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FINAL REPORT

SOURCES OF LEAD IN SOIL: A LITERATURE REVIEW

Prepared by

Battelle Memorial Institute

Technical Programs Branch
Chemical Management Division
Office of Pollution Prevention and Toxics
Office of Prevention, Pesticides, and Toxic Substances
U.S. Environmental Protection Agency
Washington, DC 20460

DISCLAIMER

AUTHORS AND CONTRIBUTORS

This study was funded and managed by the U.S. Environmental Protection Agency. The review was conducted by Battelle Memorial Institute under contract to the Environmental Protection Agency. Each organization's responsibilities are listed below.

Battelle Memorial Institute (Battelle)

Battelle was responsible for conducting the literature search, obtaining and reviewing the identified articles and reports, developing the conclusions and recommendations derived from the review, and preparing this report.

U.S. Environmental Protection Agency (EPA)

The Environmental Protection Agency was responsible for managing the review, providing guidance on the objectives for the review and report, contributing to the development of conclusions and recommendations, and coordinating the EPA and peer reviews of the draft report. In addition, EPA provided access to study results not yet available in the general literature. The EPA Work Assignment Managers were Samuel Brown and John Schwemberger; the EPA Project Officers were Jill Hacker and Sineta Wooten; the EPA Section Chief was Phil Robinson; and the EPA Branch Chiefs were Cindy Stroup and Brion Cook.

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EXECUTIVE SUMMARY

Title X of the Housing and Community Development Act, known as the Residential Lead-Based Paint Hazard Reduction Act of 1992, contains legislation designed to evaluate and reduce exposures to lead in paint, dust, and soil in the nation's housing. As amended in Title X, §403 of Title IV of the Toxic Substances Control Act (TSCA), EPA is required to "promulgate regulations which shall identify, for the purposes of this title and the Residential Lead-Based Paint Hazards Reduction Act of 1992, lead-based paint hazards, lead-contaminated dust, and lead-contaminated soil."

Integral to the development of the §403 mandated standards (especially for soil) is information on the sources, extent, and geographic breadth of elevated lead contamination of soil ("elevated" because lead is naturally present in soil in many geographic regions). Such information provides perspective when considering what level of lead in soil will be defined as hazardous, and would suggest the extent of the remediation needed for different §403 standards.

The purpose of the study summarized in this report was to search and review the scientific literature on the sources of elevated soil-lead concentrations. More importantly, the study identified the basis upon which elevated soil-lead levels were attributed to a particular source. Literature searches were conducted to identify relevant articles and were supplemented by studies previously uncovered by the authors of this report. In all, 36 relevant studies were identified and formed the basis for this report.

The results of the literature search indicate that studies assessing soil-lead concentrations and sources have been conducted in a wide variety of communities across the United States. The scientific literature, however, contains a preponderance of urban and smelter community studies. Rural studies were relatively rare, their soil-lead levels usually used only as a measure of background lead when examining results from urban environments.

Consistent with what might be expected, three sources of elevated soil-lead levels were identified in the literature: (1) lead-based paint; (2) point source emitters; and (3) leaded gasoline emissions. Eight types of supporting evidence, commonly reported in the literature as justification for asserting that a particular source contributes to elevated soil-lead levels, were identified: (1) residential area pattern (i.e., the distribution of soil-lead levels around the residence); (2) paint-lead loading on exterior walls of residence; (3) age of residence; (4) type and condition of housing; (5) distance from a hypothesized source of elevated soil-lead levels; (6) ambient air-lead levels; (7) traffic volume on roadways in the vicinity of areas being examined; and (8) community area pattern.

The implications of the reviewed information concerning questions of source apportionment were investigated. No definitive evidence was found within the literature, however, suggesting a particular source can be regularly identified as responsible for elevated soil-lead concentrations at a residence. In fact, many studies cite more than one source as commonly responsible for elevated soil-lead levels. Moreover, labor- and cost-intensive techniques for carefully apportioning the sources of lead exposure to soil suggest varying relative contributions from candidate sources. It may be possible on a case-by-case basis to apportion the responsible sources, but no generalizations are possible based on readily obtained categorical factors (e.g., urban verus rural, northeast versus southwest). It is worth noting that within the literature lead-based paint is often cited as the source responsible for higher concentrations of lead in the surrounding soil; homes with extreme lead levels in their soil were often found to be coated with lead-based paint.

Although the results of this study suggest that a single source cannot be universally associated with elevated soil-lead levels, the results do confirm the suspected pairwise associations between elevated soil-lead levels and lead-based paint, leaded gasoline emissions, or point source emissions. As such, interventions targeting these sources should prove at least partially beneficial in reducing lead contamination of soil. In particular, lead-based paint interventions, such as those prompted by the promulgation of the §403 standards, should have an additional benefit of removing a source of lead in soil, above and beyond any benefit seen in reduced indirect exposure to elevated dust-lead levels and direct exposure to paint chips.

1.0 INTRODUCTION AND BACKGROUND

Lead is not naturally present in the human body and, as it currently exists in the environment, has been identified as a health threat. In particular, there exists extensive evidence that even at low dosages, lead may contribute to mental retardation and learning disabilities in children under the age of seven exposed to lead hazards [1]. As a result, the Centers for Disease Control and Prevention (CDC) has adopted a lower standard of 10 µg/dL as the community level of concern in children. As suggested by various authors, lead may contaminate humans from various pathways including: inhalation of airborne lead particulates, consumption of water or food contaminated by lead, and ingestion (due to contamination of hands or other objects) of soil or dust contaminated with lead [1]. Several studies have indicated that young children have an increased risk due to their greater propensity for placing non-food objects into their mouths and the vulnerability of their developing neurological functions.

On October 29, 1992, President George W. Bush signed the Residential Lead-Based Paint Hazard Reduction Act (Title X of HR 5334). This Act included legislation that requires the U.S. Environmental Protection Agency (EPA) to define standards for lead in paint, dust, and soil. More specifically, §403 of Title IV of the Toxic Substances Control Act, as amended in Title X, requires that EPA "promulgate regulations which shall identify, for the purposes of this title and the Residential Lead-Based Paint Hazards Reduction Act of 1992, lead-based paint hazards, lead-contaminated dust, and lead-contaminated soil."

Integral to the development of the §403 mandated standards (especially for soil) is information on the sources, extent, and geographic breadth of elevated lead contamination of soil. Such information provides perspective when considering what level of lead in soil will be defined as hazardous, and is suggestive of the potential efficacy of some interventions prompted by promulgation of the standards.

Lead is present naturally in soil, though in most regions at relatively low levels. The U.S. Geological Survey has estimated the concentration of naturally occurring lead in soil to have a national geometric mean of 16 ppm [2]. There are many sources that may contribute to increased levels of lead in residential soils including (but not exclusively): peeling, chalking, or active removal of lead-based paint; fallout from the discharge of community waste incinerators, smelters, or foundries; dumping or burning of lead batteries and their casings; and emission fallout from vehicles fueled with leaded gasoline.

The purpose of the study summarized in this report was to search and review the scientific literature on the sources of elevated soil-lead concentrations. More specifically, this report documents an effort to identify in the literature the basis upon which elevated soil-lead levels were attributed to a particular source, that is, the evidence that was cited as justification for attributing elevated soil-lead levels to a particular source.

1.1 ORGANIZATION OF THIS REPORT

This report is organized into six chapters. In Chapter 2, the objectives of the task are presented in greater detail. The methodology employed in the searches is detailed in Chapter 3. The results of the literature including an in-depth discussion of each source and the types of evidence used to support the hypothesis that it is responsible for elevated soil-lead levels is presented in Chapter 4. Conclusions of the study are presented in Chapter 5. The final chapter contains the citation reference with links to the corresponding study abstract.

2.0 OBJECTIVES

The primary objective of this literature review was to acquire a greater understanding of the sources and associated evidence of lead in contaminated soil through a review of the scientific literature. One aspect of this objective was to identify commonly cited sources of lead in soil. Another aspect was to identify the supporting evidence used to justify an assertion that a particular source contributes to elevated soil-lead levels. As additional objectives, a bibliography of relevant studies and a summary of each study, in standard format, were developed.

It is important to note that this study was not conducted to estimate national levels of soil-lead contamination nor to relate soil contamination from a particular source to the manifested lead exposure observed in resident children. As such, only a subset of all published articles with documented soil-lead levels were considered (i.e., those articles tracing or addressing the source responsible for elevated soil-lead levels).

3.0 METHODOLOGY OF LITERATURE REVIEW

Relevant studies were identified either by pre-existing knowledge on the part of the authors or through literature searches. While the focus of this task was not on exposure studies, some exposure studies were incidentally identified in the literature searches. Studies were included in this report if they provided insight into the sources of elevated soil-lead levels.

The review of the scientific literature was conducted by examining a list of articles and reports identified in several literature searches. The primary literature search focused only on studies addressing the sources of elevated soil-lead levels and is presented in detail in Section 3.1. In addition to this search, results from prior searches of a somewhat similar nature conducted on behalf of the EPA were examined. A re-examination of the results of these searches was conducted to supplement studies identified in the primary search. Literature relevant to the current issues were identified and included in this report. The methodology and objectives of the additional literature searches are presented in Section 3.2. In all, 36 studies were identified using the two search methodologies. These studies form the basis for this report.

3.1 PRIMARY LITERATURE SEARCH METHODOLOGY

The primary literature search concentrated on identifying field studies that examined the source and the accompanying supporting evidence of elevated soil-lead levels. Twenty-five public health and environmental databases including NTIS, Federal Register, and Enviroline were searched for relevant articles.

The search was conducted by selecting keywords, search dates, and abstract keys, and defining the relationships between them. The search followed a progressively more restrictive hierarchy to identify relevant journal articles and reports. At each step, the selection criteria were narrowed until a manageable number of potentially relevant articles were identified.

As an initial starting point, databases were examined for articles with the keyword “soil” used anywhere in the article. A total of 634,074 articles were found satisfying this criterion. Searching the same databases for articles mentioning “Lead” or “Pb” reduced the number of potentially relevant articles to 394,173. To further refine the list of articles a third, more restrictive selection criterion was imposed. In this third step, the search was restricted to those articles with "Lead" or "Pb" and "Soil" in the title. Finally, the list was further refined by retaining only those articles or reports written in English and by eliminating any redundant entries. Table 3-1 presents the resulting numbers of identified articles partitioned by year of publication.

Table 3-1. Results of Literature Search by Year

Breakdown By Year	Number of Articles Found	Number of Articles (English only)	Number of Unique Articles (English only)
1970-1974	480	325	142
1975-1979	888	673	232
1980-1984	912	667	248
1985-1989	994	776	282
1990-1992	515	446	169
Total	3789	2887	1073

In order to have a manageable number of entries to review, only articles written after 1980 were considered. Due to environmental and exposure pathway changes prompted by regulations in leaded gasoline and paint, articles published prior to 1980 were less likely to be relevant to current issues. By limiting the literature search to unique, English only articles published after 1980 with "Lead" or "Pb" and "Soil" in the title, 699 articles were identified as potentially relevant to this task. The abstracts for these articles were reviewed, and 28 papers were identified, read, and reviewed. From these, 18 studies were abstracted.

3.2 SECONDARY LITERATURE SEARCHES METHODOLOGY

The secondary approach to identifying relevant studies was to review the results of four similar, but more general, literature searches previously conducted by the EPA [47 (2 searches), 69, 70]. Each of these literature searches was conducted in a similar manner to that of the primary literature search. However, the focus of these searches was on field exposure studies that measured lead in both multiple environmental media and blood. As such, they involved more general keywords and broader selection criteria. Additionally, articles were also identified by reviewing the reference sections of known, relevant articles. In all, over 500 titles, abstracts, or journal articles were reviewed and 122 possible studies were identified. These studies were re-examined, and 18 were determined to be pertinent to this study.

4.0 RESULTS OF THE LITERATURE SEARCH

This chapter presents the results of the literature search in five sections. First, Section 4.1 presents an overview of the results of the literature search. A summary of the types of supporting evidence and statistical methodology used to assert that a particular source is responsible for elevated soil-lead levels is given in Section 4.2. The remaining three sections, 4.3, 4.4, and 4.5, discuss in detail each identified source and the supporting evidence used to justify the hypothesis that the source was responsible for elevated soil-lead levels.

4.1 OVERVIEW OF RESULTS

Studies assessing soil-lead concentrations (PbS) and its sources have been conducted in a wide variety of communities. They range from large urban centers such as Boston, Massachusetts, to smaller cities like Butte, Montana, to small towns such as Telluride, Colorado. Studies have been conducted over the entire United States, from Maine to California. The sites where studies were conducted to assess soil-lead levels are indicated in Figure 4-1. Darkened circles on the map represent communities where soil-lead concentration has been examined and documented within the literature.

The literature contains a preponderance of urban and smelter community studies. This emphasis is likely the result of attempts to target the populations most at risk and examine communities with extensive environmental lead exposure. Heavily populated urban environments are commonly contaminated with lead from both leaded gasoline emissions and lead-based paint. Smelter communities often have widespread lead contamination of their environmental media. Environmental lead studies in rural communities, on the other hand, are rare and are usually only used as a measure of background lead when examining the soil-lead concentration results from urban environments.

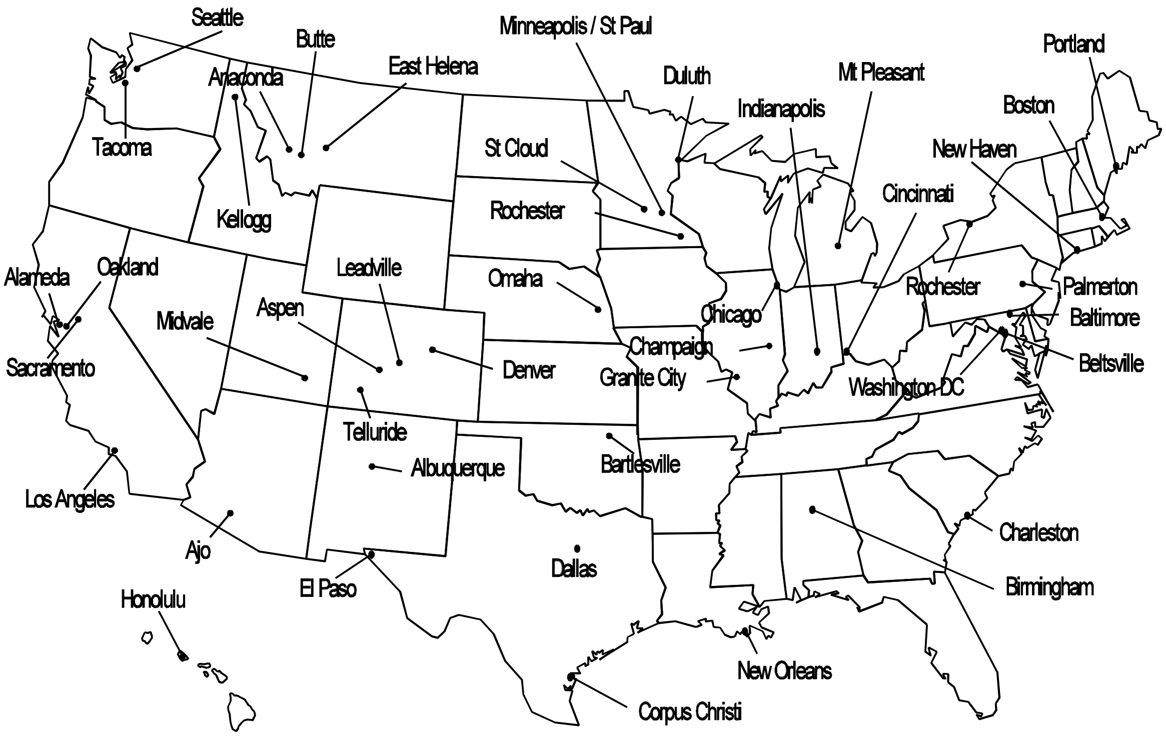

Figure 4-1. Locations of Identified Studies Examining Sources of Elevated Soil-Lead Concentrations.

Three sources of elevated soil-lead levels were identified in the literature. In addition, the supporting evidence used to assert that a particular source was responsible for elevated soil-lead levels was identified. The three sources identified were:

- Lead-based paint on exterior surfaces such as the walls of buildings
- Point source emitters such as smelters, batteries, or mine tailings
- Leaded gasoline emissions from automobiles.

The types of supporting evidence reported in the literature as justification for asserting that a particular source contributes to elevated soil-lead levels were:

- Residential area pattern, such as the distribution of soil-lead levels around the residence
- Paint-lead loading[1] on exterior walls of the residence
- Age of residence
- Type and condition of housing
- Distance from a hypothesized source of elevated soil-lead levels
- Ambient air-lead levels
- Traffic volume on roadways in the vicinity of the area being examined
- Community area pattern, such as highway infrastructure or residential density of city.

Table 4-1 presents all of the sites identified in the review. For each site, the table provides: a reference for the study, the year the study was conducted, the total number of soil samples collected, the range in soil-lead concentrations, the hypothesized sources of the lead, and the types of supporting evidence cited in determining the lead source. The range is reported since consistent measures of central tendency were unavailable. For example, one study reports arithmetic means by type of housing, while another documents geometric means by volume of traffic on nearby roadways. The table is sorted alphabetically by state and community within each state.

As an example of the information given in the table, consider the Boston, Massachusetts entry. From Table 4-1, it can be noted that in this 1981 study, 195 soil samples were collected, and soil-lead levels were reported to range from 7 to 13,240 ppm. Distance from the source, paint-lead loading, and traffic volume are cited by the authors as supporting evidence for their

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[1] Paint-lead loading is defined as the milligrams of lead per unit area sampled, typically reported as mg/ft^2 or mg/cm^2

assertion that lead-based paint and leaded gasoline emissions were the sources responsible for the elevated soil-lead levels.

Table 4-1. Studies Identified in the Literature

Study Location	Ref. #	Abs. #	Year	# of Samples	Range (ppm)	Source	Supporting Evidence
HUD National Lead Survey	6	A-11	1990	762	1-22974	1	2,3,4
Birmingham, Alabama	40	A-10	1989	92	89-9711	1	2
Ajo, Arizona	60	A-27	1978-1979	53	na	2	5
Alameda County (including Oakland), California	64	A-31	1987-1991	292	56-88176	1	1,2,3,
Alameda County, California	56	A-28	1993	138	22-3187	3	7
Los Angeles County, California	64	A-31	1987-1991	327	30-1973	1	1,2,3
Oakland, California	61	A-30	1978-1979	12	480-7130	1	2
Sacramento County, California	64	A-31	1987-1991	227	26-2664	1	1,2,3
Aspen, Colorado	42	A-22	1983	65	135-21700	2	5
Denver, Colorado	40	A-10	1989	131	49-1331	1	2
Leadville, Colorado	39	A-9	1987	651	2.7-27800	2	1,8
Telluride, Colorado	12	A-18	1986	90	16-1895	1,2	2,5,8
New Haven, Connecticut	13	A-15	1974-1977	487	30-7000	1	1,2,3,4,6
Washington, DC	55	A-36	Unkwn	239	10-6015	1	2,8
Washington, DC	40	A-10	1989	27	99-2678	1	2
Honolulu, Hawaii	25	A-17	1972, 1987	14, 18	na na	3	5,7
Kellogg, Idaho	17	A-12	1983	597	37-41200	2	1,5,6,8
Champaign, Illinois	63	A-32	1976	288	20-1060	1,3	2,5,7
Chicago, Illinois	30	A-20	1985	276	na	1,3	5,7,8
Granite City, Illinois	54	A-34	1991	338	37-3010	1,2	2,3,4,5
Indianapolis, Indiana	40	A-10	1989	105	47-4743	1	2
New Orleans, Louisiana	34	A-16	1991	na	na	1,3	1,3,8
Portland, Maine	11	A-25	1988	100	50-10900	1	1,2,3,4
Baltimore, Maryland	40	A-10	1989	27	159-3621	1	2
Baltimore, Maryland	32	A-3	1982	422	1-10900	3	8
Beltsville, Maryland	24	A-26	1971-1977	108	0.8-246	3	5,7

Source: (1) lead-based paint; (2) point source emitter; (3) leaded gasoline emissions.

Supporting Evidence: (1) residential area pattern; (2) paint-lead loading; (3) age of residence; (4) type and condition of housing; (5) distance from source; (6) ambient air-lead levels; (7) traffic volume; (8) community area pattern.

Table 4.1 Continued

Study Location	Ref. #	Abs. #	Year	# of Samples	Range (ppm)	Source	Supporting Evidence
Boston, Massachusetts	3	A-4	1981	195	7-13240	1,3	2,5,6,7
Mt. Pleasant, Michigan	10	A-19	1990	189	100-16839	1,3	1,3,4,5,6,7, 8
Duluth, Minnesota	7	A-14	1986	32	12-11110	1,3	1,2,7,8
Minneapolis, Minnesota	7	A-14	1986	199	35-20136	1,3	1,2,7,8
Rochester, Minnesota	7	A-14	1986	19	2-1930	1,3	1,2,7,8
St. Paul, Minnesota	7	A-14	1986	127	3-7994	1,3	1,2,7,8
St. Cloud, Minnesota	7	A-14	1986	13	5-1952	1,3	1,2,7,8
Anaconda, Montana	60	A-27	1978-1979	49	na	2	5
Butte, Montana	41	A-5	1990	650	20-2460	1,2	1,2,3,4,5
East Helena, Montana	20	A-2	1983	731	3-7964	2	5,6
Omaha, Nebraska	26	A-8	1971-1977	185	16-4792	1,2,3	1,6,8
Albuquerque, New Mexico	62	A-29	1981	43	3-5280	1,3	5,7,
Rochester, New York	53	A-35	1991-1992	528	30-18565	1	1
Cincinnati, Ohio	59	A-33	1990	60	2-3166[1]	3	3,5,6,7
Cincinnati, Ohio	16	A-7	1980	80	76-54519	1	2,3,4
Bartlesville, Oklahoma	60	A-27	1978-1979	38	na	2	5
Palmerton, Pennsylvania	60	A-27	1978-1979	42	na	2	5
Charleston, South Carolina	29	A-6	1973	164	9-7890	1,3	2,4,5,7,8
Corpus Christi, Texas	31	A-24	1984	485	8-2969	3	5,7
Dallas, Texas	23	A-21	1982	2795	200-3000[2]	2	5,8
El Paso, Texas	19	A-23	1972-1973	54	560-11450	2	5,6
Midvale, Utah	22	A-13	1989	288	1-6665	1,2	2,3,4,5
Seattle/Tacoma Washington	40	A-10	1989	99	40-7382	1	2

[1] Mean ± 1 Standard Deviation

[2] Estimated Isopleth Level

Source: (1) lead-based paint; (2) point source emitter; (3) leaded gasoline emissions.

Supporting Evidence: (1) residential area pattern; (2) paint-lead loading; (3) age of residence; (4) type and condition of housing; (5) distance from source; (6) ambient air-lead levels; (7) traffic volume; (8) community area pattern.

4.2 SOURCE APPORTIONMENT METHODOLOGY

The process of determining the source responsible (whether based on chemistry, physical properties, or measures of association) for elevated levels of lead in soil is commonly termed “source apportionment.” For this purpose, certain evidence or reasoning are cited in the literature as justification for asserting that a particular source is responsible for elevated soil-lead levels. These reasons are defined in this study as “types of supporting evidence.” There were eight types of supporting evidence identified in the literature: (1) residential area pattern; (2) paint-lead loading on exterior walls of residence; (3) age of residence; (4) type and condition of housing; (5) distance from a hypothesized source of elevated soil-lead levels; (6) ambient air-lead levels; (7) traffic volume on roadways in the vicinity of area being examined; and (8) community area pattern.

In general, each type of supporting evidence is based upon an observed relationship with soil-lead levels. For example, residential area patterns and community area patterns are based upon relating soil-lead levels around a home or community to the locations where the samples were taken. Paint-lead loading on exterior walls of the residence, ambient air-lead levels, and traffic volume on roadways are usually cited as types of supporting evidence because of an observed positive association with soil-lead levels (i.e., higher lead loadings, air-lead levels, and traffic volume were associated with higher soil-lead levels). Similarly, age of the residence, type and condition of housing, and distance from hypothesized source are typically cited as supporting evidence because the author has observed a significant association (in these cases negative) with soil-lead levels (e.g., older, deteriorated homes associated with higher soil-lead levels).

Within the literature, a variety of methods were used to examine the relationships and associations between the various types of supporting evidence and elevated soil-lead levels. At the very least, most of the identified studies cite some sort of descriptive statistic such as geometric or arithmetic means and standard deviations of lead loadings or concentrations, stratified by levels consistent with the type of supporting evidence used (e.g., at various distances from a source of lead). In some instances, medians and percentiles were presented. Geometric means and medians were used by authors reporting skewed distributions for soil. Additionally, frequency counts and correlations between sampling locations and other environmental variables such as paint-lead loading were also reported.

Analysis of variance methods and t-tests were sometimes used to compare soil-lead levels between sample locations or to compare soil-lead levels across levels of related variables (e.g., by age and condition of the residence). Odds ratios and other cross-tabulation measures were also reported. Nonparametric methods were sometimes used in place of the parametric methods mentioned above.

Multiple and simple linear regressions were used to determine the relationship between soil-lead levels and related variables such as traffic volume, lead-based paint loading, and distance from the hypothesized source. Stepwise procedures were sometimes used to select the best set of regressor variables for predicting soil-lead levels.

Some of the studies used structural equations models (SEM) to duplicate the varied associations among the measured environmental and body burden variables, including soil on blood-lead levels. The main idea of SEM is to construct a set of linear dependence relationships that describe the mechanisms by which lead travels from one media or location to another. Studies identified in this report usually used SEM to describe mechanisms by which lead goes from a source such as lead-based paint or from a point source emitter to soil and then on to dust or blood-lead. Thus, one of the dependent linear equations in the set usually addresses the source of lead in soil.

Two studies, Baltimore Urban Garden Soil Study [32] and the New Orleans Lead Study [34], use a nonparametric test based on multi-response permutation procedures (MRPP). MRPP was used to examine the geographic clustering of elevated soil-lead levels throughout the community. The basic idea of MRPP is that soil samples are separated into two groups, high and low, and a test statistic based on the geographic distance between pairs of observations in the high group is calculated. Usually, the two groups are constructed by using the median soil-lead value. Samples with soil-lead measurement higher than the median are put into the higher group while the rest go into the lower group.

Kriging is another geographic method used to examine soil-lead levels throughout the community. Kriging is a statistical interpolation method for analyzing spatially and temporally varying data. It is used to estimate soil-lead levels on a dense grid of spatial and temporal locations covering the region of interest. At each location, an estimate of the soil-lead levels and the precision of the estimate is calculated. Generally, the degree to which soil-lead measurements taken at two locations are different is a function of the distance and direction between the two sampling locations. Kriging differs from other classical interpolation and contouring algorithms in that it produces statistically optimal estimates (under certain assumptions) and associated precision measures.

4.3 LEAD-BASED PAINT

Lead-based paint was cited as one source of elevated soil-lead levels in studies across the United States. Locations of these studies are identified in Figure 4-2. Two mechanisms for lead-based paint contributing to soil lead have been identified. Because paint is designed to naturally chalk, weathering of exterior lead-based paint may cause it to crumble or peel, and the resulting paint chips and particles then contaminate the surrounding soil. Abatement of the paint using scraping or sandblasting techniques (without an attached vacuum collection device) may also result in lead contribution to the soil. There is varied but extensive evidence for these mechanisms of exposure.

The literature reports four general types of supporting evidence used to demonstrate that lead-based paint is a source of lead in soil: 1) residential or community area pattern, 2) relationship to paint-lead loading, 3) association to age of residence, and 4) association with type and condition of residence. Table 4-2 presents measures of central tendency (broken down by the type of supporting evidence) as reported in studies identifying lead-based paint as a source. In some instances, such as the Boston Brigham and Women's Hospital Longitudinal Lead Study [3], only a single overall central tendency measure was reported. While this central tendency measure may not be entirely comparable to other measures reported in the table, it is included for completeness.

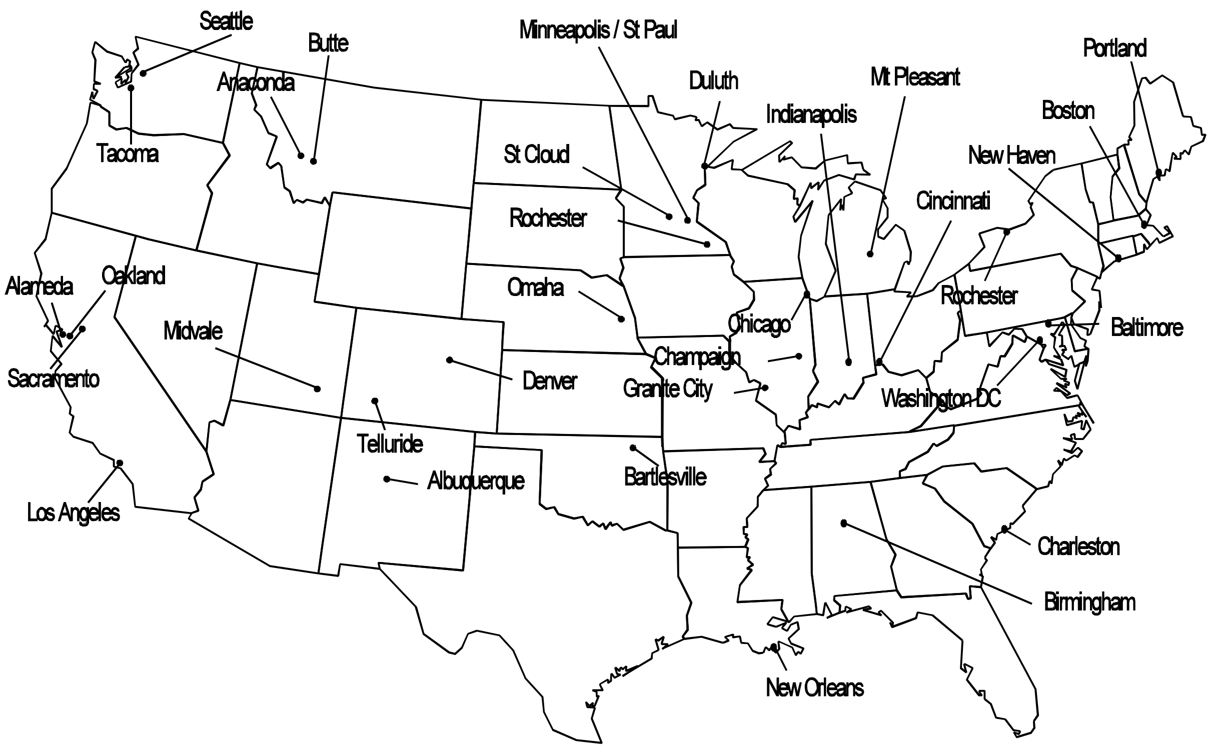

Figure 4-2. Locations of Studies Identified as Citing Lead-Based Paint as a Source of Soil Lead.

Some studies identify an area pattern to lead contamination of soil at a residence. In general, samples collected near the foundation of residences have higher lead concentrations than samples collected at more remote locations. The geometric mean soil-lead concentrations for samples collected at the drip line of dwelling units examined in the HUD National Lead Survey [6] was 72 ppm (geometric standard deviation: 5.37), compared to 47 ppm (GSD: 4.14) for samples collected at remote locations (Table 4-1). Schmitt [7] considered soil samples collected from a number of locations surrounding residences in five Minnesota communities. As can be seen in Table 4-2, the geometric mean soil-lead concentration was higher for foundation samples than for open area samples[1] in all of the five Minnesota communities examined (Figure 4-3). Of the residences examined in this survey, 213 had wood exteriors and 88 were brick. The wood exterior residences had a geometric mean soil-lead concentration of 522 ppm (geometric SD:

[1] Open samples were collected from sites without buildings, such as vacant lots or undeveloped rural areas.

Table 4-2. Reported Measures of Central Tendency of Soil-Lead Concentrations for Studies Identifying Paint as Responsible Source

Study Name	Location	Type of Supporting Evidence	Description	Mean or Median (ppm)	Std. Dev. (ppm)	No. of Soil Samples
HUD National Lead Survey [A-11]	30 Counties in 48 States	Residential area pattern	Geometric Mean and Std. Dev. by soil location Entryway Remote Drip Line	83 47 72	4.35 4.14 5.37	260 253 415
California Lead Study: Three High Risk Communities [A-31]	Alameda, Sacramento, and Los Angeles Counties, CA	Residential Area Pattern	Geometric mean by community and sampling location Oakland: Front Yard Rear Yard Side Yard Los Angeles: Front Yard Rear Yard Side Yard Sacramento: Front Yard Rear Yard Side Yard	716 889 942 181 215 203 225 217 290	na na na na na na na na na	231 141 147 290 236 245 221 197 198
Champaign-Urbana Lead Study [A-32]	Champaign-Urbana, IL	Residential Area Pattern	Median by location Near Side Lawn Near Rear Lawn Far Front Lawn Far Lawn	50 100 70 40	na na na na	na na na na
Midvale Community Lead Study: Final Report [A-13]	Midvale, UT	Residential Area pattern	Geometric Mean and Std. Dev. by soil locations Perimeter Garden Bare Surface	341.81 294.59 313.20 77.95	2.45 2.65 2.60 5.52	112 46 88 42

Table 4-2. Continued

Study Name	Location	Type of Supporting Evidence	Description	Mean or Median (ppm)	Std. Dev. (ppm)	No. of Soil Samples
Minnesota Soil Lead Study [A-14]	Duluth Minneapolis Rochester St. Cloud St. Paul, MN	Residential Area Pattern	Geometric means and Std. Dev Duluth- Foundation Open Area Minneapolis- Foundation Open Area Rochester- Foundation Open Area St. Cloud- Foundation Open Area St. Paul- Foundation Open Area	455 38 665 39 65 23 85 25 472 66	5.2 2.7 3.5 3.7 8.4 4.1 7.5 4.9 4.5 3.7	32 19 199 51 19 15 13 18 127 95
Rochester Side-by-Side Dust Collection Study [A-35]	Rochester, NY	Residential Area Pattern	Geometric Mean by location Foundation Coarse Foundation Fine Play Coarse Play Fine	981 732 299 271	na na na na	182 182 82 82
Illinois Soil Lead Study [A-20]	Chicago Chicago suburbs Downstate	Community area pattern	Geometric Means for Chicago Surface Soil Chicago Suburbs Downstate	157 83 44	na na na	256 244 167

Table 4-2. Continued

Study Name	Location	Type of Supporting Evidence	Description	Mean or Median (ppm)	Std. Dev. (ppm)	No. of Soil Samples
New Orleans Lead Study [A-16]	New Orleans, LA	Community area pattern	Median by location in community and around the home			
			Inner City- Foundation	840	201	na
			Streetside	342	723	na
			Open Area	212	74	na
			Mid City- Foundation	110	220	na
			Streetside	110	765	na
			Open Area	40	80	na
			Suburban- Foundation	50	332	na
			Streetside	86	195	na
			Open Area	28	114	na
Omaha Lead Study [A-8]	Omaha, NA	Community area pattern	Geometric Means by location in community Site C	262	na	69
			Site M	339	na	56
			Site S	81	na	51
Washington, DC Soil Lead Study [A-36]	Washington, DC	Community Area Pattern	Median by City Wards Ward 1	444	na	30
			Ward 2	471	na	30
			Ward 3	54	na	30
			Ward 4	199	na	30
			Ward 5	222	na	30
			Ward 6	260	na	30
			Ward 7	144	na	30
			Ward 8	130	na	30
Butte-Silver Bow Environmental Lead Study [A-5]	Butte, MT	Paint Loading	Geometric Means by paint loading 0-.99 mg/cm^2	200	na	na
			1-2.99 mg/cm^2	300	na	na
			3-11.99 mg/cm^2	650	na	na
			>12 mg/cm^2	1100	na	na

Table 4-2. Continued

Study Name	Location	Type of Supporting Evidence	Description		Mean or Median (ppm)	Std. Dev. (ppm)	No. of Soil Samples
Charleston Lead Study [A-6]	Charleston, SC	Paint Loading	Median paint loading content (mg/cm^2) by location and soil-lead level				
			Porch Railing -	PbS<585 ppm	0.0	na	na
				PbS>585 ppm	1.2	na	na
			Exterior Siding -	PbS<585 ppm	0.0	na	na
				PbS>585 ppm	3.7	na	na
			Window Sill -	PbS<585 ppm	1.7	na	na
				PbS>585 ppm	2.5	na	na
			Door Frame -	PbS<585 ppm	4.0	na	na
				PbS>585 ppm	3.1	na	na
			Porch Railing -	PbS<585 ppm	1.0	na	na
				PbS>585 ppm	1.4	na	na
New Haven, Connecticut Lead Study [A-15]	New Haven, CT	Age of Residence	Geometric means and Std. Dev by year of construction and soil location				
			1910-1919	Near	1200.1	63.1	41
				Far	798.2	39.8	41
			1920-1929	Near	1273.3	79.4	42
				Far	770.1	39.8	42
			1930-1939	Near	1299	251.2	29
				Far	917.6	39.8	29
			1940-1949	Near	444	1258.9	86
				Far	507.4	316.2	86
			1950-1959	Near	929.6	398.1	29
				Far	479.3	100	29
			1960-1969	Near	309.7	501.2	30
				Far	390.2	50.1	30
			1970-1977	Near	131.3	50.1	3
				Far	310.9	63.1	3

Table 4-2. Continued

Study Name	Location	Type of Supporting Evidence	Description	Mean or Median (ppm)	Std. Dev. (ppm)	No. of Soil Samples
Maine Urban Soil Study [A-25]	Portland, ME	Age of Residence	Geometric Mean Homes over 30 yrs old Parks and Playgrounds	1275 205	na na	75 25
Cincinnati Longitudinal Lead Study [A-7]	Cincinnati, OH	Age/condition of Housing	Geometric Mean by age/condition 20th Century/Public 19th C. /Rehabilitated 19th C./Satisfactory 19th C./Deteriorated	572 804 2540 2670	na na na na	14 18 7 13
Mt. Pleasant Soil Lead Study [A-19]	Mt. Pleasant, MI	Condition of Housing	Arithmetic Means and Std. Dev. by condition of home Excellent Good Fair Poor	203 347 2537 1346	60 446 4631 858	6 18 13 18

Table 4-2. Continued

Study Name	Location	Type of Supporting Evidence	Description		Mean or Median (ppm)	Std. Dev. (ppm)	No. of Soil Samples
Albuquerque Street Dirt Lead Study [A-29]	Albuquerque, NM	Distance from Source	Arithmetic Mean and Std. Dev. by sampling locations				
			Site A	Close	1170	240	na
				Distant	1120	190	ns
			Site B	Close	3720	820	ns
				Distant	2600	180	ns
			Site C	Close	4860	430	ns
				Distant	3660	220	ns
The HUD Abatement Demonstration Study [A-10]	Baltimore, MD; Washington, DC Seattle, WA; Tacoma, WA; Indianapolis, IN; Denver, CO; Birmingham, AL	na	Arithmetic Means				
				Before Abatement	755.0	na	455
				After Abatement	867.5	na	455
Brigham and Women's Hospital Longitudinal Lead Study [A-4]	Boston, MA	na	Median soil-lead level		365	na	195
Granite City Lead Exposure Study [A-34]	Granite City, IL	na	Arithmetic Mean and Std. Dev.		449	420	338
Identification of Lead Sources through Stable Isotope Ratio Techniques: Case Studies [A-30]	Oakland, CA	na	Median soil-lead concentration by case and sampling location				
			Case I:	Backyard	1160	na	2
				Curbside	1300	na	2
			Case II:	Front Yard	2430	na	4
				Side Yard	1420	na	1
				Back Yard	1100	na	2
				Neighbors	990	na	1

Table 4-2. Continued

Study Name	Location	Type of Supporting Evidence	Description	Mean or Median (ppm)	Std. Dev. (ppm)	No. of Soil Samples
Telluride Lead Study [A-18]	Telluride, CO	na	Geometric Mean and Std. Dev Surface Soil Core	178 145	2.5 3.2	45 45

na = Not available

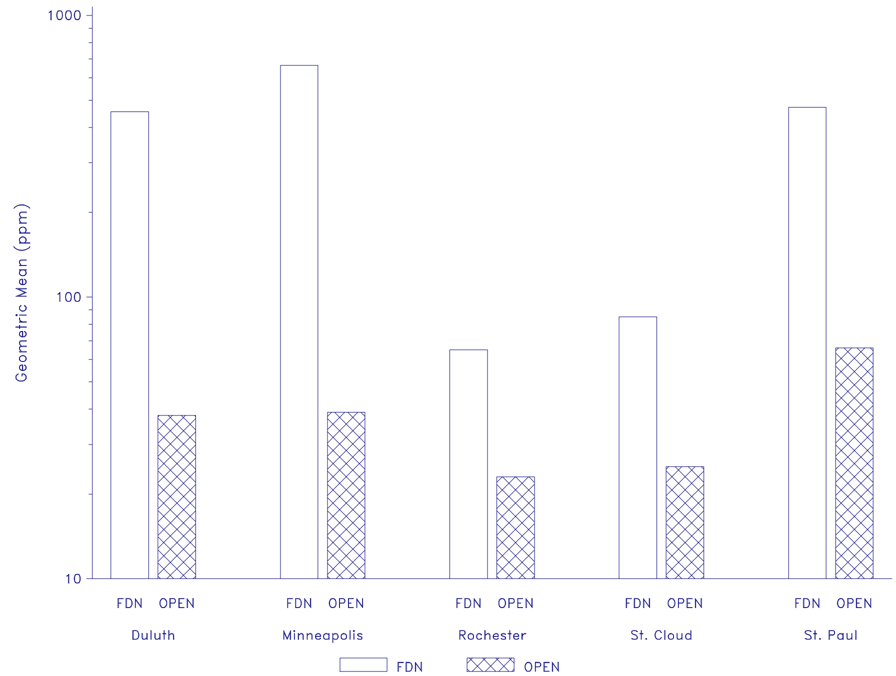

Figure 4-3. Geometric Means for Foundation and Open Samples Reported in the Minnesota Soil Lead Study.

6.4), compared to 158 ppm (GSD: 4.3) for the brick residences. Furthermore, "virtually every sample exceeding 2000 [ppm] and 140 of 160 samples exceeding 1000 [ppm] were collected near house foundations." Deteriorating lead-based paint may primarily supply soils immediately adjacent to the weathered surface.

Other studies cited a relationship between XRF lead loadings[1] on exterior surfaces and soil-lead concentrations. The Butte-Silver Bow study [41] noted that as exterior paint-lead loading increased, the associated geometric mean of soil-lead concentration also increased (Table 4-2). Correlations are often given between soil-lead and paint-related variables as evidence of a relationship between paint-lead loadings and soil-lead levels. Table 4-3 presents the correlations reported in studies identified in the literature.

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1 X-ray fluorescence (XRF) is a portable instrument that measures the lead-paint loading (mg/cm^2). EPA is currently examining the performance of these devices.

Table 4-3. Correlation Results Reported Between Soil-Lead and Exterior Paint-Lead Variables

Study Name	Reported Correlation
The Butte-Silver Bow Environmental Health Lead Study	
* Perimeter soil sample with XRF on exterior paint	0.59
Brigham and Women's Hospital Longitudinal Lead Study	
* Soil Lead with paint score (based on lead-loading)	-0.07
The Cincinnati Longitudinal Lead Study	
* Soil Lead with XRF based paint hazard score	0.41
The HUD National Lead Survey	
* Drip line soil lead with exterior paint loading	0.41
* Remote soil lead with exterior paint loading	0.40
* Entryway soil lead with exterior paint loading	0.38
Midvale Community Lead Study: Final Report	
* Maximum soil-lead value with exterior XRF	0.43
New Haven, Connecticut Lead Study	
* Far soil lead with exterior paint loading	0.28
* Near soil lead with exterior paint loading	0.43
Telluride Lead Study	
* Surface scrape soil-lead with exterior XRF	0.40
* Soil core soil lead with exterior XRF	0.49
Rochester Side-by-Side Dust Collection Study	
* Foundation Coarse soil with exterior paint XRF	0.37
* Foundation Fine soil with exterior paint XRF	0.34

Additionally, 102 housing units in the HUD National Lead Survey [6] with paint-lead loadings on at least one surface measured at or above 1.0 mg/cm^2 had a geometric mean soil-lead concentration of 140.24 ppm, compared to 27.46 ppm for 80 units without any such surfaces. These studies suggest that higher paint-lead loadings on exterior surfaces are associated with increased lead concentration in the surrounding soil.

Age of residence is sometimes used as an indicator for the presence of lead-based paint. The use of lead in interior and exterior house paint has markedly declined since the 1940s. In the 1970s, it was virtually banned from use in residential paints. Homes built before this period, therefore, are more likely to contain lead-based paint. A re-analysis of the soil samples collected in the HUD National Lead Survey [6] found dwelling unit age to be among "the strongest predictors of soil lead." Francek [10] found the following relationship in Mt. Pleasant, Michigan between age of home and median soil-lead concentration at the home's foundation: less than 20 years, 200 ppm; 20-100 years, 960 ppm; greater than 100 years, 1040 ppm. He also noted a significant correlation, 0.59, between home age and soil-lead concentration. In Portland, Maine, Krueger [11] reported that the average soil-lead concentration collected from the foundations of painted frame buildings at least 30 years old was higher than those collected from other structures (Table 4-2). Figure 4-4 presents geometric means of soil-lead concentrations for samples collected near and far from home by age of housing for the New Haven, Connecticut Lead Study [12].

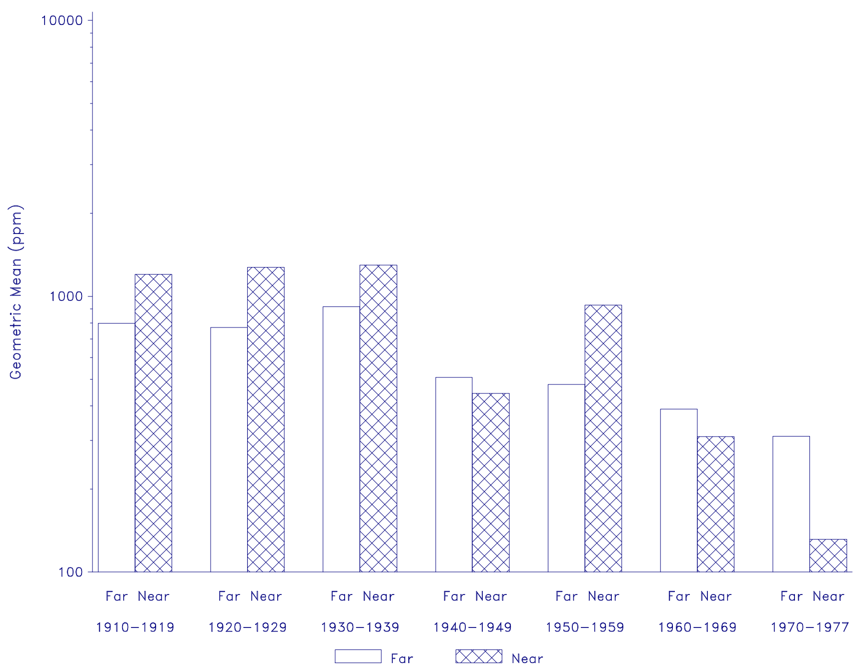

Figure 4-4. Geometric Means of Soil-Lead Concentrations by Year of Construction, Near and Far Samples, New Haven, Connecticut Lead Study.

The type and condition of the residence has also been used in place of direct measurement of paint-lead loading. As a residence deteriorates, paint can enter the soil in the form of flakes or chips. If the home contains lead-based paint, these paint chips could then be a source of lead in the surrounding soil. Thus, older homes, which are more likely to contain lead-based paint, pose an additional hazard as these homes are also the most likely to be in poor condition. In the Cincinnati Longitudinal Lead Study, Bornschein [16] examined the relationship between age, housing condition and soil-lead levels (Table 4-2). As can be seen in Figure 4-5, Bornschein found that older, 19th-century homes in deteriorated condition have a higher geometric mean soil-lead concentration. In addition, a lead-based paint measure, XRF-hazard, which incorporated XRF readings with the condition of the surface sampled, was also developed. A significant correlation coefficient between log(soil-lead concentration) and log(XRF-hazard) was noted (Table 4-3). A study in Mt. Pleasant, Michigan [10] also documented the effect on soil-lead concentrations from lead-based paint as the condition of the building deteriorates. In this study, Francek found a similar relationship between median foundation soil-lead concentrations and condition of the home (Table 4-2).

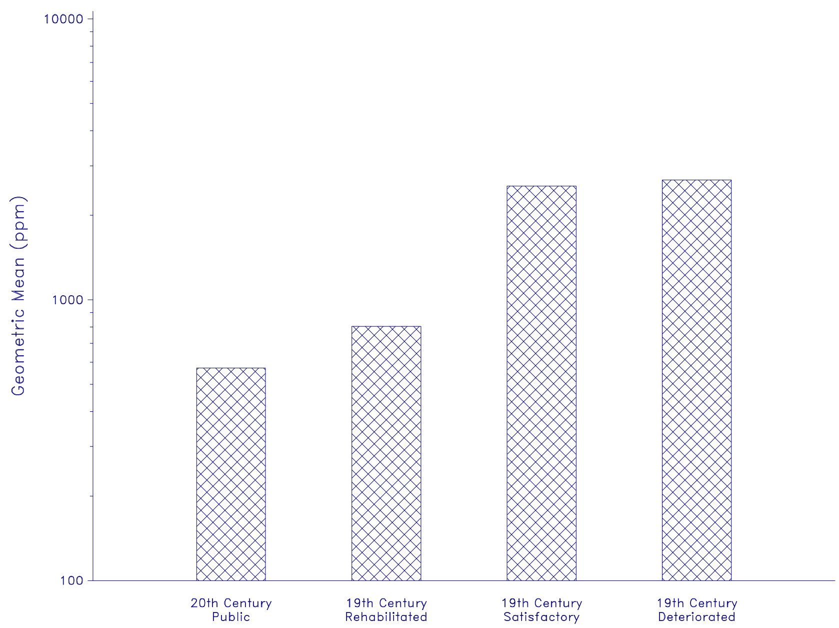

Figure 4-5. Geometric Means of Soil-Lead Concentration by Age and Condition of Home, The Cincinnati Longitudinal Lead Study.

4.4 POINT SOURCE EMITTERS

A point source emitter is a fixed site from which lead emanates. Examples include operating metal smelters and refuse incinerators, areas containing mine tailings, and dump sites for lead-acid batteries. Locations where a point source emitter has been identified as a source of

Figure 4-6. Locations of Studies Identified as Citing a Point Source Emitter as a Source of Soil Lead.

elevated soil lead are identified in Figure 4-6. Unlike leaded gasoline emissions, point-source emissions are particular to an area. There is only a fixed range over which contamination from the emitter may spread. Not surprisingly, the mechanisms by which surrounding soil may be supplied with lead are varied. Mine dross, for example, may spread via erosion and airborne transmittal. A significant portion of the literature on lead contamination has focused on point source emitters, especially formerly operating smelters. Two general types of supporting evidence are commonly employed in assessing point source emitters as the source of elevated soil-lead levels: 1) distance from the source, and 2) association to ambient air-lead concentration. Table 4-4 presents measures of central tendency of soil-lead concentrations (broken down by the type of supporting evidence) as reported in studies identifying a point source emitter as a source of soil lead.

Lead pollution caused by emitters is usually assessed by collecting environmental and body burden measures from homes or individuals residing at varying distances from the point

Table 4-4. Reported Measures of Central Tendency of Soil-Lead Concentrations for Studies Identifying Point Source Emitters as Responsible Source

Study Name	Location	Type of Supporting Evidence	Description	Mean or Median (ppm)	Std. Dev. (ppm)	No. of Soil Samples
Heavy Metal Exposure Smelter Study [A-27]	Bartlesville, OK; Palmerton, PA; Ajo, AZ; Anaconda, MT	Distance from source	Median by distance from the source and community			
			Bartlesville: 3.5-24.0 km	38.4	na	38
			1.3-3.7 km	243	na	38
			0.8-4.3 km	829	na	38
			Palmerton: 11.0-26.0 km	532	na	42
			5.4-14.5 km	117	na	42
			3.3-9.9 km	326	na	42
			Ajo: 3.4-68.0 km	57.8	na	53
			1.0-6.4 km	64.5	na	53
			0.5-2.3 km	76.5	na	53
			Anaconda 10.0-26.0 km	75	na	49
			3.5-21.0 km	115	na	49
			2.0-11.0 km	294	na	49
Butte Silver-Bow Environmental Lead Study [A-5]	Butte, MT	Distance from source	Geometric Mean and Std. Dev for perimeter soil level by community area: Area A	750.24	2.45	145
			Area B	249.75	1.70	10
			Area C	139.45	2.70	7
			Area D	234.31	2.33	9
			Area E	151.02	2.14	21
			Area F	178.17	1.89	12
			Area G	1030.56	1.46	11
Dallas Soil-Lead Contamination Study [A-21]	Dallas, TX	Distance from source	Isopleth Estimate of Lead Conc: DMC-Smelter 1			
			Inside Area	3000	na	na
			Outside Area	300	na	na
			RSR-Smelter 2			
			Inside Area	2500	na	na
			Outside Area	300	na	na
			Reference			
			Inside Area	500	na	na
			Outside Area	200	na	na
El Paso, Texas Lead Study [A-23]	El Paso, TX	Distance from source	Geometric Mean by proximity to smelter: Area 1 (0-2.1 miles)	1791	na	82
			Area 2 (2.1-4.2 miles)	684	na	184
			Area 3 (4.2-6.3 miles)	370	na	200
			Within 200 meters	3457	na	54

Table 4-4. Continued

Study Name	Location	Type of Supporting Evidence	Description		Mean or Median (ppm)	Std. Dev. (ppm)	No. of Soil Samples
Helena Valley Lead Study [A-2]	East Helena, MT	Distance from source	Geometric Mean by area and soil location	Area 1 (<1 mile)			
				Comp.	720	na	71
				Side	796	na	71
				Play	365	na	55
				Garden	539	na	27
				Area 2 (1-2.25 miles)			
				Comp.	217	na	167
				Side	169	na	93
				Play	121	na	117
				Garden	179	na	49
				Area 3 (>5 miles)			
				Comp.	86	na	28
				Side	92	na	28
				Play	73	na	20
				Garden	95	na	5
Silver Valley - Revisited Lead Study [A-12]	Kellogg, ID	Distance from source	Geometric Mean by area and soil location	Area 1 (1 mile)			
				Comp.	3474	na	28
				Foundation	5163	na	29
				Play	3616	na	11
				Garden	507	na	2
				Area 2 (1-2.25 miles)			
				Comp.	2632	na	129
				Foundation	2512	na	121
				Play	996	na	59
				Garden	978	na	17
				Area 3 (2.56 miles)			
				Comp.	481	na	78
				Foundation	541	na	74
				Play	431	na	29
				Garden	318	na	20

Table 4-4. Continued

Study Name	Location	Type of Evidence	Description		Mean or Median (ppm)	Std. Dev. (ppm)	No. of Soil Samples
Leadville Metals Exposure Study [A-9]	Leadville, CO	Residential Area pattern	Geometric Mean and Std. Dev. by residential soil location	Core front Core rear Core play Surface play Surface entry	1108.3 914.7 572.3 868.1 1878.9	2.8 3.1 3.3 3.7 2.2	168 166 37 111 169
Midvale Community Lead Study: Final Report [A-13]	Midvale, UT	Residential Area pattern	Geometric Mean and Std. Dev. by soil locations	Perimeter Garden Bare Surface	341.81 294.59 313.20 77.95	2.45 2.65 2.60 5.52	112 46 88 42
Omaha Lead Study [A-8]	Omaha, NA	Community area pattern	Geometric Means by location in community	Site C Site M Site S	262 339 81	na na na	69 56 51
Aspen Garden Soil-Lead Study [A-22]	Aspen, CO	na	Arithmetic Mean and Std. Dev.		172	155	65
Granite City Lead Exposure Study [A-34]	Granite City, IL	na	Arithmetic Mean and Std. Dev.		449	420	338
Telluride Lead Study [A-18]	Telluride, CO	na	Geometric Mean and Std. Dev	Surface Soil Core	178 145	2.5 3.2	45 45

na = Not available

Table 4-4. Continued

Study Name	Location	Type of Evidence	Description		Mea Med (p
Leadville Metals Exposure Study [A-9]	Leadville, CO	Residential Area pattern	Geometric Mean and Std. Dev. by residential soil location	Core front	110
				Core rear	91
				Core play	57
				Surface play	86
				Surface entry	187
Midvale Community Lead Study: Final Report [A-13]	Midvale, UT	Residential Area pattern	Geometric Mean and Std. Dev. by soil locations	Perimeter	34
				Garden	29
				Bare	313
				Surface	77
Omaha Lead Study [A-8]	Omaha, NA	Community area pattern	Geometric Means by location in community	Site C	2
				Site M	3
				Site S	[illegible]
Aspen Garden Soil-Lead Study [A-22]	Aspen, CO	na	Arithmetic Mean and Std. Dev.		1
Granite City Lead Exposure Study [A-34]	Granite City, IL	na	Arithmetic Mean and Std. Dev.		4
Telluride Lead Study [A-18]	Telluride, CO	na	Geometric Mean and Std. Dev		
				Surface Soil	1
				Core	1

na = Not available

source. Often, the community is partitioned into three or more areas of varying distance from the point source emitter (Table 4-4). For example, in the Silver Valley-Revisited Lead Study [17] the community was partitioned into three concentric rings emanating from the smelter site. The soil-lead levels from various locations, such as foundation or play areas, were then compared over the locations to determine if differences exist due to distance from the point source. Figure 4-7 displays geometric means of lead loading for composite soil samples by distance from point source for three smelter studies: El Paso, Texas Lead Study [19], Helena Valley Lead Study [20], and Silver Valley-Revisited Lead Study [17]. In the Midvale Community Lead Study [22] a correlation coefficient of -0.68 between maximum soil-lead concentration at the residence and the distance to the mill building was reported. Brown [23] used geostatistical methods to generate isopleths of constant soil-lead concentrations in the area of two Dallas, Texas smelters. The isopleths, which show increasing soil-lead concentrations in the vicinity of the smelters, "support the conclusion that the smelters are the primary sources of lead contamination in the area." In addition, the Heavy Metal Exposure Study [60] found that "there was a general trend toward increasing levels of environmental metal burdens with proximity to the smelter." The evidence for the emitter being the contributing source of the lead, therefore, stems from increasing soil-lead concentrations with decreasing distance from the emitter.

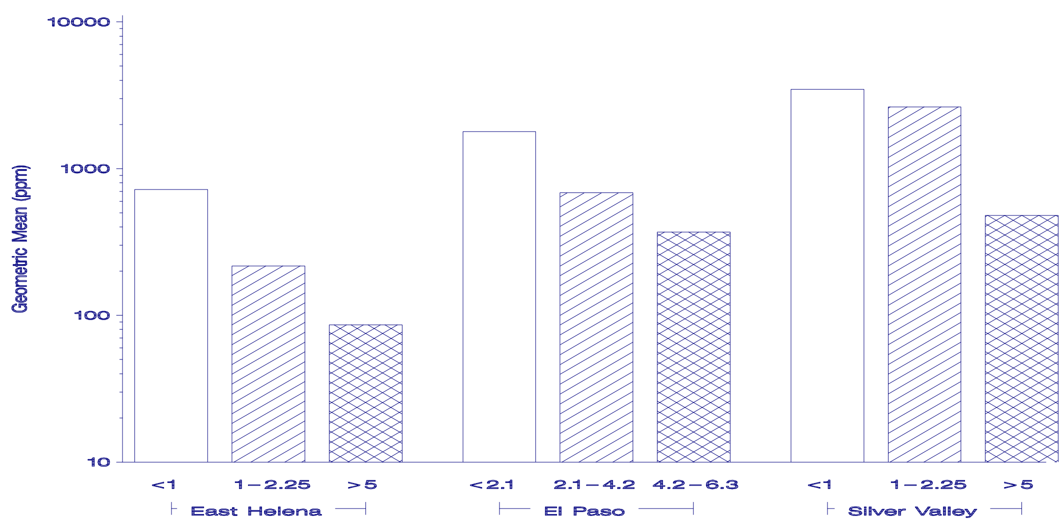

Figure 4-7. Geometric Means of Lead Loading for Composite Soil Samples by Distance from Point Source (miles).

In those instances where the emitter consistently produces airborne lead emissions, relationships may sometimes be drawn between ambient air-lead levels and soil-lead concentration. The Silver Valley-Revisited Lead Study [17] conducted in northern Idaho, for example, found a 0.52 correlation coefficient between composite soil-lead concentration from the residence and ambient air-lead levels. Other studies have noted that soil-lead concentrations may follow geographical distributions similar to those determined for ambient air-lead levels [19]. If the emitter is the primary active source of lead into the environment, it should not be surprising to find associations between ambient air-lead levels and soil-lead concentration.

4.5 LEADED GASOLINE EMISSIONS

Until its phase-out in the 1980s, the primary use of lead in the United States was as a performance additive to gasoline. Unfortunately, most of that lead (approximately 75%) was discharged into the environment through vehicle exhaust. The emitted lead particles have spread well beyond the confines of the roadway. After decades of leaded gasoline usage, the environment now contains a tremendous reservoir of lead. This reservoir is retained in the surrounding soil and dust. Locations where leaded gasoline emission has been identified as a source of elevated soil lead are identified in Figure 4-8.

Studies of this source of contamination have included assessments of soil-lead contamination near highways and the implications of leaded gasoline emissions in the urban environment. Four general types of supporting evidence have been used within the literature in examining leaded gasoline as a source of lead in soil: 1) distance from the roadway, 2) association with ambient air-lead levels, 3) association with traffic volume, and 4) community area pattern. Table 4-5 presents measures of central tendency of soil-lead concentrations (broken down by type of supporting evidence) as reported in studies identifying gasoline emissions as a source of soil lead.

Figure 4-8. Locations of Studies Identified as Citing Gasoline Emissions as a Source of Soil Lead.

Approximately, 40% of the lead emitted as vehicular exhaust is in sufficiently large particles to be deposited near the roadway. It seems reasonable, therefore, that soil-lead concentration would decrease with increasing distance from the roadway. This, in fact, is borne out in the literature. A longitudinal study of soil-lead concentration adjacent to a newly constructed roadway conducted near Beltsville, Maryland [24] noted that, “soil Pb levels decreased with distance from the roadway [8, 25, 50 meters] and with depth [0-5, 5-10, 10-15 cm] in the soil profile.” (Figure 4-9, Table 4-5). In Honolulu, Hawaii, Fu [25] noted that soil-lead concentration from a boulevard median strip adjacent to a park was 1650 ppm, and that, “elsewhere through the park, soil [lead levels] fell with distance from the boulevard but rose again as the beach road was reached.” Even in the more rural community of Mt. Pleasant, Francek [10] measured median soil-lead concentration in roadside soils of 280 ppm (range: 100-840 ppm), compared to 200 ppm (range: 100-220 ppm) in background soils.

Table 4-5. Reported Measures of Central Tendency of Soil-Lead Concentrations for Studies Identifying Gasoline Emissions as Responsible Source

Study Name	Location	Type of Supporting Evidence	Description		Mean or Median (ppm)	Std. Dev. (ppm)	No. of Soil Samples
Albuquerque Street Dirt Lead Study	Albuquerque, NM	Distance from Source	Arithmetic Mean and Std. Dev. by sampling locations				
			Site A	Close	1770	240	na
				Distant	1120	190	ns
			Site B	Close	3720	820	ns
				Distant	2600	180	ns
			Site C	Close	4860	430	ns
				Distant	3660	220	ns
Beltsville Roadway Study	Beltsville, MD	Distance from source	Arithmetic Mean and Std. Dev. by side and distance from roadway, samples collected 0-5 cm in depth	East Side			
				8 meters	108.8	98.6	5
				25 meters	32.72	18.29	5
				50 meters	14.16	8.49	5
				West Side			
				8 meters	87.37	60.46	7
				25 meters	25.42	8.96	7
				50 meters	19.2	4.88	7
Corpus Christi Soil Lead Study	Corpus Christi, TX	Distance from source	Arithmetic mean and Std. Dev	Near Major Highways	250	250	379
				Not Near Major Highways	55	66	94
				Parks	57	77	12
				Schools			

Table 4-5. Continued

Study Name	Location	Type of Supporting Evidence	Description	Mean or Median (ppm)	Std. Dev. (ppm)	No. of Soil Samples
Charleston Lead Study	Charleston, SC	Traffic Volume	Median traffic volume (cars / day) by location and soil level (ppm): Facing Street PbS<585	100	na	na
			Facing Street PbS>585	100	na	na
			All Streets w/in 76 m PbS<585	8875	na	na
			All Streets w/in 76 m PbS>585	8550	na	na

Table 4-5. Continued

Study Name	Location	Type of Supporting Evidence	Description	Mean or Median (ppm)	Std. Dev. (ppm)	No. of Soil Samples
Cincinnati Roadside Soil Study	Cincinnati, OH	Traffic Volume	Arithmetic Mean and Std. Dev by Average Daily Traffic Volume >20,000 8,000-20,000 <8,000	1125.7 999.7 886.9	1282.8 1043.5 623.5	60 60 60
Illinois Soil Lead Study	Chicago, IL	Traffic Volume	Arithmetic mean and Std. Dev. for surface samples not near play equipment by traffic volume (cars / day) <5000 5000-9999 10000-19999 20000-49999 >50000	90 141 187 265 236	13 33 23 26 41	96 30 77 87 63
Mt. Pleasant Soil Lead Study	Mt. Pleasant, MI	Traffic Volume	Arithmetic means and Std. Dev. by average daily traffic volume Heavy (ADT: >20000) Moderate (ADT:8000-20000) Light (ADT:<8000)	343 345 286	106 170 126	33 14 26
Baltimore, MD Urban Garden Soil Study	Baltimore, MD	Area Pattern	Median for all inner city residences (largely non-painted brick)	100	na	422
Champaign-Urbana Lead Study	Champaign-Urbana, IL	Residential Area Pattern	Median by location Near Side Lawn Near Rear Lawn Far Front Lawn Far Lawn	50 100 70 40	na na na na	na na na na

Table 4-5. Continued

Study Name	Location	Type of Supporting Evidence	Description	Mean or Median (ppm)	Std. Dev. (ppm)	No. of Soil Samples
Minnesota Soil Lead Study	Duluth Minneapolis Rochester St. Cloud St. Paul, MN	Residential Area Patterns	Geometric means and Std. Dev			
			Duluth- Foundation	455	5.2	32
			Open Area	38	2.7	19
			Minneapolis- Foundation	665	3.5	199
			Open Area	39	3.7	51
			Rochester- Foundation	65	8.4	19
			Open Area	23	4.1	15
			St. Cloud- Foundation	85	7.5	13
			Open Area	25	4.9	18
			St. Paul- Foundation	472	4.5	127
			Open Area	66	3.7	95
New Orleans Lead Study	New Orleans, LA	Community area pattern	Median by location in community and around the home			
			Inner City- Foundation	840	201	na
			Streetside	342	723	na
			Open Area	212	74	na
			Mid City- Foundation	110	220	na
			Streetside	110	765	na
			Open Area	40	80	na
			Suburban- Foundation	50	332	na
			Streetside	86	195	na
			Open Area	28	114	na
Omaha Lead Study	Omaha, NA	Community area pattern	Geometric Means by location in community Site C	262	na	69
			Site M	339	na	56
			Site S	81	na	51
Survey of Lead Levels Along Interstate 880	Alameda County, CA	na	Arithmetic Mean East of Highway	594.3	na	116
			West of Highway	263.3	na	22
Brigham and Women's Hospital Longitudinal Lead Study	Boston, MA	na	Median soil-lead level	365	na	195

Table 4-5. Continued

Study Name	Location	Type of Supporting Evidence	Description	Mean or Median (ppm)	Std. Dev. (ppm)	No. of Soil Samples
Honolulu Park Soil Lead and Mercury Study	Honolulu, HI	na	Arithmetic Means and Std. Dev. 1972 Survey 1987 Survey	467 367	93 37	14 18

na = Not available

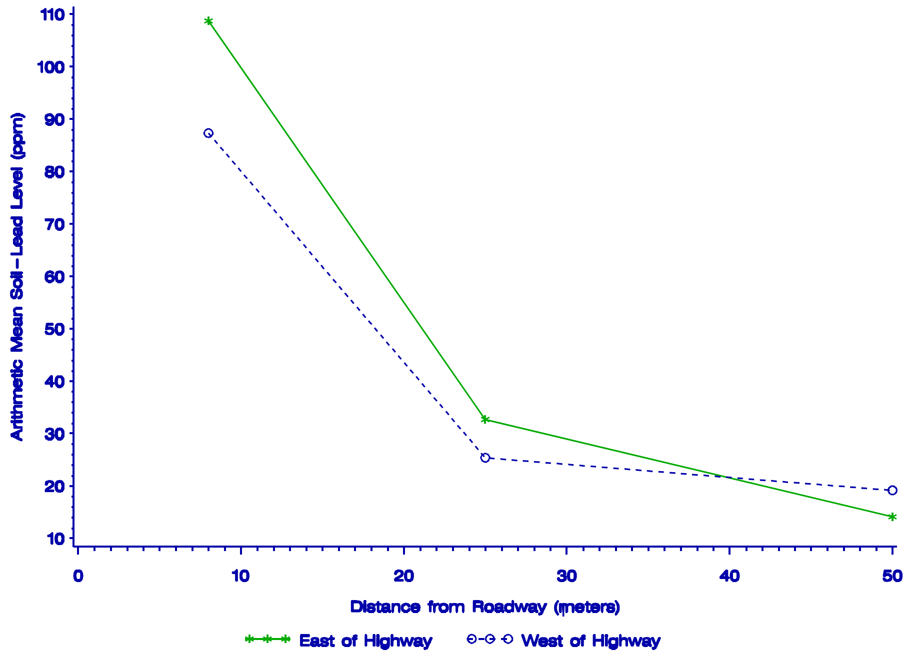

Figure 4-9. Arithmetic Mean Soil-Lead Concentrations for 0-5 cm Samples Collected 8, 25, and 50 Meters from a Roadway, Beltsville Roadway Study.

Some studies have found associations between ambient air-lead levels and the concentration of lead in the surrounding soil. Even if a point source emitter is not located nearby, such association may suggest leaded gasoline as a source only if the study was conducted while leaded gasoline was still commonly utilized. A 1977 study in Omaha, Nebraska reported a 0.37 correlation coefficient between ambient air-lead levels and composite residence soil-lead concentration [26]. Similarly, a Boston, Massachusetts study in the early 1980s estimated a 0.18 correlation coefficient [3]. Both studies were conducted while leaded additives were prevalent. With the phase-out of these additives, such associations are unlikely to be observed, but there are other approaches, such as tracer analysis, for considering the extent of the relationship between leaded gasoline emissions and lead in soil.

Soil-lead concentrations were also analyzed as a function of traffic volume on nearby roadways. As the number of vehicles emitting lead exhaust increases, one would expect the lead concentration in surrounding soil to elevate. In Charleston, South Carolina, Galke [29] noted that for residences with soil-lead concentration less than 585 ppm, the median traffic volume within 250 feet was 1100 cars/day. In contrast, residences with soil-lead concentration exceeding 585 ppm had a median traffic volume of 3200 cars/day. Figure 4-10 shows arithmetic means of soil-lead concentrations by traffic volume as reported in the Illinois Soil Lead Study [30].

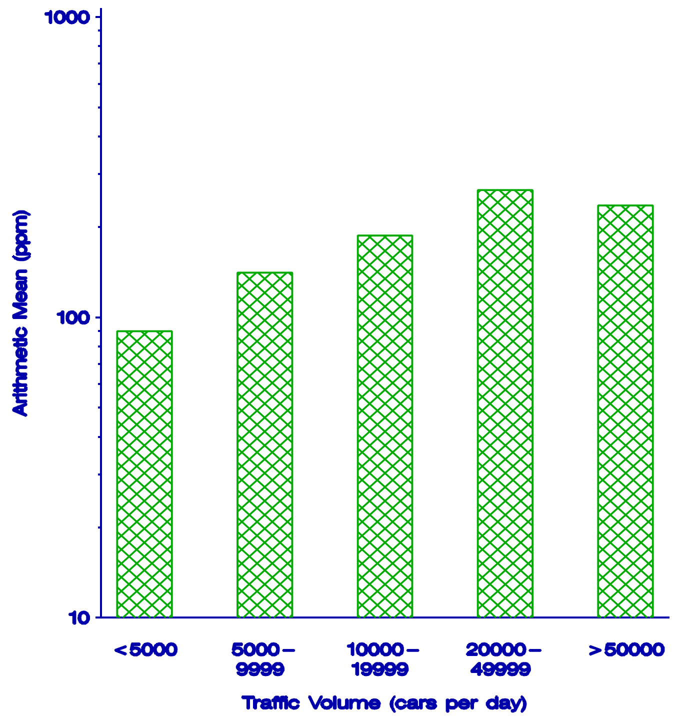

Figure 4-10. Arithmetic Means of Soil Lead Concentrations by Traffic Volume as Reported in the Illinois Soil Lead Study.

Some authors have hypothesized that traffic volume alone is insufficient to explain the nearby soil-lead levels. Harrison [31], for example, suggests that the velocity of the traffic is also important. Heavily congested roadways with gridlocked, idling traffic may produce higher soil-lead levels than more rapidly moving traffic. There is some evidence to support this hypothesis.

Researchers have found that soil-lead concentration area patterns in communities often follow the highway infrastructure. This is particularly true in urban environments. Mielke has reported that the highest lead concentrations in soil in both Baltimore [32] and Minneapolis-Saint Paul [33] were clustered toward the center of the city. Preliminary results in the city of New Orleans [34] suggested a similar pattern. In the case of Baltimore, the probability that the clustering occurred by chance was less than 10^{-23}. Furthermore, "the most consistently high garden soil Pb levels were found in the area of the city that was predominantly unpainted brick buildings [35].” In Corpus Christi, Texas [31], soil-lead concentration was reported to be concentrated in and around its roadways. Angle examined three communities in Omaha, Nebraska [26]: a suburban neighborhood (S), an urban-commercial area (C), and an urban area contiguous to downtown (M) (Table 4-5). Most inner cities have tightly clustered, congested roadways. These roadways spread out as they emanate from the city’s center. Leaded gasoline emissions appear to have often polluted the surrounding soil accordingly.

5.0 CONCLUSIONS

This study confirmed the commonly assumed pairwise associations between elevated soil-lead levels and lead-based paint, leaded gasoline emissions, or point source emissions. Such a confirmation is not altogether surprising, but it is an important step in any effort to reduce and preclude childhood exposure to elevated soil-lead concentrations. No definitive evidence was found within the literature, however, suggesting a particular source can be regularly identified as responsible for elevated soil-lead concentrations at a residence. In fact, many studies cite more than one source as commonly responsible for elevated soil-lead levels. Moreover, labor- and cost-intensive techniques for carefully apportioning the sources of in soil suggest varying relative contributions from candidate sources. It may be possible on a case-by-case basis to apportion the responsible sources, but no generalizations are possible based on readily obtained categorical factors (e.g., urban verus rural, northeast versus southwest). Nevertheless, as the associations between these sources and elevated soil-lead levels have been confirmed, interventions targeting these sources should prove beneficial in reducing the instances of elevated lead levels in soil. In particular, lead-based paint interventions, such as those prompted by promulgation of the §403 standards, will have the additional benefit (above and beyond any benefit seen in reduced indirect exposure to elevated dust-lead levels and direct exposure to paint chips) of removing a source of lead in soil.

In many communities, the elevated soil-lead levels are due to a combination of sources, and it is often difficult to determine whether the elevated soil-lead levels are a function of a point source emitter, lead-based paint, or leaded gasoline emissions. Lead contamination of soil is additive; additional sources simply increase the extent of the contamination. One difficulty in determining which potential source contributes to elevated soil-lead levels, therefore, is due to the fact that there are often multiple sources within a community. In addition, differences in study design and confounding regional differences also hinder attempts to determine whether a particular source is responsible for elevated soil-lead levels.

Rural environments with old, painted structures or urban communities with brick buildings may be easily classified. Urban communities with painted structures, however, are more difficult. Even more complex to classify are those cities with smelter or waste incinerator sites. Urban renewal, soil erosion, and landscaping confound the issue. The problem stems, to some extent, from the mechanism of lead contamination by vehicular emissions. Whereas approximately 40% of the discharged lead from leaded gasoline was in large particles, 35% or so was in the form of tiny particles able to disperse over large areas from the roadway [1]. In a typical urban environment, these small particles may have spread lead over the majority of the city. The extent of resulting lead exposure may be a function of wind direction and weather pattern. Chaney and Mielke [35], among others, assert that the particles, "waft through the city and adhere to surfaces they come in contact with." These particulates may then be washed down into the surrounding soil. Areas with large surfaces would, by this hypothesis, attract more of these small particles. This suggests that elevated soil-lead concentration at an urban residence's foundation may not strictly be a function of lead-based paint. Elevated levels may also stem from leaded gasoline emissions due to the large surface area presented by the external walls and roof of the residence. For residences with large yards, this suggests a pattern of soil lead exposure highest near the roadway, gradually decreasing toward the center of the yard, only to elevate again near the residence's foundation.

While there is no definitive assessment concerning this hypothesis, some supporting evidence does exist. Soil samples collected next to the roadways in the Twin Cities [46] were found to be closely related to samples collected at the foundations of adjacent residences. A significant correlation coefficient of 0.72 was reported. Linton [36] employed sophisticated source identification techniques to inspect a foundation soil sample collected next to a brick building with lead-based paint covering the window trim. Despite the building being more than 50 feet removed from a major roadway (2000 cars/day), "it is estimated that 80-90% of lead present in this building line sample is derived from paint chips with the remaining 10-20% being of automobile origin." In addition, a few studies such as Mt. Pleasant Soil Lead Study [10] have found elevated foundation soil-lead concentration near modern homes. Due to the fact that these are modern homes, they were considered to have a low risk of containing lead-based paint.

Another complicating factor in identifying the responsible source of soil-lead concentration is that many cities in the United States grew outward from a central core. Older homes, which are more likely to have been coated with lead-based paint, are typically located in the center of the city. Thus, residences with lead-based paint already elevating their surrounding soil were also exposed to higher leaded gasoline emissions. Differentiating between the two prospective sources becomes extremely difficult. If these same communities are also the city's poorest, the deteriorated condition of the dwellings make differentiation nearly impossible.

Finally, regional differences are often confounded with differences in study design and objectives. In many cases, the age distribution and composition of the sampled houses differs from region to region across the United States. In addition, the soil composition and background levels may vary substantially from region to region. These regional differences hinder attempts to compare from study to study, the relative contamination from a particular source. There are simply too few studies conducted under sufficiently similar circumstances to allow reasonable comparison. For this reason, it is difficult to make any sweeping generalizations about the geographic distribution of the sources of elevated soil lead.

It does appear, however, that lead-based paint is often responsible for higher concentrations of lead in the surrounding soil. Within the literature, the highest soil-lead concentration levels are invariably at the foundation of buildings with flaking lead-based paint. For example, geometric mean soil-lead concentrations adjacent to wood-sided residences were more than three times higher than those adjacent to brick residences (522 ppm/158 ppm) in the Minnesota Soil Lead Study [7]. Whereas leaded gasoline emissions spread their lead exposure over a wide area, lead-based paint likely contaminates a relatively small region about the residence. The remarkably high concentrations of lead found in the soils adjacent to residences may be a function of the sheer volume and concentration of lead in the painted surfaces.

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