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# The influence of soil remediation on lead in house dust

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## Abstract

Lead in house dust has long been recognized as a principal source of excess lead absorption among children at the Bunker Hill Superfund Site (BHSS) in northern Idaho. House dust lead concentration from homeowner's vacuum cleaner bags has been monitored since the epidemic of childhood lead poisoning in 1974. Geometric mean house dust lead concentrations decreased from >10 000 mg/kg in 1974 to approximately 4000 mg/kg in 1975, in response to air pollution control initiatives at the defective primary lead smelter. After smelter closure, 1983 mean dust lead concentrations were near 3000 mg/kg and were most dependent on soil sources. Following emergency soil removals from public areas and roadsides and fugitive dust control efforts in the mid-1980s, house dust lead decreased by approximately 40–60% to 1200–1500 mg/kg. In 1992, a cleanup goal of 500 mg/kg dust lead community average, with no individual home exceeding 1000 mg/kg, was adopted. This goal was to be achieved by a combination of contaminated soil removals and fugitive dust control efforts throughout the 21 square mile BHSS. Continual reductions in house dust lead concentrations have been noted throughout the residential area soil cleanup. Geometric mean house dust lead concentrations averaged approximately 500–600 mg/kg from 1996 to 1999 and dropped below 500 mg/kg in 2000. Analysis of these data indicates that approximately 20% of the variance in dust lead concentrations is attributed to yard, neighborhood, and community soil lead concentrations. Since 1996, dust lead concentrations and dust and lead loading rates have also been measured by dust mats placed at entryways into the homes. Neighborhood soil lead concentrations, household hygiene, the number of adults living in the home, and the number of hours a child spends outdoors in summer explain approximately 26% of the variance in mat dust lead loading rates. It is estimated that post-remedial house dust lead concentrations will stabilize at 400–500 mg/kg, as compared to approximately 200 mg/kg in socio-economically similar background communities; the difference possibly attributed

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to residual soil concentrations (3–6 times background), recontamination of rights-of-way, tracking of non-residential mining district soils and dusts, fugitive dusts associated with the remediation, and residual structural or carpet dusts.


*Keywords:* Lead; Soil; House dust; Bunker Hill Superfund Site; Cleanup; Remediation

## 1. Introduction

Lead in soils and house dust has long been recognized as a principal source of excess lead absorption among young children (Landrigan et al., 1975; Yankel et al., 1977; Charney et al., 1980; Roels et al., 1980; Bornschein et al., 1985; Rabinowitz et al., 1985; Lanphear et al., 1996, 1998). Interior lead-based paint contributes directly to house dust inside the home through chalking and chipping of the paint (Bellinger et al., 1986; Marcus and Elias, 1994; Lanphear and Roghmann, 1997). Investigators have noted that exterior sources, such as soil, paint and street dust, become entrained in house dust via airborne routes or tracking of these exterior media into the home (Charney et al., 1980; Duggan and Inskip, 1985; Calabrese and Stanek, 1992; Tong and Lam, 2000). Several case studies have documented soils and house dusts contaminated with heavy metals from nonferrous metal smelters and mining districts (Landrigan and Baker, 1981; Cook et al., 1993; Calderón-Salinas et al., 1996; Murgueytio et al., 1998; von Braun et al., 2002).

The Bunker Hill Superfund Site (BHSS), a historic mining and smelting district, is a 21 square mile area located in the Coeur d'Alene Basin in northern Idaho. Five residential communities of Pinehurst, Kellogg, Smelterville, Wardner, and Page are located within the BHSS. A century of discharges and emissions from mining and smelting activities has left several thousand acres contaminated with heavy metals. In the early 1970s, lead poisoning was epidemic among young children residing within the BHSS. Exposure to environmental media, such as soil, house dust, and air, was the major cause of excess absorption (Yankel et al., 1977; Walter et al., 1980). After the smelter closure in 1981, childhood lead exposure was primarily due to residual contamination in area soils and house dust (PHD, 1986; TerraGraphics, 1997, 2000).

Superfund activities commenced in 1984 and interim cleanup and lead health intervention activities were instituted at that time. The final cleanup strategy, adopted in two Records of Decision in 1991 and 1992, was based on partial removal of contaminated surface soils and capping of subsurface contaminants and waste piles throughout the site (USEPA, 1991, 1992). Establishing barriers over contaminated sources served the dual purpose of preventing direct contact by the population and keeping contaminants in place. An integral element in this strategy was that house dust lead levels would progressively decline to acceptable concentrations as waste pile sources and contaminated yards were eliminated or contained. In order to achieve the remedial strategy, all residential yards having soil lead concentrations greater than 1000 mg/kg would be replaced with clean soil and the site would achieve a geometric mean yard soil lead concentration of less than 350 mg/kg for each community. These criteria also apply to commercial properties, parks, playgrounds, and rights-of-ways (ROWs).

A remedial action objective (RAO) for house dusts was adopted requiring that each community within the site achieve a geometric mean house dust lead concentration of 500 mg/kg or lower, with no individual home exceeding 1000 mg/kg (USEPA, 1992). The RAO also required that, following completion of soil remediation in a community, any home with house dust concentrations at or above 1000 mg/kg would be considered for interior remediation. The rationale for this decision derived from a 1990 pilot cleaning study in which several homes at the site received comprehensive interior cleaning, yet carpets in the home became recontaminated within 1 year (CH2M Hill, 1991; TerraGraphics, 1997). As a result, it was determined that home interiors could not be permanently remediated until exterior contamination sources were addressed. It was recognized that success of the remedial strategy depended on house dust lead concentrations decreasing to levels similar to post-remedial soil lead concentrations.

The Lead Health Intervention Program (LHIP) offered by the Panhandle Health District (PHD) was also designated as a critical component of the cleanup strategy. The program involves an annual door-to-door blood lead survey and nursing follow-up, and public education modules aimed at local schools, parent and service groups, and health care providers. The annual blood lead survey provides health department representatives direct contact with local families to remind them of the risks and precautions that can be taken to reduce the incidence and severity of lead poisoning. Home visits, individualized counseling, and, if appropriate, recommendation for medical follow-up are provided to children above the intervention blood lead level, 10 μg/dl since 1992 (PHD, 1999).

Under Superfund law, the 5-year review process was initiated in 1999 and completed in 2000. This paper summarizes the house dust analyses of the Populated Areas Five Year Review (TerraGraphics, 2000). The objectives were to (i) review the trends in soil and house dust lead concentrations (and lead and dust loading rates) for each community, (ii) examine the soil to house dust relationship at the site, (iii) analyze the dust mat sampling technique compared to the vacuum bag sampling technique, and (iv) identify those factors contributing to elevated house dust lead concentrations and loading rates. The overall purpose was to evaluate if the current remedial strategy is sufficient to achieve the established dust RAO.

## 2. Methods and materials

### 2.1. Soil sampling

Residential yard soils are sampled to determine eligibility for remediation by the BHSS potentially responsible parties conducting the cleanup. Samples are collected at 0–1, 1–6, 6–12 and 12–18 in. depth intervals for each 500 square feet of yard surface. The sub-samples are composited by depth interval and sieved to minus-80 mesh, acid digested and analyzed by atomic absorption or ICP (USEPA, 2000). Any composite sample from one of the three upper horizons (0–12 inch), that exceeds 1000 mg/kg lead triggers remediation for the entire yard.

### 2.2. Dust sampling

House dusts have been monitored at the site as part of the LHIP since 1974. House dust has been sampled from homes with young children by collecting the homeowner's vacuum cleaner bag during the annual blood lead survey in July/August. A vacuum sample is obtained by collecting the disposable bag or the entire contents of permanent bags; provided the resident has not used the vacuum in a car, outdoors, or at another house since the bag was last changed. The contents are sieved and analyzed in the same manner as soils. The vacuum bag sample represents the actual media being managed by the resident, and provides a general representation of the lead concentration in the home. This method has the advantage of being quick, easy, and relatively inexpensive to collect and has been used in exposure analyses at this site for decades. However, there are drawbacks to the technique, as it is uncontrolled and residents' habits, frequency of cleaning, and efficiencies of vacuum methods and machinery may vary. A principal weakness is that this method does not provide a measure of dust and lead loading rates. Historically, 50–80% of 9-month to 9-year-old children in the site participate in the annual surveys. Vacuum bags are obtained from about half of these families.

Since 1996, dust has also been sampled using a commercial floor mat placed inside the main entryway (Fig. 1) (ATSDR, 2000). This methodology provides an index of dust and lead loading rates into the home (mass/area/time) as well as lead concentration. Instructions are left with the resident not to vacuum, shake or move the mat. After approximately 3 weeks, the mat is retrieved and carefully placed and stored right-side-up in a clean

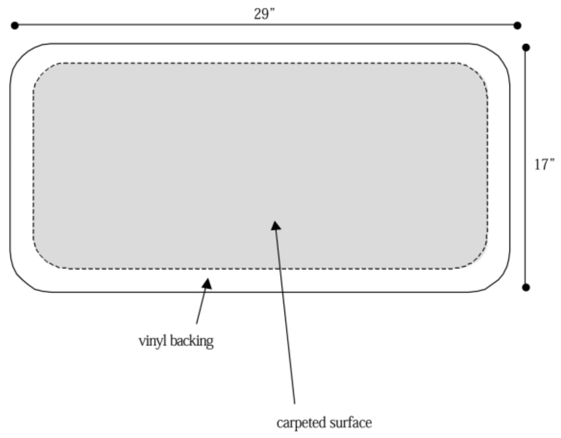


Fig. 1. Floor Sentry® model floor mat used at the BHSS since 1996 (area = 0.318 $m^2$).

sealed envelope. The mat is vacuumed to collect the dust retained on the mat in a special laboratory (Bero, 1984). The mass of dust collected is used to determine the dust loading rate (mg dust/$m^2$/day). The sample is sent to a laboratory for determining lead concentration, from which the lead loading rate (mg lead/$m^2$/day) can be calculated.

Since 1996, the LHIP has sampled homes using both the dust mat technique and the vacuum cleaner bag sample. LHIP participants are generally characterized as families with young children that provide blood samples and mats are obtained from the majority of participants. Additionally, Site-wide sampling included homes in Smelterville in 1997, and homes in both Smelterville and Kellogg in 1998 (TerraGraphics, 1999). These Site-wide homes are generally characterized as having families with either no children or older children, are not involved in the LHIP and are considered representative of the community at-large. In 1997, all homes in Smelterville were targeted and 200 of an estimated 321 homes were sampled. In 1998, 76 homes in Smelterville and 198 (of an estimated 1454) homes in Kellogg were randomly selected and sampled by the mat methodology (TerraGraphics, 2000).

### 2.3. Questionnaire

An in-home inspection and questionnaire is conducted when the mats are retrieved. The LHIP uses this information to assess potential risk factors that could influence lead concentration and dust and lead loading rates in the home. Questions address such factors as house age, lawn covering in the yard, condition of painted surfaces, whether the resident owns or rents, occupancy time, number of hours children spend outside, use of floor mats at entrances, number of children, adults, visitors, and pets, recreational activities and other occupational and hobby related factors.

### 2.4. Statistical analysis techniques

The historic soil and house dust data are observational and not part of a designed experiment, but were collected to support remedial and intervention activities. Nevertheless, statistical analyses of this large data base can be applied to develop useful insights about the complex relationships between environmental media and risk factors. The data were paired by observation, log transformations were computed to meet statistical assumptions for some variables, and correlation matrices were computed for the combined database (all cities, all years), and for the separate cities and years. These matrices were examined to assess the linear association between the pairs of variables and to preliminarily identify the best predictors of house dust lead concentrations for multiple regression model analysis. Backward and forward stepwise multiple regression analysis (at the 0.1 significance level) was employed to develop models describing the relationship between house dust and soil lead levels.

Similar analyses were conducted with the dust mat data to assess the relationships among dust and lead loading rates, soil lead concentrations and questionnaire factors. Prior to regression analysis, examination of the neighborhood soil database suggested that apartment complexes tend to have a different relationship with outdoor soils than detached dwelling and smaller multiple unit complexes. Two factors that possibly explain this

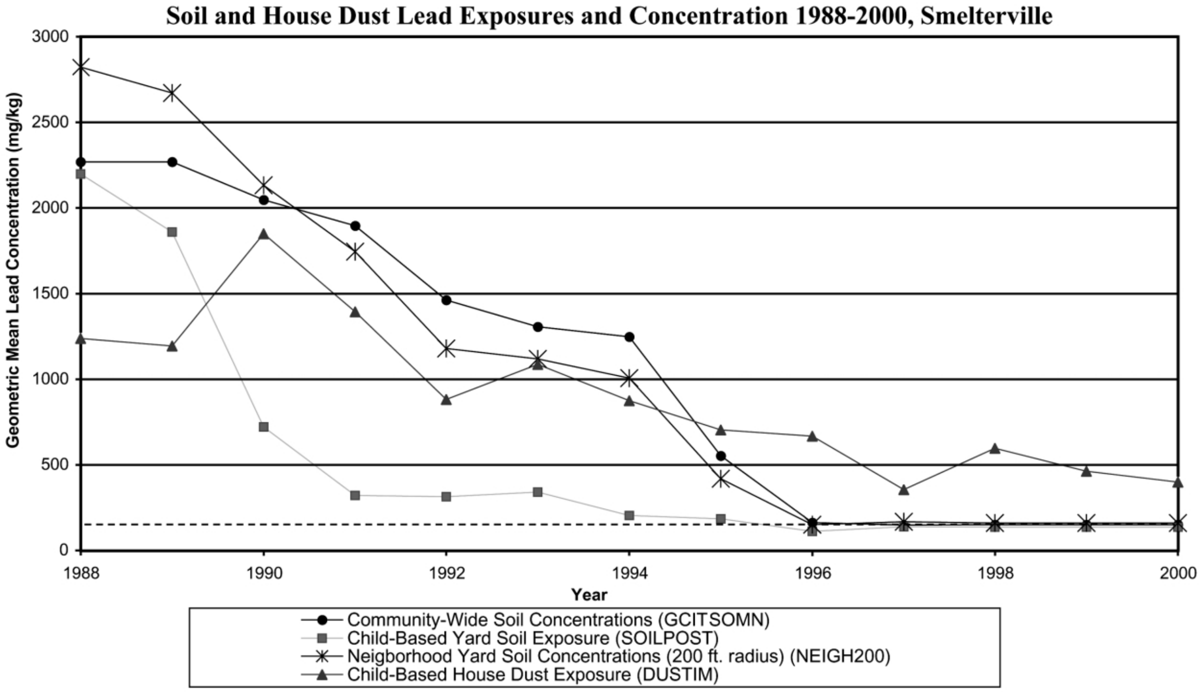


Fig. 2. Soil and house dust lead exposures and concentration 1988–2000, Smelterville.

difference were that larger apartment complexes typically have hallways, stairs and separate entrances between the yard and the home that could affect the amount of soil brought into the home from outside. Also, the complex itself may enclose much of the 200-foot radius employed to estimate the neighborhood soil variable. To exclude this confounding factor, apartment complexes with five and more units were removed from the data set.

A preliminary analysis of the questionnaire factors was performed to assess their influence on dust and lead loading rates using mat data only. Due to the imbalance in the levels of the many different factors, factorial analysis of variance (ANOVA) was not employed. Rather, univariate ANOVA was performed on the dependent variables (dust and lead loading rates) for each questionnaire factor (e.g. house age). A significance criterion of $P \leqslant 0.05$ was applied to determine whether the difference between categories within the same factor was statistically significant. Dust mat lead concentrations, dust and lead loading rates were also analyzed using ANOVA to determine whether significant differences exist between the two survey populations (LHIP versus Site-wide), different cities, and over time.

## 3. Results and discussion

### *3.1. Trends in soil and house dust lead levels*

Due to the complicated nature of the cleanup and population mobility, four different soil and dust exposure variables are tracked and used in assessing remedial effectiveness. Fig. 2 illustrates these metrics for Smelterville where cleanup activities were completed in 1997. These different concentration measures demonstrate the complex effect of the residential soil cleanup on individual soil and dust exposures over the course of remedial activities. The geometric mean community-wide

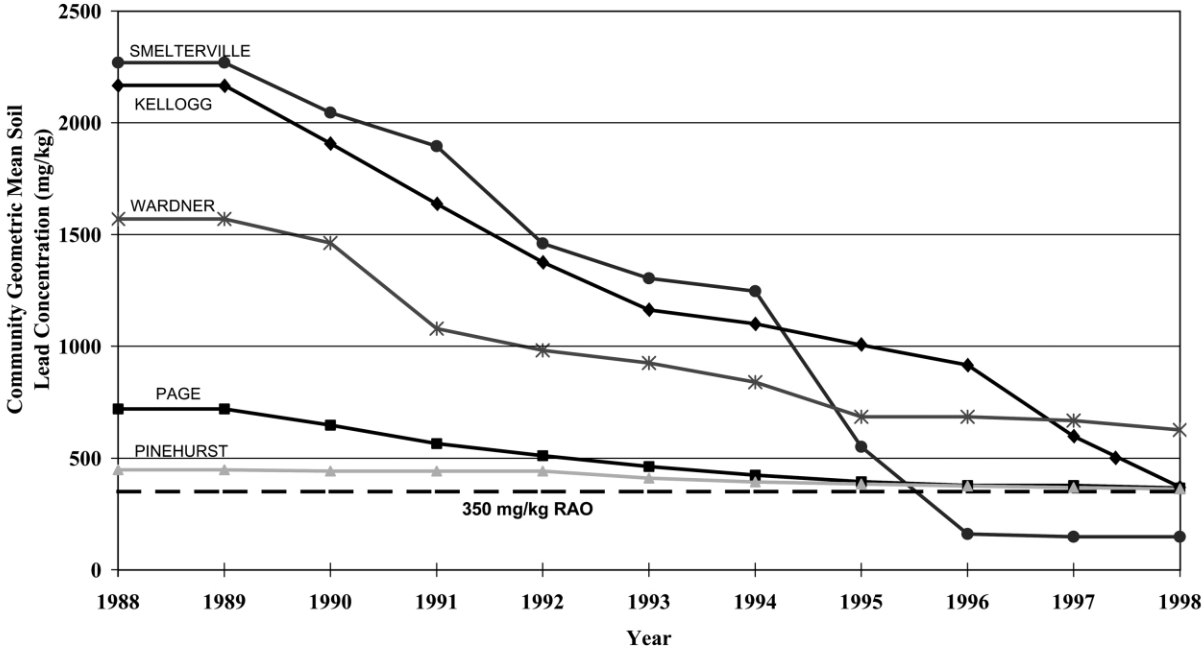


Fig. 3. Community geometric mean soil lead concentrations and progress toward RAO, 1988–1998.

soil lead concentrations for all home yards represents the overall soils in each town; the child-based mean yard soil lead exposure and house dust exposure represent individual homes occupied by children 9 years of age or less. In addition, the neighborhood soil concentrations are estimated by GIS techniques aggregating all soil lead observations within various radii around each home, excluding that home. The top inch soil horizon lead concentration is used for the analyses presented in this paper. Remediated yards are assumed to have a nominal soil lead concentration of 100 mg/kg.

Fig. 3 shows the geometric mean soil concentrations for all home yards in each city showing the progress in achieving the 350 mg/kg RAO. From 1988 to 1998, total lead in yard soils was reduced by 95% in Smelterville, 85% in Kellogg, 51% in Page, 61% in Wardner, and 20% in Pinehurst.

Fig. 4 shows the historic trend in house dust lead exposures and progress toward the 500 mg/kg RAO. Geometric mean house dust lead exposures in Smelterville and Kellogg, Wardner, and Page decreased remarkably, from approximately 10 000 mg/kg in 1974 to approximately 4000 mg/kg in 1975, in response to air pollution control initiatives at the smelter. Following smelter closure by 1983, house dust lead exposures in Kellogg and Smelterville averaged near 3000 mg/kg (geometric mean) and were most dependent on soil sources (Yankel et al., 1977; PHD, 1986). Following fast track (expedited soil removals from public areas such as parks, playgrounds, and roadsides) and fugitive dust control efforts from 1985–1987, 1988 house dust lead exposures decreased by approximately 40–60% to 1500 and 1200 mg/kg (geometric mean) in Kellogg and Smelterville, respectively. Continual reductions in house dust lead levels have been noted since 1990. House dust lead exposures averaged approximately 350–650 mg/kg (geometric mean) in Kellogg and Smelterville from 1996 to 1999 and for both communities were approximately 350 mg/kg in 2001. Prior to 1997, house dust was sampled only in the homes of children participating in the LHIP blood lead surveys; as a result, the dust lead concentrations observed may be biased toward homes with remediated yard soils (i.e. the yard

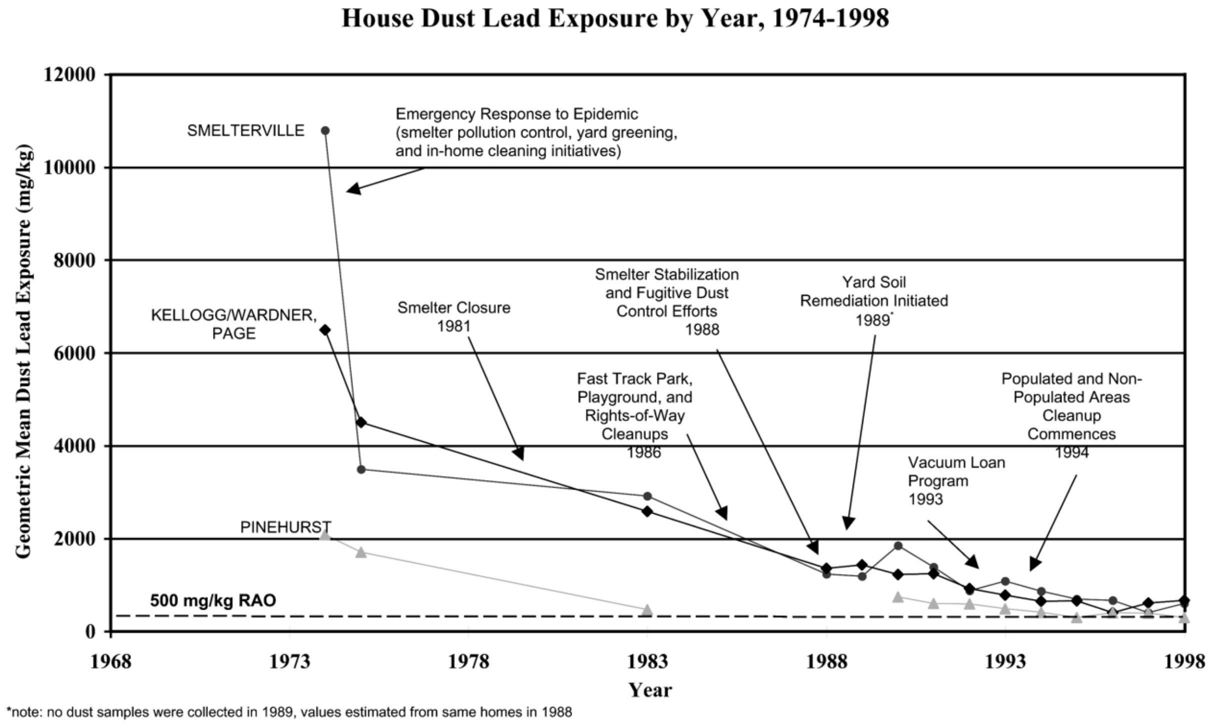


Fig. 4. House dust lead exposure by year, 1974–1998.

remediation program is targeted to high-risk children in this group). As a result, these house dust lead concentrations are referred to as house dust exposures.

### 3.2. Soil and house dust relationships

Table 1 presents the overall correlation matrix for all data and all years. Two factors, in particular, confound the quantitative analysis of these data. The first factor concerns the population from which the house dust samples were obtained. The historic samples were collected from residents' vacuum cleaners only at the homes of children who participated in the annual blood lead survey. These values may not be representative of house dust lead concentrations at all homes in each residential area. The second confounding factor is related to the manner in which the cleanup was conducted. Remediation of soils was targeted at high-risk homes or those with children or pregnant women and the highest yard soil lead concentrations. These homes' soil lead levels were immediately reduced to less than 100 mg/kg. The cleanup of these yards and associated ROW also contributed to both the reduction in community-wide mean soil concentrations. As a result, individual soil remediation markedly affected the home yard soil and had a gradual influence on neighborhood and community soil lead levels.

Examination of the correlation matrix shows that log-transformed house dust lead is significantly correlated with yard soils, neighborhood soils, community soils, and air lead levels. The highest correlations are with the geometric mean community-wide soil lead ($r=0.418$, $P=0.0001$), followed by the neighborhood mean soil lead variable ($r=0.327$, $P=0.0001$), non-log-transformed individual yard soil lead ($r=0.253$, $P=0.0001$), and air lead concentration ($\mu g/m^3$) ($r=0.188$, $P=0.0001$).

Backward stepwise regression techniques were applied with various combinations of source variables and the final model selected suggests that

Table 1
Correlation matrix on combined data (all cities, all years)

| | DUSTPB | LNDUSTPB | SOILPB | LNSOILPB | CITSOMN | GCITSOMN | ANPBPPM | ANPBUGM | SOIL200 | GSOIL200 |
|---|---|---|---|---|---|---|---|---|---|---|
| DUSTPB | 1 | | | | | | | | | |
| LNDUSTPB | 0.588* | 1 | | | | | | | | |
| SOILPB | 0.160* | 0.253* | 1 | | | | | | | |
| LNSOILPB | 0.143* | 0.201* | 0.844* | 1 | | | | | | |
| CITSOMN | 0.186* | 0.395* | 0.276* | 0.115* | 1 | | | | | |
| GCITSOMN | 0.247* | 0.418* | 0.366* | 0.275* | 0.902* | 1 | | | | |
| ANPBPPM | 0.119* | 0.164* | 0.197* | 0.192* | 0.165* | 0.327* | 1 | | | |
| ANPBUGM | 0.152* | 0.188* | 0.211* | 0.214* | 0.137* | 0.323* | 0.882* | 1 | | |
| SOIL200 | 0.162* | 0.327* | 0.303* | 0.111* | 0.721* | 0.647* | 0.100** | 0.089** | 1 | |
| GSOIL200 | 0.194* | 0.326* | 0.343* | 0.205* | 0.670* | 0.700* | 0.195* | 0.194* | 0.892* | 1 |

DUSTPB, vacuum dust lead concentration; LNDUSTPB, log-transformed vacuum dust lead concentration; SOILPB, yard soil lead concentration; LNSOILPB, log-transformed yard soil lead concentration; CITSOMN, arithmetic mean city soil lead concentration; GCITSOMN, geometric mean city soil lead concentration; ANPBPPM, annual air lead dust concentration in milligrams per kilogram; ANPBUGM, annual air lead dust concentration in micrograms per meter cubed; SOIL200, arithmetic mean yard soil lead concentration within a 200-foot radius; GSOIL200, geometric mean yard soil lead concentration within a 200-foot radius.

* $P \leqslant 0.001$.

** $P \leqslant 0.05$.

Table 2
General linear model procedure and standardized estimates of regression coefficients

| Variable | Estimate | Pr > *F* | Standardized estimate |
|---|---|---|---|
| Intercept | 5.6553 | 0.0001 | 0.0000 |
| LNSOILPB | 0.0721 | 0.0002 | 0.1157 |
| GSOIL200 | 0.0001 | 0.0096 | 0.1047 |
| GCITSOMN | 0.0005 | 0.0001 | 0.3132 |

Dependent variable: log-transformed vacuum bag house dust exposure. $R^2=0.192$ ($P<0.0001$). LNSOILPB, log-transformed yard soil lead concentration; GSOIL200, geometric mean yard soil lead concentration within a 200-foot radius; GCITSOMN, geometric mean city soil lead concentration.

the individual yard, the immediate neighborhood and the community-wide mean soil lead concentration are all significant. The 200-foot radius definition for the neighborhood variable was selected based on improved $R^2$ values after several iterations with various distances. These three variables together explain approximately 20% of the variation in house dust lead levels (Table 2). Caution should be exercised in interpreting this model, as the soil lead variables are inter-correlated, and the dust samples were collected from the homes where children's blood lead levels were tested and subject to the confounders introduced through the LHIP's intervention efforts. All three variables are significant, though in all combinations, with community soil and individual yard soil exhibiting the highest two variable $R^2$.

All three variables are important to include in the model as they represent different plausible routes and mechanisms of soil lead contribution to house dust. The individual home yard concentration is specific to the dependent dust variable observation and represents soils that are tracked-in or originate as suspended dust from the immediate home environment. The neighborhood variable represents soils that might be tracked or suspended from neighboring yards, streets and alleyways. Because the home yard is excluded from the calculation, the neighborhood value is independent of the yard concentration. For the first 6 years in Smelterville, 8 years in Kellogg, and 10 years in Pinehurst homes were remediated individually based on risk. Beginning in 1996, select neighborhoods were remediated in addition to high-risk individuals across the site, so some high-risk homes and neighborhoods were cleaned simultaneously since that time. The overall correlation between home yard soil (LNSOILBP), and neighborhood soil (GSOIL2000) lead concentrations is, $r=0.205$ ($P<0.001$).

The community mean soil concentration represents soils and roadside dusts from throughout the town that might eventually contribute to household dusts through longer distance tracking or airborne mechanisms. This estimate is based on the entire population of several hundred homes sampled in each community. This variable could also be a surrogate for time and/or progress in the overall cleanup. As such, it is significantly correlated with the neighborhood variable ($r=0.700$, $P<0.001$), and to a lesser degree the individual yard soil ($r=0.275$, $P<0.001$).

These results suggest that the soil source variables, although significant, explain a small portion of the variation in vacuum bag dust lead levels. Other factors not included in the model, but likely important in explaining the dust lead variation, are contributions from other potential sources (paint, hobbies and occupations, etc.) and mitigating factors associated with individual behaviors and housing and socio-economic conditions. Some of these factors are explored below with a different database.

Table 3 shows the overall reduction in dust lead levels and the decrease per unit of soil lead reduction for each of the variables. These results show a 0.53 mg/kg observed decrease in dust lead for each 1.0 mg/kg decrease in community geometric mean, a 0.60 mg/kg reduction for individual yard soil and a 0.55 mg/kg reduction for neighborhood soil. These values suggest that on average, a 0.56 mg/kg reduction in dust lead per 1 mg/kg reduction in soils is observed. These results suggest that mean house dust lead levels are likely to be between 400 and 500 mg/kg for the BHSS, even if soils are reduced to less than the national background default value of 200 mg/kg (USEPA, 1994). This compares with a background house dust level of approximately 200 mg/kg and soil background of 50 mg/kg found for homes of similar age and socio-economic status in

Table 3
Estimated dust lead decrease per 1 mg/kg of soil lead reduction

| | Geometric mean yard soil concentration (mg/kg) | Geometric mean neighborhood soil concentration (200-foot radius) (mg/kg) | Geometric mean community soil concentration (mg/kg) | Geometric mean house dust lead concentration (mg/kg) |
|---|---|---|---|---|
| Before (1988) | 1715 | 2048 | 1996 | 1435 |
| After (1998) | 208 | 415 | 308 | 538 |
| Decrease | 1507 | 1633 | 1688 | 897 |
| Ratio of house dust decrease to soil decrease | 0.60 | 0.55 | 0.53 | NA |

mg/kg, milligrams per kilogram; NA, not applicable.

northern Idaho communities unaffected by the mining and smelting industry (Spalinger, 2000).

Assuming the background concentration accounts for typical lead-based paint sources and historical use of leaded gasoline, comparison of these results suggests that typically about half of residual house dust lead contamination expected following the soil cleanup will be associated with paint and other consumer products, unrelated to mineral industry sources. About half of the remaining lead can be accounted for by the higher than background soil lead remaining after remediation. A similar portion of residual house dust lead at the BHSS remains unaccounted for and likely derives from unknown sources not associated with either the contaminated soil variables or potential lead-based paint or housing factors. Possible sources of the additional lead could be residual contamination from past industrial practices trapped within the structures or soft surface dust reservoirs in the home, occupational or hobby derived dusts brought into the home, tracking of soils and dusts from mining-impacted non-residential portions of the BHSS or the greater Coeur d'Alene Basin, recontamination of ROWs within the residential areas of the Site, and/or fugitive dusts associated with ongoing cleanup.

### 3.3. Dust mat sampling results

Table 4 presents the dust mat lead concentrations as well as dust and lead loading rates for the two population groups for 1996–1998. These data were analyzed by using ANOVA to determine whether significant differences exist between the two populations (LHIP vs. Site-wide), over time and among the different cities. Notable differences were observed between population groups, among years and these were subsequently analyzed separately. Comparisons between the two populations were only possible in 1997 in Smelterville and in 1998 for both Smelterville and Kellogg. No significant differences between the two populations, LHIP and Site-wide, were observed in 1997. However, in 1998, significant differences were observed in both Smelterville and Kellogg for concentrations and loading rates. Changes over time suggest that overall dust loading rates have decreased considerably in all areas since 1996.

For data collected from Kellogg and Smelterville in 1998, however, dust and lead loading rates were typically twice as high in the LHIP population versus the Site-wide population. This results in more total lead coming into the homes of LHIP children, albeit at lower concentrations. One possible explanation for this reduction is that the remedial strategy focused on cleaning up the exterior yards of homes with young children. As a result, the average soil lead concentration for LHIP participating homes is lower than that of the community at-large, and that component of house dust has a lower concentration. However, more dust is moving into the LHIP homes possibly associated with more people in the home, children, pets and socio-economic status (TerraGraphics, 2000).

In 1997 and 1998, significant differences were observed among cities (Table 4). Kellogg consistently showed higher dust lead concentrations, typically twice those observed in Smelterville and Pinehurst. This corresponds to higher soil lead concentrations in Kellogg where cleanup activities

Table 4
LHIP and Site-wide (SW) dust mat survey results, geometric means comparisons among cities by year

| City | *N* | Mean | Standard deviation | Geometric mean | Geometric standard deviation |
|---|---|---|---|---|---|
| (1) 1996—LHIP | | | | | |
| *Mat lead concentration* (mg/kg) | | | | | |
| Kellogg | 41 | 1526 | 1306 | 1154 | 2.118 |
| Pinehurst | 21 | 887 | 566 | 764 | 1.705 |
| Smelterville | 8 | 1677 | 1204 | 1270 | 2.333 |
| *Dust loading rate* (mg/m²/day) | | | | | |
| Kellogg | 65 | 1029 | 1250 | 576 | 3.077 |
| Pinehurst | 27 | 1079 | 1101 | 682 | 3.091 |
| Smelterville | 10 | 838 | 620 | 571 | 3.103 |
| *Lead loading rate* (mg/m²/day) | | | | | |
| Kellogg | 41 | 1.9 | 2.0 | 1.318 | 2.502 |
| Pinehurst | 21 | 1.1 | 0.8 | 0.794 | 2.323 |
| Smelterville | 8 | 2.0 | 2.3 | 1.108 | 3.672 |
| (2) 1997-LHIP | | | | | |
| *Mat lead concentration* (mg/kg)* | | | | | |
| Kellogg | 85 | 1927 | 1517 | 1430 | 2.251 |
| Pinehurst | 12 | 945 | 732 | 763 | 1.920 |
| Smelterville | 20 | 719 | 418 | 627 | 1.692 |
| *Dust loading rate* (mg/m²/day)** | | | | | |
| Kellogg | 85 | 687 | 790 | 436 | 2.529 |
| Pinehurst | 12 | 719 | 981 | 397 | 2.844 |
| Smelterville | 18 | 650 | 560 | 440 | 2.613 |
| *Lead loading rate* (mg/m²/day)** | | | | | |
| Kellogg | 85 | 1.326 | 1.751 | 0.623 | 3.600 |
| Pinehurst | 12 | 0.662 | 0.718 | 0.301 | 4.146 |
| Smelterville | 18 | 0.532 | 0.532 | 0.298 | 3.392 |
| (3) 1998-LHIP | | | | | |
| *Mat lead concentration* (mg/kg)* | | | | | |
| Kellogg | 113 | 1496 | 2104 | 1048 | 2.17 |
| Pinehurst | 54 | 651 | 577 | 525 | 1.87 |
| Smelterville | 29 | 810 | 462 | 715 | 1.64 |
| *Dust loading rate* (mg/m²/day)** | | | | | |
| Kellogg | 112 | 749 | 1204 | 453 | 2.56 |
| Pinehurst | 53 | 1074 | 1157 | 638 | 2.98 |
| Smelterville | 29 | 1058 | 855 | 779 | 2.26 |
| *Lead loading rate* (mg/m²/day) | | | | | |
| Kellogg | 112 | 1.080 | 2.203 | 0.475 | 3.27 |
| Pinehurst | 53 | 0.674 | 0.979 | 0.337 | 3.29 |
| Smelterville | 29 | 0.773 | 0.694 | 0.558 | 2.33 |
| (4) 1998-Site-wide | | | | | |
| *Mat lead concentration* (mg/kg)** | | | | | |
| Kellogg | 198 | 1923 | 3746 | 1195 | 2.26 |
| Smelterville | 76 | 1074 | 570 | 925 | 1.78 |
| *Dust loading rate* (mg/m²/day)** | | | | | |
| Kellogg | 198 | 366 | 472 | 233 | 2.54 |

Table 4 *(Continued)*

| City | $N$ | Mean | Standard deviation | Geometric mean | Geometric standard deviation |
|---|---|---|---|---|---|
| Smelterville | 76 | 447 | 442 | 310 | 2.36 |
| *Lead loading rate* ($mg/m^2/day$) | | | | | |
| Kellogg | 198 | 1.138 | 5.074 | 0.278 | 3.78 |
| Smelterville | 76 | 0.435 | 0.478 | 0.285 | 2.54 |

mg/kg, milligram per kilogram; $mg/m^2/day$, milligram per meters squared per day; $N$, number of samples used in the analysis.
* $P \leqslant 0.0001$.
** $P \leqslant 0.05$.

have not yet been completed. In 1997, the increased lead content of dusts translated to a significantly greater lead loading rate in Kellogg, as well. The Kellogg lead loading rate was about twice that observed in Pinehurst and Smelterville in 1997.

In the 1998 Site-wide survey, mat lead concentrations for Kellogg homes were higher than Smelterville homes. However, dust loading rates in Kellogg were significantly lower than Smelterville. This result is similar to the LHIP 1998 population. These countering effects resulted in no significant difference in lead loading rate among the three cities (i.e. more lead in less dust in Kellogg and more dust with less lead in Pinehurst and Smelterville). This finding suggests that the lead loading rates in Kellogg are most associated with non-remediated soil lead observed in mat dust. These concentrations should decrease as the cleanup is completed in Kellogg and soil lead levels approach those accomplished in Smelterville and Pinehurst.

Some decrease in lead loading rate can also be expected in Pinehurst as the cleanup progresses. However, cleanup efforts have been completed in Smelterville and soil concentrations were at a historical low in 1997–1998 and are unlikely to decrease in the future. As a result, lead loading rates in Smelterville and Pinehurst will probably depend on dust loading rates in the future (as opposed to concentration in Kellogg). Possible explanations for the higher dust loading rates in Smelterville and Pinehurst are the more rural setting, proximity to the non-residential Smelterville Flats cleanup in 1997–1998, and infrastructure considerations associated with curbs, gutters and paved alleys in Kellogg versus gravel ROWs in the other cities (TerraGraphics, 2000).

In summary, dust concentrations and dust and lead loading rates in homes have decreased across the site. Comparison between these populations indicates that both dust and lead loading rates are higher for the LHIP population (where young children are present) than for those of the Site-wide (or community at-large) group. However, house dust lead concentrations in the Site-wide population are higher than those of the LHIP participants.

### *3.4. Comparison of dust lead concentration by sampling method*

For houses where both vacuum bag and dust mat lead samples were collected, paired *t*-tests were performed to determine whether significant differences exist in dust lead concentration between the two techniques (Table 5). The assumption of normally distributed differences between the vacuum and mat lead concentrations was satisfied for log-transformed data. Geometric mean concentrations for the two techniques are significantly different ($P = 0.0001$). Generally, vacuum bag lead concentrations are approximately 30–40% lower than mat concentrations but are correlated ($r = 0.42$). These results suggest that dust mats reflect the contribution of exterior soils to indoor dusts and that a significant dilution (30–40%) occurs in the vacuum bag. It is also possible that the mats perform an intervention effect by capturing lead at the door that might have otherwise been observed in the vacuum bag. This, however, is not likely to have a large effect as mats are in the home for 2–3 weeks and vacuum bags generally accumulated dust for several months.

Table 5
Paired *t*-test of mat lead versus vacuum bag lead concentrations

| | Year | Geometric mean dust lead concentration (mg/kg) | | | |
|---|---|---|---|---|---|
| | | No. of observations | Dust mat | Vacuum bag | *P*-value |
| Overall (combined) | 1996 | 63 | 1009 | 567 | 0.0001 |
| Paired data only | 1997 | 172 | 919 | 635 | 0.0001 |
| | 1998 | 184 | 897 | 625 | 0.0001 |
| | All years | 419 | 922 | 620 | 0.0001 |

mg/kg, milligrams per kilogram.

### *3.5. Factors contributing to elevated house dust lead levels and loading rates*

The 1998 questionnaire data were used to analyze house dust lead levels. Because the population characteristics are different for the two surveys, the data sets were analyzed separately. Univariate ANOVA was used to determine significant differences. Although factorial ANOVA would have been the preferred analysis, these observational data were missing many factorial combinations that would make factorial results difficult to interpret. The following factors were found to be significant; non-significant factors are not discussed. Table 6 presents questionnaire factors, categories within the factors, and the corresponding geometric means for each category.

(1) *House age:* Lead loading rate increases significantly with house age ($P=0.022$) for the LHIP participants, but not for the Site-wide population ($P=0.100$). The dust loading rate is significantly higher in newer homes for the Site-wide group ($P=0.007$), but not for the LHIP participants ($P=0.277$). However, these results are confounded by the small number of newer homes in this economically depressed community.

(2) *Number of adults:* More adults regularly living at the home are associated with increased lead loading rate (LHIP $P=0.039$, Site-wide $P=0.053$) and dust loading rate (LHIP $P=0.016$, Site-wide $P=0.016$) for both populations.

(3) *Hours spent outside by children* (*summer, winter*)*:* The number of hours spent outside by the oldest child is associated with increased dust and lead loading rate for both populations (see *P*-values in Table 6). In summer, loading rates approximately double as the child's hours spent outside increase from $<4$ to $\geqslant 8$ h/day. A clear trend is not evident during the winter season, most likely due to the small number of observations.

(4) *Number of recreational activities:* Both populations show that, with an increase in the number of the recreational activities, dust loading rate increases (LHIP $P=0.037$, Site-wide $P=0.016$); but lead loading rate does not change significantly (LHIP $P=0.230$, Site-wide $P=0.111$). More recreational activities likely bring more soil and dirt, but not necessarily lead, into the home.

(5) *Occupation:* For the LHIP population, only 'landscaping' showed a significant effect on dust loading rate (nearly doubled rates) ($P=0.016$). However, only 15 of the total 133 survey participants who answered this question had this occupation. For the Site-wide group, only 'carpentry' showed a significant increase in dust loading rate ($P=0.003$), although there were also few responses for this factor. The geometric mean lead loading rate was also higher for carpenters.

(6) *Number of pets:* The dust loading rate for the LHIP families significantly increased with more pets ($P=0.019$), but the lead loading rates did not ($P=0.563$). Neither was significant for the Site-wide group.

(7) *Pet use of door by mat:* If pets used the door where the mat is placed, the dust loading rate for the LHIP population was significantly increased ($P=0.01$). The lead loading rate was almost the same. These results are likely confounded by the number of pets.

(8) *Paint conditions* (*interior, exterior*)*:* The condition of interior paint was significantly associated with increased dust and lead loading rates

Table 6
ANOVA for the LHIP and Site-wide survey dust mat loading data

| Factor | Categories | LHIP survey | | | | | Site-wide (SW) survey | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *N* | Dust loading rate (mg/m²/day) | | Lead loading rate (mg/m²/day) | | *N* | Dust loading rate (mg/m²/day) | | Lead loading rate (mg/m²/day) | |
| | | | Geometric mean | *P*-value | Geometric mean | *P*-value | | Geometric mean | *P*-value | Geometric mean | *P*-value |
| House age | | | | 0.277 | | *0.022* | | | *0.007* | | 0.100 |
| | <1960 | 71 | 505 | | 0.516 | | 125 | 210 | | 0.226 | |
| | 1960–1978 | 22 | 584 | | 0.396 | | 22 | 290 | | 0.310 | |
| | >1979 | 6 | 263 | | 0.121 | | 6 | 606 | | 0.578 | |
| Own/Rent | | | | 0.614 | | 0.568 | | | *0.010* | | *0.001* |
| | Rent | 62 | 557 | | 0.505 | | 65 | 318 | | 0.384 | |
| | Own | 88 | 513 | | 0.454 | | 142 | 221 | | 0.213 | |
| Occupancy time | | | | 0.447 | | 0.891 | | | *0.009* | | *0.038* |
| | <1 mo | | | | | | | | | | |
| | 1–2 mo | 11 | 640 | | 0.570 | | 8 | 276 | | 0.333 | |
| | 2–3 mo | 6 | 472 | | 0.381 | | 6 | 441 | | 0.366 | |
| | 3–6 mo | 10 | 622 | | 0.371 | | 7 | 328 | | 0.287 | |
| | 6–12 mo | 17 | 596 | | 0.581 | | 14 | 262 | | 0.182 | |
| | 1–5 yr | 65 | 588 | | 0.491 | | 68 | 325 | | 0.371 | |
| | >5 yr | 42 | 408 | | 0.444 | | 103 | 195 | | 0.203 | |
| Remodeled | | | | 0.746 | | 0.932 | | | *0.005* | | 0.136 |
| | Yes | 58 | 563 | | 0.487 | | 95 | 204 | | 0.225 | |
| | No | 83 | 534 | | 0.479 | | 102 | 300 | | 0.294 | |
| Number of entry mats | | | | 0.145 | | 0.272 | | | 0.079 | | *0.022* |
| | None | 24 | 770 | | 0.726 | | 36 | 346 | | 0.457 | |
| | At one | 66 | 550 | | 0.462 | | 89 | 246 | | 0.222 | |
| | At some | 15 | 482 | | 0.410 | | 20 | 194 | | 0.224 | |
| | At all | 45 | 441 | | 0.431 | | 60 | 226 | | 0.254 | |
| Remove shoes | | | | 0.340 | | 0.493 | | | *0.015* | | 0.170 |
| | Yes | 16 | 442 | | 0.407 | | 25 | 162 | | 0.186 | |
| | No | 132 | 563 | | 0.500 | | 171 | 264 | | 0.268 | |
| Number of adults | | | | *0.016* | | *0.039* | | | *0.016* | | 0.053 |
| | <3 | 126 | 493 | | 0.442 | | 189 | 236 | | 0.246 | |
| | ⩾3 | 24 | 829 | | 0.745 | | 25 | 382 | | 0.409 | |
| Child 1-summer | | | | *0.0001* | | *0.008* | | | *0.0005* | | *0.013* |
| Hours outside | <4 | 64 | 372 | | 0.353 | | 160 | 218 | | 0.237 | |
| | <8 | 61 | 638 | | 0.537 | | 33 | 331 | | 0.261 | |
| | ⩾8 | 27 | 848 | | 0.754 | | 21 | 455 | | 0.549 | |

Table 6 *(Continued)*

| Factor | Categories | LHIP survey | | | | | Site-wide (SW) survey | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *N* | Dust loading rate (mg/m²/day) | | Lead loading rate (mg/m²/day) | | *N* | Dust loading rate (mg/m²/day) | | Lead loading rate (mg/m²/day) | |
| | | | Geometric mean | *P*-value | Geometric mean | *P*-value | | Geometric mean | *P*-value | Geometric mean | *P*-value |
| Child 1-winter | | | | *0.001* | | *0.005* | | | *0.0001* | | *0.017* |
| Hours outside | <4 | 127 | 470 | | 0.421 | | 196 | 230 | | 0.243 | |
| | <8 | 22 | 1068 | | 0.971 | | 14 | 622 | | 0.626 | |
| | ⩾8 | 3 | 747 | | 0.553 | | 4 | 541 | | 0.393 | |
| Number of recreational | | | | *0.037* | | 0.230 | | | *0.016* | | 0.111 |
| activities | None | 55 | 428 | | 0.379 | | 115 | 206 | | 0.226 | |
| | 1 | 44 | 490 | | 0.510 | | 46 | 311 | | 0.372 | |
| | 2 | 24 | 704 | | 0.520 | | 32 | 315 | | 0.238 | |
| | ⩾3 | 29 | 739 | | 0.630 | | 21 | 309 | | 0.309 | |
| Carpentry job | | | | 0.160 | | 0.976 | | | *0.003* | | 0.057 |
| | Yes | 9 | 819 | | 0.480 | | 14 | 493 | | 0.471 | |
| | No | 124 | 513 | | 0.485 | | 165 | 233 | | 0.245 | |
| Landscape job | | | | *0.016* | | 0.196 | | | 0.125 | | 0.492 |
| | Yes | 15 | 942 | | 0.698 | | 11 | 355 | | 0.315 | |
| | No | 118 | 500 | | 0.466 | | 164 | 231 | | 0.245 | |
| Wet mat | | | | 0.223 | | 0.284 | | | *0.014* | | *0.0002* |
| | Yes | 16 | 712 | | 0.647 | | 16 | 426 | | 0.764 | |
| | No | 134 | 521 | | 0.470 | | 188 | 235 | | 0.234 | |
| Pets | | | | *0.019* | | 0.563 | | | 0.154 | | 0.657 |
| | None | 64 | 390 | | 0.410 | | 85 | 216 | | 0.244 | |
| | 1 | 42 | 566 | | 0.465 | | 69 | 250 | | 0.237 | |
| | 2 | 25 | 701 | | 0.546 | | 32 | 314 | | 0.298 | |
| Pet use door by mat | | | | *0.010* | | 0.543 | | | 0.406 | | 0.259 |
| | Yes | 69 | 704 | | 0.511 | | 82 | 288 | | 0.291 | |
| | No | 52 | 447 | | 0.453 | | 68 | 253 | | 0.231 | |
| General condition interior | | | | *0.003* | | *0.046* | | | 0.111 | | 0.107 |
| Paint | Good | 33 | 416 | | 0.366 | | 24 | 216 | | 0.192 | |
| | Chipping | 50 | 786 | | 0.595 | | 17 | 373 | | 0.391 | |
| General condition exterior | | | | *0.038* | | 0.655 | | | *0.028* | | 0.060 |
| Paint | Good | 57 | 461 | | 0.467 | | 119 | 206 | | 0.215 | |
| | Chipping | 68 | 658 | | 0.514 | | 46 | 295 | | 0.326 | |

Table 6 *(Continued)*

| Factor | Categories | LHIP survey | | | | | Site-wide (SW) survey | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *N* | Dust loading rate (mg/m²/day) | | Lead loading rate (mg/m²/day) | | *N* | Dust loading rate (mg/m²/day) | | Lead loading rate (mg/m²/day) | |
| | | | Geometric mean | *P*-value | Geometric mean | *P*-value | | Geometric mean | *P*-value | Geometric mean | *P*-value |
| Percent yard grassed | | | | *0.016* | | 0.517 | | | *0.016* | | *0.016* |
| | <25 | 10 | 842 | | 0.600 | | 3 | 582 | | 0.961 | |
| | 26–50 | 6 | 1136 | | 0.782 | | 5 | 385 | | 0.382 | |
| | 51–75 | 23 | 718 | | 0.557 | | 16 | 412 | | 0.511 | |
| | 76–100 | 99 | 462 | | 0.442 | | 180 | 226 | | 0.231 | |
| General household hygiene | | | | *0.002* | | *0.006* | | | *0.00003* | | *0.001* |
| | Poor | 16 | 812 | | 0.907 | | 2 | 610 | | 0.557 | |
| | Fair | 43 | 768 | | 0.582 | | 26 | 390 | | 0.371 | |
| | Good | 39 | 529 | | 0.501 | | 69 | 278 | | 0.314 | |
| | Excellent | 18 | 316 | | 0.246 | | 40 | 153 | | 0.139 | |

$P < 0.05$ are in italics (single-factor ANOVA). *N*, number of mats used in the analysis; mg/kg, milligram per kilogram; mg/m$^2$/day, milligram per meters squared per day.

($P=0.003$ and $P=0.046$, respectively) for LHIP families. Exterior paint chipping was associated with increased dust loading rates for both the LHIP and Site-wide groups ($P=0.038$ and $P=0.028$, respectively). Lead loading rate did not increase significantly with chipping exterior paint for either population.

(9) *Percentage of yard grassed:* A higher percentage of the yard's grass coverage shows significantly decreased dust and lead loading rates ($P=0.016$ and $P=0.016$, respectively) for the Site-wide group. The LHIP population showed decreased dust loading rate ($P=0.016$), but not lead loading rate ($P=0.517$), perhaps because most LHIP yards had been remediated. These results are also complicated by the low number of observations in yards with less than 50% grass cover.

(10) *General household hygiene:* General household hygiene shows a significant effect for both dust and lead loading rates (see *P*-values in Table 6). Both rates decreased as the household hygiene improved.

(11) *House owned/rented and length of occupancy:* Whether the house is owned or rented and the length of occupancy time significantly affected dust and lead loading rate for the Site-wide group only (see *P*-values in Table 6). Renters show higher dust and lead loading rates than owners. Although the rates vary with the length of occupancy, the general trend is lower dust and loading rates with longer residency time.

(12) *Remodeling:* Also for the Site-wide group only, remodeling indicates a significantly lower (≈30%) dust loading rate ($P=0.005$).

(13) *Entry mats and shoe removal:* As the number of entry mats increase for the Site-wide group, lead loading rate significantly decreased ($P=0.022$). Removing shoes for the Site-wide group showed decreased dust loading rate by approximately 1.6 times ($P=0.015$), but not lead loading rate ($P=0.170$). No significant differences in any category were noted for the LHIP group.

Stepwise multiple regression analysis was then applied to the combined questionnaire and environmental data for 1998. Several combinations of both source and categorical variables from each of the questionnaire categories were evaluated. This approach was used to maximize the number of observations available for the various models.

Table 7
Multiple regression models for dust and lead loading rates using questionnaire factors

| Parameter | Estimate | Pr>*F* |
|---|---|---|
| Dependent variable: dust loading rate | | |
| $R^2=0.213$ ($P=0.0001$) | | |
| Intercept | 6.293 | 0.0001 |
| HYGIENE | −0.389 | 0.0001 |
| REGADULT | 0.225 | 0.0014 |
| CHI1SUM | 0.079 | 0.0001 |
| Dependent variable: Lead loading rate | | |
| $R^2=0.261$ ($P=0.0001$) | | |
| Intercept | −1.077 | 0.0015 |
| GSOIL200 | 0.001 | 0.0002 |
| HYGIENE | −0.397 | 0.0001 |
| REGADULT | 0.322 | 0.0003 |
| CHI1SUM | 0.068 | 0.0011 |

$R^2=0.213$ ($P=0.0001$). HYGIENE, general household hygiene; REGADULT, number of adults regularly living at home; CHI1SUM, hours spent outside by the child during summer; GSOIL200, neighborhood geometric mean soil lead concentration within a 200-foot radius.

The selected models are presented in Table 7. The dust loading rate model suggests that the dust accumulation rate on interior dust mats is a function of home hygiene, the number of adults regularly in the home, and the number of hours children spend outdoors. The model explains 21% of the variation in the dust loading rate. Home hygiene is negatively related to the dust loading rate (i.e. poor hygiene results in more dust accumulation). The more adults reported in the home, the greater the dust loading rate. The more time children spend playing outside, the more dust is brought into the home.

The same variables are also significant in the lead loading rate model with the addition of the neighborhood soil lead concentration variable. The model explains 26% of the variation in the lead loading rate. The model suggests that neighborhood soils are significant sources of lead to the home and are influenced by the same variables as the dust loading rate model. The individual yard soil variable was not significant in these models. However, this result could be due to the timing of this survey. Most of the homes sampled in 1997 and 1998 had been remediated or exhibit low yard soil lead levels and have probably become an insignificant source of lead contribution by that time.

These models are difficult to interpret. The relationship between the three factors (general household hygiene, number of adults, and hours spent outside by the child) is complex. Larger family units (i.e. more adults and children in the home) also have children that spend more time outdoors and their homes and yards tend to be in better condition. There is a strong correlation between home hygiene and interior paint condition (i.e. chipping and peeling). Each variable had similar effects in the model, but paint condition was not significant when included with hygiene. Hygiene was selected for inclusion, as it substantially increased the number of observations available for the model. Interior paint condition is not significant in the dust loading rate model, but hygiene is significant. Overall, the information provided by the questionnaire administered after picking up the dust mat provides valuable insight and identifies significant factors affecting lead concentration, dust loading and lead loading rates.

The analysis of the questionnaire data suggests that house age is a possible factor affecting interior house dust lead content, perhaps due to lead paint or residual lead contamination from smelter operations. Some of the factors describing socio-economic and demographic status of the residents (own/rent, number of people living in the house) also influence house dust and lead loading rate. Socio-economic status seems to play a complex role in dust loading rate relationships. In the presence of active sources of lead (i.e. contaminated soils or paint), these factors result in higher lead loading. People's habits and activities (number of hours spent outside by children, recreational activities, entry precautions, number of pets) are also important factors. As expected, paint condition can influence dust and lead loading rates inside the house, although this may be related to home condition and socio-economic status, as well as a possible source of lead. Grass cover of the yard and general household hygiene were significant factors for both populations. Analysis of occupation effects on lead concentration and dust and lead loading rates lacked a sufficient number of responses to appropriately interpret the results.

## 4. Conclusions

The remedial strategy adopted to reduce exposure, risk, and blood lead levels at the BHSS was to decrease residential soil lead concentrations to RAOs of <1000 mg/kg individual home and < 350 mg/kg community mean. This was to be accomplished through replacement and covering of contaminated soils with clean material. Subsequently, these actions were anticipated to reduce house dust lead levels to the 500 mg/kg community mean RAO. As the cleanup was completed in Smelterville and continues in other communities, progress toward these goals was examined in the 5-year review for the BHSS.

From 1988 to 1998, total lead in yard soils was reduced by 95% in Smelterville, 85% in Kellogg, 51% in Page, 61% in Wardner, and 20% (since 1990) in Pinehurst, and geometric yard soil lead concentrations are all approaching the 350 mg/kg RAO. Smelterville's geometric yard soil lead mean was approximately 150 mg/kg at the completion of soil remediation. The soil lead criteria should be met in all communities following cleanup. House dust lead concentrations measured in homeowner vacuum cleaners in Smelterville have decreased by approximately 50%, from means in the 1200–1800 mg/kg range in 1988–1990, to means between 450 and 600 mg/kg in 1999. Most of the decrease occurred from 1989 to 1992 when the majority of the yards of homes occupied by children (i.e. those homes where dust samples are collected) were remediated. Overall, a 0.5–0.6-mg/kg drop in house dust lead per 1.0 mg/kg reduction in soil lead has been observed. Approximately 80% of pre-remedial, and an estimated 60% of post-remedial lead in house dust originates from outdoor soils. Vacuum bag dust lead concentrations are expected to range from 400 to 500 mg/kg, and meet the 500-mg/kg mean RAO, in post-remedial conditions. In 1998–1999, mean vacuum bag house dust lead concentrations at the BHSS were near the RAO. By 2001 these levels were near 400 mg/kg lead.

However, lead concentrations collected by the dust mat sample technique continue to exceed house dust RAOs. Dust lead concentrations obtained from vacuum and dust mat methodologies are correlated, but are significantly different. Mat lead concentrations are generally 30–40% higher than vacuum cleaner bag lead concentrations at the BHSS, although these concentrations are similar in background communities. Significant dilution of dust lead levels seems to occur between the entry mat and the homeowner vacuum cleaner in the BHSS. Soil lead levels are significantly correlated with, but explain only approximately 20% of the variation in, house dust lead concentration. Soil lead concentrations in the home yard, immediate neighborhood and greater community are all significant predictors of dust lead levels. Much of the variation in house dust lead levels is associated with housing, socio-economic, behavioral, family, occupational and recreational related factors. Neighborhood soil lead concentrations, household hygiene, the number of adults living in the home, and the number of hours a child spends outdoors in summer explain approximately 21 and 26% of the variation in dust and lead loading rates, respectively.

In 1998–1999, lead concentrations in BHSS vacuum cleaner bag dust were 3–6 times greater than in socio-economically comparable, non-mining, background communities in northern Idaho and from 8 to 15 times higher in floor mat dust. Assuming that the background component accounts for potential lead paint, housing and socio-economic confounders, the additional lead content at the BHSS is possibly associated with (i) the post-remedial soil concentrations (≈3–6 times background community soil concentrations after cleanup), (ii) residual contamination within the structures or soft surface dust reservoirs in the home, (iii) occupationally or hobby derived dusts brought into the homes, (iv) tracking of soils and dusts from non-residential portions of the BHSS or the greater Coeur d'Alene Basin, (v) recontamination of ROW within the residential areas of the BHSS, and (vi) fugitive dusts associated with ongoing cleanup activities.

In total, these analyses suggest that house dusts are difficult to measure and show great variation in lead concentration and loading rates associated with complex socio-economic and behavioral factors. Mean vacuum bag lead concentration will likely stabilize between 400 and 500 mg/kg, near the RAO, at the completion of soil remediation, while dusts measured by the floor mat method will likely not meet the RAO, at least for some time. Individual homes subject to the additional sources mentioned above may exceed the 1000 mg/kg individual RAO.

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