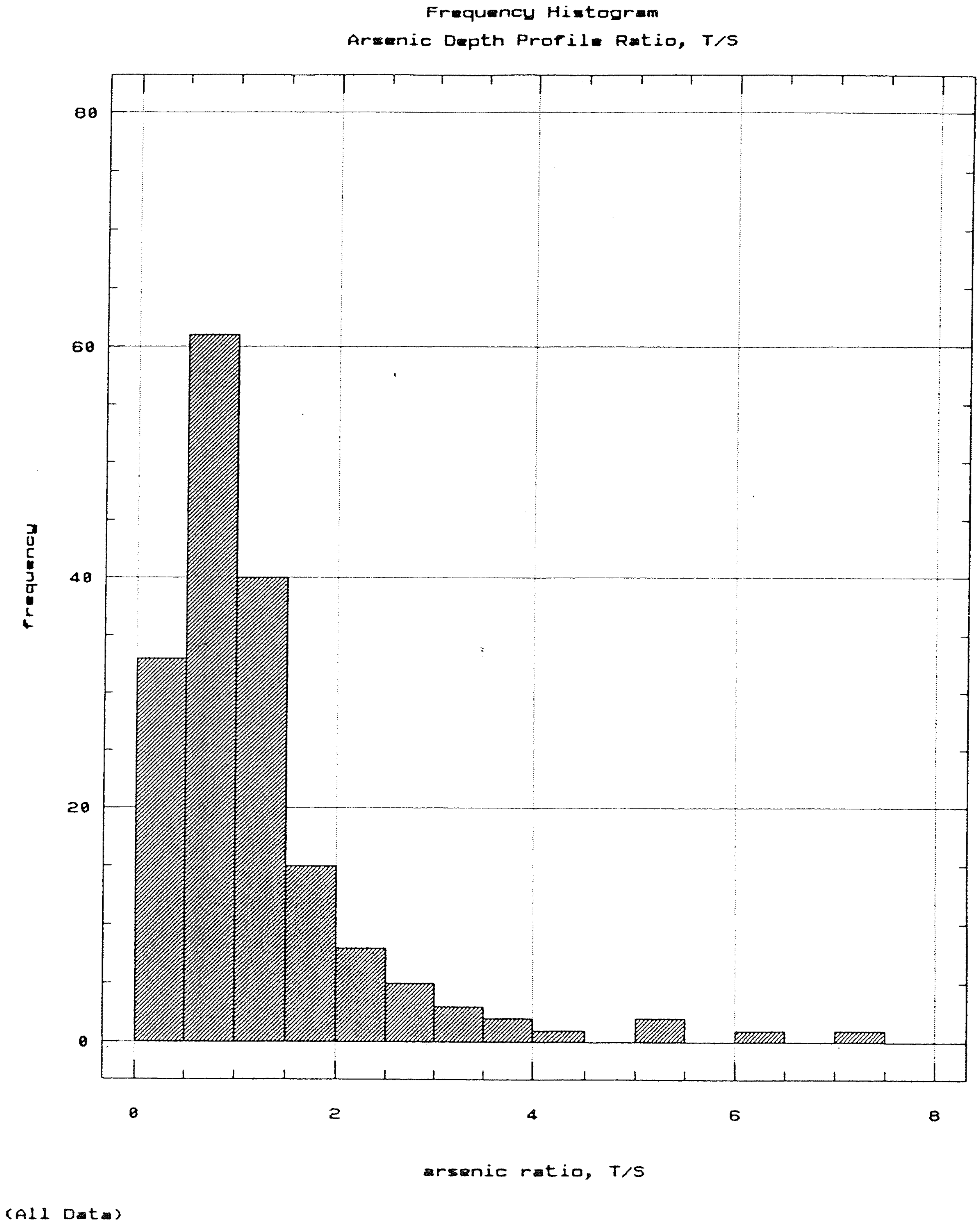


Figure 24
Frequency Histogram: Arsenic Depth Profile Ratios, T/S (All Data)

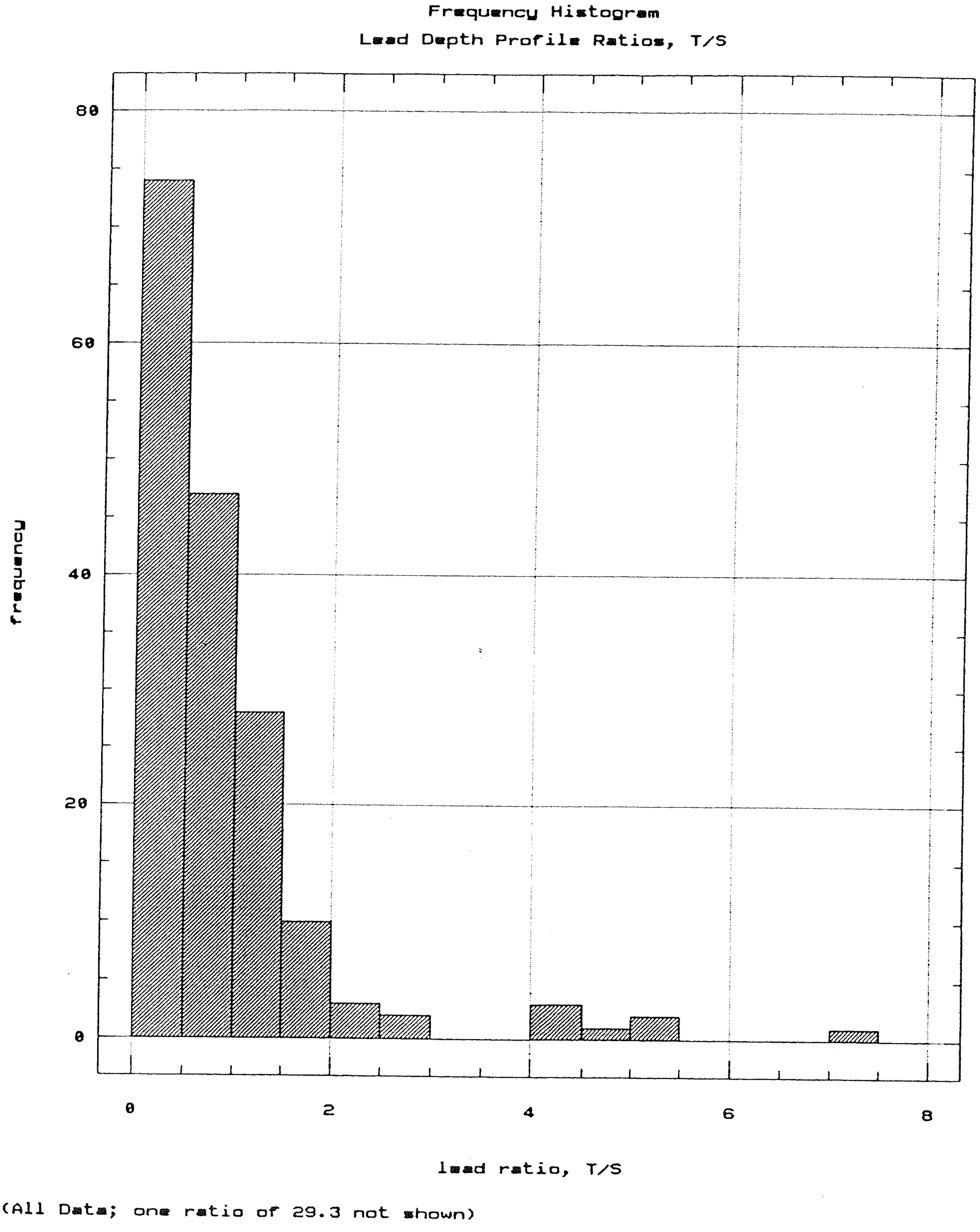


Figure 25
Frequency Histogram: Lead Depth Profile Ratios, T/S (All Data)

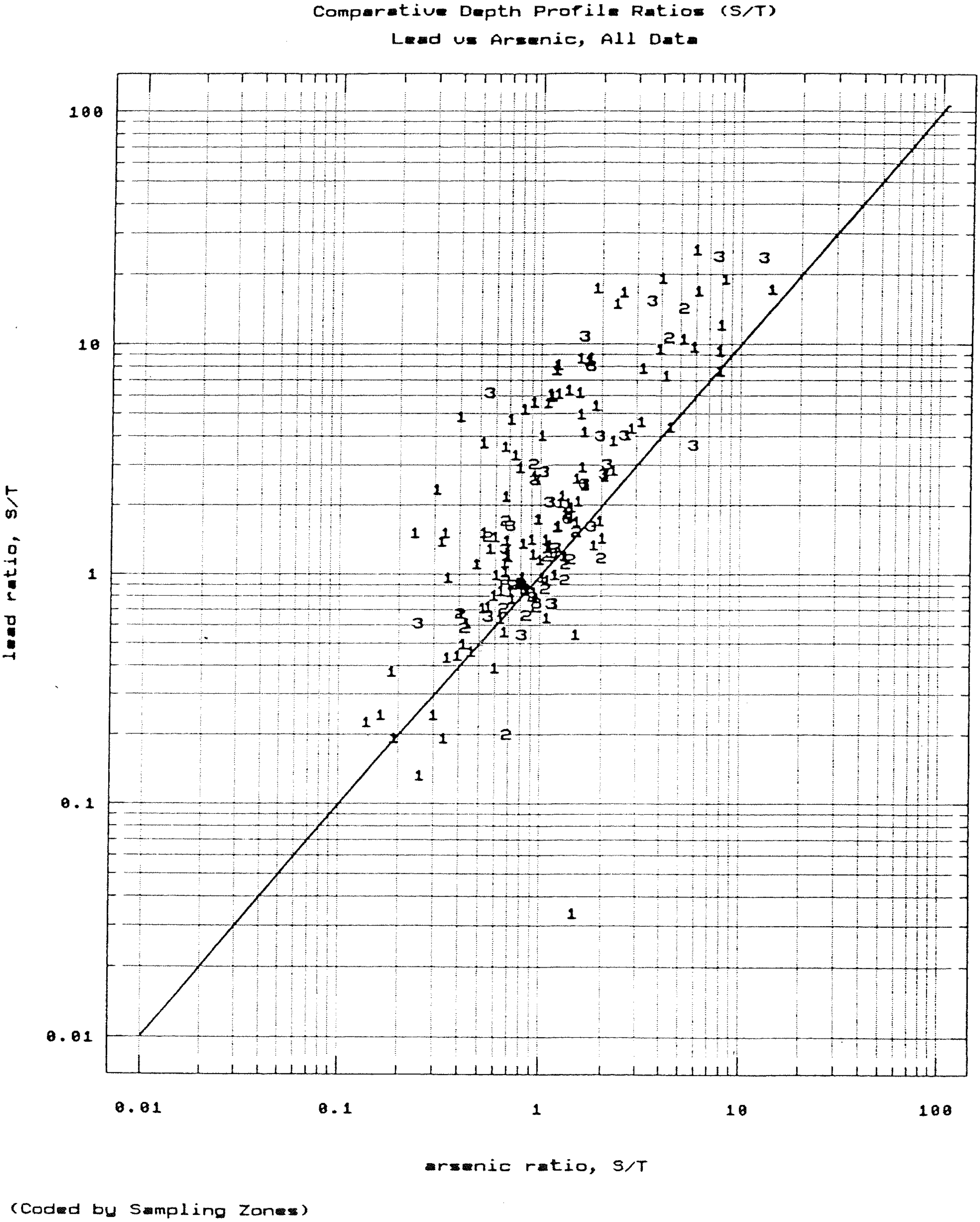


Figure 26
Comparative Depth Profile Ratios, S/T: Lead versus Arsenic

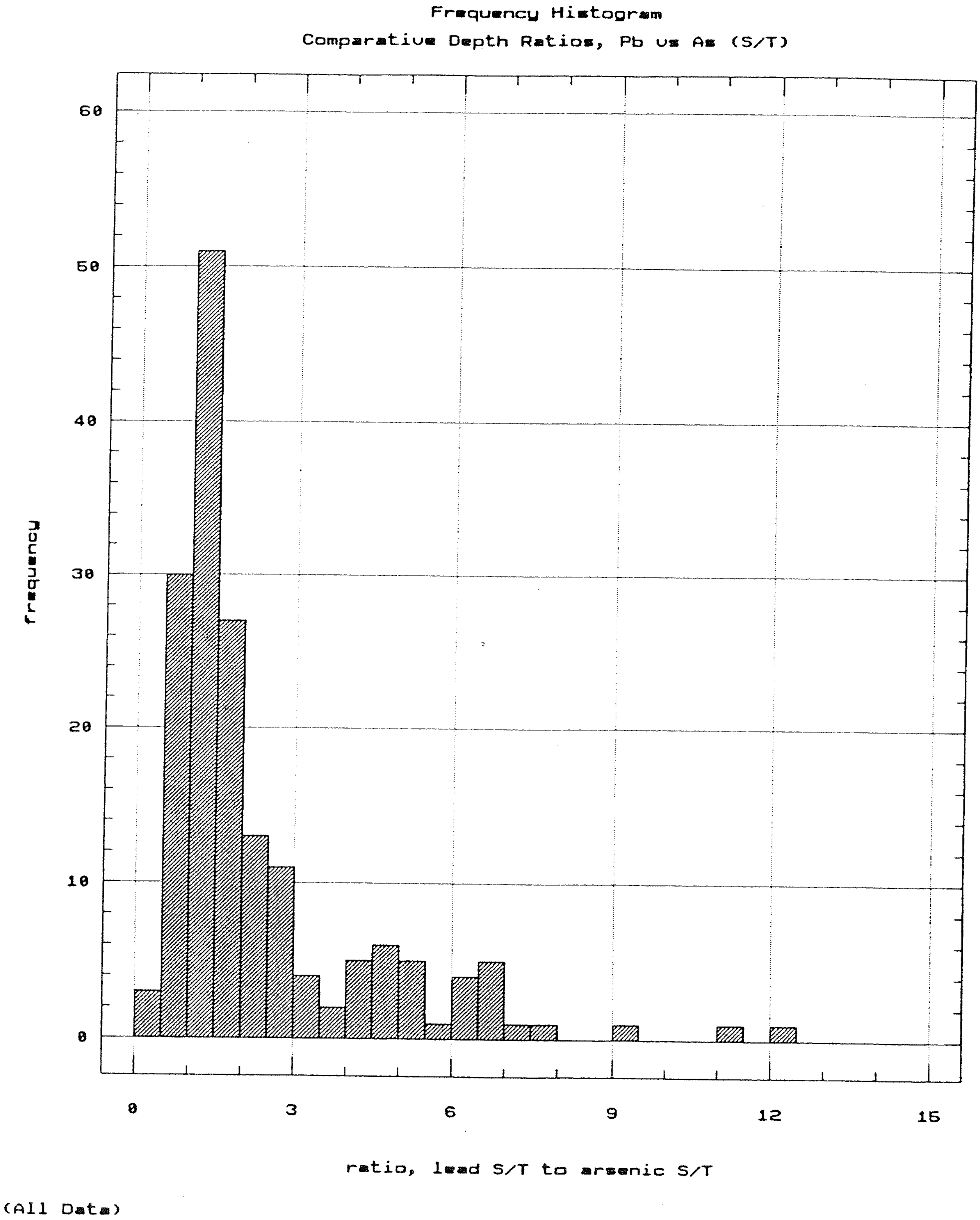


Figure 27
Frequency Histogram: Comparative Depth Ratios, S/T, Lead versus Arsenic

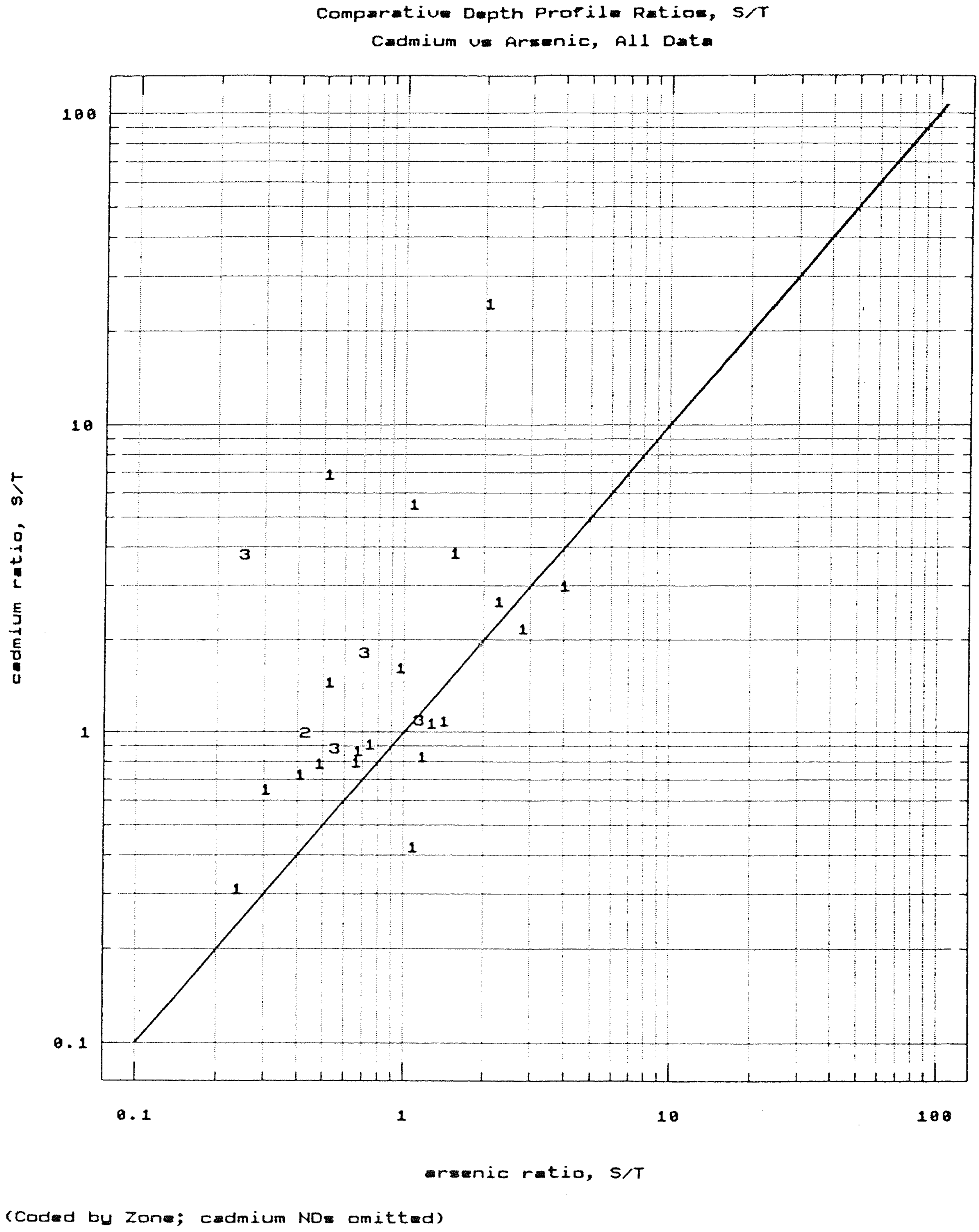


Figure 28
Comparative Depth Profile Ratios, S/T: Cadmium versus Arsenic

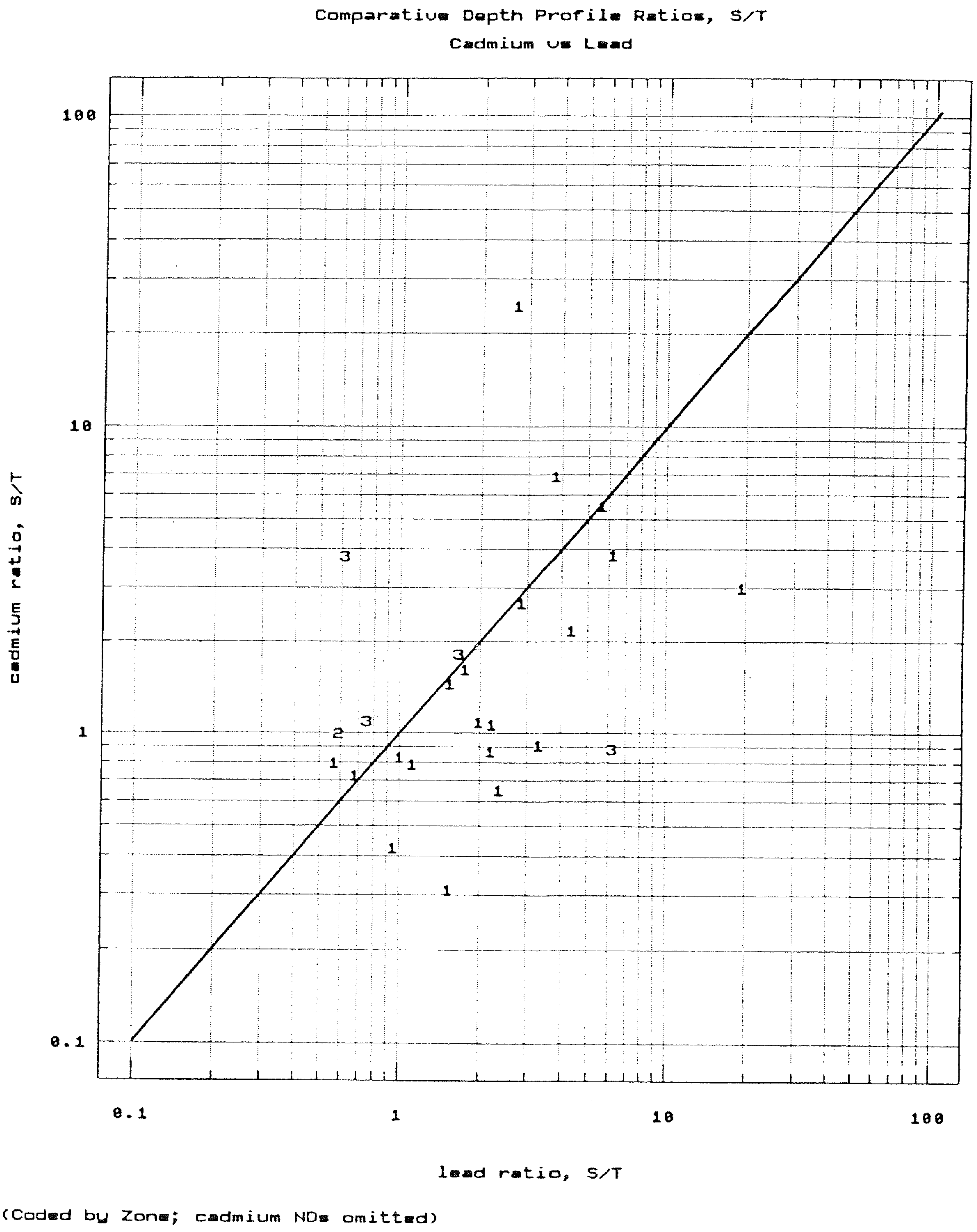


Figure 29
Comparative Depth Profile Ratios, S/T: Cadmium versus Lead

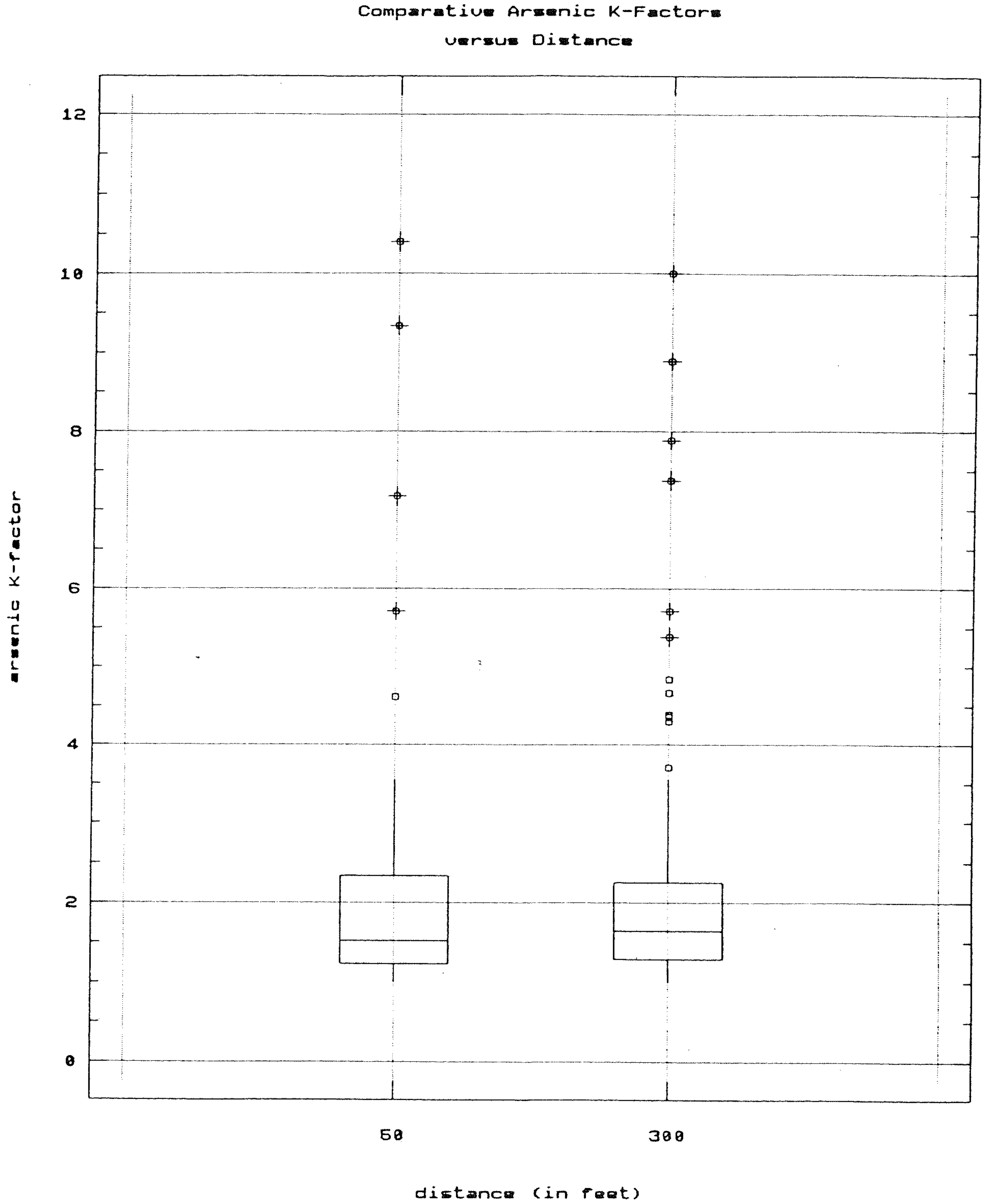


Figure 30
Box-and-Whisker Plot: Arsenic K-Factors versus Distance

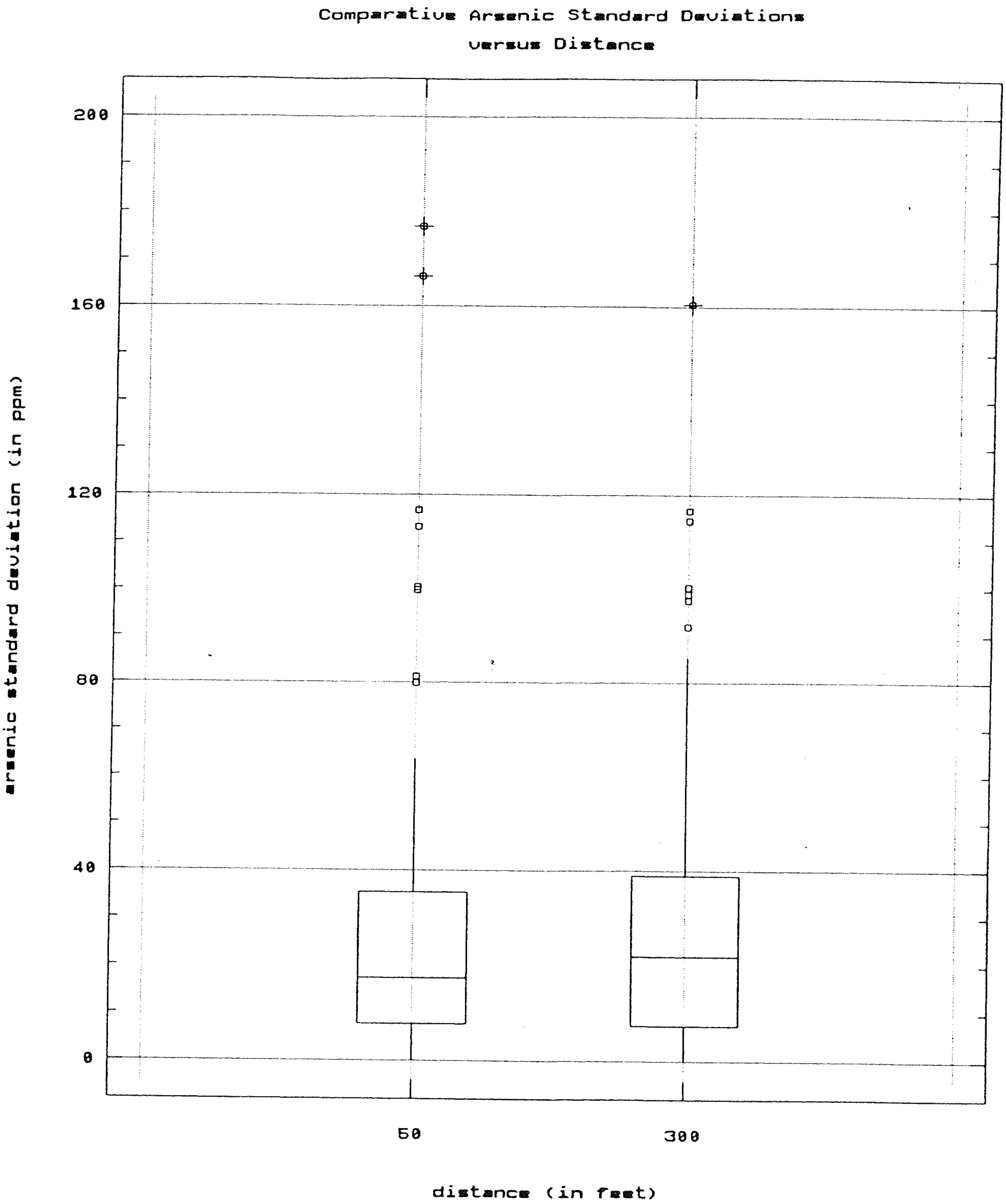


Figure 31
Box-and-Whisker Plot: Arsenic Standard Deviations versus Distance

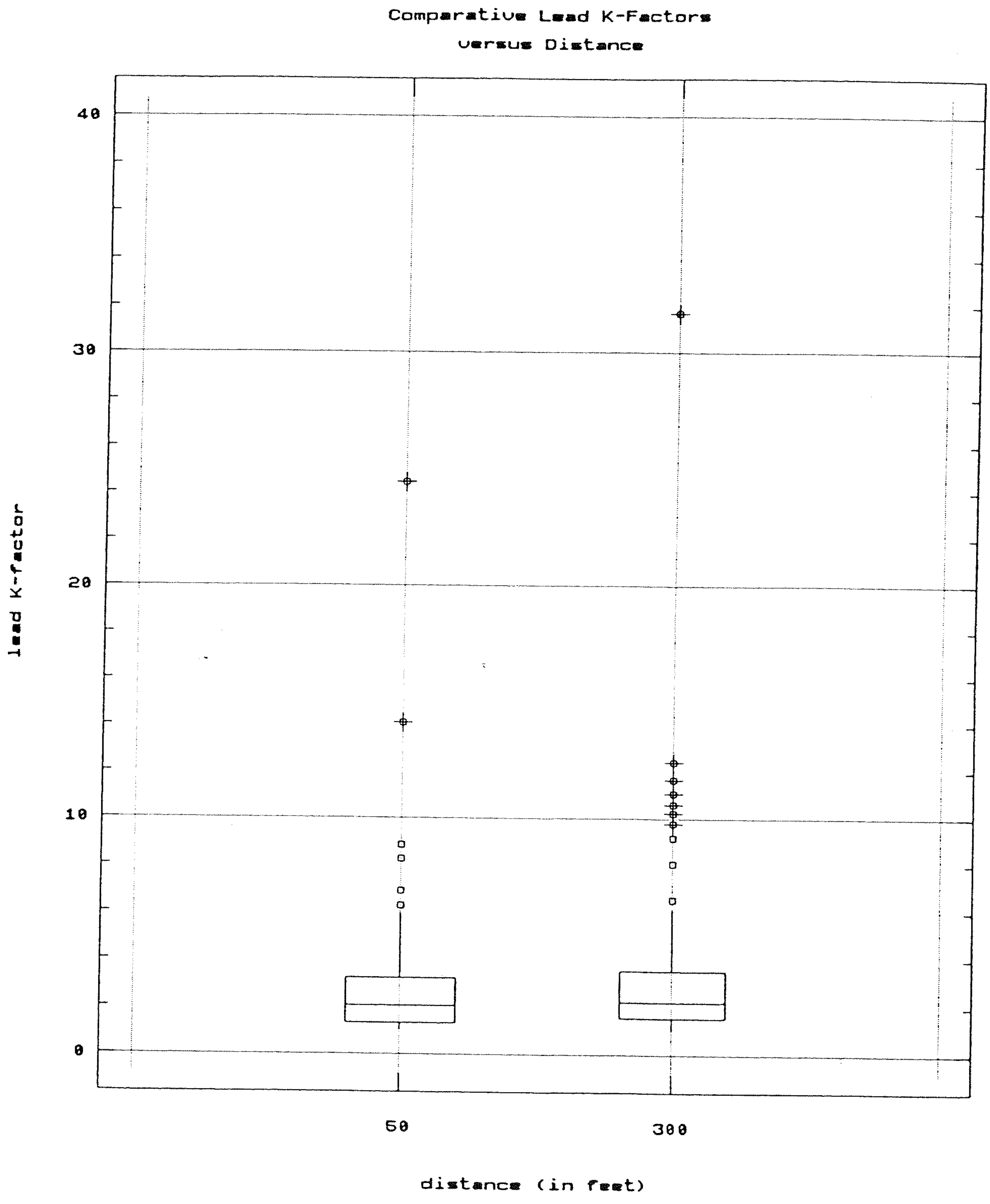


Figure 32
Box-and-Whisker Plot: Lead K-Factors versus Distance

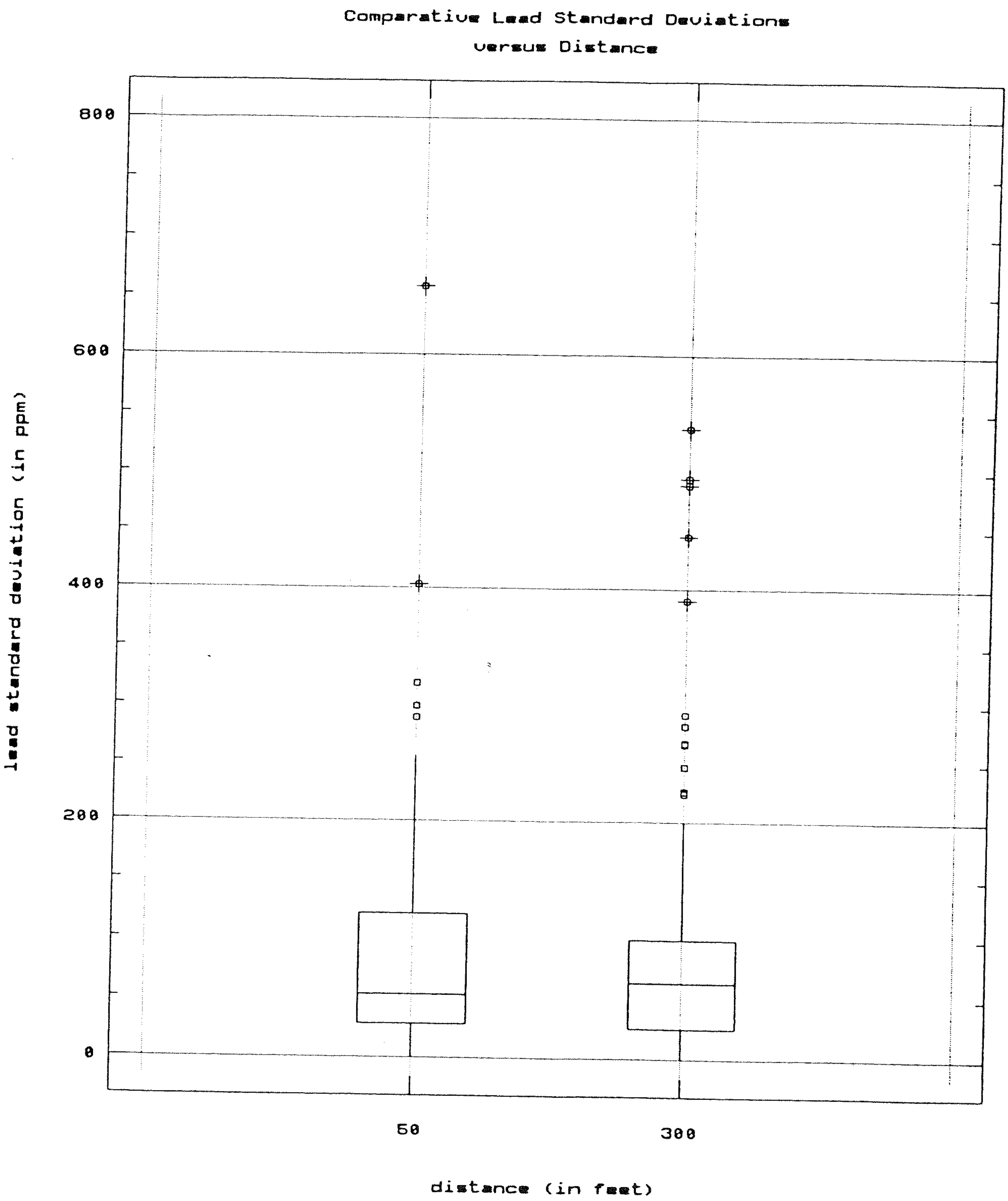


Figure 33
Box-and-Whisker Plot: Lead Standard Deviations versus Distance

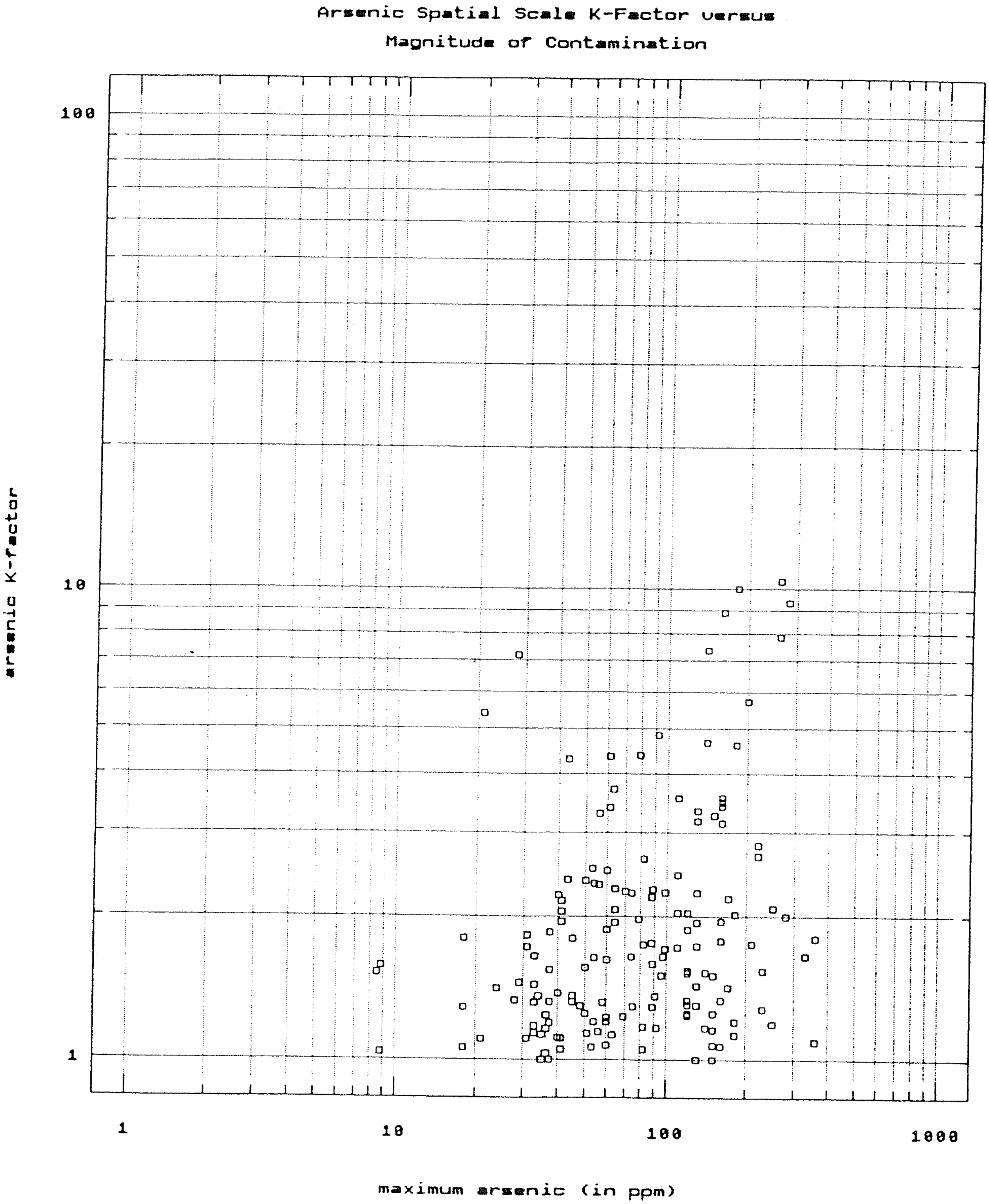


Figure 34
Scatterplot: Arsenic K-Factors versus Magnitude of Contamination

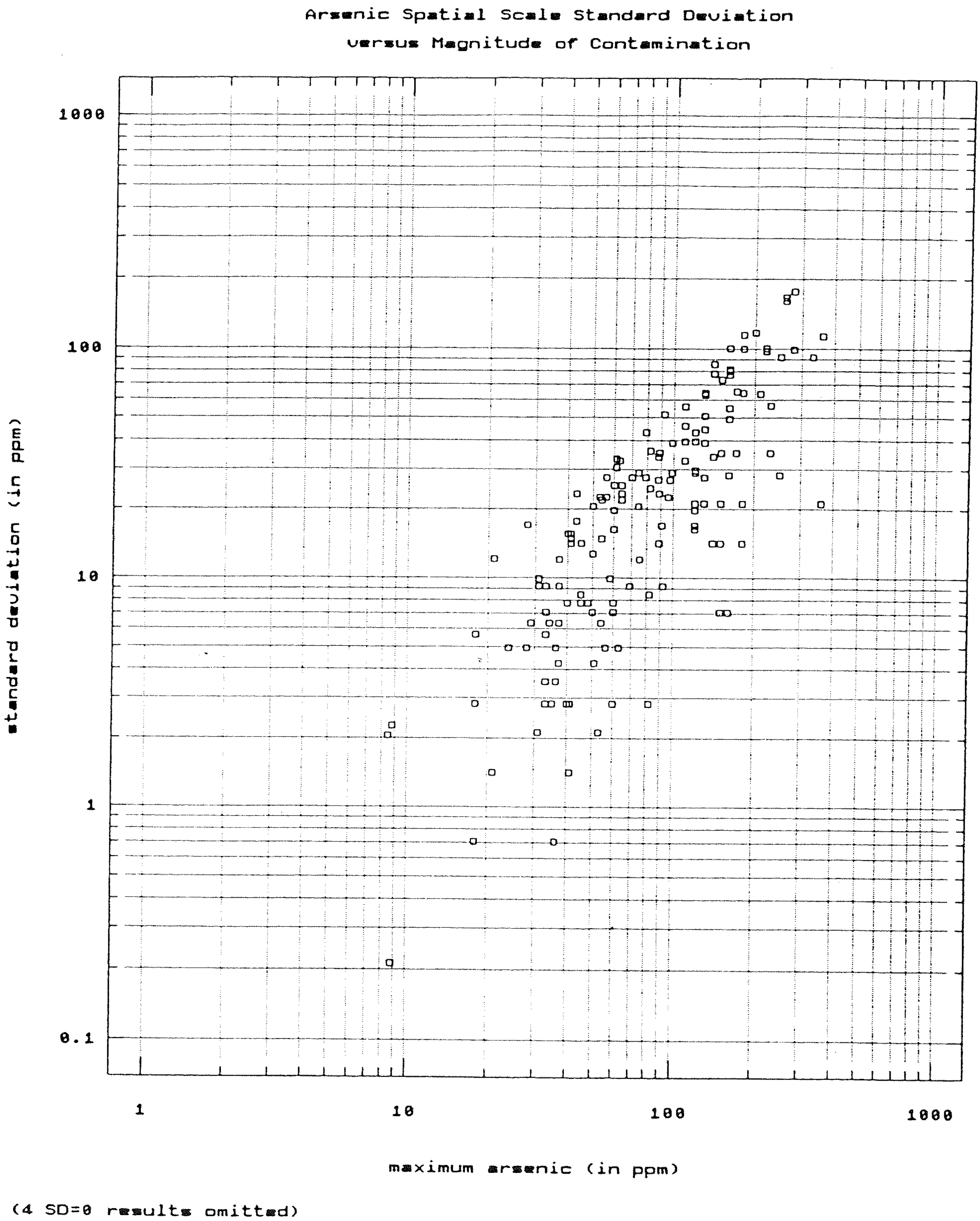


Figure 35
Scatterplot: Arsenic Standard Deviations versus Magnitude of Contamination

ATTACHMENT A

Access Agreement Form

Public Health
Seattle & King County
HEALTHY PEOPLE. HEALTHY COMMUNITIES.

Date:

To the King County Property Owner:

RE: Property located at

Public Health – Seattle & King County, the Environmental Health Division, has obtained a grant from the Washington State Department of Ecology (Ecology) to sample and analyze soils for the presence of arsenic, cadmium and lead on Vashon/Maury Islands and a portion of the mainland. This project is designed to provide test information that can be used to define the magnitude and extent of heavy metal soil contamination in King County. Most likely the contamination is from the former ASARCO Smelter in Tacoma so that testing will be conducted in areas downwind from the smelter. The results of this study will be made available to Ecology for evaluation under the Model Toxics Control Act Regulations.

In order to do the best job and give residents/property owners the most accurate information, we need access to over 200 properties. At each specified property identified in our sampling plan, Health Department staff will take about one cup of soil from at least one, or possibly up to three locations. The sampled site(s) will be approximately a six inch square to a depth of six inches. Sampling site(s) will be returned to its original condition.

We would like to ask if you would be willing to participate in the study by signing the attached consent form and returning it in the enclosed, stamped envelope at your earliest convenience. If you do not return the consent form, we will attempt to contact you by phone or at your home for permission. If you have any questions please contact Wally Swofford 206-296-4784 or Todd Yerkes at 206-296-4767.

Your cooperation will be greatly appreciated!

Attachment A

Environmental Health Division
999 3rd Avenue, Suite 700 · Seattle, WA 98104-4039
T (206) 296-4722 F (206) 296-0189 · www.metrokc.gov/health

City of Seattle
Paul Schell, Mayor
King County
Ron Sims, Executive

CONSENT TO ENTER PROPERTY AND TAKE SOIL SAMPLES

I am the **owner / tenant** (circle one) of the property identified below, and give my permission for representatives of the Seattle-King County Department of Public Health to enter the property and take multiple soil samples for the purpose of analyzing the soil to determine whether it contains deposits of heavy metals.

____
Name (Printed)

______________________________ ______________________________
Signature Date

Address of Property: ______________________________
____
____

Parcel Number: ______________________________

King County, WA ______________
(Zip Code)

ATTACHMENT B

Laboratory Results, Soil Analyses for Arsenic, Lead, and Cadmium

	A	B	C	D	E	F	G	H
1	**VASHON/MAURY ISLAND SOIL STUDY**							
2	**Public Health - Seattle & King County**							
3	**Final Database: May 2000**							
4	**Contact: Lee Dorigan 206-296-3978**							
5								
6								
7								
8	**Sample ID**	**Place ID**	**As**	**Pb**	**Cd**			
9	AB1-001-S	10012P	67	ND	ND			
10	AB1-001-T	10016P	46	79	0.89			
11	A1-002A-S	10022PA	120	370	1.4			
12	A1-002A-T	10026PA	88	180	NT			
13	A1-003-S	10032P	59	360	1.4			
14	A1-003-SY	10032Y	120	280	0.99			
15	A1-003-SZ	10032Z	97	520	1.1			
16	A1-003-TY	10036Y	15	23	ND			
17	B1-004-S	10042P	54	170	1			
18	B1-005A-S	10052PA	85	140	0.95			
19	B1-005A-T	10056PA	85	120	NT			
20	B1-007A-S	10072PA	48	140	1.6			
21	B1-007A-T	10076PA	21	49	0.6			
22	AB1-008-S	10082P	90	330	3.9			
23	AB1-008-T	10086P	38	22	ND			
24	AB1-009-S	10092P	110	260	1.7			
25	AB1-009-T	10096P	41	64	ND			
26	AB1-010A-S	10102PA	47	88	1.2			
27	AB1-010A-S	10102PA	65	97	NT			
28	AB1-010A-T	10106PA	67	73	NT			
29	B1-011-S	10112P	41	60	0.61			
30	B1-011-T	10116P	34	37	NT			
31	B1-012-S	10122P	42	110	1.1			
32	B1-012-T	10126P	51	80	NT			
33	B1-015-S	10152P	38	210	1.2			
34	B1-015-T	10156P	39	120	0.74			
35	B1-016-S	10162P	60	210	0.79			
36	B1-016-SY	10162Y	49	60	ND			
37	B1-016-SZ	10162Z	56	130	ND			
38	B1-016-T	10166P	44	33	NT			
39	B1-016-TY	10166Y	58	70	ND			
40	B1-016-TZ	10166Z	99	100	NT			
41	B1-017-S	10172P	64	110	ND			
42	B1-017-T	10176P	15	15	ND			
43	B1-018-S	10182P	25	67	0.86			
44	B1-018-T	10186P	32	32	NT			
45	A1-019A-S	10192PA	25	41	ND			
46	A1-019A-T	10196PA	39	48	NT			
47	AB1-021A-S	10212PA	63	130	ND			
48	AB1-021A-T	10216PA	210	530	ND			
49	AB1-022-S	10222P	88	430	1			
50	AB1-022-SY	10222Y	50	210	0.86			
51	AB1-022-SZ	10222Z	40	170	0.78			
52	AB1-022-T	10226P	50	49	NT			
53	AB1-022-TY	10226Y	32	24	NT			
54	AB1-022-TZ	10226Z	60	150	ND			
55	AB1-023-S	10232P	150	170	1.7			
56	AB1-023-T	10236P	19	22	NT			
57	AB1-024-S	10242P	35	180	1.9			

Attachment B

	A	B	C	D	E	F	G	H
58	AB1-024-T	10246P	100	410	NT			
59	AB1-025-S	10252P	42	48	0.69			
60	AB1-025-T	10256P	45	57	NT			
61	B1-027-S	10272P	54	140	ND			
62	B1-027-SY	10272Y	33	85	ND			
63	B1-027-SZ	10272Z	23	36	ND			
64	B1-027-T	10276P	41	76	NT			
65	B1-027-TY	10276Y	21	17	ND			
66	B1-027-TZ	10276Z	19	22	NT			
67	B1-029A-S	10292PA	110	73	0.69			
68	B1-029A-T	10296PA	60	54	NT			
69	A1-030-SK	10302K	47	180	ND			
70	A1-030-S	10302P	49	190	ND			
71	A1-030-SY	10302Y	37	92	ND			
72	B1-030-SZ	10302Z	37	84	ND			
73	A1-030-T	10306P	110	300	NT			
74	AB1-030-TY	10306Y	54	75	NT			
75	B1-030-TZ	10306Z	45	86	0.76			
76	B1-031-S	10312P	52	99	0.91			
77	B1-031-T	10316P	42	48	NT			
78	AB1-032-S	10322P	63	53	ND			
79	AB1-032-T	10326P	14	12	NT			
80	B1-033A-S	10332PA	110	290	2.3			
81	B1-033A-SK	10332PKA	160	370	3			
82	B1-033A-T	10336PA	200	150	3.1			
83	A1-034A-S	10342PA	100	650	1			
84	A1-034A-T	10346PA	85	650	1.2			
85	AB1-036-S	10362P	120	190	2.1			
86	AB1-036-T	10366P	8.4	11	NT			
87	B1-037-S	10372P	76	86	0.61			
88	B1-037-T	10376P	13	8.8	NT			
89	B1-040-S	10402P	130	180	ND			
90	B1-040-SY	10402Y	67	81	ND			
91	B1-040-SZ	10402Z	91	84	ND			
92	B1-040-T	10406P	25	17	ND			
93	B1-040-TY	10406Y	34	47	NT			
94	B1-040-TZ	10406Z	45	58	NT			
95	B1-041-S	10412P	80	290	1.3			
96	B1-041-T	10416P	13	17	ND			
97	A1-043-S	10432P	58	320	1.6			
98	A1-043-T	10436P	48	39	NT			
99	A1-044A-S	10442PA	75	180	1			
100	A1-044A-T	10446PA	47	61	NT			
101	A1-046-S	10462P	47	220	ND			
102	A1-046-T	10466P	79	270	ND			
103	A1-047-S	10472P	36	88	ND			
104	A1-047-T	10476P	35	90	NT			
105	A1-048-S	10482P	89	370	ND			
106	A1-048-SY	10482Y	39	100	ND			
107	A1-048-SZ	10482Z	180	460	1.3			
108	A1-048-T	10486P	140	570	NT			
109	A1-048-TY	10486Y	260	420	ND			
110	A1-048-TYK	10486YK	290	450	ND			
111	A1-048-TZ	10486Z	30	18	NT			
112	AB1-049A-S	10492PA	10	11	ND			
113	AB1-049A-T	10496PA	14	13	ND			
114	A1-050-S	10502P	140	230	ND			

	A	B	C	D	E	F	G	H
115	AB1-050-SY	10502Y	120	320	1.1			
116	AB1-050-SZ	10502Z	150	210	0.84			
117	A1-050-T	10506P	82	27	NT			
118	AB1-050-TY	10506Y	160	96	1.2			
119	AB1-050-TZ	10506Z	47	45	NT			
120	A1-051-S	10512P	120	380	2.2			
121	A1-051-SK	10512PK	150	240	0.88			
122	A1-051-T	10516P	110	140	1.4			
123	B1-052A-S	10522PA	75	190	ND			
124	B1-052A-SY	10522YA	58	72	1.1			
125	B1-052A-SZ	10522ZA	130	220	ND			
126	B1-052A-T	10526PA	74	47	NT			
127	B1-052A-TY	10526YA	45	59	NT			
128	B1-052A-TZ	10526ZA	33	23	NT			
129	A1-053-S	10532P	170	730	1.2			
130	A1-053-T	10536P	120	370	1.1			
131	A1-054-S	10542P	120	620	3.5			
132	A1-054-T	10546P	130	110	NT			
133	AB1-055-S	10552P	150	230	ND			
134	AB1-055-SY	10552Y	180	860	1.9			
135	AB1-055-SZ	10552Z	150	580	ND			
136	AB1-055-T	10556P	18	12	NT			
137	AB1-055-TY	10556Y	160	140	NT			
138	AB1-055-TZ	10556Z	180	110	NT			
139	AB1-057A-S	10572PA	95	230	1.6			
140	AB1-057A-T	10576P	180	150	1.1			
141	B1-058A-S	10582PA	12	16	ND			
142	B1-058A-T	10586PA	13	13	NT			
143	B1-059-S	10592P	130	820	9.4			
144	B1-059-SK	10592PK	110	570	6.7			
145	B1-059-SY	10592Y	160	300	ND			
146	B1-059-SZ	10592Z	90	570	2.5			
147	B1-059-T	10596P	64	40	NT			
148	B1-059-TY	10596Y	120	160	NT			
149	B1-059-TZ	10596Z	96	210	NT			
150	B1-060-S	10602P	72	130	ND			
151	B1-060-T	10606P	120	330	1.5			
152	B1-062A-S	10622PA	330	540	3.6			
153	B1-062A-SY	10622YA	200	370	2.8			
154	B1-062A-SZ	10622ZA	360	1300	3.2			
155	B1-062A-T	10626PA	82	28	1.2			
156	B1-062A-TY	10626YA	78	22	NT			
157	B1-062A-TZ	10626ZA	220	310	NT			
158	A1-063A-S	10632PA	130	400	3.7			
159	A1-063A-T	10636PA	46	92	1.7			
160	AB1-065-S	10652P	130	270	2.1			
161	B1-065-SY	10652Y	130	280	ND			
162	B1-065-SZ	10652Z	100	180	0.81			
163	AB1-065-T	10656P	79	110	NT			
164	B1-065-TY	10656Y	120	430	NT			
165	B1-065-TZ	10656Z	92	190	1.9			
166	AB1-066-S	10662P	220	460	2			
167	AB1-066-T	10666P	96	120	NT			
168	B1-067-S	10672P	100	200	2.3			
169	B1-067-T	10676P	110	140	NT			
170	AB1-068-S	10682P	96	340	2.3			
171	AB1-068-T	10686P	140	240	NT			

	A	B	C	D	E	F	G	H
172	AB1-069A-S	10692PA	39	130	0.93			
173	AB1-069A-T	10696PA	85	280	NT			
174	AB1-070A-S	10702PA	78	170	2.7			
175	AB1-070A-T	10706PA	190	250	3.7			
176	AB1-071-S	10712P	21	37	ND			
177	AB1-071-T	10716P	110	190	ND			
178	A1-073-S	10732P	39	46	ND			
179	AB1-073-SY	10732Y	41	110	1.9			
180	AB1-073-SZ	10732Z	130	150	0.99			
181	A1-073-T	10736P	36	35	ND			
182	AB1-073-TY	10736Y	29	61	NT			
183	AB1-073-TZ	1073Z	40	19	NT			
184	B1-074A-S	10742PA	170	710	3.1			
185	B1-074A-T	10746PA	91	130	NT			
186	B1-075-S	10752P	65	82	ND			
187	B1-075-T	10756P	49	68	ND			
188	A1-076-S	10762P	54	140	ND			
189	A1-076-T	10766P	160	720	NT			
190	A1-077A-S	10772PA	34	36	ND			
191	A1-077A-T	10776PA	39	41	ND			
192	A1-082A-S	10822PA	84	130	1.8			
193	A1-082A-T	10826PA	55	62	NT			
194	AB1-083-S	10832P	26	91	1.9			
195	AB1-083-T	10836P	140	240	NT			
196	AB1-084-S	10842P	23	120	9.3			
197	AB1-084-T	10846P	140	490	NT			
198	AB1-085-S	10852P	310	670	6.2			
199	AB1-085-SK	10852PK	260	650	5.9			
200	AB1-085-T	10856P	430	640	NT			
201	B1-086A-S	10862PA	290	250	14			
202	B1-086A-T	10866PA	140	93	0.57			
203	B1-087-S	10872P	67	220	1.7			
204	B1-087-T	10876P	110	220	NT			
205	C1-088A-S	10882PA	65	450	1.4			
206	C1-088A-T	10886PA	200	320	NT			
207	AB1-089-S	10892P	46	79	1.1			
208	AB1-089-T	10896P	63	100	NT			
209	A1-090-S	10902P	220	310	ND			
210	A1-090-T	10906P	28	33	ND			
211	C1-091-S	10912P	340	920	6.7			
212	C1-091-T	10916P	280	150	NT			
213	A1-092-S	10922P	150	290	2.2			
214	A1-092-T	10926P	100	110	NT			
215	AB1-093A-S	10932PA	210	490	4.2			
216	AB1-093A-SK	10932PKA	120	490	4.9			
217	AB1-093A-T	10936PA	110	79	1.2			
218	C1-094A-S	10942PA	97	860	9.5			
219	C1-094A-T	10946PA	200	770	12			
220	B1-095-S	10952P	74	200	ND			
221	B1-095-T	10956P	69	140	NT			
222	AB1-096-S	10962P	36	92	6.3			
223	AB1-096-T	10966P	140	690	ND			
224	B1-098-S	10982P	130	770	1.4			
225	B1-098-T	10986P	110	99	NT			
226	C1-099A-S	10992PA	63	200	1.9			
227	C1-099A-T	10996PA	150	400	NT			
228	A1-100-S	11002P	78	180	2			

	A	B	C	D	E	F	G	H
229	A1-100-T	11006P	150	250	NT			
230	A1-101-S	11012P	120	210	0.88			
231	A1-101-T	11016P	180	370	1.1			
232	B1-102-S	11022P	130	360	1.6			
233	B1-102-T	11026P	370	370	NT			
234	B1-103-S	11032P	170	400	0.99			
235	B1-103-SY	11032Y	120	400	2			
236	B1-103-SZ	11032Z	78	260	ND			
237	B1-103-T	11036P	150	67	NT			
238	B1-103-TY	11036Y	180	110	NT			
239	B1-103-TZ	11036Z	230	170	NT			
240	AB1-104A-S	11042PA	120	220	ND			
241	AB1-104A-S	11042PA	130	260	NT			
242	AB1-104A-T	11046PA	200	150	2.3			
243	A1-105-S	11052P	52	130	0.98			
244	A1-105-T	11056P	170	55	1.5			
245	A1-106A-S	11062PA	120	940	6.9			
246	A1-106A-T	11066PA	230	250	1			
247	AB1-107-S	11072P	190	500	3.3			
248	AB1-107-T	11076P	240	170	NT			
249	B1-108A-S	11082PA	30	41	ND			
250	B1-108A-T	11086PA	20	24	NT			
251	AB1-109-S	11092P	190	460	ND			
252	AB1-109-T	11096P	170	340	NT			
253	AB1-110-S	11102P	110	380	2.4			
254	AB1-110-T	11106P	280	850	NT			
255	AB1-111A-S	11112PA	150	670	3.8			
256	AB1-111A-T	11116PA	270	920	NT			
257	AB1-112-S	11122P	110	1000	4.6			
258	AB1-112-SK	11122PK	100	1100	4.8			
259	AB1-112-T	11126P	460	720	15			
260	B1-113-S	11132P	100	200	ND			
261	B1-113-SY	11132Y	150	330	3.9			
262	B1-113-SZ	11132Z	130	900	9.4			
263	B1-113-T	11136P	250	41	NT			
264	B1-113-TY	11136Y	210	69	NT			
265	B1-113-TZ	11136Z	120	160	1.7			
266	AB1-114-S	11142P	140	88	0.85			
267	AB1-114-T	11146P	94	160	ND			
268	C2-001-S	20012P	79	170	ND			
269	C2-001-SY	20012Y	18	26	ND			
270	C2-001-SZ	20012Z	40	130	1.4			
271	C2-001-T	20016P	53	110	NT			
272	C2-001-TY	20016Y	21	39	NT			
273	C2-001-TZ	20016Z	50	140	NT			
274	C2-002-S	20022P	33	54	ND			
275	C2-002-T	20026P	39	62	NT			
276	C2-003-S	20032P	54	190	ND			
277	C2-003-T	20036P	41	170	ND			
278	C2-004-S	20042P	51	89	0.84			
279	C2-004-SY	20042Y	160	230	1.9			
280	C2-004-SZ	20042Z	45	140	ND			
281	C2-004-T	20046P	70	98	NT			
282	C2-004-TY	20046Y	31	16	NT			
283	C2-004-TZ	20046Z	82	95	NT			
284	C2-005-S	20052P	35	41	ND			
285	C2-005-SY	20052Y	35	61	ND			

	A	B	C	D	E	F	G	H
286	C2-005-SZ	20052Z	200	420	ND			
287	C2-005-T	20056P	33	47	NT			
288	C2-005-TY	20056Y	25	52	ND			
289	C2-005-TZ	20056Z	260	460	NT			
290	C2-006-S	20062P	52	180	ND			
291	C2-006-SK	20062PK	53	190	ND			
292	C2-006-T	20066P	79	110	1.1			
293	C2-007-S	20072P	21	20	ND			
294	C2-007-T	20076P	16	21	NT			
295	C2-008-S	20082P	22	33	ND			
296	C2-008-T	20086P	24	41	NT			
297	C2-009-S	20092P	31	94	ND			
298	C2-009-SY	20092Y	64	200	1.7			
299	C2-009-SZ	20092Z	110	160	2.1			
300	C2-009-T	20096P	46	98	NT			
301	C2-009-TY	20096Y	150	340	1.7			
302	C2-009-TZ	20096Z	160	790	NT			
303	C2-010-S	20102P	33	61	ND			
304	C2-010-T	20106P	50	85	ND			
305	C2-011-S	20112P	110	580	3.6			
306	C2-011-T	20116P	120	190	NT			
307	C2-012-S	20122P	170	290	1.4			
308	C2-012-T	20126P	39	27	NT			
309	C2-013-S	20132P	17	32	ND			
310	C2-013-T	20136P	42	47	NT			
311	C2-014-S	20142P	52	110	ND			
312	C2-014-T	20146P	48	91	ND			
313	C2-015-S	20152P	27	48	ND			
314	C2-015-T	20156P	28	66	ND			
315	C2-016-S	20162P	9.6	11	ND			
316	C2-016-T	20166P	4.8	9.3	NT			
317	AB3-001-S	30012P	11	21	ND			
318	A3-002A-S	30022PA	6.5	17	ND			
319	B3-003-S	30032P	9.9	41	ND			
320	A3-004A-S	30042PA	19	36	ND			
321	A3-005A-S	30052PA	7.2	21	ND			
322	A3-006-S	30062P	14	26	ND			
323	A3-006-SY	30062Y	99	170	1.4			
324	A3-006-SYK	30062YK	22	71	0.63			
325	A3-006-SZ	30062Z	18	61	ND			
326	A3-006-T	30066P	21	20	ND			
327	A3-007A-SK	30072KA	5.7	19	ND			
328	A3-007A-S	30072PA	14	42	ND			
329	A3-007A-T	30076A	5.6	19	ND			
330	AB3-008-S	30082P	11	30	ND			
331	AB3-009A-S	30092PA	10	45	ND			
332	AB3-010-S	30102P	16	91	ND			
333	AB3-011A-S	30112PA	17	50	ND			
334	AB3-011A-SY	30112YA	24	49	ND			
335	AB3-011A-SZ	30112ZA	56	220	ND			
336	AB3-011A-T	30116PA	21	91	0.68			
337	B3-012-S	30122P	3.7	46	ND			
338	A3-013A-S	30132PA	10	23	ND			
339	A3-014A-S	30142PA	60	160	ND			
340	A3-014A-SY	30142YA	37	62	ND			
341	A3-014A-SZ	30142ZA	24	61	ND			
342	A3-015-S	30152P	14	21	ND			

	A	B	C	D	E	F	G	H
343	A3-016-S	30162P	32	75	0.83			
344	A3-016-T	30166P	29	36	ND			
345	A3-017-S	30172P	28	77	ND			
346	A3-017-SK	30172PK	27	80	ND			
347	A3-017-SY	30172Y	31	220	0.84			
348	A3-017-SZ	30172Z	37	220	1			
349	AB3-018A-S	30182PA	27	44	ND			
350	AB3-018A-T	30186PA	20	25	ND			
351	AB3-019-S	30192P	35	79	ND			
352	A3-021-S	30212P	18	33	ND			
353	B3-021-S	30212P	26	77	ND			
354	B3-022A-S	30222PA	18	32	ND			
355	B3-024-S	30242P	20	81	ND			
356	AB3-026-S	30262P	32	120	0.8			
357	A3-027-S	30272P	25	45	0.83			
358	AB3-028-S	30282P	64	140	0.71			
359	AB3-028-SY	30282Y	28	64	ND			
360	AB3-028-SZ	30282Z	33	71	ND			
361	AB3-028-TZ	30286Z	28	54	ND			
362	B3-029-S	30292P	62	320	ND			
363	B3-030A-S	30302PA	19	33	ND			
364	B3-030A-SY	30302YA	140	410	ND			
365	B3-030A-SZ	30302ZA	92	350	ND			
366	B3-030A-T	30306PA	9.3	12	ND			
367	AB3-031-S	30312P	29	120	ND			
368	AB3-031-SY	30312Y	20	170	1.7			
369	AB3-031-SZ	30312Z	33	120	0.78			
370	AB3-031-TZ	30316Z	29	160	0.71			
371	B3-032-S	30322P	11	41	ND			
372	B3-033-S	30332P	27	150	ND			
373	A3-034-S	30342P	18	53	ND			
374	A3-034-SY	30342Y	17	42	ND			
375	A3-034-SZ	30342Z	31	96	ND			
376	B3-035A-S	30352PA	20	120	ND			
377	AB3-036-S	30362P	7.3	11	ND			
378	AB3-037A-S	30372PA	33	210	0.8			
379	AB3-038-S	30382P	24	31	ND			
380	AB3-038-T	30386P	25	41	ND			
381	B3-039A-S	30392PA	23	39	ND			
382	AB3-040A-S	30402PA	20	30	ND			
383	AB3-040A-SY	30402YA	41	56	ND			
384	AB3-040A-SZ	30402ZA	37	54	ND			
385	B3-041-S	30412P	45	180	ND			
386	B3-042-S	30422P	39	85	ND			
387	B3-042-T	30426P	15	21	ND			
388	AB3-043A-S	30432PA	40	64	0.73			
389	AB3-043A-T	30436PA	3.1	ND	ND			
390	A3-044-S	30442P	10	35	ND			
391	A3-044-SY	30442Y	18	73	ND			
392	A3-044-SZ	30442Z	43	170	1.1			
393	A3-044-T	30446P	8.8	28	ND			
394	A3-044-TY	30446Y	8.5	24	ND			
395	A3-044-TZ	30446Z	5.6	7.1	ND			
396	AB3-045-S	30452P	32	69	ND			
397	B3-046-S	30462P	34	58	ND			
398	B3-047-S	30472P	85	280	0.62			
399	AB3-048-SK	30482K	15	78	3.8			

	A	B	C	D	E	F	G	H
400	AB3-048-S	30482P	19	82	3.8			
401	AB3-048-SY	30482Y	63	300	1.6			
402	AB3-048-SZ	30482Z	56	120	1			
403	AB3-048-T	30486P	68	130	1			
404	B3-049-S	30492P	50	81	ND			
405	B3-049-T	30496P	8.6	22	ND			
406	AB3-050-S	30502P	63	170	ND			
407	AB3-050-T	30506P	36	21	ND			
408	B3-051-SK	30512K	53	89	ND			
409	B3-051-S	30512P	25	21	ND			
410	B3-051-T	30516P	24	22	ND			
411	B3-052-S	30522P	31	130	0.63			
412	B3-052-SY	30522Y	35	100	ND			
413	B3-052-SZ	30522Z	36	58	ND			
414	B3-052-T	30526P	56	21	0.71			
415	B3-053A-S	30532PA	69	95	0.64			
416	B3-054-S	30542P	29	130	ND			
417	B3-054-T	30546P	28	46	ND			
418	B3-055A-S	30552PA	59	330	1.1			
419	B3-056-S	30562P	42	140	ND			
420	B3-057-S	30572P	ND	51	ND			
421	A3-058-S	30582P	23	58	0.73			
422	B3-059A-S	30592PA	30	39	ND			
423	B3-060A-S	30602PA	27	190	ND			
424	B3-060A-T	30606PA	29	73	ND			
425	AB3-061A-S	30612PA	110	370	0.85			
426	AB3-061A-T	30616PA	68	34	ND			
427	AB3-062-S	30622P	39	96	ND			
428	B3-063A-SK	30632KA	77	130	ND			
429	B3-063A-S	30632PA	73	120	ND			
430	A3-064A-S	30642PA	53	440	1.1			
431	AB3-065-S	30652P	56	130	1.2			
432	AB3-065-T	30656P	79	79	0.66			
433	A3-066-S	30662P	89	150	ND			
434	A3-066-SY	30662Y	69	96	ND			
435	A3-066-SZ	30662Z	56	250	ND			
436	A3-066-T	30666P	25	9.7	ND			
437	A3-067-S	30672P	22	35	ND			
438	AB3-068-S	30682P	28	58	0.98			
439	A3-069-S	30692P	47	210	0.86			
440	A3-069-T	30696P	24	52	ND			
441	A3-070-S	30702P	21	49	ND			
442	A3-070-SY	30702Y	28	140	ND			
443	A3-070-SZ	30702Z	3.9	17	ND			
444	A3-070-TK	30706K	38	74	ND			
445								
446								
447								
448								
449								
450								
451	**VASHON/MAURY ISLAND SOIL STUDY**							
452	**Public Health - Seattle & King County**							
453	**Final Database: May 2000**							
454	**Contact: Lee Dorigan 206-296-3978**							
455								
456								

	A	B	C	D	E	F	G	H
457	NOTES							
458								
459	Sample ID codes show: sampling team and sampling zone - location - depth, spatial scale, and field duplicate							
460								
461		sampling team [A,B,C]						
462		sampling zone [1,2,3]						
463		location [sampling grid 001 through 114; A=field adjusted location]						
464		depth [S=0 to 2 inch; T=2 to 6 inch]						
465		spatial scale [Y,Z for closer-spaced samples]						
466		field duplicate sample [K]						
467								
468	ND = below limit of quantification							
469	NT = not tested [not analyzed in that soil sample]							
470								
471	Sample IDs AB1-010A-S and AB1-104A-S: two independent lab analyses were performed; the first results							
472		are used for statistical evaluations						
473								
474	Sample IDs A3-021-S and B3-021-S: two independent field samples collected and analyzed for one grid cell							
475		location; the B3- sample is considered more representative and is used						
476								
477	Sample ID B1-018-T analyses exceeded a six-month sample hold time (collected 9/22/99, extracted 4/27/00);							
478		results are estimated ("J" flag) and are not used for statistical evaluations						
479								
480	Sample ID A3-070-TK: both a -T and a field duplicate -TK sample were collected; only the -TK sample							
481		was analyzed						
482								
483	Data Validation performed by PH - S&KC							

ATTACHMENT C

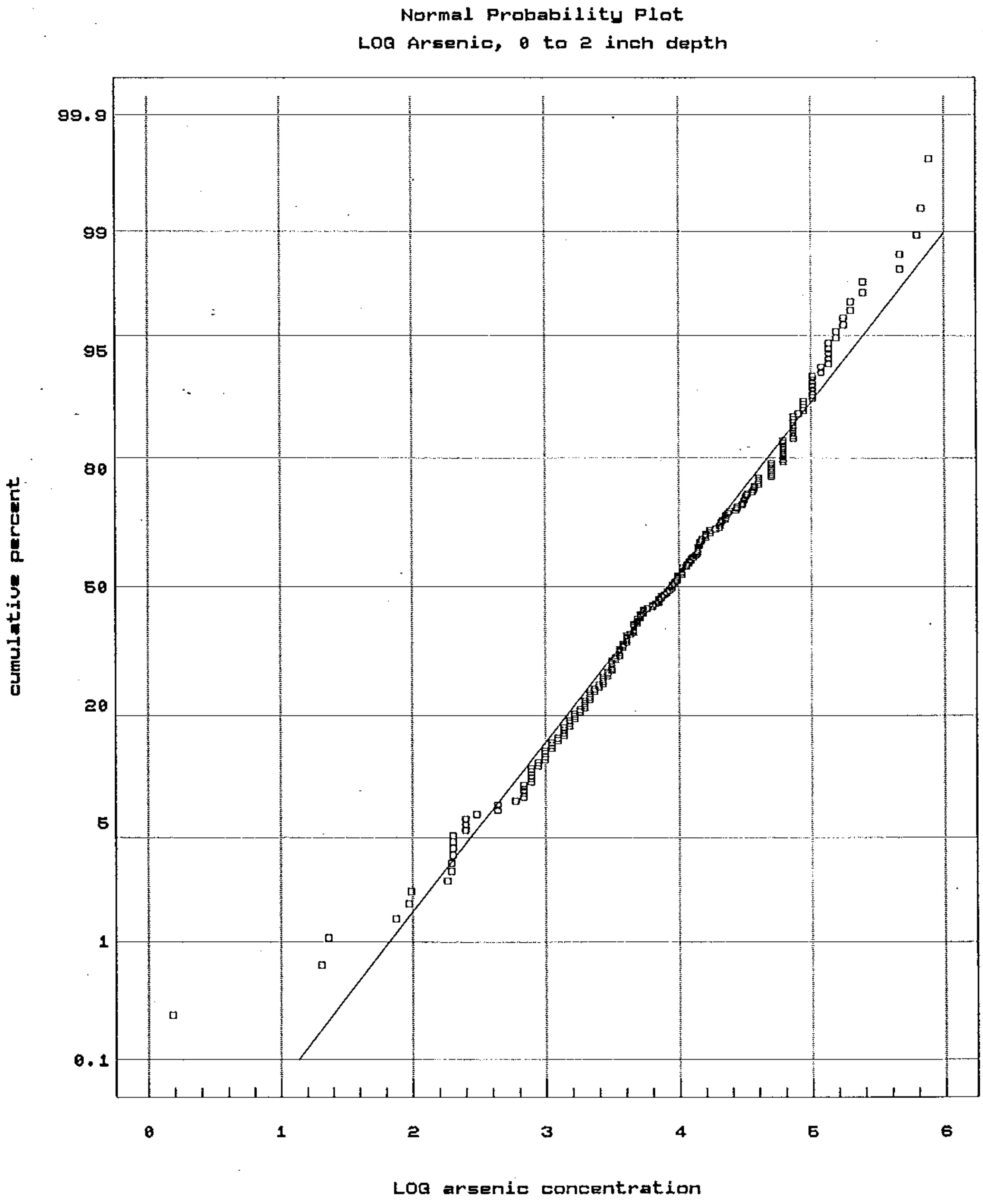
Data Validation Report:
Summary, Inorganic Data Assessment

AVAILABLE UPON REQUEST

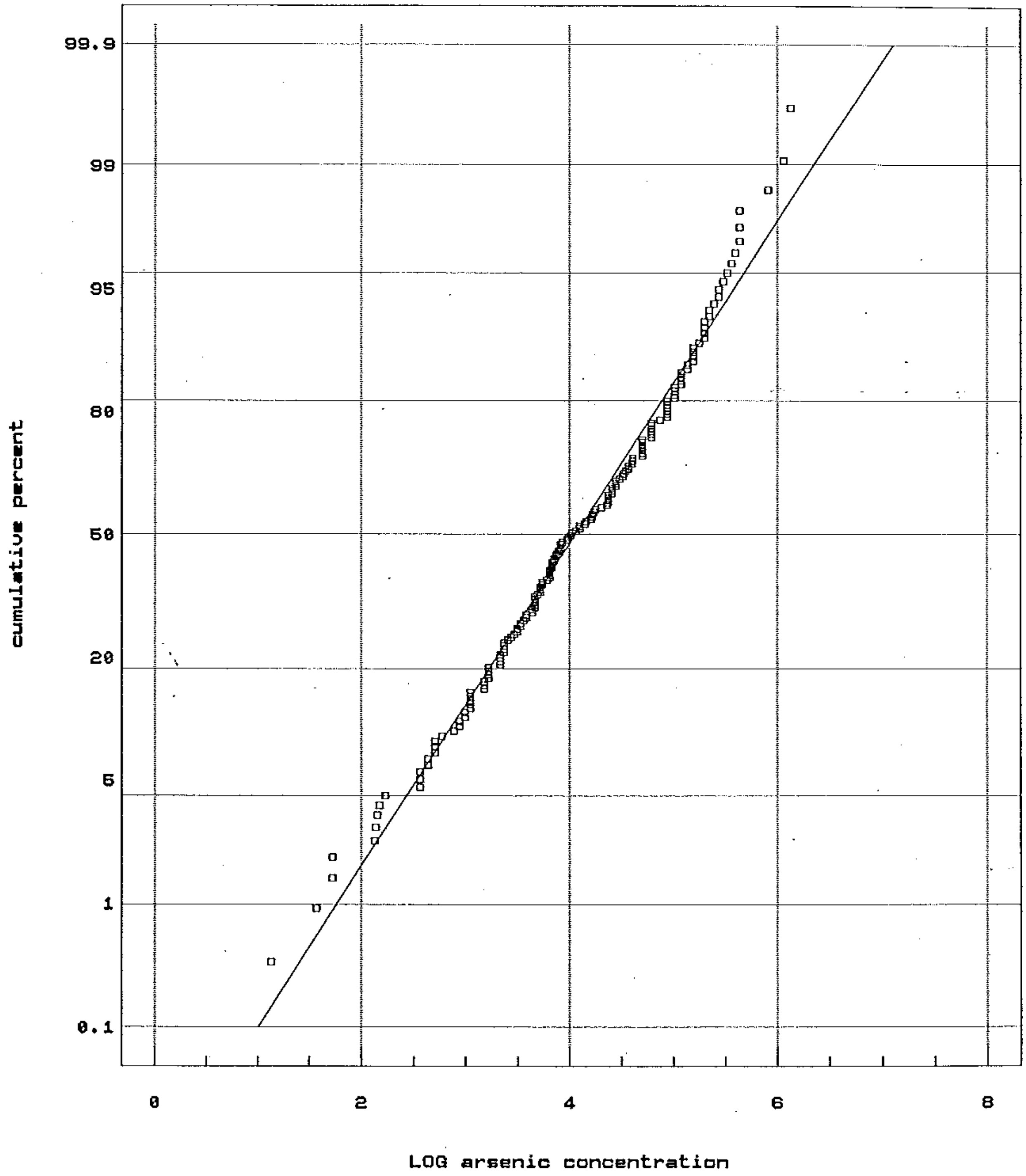
ATTACHMENT D

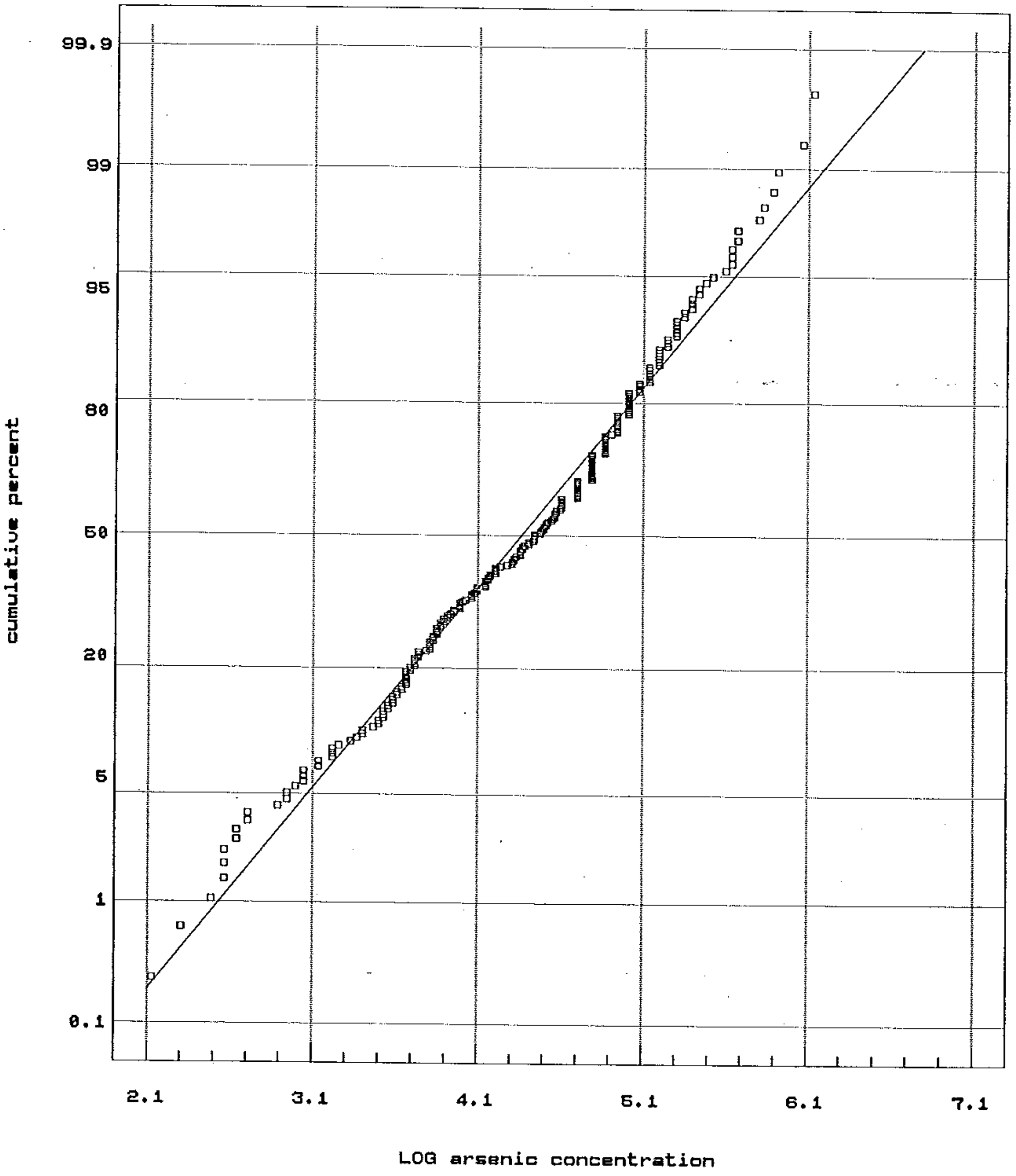
Additional Statistical Evaluations
and
Data Plots

MAGNITUDE OF SOIL CONTAMINATION

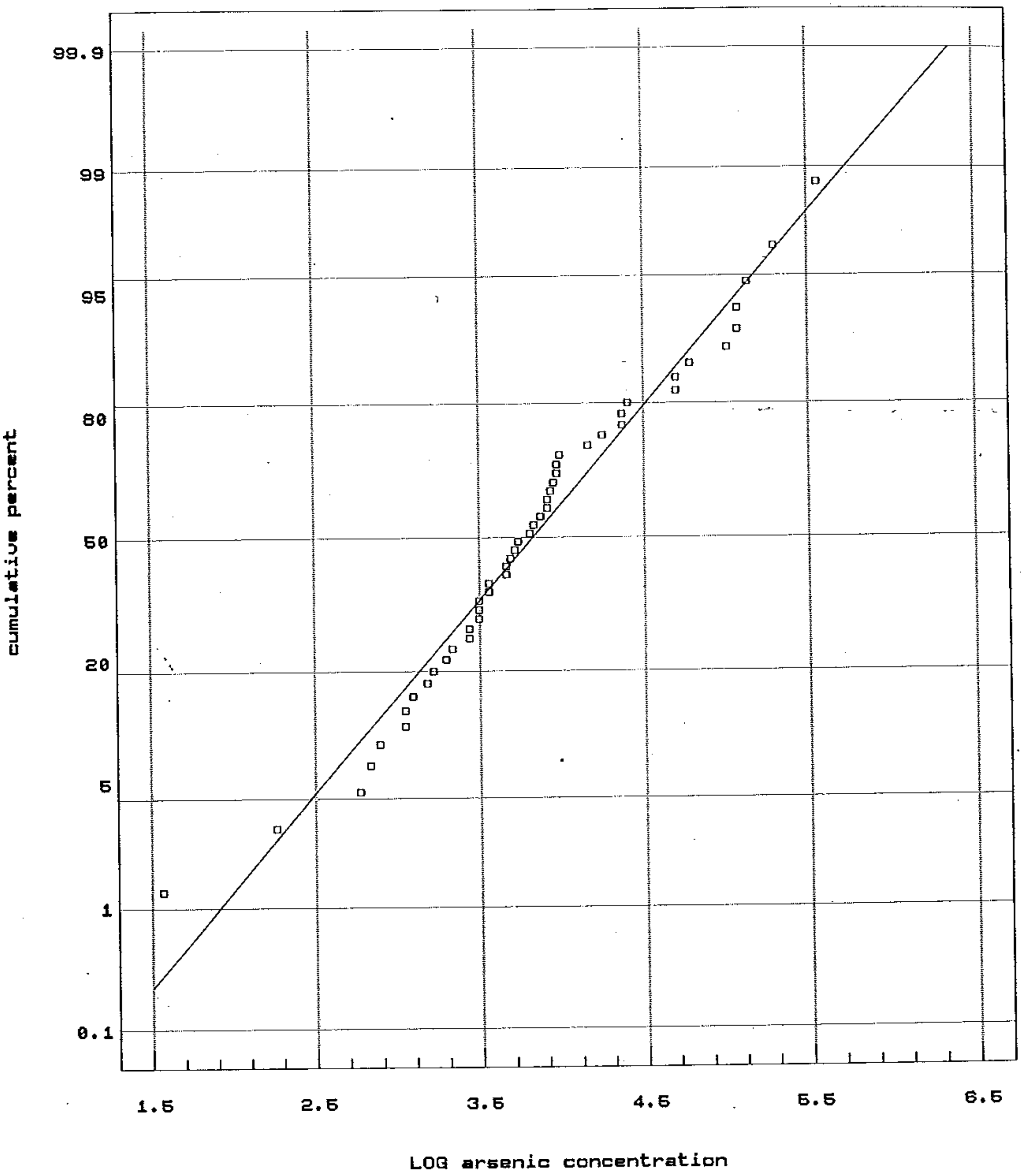

Normal Probability Plot
LOG Arsenic, 0 to 2 inch depth
99.9
99
95
80
50
20
5
1
0.1
cumulative percent
0
1
2
3
4
5
6
LOG arsenic concentration

Normal Probability Plot
LOG Arsenic, 2 to 6 inch depth

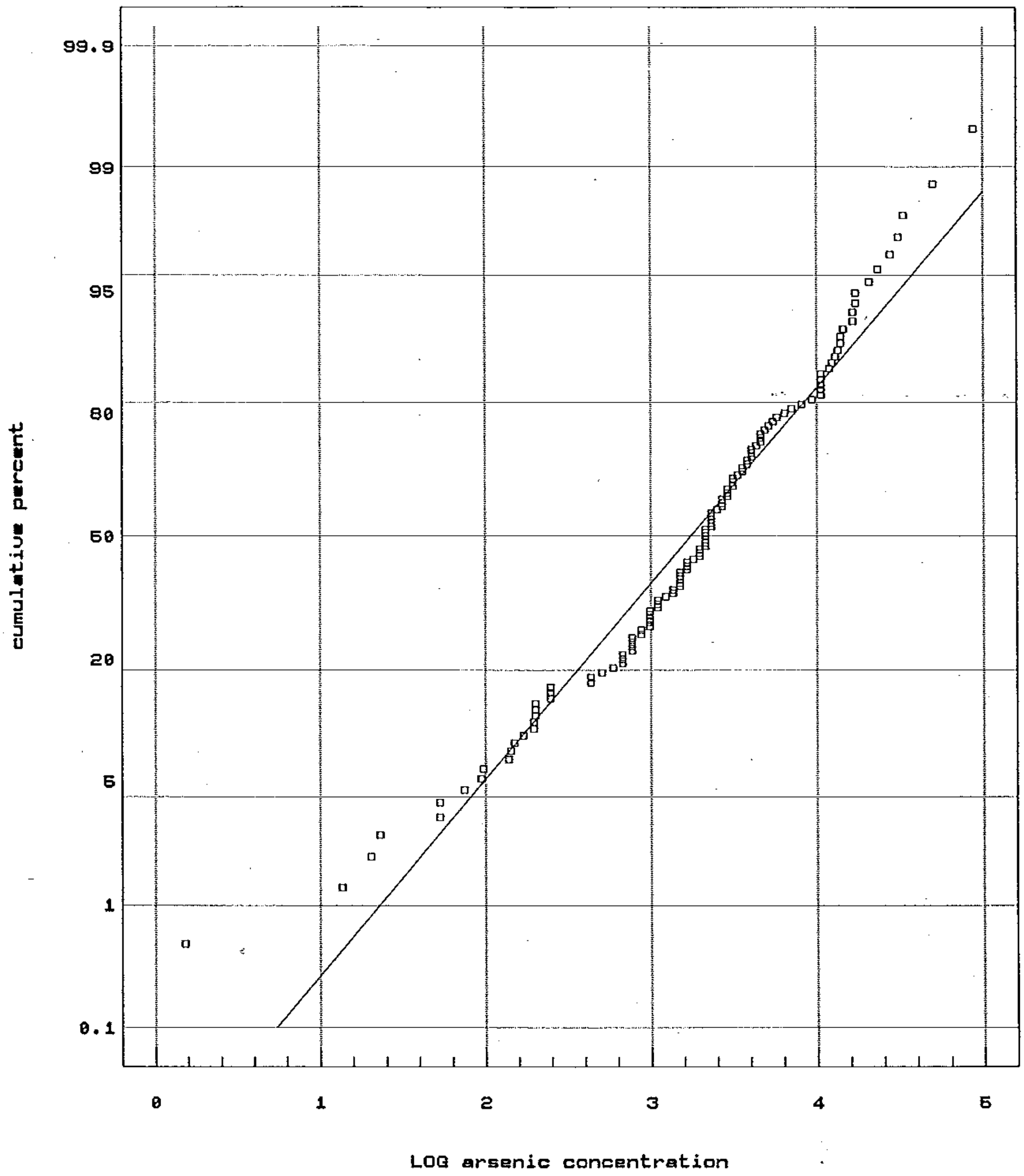


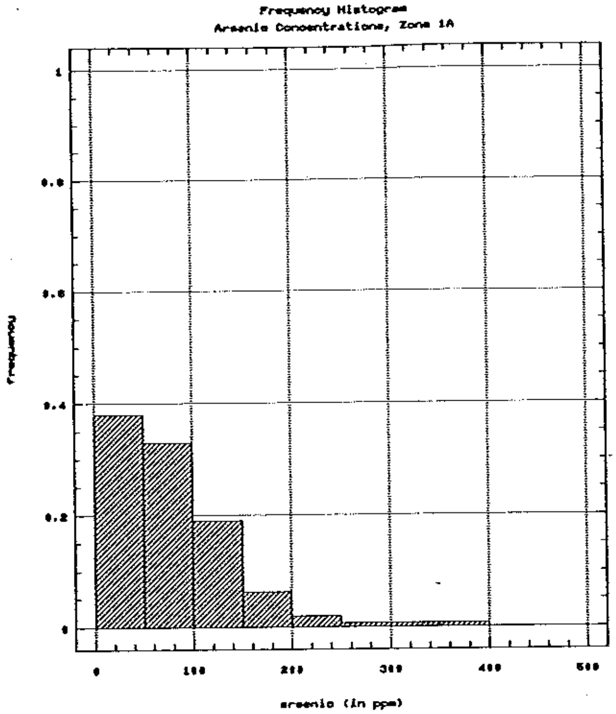

Normal Probability Plot
LOG Arsenic, Zone 1

Normal Probability Plot
LOG Arsenic, Zone 2

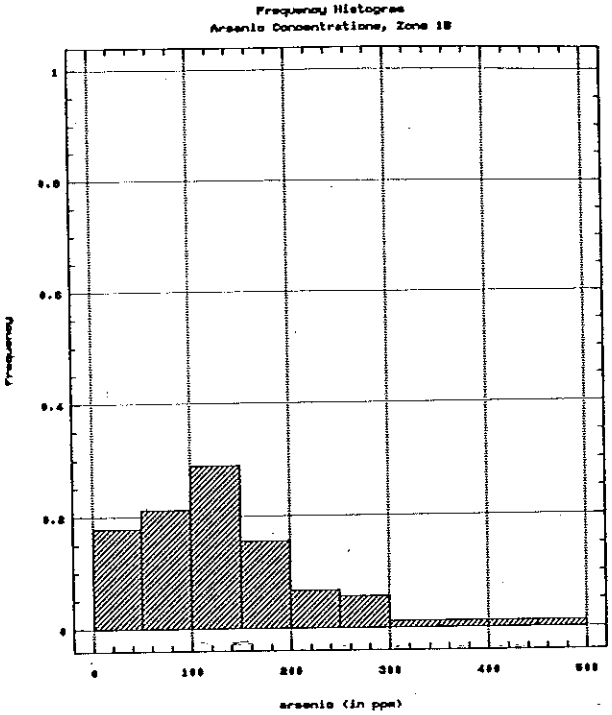


Normal Probability Plot
LOG Arsenic, Zone 3

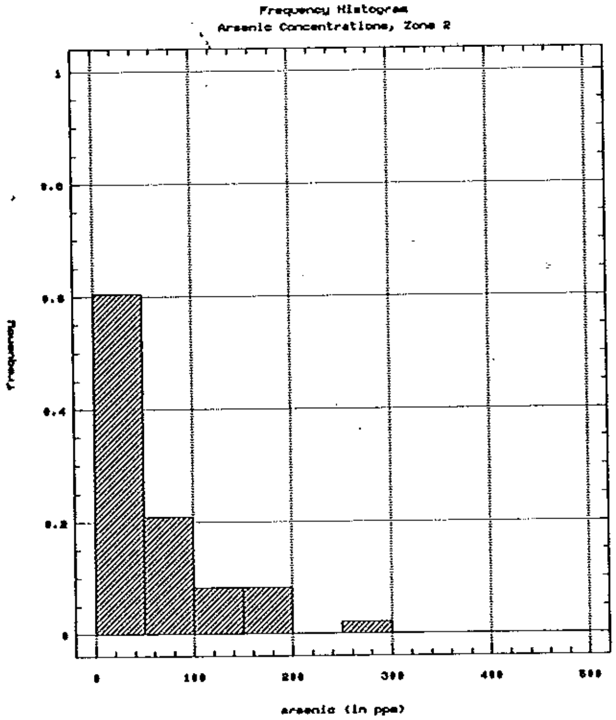




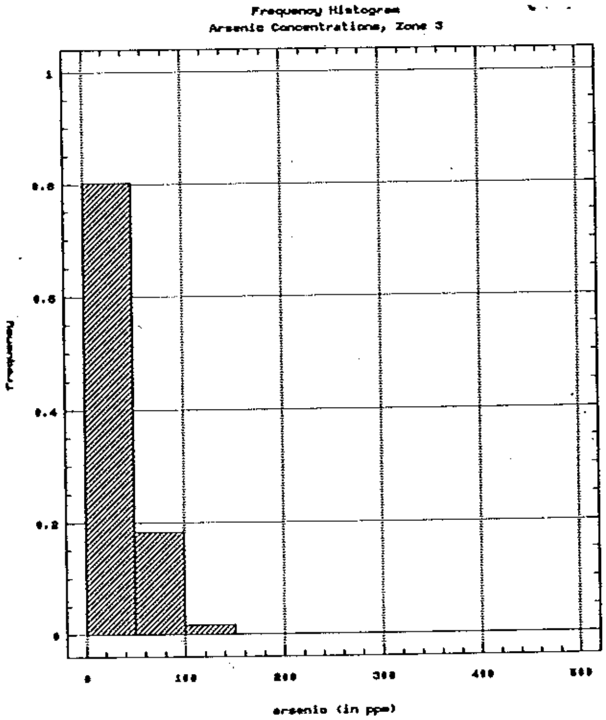
(South Vashon Island)



(Maury Island)

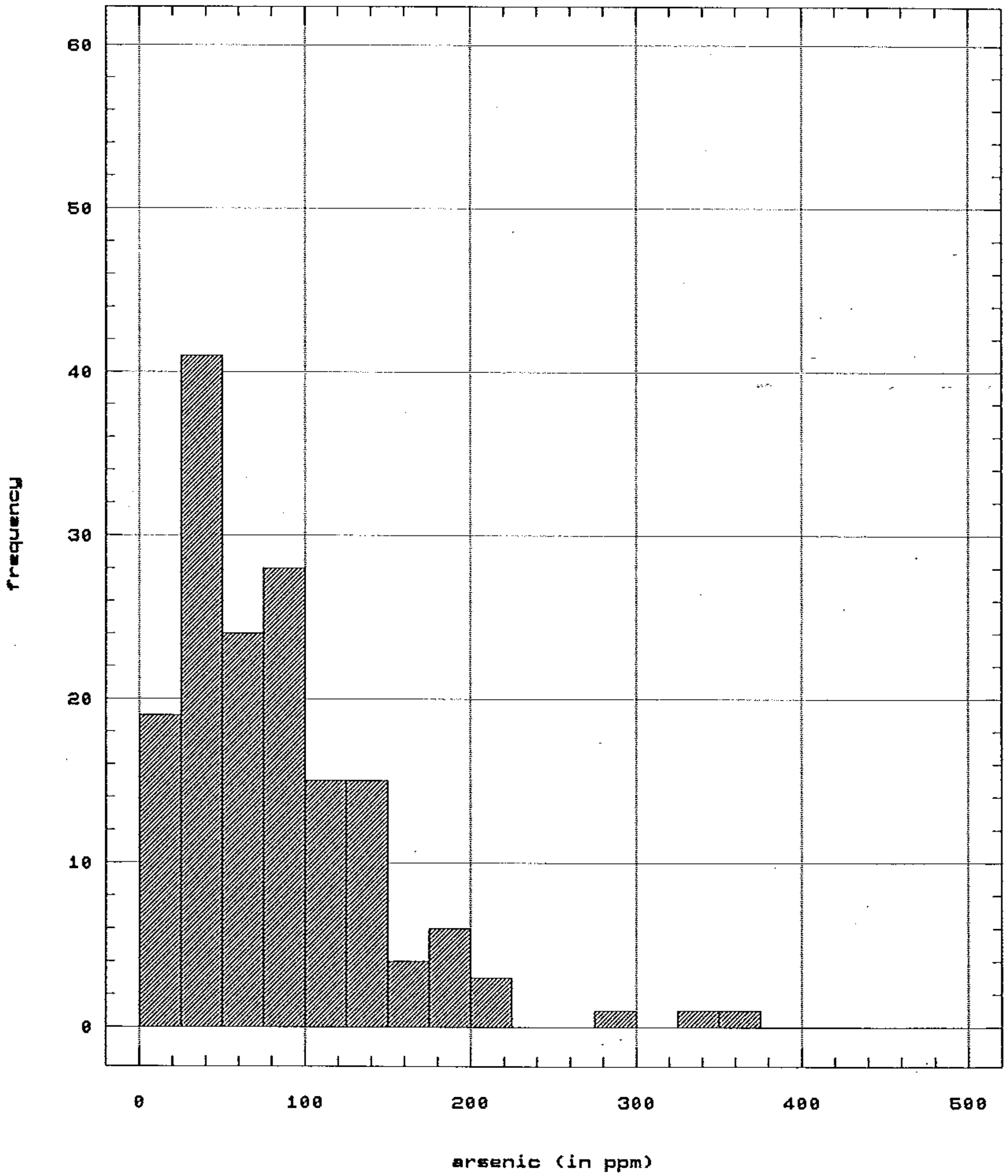


(Mainland)



(North Vashon Island)

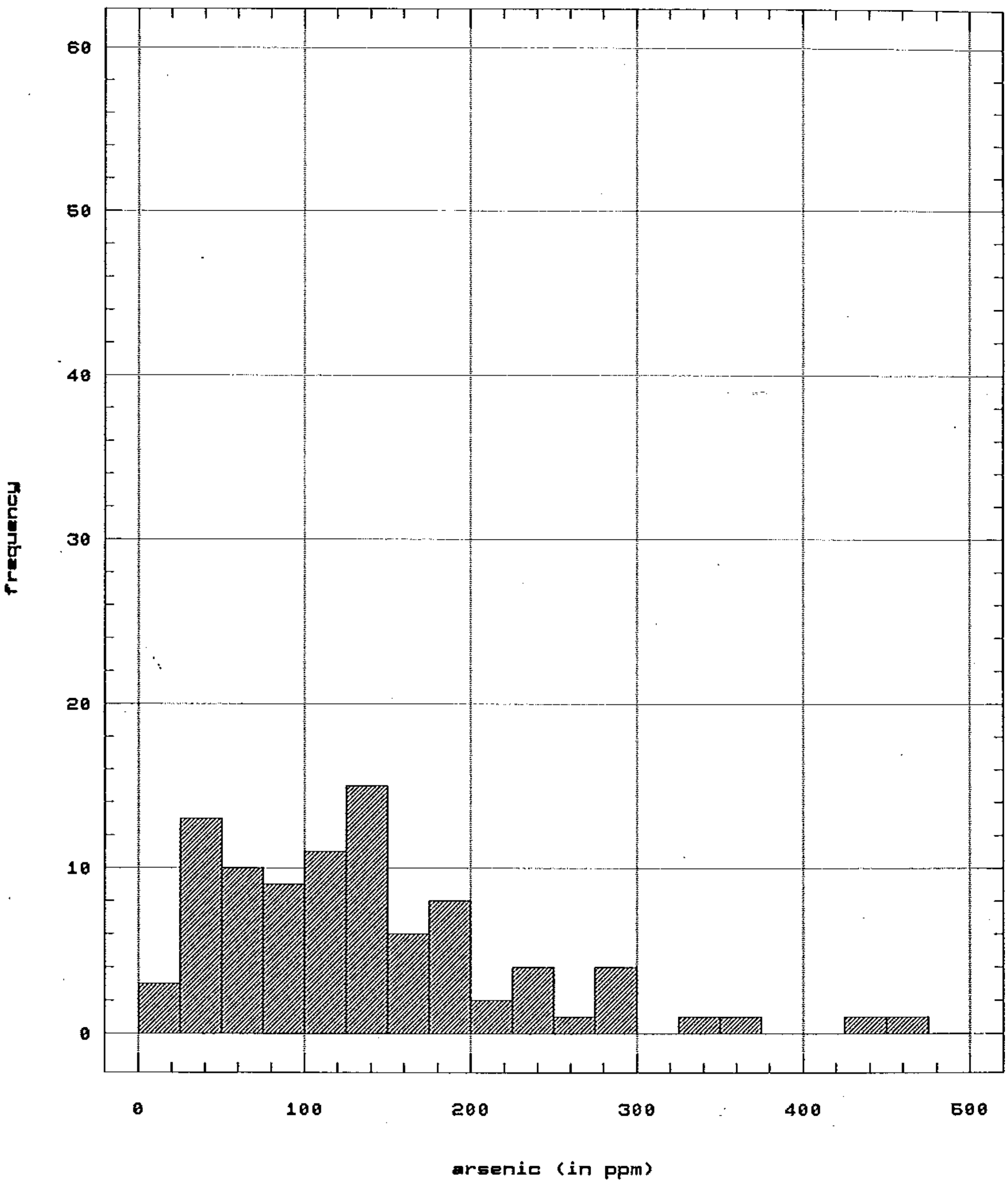
Frequency Histogram
Arsenic Concentrations, Zone 1A



(South Vashon Island)

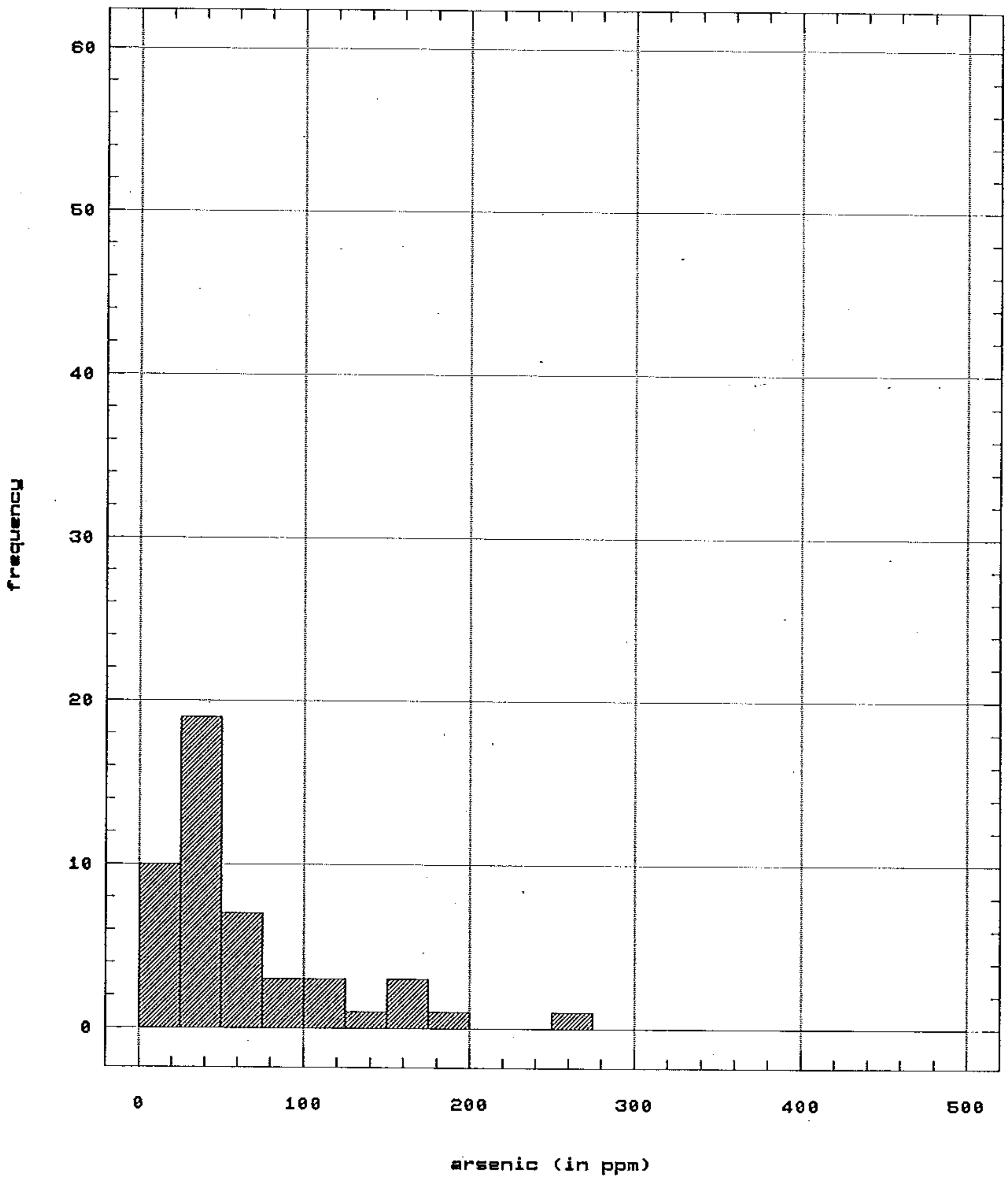
Frequency Histogram

Arsenic Concentrations, Zone 1B



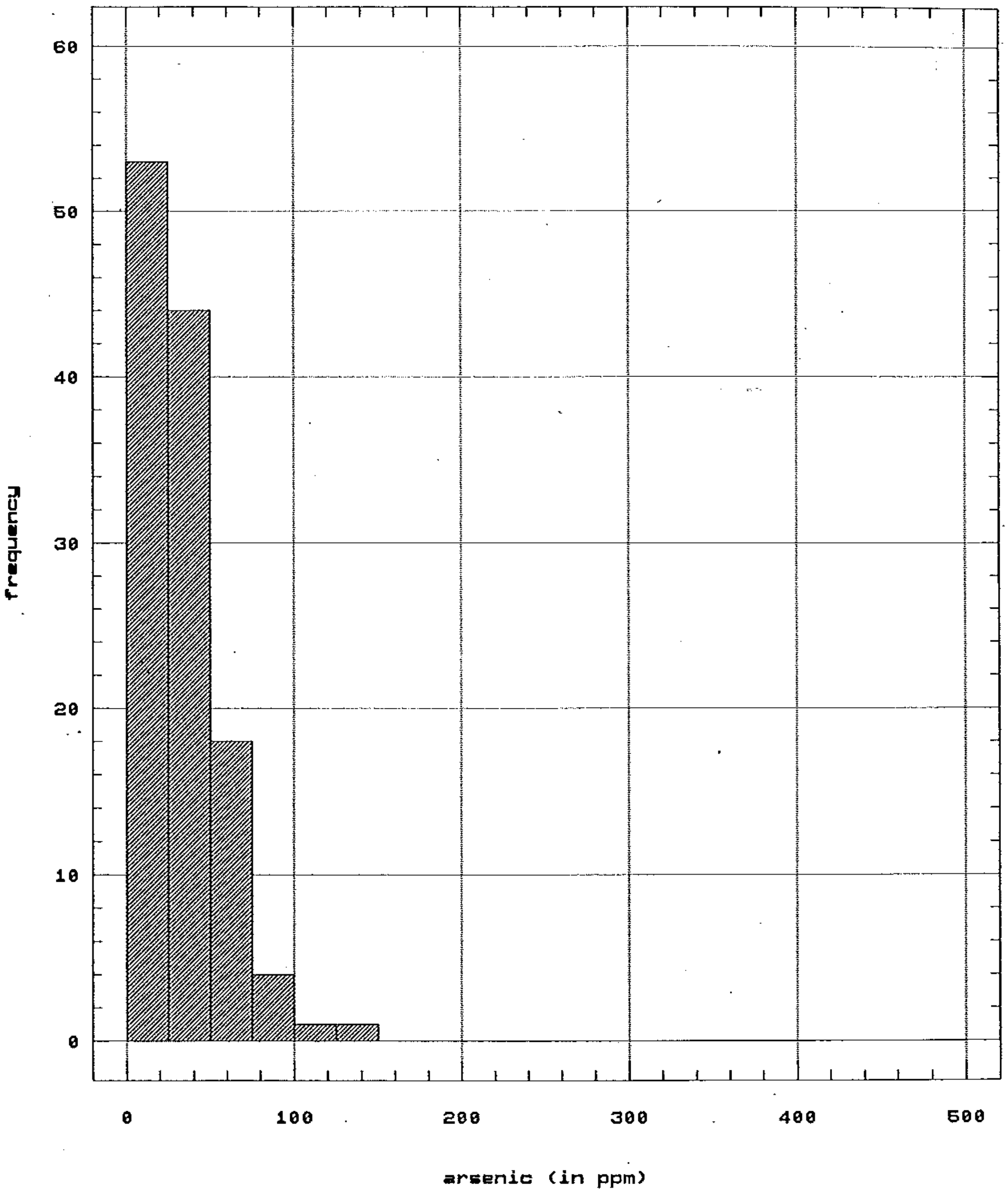
(Maury Island)

Frequency Histogram
Arsenic Concentrations, Zone 2



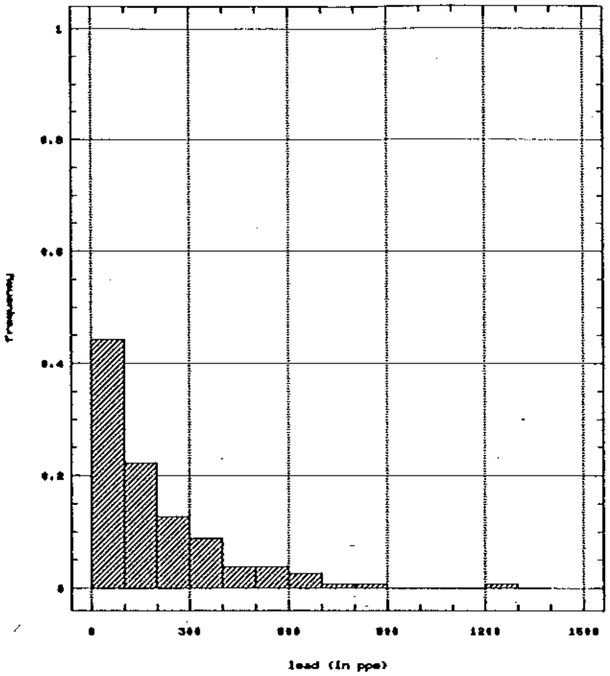
(Mainland)

Frequency Histogram
Arsenic Concentrations, Zone 3



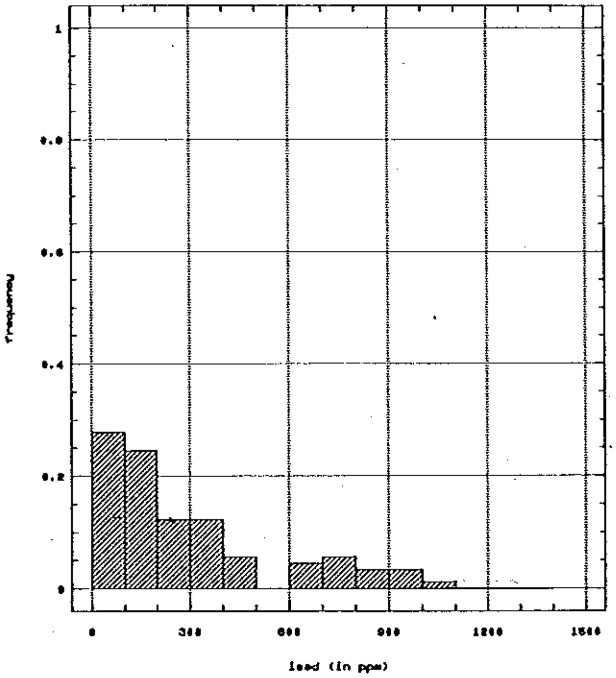
(North Vashon Island)

Frequency Histogram
Lead Concentrations, Zone 1A



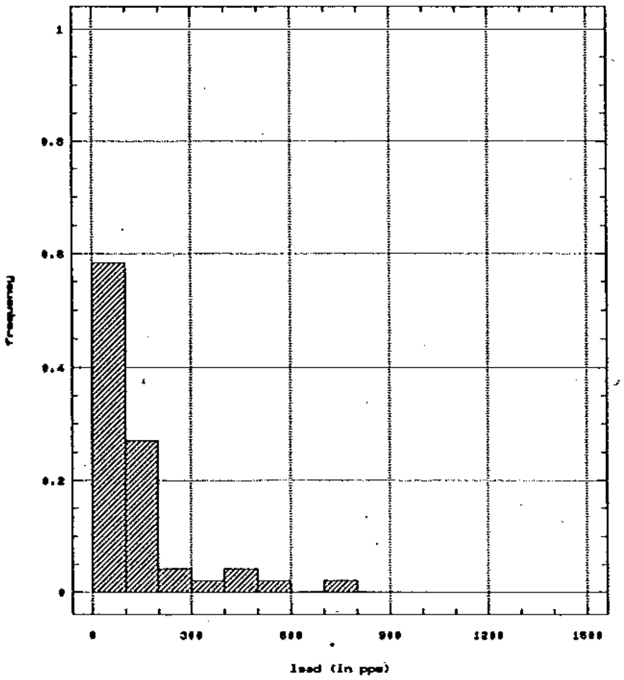
(South Vashon Island)

Frequency Histogram
Lead Concentrations, Zone 1B



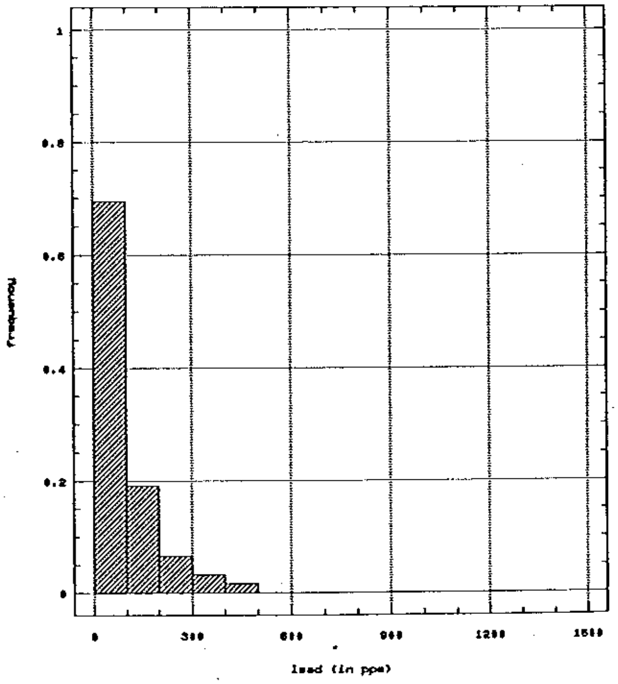
(Maury Island)

Frequency Histogram
Lead Concentrations, Zone 2



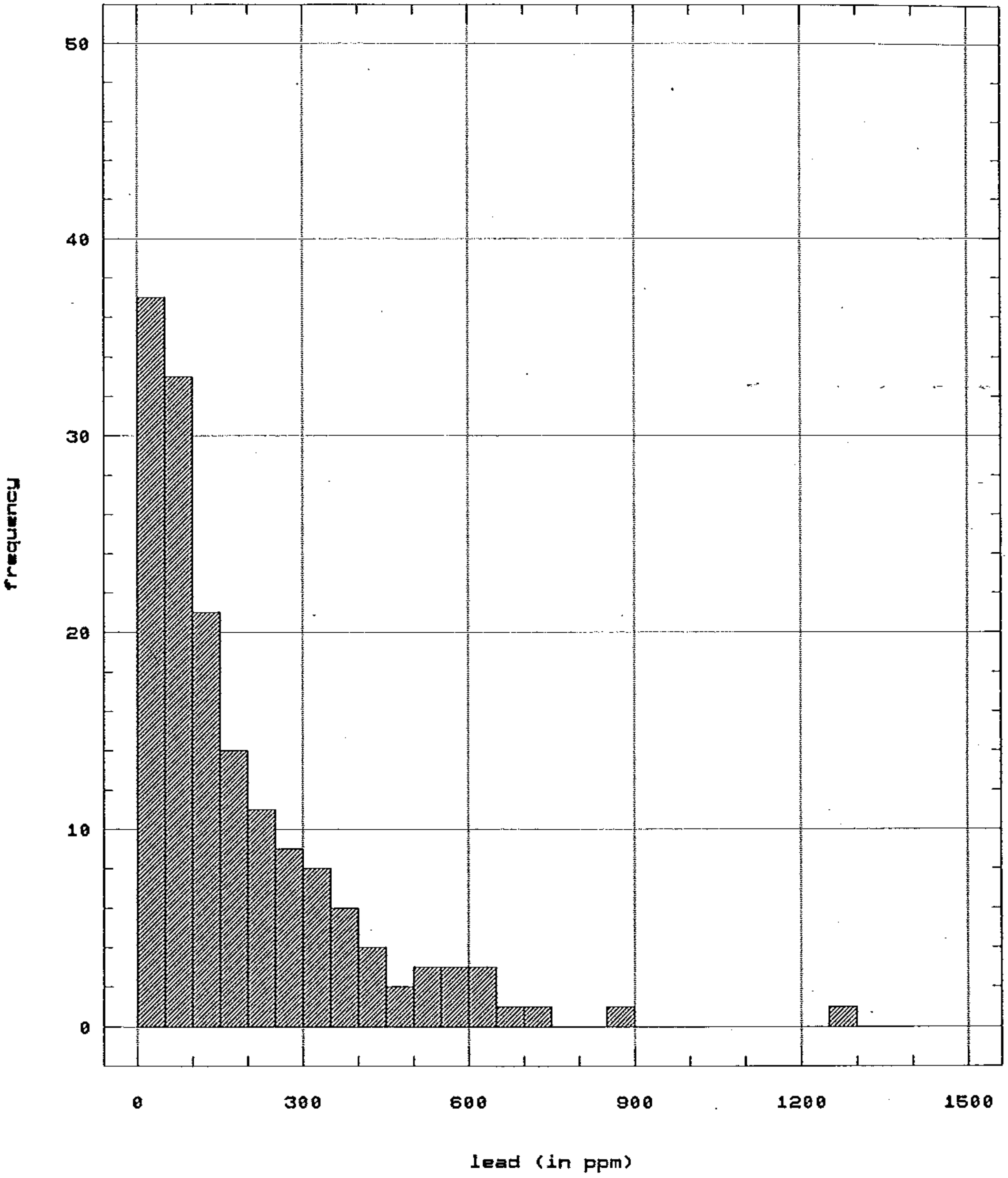
(Mainland)

Frequency Histogram
Lead Concentrations, Zone 3



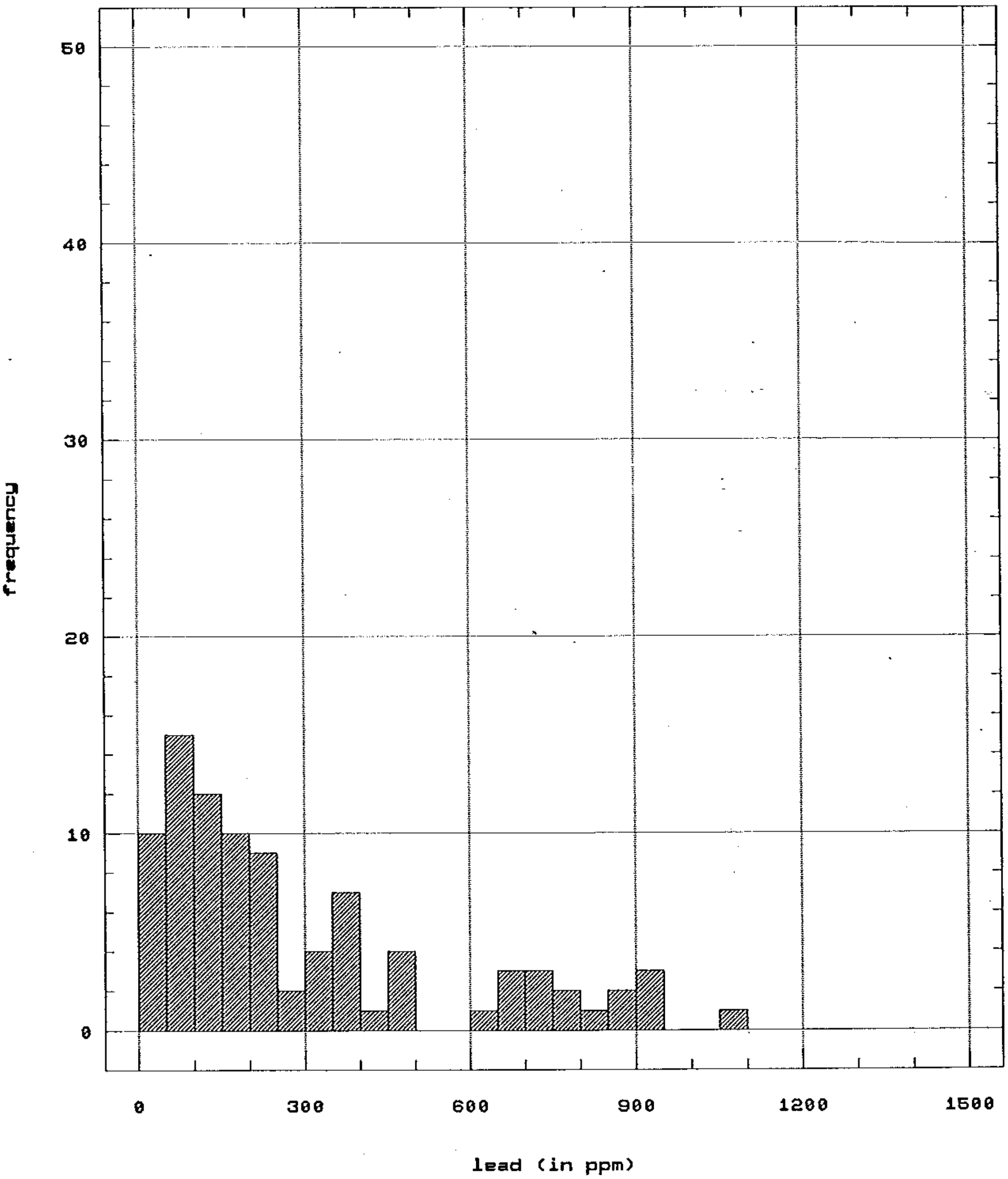
(North Vashon Island)

Frequency Histogram
Lead Concentrations, Zone 1A



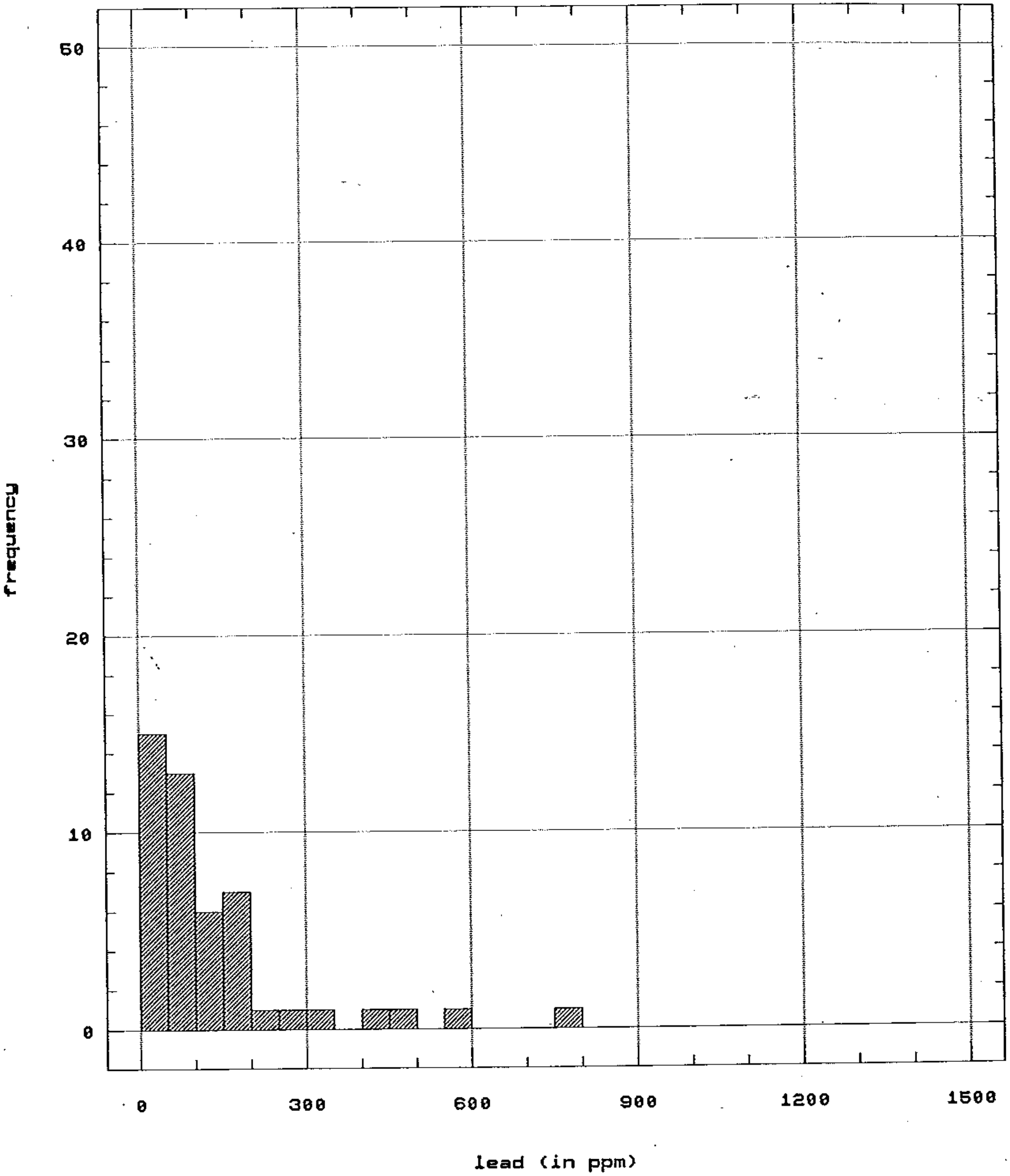
(South Vashon Island)

Frequency Histogram
Lead Concentrations, Zone 1B



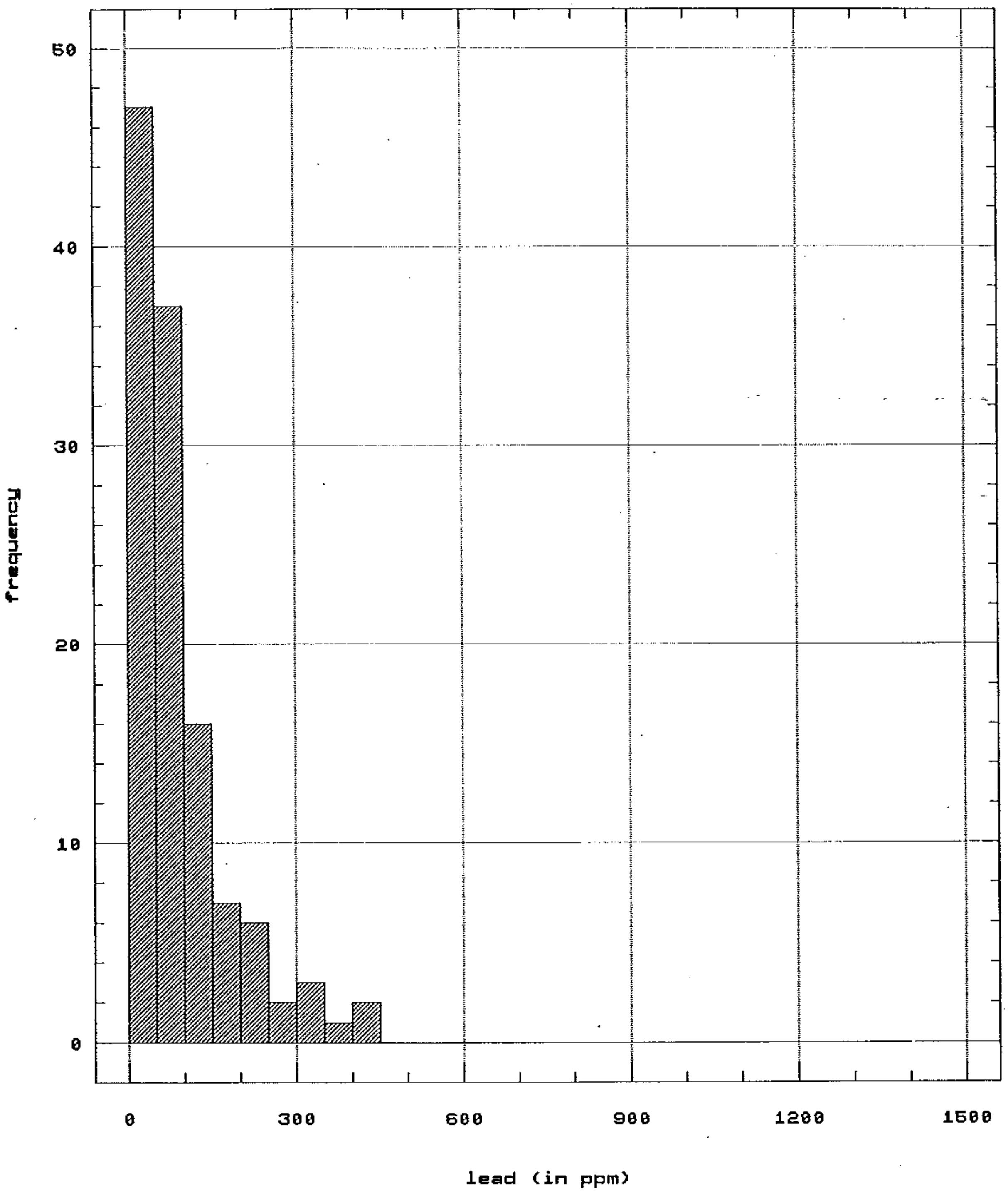
(Maury Island)

Frequency Histogram
Lead Concentrations, Zone 2

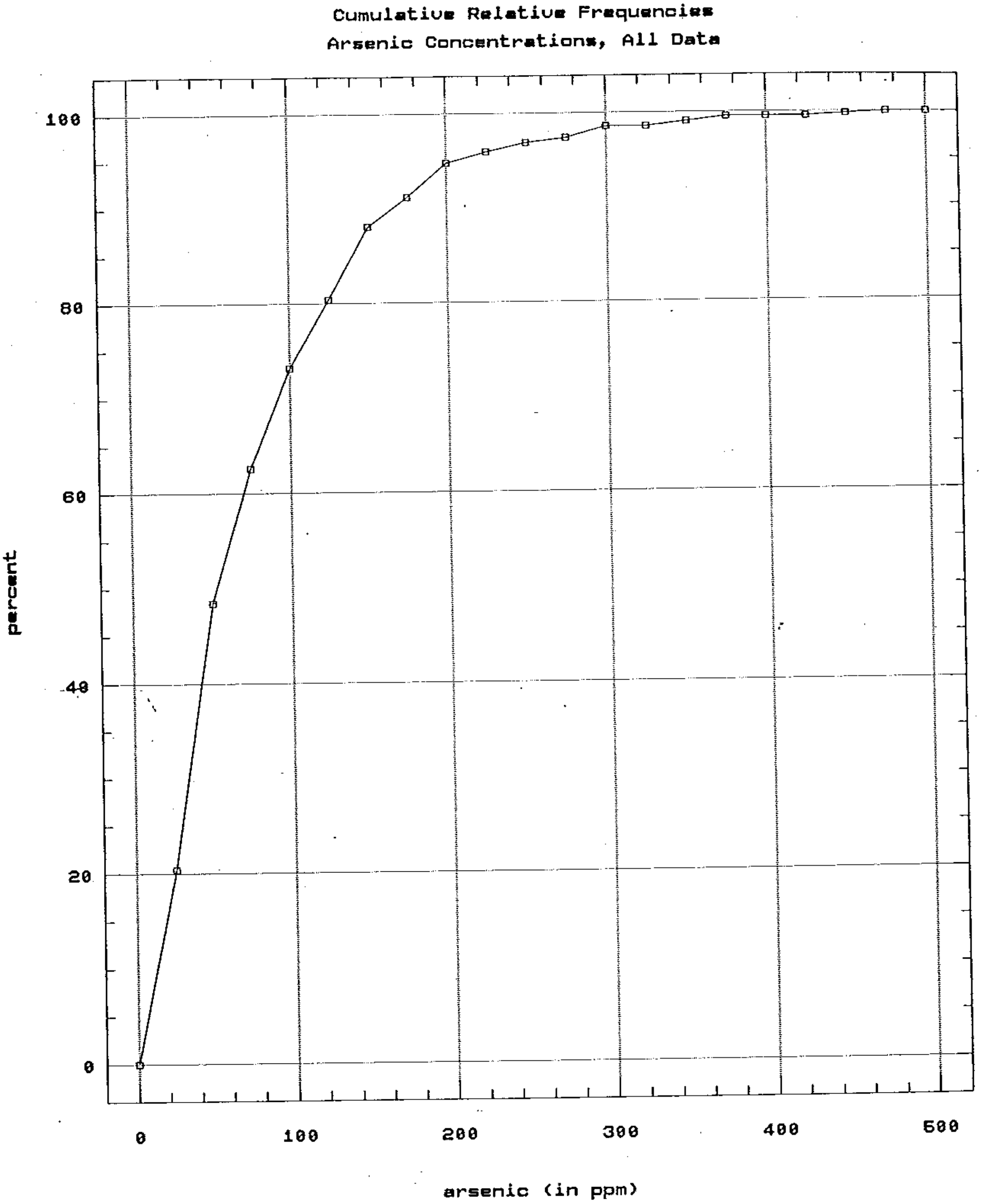


(Mainland)

Frequency Histogram
Lead Concentrations, Zone 3

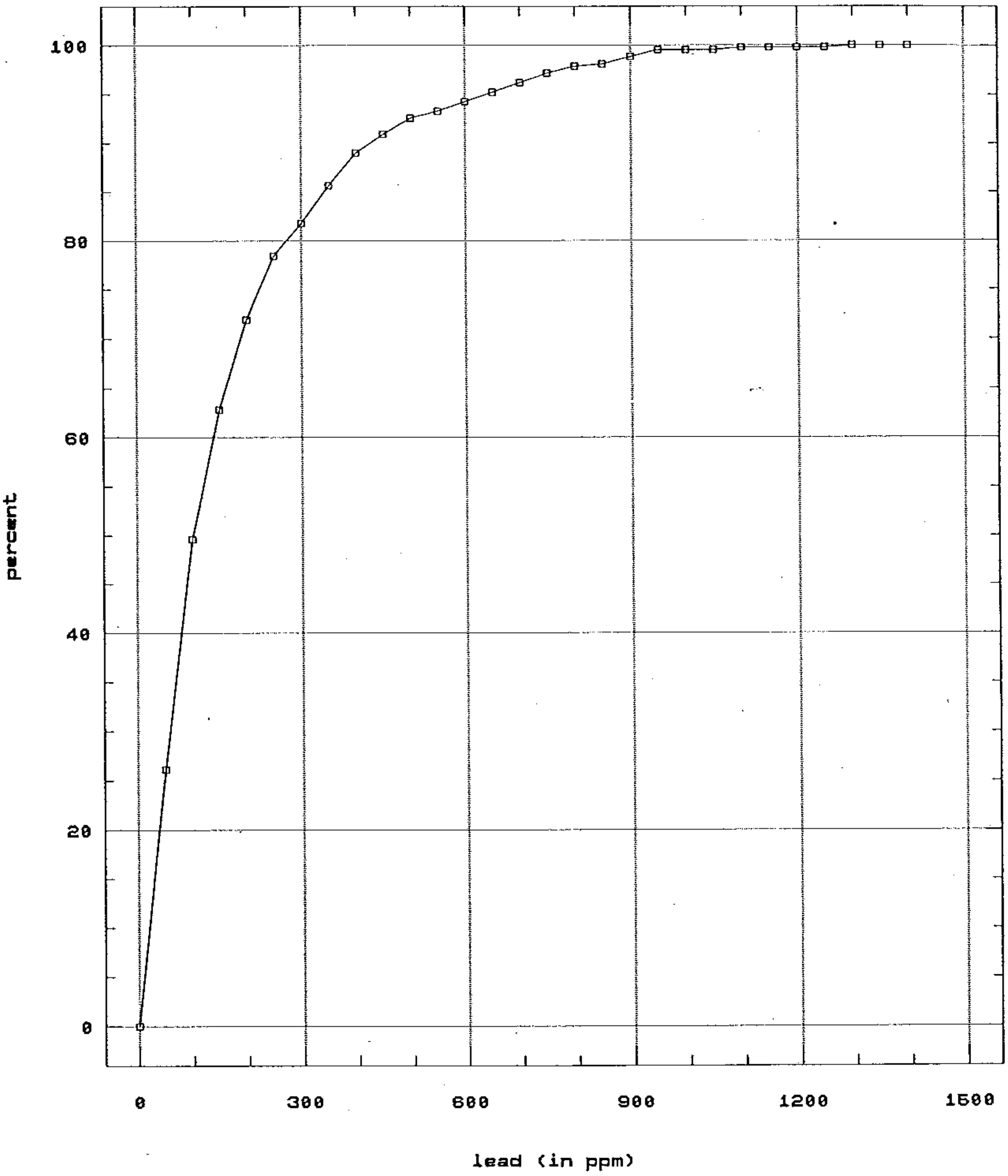


(North Vashon Island)

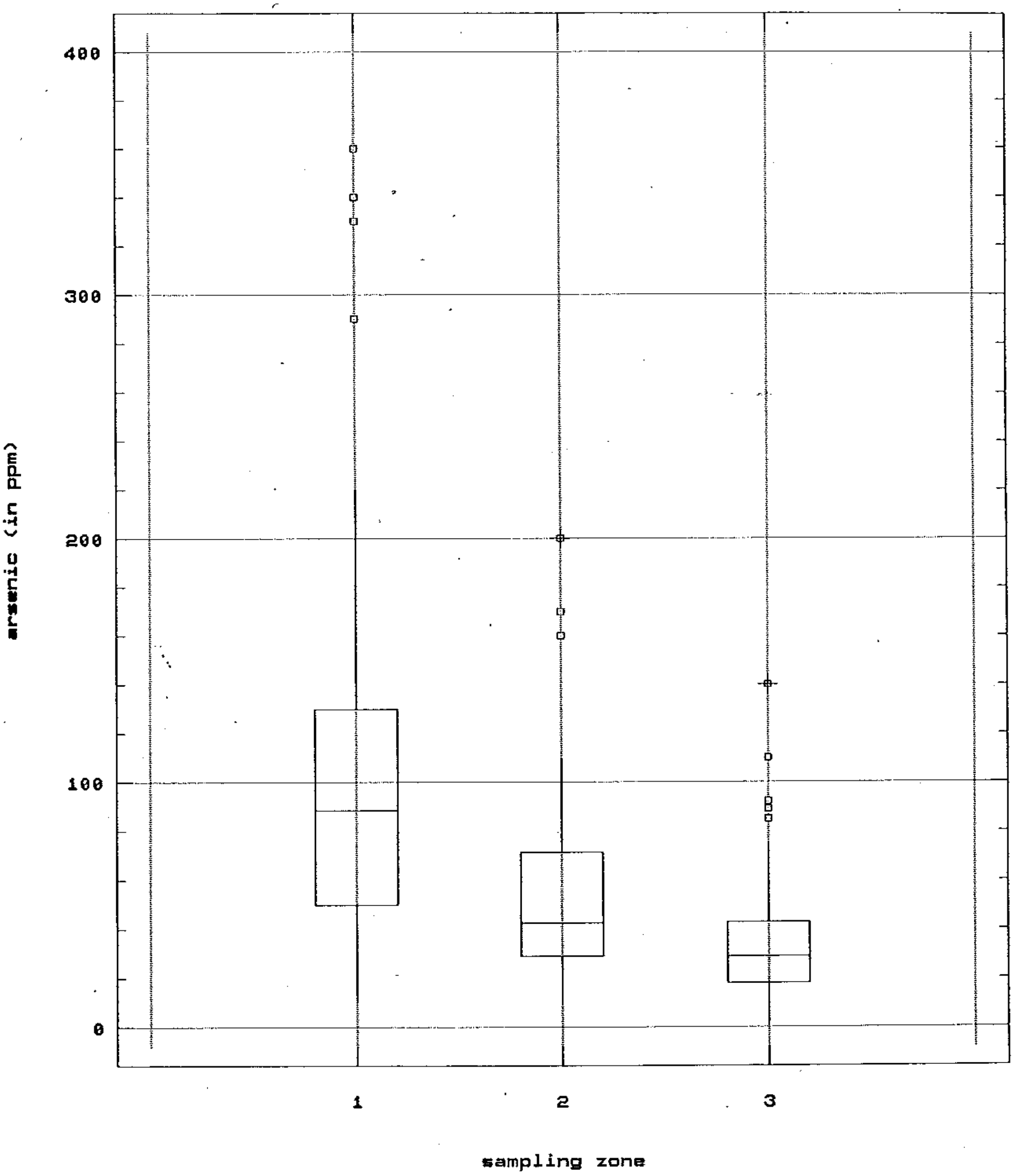


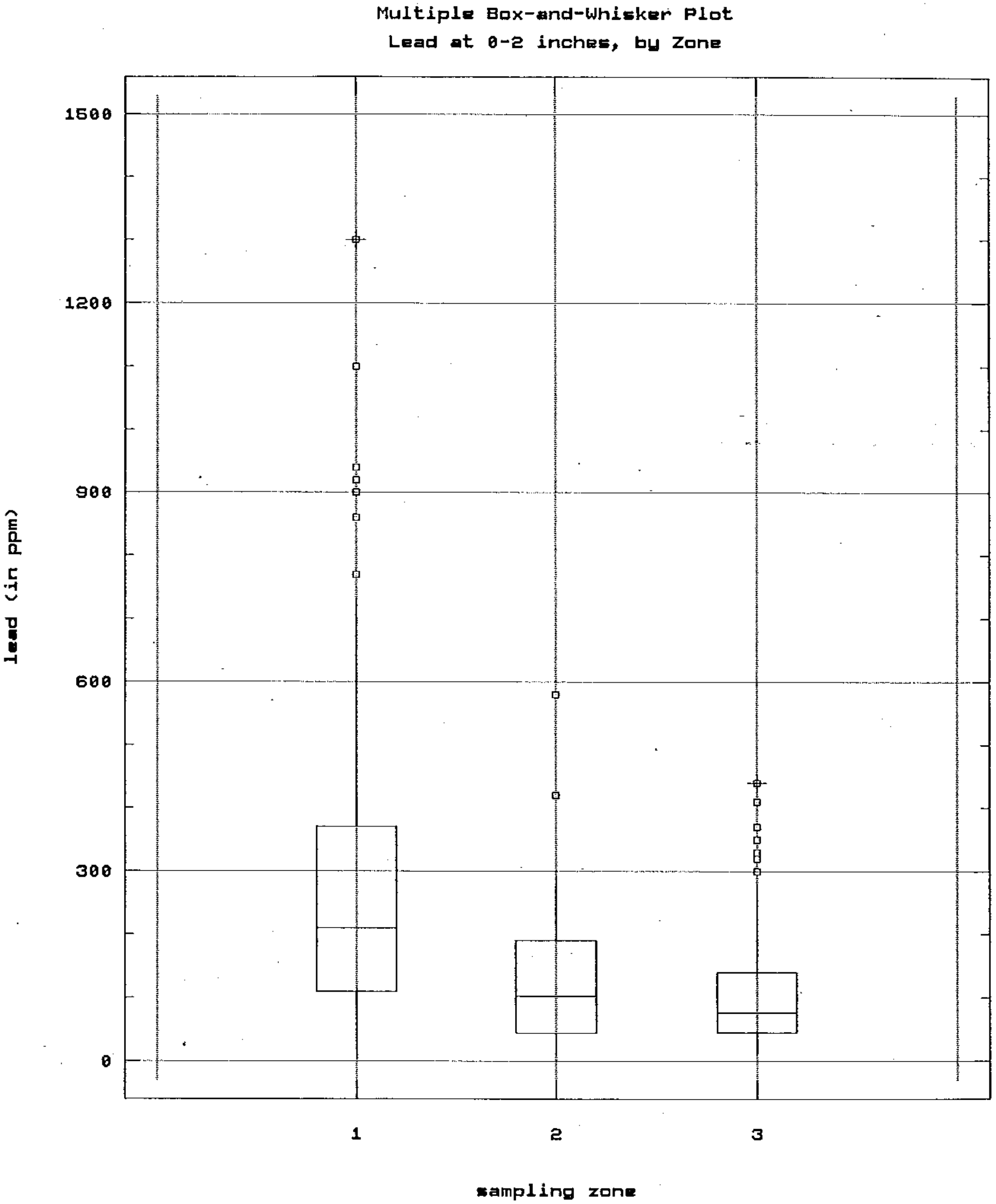
Cumulative Relative Frequencies
Arsenic Concentrations, All Data
100
80
60
40
20
0
percent
0
100
200
300
400
500
arsenic (in ppm)

Cumulative Relative Frequencies
Lead Concentrations, All Data



Multiple Box-and-Whisker Plot
Arsenic at 0-2 inches, by Zone

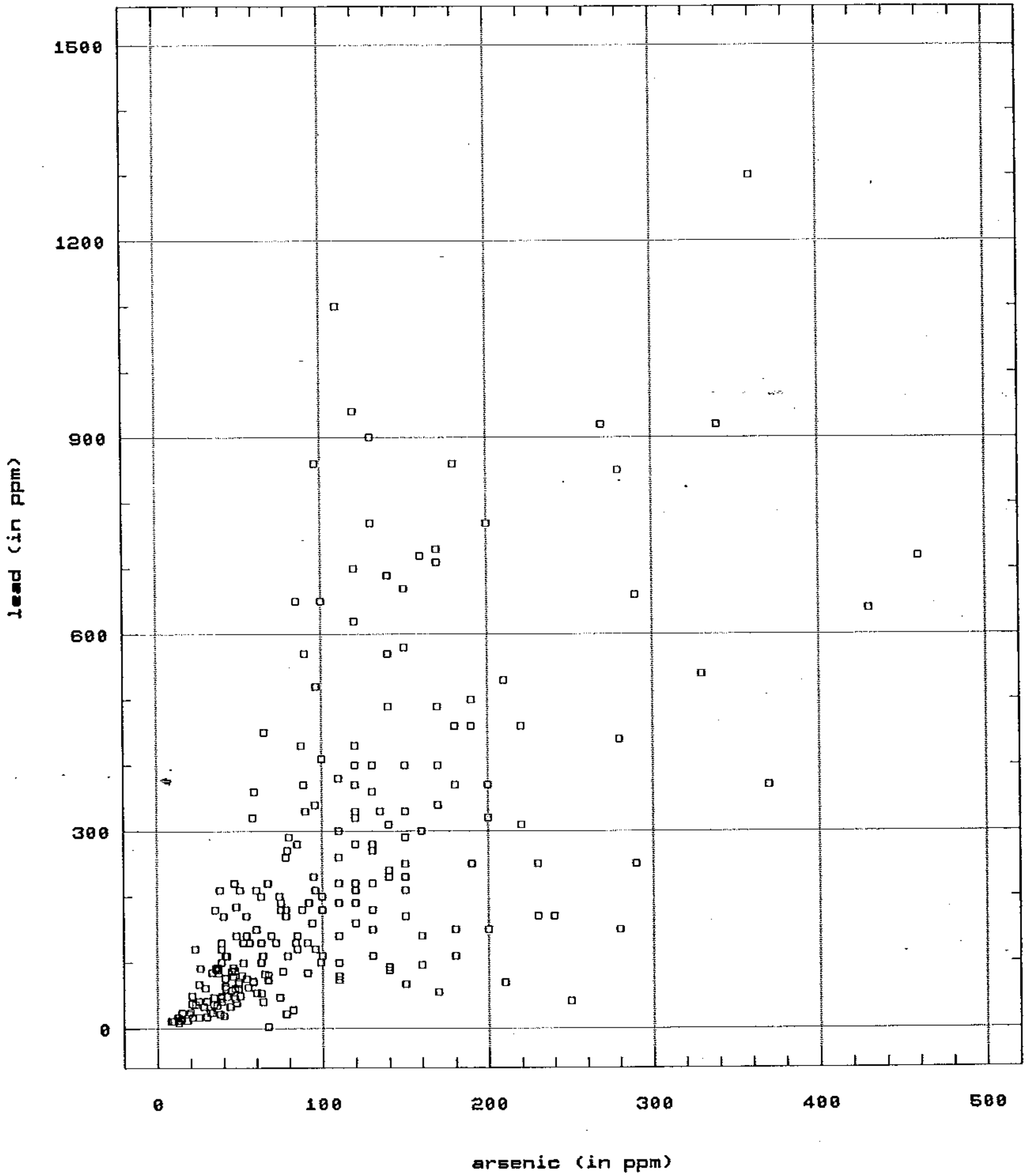



Multiple Box-and-Whisker Plot
Lead at 0-2 inches, by Zone
1500
1200
900
600
300
0
lead (in ppm)
1
2
3
sampling zone

CONTAMINANT CORRELATION/REGRESSION

Scatterplot: Individual Data Points

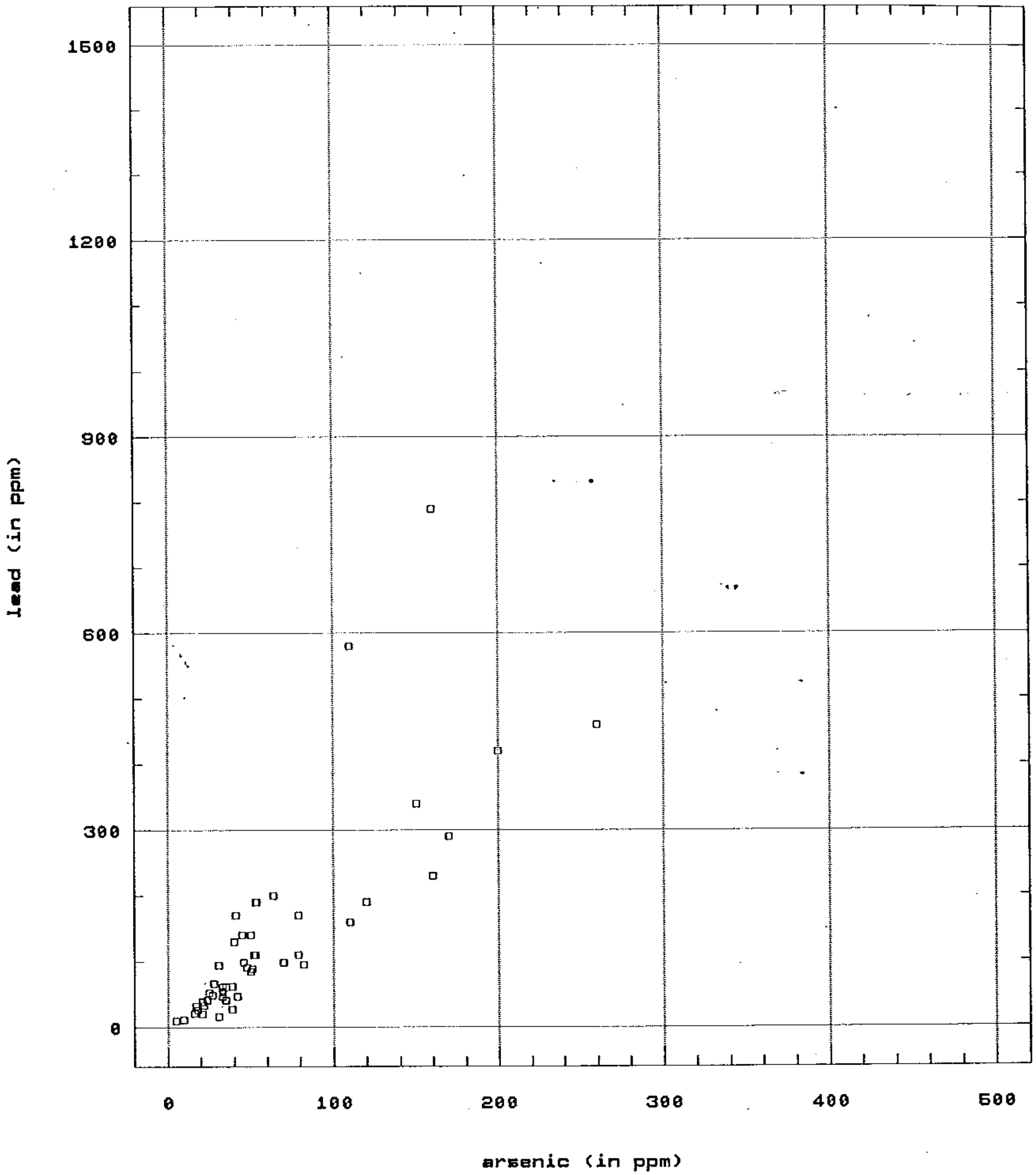
Zone 1 Lead vs Arsenic Concentrations



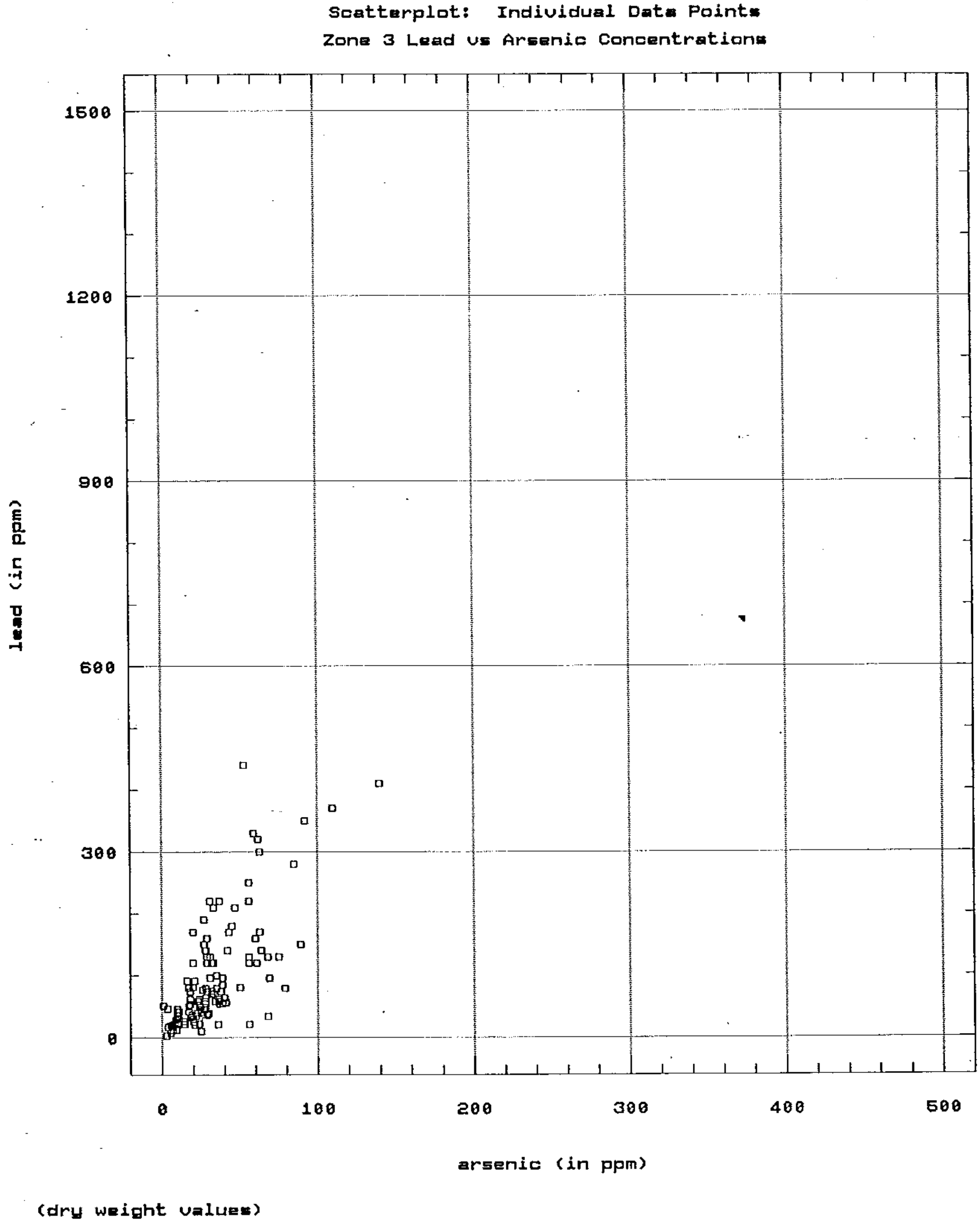
(dry weight values)

Scatterplot: Individual Data Points

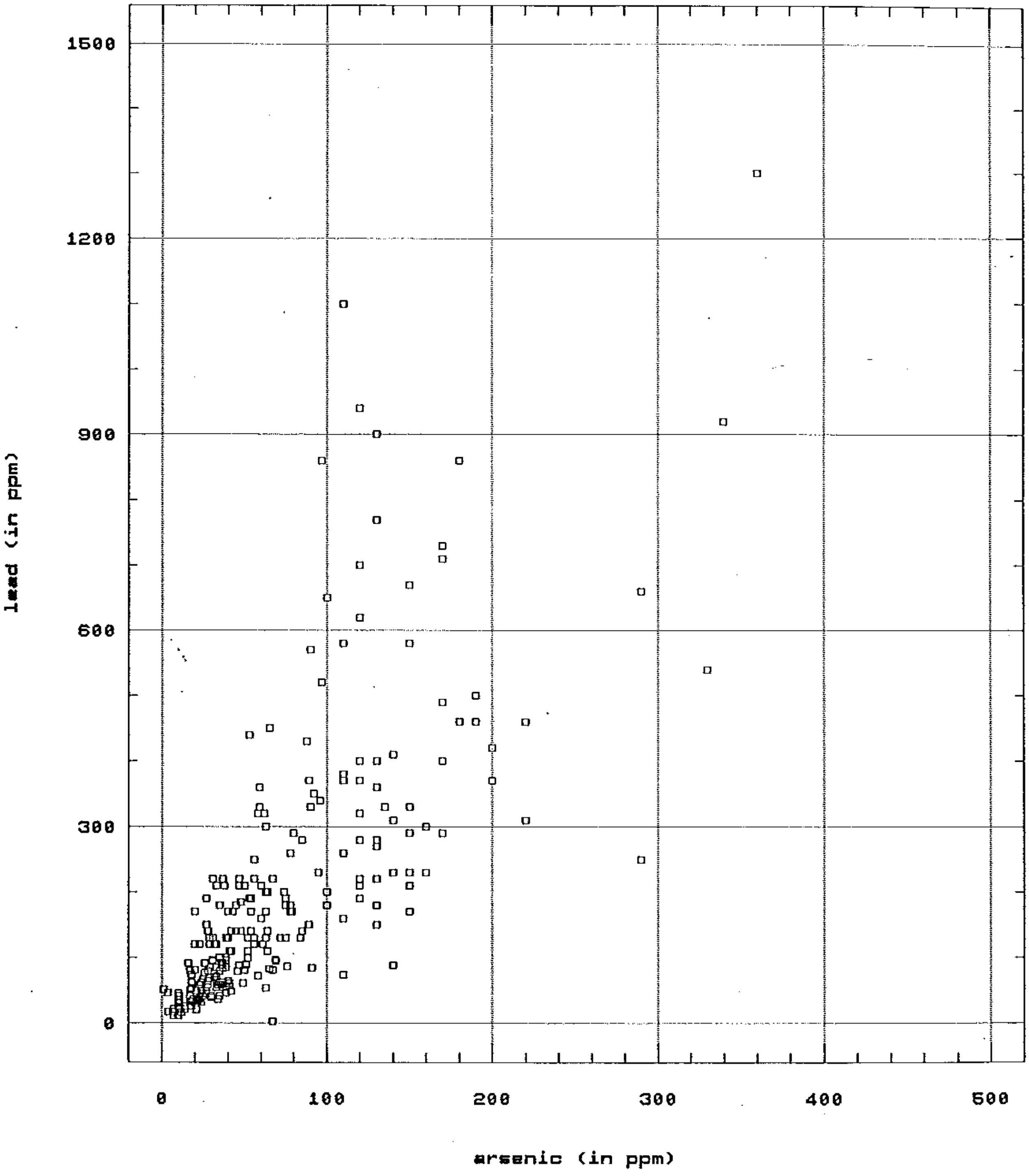
Zone 2 Lead vs Arsenic Concentrations



(dry weight values)

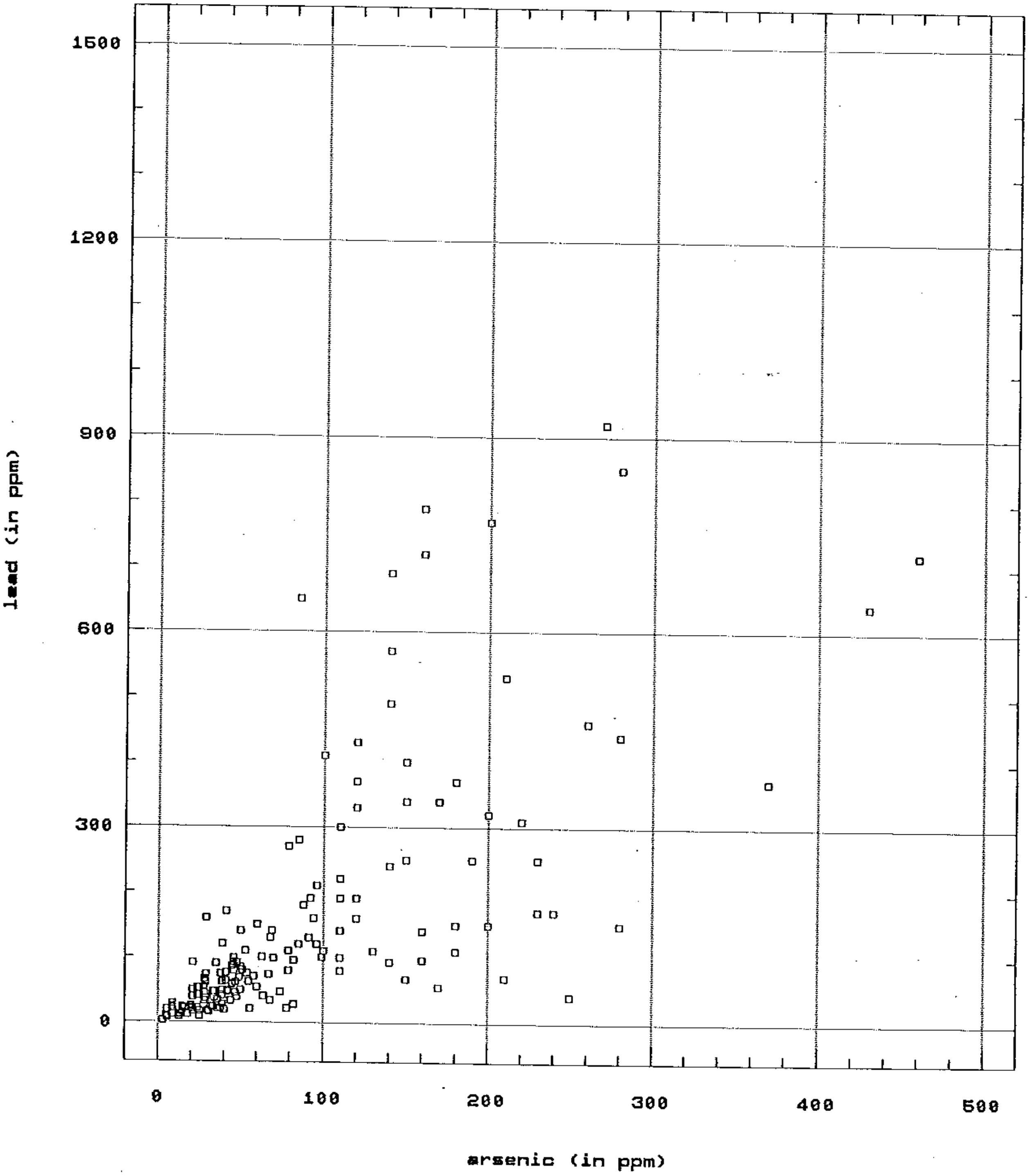

Scatterplot: Individual Data Points
Zone 3 Lead vs Arsenic Concentrations
lead (in ppm)
1500
1200
900
600
300
0
0
100
200
300
400
500
arsenic (in ppm)
(dry weight values)

Scatterplot: Individual Data Points
Lead vs Arsenic Concs. at 0 to 2 inches



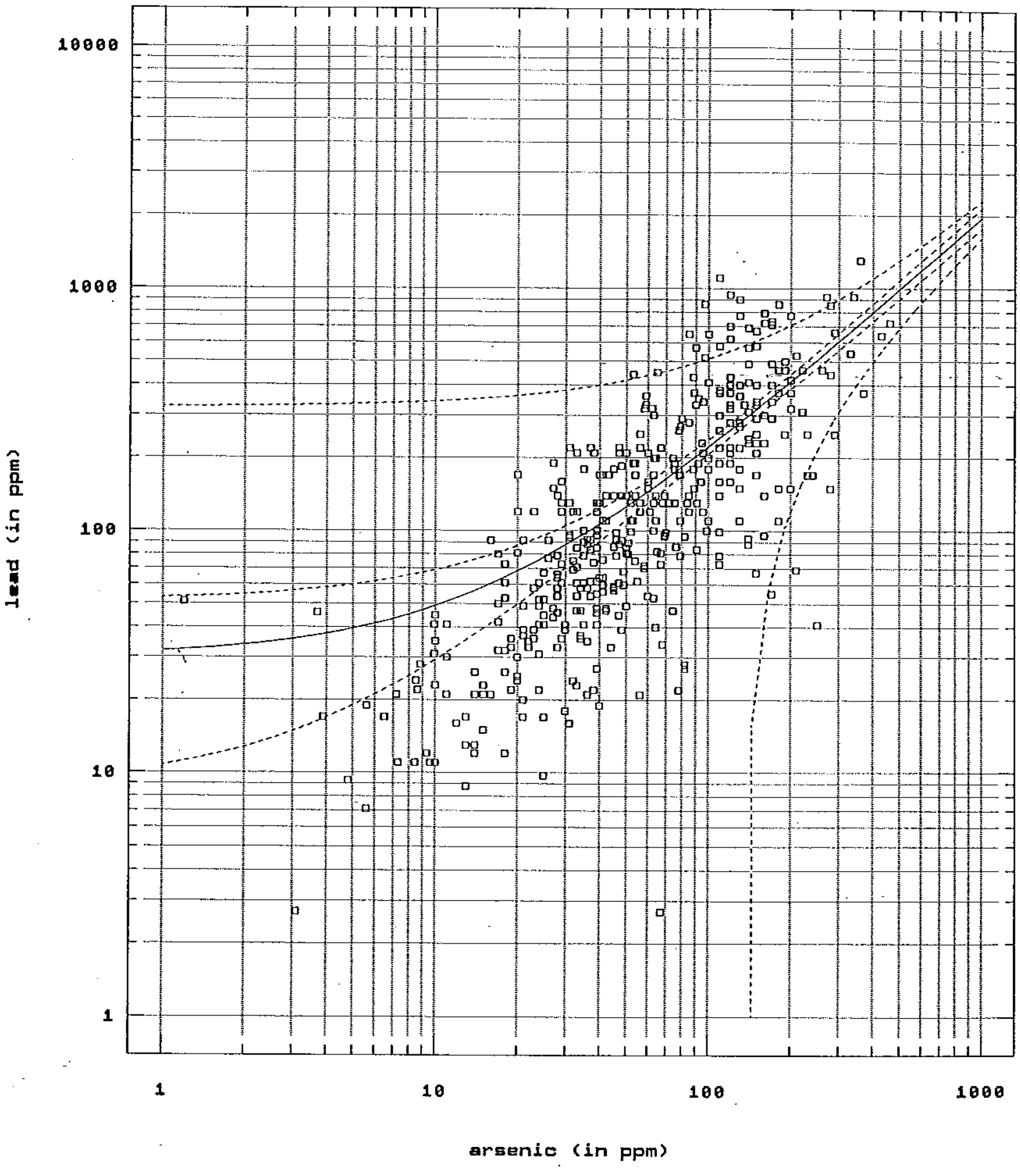
(dry weight values)

Scatterplot: Individual Data Points
Lead vs Arsenic Concs. at 2 to 6 inches



(dry weight values)

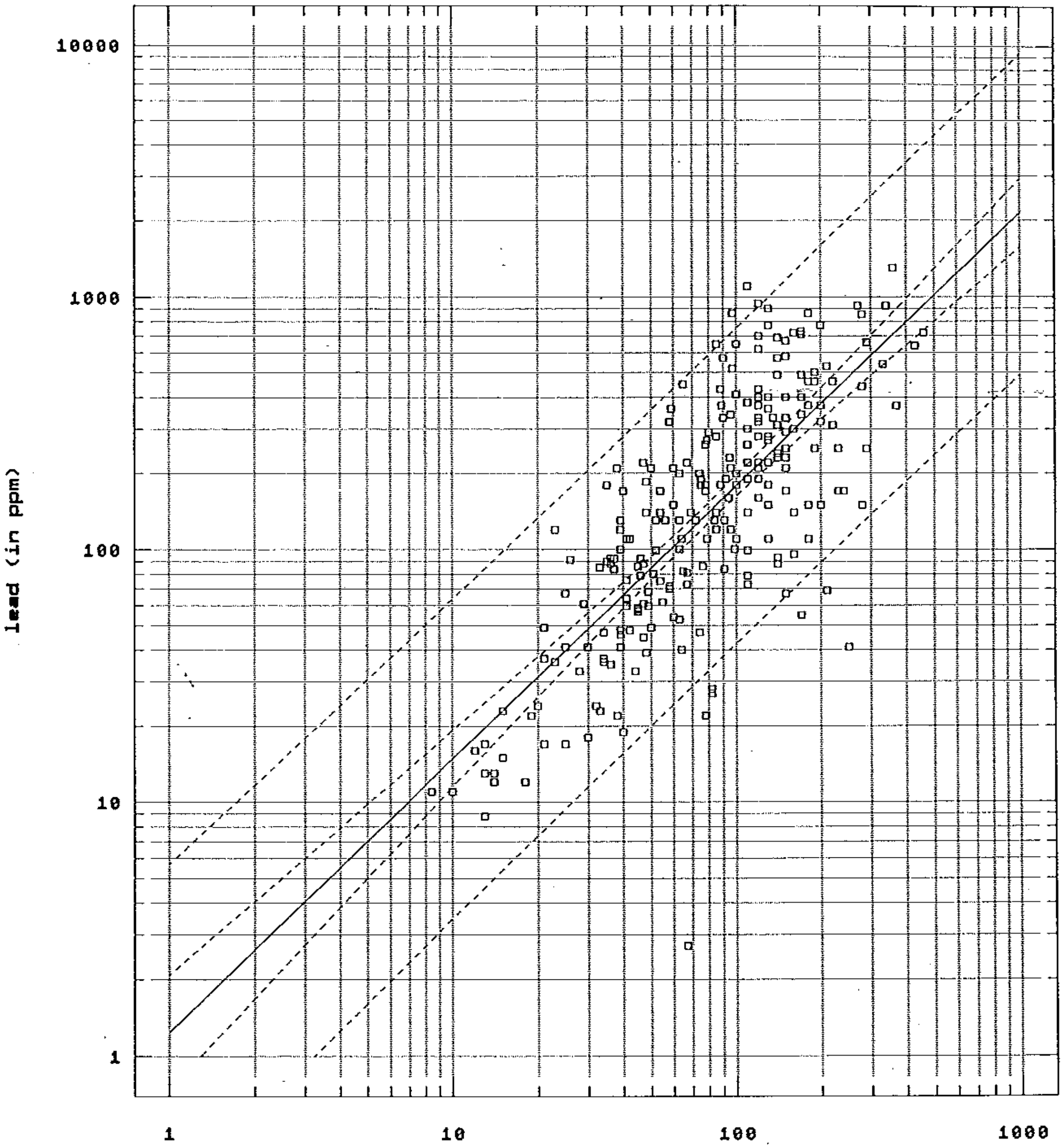
Regression: Individual Data Points
Lead vs Arsenic Concentrations



(linear model)

```
Regression Analysis - Linear model: Y = a+bX
-------------------------------------------------------------------------------
Dependent variable: FVPB                              Independent variable: FVAS
-------------------------------------------------------------------------------
                               Standard            T            Prob.
Parameter       Estimate         Error           Value          Level
-------------------------------------------------------------------------------
Intercept        29.9559        10.8367         2.7643         .00596
Slope            1.91998       0.103329        18.5811         .00000
-------------------------------------------------------------------------------
                           Analysis of Variance
-------------------------------------------------------------------------------
Source             Sum of Squares     Df  Mean Square    F-Ratio  Prob. Level
Model                   7580981.6      1    7580981.6        345       .00000
Residual                9112313.9    415      21957.4
   Lack-of-fit          2932412.9    120      24436.8          1       .14997
   Pure error           6179901.0    295      20948.8
-------------------------------------------------------------------------------
Total (Corr.)            16693296    416
Correlation Coefficient = 0.673894          R-squared =  45.41 percent
Stnd. Error of Est. = 148.18
```

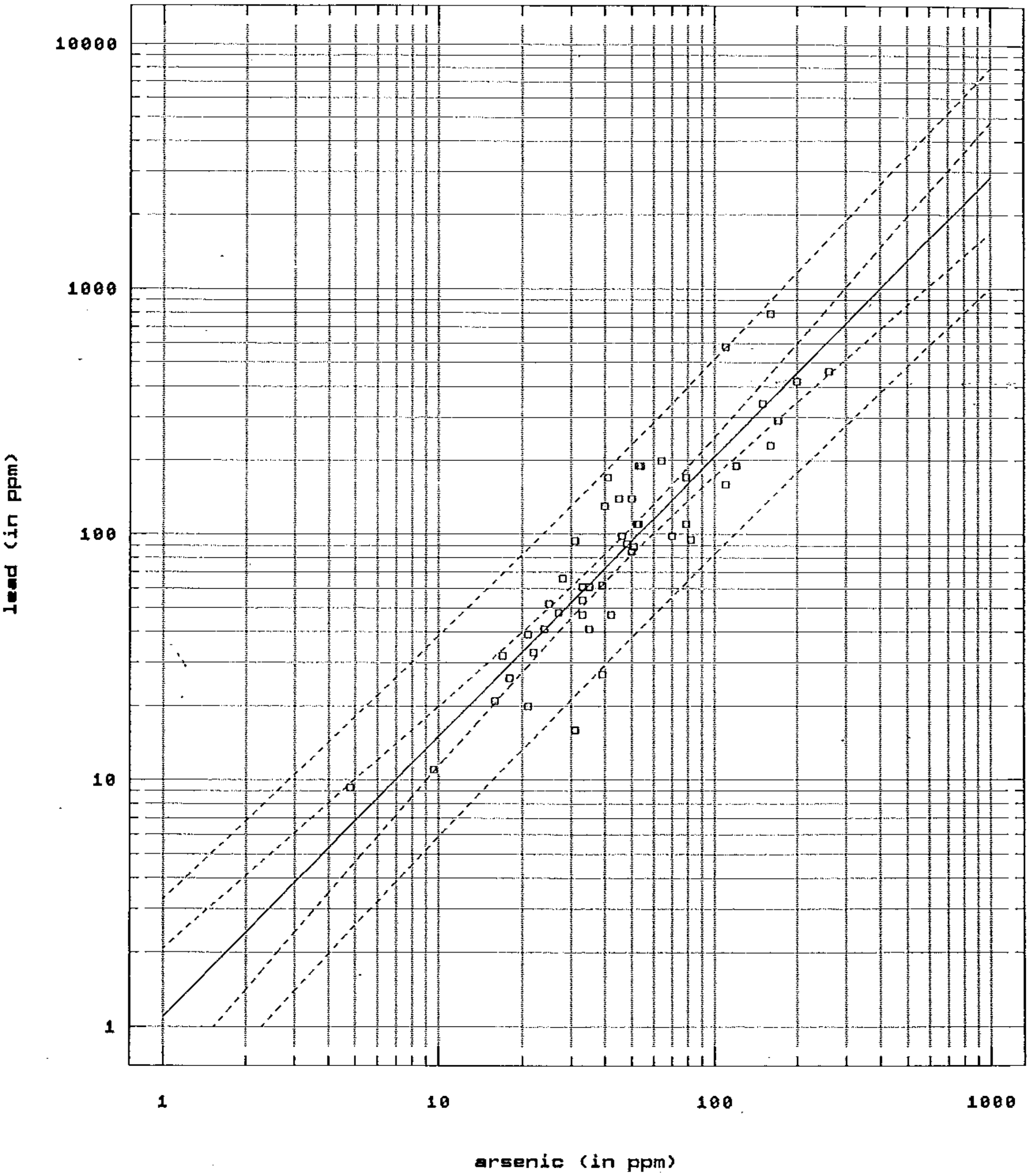
Regression: Individual Data Points
Zone 1 Lead vs Arsenic Concentrations



(LOG-LOG linear = multiplicative model)

```
Regression Analysis - Multiplicative model: Y = aX^b
-----------------------------------------------------------------------------------
Dependent variable: FVPB SELECT FVZONE E               Independent variable: FVAS
-----------------------------------------------------------------------------------
                               Standard              T              Prob.
Parameter       Estimate        Error              Value            Level
-----------------------------------------------------------------------------------
Intercept*      0.212998        0.263892          0.807143          .42036
Slope            1.07913         0.05958           18.1122          .00000
* NOTE: The Intercept is equal to Log a.
-----------------------------------------------------------------------------------
                              Analysis of Variance
-----------------------------------------------------------------------------------
Source                 Sum of Squares     Df  Mean Square    F-Ratio  Prob. Level
Model                       173.74844      1    173.74844   328.0534       .00000
Residual                    130.29013    246       .52963
   Lack-of-fit              48.046632     91      .527985     .99507       .50407
   Pure error                82.24350    155       .53060
-----------------------------------------------------------------------------------
Total (Corr.)               304.03857    247
Correlation Coefficient = 0.755955              R-squared =  57.15 percent
Stnd. Error of Est. = 0.72776
```

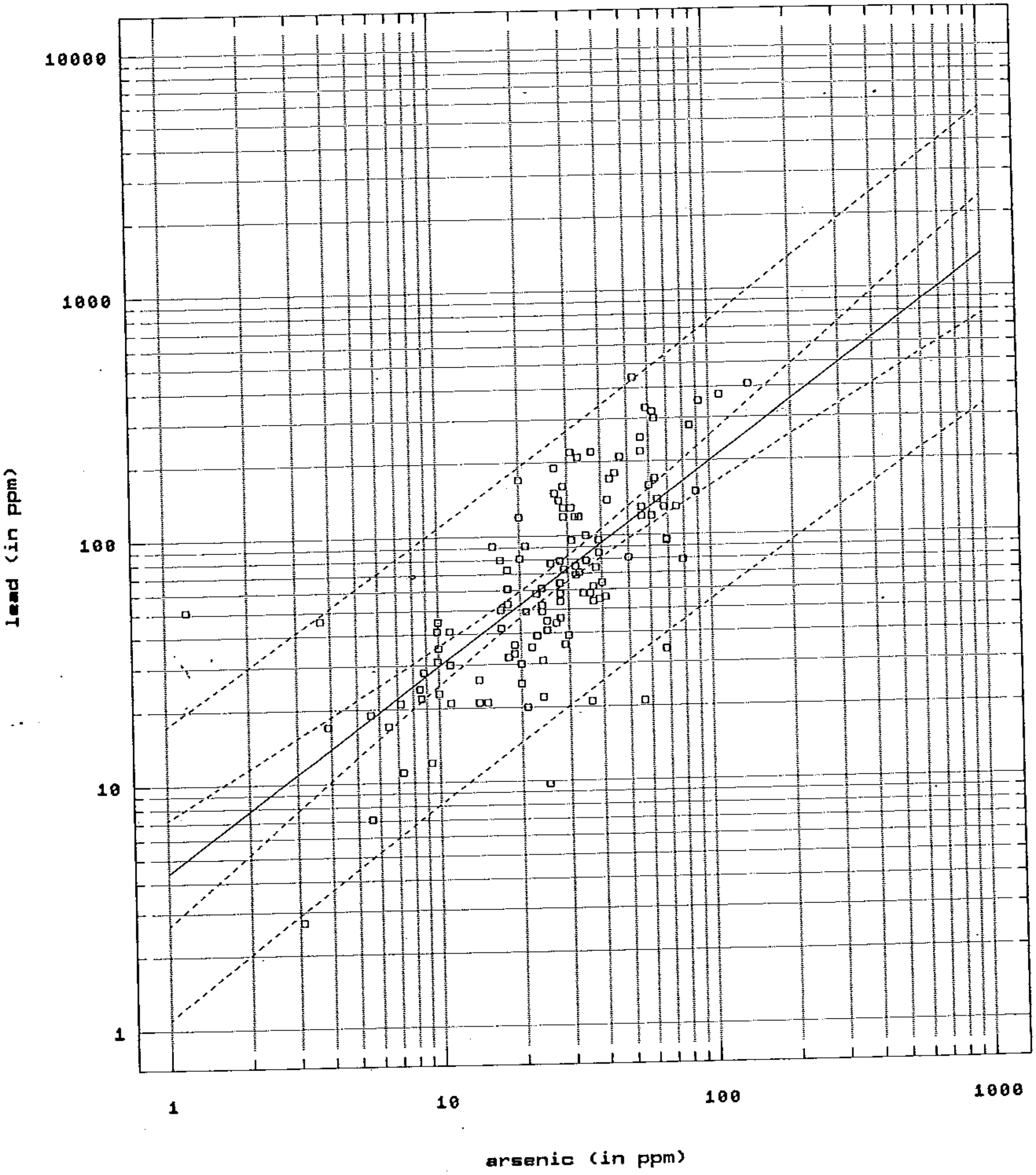
Regression: Individual Data Points
Zone 2 Lead vs Arsenic Concentrations



(LOG-LOG linear = multiplicative model)

```
Regression Analysis - Multiplicative model: Y = aX^b
--------------------------------------------------------------------------------
Dependent variable: FVPB SELECT FVZONE E            Independent variable: FVAS
--------------------------------------------------------------------------------
                                 Standard              T                Prob.
Parameter          Estimate        Error              Value             Level
--------------------------------------------------------------------------------
Intercept*        0.0927067       0.318722           0.29087           .77246
Slope                1.1375      0.0816598           13.9297           .00000
* NOTE: The Intercept is equal to Log a.
--------------------------------------------------------------------------------
                              Analysis of Variance
--------------------------------------------------------------------------------
Source                   Sum of Squares      Df  Mean Square    F-Ratio  Prob. Level
Model                          38.37633       1     38.37633   194.0366        .00000
Residual                       9.097824      46      .197779
   Lack-of-fit                 4.889430      35      .139698     .36515        .98850
   Pure error                  4.208394      11      .382581
--------------------------------------------------------------------------------
Total (Corr.)                 47.474156      47
Correlation Coefficient = 0.89909                R-squared =  80.84 percent
Stnd. Error of Est. = 0.444723
```

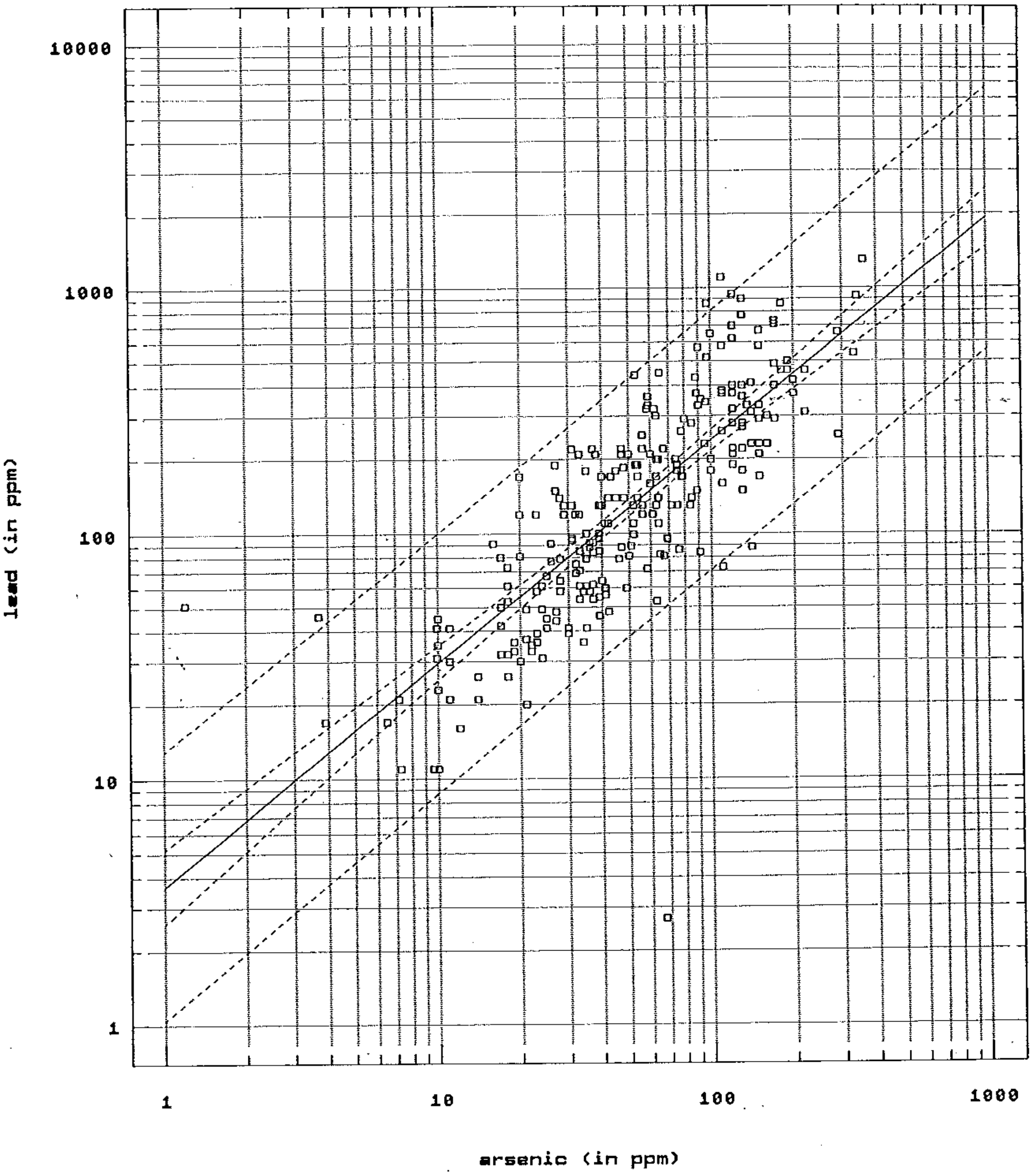
Regression: Individual Data Points
Zone 3 Lead vs Arsenic Concentrations



(LOG-LOG linear = multiplicative model)

```
Regression Analysis - Multiplicative model: Y = aX^b
--------------------------------------------------------------------------------
Dependent variable: FVPB SELECT FVZONE E            Independent variable: FVAS
--------------------------------------------------------------------------------
                                 Standard              T              Prob.
Parameter        Estimate          Error             Value            Level
--------------------------------------------------------------------------------
Intercept*        1.48254        0.251273            5.9001           .00000
Slope            0.827869       0.0753354           10.9891           .00000
* NOTE: The Intercept is equal to Log a.
--------------------------------------------------------------------------------
                              Analysis of Variance
--------------------------------------------------------------------------------
Source                 Sum of Squares     Df  Mean Square    F-Ratio  Prob. Level
Model                        50.78450      1     50.78450   120.7605       .00000
Residual                     50.04416    119       .42054
   Lack-of-fit              30.687768     63      .487107    1.40925       .09635
   Pure error               19.356389     56      .345650
--------------------------------------------------------------------------------
Total (Corr.)               100.82865    120
Correlation Coefficient = 0.709698              R-squared =  50.37 percent
Stnd. Error of Est. = 0.64849
```

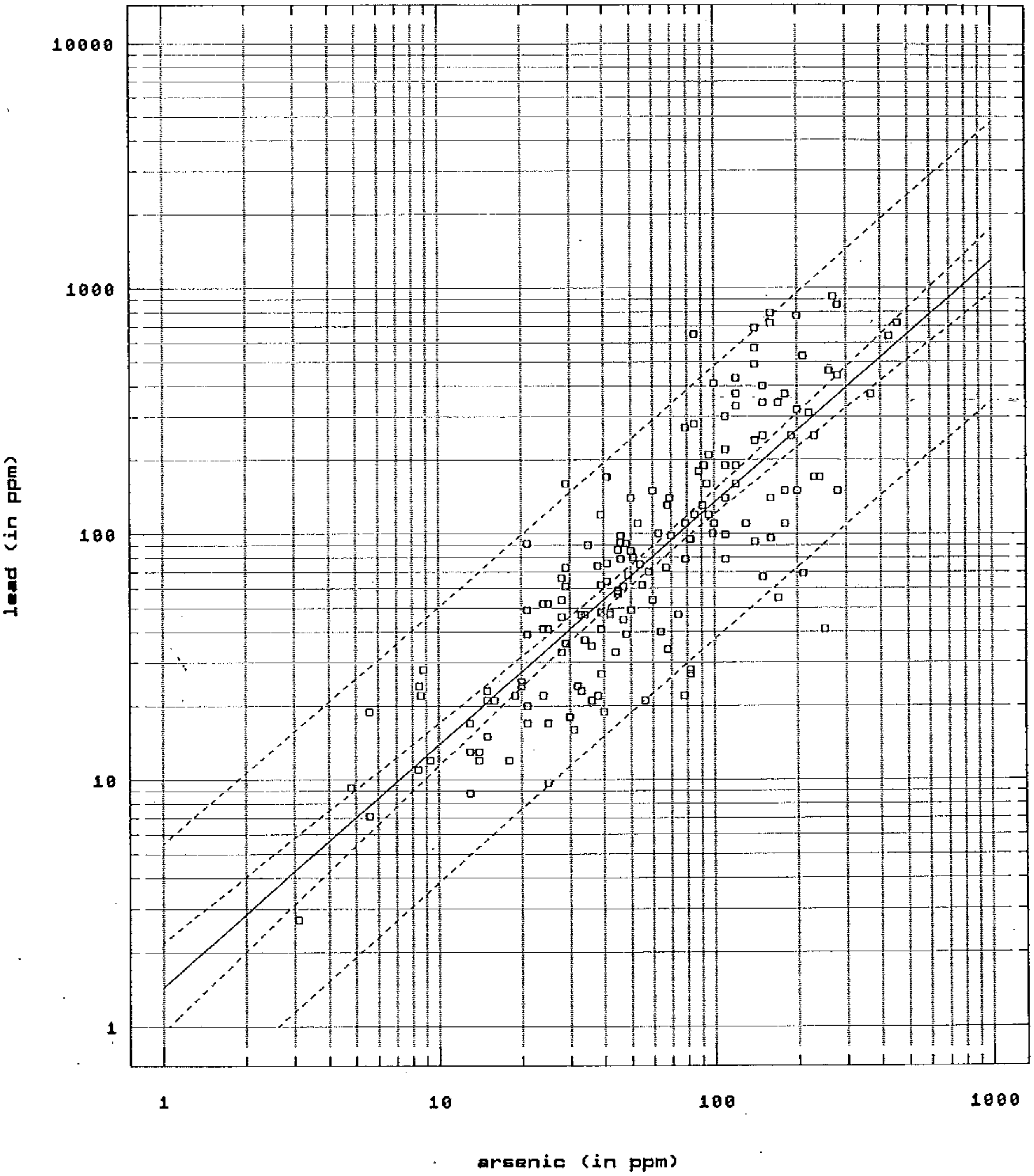
Regression: Individual Data Points
Lead vs Arsenic Concs. at 0 to 2 inches



(LOG-LOG linear = multiplicative model)

```
Regression Analysis - Multiplicative model: Y = aX^b
-------------------------------------------------------------------------------
Dependent variable: FVPB SELECT FVDP EQ              Independent variable: FVAS
-------------------------------------------------------------------------------
                              Standard              T               Prob.
Parameter        Estimate       Error             Value             Level
-------------------------------------------------------------------------------
Intercept*        1.29976     0.177721            7.3135            .00000
Slope            0.906244    0.0442731           20.4694            .00000
* NOTE: The Intercept is equal to Log a.
-------------------------------------------------------------------------------
                             Analysis of Variance
-------------------------------------------------------------------------------
Source                 Sum of Squares     Df  Mean Square    F-Ratio  Prob. Level
Model                       157.27088      1    157.27088   418.9964       .00000
Residual                     91.21038    243       .37535
   Lack-of-fit              42.223674     93      .454018    1.39023       .03632
   Pure error                48.98671    150       .32658
-------------------------------------------------------------------------------
Total (Corr.)               248.48126    244
Correlation Coefficient = 0.795568           R-squared =  63.29 percent
Stnd. Error of Est. = 0.612659
```

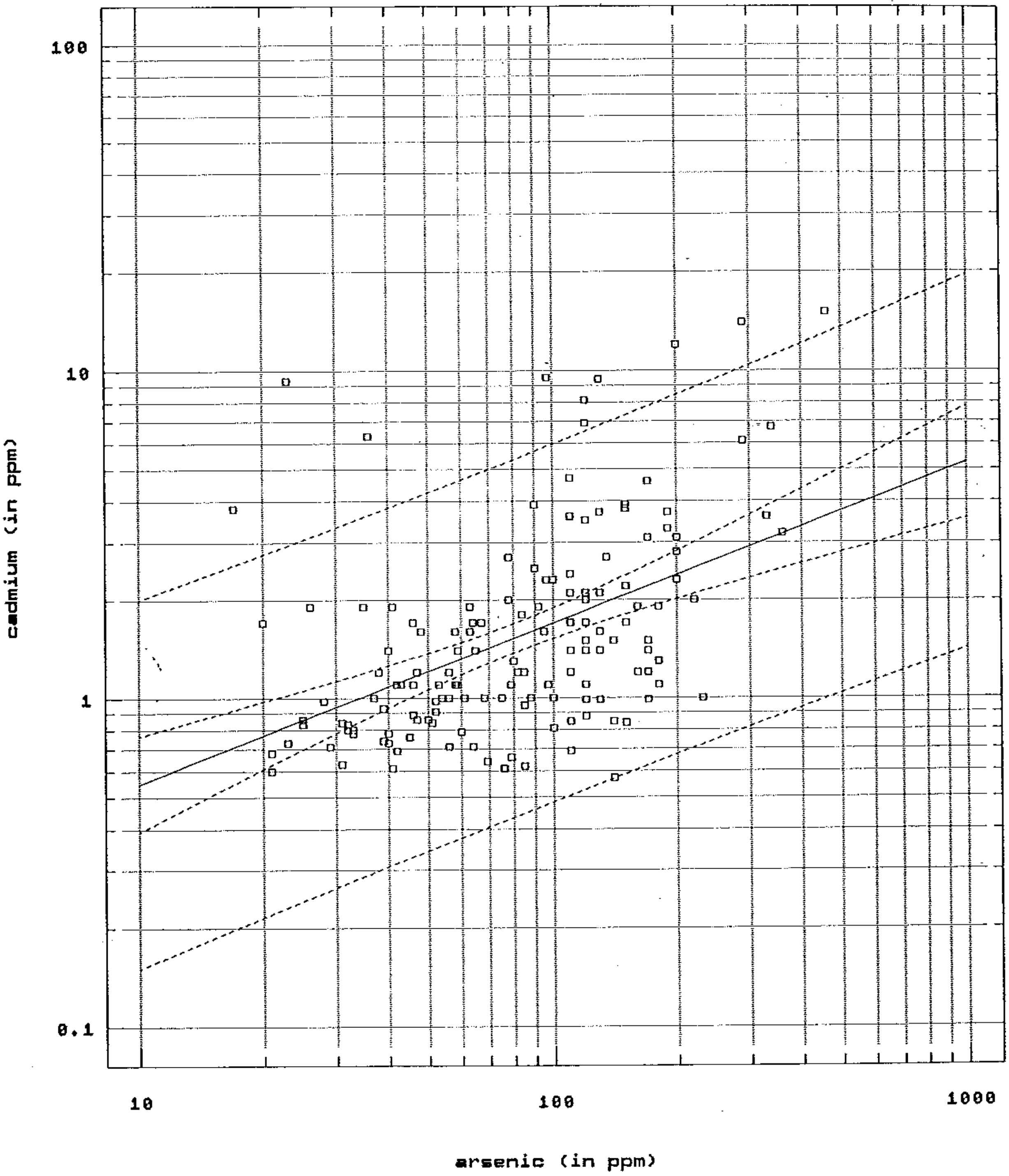
Regression: Individual Data Points
Lead vs Arsenic Concs. at 2 to 6 inches



(LOG-LOG linear = multiplicative model)

```
Regression Analysis - Multiplicative model: Y = aX^b
-------------------------------------------------------------------------------
Dependent variable: FVPB SELECT FVDP EQ              Independent variable: FVA
-------------------------------------------------------------------------------
                                Standard             T              Prob.
Parameter       Estimate         Error             Value            Level
-------------------------------------------------------------------------------
Intercept*      0.366456        0.211137          1.73563          .08444
Slope           0.983389        0.0506005         19.4344          .00000
* NOTE: The Intercept is equal to Log a.
-------------------------------------------------------------------------------
                           Analysis of Variance
-------------------------------------------------------------------------------
Source                 Sum of Squares     Df  Mean Square    F-Ratio  Prob. Level
Model                       157.04181      1    157.04181   377.6954       .00000
Residual                     70.68423    170       .41579
   Lack-of-fit              35.858503     83      .432030    1.07928       .36230
   Pure error               34.825728     87      .400296
-------------------------------------------------------------------------------
Total (Corr.)               227.72604    171
Correlation Coefficient = 0.830427           R-squared =  68.96 percent
Stnd. Error of Est. = 0.644817
```

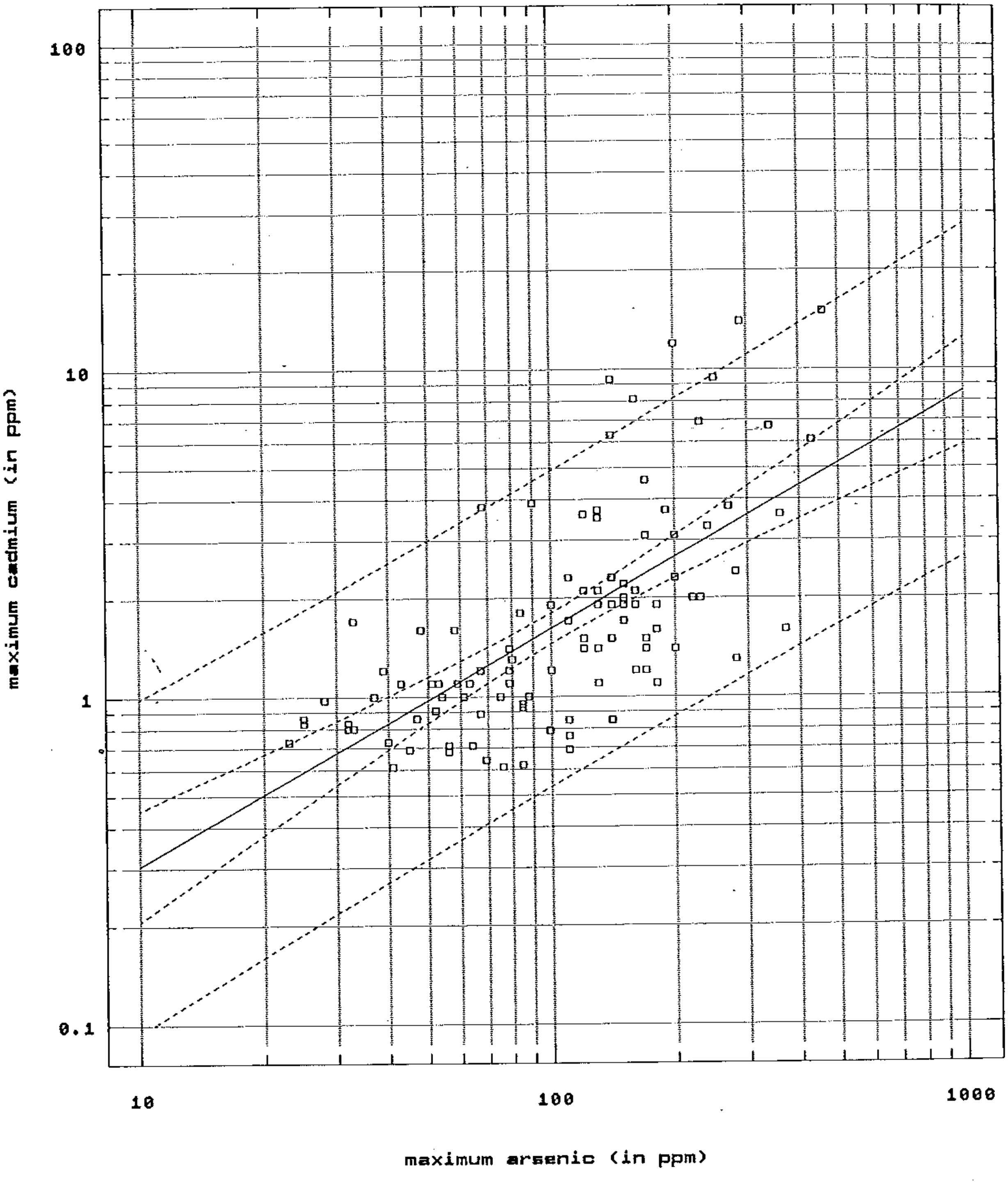
Regression: Individual Data Points
Cadmium vs Arsenic Concentrations



(not detected cadmium results omitted)

```
Regression Analysis - Multiplicative model: Y = aX^b
--------------------------------------------------------------------------------
Dependent variable: FVCD SELECT FVCDND E              Independent variable: FVA
--------------------------------------------------------------------------------
                                 Standard               T              Prob.
Parameter       Estimate           Error              Value            Level
--------------------------------------------------------------------------------
Intercept*      -1.73015         0.340826          -5.07634           .00000
Slope           0.490553         0.0763931          6.42144           .00000
* NOTE: The Intercept is equal to Log a.
--------------------------------------------------------------------------------
                           Analysis of Variance
--------------------------------------------------------------------------------
Source                 Sum of Squares     Df  Mean Square    F-Ratio  Prob. Level
Model                       16.494733      1    16.494733   41.23485       .00000
Residual                     58.00278    145       .40002
   Lack-of-fit              30.608082     71      .431100    1.16451       .25860
   Pure error               27.394702     74      .370199
--------------------------------------------------------------------------------
Total (Corr.)                74.49752    146
Correlation Coefficient = 0.470546               R-squared =  22.14 percent
Stnd. Error of Est. = 0.632471
```

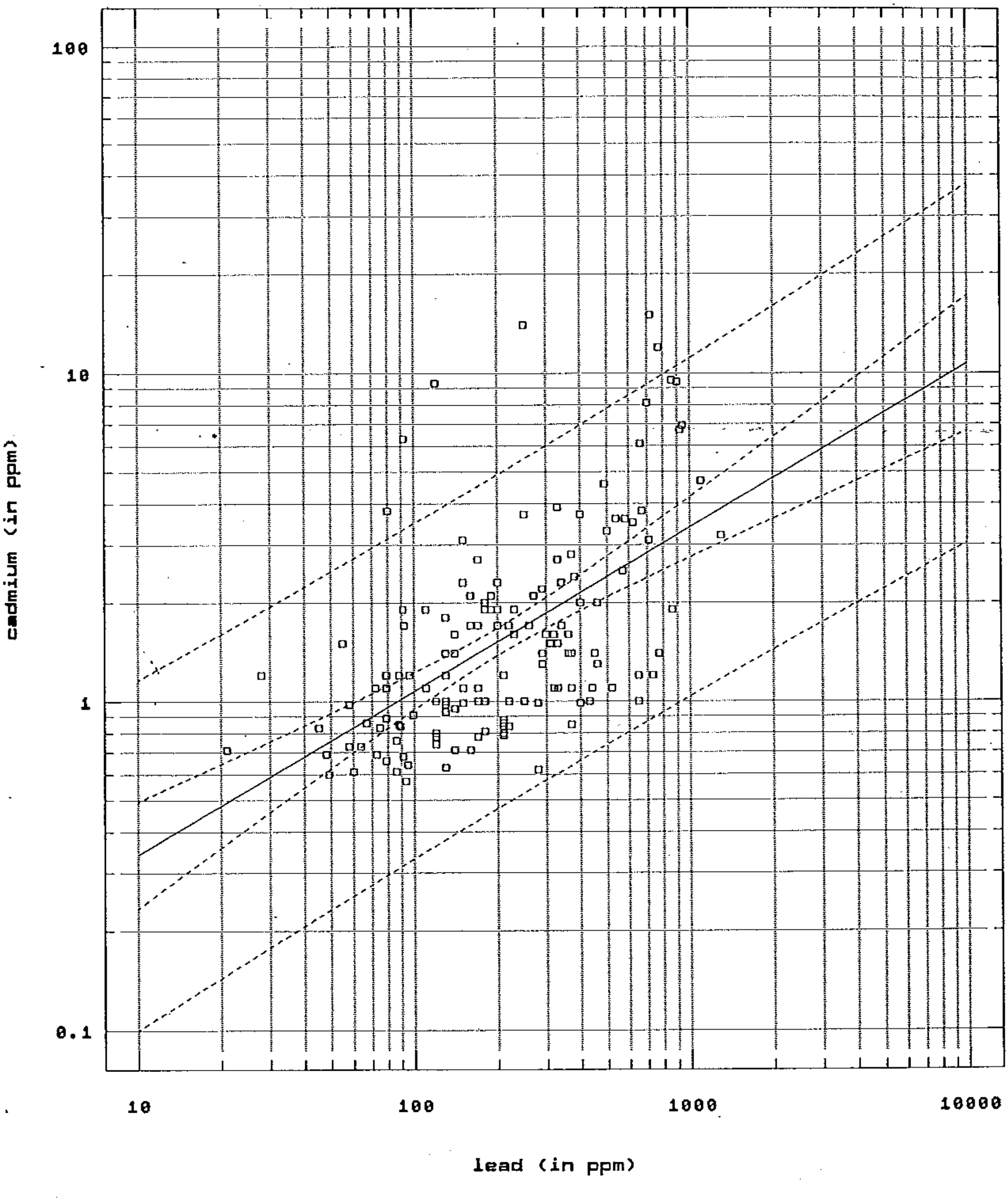
Regression: Maximum Location Values
Cadmium vs Arsenic Concentrations



(not detected cadmium results omitted)

```
Regression Analysis - Multiplicative model: Y = aX^b
--------------------------------------------------------------------------------
Dependent variable: FVMCD SELECT FVMCDND            Independent variable: FVMAS
--------------------------------------------------------------------------------
                               Standard              T              Prob.
Parameter       Estimate         Error             Value            Level
--------------------------------------------------------------------------------
Intercept*      -2.85452          0.3783          -7.54564          .00000
Slope           0.724066       0.0805254           8.99177          .00000
* NOTE: The Intercept is equal to Log a.
--------------------------------------------------------------------------------
                           Analysis of Variance
--------------------------------------------------------------------------------
Source                 Sum of Squares     Df  Mean Square    F-Ratio  Prob. Level
Model                       25.129842      1    25.129842   80.85193       .00000
Residual                     31.70294    102       .31081
   Lack-of-fit              16.854205     56      .300968     .93237       .60145
   Pure error               14.848737     46      .322799
--------------------------------------------------------------------------------
Total (Corr.)                56.83278    103
Correlation Coefficient = 0.66496            R-squared =  44.22 percent
Stnd. Error of Est. = 0.557506
```

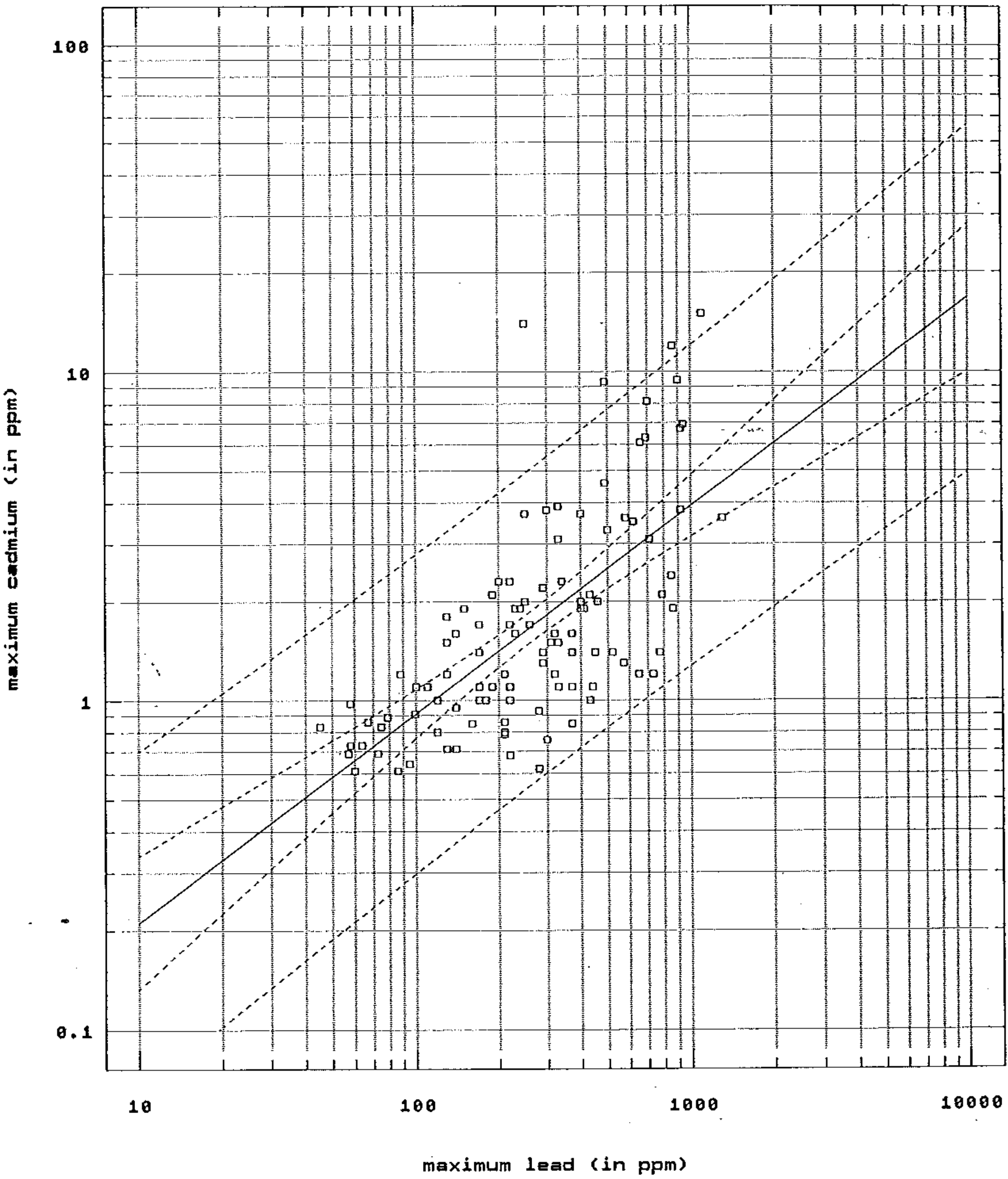
Regression: Individual Data Points
Cadmium vs Lead Concentrations



(not detected cadmium results omitted)

```
Regression Analysis - Multiplicative model: Y = aX^b
-------------------------------------------------------------------------------
Dependent variable: FVCD SELECT FVCDND E          Independent variable: FVP
-------------------------------------------------------------------------------
                               Standard              T              Prob.
Parameter       Estimate         Error             Value            Level
-------------------------------------------------------------------------------
Intercept*      -2.22804       0.324867          -6.85832          .00000
Slope           0.499178       0.0602599          8.28375          .00000
* NOTE: The Intercept is equal to Log a.
-------------------------------------------------------------------------------
                           Analysis of Variance
-------------------------------------------------------------------------------
Source                 Sum of Squares     Df  Mean Square    F-Ratio  Prob. Level
Model                       23.930558      1    23.930558   68.62052       .00000
Residual                     50.56696    145       .34874
   Lack-of-fit              28.452952     74      .384499    1.23449       .18661
   Pure error               22.114007     71      .311465
-------------------------------------------------------------------------------
Total (Corr.)                74.49752    146
Correlation Coefficient = 0.566768           R-squared =  32.12 percent
Stnd. Error of Est. = 0.59054
```

Regression: Maximum Location Values
Cadmium vs Lead Concentrations



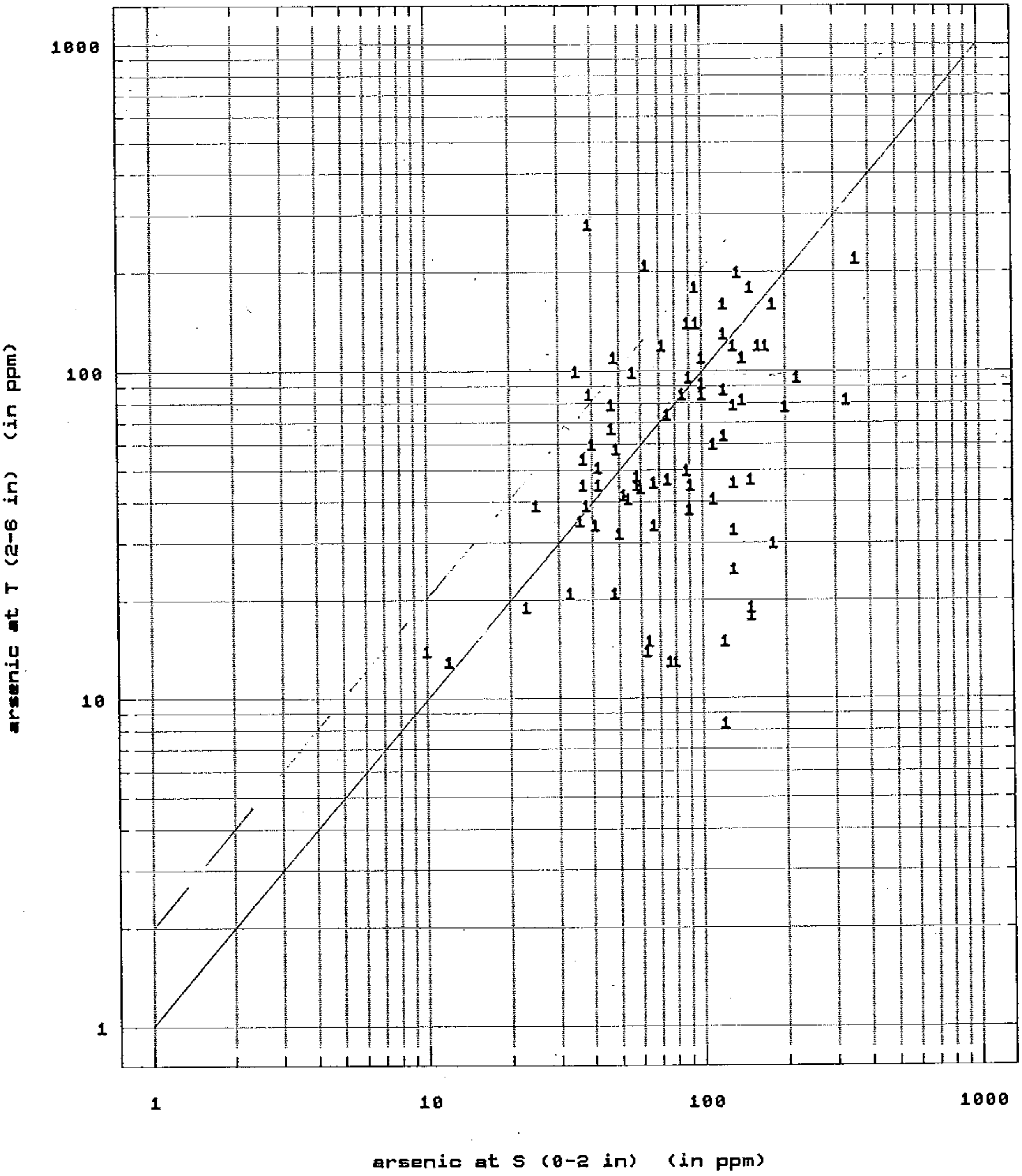
(not detected cadmium results omitted)

```
Regression Analysis - Multiplicative model: Y = aX^b
------------------------------------------------------------------------------
Dependent variable: FVMCD SELECT FVMCDND          Independent variable: FVMPI
------------------------------------------------------------------------------
                               Standard            T              Prob.
Parameter       Estimate         Error            Value            Level
------------------------------------------------------------------------------
Intercept*      -3.01043       0.392542         -7.66906          .00000
Slope           0.633028       0.0698749         9.05945          .00000
* NOTE: The Intercept is equal to Log a.
------------------------------------------------------------------------------
                          Analysis of Variance
------------------------------------------------------------------------------
Source                 Sum of Squares     Df  Mean Square    F-Ratio  Prob. Level
Model                       25.340268      1    25.340268   82.07370      .00000
Residual                     31.49252    102       .30875
   Lack-of-fit              21.600618     63      .342867    1.35179      .15762
   Pure error                9.891899     39      .253638
------------------------------------------------------------------------------
Total (Corr.)                56.83278    103
Correlation Coefficient = 0.667738           R-squared =  44.59 percent
Stnd. Error of Est. = 0.555653
```

DEPTH PROFILES

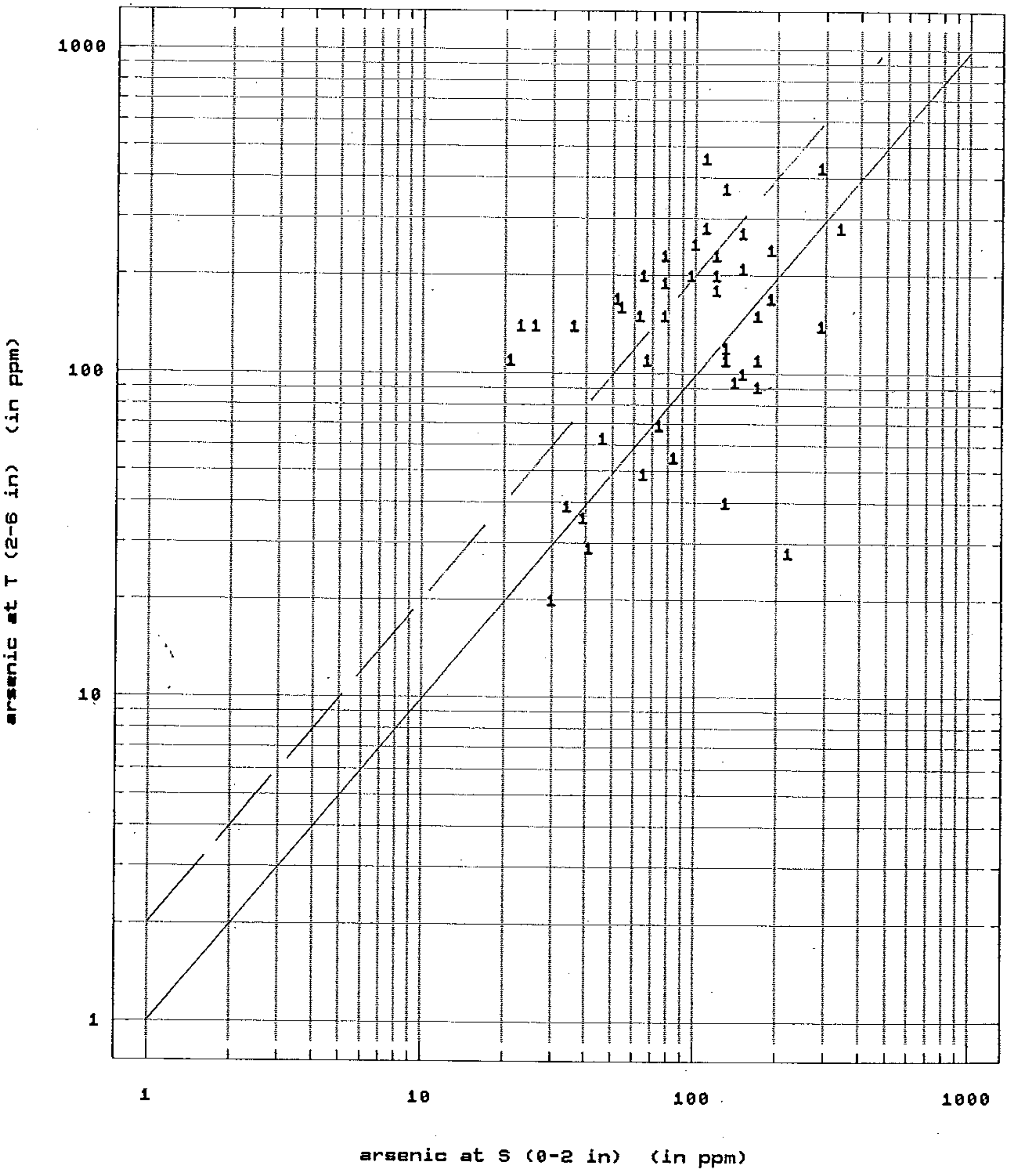
Arsenic Depth Profiles: Zone 1A

T (2-6 in) vs S (0-2 in)



(South Vashon Island locations)

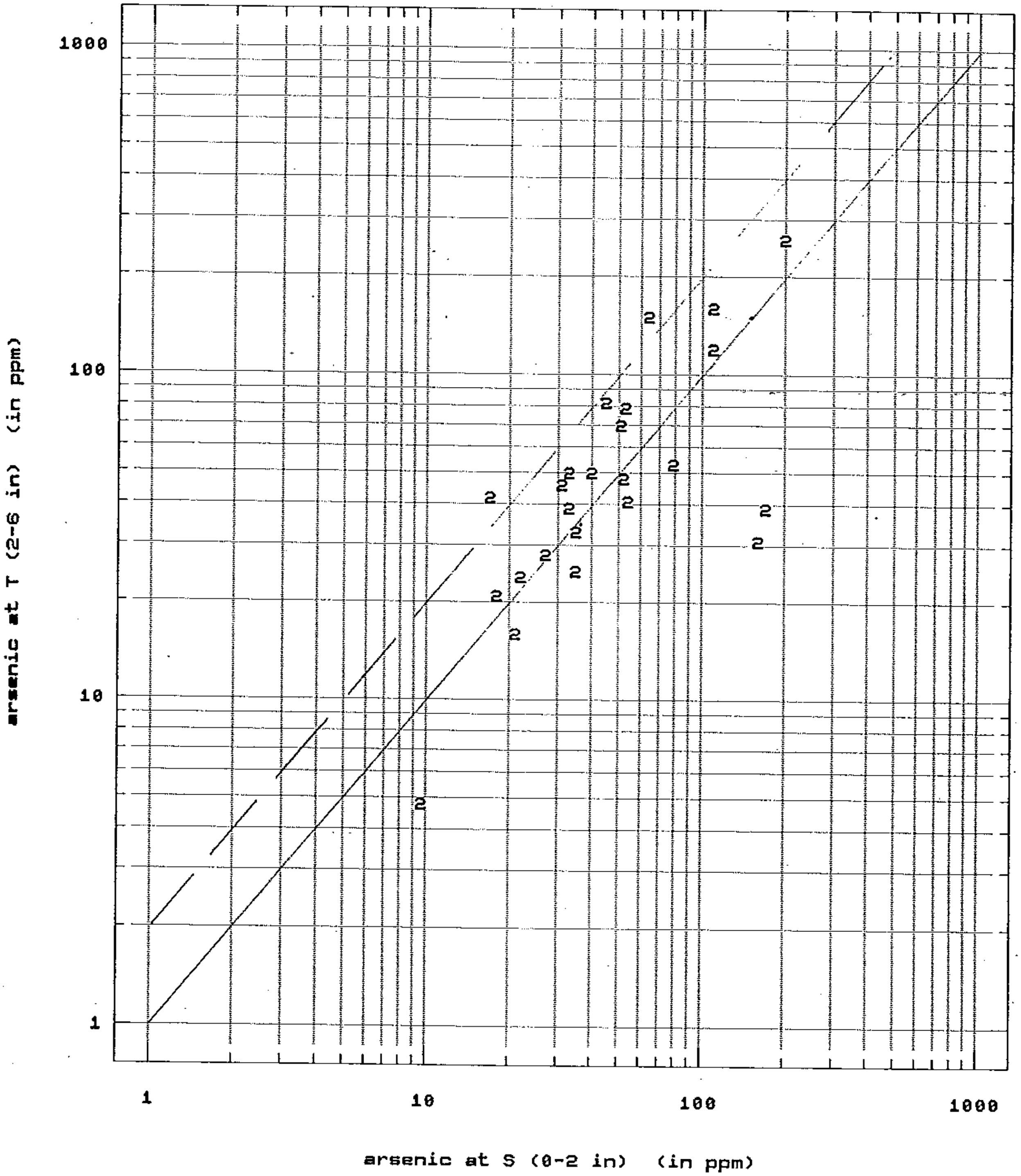
Arsenic Depth Profiles: Zone 1B
T (2-6 in) vs S (0-2 in)



(Maury Island locations)

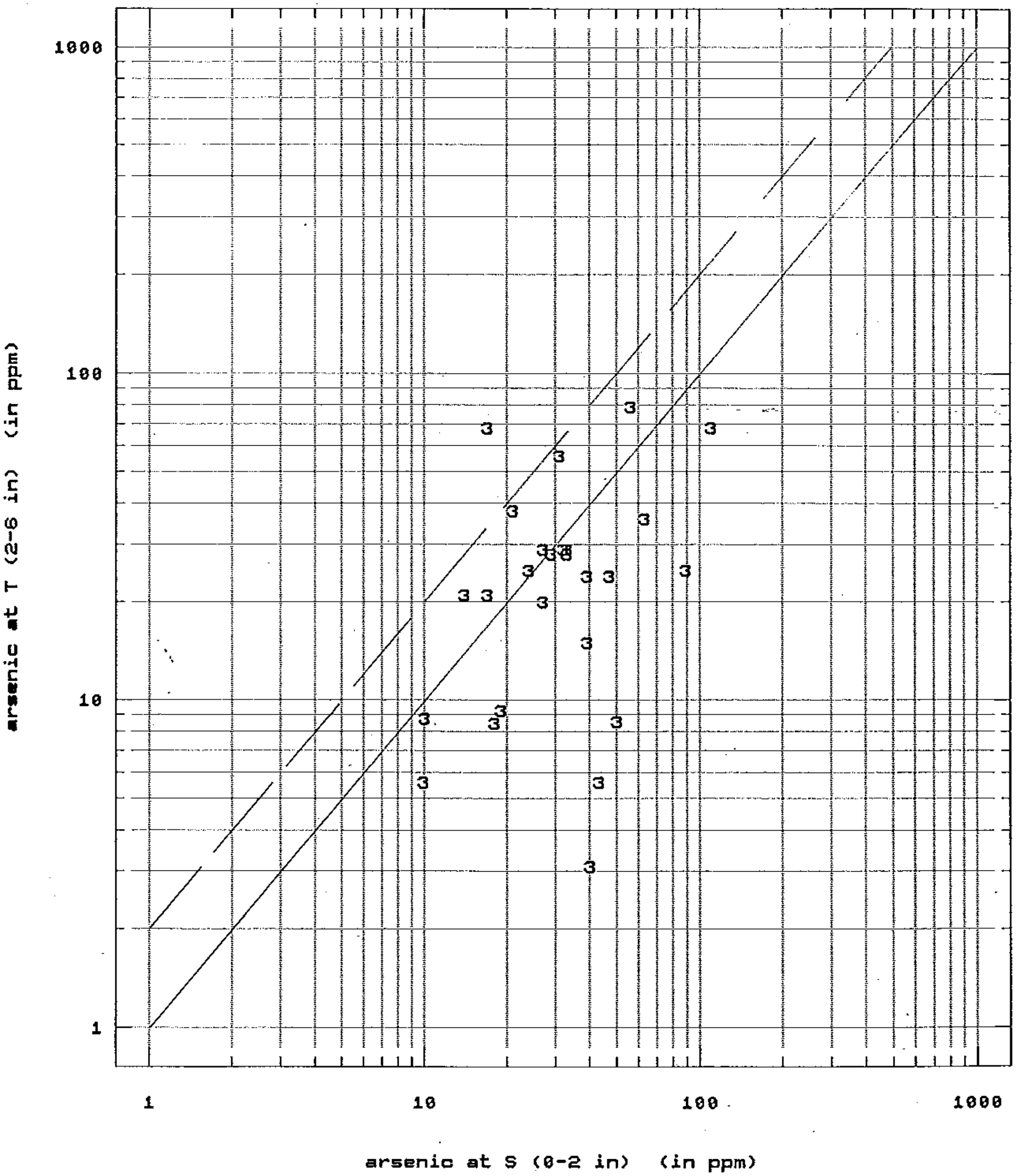
Arsenic Depth Profiles: Zone 2

T (2-6 in) vs S (0-2 in)



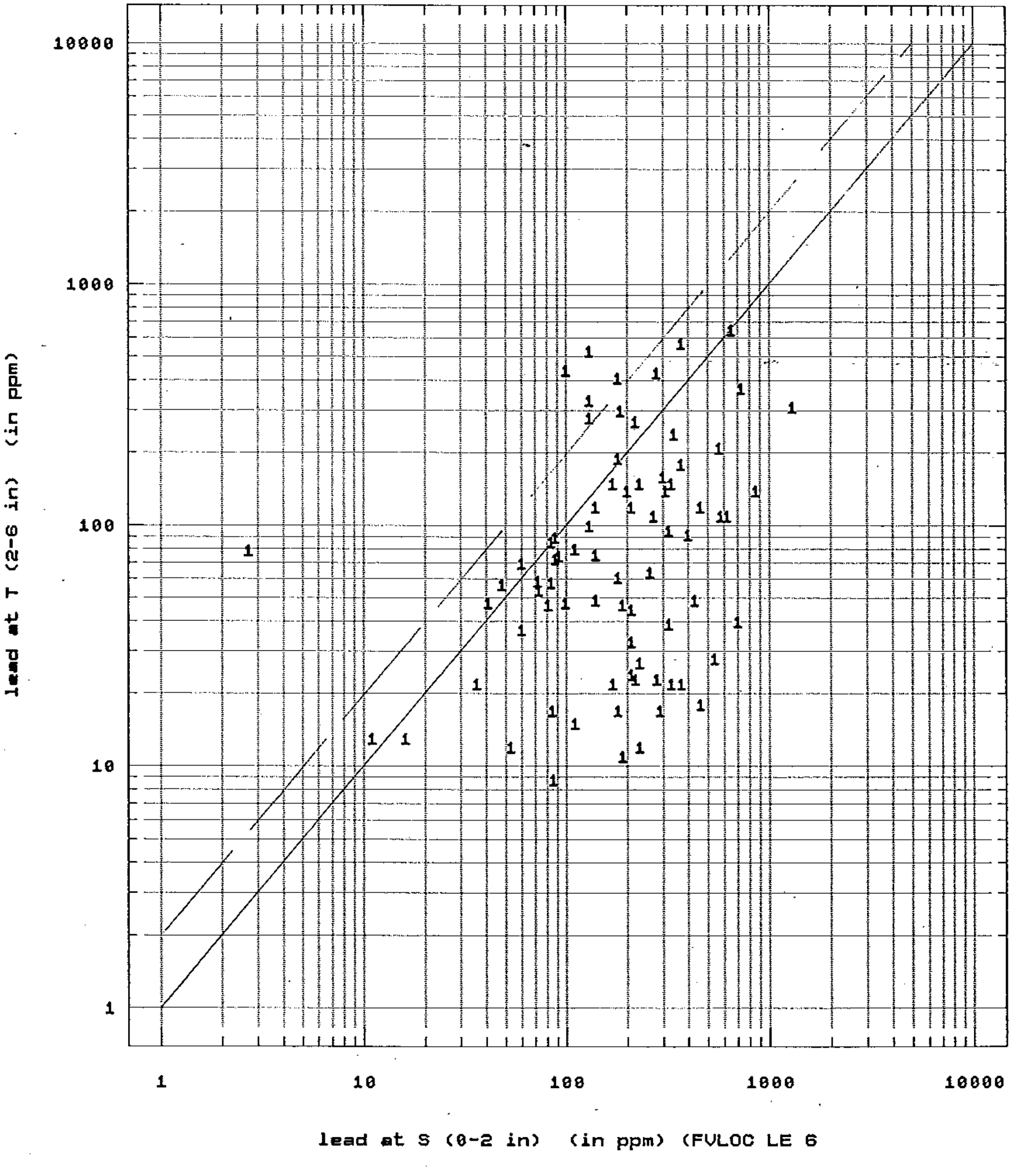
(Mainland locations)

Arsenic Depth Profiles: Zone 3
T (2-6 in) vs S (0-2 in)



(North Vashon Island locations)

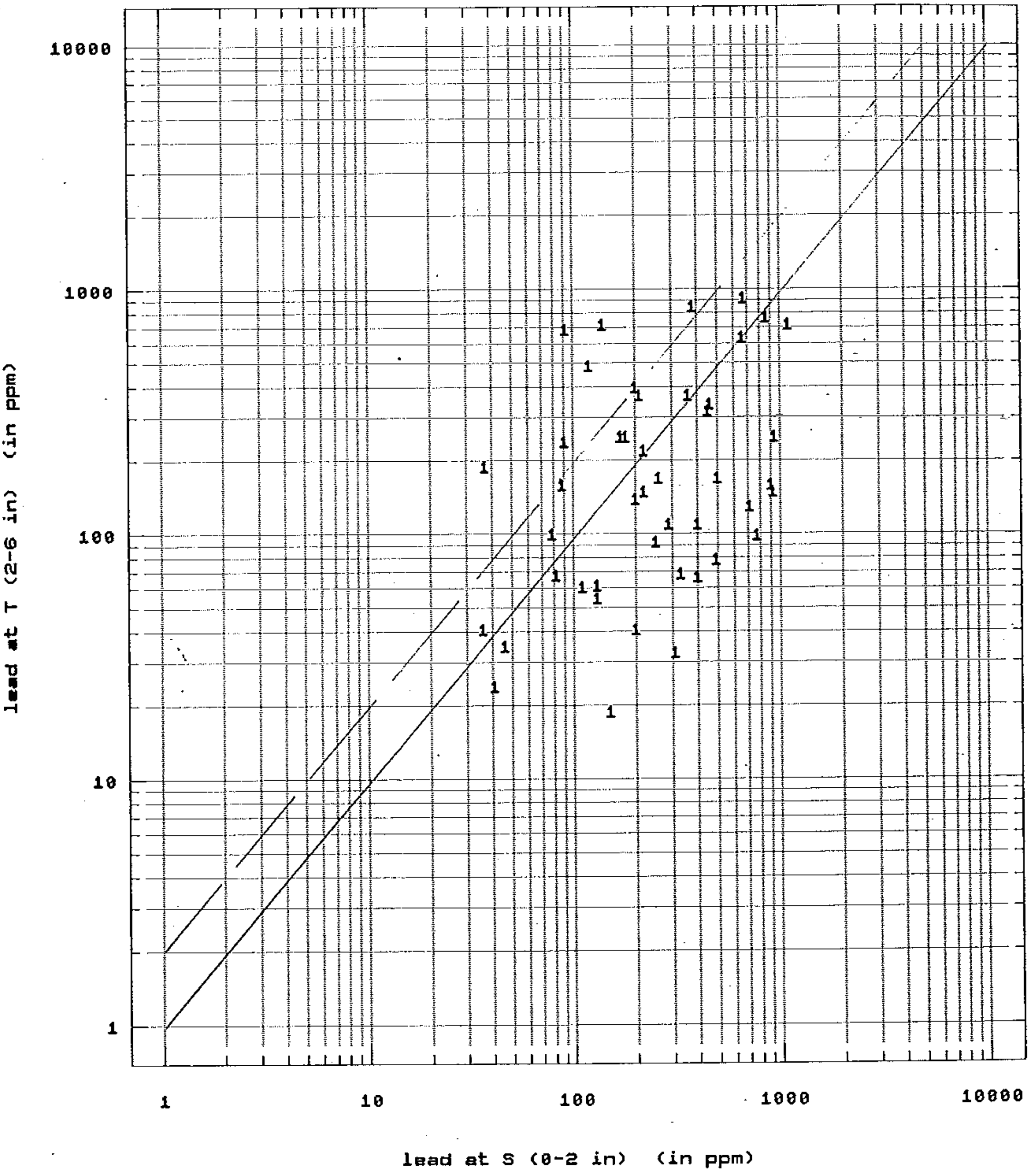
Lead Depth Profiles: Zone 1A
T (2-6 in) vs S (0-2 in)



(South Vashon Island locations)

Lead Depth Profiles: Zone 1B

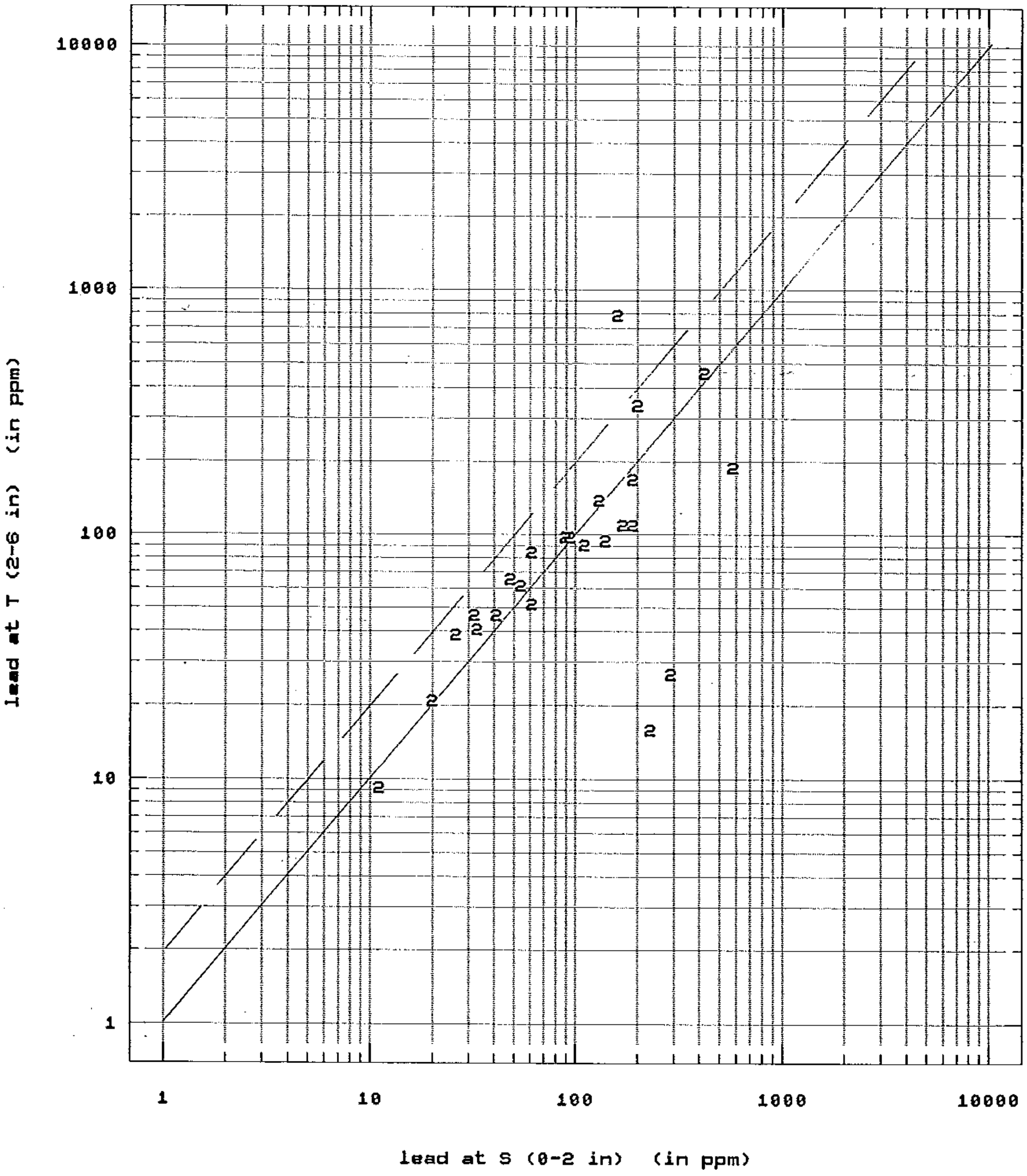
T (2-6 in) vs S (0-2 in)



(Maury Island Locations)

Lead Depth Profiles: Zone 2

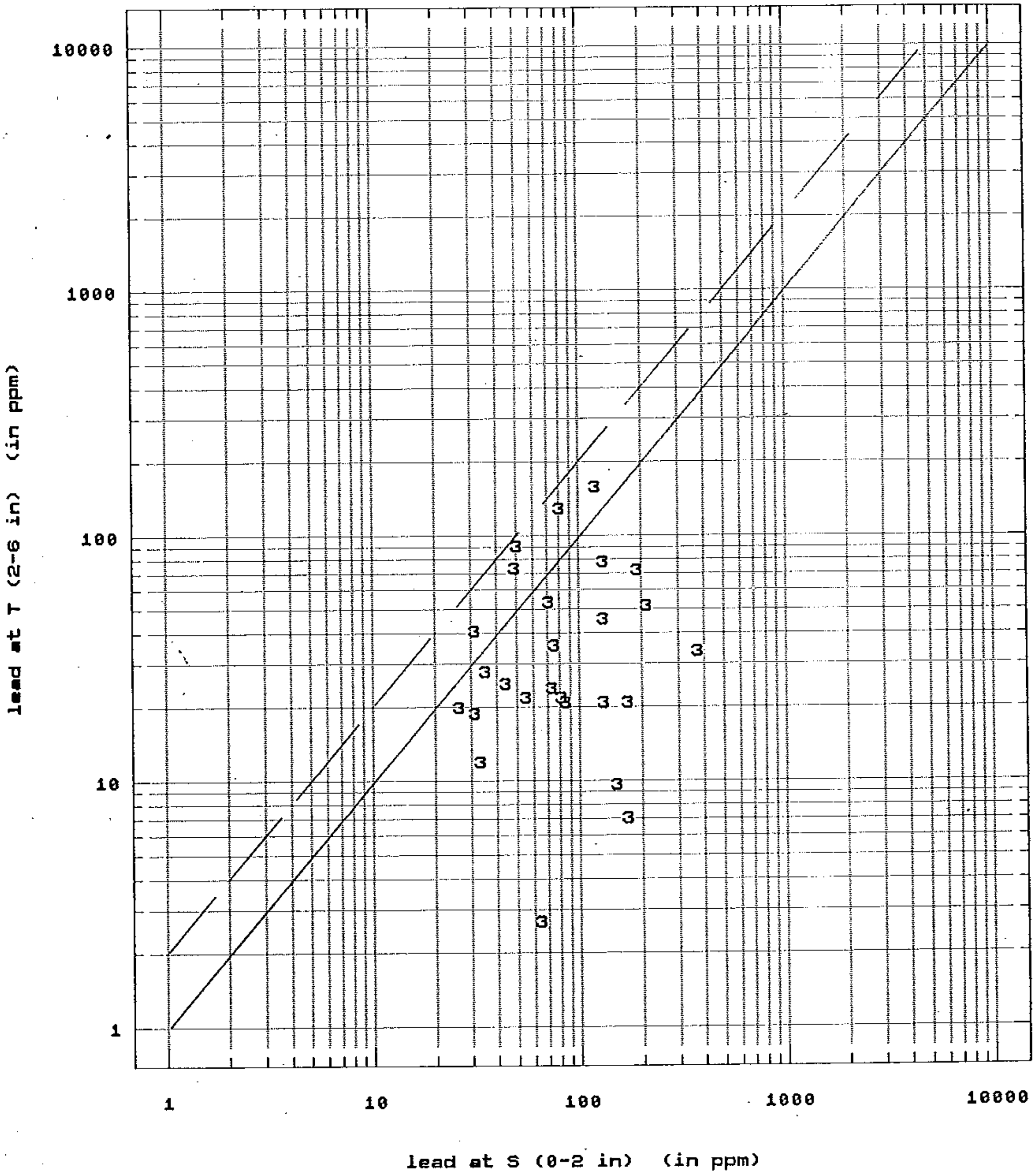
T (2-6 in) vs S (0-2 in)



(Mainland locations)

Lead Depth Profiles: Zone 3

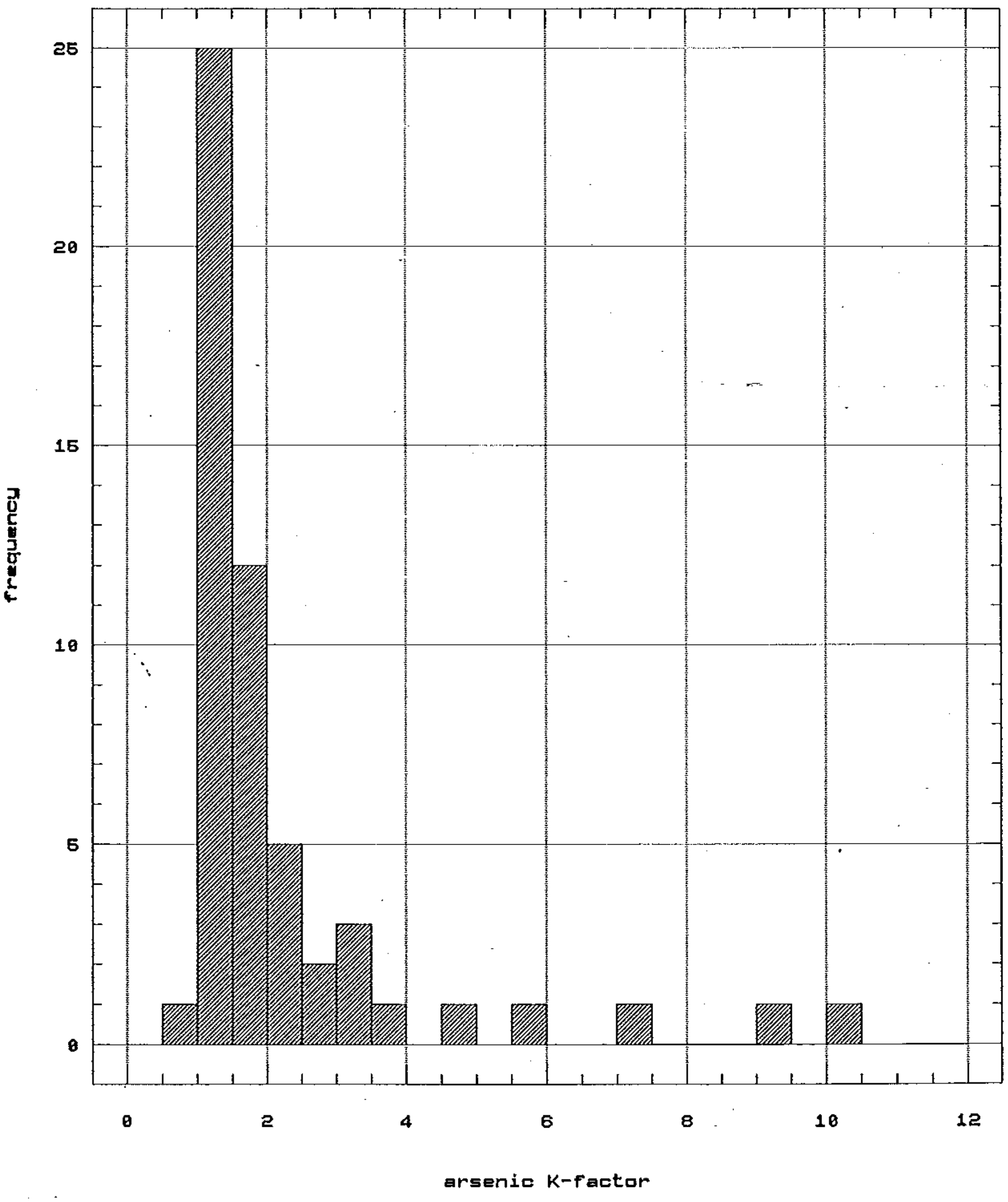
T (2-6 in) vs S (0-2 in)

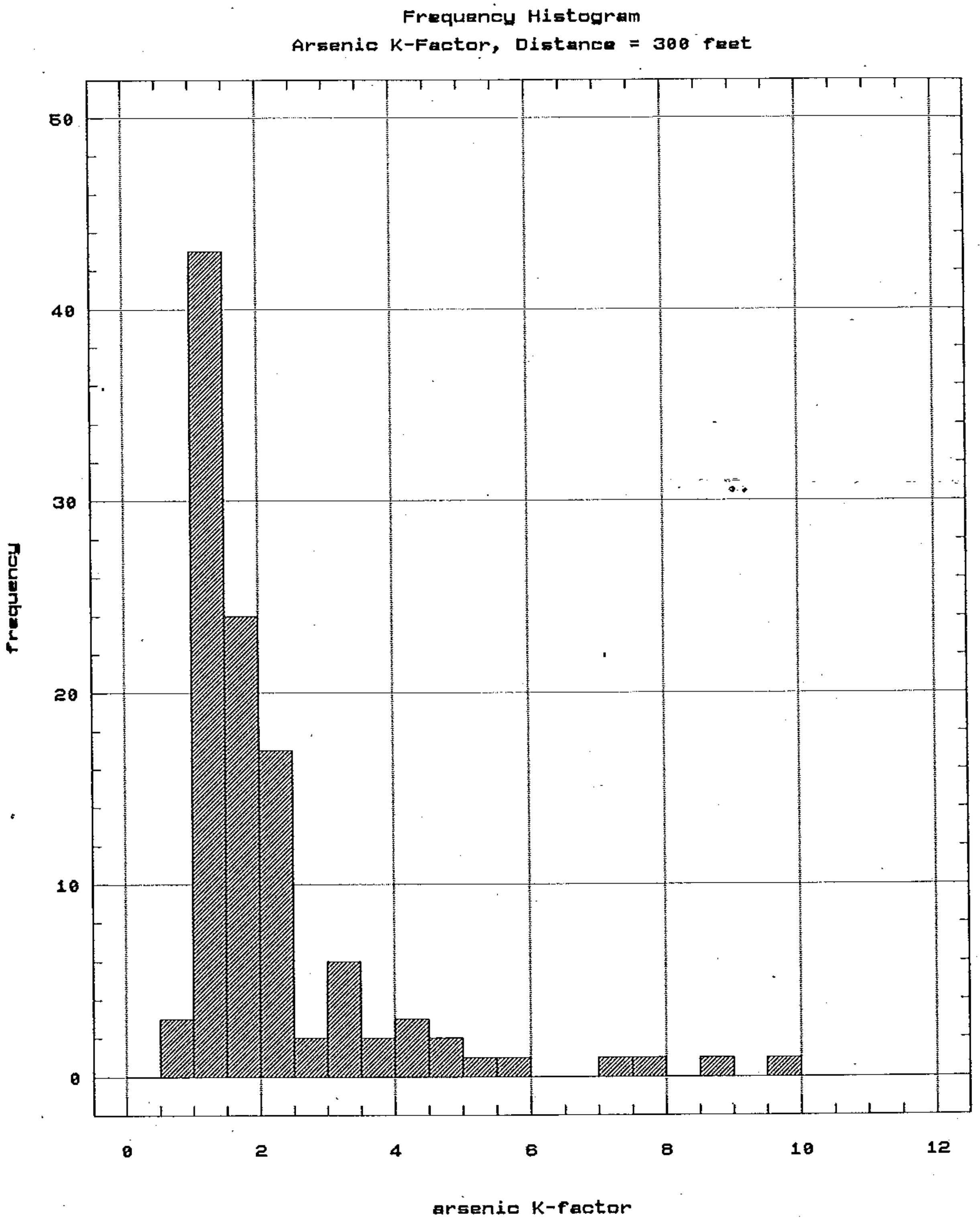


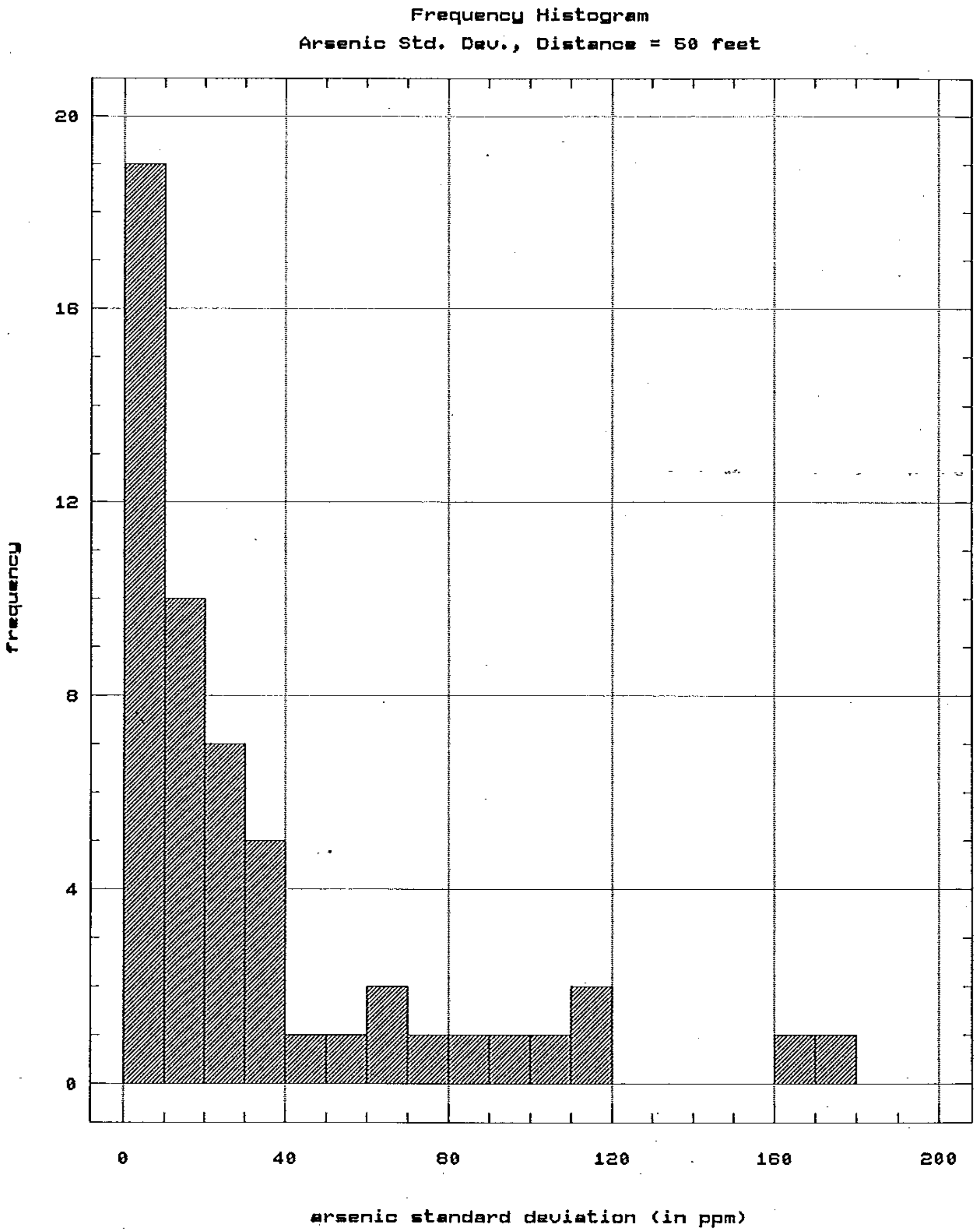
(North Vashon Island locations)

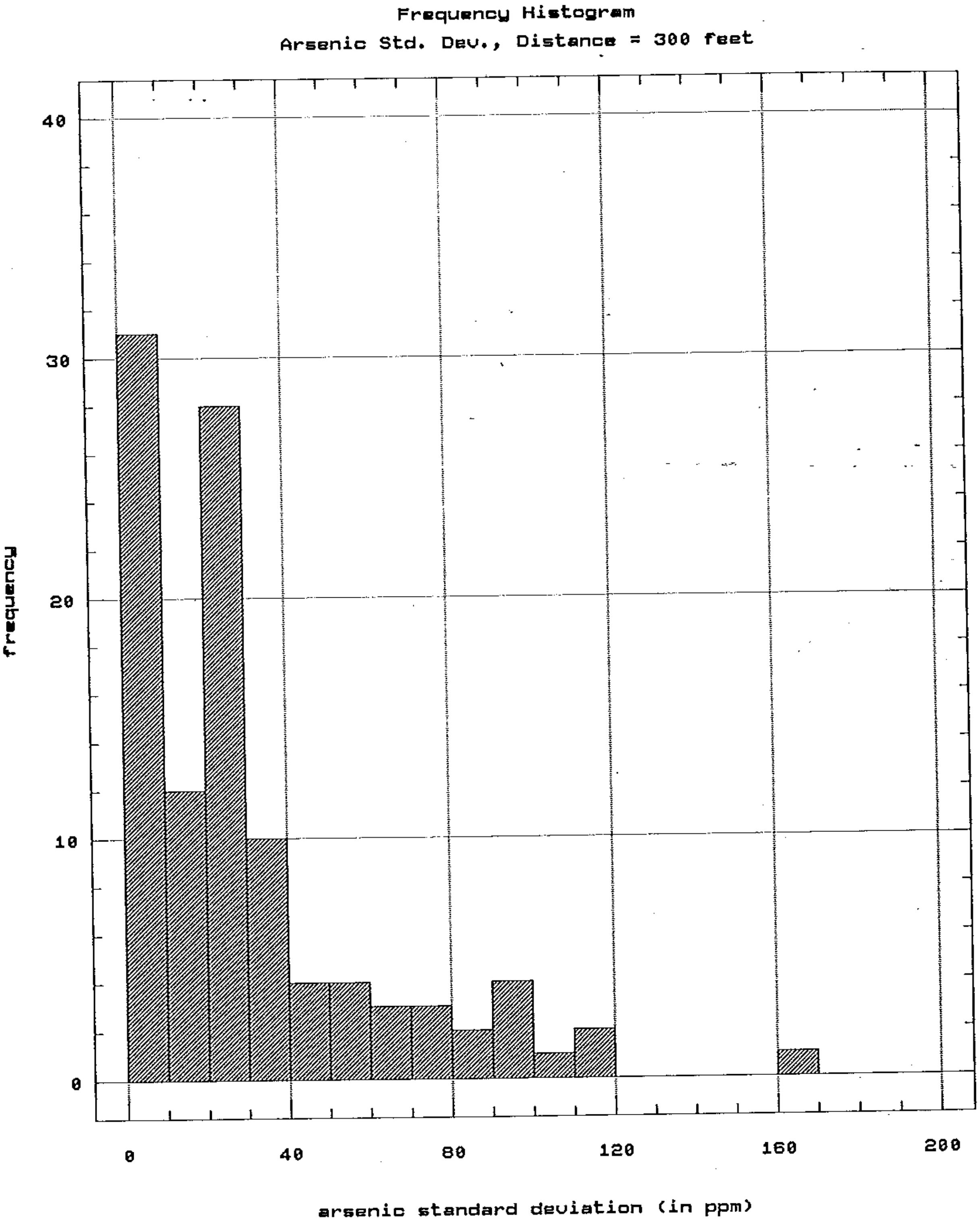
SPATIAL SCALE
and
VARIABILITY

Frequency Histogram
Arsenic K-Factor, Distance = 50 feet

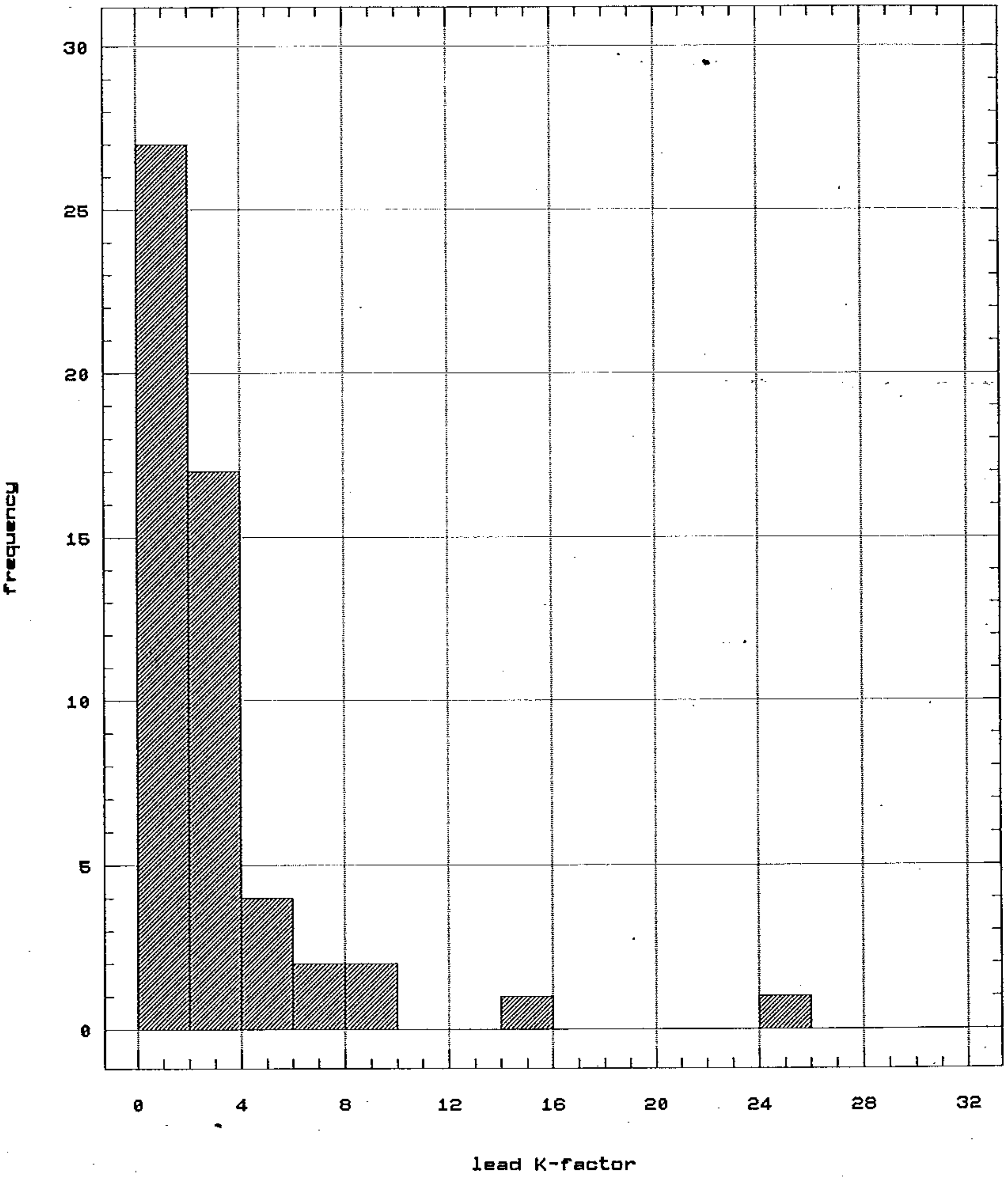



Frequency Histogram
Arsenic K-Factor, Distance = 300 feet
frequency
50
40
30
20
10
0
0
2
4
6
8
10
12
arsenic K-factor

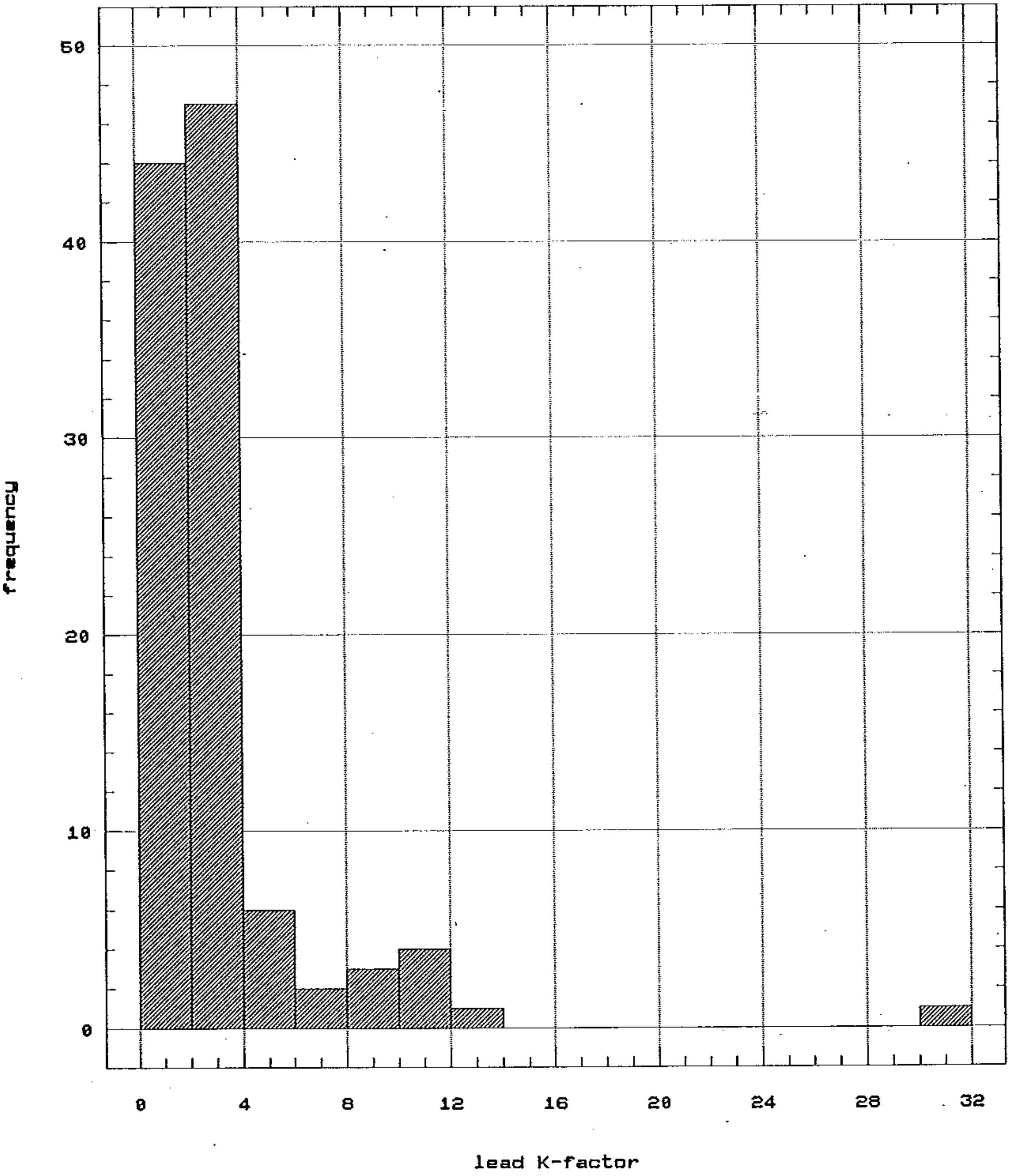

Frequency Histogram
Arsenic Std. Dev., Distance = 50 feet
frequency
20
16
12
8
4
0
0
40
80
120
160
200
arsenic standard deviation (in ppm)


Frequency Histogram
Arsenic Std. Dev., Distance = 300 feet
frequency
40
30
20
10
0
0
40
80
120
160
200
arsenic standard deviation (in ppm)

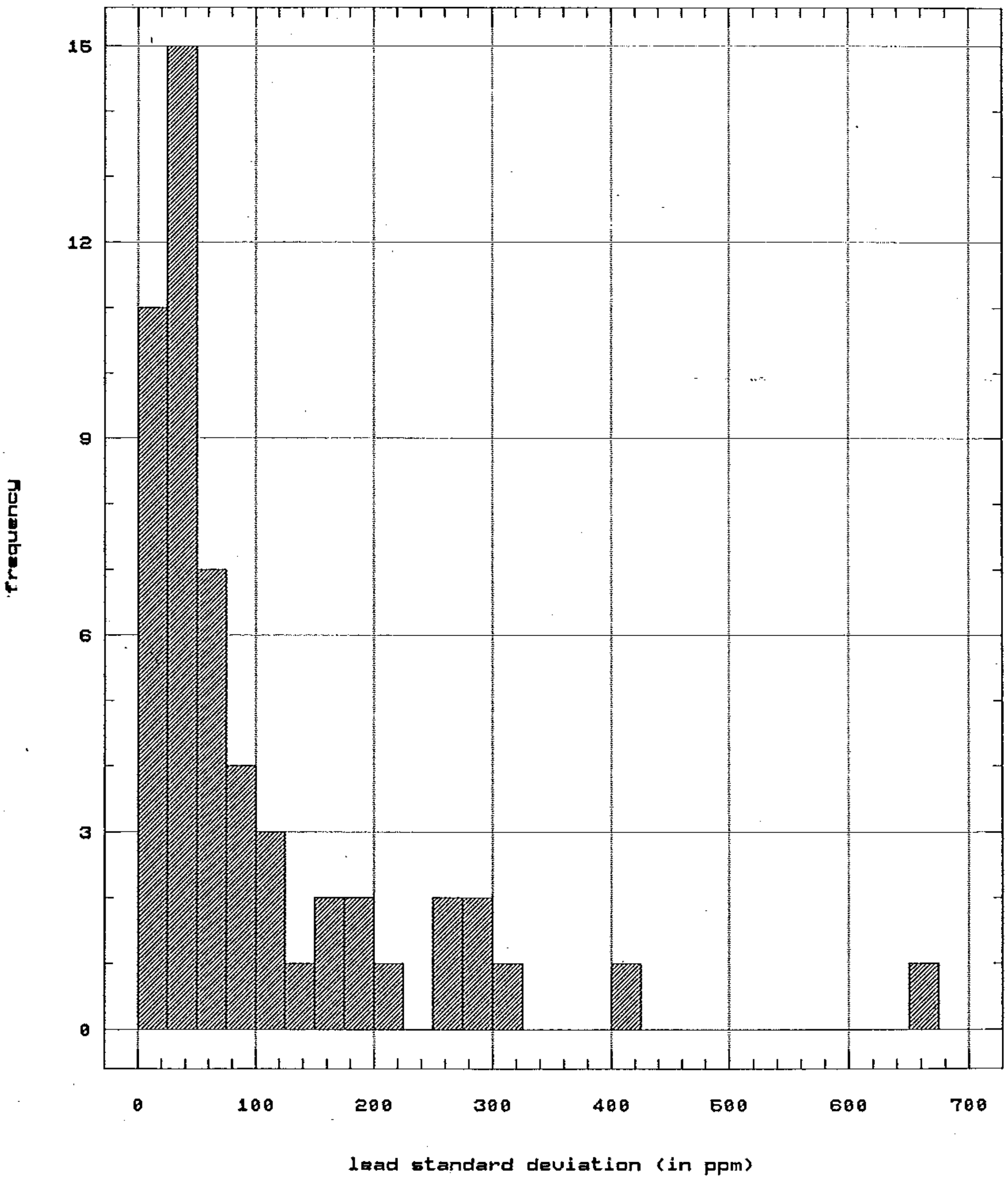
Frequency Histogram
Lead K-Factor, Distance = 50 feet



Frequency Histogram
Lead K-Factor, Distance = 300 feet

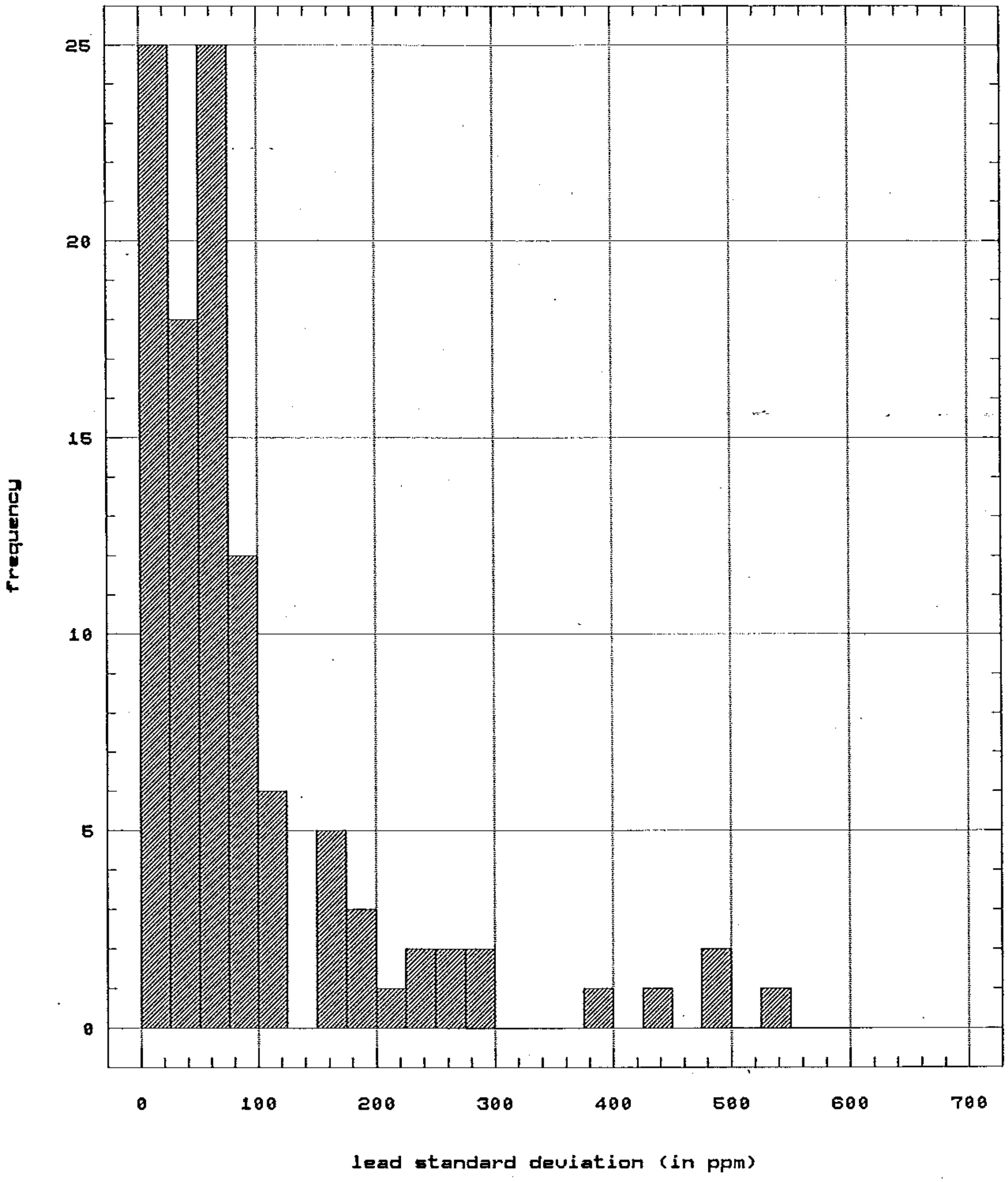


Frequency Histogram
Lead Std. Dev., Distance = 50 feet

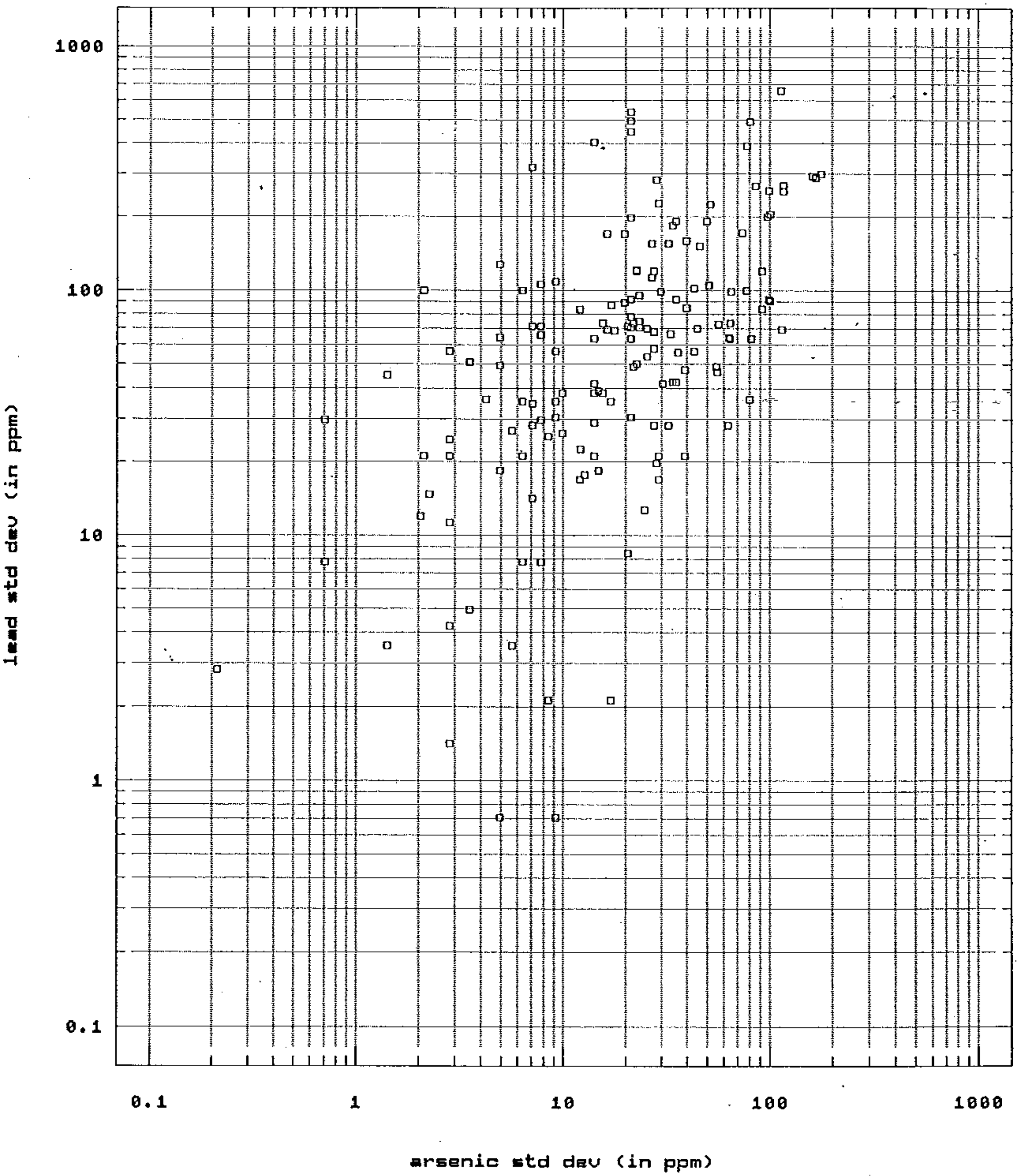


Frequency Histogram

Lead Std. Dev., Distance = 300 feet

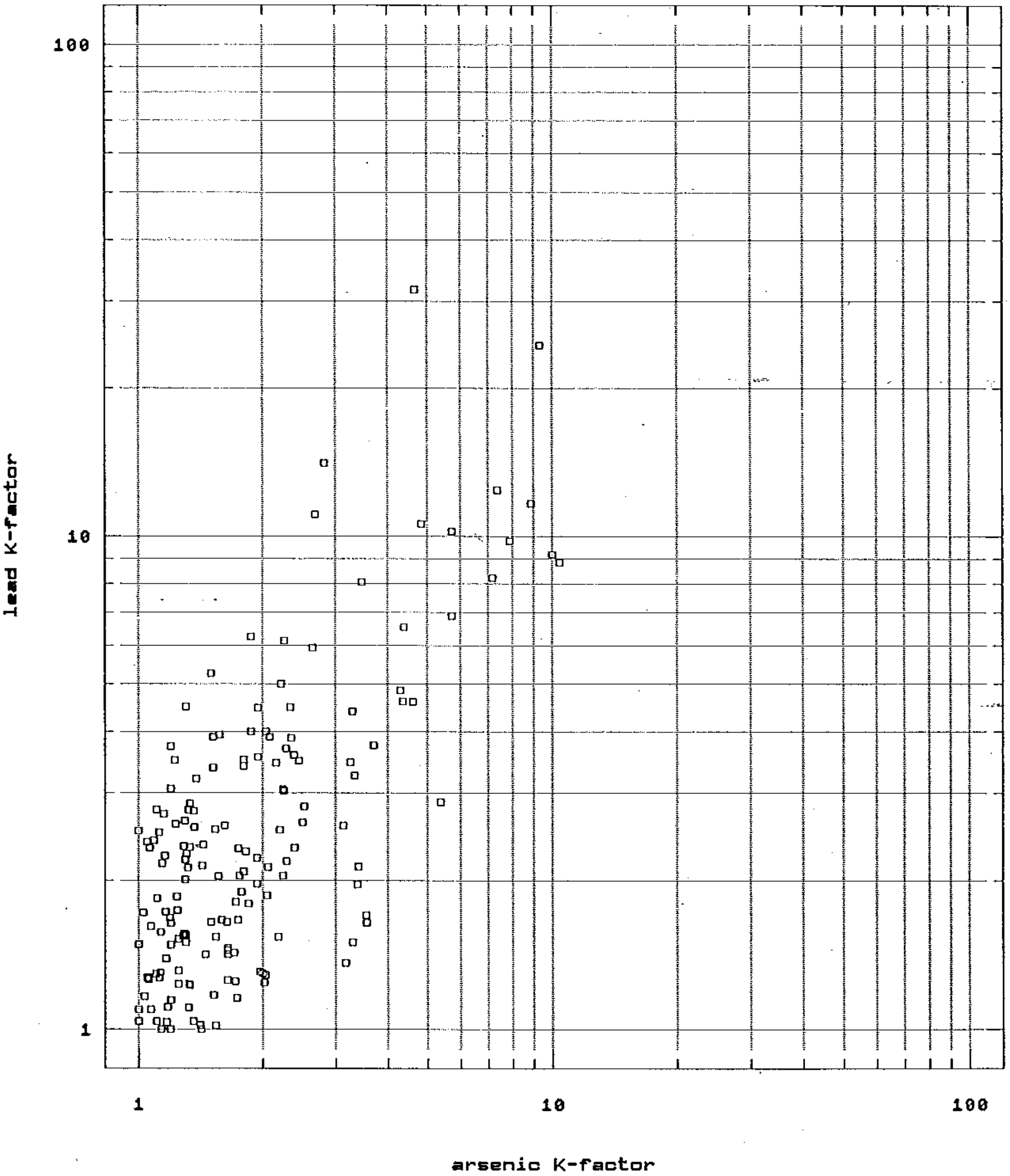


Comparison of Standard Deviations
Arsenic versus Lead (Spatial Scale)



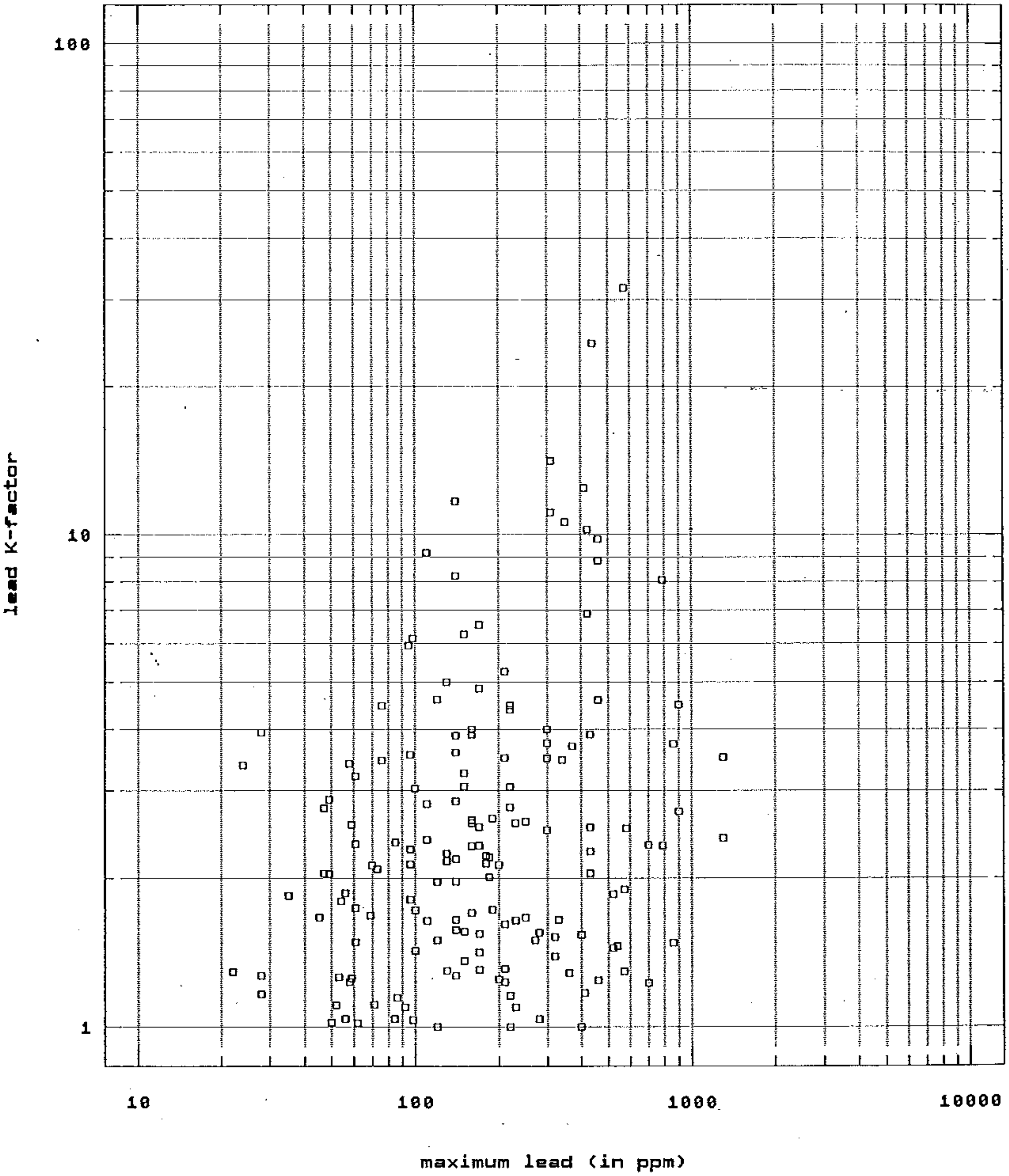
(7 SD=0 results omitted)

Comparison of K-Factors
Arsenic versus Lead

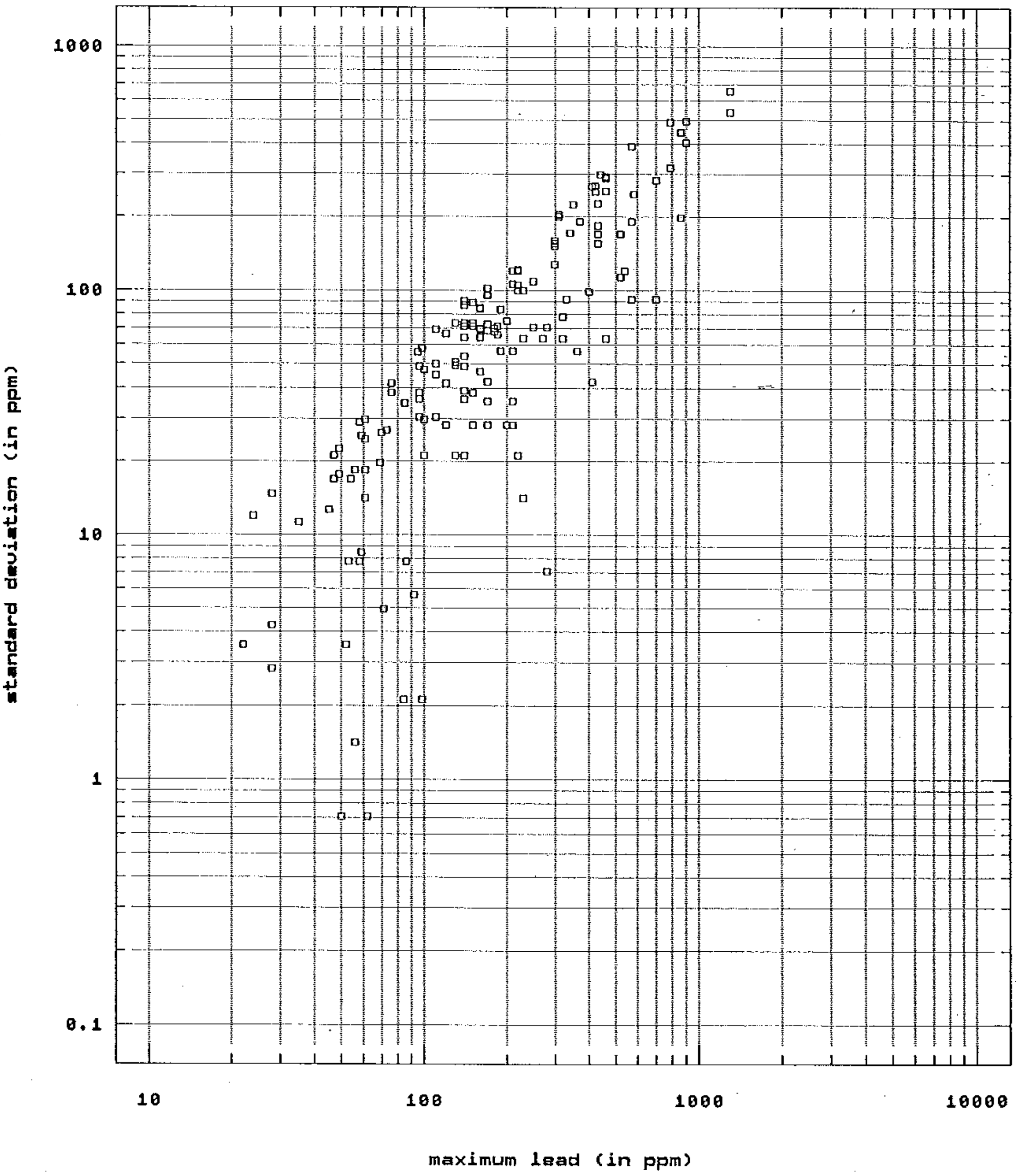


(combined 50 ft and 300 ft data)

Lead Spatial Scale K-Factor versus Magnitude of Contamination



Lead Spatial Scale Standard Deviation
versus Magnitude of Contamination



(3 SD=0 results omitted)