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Evaluation of landscape coverings to reduce soil lead hazards in urban residential yards: The Safer Yards Project

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Abstract

This study was designed primarily to evaluate the effectiveness of landscape coverings to reduce the potential for exposure to lead-contaminated soil in an urban neighborhood. Residential properties were randomized in to three groups: application of ground coverings/barriers plus placement of a raised garden bed (RB), application of ground coverings/barriers only (no raised bed, NRB), and control. Outcomes evaluated soil lead concentration (employing a weighting method to assess acute hazard soil lead [areas not fully covered] and potential hazard soil lead [all soil surfaces regardless of covering status]), density of landscape coverings (6 = heavy, >90% covered; 1 = bare, <10% covered), lead tracked onto carpeted entryway floor mats, and entryway floor dust lead loadings. Over 1 year, the intervention groups had significantly reduced acute hazard soil lead concentration (median change: RB, −478 ppm; NRB, −698 ppm; control, +52 ppm; Kruskal–Wallis, $P = 0.02$), enhanced landscape coverings (mean change in score: RB, +0.6; NRB, +1.5; control, −0.6; ANOVA, $P < 0.001$), and a 50% decrease in lead tracked onto the floor mats. The potential hazard soil lead concentration and the entryway floor dust lead loading did not change significantly. Techniques evaluated by this study are feasible for use by property owners but will require continued maintenance. The long-term sustainability of the method needs further examination.

Keywords: Lead-contaminated soil; Landscape; Soil lead hazard; Intervention; Residential yards

1. Introduction

Lead is a ubiquitous environmental contaminant, which negatively impacts child health by causing cognitive and behavioral impairments (Centers for Disease Control and Prevention (CDC), 2002). Children living in urban areas are at increased risk for lead poisoning. The prevalence of an elevated blood lead level (defined as blood lead ⩾10 μg/dL) among children living in older homes in urban areas with a population of one million or more is approximately twice that found for children living in older homes in less populated areas (CDC, 1997). One risk factor for lead exposure that may differ between urban and nonurban areas is lead contamination of soil. Urban soils may be highly contaminated (Mielke, 1991, 1994; Shinn et al., 2000). Further, models describing movement of lead in the environment indicate transference of lead from exterior to interior sites (Succop et al., 1998).

The contribution of various sources of lead, including lead-contaminated soil, to childhood lead poisoning has been clearly demonstrated (Lanphear et al., 1998a, b; von Lindern et al., 2003). Recently, the US Environmental Protection Agency (USEPA) evaluated published research and used modeling methods to further

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evaluate the risks of lead-contaminated soil and to aid in setting soil-lead hazard standards (Federal Register, 1998, 2001). The USEPA Final Rule on lead established a soil lead hazard at 400 parts per million (ppm) for bare soil in play areas and an average of 1200 ppm for bare soil in the remainder of the yard (Federal Register, 2001). They estimated that 1–5% of children exposed to soil lead concentrations at levels generally at or below 500 ppm would, as a result, develop a blood lead level at or above 10 μg/dL (Federal Register, 1998). The risk was estimated to be much greater for exposure to soil lead at a concentration of 1200 ppm; at that level 30–60% of exposed children would have a blood lead level at or above 10 μg/dL (Federal Register, 2001).

Lead contamination of soil in US cities occurred over many decades, with sources of lead from paint, gasoline, and industry contributing to the lead burden (CDC, 1991). Lead is relatively immobile in soil (USEPA, 1986a) and does not biodegrade or decay. It is unevenly distributed in residential yards, with higher levels generally found near building foundations (USEPA, 1993). Because of its invisible and lasting nature, contamination of residential yards will continue to threaten children's health, even after interior and exterior building lead hazards have been repaired. Therefore, it is important to examine ways to reduce the potential for exposure to lead-contaminated soil.

This study was designed to evaluate lead contamination of urban residential yards and the effectiveness of lower-cost strategies—those that may be affordable to homeowners or tenants and do not involve costly soil removal and replacement—to reduce the potential for exposure to hazards posed by lead-contaminated soil. The major strategy employed involved creating barriers to bare soil through enhanced landscape coverings. Outcome measures included soil lead concentration, assessments of the density of ground coverings, measurement of lead tracked onto entryway carpeted floor mats, and assessments of entryway floor dust lead loadings.

2. Methods

2.1. Subjects

The study was conducted in two residential areas of Chicago (one of four blocks, one of six blocks) approximately 1 mile apart. It builds upon work previously conducted in one of these areas (Shinn et al., 2000). Property owners were recruited for a longitudinal study designed to assess effectiveness of lower-cost methods applied to reduce potential exposure to lead-contaminated soil. Those expressing the intent of selling their property within 2 years were not enrolled. Primary residence of the property owner at the site was not required for participation nor was the presence of children in residence at the property. Additionally, there was no requirement for prior control of exterior lead paint hazards nor was such offered by the project. The children or families living at the property were not the subjects of study, although all were notified of the project and provided with lead education materials. A goal of enrolling 60 properties, 30 in each area, was sought.

The year of construction for the residence at each property was determined from tax records (available at http://www.newschicago.org; last accessed 10/27/03). This study was approved by the Institutional Review Board of Children's Memorial Hospital.

2.2. Measures

A variety of measures were used to evaluate soil lead contamination, landscape coverings, and track-in of lead. All aspects of the measures and assessments were conducted in Spring 2000 (baseline) and again in Spring 2001 (12 months). Components of the assessments were also conducted at some properties in Fall 2000 (6 months) and Fall 2001 (18 months). Property easement areas (i.e., the area between the sidewalk and the street, which is owned by the city) were evaluated and received intervention but were not included in analyses.

Laboratory tests were conducted at the Illinois Department of Public Health State Laboratory. This laboratory is accredited with the American Industrial Hygiene Association Environmental Lead Laboratory Accreditation Program and successfully participated in its proficiency-testing program for soil and dust wipe samples during the study period. The laboratory reported the full range of results, including results that were below the value defined as the instrumental detection limit. Analyses used values both above and below the defined instrumental detection limit, as has been established (personal communication, Warren Galke, Ph.D., National Center for Healthy Housing, Columbia, MD [now at National Institute of Child Health and Human Development, Bethesda, MD], presented at the 127th Annual Meeting & Exposition. American Public Health Association, Chicago, Illinois; November 10, 1999).

Property assessments. Illinois-licensed lead risk assessors conducted property assessments and collected samples. There were three lead risk assessors who participated in these assessments. Assessors worked in pairs until each had established familiarity with methods and assessment techniques. Each property was mapped using a grid scale of 6 inches. At the baseline evaluation, functional areas of each property were defined on the map by location, type of covering, and use. For example, garden and lawn areas were surveyed and mapped as separate, distinct zones. At all properties, the areas of foundation perimeter soil were mapped separately from surrounding land. A median of 8 zones (range 2–15) were defined per property at the baseline evaluation. At later evaluations, the zones were subdivided on the map, as necessary, to account for changes in ground covering and use. The area of each map-defined zone was calculated by entering the coordinates into computer-aided design software (AutoCAD Release 14.01; Autodesk, Inc., 1998).

Building assessments. Visual assessments of building exteriors and the interior at the most commonly used entryway were conducted in Spring 2000 and Spring 2001. Entryway location and paint conditions of individual components using intact, fair, or poor designation standards detailed in published guidelines (US Department of Housing and Urban Development (USHUD), 1995) were noted. Building exterior construction was classified into three groups: brick or stone, brick or stone plus other (e.g., brick front façade with wood or siding at sides and back or brick building with enclosed back porch of wood), and other (no brick or stone exterior components).

Portable X-ray fluorescence measurements of paint-lead content were conducted on entryway components in poor condition on one occasion, either Spring 2000 or Spring 2001. Forty-two properties had an entryway component with paint in poor condition and 39 of these (93%) were evaluated by X-ray fluorescence to determine whether the paint in poor condition had a lead content greater than or equal to 1.0 mg/cm^2.

Ground coverings assessments. For each defined zone of the property, the density of the ground covering was graded using a six-point scale (6 = heavy, > 90%; 5 = mostly covered, 75–90%; 4 = medium, 50–74%; 3 = some covering, 25–49%; 2 = very sparse, 10–24%; 1 = bare, < 10%). Additionally, the assessors noted the most probable use of the zone (e.g., lawn, garden, play area, etc.) and the type of covering (e.g., grass, flowers/vegetables, shrubs, mulch, stone, etc.). All zones graded at baseline were reevaluated and graded at followup. The evaluation of ground coverings was accomplished in Spring and Fall 2000 and Spring and Fall 2001.

Soil samples. Samples of surface soil (top $\frac{1}{2}$ inch) were obtained from every zone defined in the mapping process in Spring 2000, Spring 2001, and Fall 2001 (baseline, 12 months, and 18 months, respectively). Each sample included 3–10 aliquots of soil that were placed together in the sampling container according to established methods (USHUD, 1995). Soil was obtained from both the bare areas and the areas where the soil could be reached by easy removal of ground coverings, such as mulch, vegetation, or stone. Soil under landscape fabric (which was used to separate coverings from surface soil) was not sampled. Adjacent zones that had similar covering and use were sampled together. For example, lawn areas on the same side of a building separated by a sidewalk were mapped as separate zones, but sampled together. However, soil from lawn areas at the front and back of the home would never be in the same sample. Foundation perimeter soil was always sampled separately from adjoining soil. These methods comprised the strategy that determined the number of soil samples obtained at the property. Baseline soil sampling included a median of 6 samples per property (range 1–13).

A second soil sampling strategy (USHUD sampling strategy) was also applied at baseline (USHUD, 1995). Composite soil samples of (1) foundation perimeter soil and (2) *bare areas* throughout the rest of the yard were obtained at each property according to established protocols.

Soil samples were homogenized by disaggregating compacted soil or debris in the soil sample matrix using a ball grinder with disposable plastic parts for this purpose. Samples were not sieved. Soil samples were analyzed using flame atomic absorption spectrometry instrumentation methodology using SW 846 EPA Method 3050 (USEPA, 1986b), with an instrumental detection limit defined at 60 ppm. A spiked soil sample was submitted for approximately every 50 samples. All spiked samples with low lead concentration (NIST Soil Standard: SRM 2709, San Joaquin Soil [13 μg lead/g soil]) were reported as between 0 and 26 ppm lead. All spiked samples with more elevated lead concentration (NIST Soil Standard: SRM 2711, Montana Soil [1100 μg lead/g soil]) were 87–100% of the expected value.

Dust lead loading. At the time of placement of the floor mat, three floor dust wipe samples were obtained from the commonly used entryway that received the visual evaluation. Standard wipe techniques and materials acceptable in Spring 2000 were used for sampling of surfaces (USHUD, 1995). Dust samples obtained in Spring 2000 (baseline) were analyzed using flame atomic absorption spectrometry with a detection limit of 30 μg lead. Those obtained in Spring 2001 (12 months) were analyzed using inductively coupled plasma-atomic emission spectrometry, having a detection limit of 10 μg, as the laboratory procedures had changed to accommodate lowered dust hazard standards (Federal Register, 2001). On each day of dust sample collection, a blank dust sample was also submitted for analysis and this result subtracted was from sample results for that day. Twenty-five dust blank samples were obtained in each of Spring 2000 and Spring 2001. In Spring 2000 the dust blank median was 3 μg lead, four results were 10–19 μg lead, and one was 77 μg lead. These five higher dust blank results were obtained at homes having very high dust lead loading, so subtraction from the dust sample averages for those properties did not substantially alter dust lead loading distributions. Because only 1 blank sample was obtained per day, the dust blank results of 19 and 77 μg lead were each also applied to a home with very low dust lead loading, so dust lead loading averages at those homes fell from <10 to 0 μg lead/ft^2. In Spring 2001, the dust blank median was 0.6 μg lead, with a maximum value of 2.9 μg lead. A spiked dust sample was submitted for approximately every 50 samples. Results of dust sample spikes were within 90–115% of the expected value.

Carpeted floor mats. Floor mats with a short pile (0.6 cm) fused to a rubber backing (size: 43×74 cm including 2.6-cm rubber border; "Floor Sentry;" AKRO, Canton, OH) were placed at the interior of a commonly used entryway for a period of 7–21 days. The entryway selected also received visual evaluation and dust sampling. The length of the mat was positioned parallel to the doorway threshold and secured to the floor with duct tape. During the period of mat placement, a mechanical device to count door openings that was developed by the project was applied to the door immediately adjacent to the mat. Mats were collected onto $\frac{1}{4}$-inch plywood and wrapped, laterally and lengthwise in 6-mil polyethylene sheeting for transport to the laboratory. The method of Farfel et al. (2001) was adapted for floor mat sample collection. In the laboratory, the entire mat was vacuumed in vertical and horizontal S patterns for 4 min total using a hand-held Dirt-Devil vacuum modified with a cyclone attachment connected to Tygon tubing leading to a nozzle with a serrated tip. The vacuum drew up the surface dust which was trapped in certified contaminant-free nalgene collection bottles. The sample was weighed and lead content analyzed using methods as described for dust above. Floor mat data collection occurred in Spring 2000 (baseline) and Spring 2001 (12 months). Residents at one property declined collection of mat data at the 1-year followup, so data for mat-related measures at that property were not included in analyses.

2.3. Randomization

Following completion of baseline assessments, each property was randomized to one of three groups: (1) intervention with consideration of application of a 4 by 6-foot raised garden bed for testing garden plants (raised bed (RB) group), (2) intervention with consideration of application of a grade-level plant test bed (no raised bed (NRB) group), and (3) deferred intervention (control). Intervention activities were conducted among RB and NRB groups in Summer 2000. Control properties were randomized to RB or NRB groups and had interventions applied in Summer 2001.

2.4. Interventions

Landscape interventions were provided by a nonprofit community agency whose mission is to provide expertise and staffing for community projects that reclaim green space in the city for community use. That agency employed an administrator/director, landscape designer, community crew chief, and a crew of community workers. Property maps and soil lead concentration results guided the landscape design. Additionally, the shade and moisture conditions of each property were evaluated prior to planning the design. Landscape designs and materials were reviewed and approved by property owners.

Design strategies varied by property, but, in general, the following methods were used. For lawn areas in poor condition, existing vegetation was killed using Roundup. The area was then tilled. If below grade, additional topsoil (a sample tested at 14 ppm lead) was applied to meet grade. The areas that received additional topsoil were not tracked. Grass seed blends for shade or sun conditions, as appropriate, were applied. Other grass areas not in poor condition received overseeding. Shady areas or areas too small to mow or not conducive to grass growth were prepared and planted with a perennial groundcover (vinca); then hardwood mulch was applied. Foundation perimeter soil areas and areas under porches with lead content of ⩾2000 ppm were prepared and covered with a landscape fabric and a plastic edging placed before application of 2 in of rotten granite (a red-colored compactable stone). An alternative strategy for areas under porches was to make these areas inaccessible using lattice barriers. Foundation perimeter soil and area under porches with lead content <2000 ppm received treatments similar to the rest of the property. Garden areas received a hardwood mulch covering.

At each intervention property, an attempt to determine a sunny location in which to develop a garden test bed was made. Either (1) creation of a raised test bed or (2) applications of plants grown in a grade-level test bed and/or scattered among existing vegetation was considered according to the randomization strategy for the property. At some properties the test bed was in the foundation perimeter area, so, if indicated by soil lead levels, stone application to those areas was delayed until Fall 2001. Sometimes the sunny conditions of the easement made that area the most suitable location for the test bed. Because analyses do not consider easements, in such cases the property was not counted as having a test bed applied. Raised test beds were created using cedar timbers and purchased soil. While mulch was applied to grade-level garden areas, this was not the case for the raised test beds, which were left uncovered.

Intervention yards were tended throughout the summer and fall of 2000, with final project yard maintenance activity occurring in late September. Spring 2001 evaluations were conducted before yard care activities were commenced by the project at that site, after which intervention homes received reseeding of lawn areas, if needed, and watering of new seed over a

2-week period. The property owner then assumed full responsibility for maintenance of all areas except grade-level test beds, which were maintained by the project. Control properties received interventions in 2001.

2.5. Analysis

For each property, the areas represented by individual soil samples were summed to determine the *accessible soil area*. The *accessible soil area* value from the baseline evaluation was held consent in followup evaluations, except if the property had newly exposed soil. For example, if a cement sidewalk or patio that was present at the baseline evaluation had been removed, the *accessible soil area* for the followup computation increased.

The soil lead concentration of the property was determined by (1) weighting each sample result by the relative contribution that the sampled area contributed to the accessible soil area and then (2) summing the weighted results. This method of weighting was also used to determine a *ground covering score* for each property.

To evaluate soil lead concentration changes due to landscape covering applications, particularly those that may be permanently applied versus those that provide a barrier to lead-contaminated soil only if repeatedly applied, we defined the *acute* and *potential* hazard soil lead concentrations of the property at baseline and followup measurement occasions. *The acute hazard soil lead concentration* considers areas maximally covered to fully protect individuals from soil exposure at that area. The weighted computation for the acute hazard soil lead concentration set soil lead concentration at 0 ppm for areas maximally covered (ground covering grade = 6). The *potential hazard soil lead concentration* includes soil lead concentration for all accessible soil, regardless of covering. Thus, it represents risk if coverings are not maintained. When computing acute and potential hazard soil lead concentrations at followup evaluations, areas that had previously been sampled and for which the soil was no longer accessible (e.g., areas covered by fabric barriers or cement) were assigned a soil lead concentration of 0 ppm.

The following example is provided to clarify differences between *acute* and *potential* hazard soil lead concentration computations. At the baseline evaluation, the *accessible soil area* of a property was 100 ft^2, which was divided into two zones by the mapping process. *Zone* A and *Zone* B were each 50 ft^2. Thus, the *weight* to be applied to the soil lead concentration for each zone is 0.5 ($50\,ft^2/100\,ft^2 = 0.5$). Further, *Zone* A had a ground covering grade of 6 (>90% covered) and a soil lead concentration of 1000 ppm, while Zone B had a ground covering grade <6 and a soil lead concentration of 2000 ppm. Because *Zone* A was heavily covered, the computation of the *acute hazard soil lead concentration* uses a value of 0 ppm as the soil lead concentration for *Zone* A. However, since *Zone* B was not heavily covered, the soil lead concentration of 2000 ppm is used for that zone. Thus, the computation for the acute soil lead hazard concentration is $0\,ppm \times 0.5 + 2000\,ppm \times 0.5 = 1000\,ppm$. For the *potential hazard soil lead concentration* computation the measured soil lead concentration for each zone is used ($1000\,ppm \times 0.5 + 2000\,ppm \times 0.5 = 1500\,ppm$).

On the second assessment of the same property the *accessible soil area* now had three zones. *Zone* A was still 50 ft^2, so the sample weight is unchanged at 0.5. *Zone* B had been divided into two areas (*Zone* B.1 and *Zone* B.2) of 25 ft^2 each (weight: $25\,ft^2/100\,ft^2 = 0.25$). Further, *Zone* A had a ground covering grade <6 and soil lead concentration of 1000 ppm, *Zone* B.1 was covered by cement and could not be sampled, and *Zone* B.2 had a ground covering grade of 6 and a soil lead concentration of 2000 ppm. In this example, both the acute and the potential hazard soil lead concentrations have fallen from their baseline values (acute: $1000\,ppm \times 0.5 + 0\,ppm \times 0.25 + 0\,ppm \times 0.25 = 500\,ppm$; potential: $1000\,ppm \times 0.5 + 0\,ppm \times 0.25 + 2000\,ppm \times 0.25 = 1000\,ppm$).

The *average soil lead concentration* for each property was also determined (Federal Register, 2001). This method computes the simple average of soil samples obtained by the USHUD sampling strategy previously described.

The amount of lead obtained from floor mats was adjusted and reported in two ways. First, micrograms lead per count was determined by dividing the lead weight by the number of counts registered by the mechanical counter over the placement period. Second, micrograms lead per day was determined by dividing the lead weight by the time period over which the floor mat had been applied.

Data were analyzed using SAS, version 8.2 (SAS Institute, Inc., Cary, NC). Significance was set at $P < 0.05$. Distributions for each measure by study group were assessed for normality. As necessary, data were log transformed and then normality was reassessed. Analyses were conducted using χ^2 and Fisher's exact test for categorical data, Kruskal–Wallis (K–W) or Mann–Whitney U (MWU) tests for continuous data for which a normal distribution could not be achieved, and analysis of variance (ANOVA) for normally distributed continuous data.

3. Results

3.1. Recruitment and sampling

The owners of 63 properties consented to the project and their properties were assessed by mapping, evaluation of ground coverings, and soil sample collection. At 1 property, only the easement area had any accessible soil, so this property was excluded. The remaining 62 properties were randomized (Fig. 1). Fifty-seven properties (92%) completed 1 year of participation and were included in analyses. Excluded properties either were not sampled at the 1-year followup due to changes in ownership or withdrawal ($n = 4$) or received incomplete intervention due to exterior construction ($n = 1$). Five of the 19 properties that had been randomized to receive a raised garden bed did not receive that application due to property considerations or owner lack of consent. Those 5 properties were analyzed with the NRB group. Thus, final analytic groups included 14 properties in the RB group, 23 in the NRB group, and 20 in the control group.

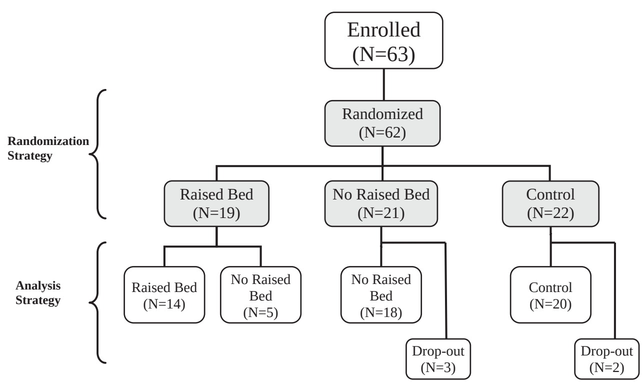

Fig. 1. Randomization and analytic strategies.

Property characteristics are reported in Table 1. Most homes were over 100 years old, owner-occupied, and of the standard size for Chicago lots (25×125 feet) with about 75% of the land covered by buildings or cement.

Baseline measures are shown in Table 2. Groups did not differ significantly on baseline acute hazard soil lead levels (K–W test, $P = 0.54$), potential hazard soil lead levels (K–W test, $P = 0.28$), ground coverings score (ANOVA, $P = 0.21$), floor mat lead/day (ANOVA, $P = 0.25$), or dust lead loading (ANOVA, $P = 0.11$). Groups differed significantly on floor mat lead/count (ANOVA, $P = 0.04$); the group receiving a RB intervention had higher levels.

Relationships between baseline measures were examined. Among the 54 properties that had entryway paint condition assessments and paint lead content evaluations using X-ray fluorescence, properties with paint in

Table 1
Baseline property characteristics

	Analytic strategy			Analytic test, P
	Raised test bed ($n = 14$)	No raised test bed ($n = 23$)	Control ($n = 20$)	
Year home built	1891	1895	1891	K–W, 0.328
Median (range)	(1885–1904)	(1880–1929)	(1879–1937)	
Owner occupied, No. (%) yes	10 (71%)	18 (78%)	15 (75%)	Fisher's exact test, 0.92
Exterior structure, No. (%)				
Brick/stone	8 (57%)	16 (70%)	4 (20%)	Fisher's exact test, 0.015
Other	3 (21%)	2 (9%)	5 (25%)	
Brick/stone + other	3 (21%)	5 (22%)	11 (55%)	
No. of blocks to busy street, No. (%)				
1 block	9 (64%)	12 (52%)	10 (50%)	χ^2, 0.68
2 or 3 blocks	5 (36%)	11 (48%)	10 (50%)	
Lot size, sq. ft.	3522	3413	3567	K–W, 0.42
Median (range)	(2775–6486)	(2784–7225)	(2760–7225)	
Accessible soil, sq. ft.	855	756	1009	K–W, 0.17
Median (range)	(601–2389)	(312–3933)	(322–4174)	
Building exterior paint condition, No. (%)				
Good condition or no paint	1 (7%)	2 (9%)	2 (10%)	Fisher's exact test, 0.27
Fair condition	0	0	3 (15%)	
Poor condition	13 (93%)	21 (91%)	15 (75%)	
Mat placement location, No. (%)	($n = 14$)	($n = 22$)	($n = 20$)	
Front	12 (86%)	20 (91%)	16 (80%)	Fisher's exact test, 0.79
Back	2 (14%)	2 (9%)	3 (15%)	
Side	0	0	1 (5%)	
Entryway paint condition and presence of lead, No. (%)				
Good/fair condition, or poor condition and no lead	9 (65%)	12 (52%)	11 (55%)	Fisher's exact test, 0.92
Poor condition, lead present	4 (29%)	10 (44%)	8 (40%)	
Poor condition, lead content unknown	1 (7%)	1 (4%)	1 (5%)	

Table 2
Measures[a]

	Measures		Between-groups test of differences[b], P
	Baseline	1 Year	
Acute hazard soil lead concentration, ppm, median (minimum, 25th percentile, 75th percentile, maximum)			
Raised test bed	1051 (41, 805, 2268, 4987)	684 (23, 237, 1162, 2031)	K–W, 0.02
No raised test bed	1060 (244, 909, 1525, 4381)	291 (0, 71, 1011, 1766)	
Control	1652 (33, 757, 2955, 7298)	1356 (0, 680, 2740, 5169)	
Potential hazard soil lead concentration, ppm, median (minimum, 25th percentile, 75th percentile, maximum)			
Raised test bed	1498 (731, 997, 2268, 5862)	1072 (79, 525, 1296, 2859)	K–W, 0.13
No raised test bed	1344 (416, 944, 1619, 4381)	774 (201, 519, 1363, 2766)	
Control	1914 (432, 1064, 3486, 7437)	1356 (0, 822, 2740, 5169)	
Covering score, median (range)			
Raised test bed	4.0 (1.3, 5.8)	4.6 (2.3, 5.6)	ANOVA, 0.0005
No raised test bed	3.5 (1.0, 5.2)	5.2 (1.8, 6.0)	
Control	4.2 (1.1, 6.0)	3.3 (1.0, 6.0)	
Dust lead loading, μg lead/ft^2, median (minimum, 25th percentile, 75th percentile, maximum)			
Raised test bed	112 (0, 33, 438, 1150)	93 (3, 21, 346, 876)	K–W, 0.20
No raised test bed	39 (0, 21, 59, 554)	45 (5, 35, 74, 517)	
Control	25 (0, 17, 146, 982)	65 (4, 12, 275, 1097)	
Floor mat, μg lead/day, geometric mean (SD)			
Raised test bed ($n = 14$)	331 (0.56)	126 (0.75)	ANOVA, 0.06
No raised test bed ($n = 22$)	214 (0.41)	102 (0.28)	
Control ($n = 20$)	162 (0.55)	158 (0.67)	
Floor mat, μg lead/count, geometric mean (SD)			
Raised test bed ($n = 14$)	19.5 (0.68)	5.6 (0.88)	ANOVA, 0.03
No raised test bed ($n = 22$)	6.2 (0.45)	4.0 (0.41)	
Control ($n = 20$)	6.9 (0.68)	8.5 (0.64)	

[a] Except where specified: raised test bed, $n = 14$; no raised test Bed, $n = 23$; control, $n = 20$.
[b] The change in measure between baseline and 1 year was computed. Then, statistical analyses were conducted to examine for significance between groups.

poor condition with lead present ($n = 32$) did not differ from properties with paint in good, fair, or poor condition without lead present ($n = 22$): baseline floor mat lead/day (K–W, $P = 0.39$), baseline floor mat lead/count (K–W, $P = 0.82$), and baseline dust lead loading (K–W, $P = 0.35$). Baseline dust lead loading was significantly correlated with baseline floor mat lead/day (Spearman's correlation coefficient, $n = 56$, $\rho = 0.31$, $P = 0.02$) and baseline floor mat lead/count (Spearman's correlation coefficient, $n = 56$, $\rho = 0.46$, $P = 0.0004$). Further, there was a strong correlation between baseline floor mat lead/day and baseline floor mat lead/count (Spearman's correlation coefficient, $n = 56$, $\rho = 0.71$, $P < 0.0001$).

To provide a frame of reference for the acute hazard soil lead concentration results, comparisons were made with yardwide results computed by the average soil lead concentration. Among the 53 properties evaluated by both of these methods, differences between the baseline acute hazard and the average soil lead concentrations varied by a median of 244 ppm (minimum −4472 ppm, 25th percentile −55 ppm, 75th percentile +1182 ppm, maximum +6595 ppm). The acute hazard lead concentration value was lower than the average soil lead concentration for 68% of properties and higher for 30% of properties, with 1 property having the same result by both methods.

3.2. Intervention application processes and cost

A total of 37 properties, including 14 that received a RB and 23 that did not (thus were analyzed in the NRB group), received an intervention in 2000. Nearly all properties had grass seed applied (93% (13/14) in RB group and 91% (21/23) in NRB group) and all properties had application of mulch to garden areas. Stone was applied to 43% (6/14) of properties in the RB group and 22% (5/23) in the NRB group (Fisher's exact test, $P = 0.26$). Lattice was applied to 4 (29%) of the NRB properties and 1 (4%) of the RB properties (Fisher's exact test, $P = 0.06$). All properties in the RB group had test plants grown in the RB and 1 additionally had a grade-level test bed location. Among the NRB group, 91% (21/23) had test plants applied to a test bed and/or scattered among existing garden areas. Intervention expenses for 2000, including labor (field staff), materials, transportation, equipment, design, and management, were estimated at \$2714 for properties with RB applications and \$2562 for properties without RB application. Of these expenses, approximately 50% went to field labor and materials.

3.3. Effects after 1 year (Spring 2000 to Spring 2001)

Soil. The soil lead concentrations at baseline and 1 year followup for both acute hazard and potential hazard analyses are shown in Table 2. Note that analyses were conducted on computations of change for a property, so simple subtraction of medians presented in Table 2 will vary from the information presented below. A significant difference between groups was found for the change (defined as 1 year followup value minus baseline value) in acute hazard soil lead concentration (median change: −478 ppm for RB group, −698 ppm for NRB group, +52 ppm for control group; K–W, $P = 0.02$). This was not the case for the change in potential hazard soil lead concentration (median change: −481 ppm for RB group, −432 for NRB group, −47 for control group; K–W, $P = 0.13$). Considering intervention properties only, there was no significant difference in the change in acute or potential hazard soil lead concentration by the application of stone (acute hazard, MWU, $P = 0.20$; potential hazard, MWU, $P = 0.47$) or the application of a RB (acute hazard, MWU, $P = 0.84$; potential hazard, MWU, $P = 0.33$).

Ground coverings. Ground covering scores were significantly higher at followup for intervention groups than for control groups (K–W, $P = 0.0005$). At the 1-year followup, the median ground covering score for both intervention groups was approximately a "5" (*mostly covered*, 75–90% covered), while the median ground covering score for the control properties was closer to a "3" (*some covering*, 25–49%).

Entryway floor mats and dust. The change in rate of lead accumulation on the floor mat placed at the main entryway achieved significance when analyzed by door opening count (ANOVA, $P = 0.03$), but only approached significance when evaluated by daily rate of lead accumulation (ANOVA, $P = 0.06$). Lead tracked onto floor mats at intervention homes fell to approximately one-half of the baseline levels.

There was no significant change in the average dust lead loading at the exterior entryway (K–W, $P = 0.20$). At followup, 64% of RB, 61% of NRB, and 55% of control properties had dust lead loading at or above 40 μg lead/ft^2, the current dust hazard standard (Federal Register, 2001).

3.4. Replication and durability

Interventions were applied to 19 properties in the control group in Summer 2001. Of these, 18 (6 RB and 12 NRB) completed evaluation of soil lead in Fall 2001 and 17 had ground coverings evaluated in Fall 2000 and 2001. Additionally, 33 of 37 (89%) properties (12 RB and 21 NRB) that had received interventions in 2000 had ground coverings evaluated in Fall 2000 and 2001 and soil lead evaluated in Fall 2001.

Soil. Figs. 2 and 3 show soil lead hazard measures for properties grouped by year of intervention. Most properties that received intervention in 2001 achieved lowering in acute and potential hazard soil lead concentrations over 6 months similar to what was demonstrated over 12 months for the 2000 intervention properties. While most properties in the 2000 intervention sustained the lower soil lead levels from Spring to

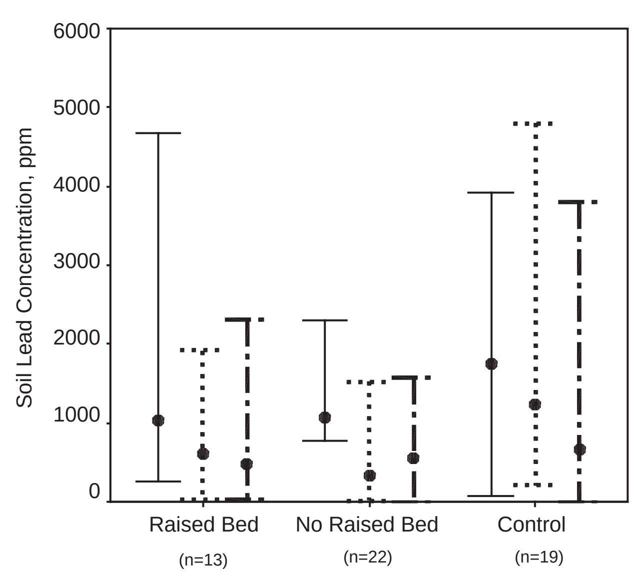

Fig. 2. Acute hazard soil lead concentration. Bars indicate 10th and 90th percentiles. Median is indicated by a circle. Evaluation period: Spring 2000 ——; Spring 2001 · · · ·; and Fall 2001 –·–·–·–·.

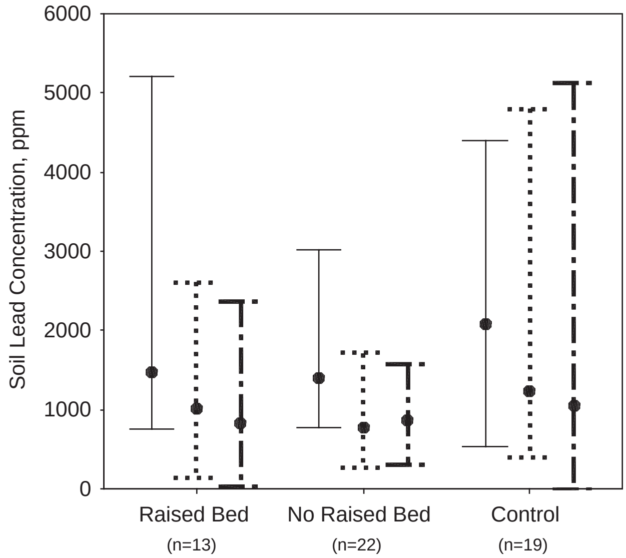

Fig. 3. Potential hazard soil lead concentration. Bars indicate 10th and 90th percentiles. Median is indicated by a circle. Evaluation period: Spring 2000 ——; Spring 2001 · · · ·; and Fall 2001 –·–·–·–.

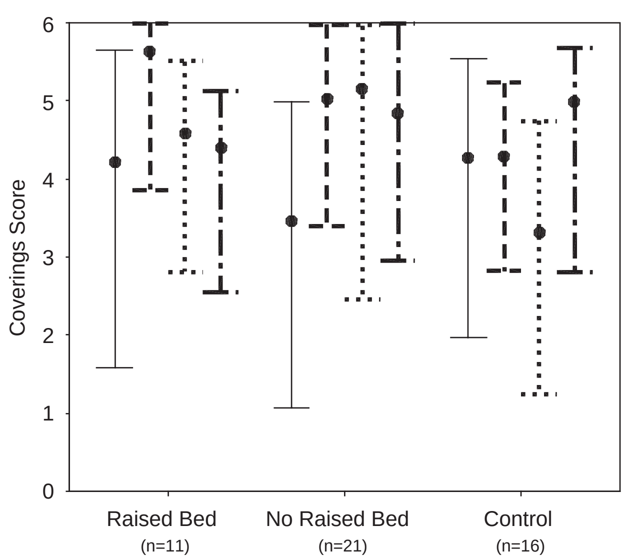

Fig. 4. Ground coverings score. Bars indicate 10th and 90th percentiles. Median is indicated by a circle. Evaluation period: Spring 2000 ——; Fall 2000 – – – –; Spring 2001 · · · ·; and Fall 2001 –·–·–·–.

Fall 2001, some were higher. At properties that had received intervention in 2000, the acute hazard soil lead rose by 500 ppm or more at 20% (7/35) of the properties over the period Spring 2001 to Fall 2001 and the potential hazard soil lead rose by 500 ppm or more at 11% (4/35) of the properties over the same period.

Ground coverings. The ground covering score showed substantial improvement between Spring and Fall 2001 at properties receiving intervention in that year (Fig. 4). The covering score at properties receiving their intervention in the prior year declined slightly. However, the absence of properties that were nearly totally bare and the continued presence of some homes with near total covering were still noted.

4. Discussion

This project demonstrates the application of lower-cost interventions intended to reduce the potential for exposure to lead-contaminated soil in an urban residential neighborhood. Methods applied resulted in lowering of acute hazard soil lead concentration through enhanced landscape coverings. However, the intervention was not sufficient to significantly reduce the potential hazard soil lead concentration or dust lead loading at the main entryway. The track-in of lead onto floor mats, a relatively new method to evaluate soil lead interventions, was reduced to approximately one-half its baseline value. Thus, our interventions influenced both the accessibility of exterior soil and the track-in of soil into the house. Lowering track-in of lead may be the most important influence for the youngest children, whose main pathway for childhood blood lead elevation is lead-contaminated floor dust adhering to a hand, which is then placed in the mouth (USEPA, 2000). Further, it has been shown that approximately 31% of interior dust originates as outdoor soil (Calabrese and Stanek, 1992).

The varied findings in dust lead loading and floor mat measures are of interest. We suspect that the dust, which was obtained from three sites at the entryway when the mat was placed, has more variability related to the cleaning and maintenance of the building than does the mat-related measurements. Use of floor mat sampling may be preferable over dust sampling for soil intervention evaluations.

4.1. Baseline measures

Results of this project confirm the presence of high levels of soil lead contamination in a Chicago neighborhood, as was previously reported (Shinn et al., 2000), and extend the findings to a nearby area. These neighborhoods are characterized by very old homes, with current facades being a mixture of brick, stone, or other materials. At baseline, 9% (5/57) of properties had an acute hazard soil lead concentration <400 ppm, which is the soil lead hazard standard for child play areas, and 51% (29/57) had a yardwide acute hazard soil lead concentration <1200 ppm, which is the soil lead hazard standard for bare soil outside of play areas (Federal Register, 2001). While our assessment and analytic methods differ from current recommendations on soil sampling and yardwide analytic evaluation methods (recommendations call for sampling of bare areas only and averaging of results) (Federal Register, 2001), the data strongly support the presence of soil lead concentrations above the federal hazard standards.

4.2. Intervention

Soil lead hazards were substantially lowered by the intervention at many properties. At the end of 18 months, 35% (19/55) of the properties had an acute hazard soil lead concentration <400 ppm and 75% (41/55) had <1200 ppm. However, the long-term sustainability of our intervention applications is unclear. Properties not substantially improved had larger areas of high lead concentration, which were not adequately addressed since we limited application of stone to building foundations and under porches. Our placement of raised beds also permanently covered contaminated soil, but these were subject to recontamination and may have lowered the ground covering score at those properties, since they were left as bare soil. Since we did not measure lead content of exterior paint (other that at the entryway) nor require lead hazard reduction of building exteriors, we could not assess whether recontamination was due to existing exterior lead hazards on the property or to lead transferred to the property from neighboring homes. We were aware of one instance where the effect of the intervention was negated due to recontamination from construction debris. Even if we had limited our applications to buildings with lead-free exteriors, travel of lead between homes is a likely explanation of recontamination (Gulson et al., 1995). Strategies that require neighborhoodwide lead hazard reduction (von Lindern et al., 2003) may be necessary to sustain soil interventions in the urban environment. Nevertheless, the techniques applied had some benefit in lowering acute hazards and may be accomplished by individual property owners. A short brochure containing instructions on application methods is published for easy access at http://www.chicagolead.org. More extensive information concerning landscape techniques to reduce soil lead hazards is available from USEPA (2001).

Several aspects of our intervention method should be mentioned. First, grass grown from seed required frequent tending and watering. Some areas required reseeding up to four times. We selected grass seeds with the intent of mimicking the most likely actions of individual property owners. Further, we used seed because many areas for grass encompassed both shade and sun, which could be adjusted for by seed variety. Sod grass varieties are intended for sunny areas. Second, we found many small areas at these properties that were not suitable for grass cover. Our strategy to apply ground cover plantings and mulch will require long-term maintenance, as the plants are planted 6 inches apart and will not provide a thick vegetative cover for several years. Third, the property owners and we were pleased with the look and success of the rotten granite stone applications. This stone is small and compactable (it is a small reddish-colored stone that is frequently used on foot trails) and is not large enough or heavy enough to damage property if thrown. Fourth, the interventions required intensive effort to maintain. Foot traffic, debris, and wear and tear on surfaces from pets were constant threats to the sustainability of the vegetative interventions. Possibly this is particularly notable in these small yards, where we found most areas to have a high likelihood of heavy use. Fifth, the interventions were applied by a relatively novice crew of community workers. The crew leader was employed through both intervention seasons, but nearly all other crew members transitioned through the project. Interventions applied by more experienced landscape companies with continued maintenance by property owners may improve outcomes. Further, application of interventions to 37 properties in 1 year with a single work crew required a considerable effort. Some properties did not begin intervention until late July. We were fortunate to have a cool, rainy summer in 2000 for the intervention, but the late start at some properties may have influenced the sustainability of vegetative interventions over the winter months.

4.3. Studies of soil lead abatement

Relatively few studies have proposed methods to reduce children's exposure to lead-contaminated soil. One method, that of replacing contaminated surface soil to a depth of 6 inches, was found to lower children's blood lead levels in Boston when accompanied by paint stabilization (Weitzman et al., 1993; Aschengrau et al., 1994). Baseline soil lead concentration fell from 2000 ppm to a postabatement level of 105 ppm; 9 months later 8 of 34 properties (23.5%) had evidence of recontamination (levels at 150–1800 ppm). However, the cost of this soil abatement strategy may be outside the scope of an average homeowner's budget, as the estimated cost was $9600 per property (Weitzman et al., 1993). A similar soil abatement strategy, also accompanied by paint stabilization, applied in Baltimore found no effect on child blood lead levels (Farrell et al., 1998). In that study, the soil lead concentration fell from 501 ppm at baseline to 34 ppm following abatement. Two years later ''significant accumulation'' was reported. A strategy of soil replacement applied over more than a decade in the Bunker Hill Superfund Site in the Silver Valley of Idaho effectively lowered soil lead concentration and contributed to the lowering of child blood lead levels (von Lindern et al., 2003). Less expensive methods, using in-place management to reduce the potential for exposure to lead-contaminated soil, have been proposed (USEPA, 2001). A study by

Mielke et al. (1992) (including 12 intervention properties and applications of ground coverings and interior cleaning) found a higher rate of improvement in the blood lead levels for children living at intervention homes than for children living at control homes. Our study, which used in-place management, also reduced soil lead concentration but to a much lesser degree than that when excavation was employed (Weitzman et al., 1993; Aschengrau et al., 1994; von Lindern et al., 2003).

4.4. Definitions of lead hazard

We propose and have evaluated our data using two definitions of soil lead hazards. Two definitions are needed to anticipate the importance that the property owner will play in maintaining reduced soil lead hazards. First, we considered the *acute hazard soil lead concentration*. This is a measure of areas assessed to be $\leqslant$90% covered. Among our measures, it is the one most similar to the current regulatory strategy for computation of a yardwide soil lead hazard, which considers soil obtained from bare areas (Federal Register, 2001). However, for most vegetation the density of ground coverings changes over time. Therefore, risks may change when areas previously covered become bare (for example, if grass covering thins or mulch is not replenished). Our second measure, termed *potential hazard soil lead concentration*, represents risk if maintenance of ground coverings is abandoned and soil previously covered becomes more accessible. Recognition of the potential hazard may encourage owners or tenants to maintain ground coverings, because they recognize their importance in lowering risks.

Dual definitions for lead paint hazards should also be considered. The presence of lead-contaminated dust or deteriorating lead-painted surfaces presents an acute hazard, while intact lead-based paint presents a potential hazard, as there are no guarantees to its long-term stability. Recognition of the presence of a potential hazard may lead to enhanced monitoring of surfaces, while the assignment of the term “lead safe” conveys the false perception that the potential for lead contamination has been removed.

4.5. Limitations

There are limitations that must be remembered when considering study findings. First, the ground covering score at control properties was much lower in Spring 2001 than in the baseline assessment done in Spring 2000. Property owners may have delayed or abandoned upkeep, realizing that that upkeep would be undertaken by the project. Also, risk assessors, who were not blinded to study group assignment (they were frequently in the field and in contact with property owners), may have been biased. However, at one control property the covering improved substantially, as that owner immediately paved over the entire accessible soil in response to our notification of soil lead results. That action reduced both the acute and the potential hazard soil lead concentrations to 0 ppm for that property. Second, although risk assessors trained together to establish uniform application of ground covering grade coding, interobserver variability was not assessed. However, not all evaluation measures depended on covering assessments. Third, soil lead preparation techniques did not include sieving, which has been found to reduce test–retest variability (Sandy M. Roda, B.S., personal communication, University of Cincinnati, Cincinnati, OH; December 11, 2000). However, as the same techniques were applied to both intervention and control sites, findings would likely be substantiated even if the soil analytic technique was changed. Fourth, since lead deposited on the soil does not disperse uniformly, it is likely that considerable variability in soil lead concentration exists within each property. This characteristic makes evaluations of change more difficult to measure. Our strategy to subdivide the yard into zones proved to be useful in planning interventions and may have aided our ability to evaluate our findings.

5. Conclusion

Landscape techniques applied in an urban area with high baseline soil lead contamination were found to lower the acute hazard soil lead level. Further, the application significantly reduced track-in of lead onto floor mats. Techniques evaluated by this study are feasible for use by property owners. The results of the study indicate, however, that the success of the various techniques to reduce lead hazards required continued maintenance. Further research on the long-term sustainability of the method used in this study and on intervention methods that require less maintenance is needed.

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References

Aschengrau, A., Beiser, A., Bellinger, D., Copenhafer, D., Weitzman, M., 1994. The impact of soil lead abatement on urban children's blood lead levels: Phase II results from the Boston Lead-in-Soil Demonstration Project. Environ. Res. 67, 125–148.

Calabrese, E.J., Stanek, E.J., 1992. What proportion of household dust is derived from outdoor soil? J. Soil Contam. 1, 253–263.

Centers for Disease Control (CDC), 1991. Preventing lead poisoning in young children. US Department of Health and Human Services, CDC, Atlanta, Georgia.

Centers for Disease Control and Prevention (CDC), 1997. Update: blood lead levels—United States, 1991–1994. Morb. Mortal. Wkly. Rpt. 46, 141–146.

Centers for Disease Control and Prevention, 2002. Developmental assessment and interventions. In: Managing Elevated Blood Lead Levels Among Young Children: Recommendations from the Advisory Committee on Childhood Lead Poisoning Prevention. CDC, Atlanta, pp. 79–95 (Chapter 5) (www.cdc.gov/nceh/lead/CaseManagement/caseManage_main.htm).

Farfel, M.R., Orlova, A.O., Lees, P.S.J., Bowen, C., Elias, R., Ashley, P.J., Chisolm Jr., J.J., 2001. Comparison of two floor mat lead dust collection methods and their application in pre-1950 and new urban homes. Environ. Sci. Technol. 35, 2078–2083 (erratum 35, 2128).

Farrell, K.P., Brophy, M.C., Chisolm Jr., J.J., Rohde, C.A., Strauss, W.J., 1998. Soil lead abatement and children's blood lead levels in an urban setting. Am. J. Public Health 88, 1837–1839.

Federal Register, 1998. Part III, Environmental Protection Agency. Lead; Identification of Dangerous Levels of Lead; Proposed Rule 63, 30301–30355.

Federal Register, 2001. Part III, Environmental Protection Agency. Lead; Identification of Dangerous Levels of Lead: Final Rule 66, 1206–1240.

Gulson, B.L., Davis, J.J., Bawden-Smith, J., 1995. Paint as a source of recontamination of houses in urban environments and its role in maintaining elevated blood leads in children. Sci. Total Environ. 164, 221–235.

Lanphear, B.P., Burgoon, D.A., Rust, S.W., Eberly, S., Galke, W., 1998a. Environmental exposures to lead and urban children's blood lead levels. Environ. Res. 76, 120–130.

Lanphear, B.P., Matte, T.D., Rogers, J., Clickner, R.P., Dietz, B., Bornschein, R.L., et al., 1998b. The contribution of lead-contaminated house dust and residential soil to children's blood lead levels: a pooled analysis of 12 epidemiologic studies. Environ. Res. 79, 51–68.

Mielke, H.W., 1991. Lead in residential soils: background and preliminary results of New Orleans. Water Air Soil Pollut. 57–58, 111–119.

Mielke, H.W., 1994. Lead in New-Orleans soils: new images of an urban environment. Environ. Geochem. Health 16, 123–128.

Mielke, H.W., Adams, J.E., Huff, B., Pepersack, J., Reagan, P.L., Stoppel, D., Mielke Jr., P.W., 1992. Dust control as a means of reducing inner-city childhood Pb exposure. Environ. Geochem. Health 14 (supplement Trace Substance in Environmental Health—XXV), 121–128.

Shinn, N.J., Bing-Canar, J., Cailas, M., Peneff, N., Binns, H.J., 2000. Determination of spatial continuity of soil lead levels in an urban residential neighborhood. Environ. Res. 81, 1–7.

Succop, P., Bornschein, R., Brown, K., Tseng, C., 1998. An empirical comparison of lead exposure pathway models. Environ. Health Perspect. 106 (Suppl. 6), 1577–1584.

US Department of Housing and Urban Development (USHUD), 1995. Soil sampling protocol for housing. In: Guidelines for the Evaluation and Control of Lead-Based paint Hazards in Housing. USHUD, pp. 1–3 (Chapter 5, Appendix 13.3).

US Environmental Protection Agency (USEPA), 1986a. Air quality criteria for lead. EPA 600/8/83/018F, Research Triangle Park, NC.

US Environmental Protection Agency (USEPA), 1986b. Test Methods for Evaluating Solid Waste: Laboratory Manual Physical Chemical Methods: Method 3050: Acid Digestion of Sediments, Sludges, and Soils, Vol. 1A. US EPA, Washington, DC.

US Environmental Protection Agency (USEPA), 1993. In: Rogers, J., Clickner, R., Vendetti, M., Rinehart, R. (Eds.), Data Analysis of Lead in Soil. Report Number EPA 747-R-93-011, US Environmental Protection Agency, Office of Pollution Prevention and Toxics.

US Environmental Protection Agency (USEPA), 2000. Analysis of Pathways of Residential Lead Exposure in Children. Report Number EPA 747-R-98-007, US Environmental Protection Agency, Office of Pollution Prevention and Toxics.

US Environmental Protection Agency (USEPA), 2001. Lead-safe yards: developing and implementing a monitoring, assessment, and outreach program for your community. Report Number EPA/625/R-00/012.

von Lindern, I., Spalinger, S., Petroysan, V., von Braun, M., 2003. Assessing remedial effectiveness through the blood lead: soil/dust lead relationship at the Bunker Hill Superfund Site in the Silver Valley of Idaho. Sci. Total Environ. 303, 139–170.

Weitzman, M., Aschengrau, A., Bellinger, D., Jones, R., Hamlin, J.S., Beiser, A., 1993. Lead-contaminated soil abatement and urban children's blood lead levels. J. Am. Med. Assoc. 269, 1647–1654.