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A case study of lead contamination cleanup effectiveness at Bunker Hill

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Abstract

A review of cleanup effectiveness at Bunker Hill Superfund Site (BHSS) has shown that yard soil cleanup is an effective tool for reducing house dust lead concentrations, thereby reducing children's blood lead levels. This review has also shown that contiguous cleanup of residences has a three-fold greater reduction of children's blood lead levels compared with cleaning only those homes where children currently reside by reducing exposures attributable to neighboring properties. This review underscores the importance of a community-wide, preventative approach to controlling lead contamination in soil and house dust. This review has further characterized the need for careful design, implementation, and perpetual maintenance of a community-wide lead cleanup. Several key areas of importance to maintain large scale mining/smelting remedies in the Bunker Hill area were analyzed and noted for further action, including: infrastructure, institutional controls for homeowner projects (post cleanup), erosion control for undeveloped hillsides with potential to impact the developed valley floor, drainage improvements and flood control, waste piles, and increasing the rate at which cleanup proceeds. Focusing on these areas is crucial to minimizing recontamination at a large scale lead cleanup.
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1. Introduction

The Seattle Regional office of the US EPA has conducted a review of the cleanup actions implemented at the Bunker Hill Superfund Site (BHSS) to protect children from lead contamination, also referred to as a 'Five Year Review.' The Five Year Review is a process required in Superfund Reauthorization in 1986 to ensure the ongoing protectiveness of remedies that leave waste in place. Table 1 lists a chronology of events which defined lead exposure at the BHSS.

The federal Superfund program was established by Congress in 1980 to investigate and respond to chemical releases and cleanup hazardous waste sites. The US Environmental Protection Agency (EPA) administers the Superfund program in cooperation with state and tribal governments.

The BHSS is located in Shoshone County in northern Idaho, approximately 65 km east of Coeur

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Table 1
Bunker Hill site chronology

Event	Date
Lead smelter startup	1917
Zinc plant startup	1928
Baghouse fire	1973
Emergency health response	1974–1975
Construction of tall smelter stacks	1977
Smelter shuts down	1981
Lead screening and intervention starts	1985
Early cleanup actions of parks and schools	1986
Early cleanup actions of residential yards	1989
Institutional Controls Program Ordinance adoption	1995
Institutional Controls Program implementation	1995
Long-term residential yard soil cleanup initiated	1989 to present

d'Alene, Idaho (see Fig. 1). The site encompasses approximately 5400 ha in the Silver Valley of the South Fork of the Coeur d'Alene River (SFCDR) and includes the 150 ha abandoned industrial complex of the former Bunker Hill Company lead/zinc mine and smelter in Kellogg, Idaho. The site is home to more than 7000 people in five residential areas including the Cities of Kellogg, Wardner, Smelterville, Pinehurst, and the unincorporated communities of Page, Ross Ranch, Elizabeth Park, and part of Montgomery Gulch. The residential neighborhoods and the abandoned complex are located on the valley floor, side gulches, or adjacent bench areas cut into steep hillsides.

A century of discharges and emissions from mining, milling, and smelting activities has contaminated several thousand hectares with heavy metals. The most significant metals are antimony, arsenic, cadmium, copper, lead, mercury, and zinc. The principal sources of metal contamination were air emissions from primary smelter operations, waste rock and mill tailings discharged to the river or confined in large waste piles on site. There has been significant transport of smelter and mine wastes throughout the area caused by air deposition, flooding, wind erosion, and anthropogenic activities. Decades of sulfur oxide emissions from smelter operations, forest fires, and extensive logging have denuded the adjacent hillsides, resulting in severe erosion.

Lead production from the late 19th century has created ubiquitous heavy metal contamination of soils and dusts throughout the site. Lead concentrations of wastes and soils within the smelter complex ranged to 100 000 mg/kg (10%) or more. Tailings in the riverine flood plain averaged greater than 20 000 mg/kg (2%) lead. Soils in residential yards in the smelter communities averaged 2500 mg/kg to 5000 mg/kg in the early 1980s, and house dust lead concentrations in vacuum cleaner bags averaged 2000 mg/kg to 4000 mg/kg.

The pathways and human health effects associated with exposure to heavy metals has been studied extensively at Bunker Hill (Landrigan et al., 1976; Yankel et al., 1977; ATSDR, 1997a,b; Stokes et al., 1998; Rao et al., 1999). Since 1974, more than 7000 blood lead samples have been obtained from children living within the BHSS (TerraGraphics, 2000). Analyses of these data in conjunction with the Remedial Investigation/Feasibility Study effort resulted in an integrated risk management and cleanup strategy designed to monitor and minimize lead exposure in children as the cleanup progresses in the 5400 ha area (TerraGraphics, 1997).

The cleanup strategy adopted was based on site-specific analyses of the relationship between observed blood lead levels among children and environmental media lead concentrations at the site (TerraGraphics, 1990). BHSS was the first site where (what later became known as) the US EPA Integrated Exposure Uptake Bio-kinetic Model (IEUBK v.99D) was used to determine the risk-

Fig. 1. Bunker Hill Superfund site location map.

based cleanup criteria for lead in soils and house dusts (Environmental Protection Agency, 1994a).

House dust has been widely recognized as a primary source of lead exposure to young children and was identified as the predominant source of exposure for young children at the BHSS (Lanphear and Roghmann, 1997; Lanphear et al., 1998; Succop et al., 1998; Manton et al., 2000; TerraGraphics, 2000). Previous analyses have suggested that the success of the overall cleanup strategy ultimately depends on reduction of interior house dust lead levels to concentrations comparable to post-remedial soils (TerraGraphics, 1990). The cleanup for the BHSS specifies that homes with dust lead concentrations greater than 1000 mg/kg will be evaluated for interior cleanup following completion of the soil cleanup (Region 10 EPA, 1991).

This cleanup strategy was developed following studies suggesting that interior dust cleanup alone was not effective in permanently reducing dust lead concentrations prior to cleanup of surrounding surface soils. Interiors of homes that were completely cleaned in 1990 were re-contaminated by outdoor sources within one year (CH2MHill, 1991). As a result, cleanup efforts were directed toward residential yard soils, commercial properties, and rights of way. In the interim, monitoring of blood lead levels and interior dust concentrations continued through the allied Lead Health Intervention Program. Parents were counseled regarding home and personal hygiene and were encouraged to clean frequently. High efficiency particulate air (HEPA) vacuums were loaned to residents by the local health district (CH2MHill, 1991).

The Bunker Hill Company mining and smelting complex ceased production in 1981. The site was added to the Superfund National Priorities List (NPL) in 1983. In the following year, federal, state, and local health agencies conducted a comprehensive lead health study (Panhandle Health District, 1986). In 1983, venous blood sampling indicated over 80% of the children, including those born since the 1981 smelter closure, had blood lead levels of 10 micrograms per deciliter (μg/dl) or more. The data from this study and subsequent studies have been analyzed in a series of reports (TerraGraphics, 1987, 1990, 1997, 1998, 1999a,b,c,d,e, 2000). Residual contamination in community soils and dusts was identified as the primary source of lead exposure to children. Inadvertent ingestion of these soils and dusts by normal hand-to-mouth and play activities was identified as the primary route of exposure.

The 1983 Panhandle Health District Lead Health Study identified several co-factors which influenced the soil/dust pathway and were related to excessive blood lead levels. These included parental income and socioeconomic status, parental education level, home hygiene practices, smokers in the home, nutritional status of the child, use of locally grown produce, exposed soil in the yard, number of hours spent outside, pica behavior, and age (Panhandle Health District, 1986). In 1996, a similar study conducted in adjacent areas east and west of the 5400 ha area identified a similar set of associations with elevated blood lead levels in children (Idaho Department of Health and Welfare Division of Health, 2000).

In 1985, the Lead Health Intervention Program was initiated to rapidly lower blood lead levels in children through health education, parental counseling, and biological monitoring efforts as the large-scale cleanup slowly progressed. The Lead Health Intervention Program, sponsored by the Centers for Disease Control (CDC) and the Agency for Toxic Substances and Disease Registry (ATSDR), is implemented by the local Panhandle Health District under the auspices of the Idaho Department of Health and Welfare (IDHW). During the entire health intervention and Superfund effort, an extensive database has been maintained by IDHW that relates children's blood lead levels, media contaminant concentrations, environmental exposures, health intervention, and remedial activities on an individual basis. The database is confidential and treated as personal medical records; only summary information is released.

Some city parks and school playgrounds were cleaned up in 1986. The yard soil cleanup program under Superfund has been conducted each summer since 1989. Initially, approximately 100 home yards were targeted for completion each year. Individual yards were selected for cleanup using risk-based criteria combining sensitive sub-population and environmental contaminant level information. From 1989 to 1993, homes of pregnant women and children under 12 years of age were identified in an annual census conducted each spring. In 1994, the program was expanded to cleanup contiguous parcels of land regardless of high risk occupancy in addition to the high risk yard program. The age criteria for high-risk priority was reduced to a maximum of six years in 1994 to focus resources on younger children in accord with guidance issued by EPA (Environmental Protection Agency, 1994b). Residents with pregnant women or young children may request priority yard cleanup during the summer. Children identified by the annual Lead Health Survey as having blood lead levels of 10 μg/dl or more are given a high priority for yard soil testing and replacement.

Long-term cleanup action was not initiated by the responsible parties until 1994. Under Superfund cleanup statute, the responsible parties, such as owners or operators of a smelter or mine, are responsible for cleanup of a site. At BHSS, the responsible parties include the Upstream Mining Group. The Lead Health Intervention Program and high-risk yard cleanups were continued by the Panhandle Health District and EPA, respectively, as negotiations with BHSS Responsible Parties were undertaken. In 1994, agreements were reached with several Responsible Parties to implement the cleanup in the communities, and the cleanup commenced in the same year. The agreements obligated the Responsible Parties to implement the ongoing high-risk, residential yard soil cleanup program; extending that program to all residential, commercial, and public properties; implementing well closures in contaminated aquifers; and financing an Institutional Controls Program, including provision of a disposal area.

Yards at each of these eligible homes are sampled and a priority list is established based on children's age and yard soil lead level. Pregnant women and children under 6 years of age living on yards with soil lead concentrations greater than 1000 mg/kg have the highest priority. Yards at these homes receive a clean soil barrier of at least 30 cm throughout the yard and 60 cm deep in garden areas. Commercial property soils exceeding 1000 mg/kg lead are excavated to 15 cm or 30 cm depths depending on lead concentration and intended use. A durable fabric marker is installed as a visual marker if contamination remains at depth, and a locally enforced Institutional Controls Program has been established to help ensure barrier integrity.

Ongoing cleanup is being performed in Kellogg, Pinehurst, Wardner, Page and has been completed in Smelterville and SilverKing. The Responsible Parties have agreed to remediate 200 residential parcels per year until all home yards, commercial properties, and rights of way with lead contaminated soils greater than or equal to 1000 mg/kg have been remediated. Completion of remedial activities in the remainder of the 5400 ha site is expected after 2005 due to delays in funding cleanup actions. Smelterville is the only town in which all residential yard, commercial property, and right of way cleanups have been completed.

Because metal contamination of soils within the site is ubiquitous and often extends to depths difficult to remove in residential settings, the remedial methods cannot remove all of the contamination present at depth. Additional constraints to completely removing contaminated soil include the large volume of materials present, limited disposal areas due to confined topography of the valley, and availability of clean replacement soil. The cleanup focuses on removing contaminated surface soils and creating barriers to isolate the remaining contaminated materials from human exposure pathways, therefore periodic reviews of the cleanup's effectiveness will be needed in perpetuity.

2. Remedy selection

The cleanup plan or Record of Decision for the communities calls for a one-time installation of barriers on residential and commercial properties (Region 10 EPA, 1991). Following cleanup, operation and maintenance including repair of recontamination by events, such as flooding, erosion, or deposition of contaminated soils, becomes the responsibility of the property owner. The Record of Decision also requires that an Institutional Controls Program be established to regulate the long-term stability of these barriers in perpetuity and to enforce the property owners' obligations.

The Institutional Controls Program is a locally adopted set of rules and regulations incorporated into land use and zoning codes to ensure barrier integrity throughout the site. The purpose of the Institutional Controls Program is to protect public health and assist local land transactions within the Superfund site. The Institutional Controls Program has been established to oversee real estate transactions, certify contractors to work safely within the BHSS, to enforce rules and regulations, and to help residents comply with the Institutional Controls Program.

The Institutional Controls Program regulates construction and use-changes on all properties where barriers and caps have been installed. The program provides education, sampling assistance, clean soils for small projects (less than one cubic meter of material), pickup of soil removed from small projects, and a disposal site for contaminated soils. The Institutional Controls Program also regulates and provides assistance with construction and renovation projects on building interiors that involve ceiling and/or insulation removal, and work in dirt basements and crawl spaces. The Institutional Controls Program main enforcement mechanisms are linked to existing local building departments and land use planning activities and include:

- contaminant management rules;
- barrier design and permitting criteria;
- ordinances requiring Panhandle Health District to approve building permits;
- ordinance amendments to comprehensive plans and zoning regulations;
- model subdivision ordinances;
- storm water management requirements; and
- road standards and design criteria.

Site-wide Remedial Action Objectives are defined in the 1991 and 1992 Records of Decision (Region 10 EPA, 1991, 1992). With respect to the blood lead level objectives, Remedial Action Objectives are to reduce the incidence of elevated blood lead levels among children in the community to:

- less than 5% of children with blood lead levels of 10 μg/dl or greater; and
- less than 1% of children exceeding 15 μg/dl.

The blood lead objectives are to be achieved by the following environmental objectives:

- cleanup of all yards, commercial properties, and rights of way that have lead concentrations greater than 1000 mg/kg;
- achieving a geometric mean yard soil lead concentration of less than 350 mg/kg for each community in the site;
- controlling fugitive dust and stabilizing and covering contaminated soils throughout the site;
- achieving geometric mean interior house dust lead levels for each community of 500 mg/kg or less, with no individual house dust level exceeding 1000 mg/kg.

2.1. Operation and maintenance costs

Since this remedy is still being implemented, a more comprehensive review of operation and maintenance costs will not be presented until the next Five Year Review. Costs to date for the Institutional Controls Program, implemented by the Panhandle Health District, are presented below:

Annual Institutional Controls Program Costs To Date in the Populated Areas

1995	$82 497
1996	$175 321
1997	$118 652
1998	$58 227

Costs may fluctuate widely until the remedy is fully implemented and costs for maintenance of the Institutional Controls Program landfill (in the design phase as this review is being completed), etc., are more clearly established. As the remedy is implemented and additional areas fall within the scope of the Institutional Controls Program, it is expected that average annual costs will increase. Costs of residential yard cleanup were not available from the Potentially Responsible Parties.

3. Results

The following topics are analyzed in this review:

3.1 blood lead levels;
3.2 house dust lead levels;
3.3 barrier effectiveness;
3.4 institutional controls program;
3.5 fugitive dust;
3.6 recontamination sources; and
3.7 infrastructure and disposal.

The above topics presented in this report are a combination of areas for which there are remedial objectives (barriers, blood lead levels, house dust lead levels, fugitive dust), areas where potential problems have been identified that could affect permanence of the remedy (disposal, infrastructure), concerns identified by the community Technical Assistance Grantee (regarding other contaminants such as arsenic and cadmium), and requirements for a Superfund Five Year Review (Applicable, Relevant, and Appropriate Requirement analysis). Each of the Remedial Action Objectives independently corresponds to an action. For example, although the blood lead levels have recently begun to meet the objectives, additional actions will be needed to meet the soil and house dust lead objectives. Each of the objectives is evaluated independently to ensure the long-term protectiveness of the remedy and to provide early detection of problems which could undermine protectiveness in the future.

3.1. Blood lead levels

Blood lead levels have been monitored at the BHSS at varying frequencies since the early 1970s. Venous blood was sampled in 1974 and 1983. In 1985, a capillary (finger stick) blood-erythrocyte protoporphyrin (EP) test was used. From 1988 through 2000, venous blood has been monitored annually for children up to 9 years. The community is surveyed each year to determine the number of eligible children using a combination of door to door collection of information in tandem with school census information (TerraGraphics, 2000). Estimates of the percentage of the eligible childhood population sampled has always exceeded 50% (TerraGraphics, 2000). Blood lead levels have trended downward, with the exception of shortly after the Milo Creek flood in 1997 which uncovered previously capped contamination in Wardner and Kellogg (TerraGraphics, 2000). Interpretation of blood lead trends is complicated because residents, who are often not home owners, move as frequently as once every 6 months. The high mobility of the residents has kept the percentage of children on contaminated yards between 15 and 30% from 1991 to 1996 despite the 200 yards remediated per year. In 1998, the proportion has decreased to less than 4% (TerraGraphics, 2000). The presence of pets has also been associated with increased levels of indoor dust which can impact blood lead levels (TerraGraphics, 2000). It has also been recently documented that approximately 30% of the population at the BHSS are below the poverty line, further complicating behavioral factors and solutions to infrastructure issues (see Section 3.3) (Lalley, 2000). The following are additional factors that have been correlated with changes (increases or decreases from the mean, respectively) in blood lead levels (Panhandle Health District, 1986; TerraGraphics, 2000). A similar set of associations was described in a study of communities located east and west of the 5400 ha area (Idaho Department of Health and Welfare Division of Health, 2000).

In 2001, a LeadCare® portable blood lead analyzer (manufactured by ESA, Chelmsford, MA) was used to screen children using capillary blood drawn from finger tips. Data were collected to evaluate the efficacy and the accuracy of modified blood lead screening protocols. In accord with recommendations from the Centers for Disease Control and Prevention, venous blood was drawn from all children with a LeadCare® capillary blood measurement of 8 μg/dl or more and the venous sample was analyzed immediately with the LeadCare® unit and a duplicate sample was sent to the ESA Laboratory in Massachusetts for a confirmatory analysis to ensure that children with elevated blood lead levels were not missed (Centers for Disease Control and Prevention, 1997). In addition to re-testing all children with capillary blood lead levels of 8 μg/dl or more, confirmatory venous blood was requested from 10% of all participants for analysis with the LeadCare® instrument and by ESA Laboratories. Together, these measures ensured that children with elevated blood lead levels were effectively identified under the new screening protocols. Comparison of the results from children whose blood was measured three times indicated that the original protocol, which relied exclusively on ESA Laboratory analysis of venous blood, reported higher results than the LeadCare capillary samples. Additionally, the LeadCare capillary levels reported higher results than the LeadCare venous levels. A small component of the observed decrease in the 2001 mean blood lead levels may have been caused by the change in protocol. However, the differences between the capillary and ESA venous readings were less than 0.5 μg/dl. It is unlikely that the new protocol would have failed to identify children

Table 2
Percentage of children above 10 μg/dl by age and year

Age	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
One year	57.1	66.7	52.6	24.3	34.8	18	26.8	30.0	22.9	16.7	22.5	14.3	13.0	4.4
Two years	60.9	72.4	54.3	25.0	31.4	22.9	28.1	21.9	26.1	15.0	20.5	15.2	6.1	9.8
Three years	62.1	84.4	43.8	27.0	32.5	15.0	17.1	25.9	21.4	16.7	11.8	2.9	13.6	2.5
Four years	36.8	53.1	44.4	21.2	32.0	30.2	14.6	25.6	20.7	10.0	9.3	8.8	3.2	4.3
All children (up to age nine)	46	56	37	15	27	15	17	15	12	11	8	6	5	3

with elevated blood lead levels because of the venous confirmatory sampling initiated at 8 μg/dl.

Associations with increased blood lead levels in young children at BHSS:

- presence of bare soil in play area;
- number of hours spent outside;
- pica behavior; and
- presence of smokers in the home.

Associations with decreased blood lead levels in young children at BHSS:

- increased parental income;
- improved socioeconomic status;
- parental education level;
- home hygiene;
- nutritional status of child;
- presence of vegetable garden; and
- increased age of child.

In addition to the above factors which have been associated with changes in blood lead levels, it is also possible that selection bias may have influenced the blood lead results in either direction, although the magnitude of effect would be limited by participation rates consistently greater than 50%. Based on interviews it was found that parents who have diligently adhered to the guidance provided by the intervention program may feel that the blood lead testing is unnecessary. For example, of the total number of refusals, 23% in 1999 stated that since their children have tested low in the past; they see no reason to get another sample.

In 1997 and 1998, 18 and 26% of parents contacted refused to participate, respectively. Because everyone is offered an opportunity to participate, there is no way of knowing what blood lead levels the remaining children may have without instituting a mandatory testing program, which is not a viable option.

Although the Remedial Action Objectives for blood lead at the site have been achieved in recent years, the blood lead objective cannot be completely evaluated until the remedy is fully in place (see Table 2). Currently, residential yard sampling and cleanup has not been completed and completion is not expected to occur prior to 2005. One concern to note is that recent measurements of blood lead levels by age indicate that 2 year olds exhibited the highest incidence of elevated blood lead levels. 'Elevated' blood lead levels are at or above 10 μg/dl (Centers for Disease Control and Prevention, 1991). For 2 year olds, the incidence was 15% in 1999, but has declined somewhat in subsequent years. The observed, age-related peak in blood leads coincides with period of greatest susceptibility to neuro-behavioral effects (Goldstein, 1990; Rodier, 1995). While this trend is expected and has been observed at other sites around the country, blood lead levels in the youngest children should be monitored closely as the remedy is completed.

3.2. House dust lead levels

Lead levels in house dust have been declining as residential yard soil cleanup has progressed, as seen in Figs. 2 and 3 (TerraGraphics, 2000). Declines in soil and dust lead occurred concurrently with declines in blood lead (Fig. 4). Lead levels are being measured in order to assess progress toward the site-wide Remedial Action Objective of a geometric mean of 500 mg/kg and a maximum level for each home of 1000 mg/kg.

Two different methods are being utilized to track the concentration of dust in the home: vacuum

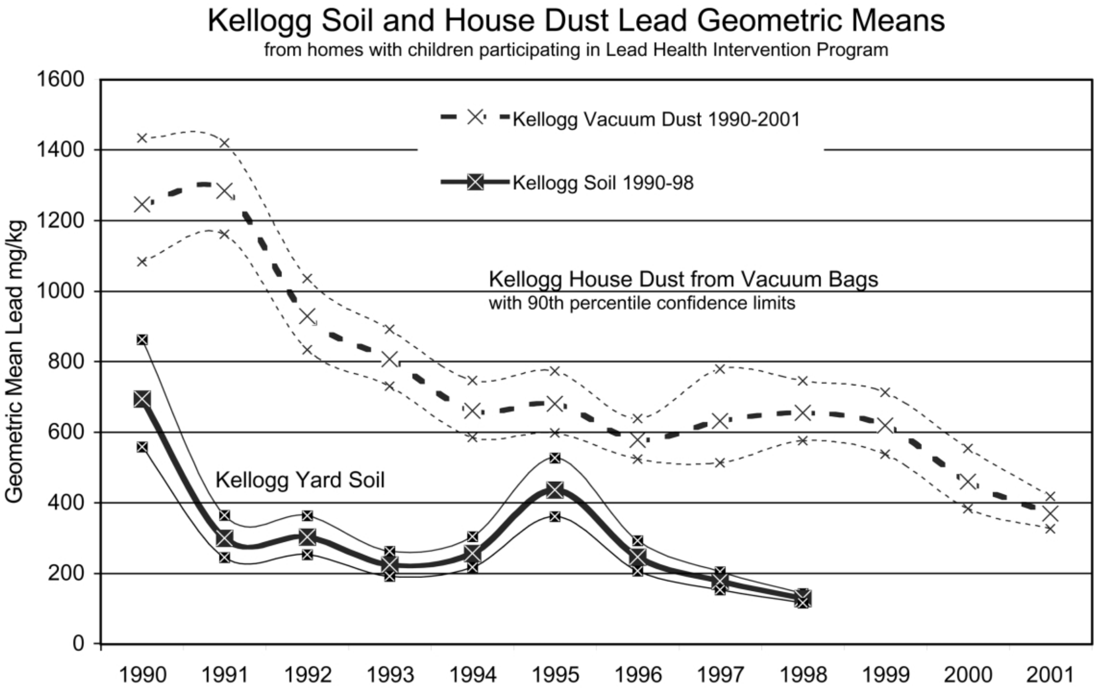

Fig. 2. Kellogg soil and house dust lead geometric means 1990–1998 from homes with children participating in the Lead Health Intervention Program.

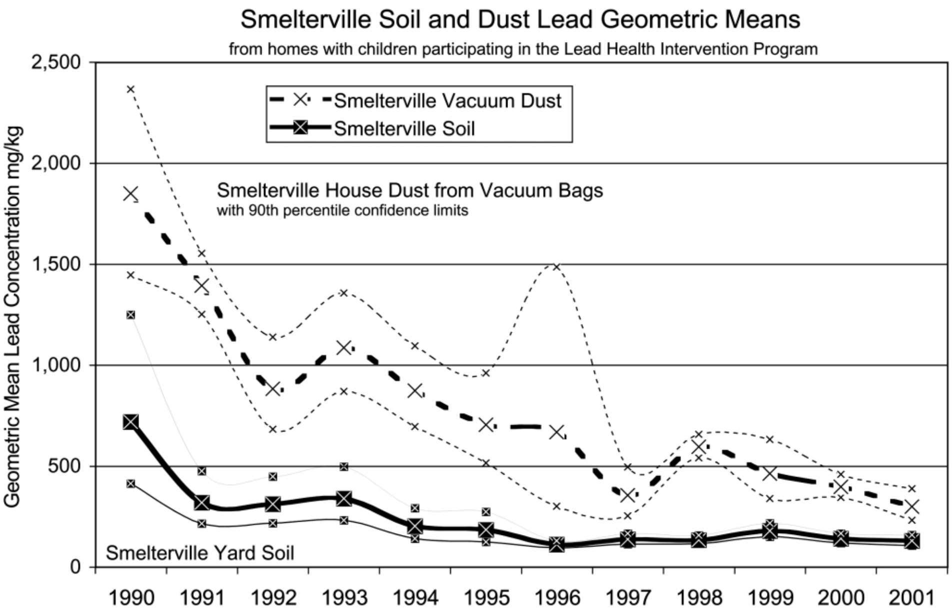

Fig. 3. Smelterville soil and house dust lead geometric means 1990–2001 from homes with children participating in Lead Health Intervention Program. Site-wide cleanup progress for residential yards with children versus elevated blood lead levels.

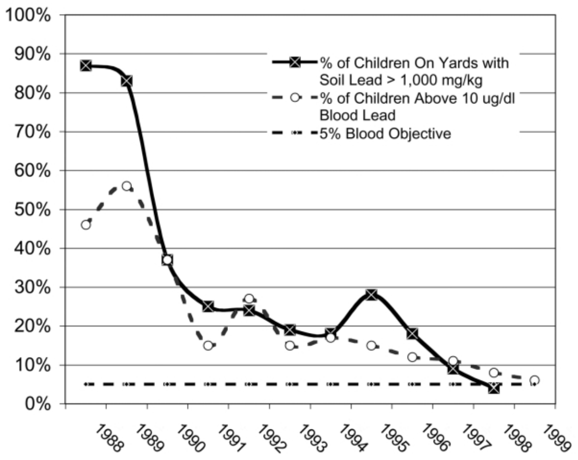

Fig. 4. Site-wide percentage of children on yards with soil lead above 1000 mg/kg vs. percentage of children with elevated blood lead levels.

bags and dust mats (TerraGraphics, 2000). In addition to providing concentration data (e.g. mg of Pb per kg of dust), dust mats also provide dust loading rates (g/m^2 day) and lead loading rates (mg/m^2 day). Lead loading rates measure the rate of dust and lead tracked into the interiors of homes. At lead concentrations well above 1000 mg/kg, the dust mats show higher lead concentrations than vacuum bags, perhaps due to dilution in vacuum bags caused by other interior dust sources. Lead concentrations in vacuum bags and mats converge at levels near 1000 mg/kg. It is estimated that 60–80% of lead in interior house dust originates from exterior soils (TerraGraphics, 2000). Other studies have identified dust as the proximate source of lead exposure to children with independent direct and indirect contributions from soil, although the combined direct and indirect soil exposure pathways are not described as percentages of total exposure (Lanphear et al., 1998; Succop et al., 1998). While lead levels in dust in houses from Pinehurst have been below the 500 mg/kg goal since 1993, other cities are approximately 600 mg/kg on average in 1999 (TerraGraphics, 2000). Annual geometric mean soil and dust lead concentrations in Kellogg and Smelterville have shown parallel declines during the period of yard soil cleanup (Figs. 2 and 3, respectively). The declines are expected to continue as cleanup progresses. In housing of similar age and character in northern Idaho, dust lead concentrations have average lead levels of approximately 200 mg/kg (TerraGraphics, 2000).

As the residential yard soil cleanup in Smelterville was completed in 1997, a house dust cleaning pilot program has been designed to evaluate the efficacy of interior cleaning in Smelterville homes with dust lead concentration above 1000 mg/kg. Ongoing sampling will evaluate trends in house dust levels to determine if vigorous interior cleaning of homes and carpet replacement will effectively reduce lead levels in homes above 1000 mg/kg. As already noted in the analysis of blood lead data, 2 year olds typically spend a significant portion of their time on the floor of residential interiors; their higher incidence of blood lead poisoning supports the need to reduce interior dust lead levels (National Academy of Sciences, 1993; Lanphear et al., 1998). The Remedial Action Objective, although not yet achieved, is expected to be protective of human health and will be further evaluated during the next 5-year review.

Elevated blood lead levels in young children support the need to reduce exposure to lead from interior house dust. The dust pathway is thought to be the most significant pathway of exposure for young children who spend much of their time playing/crawling along floors (Lanphear et al., 1998; Manton et al., 2000). Structural equation modeling and multiple regression analyses suggest an attribution of lead exposure composed of 40% house dust, 30% community soil, and 30% from the neighborhood, which is defined as the area within a 200-foot radius of the child's home, and individual yard (TerraGraphics, 2000). The structural equation modeling method is based on the EPA *Three Cities Study* (Elias et al., 1996; Succop et al., 1998). Structural equation modeling of consecutive blood lead levels paired with environmental sampling was used to estimate average changes in blood lead level following yard soil cleanup actions (absent child specific intervention activities).

The following reductions in blood lead levels apply to an average two year old residing in the BHSS (TerraGraphics, 2000):

- 1.7 μg/dl reduction due to cleanup of the child's residential yard; and
- 5.6 μg/dl reduction due to cleanup of the neighborhood and greater community (via subsequent declines in house dust lead concentration).

This decline shows that the relationship of yard soil to blood lead levels in children. Fig. 4 depicts the temporal correlation between the proportion of children living in homes where yards have soil lead concentrations above 1000 mg/kg and the proportion of children with blood lead level of 10 μg/dl or more. As blood lead levels BHSS have been decreasing, air lead deposition from gasoline fuel and lead in food have also been decreasing nationally (National Academy of Sciences, 1993; Pirkle et al., 1998). However, most of the declines in air lead concentrations from gasoline and food took place in the 1970s and 1980s before yard cleanup began; therefore the declines seen here are likely predominantly due to reduced exposures from on site contaminants rather than these broader trends. Recent lead isotope studies have shown that lead measured in the blood and urine of young children was traceable to lead on their hands and lead sampled from the floors of their homes, which included both interior and exterior sources of lead; a dietary component was not a major contributor to blood lead (Manton et al., 2000). Ongoing blood lead monitoring should continue until the next comprehensive review to monitor blood lead trends on the site and to identify children with elevated blood leads for follow-up investigation. In combination with limiting lead in the soil to 1000 mg/kg and consequently reducing lead in house dust, the blood lead Remedial Action Objective is protective of human health. Recently, the community has succeeded in meeting the blood lead goals of less than 5% above 10 μg/dl and less than 1% above 15 μg/dl. This is encouraging because the soil remedy is approximately 70% complete.

3.3. Barrier effectiveness

There are several different types of barriers at the BHSS, including those on: residential yards, commercial properties, rights of ways, common use areas, and others. Each clean soil or gravel barrier may be of a different depth depending on contaminant concentration and prescribed depth due to use. Barriers are placed when soil in a particular area exceeds the action level of 1000 mg/kg lead and in order to meet the community wide average concentration goal of 350 mg/kg lead. When placed, the material making up each barrier contains less than 100 mg/kg lead, as seen in Table 3 (McCulley Frick and Gilman, 1999). For perspective, median background levels in soil for lead, arsenic, and cadmium are 43, <10 and 0.8 mg/kg, respectively, (Gott and Cathrall, 1980). Each barrier receives different levels of use from pedestrian and vehicular traffic. These backfill concentrations for various constituents are useful as a baseline for the discussion of present day concentrations in rights of ways, residential yards, commercial properties, and in other remediated areas.

Table 3
Depth weighted average of residential/commercial/right of way backfill in mg/kg

City/area	Lead	Arsenic	Cadmium
Kellogg North of Interstate 90	29.2	15.7	0.6
Smelterville	8.2	6.0	0.18

3.3.1. Rights of way

Soil and gravel soft shouldered rights of ways along public roads have demonstrated significant and variable levels of recontamination (TerraGraphics, 1999e, 2000). Smelterville rights of way remediated in 1989, 1990, and 1991 have significantly higher concentrations than those remediated in later years (32% compared with 13% above 1000 mg/kg at the zero to 2.5-cm depth interval, respectively). In 1998, only remediated rights of way were sampled. These data indicated that 30% (3 of 10) in Kellogg and 14% (8 of 58) sampled in Smelterville exceeded 1000 mg/kg. Geometric mean lead levels for remediated rights of way in Kellogg and Smelterville were 365 mg/kg and 294 mg/kg, respectively.

Recontamination on rights of way may arise from several processes. The limited data set suggests that (a) the rate of recontamination is less than 10% annually; (b) recontamination is associated with the manner or rate of cleanup; and/or (c) material is being tracked from unpaved areas within the BHSS or from outside the site. There are insufficient data collected to date to determine if recontamination will continue. If recontamination should continue, there is also insufficient information currently available to determine at what rate properties might become re-contaminated. Because rights of way without drainage systems drain road debris onto a soft shoulder, vehicle tracking and drainage could be primary mechanisms of recontamination. The slow rate of cleanup may contribute to recontamination where previously cleaned areas are close to un-remediated areas for a sustained duration. Vehicle tracking between cleaned and un-cleaned areas (including driveways) may be an important mechanism of recontamination and will be investigated further.

3.3.2. Residential yards

Soil sampling was conducted by the State in 1999 on 11 randomly selected residential yards to determine if any recontamination had taken place since the barriers were originally installed. Of the seven residential yards in Kellogg, sample concentrations ranged from 23 mg/kg to 162 mg/kg in the top 2.5 cm of soil. Of the four yards sampled in Smelterville sample concentrations ranged from 43 mg/kg to 102 mg/kg. Upstream Mining Group sampling conducted in Kellogg in 1998 and Smelterville for yards remediated prior to 1994 indicate levels of 164 mg/kg and 188 mg/kg, respectively. The concentrations observed on residential yards seem to be somewhat higher than clean soil concentrations placed at the time of cleanup (see Table 3). However, less recontamination is observed on residential yards than driveways and rights of ways which suggests that vehicle tracking may be an important mechanism for contaminant movement. Hillside sloughing into residential yards is described in the 'Recontamination Sources' section.

3.3.3. Residential driveways

Soil and gravel from driveways and other parking areas were sampled in 1998 and 1999 to determine if vehicle tracking facilitates transport of contaminated material or if vehicular traffic reduces the integrity of barriers in general. Four driveways sampled in Kellogg ranged from 50 to 209 mg/kg in the top 2.5 cm of gravel; these values were below the community wide goal of 350 mg/kg, but indicated some degree of lead movement. Two driveways sampled in Smelterville ranged from 687 to 1290 mg/kg and were above the community wide goal of 350 mg/kg and the individual property cleanup level of 1000 mg/kg, respectively; these values were indicative of more substantial recontamination. Other sampling was conducted in 1999 by the Upstream Mining Group. This sampling showed that driveway concentrations in a variety of recently remediated properties ranged from 70 to 323 mg/kg lead. Samples taken by the Upstream Mining Group from pre-1994 properties have a range of 150 to 573 mg/kg lead also indicating some level of contaminant migration onto driveways that is likely associated with vehicle tracking or exposure of contaminants from beneath the cap.

3.3.4. Union Pacific Railroad right of way

Union Pacific Railroad soil and gravel sampling results have an average concentration of 153 mg/kg lead in composite samples from the top 15 cm along the 11 km segment of inactive railroad crossing BHSS (McCulley Frick and Gilman, 1999). Although the average is below the remedial action level of 1000 mg/kg lead, four samples exhibited concentrations above 500 mg/kg indicating some level of recontamination as compared to backfill concentrations of lead. While not widespread, contaminant migration onto the railroad right of way is located near areas of potential vehicle tracking and utility work, and indicates a need for better access control and careful oversight and scheduling of Institutional Controls Program projects.

3.3.5. Commercial properties

Only one remediated commercial property was sampled in 1999 (TerraGraphics, 2000). Two samples in the top 2.5 cm of soil were 371 and 538 mg/kg lead. Results for the top 2.5 cm of soil indicate a mechanism of recontamination likely associated with vehicle tracking. Soft barriers on commercial properties accessible by vehicles will require ongoing sampling.

3.3.6. Common areas

Four park areas were sampled by the State in 1999. Results in the top 2.5 cm ranged from 22 to 210 mg/kg lead. These results are consistent with those from residential yards indicating some minor contaminant migration above clean backfill levels.

We have measured varying degrees of contaminant migration. Potential mechanisms may include: (1) vehicle tracking during and after cleanup; (2) barrier disturbance (e.g. utility work); or (3) other undefined sources. It will be important to determine if the pace of cleanup, 200 residential properties and a limited number of commercial properties per year or 10% of the overall cleanup per year, allows unacceptable levels of contaminant transport throughout the community. Vehicular traffic may be responsible for recontamination of unpaved driveways and soft shoulder rights of way, which have exhibited the greatest amount of recontamination with a number of areas exceeding both the community wide goal of 350 mg/kg and a number exceeding the lead action level of 1000 mg/kg. Ongoing sampling of driveways and rights of way will help to determine if the increases in lead concentrations are slowing down over time, which may suggest that the rate of cleanup is a primary factor. Continued migration of lead, which is unmitigated after cleanup completion, may suggest other source areas which need to be identified and addressed.

3.4. Institutional controls program

Because the remediation strategy is based on containment of mine wastes that extend to depth throughout much of the BHSS, long-term effectiveness of the remedy relies on the success of the Institutional Controls Program to mitigate identified exposure to children and to prevent recontamination of clean soil barriers. Panhandle Health District's commitment to implementing the Institutional Controls Program has benefited from long-time staff members who have helped establish the program. The following is a summary and review of that program. Additional information can be found in the Upstream Mining Group Five Year Review Report, dated November 12, 1999, the Overview of the Silver Valley Intervention Program, dated March 25, 1999, and the TerraGraphics Five Year Review Report, dated April 2000 (McCulley Frick and Gilman, 1999; Panhandle Health District, 1999; TerraGraphics, 2000).

3.4.1. Intervention and education program

The BHSS Intervention Program is a cooperative effort amongst the Panhandle Health District, State of Idaho Department of Health and Welfare, Division of Health, Bureau of Environmental Health and Safety, Centers for Disease Control (CDC), and the Agency for Toxic Substances and Disease Registry (ATSDR). Children from the age of 9 months through 9 years are offered blood lead screening each year in Kellogg along with educational materials on preventing lead exposure pathways (Panhandle Health District, 1999). Prenatal screening is also offered. Families of children exhibiting blood lead levels above 10 μg/dl are offered follow-up service from a public health nurse with the goal of determining possible routes of exposure as a means of secondary prevention. Primary prevention is defined as preventative measures that are taken, to reduce lead exposure to a child before it occurs, while secondary prevention is defined as activities to reduce a recognized exposure after it has occurred (Centers for Disease Control and Prevention, 1991, 1997). Community wide education also is offered. The Panhandle Health District sponsors a program of physician awareness to increase diagnosis of problem lead exposures. Additionally, the Panhandle Health District visits kindergarten through third grade classrooms to offer advice on how to prevent lead exposure (Panhandle Health District, 1999). The curriculum includes a doll house puppet show for younger children to show household sources of lead and a hand washing exercise for older students with ‘glow germs’ activated by black lights to illustrate how lead is spread from hand contact. For 2 year olds, an average 3.9 μg/dl reduction in blood lead levels has been associated with intervention activities where no residential yard cleanup has taken place (TerraGraphics, 2000).

The Panhandle Health District also offers a vacuum cleaner loan program, which is funded by the Upstream Mining Group, where high efficiency particulate air filter (HEPA) vacuums are loaned out to site residents (Panhandle Health District, 1999). While the cleanup goal is to reduce house dust levels to a site-wide average of 500 mg/kg lead (see Section 3.2), the HEPA vacuum loan program has been a valuable part of the Institutional Controls Program for interior projects and also to help keep dust levels down for those who lack a vacuum cleaner. The average number of checkouts per month between 1992 and 1998 is 24, indicating that the resource is being utilized by the community. The Panhandle Health District has made the following recommendations in their 1999 vacuum loan report: increasing the program advertising budget, placing flyers in local outlets each month, and providing recommendations for maintaining a clean home interior and cleaning methods. These recommendations should be implemented in order to fully take advantage of the vacuum loan program, and to better mitigate interior dust exposures.

3.4.2. Permitting program

The Institutional Controls permitting program is a key feature in maintaining the remedy over time. Both the Upstream Mining Group and the State conducted evaluations of the Institutional Controls Program, implemented by the Panhandle Health District under local ordinance (McCulley Frick and Gilman, 1999; TerraGraphics, 2000). Both small residential and large commercial projects are in the purview of the Institutional Controls Program. The Panhandle Health District's Institutional Controls Program has been effective in identifying exterior projects by visually locating them and helping homeowners/renters comply with local ordinances. The Institutional Controls Program has had limited success in monitoring interior projects since it is more difficult to identify where these projects are taking place. However, some property owners have taken the initiative by contacting the Panhandle Health District for assistance before starting work on their homes. For large projects, there have been two recent experiences in 1998 and 1999 which have given insight to special challenges associated with the installation and maintenance of barriers. Both projects illustrated the necessity of specifying Institutional Controls Program requirements explicitly in bid documents and the additional cost for a construction project that is related to Institutional Controls Program (to prevent inadvertent recontamination). Placing temporary or permanent barriers, best management practices, and disposal and decontamination increased project cost nominally between 2 and 5%. Examples of these types of costs included: 3600 metric tons of gravel to establish temporary clean barriers, dust control, and erosion control. Most of these costs are part of standard construction practices; however, when the above measures are implemented improperly, cost increases can be far more substantial. For example, excavations performed during wet periods of the year have resulted in recontamination of adjacent areas, increasing cost on one project by an estimated 43%. Based on Panhandle Health District questionnaires given to contractors that have worked under the Institutional Controls Program, closer disposal site(s) (see Section 3.7) and pre-project sampling have been suggested as improvements for the program (TerraGraphics, 2000).

3.5. Fugitive dust

The clean-up plans required control of fugitive dust sources. These sources have included: the hillsides, waste piles, and uncapped commercial properties. In 2000, the large Central Impoundment Area of contaminated soil was closed and capped, eliminating a large potential source of fugitive dust. Since 1994, the Upstream Mining Group air monitoring during yard cleanup activities indicates four exceedances out of 2300 monitoring records, all of which were from personal air monitoring equipment worn by workers within exclusion zones (McCulley Frick and Gilman, 1999). Levels monitored by the Upstream Mining Group are compared to worker safety levels (called permissible exposure levels, or PELs) prescribed by

Occupational Safety and Health Administration. These data would suggest that airborne releases from ongoing yard cleanup activities are being sufficiently controlled and therefore are not a recontamination source to adjacent properties.

Air monitoring data indicate that a number of exceedances are concentrated around heavy haul-route areas, despite frequent use of dust suppressants such as water, lignin, and magnesium chloride. These exceedances suggest that cleanup of areas near haul routes may be best sequenced toward the end of cleanup to minimize recontamination and that haul routes should avoid residential areas.

3.6. Recontamination sources

There are several potential mechanisms of recontamination linked with both erosion and vehicle tracking processes. This section addresses recontamination in general, such as vehicle tracking, and in specific areas, including: hillside sloughing, other erosion, and mine dumps. It is not presently known what impact the recontamination observed has had (or could have) on blood lead levels.

3.6.1. Page pond

The Page repository is maintained by the Upstream Mining Group primarily for receipt of residential yard wastes. Vehicle tracking of contaminants onto old Highway 10 from the Page repository has been documented by Institutional Controls Program samples. Once on Highway 10, vehicles may track this material into the remediated area of Smelterville. Samples taken by the Institutional Controls Program range from 546 to 5937 mg/kg lead (TerraGraphics, 1999a,b,c,d,e). These samples were taken both near the gate for the landfill and on the road. Additional decontamination/drainage control procedures at the Page repository are necessary to mitigate vehicle tracking.

3.6.2. Smelter Complex gated area

Vehicle tracking at the east and west gates of the Smelter Complex exclusion zone has been documented in two soil and gravel samples containing 4279 and 6691 mg/kg lead, respectively (TerraGraphics, 2000). Therefore, additional decontamination/drainage control measures might include paving of areas leading to and away from the decontamination station or regular replacement of gravel. Apparently, the high pressure spray wash used on all departing vehicles is not completely effective.

3.6.3. Hillside sloughing

Hillsides adjacent to Smelterville, SilverKing, Wardner, and Kellogg are contaminated with smelter emissions (TerraGraphics, 1999a,b,c,d,e). Concentrations decrease with depth on hillsides to varying degrees (TerraGraphics, 2000). In some instances, soil chemistry in contaminated hillsides has been altered (low pH limiting availability of nutrients, for example) making erosion control through plant establishment difficult. Another contribution to this problem is that local zoning does not prohibit removal of the base of these hillsides, making some erosion inevitable due to residential development induced slope instability. In Smelterville, a Potentially Responsible Party had installed gabion basket walls behind several homes to hold back eroding, contaminated soil from entering residential yards. This pilot program was continued by EPA in 1996. Continuation of wall construction and other best management practices in Smelterville (and in any other areas where sloughing is contaminating clean areas) should be considered, as well as appropriate planning and zoning changes to prevent development immediately adjacent to contaminated hillsides or where modification to hillsides may exacerbate erosion.

3.6.4. Flood and storm events/storm water conveyance systems

In 1996, a flood transported and uncovered contaminated sediments up to several thousands of mg/kg lead (TerraGraphics, 1999a,b,c,d,e). In the 1997 Milo Creek flood, the deposition of sediments with high lead levels increased blood lead levels in 13 children (TerraGraphics, 2000). In this event, soil at an apartment in Kellogg, which had been remediated in 1989, had soil lead levels of 8656 mg/kg after the flood. Contaminants have only been removed during cleanup to a 30 cm depth, then capped with 30 cm of clean soil (leaving contamination from 30 cm in depth to three or more meters in some places). In most areas, inadequate infrastructure to convey flood waters and associated sediments can often lead to: (1) erosion of the clean barrier; and (2) transport and deposition of contaminated material on remediated areas. While the flood prone Milo Creek drainage is now in piped through Wardner and southeastern Kellogg via a multi-million dollar flood control improvement project, other areas of Kellogg do not have adequate storm water conveyance. Studies of Smelterville drainage infrastructure indicate that it is undersized to handle moderate snow melt and rain events, causing premature road damage and exposing lead contamination beneath paved road surfaces. Hillside drainage in Smelterville is dependent on dry wells with unknown flow capacity. These dry wells are often allowed to fill up with sediment and overflow before being cleaned out, if at all. Ongoing construction of walls and other best management practices at the base of the hills behind residences to control erosion should continue. Flooding is anticipated to result in the following potential problems: recontamination of installed barriers through the transport and deposition of metal laden sediments, destruction of installed barriers due to erosion, and damage to the City's southern flood protection dike. In cooperation with the Institutional Controls Program, additional infrastructure and regular maintenance of existing drainage systems by the state, local entities, business owners, and residents will be needed to ensure success of the remedy. Local tax revenues may not be sufficient for regular maintenance and drainage improvements.

3.6.5. Roadways

Roadways are discussed below both from the construction and maintenance perspective as well as materials applied in the winter as both may relate to recontamination. Many sections of Interstate 90 and State of Idaho roads in the BHSS were built over mine waste tailings. Exploratory pits dug in Kellogg roads indicate an average lead level of 9562 mg/kg (TerraGraphics, 1999a, b,c,d,e). Similar pits in Smelterville had an average concentration of 3262 mg/kg lead. Roads in Smelterville are currently in very poor condition to the point that many potholes expose contaminated soils exhibiting the above concentrations, which could contribute to vehicle tracking of contaminants. Further degradation of site roads could contaminate clean areas. Regular maintenance of roads and replacement of roads in total disrepair, including replacement of contaminated subgrade material, is necessary to ensure the long-term protectiveness of the remedy.

Roads throughout the 21 square area are sanded in the winter to increase traction in snow. The sanded material was suggested as a potential recontamination source by the Upstream Mining Group in their comments on the Five Year Review. The Panhandle Health District has taken several steps to ensure that sanding material is clean by Institutional Controls Program standards:

- all county and city crews are trained and licensed by the Institutional Controls Program;
- rock pit operators sample materials that are used at the site;
- Institutional Controls Program implementers go to currently operating rock pits and sample them to supplement owner sampling, if necessary; and
- material being placed on roads is tested on an intermittent basis at the discretion of the Institutional Controls Program (Jerry Cobb, Panhandle Health District, August 21, 2000, personal communication).

Therefore, road sand is unlikely as a source of recontamination.

3.6.6. Mine dumps

The Records of Decision call for stabilization of mine dumps as they relate to erosion from hillsides. Although some mine dumps have been removed or stabilized by the Bunker Limited Partnership, various mine dumps still exist on hillsides in the Milo Creek drainage in the city of Wardner as well as other areas of the site. Concentrations of lead average 5,931 mg/kg in the Wardner dumps. Average arsenic concentrations were 78.7 mg/kg site-wide with one sample above Pinehurst at 3080 mg/kg. (TerraGraphics, 1999a,b,c,d,e). Since no known exposure is currently occurring on these mine dumps, no further action is warranted at this time from a human health perspective.

3.7. Infrastructure and disposal

As ongoing maintenance of the BHSS remedy takes place, there will be an ongoing need for disposal to ensure that barriers put in place remain intact such that the overall cleanup is protective of human health and the environment.

3.7.1. Additional materials requiring disposal

As snow, leaves, and various street sweepings are collected throughout the site, lead particles become entrained in the collected material. While leaves and street sweepings are properly disposed of at onsite repositories, such as Page, snow is piled up in various locations by the cities, county, businesses, and residents. Average concentrations in material at these various piles left after the snow has melted was 4754 mg/kg lead in 1997, indicative of generally high levels of lead present on roadways. An ongoing, managed area(s) for snow disposal needs to be established to ensure areas are not re-contaminated.

3.7.2. Disposal capacity

Because the remedy relies on surface containment, breaches of barriers to conduct utility work, put up a fence, build a road, and other projects will require ongoing contaminated material disposal. For example, road building and maintenance is estimated to generate 2800 m^3/km, since most roads in place were built on inadequate subgrade material containing mine waste. Developments may generate up to 7500 m^3 for a 12-unit subdivision (TerraGraphics, 2000). A new landfill will be required to meet projected disposal needs in the future.

4. Discussion

Deficiencies were discovered during this review of the cleanup at the BHSS and are noted below. As long as corrective actions are taken, the deficiencies should not threaten the protectiveness of the remedy.

The following critical deficiencies have been identified

- Soft Shoulder rights of way have become re-contaminated in Smelterville, potentially linked to the rate of cleanup or yet to be identified sources.
- Lack of drainage maintenance by local entities and need for infrastructure improvements has resulted in recurrent flooding in many areas.
- Lack of road maintenance and need to replace failing road infrastructure has exposed underlying contamination in several areas.

Due to the nature of a containment type barrier remedy, where waste is left in place at depth, early identification and monitoring of potential sources will be needed to ensure the integrity and protectiveness of the remedy. Other than road subgrades acting as a potentially widespread source of contamination, the only other predominant source that can be identified are the areas where cleanup has not yet been completed. Because of the long duration of the cleanup, where clean and unclean properties are adjacent to one another for several years, residential yards targeted for cleanup may be tracking contaminants into areas that have been completed. It is not currently known if the costs of a complete removal of contaminated soil to depth will continue to be substantially more than the cost of the partial removal with containment remedy. The initial savings of a partial cleanup may ultimately be lost to the increased maintenance costs associated with containment.

5. Conclusions

The clean soil barrier remedy implemented at Bunker Hill has effectively reduced the blood lead levels observed in the majority of children. By replacing the upper 30 cm of yard soils with lead concentrations above 1000 mg/kg with clean soil, house dust levels and blood lead levels have been subsequently lowered. The effectiveness of the remedy can be attributed to the large areas of contaminated soil removed from the vast majority of parcels on the site. The large scale of soil removal provided compound benefits of reducing direct exposure to lead in soil and lowering the levels of lead in house dust throughout the community. Consistent with studies published subsequent to the cleanup plan, house dust was identified as the proximate source of lead exposure for young children. The large scale of cleanup addressed both direct soil and indirect (soil via house dust) exposure pathways by eliminating lead at the individual and community levels. Community cleanup at this scale presents challenges at all stages from funding, planning, construction, and maintenance into perpetuity. Clearly, the rate and scope of cleanup affects its permanence and effectiveness. Although not yet complete, the cleanup has been effective in meeting its initial goals of protecting children's health. In recent years, as fewer children have been identified with elevated blood lead levels, the future necessity of the blood lead monitoring program has been questioned. Remaining yard soil cleanups must be completed and protected by drainage improvements and maintenance to achieve and maintain the cleanup goals.

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