

ANALYSIS OF CLEANUPS OF LEAD-CONTAMINATED RESIDENTIAL SOILS AT U.S.
SMELTER SUPERFUND SITES

by

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GLOSSARY or NOMENCLATURE

BLL: Blood Lead Level

CDC: United States Centers for Disease Control and Prevention

CUL: Cleanup Level

EPA: United States Environmental Protection Agency

FOIA: Freedom of Information Act

IEUBK: Integrated Exposure Uptake Biokinetic Model for Lead in Children

NPL: National Priorities List

PRP: Potentially Responsible Party

ROD: Record of Decision

TCRA: Time Critical Removal Action

ABSTRACT

Lead contamination from historic smelting operations continues to pose a public health risk in the United States, particularly from exposure to contaminated soils. Epidemiological studies have shown that concentrations of lead in residential soils can result in unacceptable exposures, and that there is no apparent blood lead concentration that may entirely avoid adverse health effects. These findings have caused regulatory agencies to gradually reevaluate previous blood lead targets and cleanup levels for lead sites. The U.S. Environmental Protection Agency (EPA), which is responsible for conducting cleanups of large-scale lead smelting sites that are on the National Priorities List, has acknowledged current literature that demonstrates risks from trace exposures, but has not yet revised the 1994 blood lead level target of 10 µg/dL. This ambiguity is coupled with regional delegations of authority that have resulted in varied approaches to addressing lead contamination within the Superfund program. These inconsistencies create a challenge to remedial project teams tasked with determining strategies to address these future sites. I address this challenge by conducting a first-of-its-kind comprehensive evaluation of residential cleanups at lead smelter Superfund sites. By using publicly available data from decision documents for 31 lead smelter sites across the US, I identify predominant cleanup strategies. Although the evaluations demonstrate inconsistent blood lead targets and cleanup levels used between sites, they also illustrate commonalities in the type of remedy selected as well as general costs for residential cleanups conducted by EPA's removal and remedial programs. My results indicate that remedial project teams should embrace strategies that use both removal and remedial actions to address residential soil contamination and should expect to select a remedy based on excavation and backfill of contaminated properties. Soil amendments may be able to reduce lead bioavailability but have only been used for residential properties at one site and were unable to achieve residential cleanup standards. Last, my paper provides average preliminary cost estimates for residential cleanups, ranging from \$434 per yd³ removal actions, and \$125 per yd³ for remedial actions. Although costs differ substantially between sites, these general estimates provide a starting point for early planning efforts.

INTRODUCTION AND BACKGROUND

Lead Contamination in the US

Legacy contamination from historic smelter sites continues to pose a substantial threat to public health in the United States. Impacts from lead smelting operations, especially at residential properties, are of particular concern as epidemiological research continues to suggest adverse health effects resulting from even relatively low exposures to lead. However, regulatory approaches to manage lead exposure and address lead contamination continue to evolve in consideration of scientific findings. For the United States Environmental Protection Agency (EPA), which is responsible for addressing large scale lead smelting sites through the Superfund program, current lead guidance is amorphous and in a state of flux. Therefore, this presents an issue to remedial project teams and decision makers when developing early remedial strategies to address residential lead sites.

Although the EPA has dedicated substantial efforts to cleaning lead smelting sites and developing a broader lead response strategy, no overview has been performed to date that cumulatively evaluates the wide range of remedial approaches taken through historic and ongoing actions. Therefore, my paper addresses this need by conducting a comprehensive evaluation of publicly available decision documents at lead Superfund sites to highlight common approaches to residential lead cleanups and a general range of costs. Although my findings illustrate inconsistencies in the selection of risk-based cleanup levels between sites, they also highlight general remedial and programmatic strategies.

In response to multiple Freedom of Information Act (FOIA) requests from news organizations and advocacy groups, EPA released a Superfund Data Report that further demonstrates the extent of the issue. Among the 1,344 total Superfund sites, as many as 3,498 distinct properties and operable units may be impacted by smelting operations (EPA 2019). The specific contaminants of concern vary by site, but common contamination from heavy metals includes lead, arsenic, cadmium, and mercury which are commonly encountered as a result of aerial emissions, transportation, and subsequent deposition from smelting facilities.

Waste management and disposal practices at smelting facilities have the potential to adversely affect soil and potentially groundwater. The impacts of historic operations, which predate modern best management practices, are often more pronounced. An early meta-analysis of smelter lead contamination compiled soil sampling results from 22 primary and secondary smelters and found that the average lead concentrations at each of the former smelters ranged from 1,159 to 7,140 mg/kg (Rieuwerts and Farago 1995). A more recent study of indoor lead dust in Philadelphia homes situated near historic smelting sites found lead concentrations ranging from 2,000 to 3,000 mg/kg (Lusby and Reiners 2015)

In addition to onsite contamination, substantial evidence shows the potential for smokestack emission to transport and carry metal compounds and smelting biproducts aerially thus resulting in far-reaching impacts to surrounding areas. Zoltai (1988) tracked elevated lead concentrations in peat more than 100 km from Flin Flon Base Canadian Smelter. More recently, residential soil sampling in the Upper Columbia River Basin found elevated lead concentrations in soil more than 32 km south of the Trail Smelter in British Columbia, Canada (WindWard

Environmental 2015). It is generally recognized that travel distance depends on smokestack height as well as geographic and atmospheric conditions.

Environmental effects from smelting operations often accompany impacts associated with the mining and initial refinement of the raw ore. Studies have shown increased blood-level concentrations in communities surrounding mines, presumably from exposure to waste piles and airborne dust (Choudhari *et al.* 2012; Hai *et al.* 2018). Discharges of mine wastes into rivers pose another route for human exposure. For example, in 2015, an impoundment rupture in Silverton, Colorado, resulted in a sudden release of more than 3,800 m³ of waste into tributaries of the Colorado River Watershed during the Gold King Mine Spill. The release caused public and private damage claims in excess of \$900 million (Elliot 2017) and resulted in an eventual settlement between the EPA and the State of Utah for \$300 million (EPA 2020). The Gold King Mine spill received widespread media coverage, but legacy contamination from historic mining operations is common throughout the U.S. American Rivers, an environmental advocacy group, maintains an annual list of the most heavily impacted rivers in the US, many of which include effects from historic mining operations (American Rivers 2020).

In addition to smelters and mines, other sources of environmental contamination must be considered. The addition of tetraethyl lead to gasoline dates to the early 1920s and expanded rapidly with the increase in car sales and road dependency in the 1950s (Markowitz 2013). After 70 years of use, leaded gasoline was eventually banned for most passenger vehicles after the passage of the Clean Air Act in 1996. These prohibitions on leaded gasoline excluded farm equipment, marine engines, and aircraft, and allowed incidental lead concentrations in gasoline of less than 0.05 g/L.

Historic pesticides are another source of lead contamination. Lead arsenate, also referred to as lead hydrogen arsenate, was one of the more widely used insecticides in the US. Lead arsenate occurs naturally in the mineral schultenite, but was first synthesized for commercial purposes in 1882 to protect fruit orchards from gypsy moth infestation in Massachusetts. Lead arsenate was manufactured by combining lead (II) nitrate with arsenic acid to produce lead arsenate and nitric acid. Lead arsenate quickly proved an effective insecticide for fruit orchards and use proliferated in the US and other countries, including Australia, Canada, England, and France (Peryea 1998). For example, commercial orchards in Virginia alone are estimated to have applied more than 217,000 m³ of lead arsenate over a 20-year period (Schooley 2006). During its zenith, domestic production peaked at 70,000 m³ per year in 1945 (Nelson 1973). Eventual awareness of health impacts from the pesticide, coupled with the availability of equally effective and economically competitive alternatives contributed to the phase out of lead arsenate. In 1988, lead arsenate was formally banned as an insecticide by the EPA, but the legacy of lead contamination from pesticide use persists in many areas today.

The above list of potential sources of environmental soil lead contamination in the US is not exhaustive. Other sources include munitions at outdoor firing ranges or shooting areas, and residential soils impacted by weathered lead paint. Each of these sources has the potential to overlap and affect lands impacted by historic smelting operations. Relative contributions are often unknown and differ between sites. Cumulative exposure to soil lead contamination poses widespread risk to public health. Given the large magnitude of environmental impacts from mines and smelters, these sites are often addressed with federal involvement.

Health Effects

Lead and lead isotopes are abundant in the earth's crust. Naturally occurring soil lead concentrations generally range from 15 to 40 mg/kg. The national average concentration in the US is estimated at 16 mg/kg (Chacklette & Boerngen 1984). Although lead in soil and water can be the result of natural occurrence and mineralization, much of today's contamination is the result of anthropogenic causes. Predominant lead compounds found in smelter and mining areas are often distinct from non-anthropogenic lead sources. The primary forms of lead from lead smelter operations are PbSO_4 and $\text{PbO} \cdot \text{PbSO}_4$ (Table 1; Rieuwerts and Farago 1995).

TABLE 1: Dominant chemical forms of lead found in smelter and mining areas.

Smelter	Mining Areas
Areas	
PbSO_4	PbS (galena)
PbOPbSO_4	$\text{Pb}_5(\text{PO}_4)_3$ (pyromorphite)
(lanarkite)	and other Pb phosphates
PbO	$\text{PbFe}_6(\text{SO}_4)(\text{OH})_{12}$
PbS	(plumbojarosite)
PbCO_3	$\text{Pb}_4\text{SO}_4(\text{CO}_3)(\text{OH})_2$
Pb metal	(leadhillite)
Pb	Pb oxides
silicates	Pb silicates
	PbSO_4

Once released into the environment, lead compounds can degrade into lead constituents that readily adsorb to soil particles. In general, lead is held more tightly in neutral or slightly basic soils. Soil adhesion is less strong in acidic soils (Zheng *et al.* 2012) and thus more susceptible to leaching into groundwater in these cases. Given the relative neutrality of most soils, lead tends to accumulate in the top 2.5 to 5 cm. Although pH is recognized as the most important factor, other geochemical characteristics such as chloride content can also influence soil lead solubility (ATSDR 2019). As a result, contamination exposure from historic smelter sites poses risks primarily through exposure to lead-impacted soils and dusts.

Lead is not naturally present in the human body and requires exposure via an exposure pathway. Lead toxicity has been recognized for more than 2,000 years, although early observations focused on direct exposure to concentrated lead (ATSDR 2019). The primary exposure pathways are through direct and indirect (i.e., lead on hands or objects) ingestion and inhalation of lead-containing dusts. Research suggests that ingestion is of greater significance to kids, who are more sensitive to lead exposure (Lusby and Reiners, 2015). Once exposed, toxicity is driven by bioavailability, which is determined by the chemical form of the lead ingested. In general, the more toxic lead compounds are those that are more soluble in water (Biggins and Harrison 1980). Gastrointestinal absorption of ingested lead compounds found in soil typically ranges from 2-60%, although other factors such as the particle size and pH of the ingested lead can also influence bioavailability (Biggins and Harrison 1980).

Ingested lead is distributed to target organs that include the liver, brain, kidneys, and bones. The U.S. Centers for Disease Control and Prevention (CDC) and EPA use blood lead levels (BLL), a measurement of lead concentration in blood typically represented in units of

micrograms (μg) per deciliter (dL) as a proxy for measuring lead poisoning. Blood lead concentrations can aid in determining an individual's exposure to lead, however, lead can also accumulate in bones and teeth and gradually release into blood over time. Thus, BLL may have the potential to underestimate total lead and lead exposure.

Lead poisoning can cause irreversible health effects that are more pronounced in young children. Not all of the mechanisms of action are understood, but it is generally recognized that heme synthesis enzymes and thiol-containing antioxidants and enzymes are primary targets (Nesadze *et al.* 2009). Lead interferes with a number of bodily functions, including the central nervous system. Studies have repeatedly linked lead exposure to anemia, cognitive decrement, elevated blood pressure, and organ damage largely linked to reactive oxidative stress (Wani *et al.* 2015; Gidlow 2015; Evens *et al.* 2015). Inorganic lead is classified as a probable carcinogen by the International Agency for Research on Cancer. Organic lead compounds, which do not occur naturally, are not currently classified as carcinogenic. Lead toxicity causes reactive oxidative stress and is classified as a probable human carcinogen by the EPA.

Adverse health effects can result from acute and chronic exposure scenarios. Acute exposure can result in encephalopathy and is generally observable in adults at blood lead concentrations of 100 $\mu\text{g}/\text{dL}$ or greater (Vorvolakos *et al.* 2016). On the lower end, evidence suggests adverse health effects among young children and sensitive populations can be observed at laboratory detection limits (Lanphear *et al.* 2005; Canfield *et al.* 2015). The implications are that, unlike most other contaminants, there is no blood lead concentration that is entirely protective. This lack of risk-based screening level creates a regulatory challenge that continues to persist.

Regulatory Approaches

The CDC has historically used a blood lead reference value of 10 µg/dL. As a result of an Advisory Committee review of literature, the CDC lowered the reference value to 5 µg/dL, based on the 97.5th percentile of the BLL distribution among children 1-5 years old (CDC 2012). The EPA Superfund Lead-Contaminated Residential Sites Handbook cites the 1994 EPA Office of Solid Waste and Emergency Response Directive 9355.4-12. This directive sets a risk reduction goal of limiting childhood exposure so that no more than 5% exceed a blood lead level of 10 µg/dL.

To assist with setting lead cleanup levels, EPA uses two models to predict blood lead concentrations based on a site's exposure parameters: the Adult Lead Model (ALM) and the Integrated Exposure Biokinetic Model for Lead in Children (IEUBK). For residential cleanups, the IEUBK is used as the more conservative of the two models. The IEUBK model uses total lead uptake from soil, dust, air, water, and diet. Once input parameters are known for existing site conditions, the IEUBK can be used to backtrack and calculate a soil cleanup level to achieve the desired blood lead target. Traditionally, this has corresponded with a soil cleanup level of 400 mg/kg.

In 2016, EPA's Office of Solid Waste and Emergency Response issued an updated policy review memo. The memo provided a review of the CDC's revised guidelines and scientific literature. Included in the memo was a recommendation that Regions consider current scientific conclusions in determining residential soil screening levels, including current scientific literature that provides evidence of adverse health effects below 10 µg/dL (EPA, 2016). Although acknowledging a range of blood lead effects below 10 µg/dL, this memo did not rescind or

supersede the previous 1994 directive. This ambiguity, coupled with varying state-wide cleanup levels that must be considered when designing a cleanup, has perpetuated a myriad of approaches to addressing residential contamination at legacy smelting sites.

The lack of an agency-wide standard presents an additional challenge to remedial project managers and the teams tasked with developing remedial cleanup plans. In the absence of clear cleanup standards, remedial project teams may seek to use recent Proposed Plans or Records of Decision from other, more contemporary, lead cleanup sites as a jump-off point for designing a remedy. Recent cleanups may reflect consideration of contemporary guidance, but EPA's regional structure leaves discretion to each Region to develop site-specific cleanup standards. Thus, similar sites with Records of Decision published in the same year may still have differing cleanup levels.

RESEARCH OBJECTIVES

The purpose of my study is to better understand the magnitude of intra-site differences, and to assist remedial project teams with identifying preliminary cleanup strategies for former lead smelter sites. My goal is not to seek universal consistency between sites and regions because environmental and exposure considerations at each site will still differ. However, presenting this information still provides value in providing a jump-off point at early stages in the remedial process. As such, the following research questions must be addressed:

- 1) What approaches have been taken to address residential lead contamination at sites affected by legacy smelting contamination?
- 2) What is the general range of costs for residential cleanups at former smelter sites?
- 3) What lead cleanup standards have been used?

METHODS

To answer each of the three research questions, I make use of publicly available data, starting with FOIA-001 Sites with Potential Smelting Operations (SEMS Doc ID 2013546). This report pulls data from the Superfund Environmental Management System and includes sites with confirmed, or suspected impacts from smelters, including sites pending further environmental sampling and investigation (Table 2). Fields include Region (Reg), State (St), Site Name, Site ID, Address, City, Zip Code (Zip), Contaminant Name, Status on the National Priority List (NPL), Federal Facility Index (FF Ind), and Primary Site-Sub Type. Some sites are identified as being assessed or cleaned as part of a special initiative (Special Initiative).

TABLE 2: Excerpt from SEMS Doc ID 2013546 – Sites Potentially Impacted by Smelters.

Reg	St	Site Name	Site ID	EPA ID	Address	City	Zip	Contaminant Name	CoC Ind	NPL	FF Ind	Latitude	Longitude	Primary Site-Sub Type	Non-Primary Site-Sub Type	Special Initiative
01	CT	CHARLES BATCHELDER COMPANY	0100268	CTD981069180	46A SWAMP ROAD	NEWTOWN (BOTSFORD)	06470	CHROMIUM	N	Not on the NPL	N			ng/Maintenance) Primary metals/mineral processing (Manufacturing/Processing/Maintenance)		
01	CT	CHARLES BATCHELDER COMPANY	0100268	CTD981069180	46A SWAMP ROAD	NEWTOWN (BOTSFORD)	06470	COPPER	Y	Not on the NPL	N			Primary metals/mineral processing (Manufacturing/Processing/Maintenance)		
01	CT	CHARLES BATCHELDER COMPANY	0100268	CTD981069180	46A SWAMP ROAD	NEWTOWN (BOTSFORD)	06470	LEAD	Y	Not on the NPL	N			Primary metals/mineral processing (Manufacturing/Processing/Maintenance)		
01	CT	CHARLES BATCHELDER COMPANY	0100268	CTD981069180	46A SWAMP ROAD	NEWTOWN (BOTSFORD)	06470	POLYCHLORINATED BIPHENYLS	Y	Not on the NPL	N			Primary metals/mineral processing (Manufacturing/Processing/Maintenance)		
01	CT	CHARLES BATCHELDER COMPANY	0100268	CTD981069180	46A SWAMP ROAD	NEWTOWN (BOTSFORD)	06470	SELENIUM	N	Not on the NPL	N			Primary metals/mineral processing (Manufacturing/Processing/Maintenance)		
01	CT	CHARLES BATCHELDER COMPANY	0100268	CTD981069180	46A SWAMP ROAD	NEWTOWN (BOTSFORD)	06470	SILVER	N	Not on the NPL	N			Primary metals/mineral processing (Manufacturing/Processing/Maintenance)		
01	MA	CHARLESTOWN SMELTING CO	0106102	MAN000106102	235 MEDFORD	CHARLESTOWN	02129			Not on the NPL	N			Mineral Processing/Smelting Only (Mining); Mining and Mineral		Unrecognized Smelter per 2001 Report

I converted the 2019 FOIA data from pdf to an .XLS file using Adobe Acrobat Pro and formatted manually in Microsoft Excel. To help with formatting, only the following relevant fields were maintained: “State”, “Site Name”, “EPA Site ID”, “Contaminant”, “NPL Status”.

To develop a list of specifically lead sites, I filtered sites by “Contaminant Name”. After eliminating duplicate entries, this yielded 144 sites. The list was then filtered “NPL Status”. Sites that were designated as “Pre-Listing” were removed as they included sites that had not been fully characterized or did not have cleanup standards identified. Additional sites that were listed multiple times (i.e., separate entries for multiple Operable Units), were removed. At this stage, the list contained 99 lead-contaminated sites affected by former smelting operations.

After initially narrowing the list of sites, I expanded the spreadsheet with fields that were relevant to answering the research questions, and for which publicly data would be available.

The following fields were added:

Residential (Y/N): This indicator would signify whether cleanup occurred or was based on residential standards. Data for this are available in the Site Profile Page description of cleanup work completed, as well as in decision documents including Removal Action Memoranda, Proposed Plans and/or Records of Decision.

Program: Completed based on whether a cleanup was completed under EPA’s “Removal,” “Remedial,” or “Both” programs.

Removal Start: Year in which the first removal action was completed.

Removal Finish: Latest year in which a removal action was completed.

Remedial Start: Year in which the first remedial action was completed. This includes interim cleanups completed under an Interim Remedial Decision (IROD).

Remedial Finish: Final year in which a removal action was completed. Site with ongoing remedial actions occurring were designated as “ongoing”. This includes interim cleanups completed under an IROD.

Latest Cleanup Year: Latest year where remedial and/or removal action occurred.

ROD (year): Year in which the Record of Decision for a remedial action was finalized. This includes IRODs.

Residential CUL (mg/kg): The residential cleanup level used in removal or remedial decision document. Units are expressed in mg/kg.

BLL Target: The blood lead level target used to determine the cleanup level, expressed in $\mu\text{g/dL}$.

Removal Cost: Total/cumulative cost of the removal action(s) based on removal cost estimates provided in Removal Action memoranda. This only includes removal actions for which data were available.

Removal Yards Cleaned: The total number of discrete yards (properties) addressed by removal actions. Only yards in which data were available are included in the count. This was included as some cost estimates were provided as fixed price cost estimates per yard or property cleaned in place of per/cubic yard and is a forward-looking estimate.

Removal \$/Yard: Calculated by dividing “Removal Cost” by “Removal Yards Cleaned”.

Removal CY: Total number of cubic yards (CY) addressed by removal actions. This is a forward-looking estimate and only includes available data.

Removal \$/CY: Calculated by dividing “Removal Cost” by “Removal CY”.

Remedial Cost: Total/cumulative cost of the remedial action(s) based on removal cost estimates provided in the Record of Decision. If Record of Decision price information was unavailable, data from the Proposed Plan were used. This only includes remedial actions for which data was available.

Remedial Yards Cleaned: The total number of discrete yards (properties) addressed by remedial actions. Only yards in which data were available are included in the count. This was included as some cost estimates were provided as fixed price cost estimates per yard or property cleaned in place of per/cubic yard and is a forward-looking estimate.

Remedial \$/Yard: Calculated by dividing “Remedial Cost” by “Remedial Yards Cleaned”.

Remedial CY Cleaned: Total number of cubic yards (CY) addressed by remedial actions. This is a forward-looking estimate and only includes available data.

Remedial \$/CY: Calculated by dividing “Remedial Cost” by “Remedial CY Cleaned”.

Remedy: Brief summary of the remedy selected by the removal and/or remedial actions.

Notes: General inputs to provide information on the source of data and any unique site-specific circumstances that may have affected the previous fields.

I gathered data for each of these fields by manually reviewing publicly available site records and performing key word searches. I prioritized the following resources in hierarchical order:

1. Record of Decision or Removal Action Memorandum
2. Proposed Plan
3. The latest Five-Year Review completed (including summaries of previous response actions)

4. Superfund Site Profile Page; including timeline of cleanups completed to date and summary of work conducted at each operable unit

A separate field labeled, “Relevant” was added to include a Y/N response. Sites in which insufficient cleanup data were available, or where the remedial action did not include any action (i.e., No Further Action Determinations), were marked as “N”. After reviewing the decision documents for each of the sites, sites marked as “N” in the “Residential” and/or “Relevant” fields were removed.

I made the decision to differentiate between cleanup actions taken under EPA’s Removal and Remedial Programs. Actions taken by the EPA’s removal program were typically taken as Time Critical Removal Actions (TCRA). Because each program is subject to differing statutory and regulatory requirements, approaches and costs differed significantly between the two. Additionally, information on the number of cleanups and relative contribution of each program to smelter sites can be beneficial to project teams in developing initial remedial strategies for a lead smelter site.

The evaluation includes remedial and removal actions spanning from 1995 to present. I did not adjust historic costs to present day values because removal and remedial cost estimates require that costs be presented in decisional documents in terms of net present worth, often using a conservative discount rate of 7% for future expenses. As a result, inflation was built into the estimates included in the decision documents, although it may not have continued through present. Cost data are included in this report to provide a general range of costs, with the understanding the expenses will vary widely between sites due to site-specific factors. The level

of accuracy without further inflation adjustment was deemed appropriate to serve my research objective.

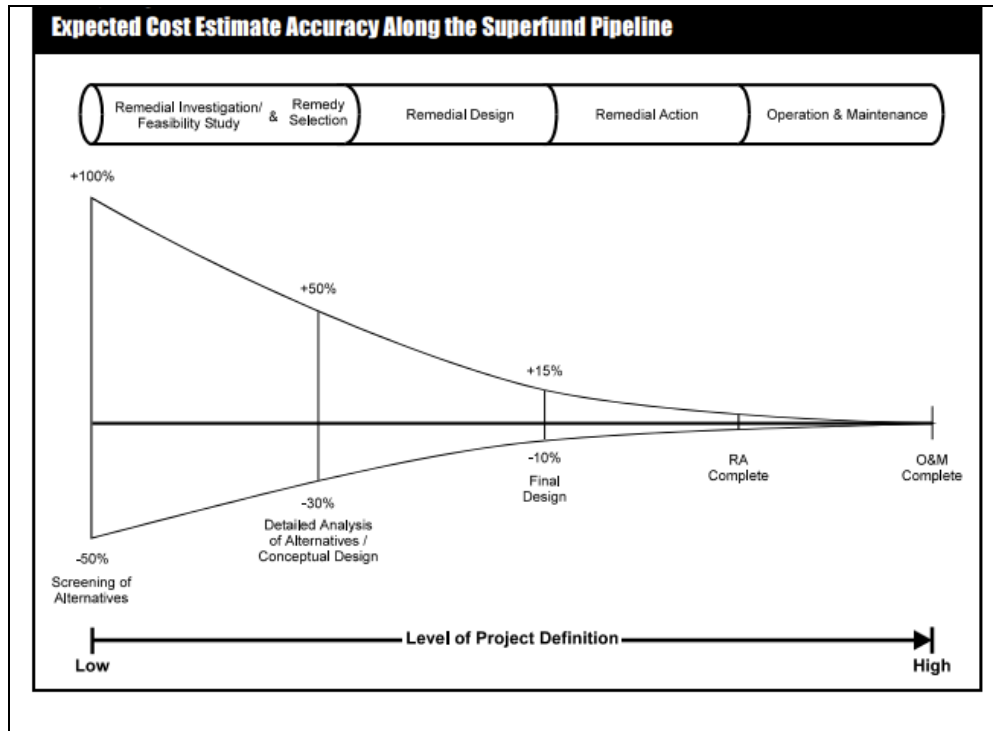


FIGURE 1: Expected Cost Estimate Accuracy Along the Superfund Pipeline

RESULTS AND DISCUSSION

The final database included 47 smelter-related sites from residential properties with lead soil contamination. After narrowing the list to include only those sites with relevant data available on cleanup levels and or cleanup volume and/or cost data, the final list included 31 sites. A summary of key findings is included below, including information on the regional distribution of lead smelter sites, the EPA programs used to conduct the cleanups, the remedies selected, the cleanup costs, and cleanup levels used.

Regional Distribution

From my evaluation, I was able to determine and illustrate the regional distribution of smelter sites with residential lead impacts (Figure 2). EPA Regions 8 (which includes North Dakota, South Dakota, Wyoming, Utah, and Colorado) and 5 (which includes Minnesota, Wisconsin, Michigan, Illinois, Indiana, and Ohio) had the most sites at 10 and 9, respectively. The frequency of lead sites in these regions is a good representation of the size of heavy metal mining industries in each. Missouri and Utah have the greatest number of sites, each having 5.

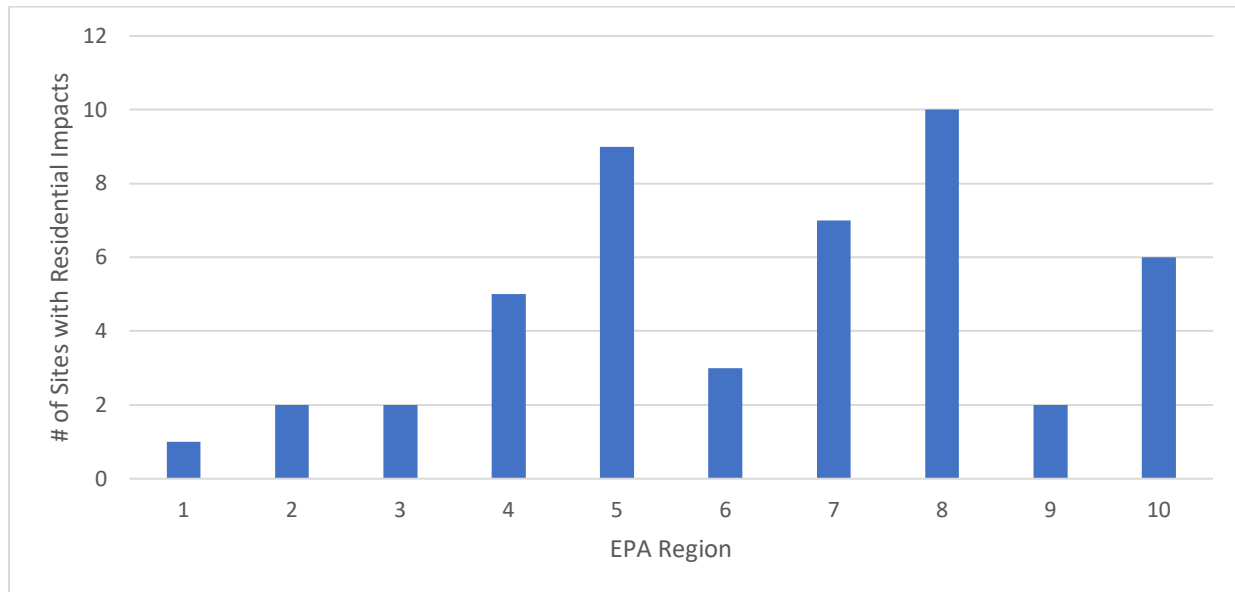


FIGURE 2: Regional Distribution of Residential Lead Smelting Sites

Program Involvement

The final list of sites only includes the 31 sites for which relevant data were publicly available at the time of my analysis. This includes information on whether responses to residential contamination were addressed through either removal actions, remedial actions, or both. A total of 20 sites had residential properties cleaned under both the remedial and removal programs. Of the sites, five had properties cleaned solely by the removal program, and six solely by the remedial program (Figure 3). This demonstrates that removal actions are an equally common approach used to address residential lead properties that are impacted by smelter sites and should be considered by remedial project teams in developing a response strategy. Removal actions can typically be completed on a faster timeline than remedial actions, which are subject to additional requirements as outlined in the NCP. This approach is better suited for residential properties with high concentrations of soil lead that pose risks through acute levels of exposure.

Most of the removal actions were completed by EPA, but it should be noted that some of the sites had removal actions completed by the Potentially Responsible Party (PRP).

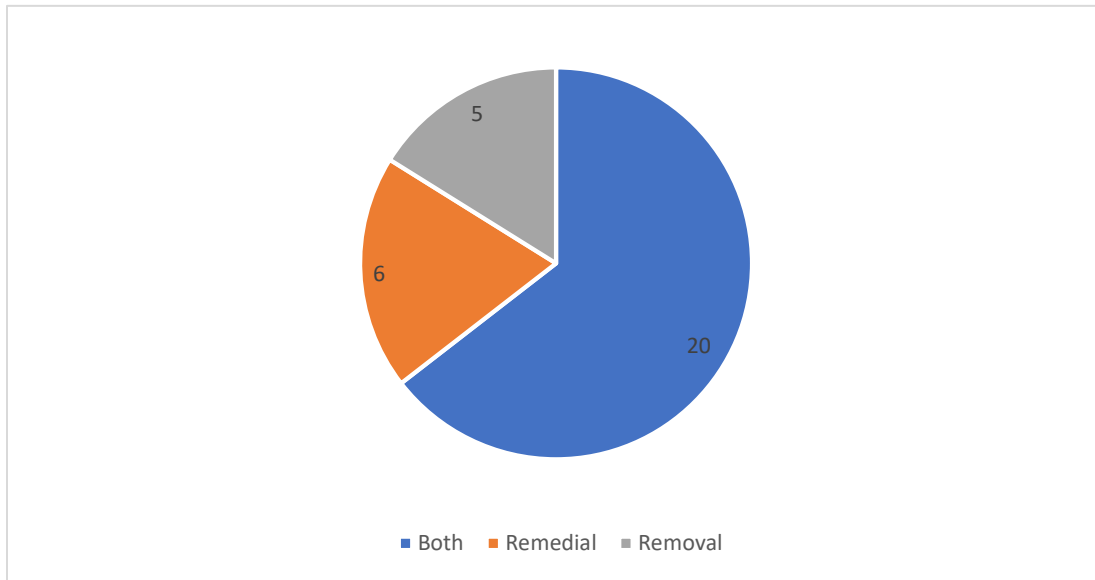


FIGURE 3: Number of Residential Sites Cleaned by EPA's Removal and Remedial Programs.

Remedy Selection

At all 31 sites evaluated, the selected remedy consisted of some form of excavation and backfill. This was true for cleanups conducted through removal actions as well as through remedial actions. Slight variations existed between sites. For example, the 2002 Record of Decision for the Bunker Hill site in Idaho called for a hybrid approach in which residential soils with lead concentrations above 1,000 mg/kg were excavated and vegetative barriers were used for properties with lead concentrations between 700 and 1,000 mg/kg (EPA 2002). However, this approach seems to have been abandoned with more recent cleanup actions calling only for excavation and backfill.

Soil amendments were considered at four sites: Omaha Lead, East Helena Site, Colorado Smelter, and the Oronogo-Duenweg Mining Belt. For Omaha Lead, treatment of soils with

phosphate amendments was considered in the 2004 Feasibility Study, but was not selected in the 2009 Record of Decision. This was attributed at least in part to significant changes in cost and availability of phosphoric acid. For the East Helena Site, phosphate amendments were evaluated and selected as part of the remedy for undeveloped lands only. For these properties, the 2009 Record of Decision called for deep tillage and treatment of soils with lime or other soil amendments with the ability to decrease the bioavailability of lead. In the 2017 Record of Decision at the Colorado Smelter, alternative treatments such as phosphate amendments were considered, but eliminated due to technical limitations and the combined presence of arsenic in soil, which could become more bioavailable with the addition of amendments. The only site evaluated that did select use of soil amendments for residential properties was the Oronogo-Duenweg Mining Belt. In situ phosphate treatment was used and evaluated for residential cleanup for six years after consideration in the 1996 Proposed Plan. Even though treatment resulted in a 40% reduction in lead bioavailability, this approach was abandoned after the post-treatment concentrations still exceeded remedial cleanup targets.

Costs

The total combined cost of all removal and remedial actions I evaluated was \$453,243,832. Of this, \$24,713,946 was projected for removal actions and \$428,529,886 was for remedial actions. Table 3 provides summaries with and without the Price Battery Lead Smelter, which was a substantial outlier. Remedial and removal costs are kept separate due to unique distinctions between the two programs. Of the removal data evaluated, 738 discrete yards and approximately 51,286 cubic yards of impacted material was removed and disposed of. The approximate cost per yard cleaned was \$33,488 and the approximate volumetric cost was

\$482/cubic yard. Of the remedial data evaluated, 17,173 discrete yards and approximately 3,298,959 cubic yards of material were removed and disposed of. The approximate cost per yard cleaned was \$24,413 and the approximate volumetric cost was \$130/cubic yard.

TABLE 3. Remedial and Removal Cleanup Cost Summaries at Lead Sites

Cleanup Cost Summaries at All 31 Sites									
Total Removal Costs	Total Removal Yards Cleaned	Removal \$/Yard	Total Removal CY Cleaned	Removal \$/CY	Total Remedial Cost	Remedial Yards Cleaned	Remedial \$/Yard	Total Remedial CY Cleaned	Remedial \$/CY
\$24.7M	738	\$33,488	51,286	\$482	\$428.5M	17,173	\$24,413	3,298,959	\$130
		SD: \$21,477		SD: \$7,982			SD: \$26,012		SD: \$666
		CV: 0.55		CV: 1.8			CV: 0.76		CV: 2.10
Cleanup Cost Summaries (Excluding Price Battery Lead Smelter)									
Total Removal Costs	Total Removal Yards Cleaned	Removal \$/Yard	Total Removal CY Cleaned	Removal \$/CY	Total Remedial Cost	Remedial Yards Cleaned	Remedial \$/Yard	Total Remedial CY Cleaned	Remedial \$/CY
\$22.2M	441	\$50,372	51,173	\$434	\$412.6M	16,998	\$24,271	3,293,559	\$125
		SD: \$18,781		SD: \$775			SD: \$27,026		SD: \$91
		CV: 0.42		CV: 0.87			CV: 0.78		CV: 0.62

It is important to note that these amounts are forward-looking cost projections and do not reflect the actual costs which were not publicly available. Because of the timing, scope, and process for requesting funds for remedial actions, it is highly likely that the removal cost estimates are a closer approximation than the remedial cost projections, which are developed before remedial design. However, despite the imprecision of these figures, the following general conclusions can be drawn.

Per yard and volumetric costs tended to be less for cleanups conducted through remedial actions. This is even though many of the remedial action estimates included additional lifecycle

costs required by the National Contingency Plan, such as Operations and Maintenance Fees, Five-Year Review and reporting expenses, larger contingency percentages, EPA indirect costs and overhead, and/or oversight expenses. In several of the sites, the remedy called for the construction and maintenance of onsite storage repositories to hold excavated contaminated material. These costs were often bundled into the cost estimates. However, while these startup and lifecycle costs were included, it is assumed that the total costs benefited from economies of scale. In cases where established hazardous waste landfills were not used, this likely resulted in cost savings despite initial construction overlays.

Costs varied widely. For the removal cost per yard and cost per cubic yard, the coefficient of variation was 0.55 and 1.8, respectively. For the remedial cost per yard and cost per cubic yard, the coefficient of variance was 0.76 and 2.10, respectively. This reflects the variety of site-specific factors that influence costs. Excluding the Price Battery Lead Smelter, which was a substantial outlier, the coefficients of variance drop to 0.42 and 0.87 (removal) and 0.78 and 0.62 (remedial). Remedial costs at the Price Batter Site were higher largely because the remedy required indoor remediation of lead dust in addition to outdoors soil excavation. Indoor cleanup costs included disposal of carpet and cleaning of contaminated surfaces, as well as temporary relocation fees for residents during cleaning. The remedy also set aside funding for an ongoing HVAC rental program to be available to residents. At other sites, the location and volumetric disposal rate at the landfill receiving waste material was a primary factor that influences site costs. Restoration expenses of properties after contaminated media was removed also varied widely between sites. The variance between costs/yard was less than the volumetric estimates. This was somewhat unexpected as yards or lot sizes vary as did the cleanup strategies

for each yard. The excavation depth between sites also varied, although most cleanups call for excavation of as much as 30 to 45 cm.

In addition to site-specific differences, there were also distinct differences in how the project costs were calculated, which signifies differing interpretation or selective adoption of EPA's "A Guide to Developing and Documenting Cost Estimates During the Feasibility Study" (EPA and USACE 2000). For example, the discount rate used to convert total costs to net present values varied from four to ten percent per year.

Cleanup Levels/Blood Lead Level Targets

Of the 31 sites included in this review, only 26 cited a clear cleanup level and/or associated blood lead level target in the associated decisional document. The reason that a cleanup level is absent varies by site. For example, residential cleanups at the Bunker Hill site were covered under Time Critical Removal Actions from 1997-2000. The removal action memorandum was unavailable, but was summarized in the 2002 remedial Record of Decision. The 2002 Record of Decision did not include residential areas, and thus did not include a residential cleanup level. The Remedy at the Lava Camp Mine in California included permanent relocation of impacted residents, and the Smokey Mountain Smelters Site in Tennessee only covered vacated historic residential properties. As such, neither of these sites selected remedies that were based on residential exposure scenarios. Record of Decision documents were not available for either the RSR Corporation or the Tex-Tin Corporation sites, both located in Texas. Some sites, like the Sharon Steel site in Utah justified not including a specific cleanup level as lead was not listed as the primary risk driver and that the selected remedy (dig and haul) would also achieve blood lead targets.

Of the 25 sites for which lead cleanup levels were identified, 16 set a residential cleanup level of 400 mg/kg. This is unsurprising as the Superfund Lead-Contaminated Residential Sites Handbook (EPA 2003) cites the TSCA §403 Soil Hazard Rule, which establishes a soil-lead hazard of 400 mg/kg for bare play areas, often used as a representative measure for residential exposure scenarios. The most aggressive soil cleanup level was 231 mg/kg at the International Smelting and Refining Site in Utah. The least aggressive cleanup level was 1,000 mg/kg at the East Helena Smelter Site in Montana. However, in this case, the CUL also serves as a trigger level, meaning that residential properties that exceeded 1,000 mg/kg would be cleaned to a target concentration of 500 mg/kg.

For BLL targets, all but two of the sites based cleanup levels on achieving a 5% or less probability of child BLLs exceeding 10 µg/dL. The International Smelting and Refining Site in Utah had the most aggressive cleanup level at nearly half that of other sites, but still based it on achieving a BLL target of 10 µg/dL. The difference is explained in the 2002 Record of Decision; inputs into the IEUBK model reflected additional exposure to contaminated dust through increased recreational activities, primarily wide-spread use of motorized dirt bikes and ATVs. The two sites that selected more aggressive BLL targets were the Colorado Smelter (BLL target of 6.24 µg/dL) and the Southside Chattanooga Lead Smelter (BLL target of 8 µg/dL). These two sites demonstrate key differences in approaches in setting cleanup targets. The Colorado Smelter Sites started with cleanup target and used the IEUBK model to determine the expected BLL, and then verified whether or not it fell within the EPA's recommend range of 3-8 µg/dL. The Chattanooga Lead Smelter started with a BLL target at the high end of the recommended range and back calculated what soil concentration would produce the target in the IEUBK.

From my evaluation, I was able to sort and display the sites the year in which the cleanup level and/or blood lead level targets were first identified, either through a removal or remedial action (Table 4). This was appropriate as the original cleanup levels did not change with subsequent cleanup activities at any of the sites evaluated. Unsurprisingly, the two most aggressive BLL targets were selected after the EPA's 2013 Updated Lead Guidance was issued, in 2018 and 2019. However, other sites with Records of Decision published after the 2013 guidance reflect differing interpretations. For example, the ACM Smelter and Refinery in Montana set a cleanup level in 2020 that is in line with traditional guidance at 400 mg/kg and 10 µg/dL.

TABLE 4: Cleanup Level and Blood Lead Level Comparisons

Site Name	Year CUL Selected	Removal Start	ROD (year)	Residential CUL (ppm)	BLL Target (ug/dL)
SHARON STEEL CORP. (MIDVALE)	1989	1989	1990	NA	10
RSR CORPORATION	1991	1991	1995	NA	NA
ORONOGO-DUENWEG MINING BELT	1995	1995	1996	400	10
OMAHA LEAD	1995	1995	2009	400	10
SPOKANE JUNKYARD/ASSOCIATED	1996	1996		360	10
BUNKER HILL MINING & CONTINENTAL STEEL CORP.	1997 1997	1997 1997	2002 1998	NA 400	NA 10
DELATTE METALS	1998	1998	2000	500	10
EAST HELENA SITE	1998	1998	2009	1000	10
TEX-TIN CORP.	1999	1999	2000	NA	NA
JACOBS SMELTER	1999	1999	1999	500	10
INTERNATIONAL SMELTING AND REFINING	2001	2001	2002	231	10

OLD AMERICAN ZINC PLANT	2002	2002	2012	400	10
PRICE BATTERY LEAD SMELTER	2002	2002	2009	572	10
DAVENPORT AND FLAGSTAFF	2002		2002	600	10
MADISON COUNTY MINES	2003	2003	2008;2015	400	10
IRON KING MINE - HUMBOLDT SMELTER	2006	2006	pending	400	10
FORMER UNITED ZINC & ASSOCIATED	2006	2006	2017	400	10
WASHINGTON COUNTY LEAD DISTRICT POTOSI	2006	2006	2011	400	10
WASHINGTON COUNTY LEAD DISTRICT OLD MINES	2006	2006	2011	400	10
WASHINGTON COUNTY LEAD DISTRICT RICHWOODS	2006	2006	2011	400	10
U.S. SMELTER AND LEAD REFINERY, SANDOVAL ZINC COMPANY	2008	2008	2012	400	10
	2011	2011	2017	400	10
SOUTHSIDE CHATTANOOGA LEAD	2012	2012	2019	360	8
ANACONDA CO. SMELTER	2013		2013	400	10
SMOKEY MOUNTAIN SMELTERS	2015		2015	NA	NA
HEGELER ZINC	2016	NA	2016	400	10
COLORADO SMELTER	2017		2017	350	6.24
DEPUE/NEW JERSEY ZINC/MOBIL	2017	NA	2017	400	10
ACM SMELTER AND REFINERY	2020	2020	2020	400	10

CONCLUSION

My paper aims to serve as a tool for remedial project teams in developing early strategies to respond to legacy smelting sites with effects on residential properties. The need for my analysis is evidenced through its findings. EPA's on-the-ground lead strategy has differed widely between sites, which is likely a direct reflection of ambiguous direction by the Agency and inconsistent interpretations by the regional offices. These differences have persisted despite more recent efforts to update the Agency's blood lead targets.

By conducting a comprehensive review of smelting sites addressed through EPA's Superfund program, I identified commonalities and differences between sites and identified potential paths forward for future lead cleanups. For example, the overwhelming majority of sites used both the removal and remedial programs to address residential contamination. This hybrid approach leverages the flexibility of the removal program to address high-priority areas with greater residential exposure concentrations, while also leveraging the greater resource and cost efficiencies of the remedial program to address broader contamination. My paper demonstrates precedent for this approach and suggests that remedial project managers should adopt a similar strategy.

My evaluation also demonstrated that remedial project teams should expect to select a remedy that is based on excavation of contaminated soils and replacement with clean backfill. Although use of soil amendments as an alternative remedial approach were considered at four sites, only one site, the Oronogo-Duenweg Mining Belt, used amendments for residential properties. This was discontinued after the amendments were unable to reduce bioavailability to the necessary cleanup levels. This suggests that remedial project teams should taper their

expectations when considering the use of remedial strategies for smelter sites, particularly with regards to soil amendments. A more important consideration may be whether sufficient landfill capacity exists to accommodate excavated waste material, or whether an on-site repository may be necessary.

From my review, I was able to provide rough order-of-magnitude cost estimates for both removal and remedial cleanups. For remedial cleanups, project teams should anticipate a cost of approximately \$50,000 per yard, or approximately \$424 per cubic yard of material removed. For remedial cleanups, the approximate costs are \$24,271 per yard or \$125 per cubic yard of material removed. These numbers should be used only for early planning purposes and come with substantial uncertainties due to site-specific factors and inconsistent methods used to project costs between decision documents. Additionally, it is not uncommon for actual remedial action costs to differ from the early cost projections (Figure 1). This could be remedied to some extent by using Remedial Design documents, which are developed after a remedy is selected, but these were not readily available for many of the sites. These documents can be requested through Freedom of Information Requests; however, additional timing is required for an agency to respond to these requests. Still, despite the inherent inaccuracies built into this evaluation, we are still able to glean rough cleanup costs, as well as identify the upper and lower bounds. As more specificity is required, additional site-specific characteristics should be used to develop more precise cost estimates. This order-of-magnitude approach has merit in early stages of remedial planning as costs may impact which program is appropriate, be it removal, remedial or some combination of the two.

My paper does not seek to achieve uniformity between sites. Perfect consistency is an unrealistic expectation as too many site-specific factors exist. In addition, the methods used in my evaluation come with several key caveats. Data were gleaned from only decision documents that were publicly available at the time of this report. It was evident during this review that the availability of decision documents differs by site and region. Although decision documents are published in the Federal Register, it is not uncommon for posting of the electronic files on EPA's site profile pages to lag behind. In general, more recent remedial documents were readily available. Conversely, there was a paucity of publicly available data for historic removal documents, which would have provided closer approximations to actual cleanup costs than the forward-looking remedial Records of Decision. Despite these issues with data quality, my paper still provides a first-of-its kind evaluation of the entire breadth of sites cleaned through EPA's Superfund Program.

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