



Practice-based evidence informs environmental health policy and regulation: A case study of residential lead-soil contamination in Rhode Island

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HIGHLIGHTS

- Practice-based evidence informs environmental health policy and regulation
- Surface samples alone were insufficient to classify property as “lead safe”.
- Moderately high lead-soil concentrations persisted at depths of 6- and 12-inches.
- Regulatory congruency across state and federal agencies recommended
- Practice-based evidence did not support existing regulation in real world context.

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ABSTRACT

Prior to 1978, the exteriors of Rhode Island's municipal water towers were painted with lead-containing paint. Over time, this lead-containing paint either flaked-off or was mechanically removed and deposited on adjacent residential properties.

Residents challenged inconsistencies across state agencies and federal requirements for collecting and analyzing soil samples.

The purpose of this case study was to evaluate the efficacy of Rhode Island Department of Health (RIDOH) soil sampling regulations in determining the extent of lead contamination on residential properties using real world data. Researchers interviewed key government personnel, reviewed written accounts of events and regulations, and extracted and compiled lead data from environmental soil sampling on 31 residential properties adjacent to six municipal water towers. Data were available for 498 core samples.

Approximately 26% of the residential properties had lead soil concentrations >1000 mg/kg. Overall, lead concentration was inversely related to distance from the water tower. Analysis indicated that surface samples alone were insufficient to classify a property as “lead safe”. Potential for misclassification using RIDOH regulations was 13%. For properties deemed initially “lead free”, the total number of samples was too few to analyze. Post-remediation lead-soil concentrations suggest the extent of lead contamination may have been deeper than initially determined. Additional data would improve the ability to draw more meaningful and generalized conclusions.

Inconsistencies among regulatory agencies responsible for environmental health obfuscate transparency and erode the public's trust in the regulatory process. Recommendations for improvement include congruency across departmental regulations and specific modifications to lead-soil sampling regulations reflective of lowered CDC reference blood lead value for children 1 to 5 years old (5 µg/dL). While scientific research informed the initial development of these environmental health policies and regulations, practice-based evidence did not support their efficacy in context of real world practice.

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1. Introduction

Practice-based evidence (PBE) refers to translational or evaluation research where scientific knowledge is applied to various settings, populations, and contexts as a test for external validity (Green and Ottoson, 2004). Practice-based evidence narrows the gap between scientific

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inquiry and praxis (Green, 2007, 2008). At its core, PBE methodology is used to evaluate real-world practices that are often shaped by political, social and public interests (Bowen and Zwi, 2005). It serves as a credible platform for evaluating current practices and informing future decisions (Dunet et al., 2012).

The purpose of this case study was to evaluate the efficacy of Rhode Island Department of Health (RIDOH) soil sampling regulations in determining the extent of lead contamination on residential properties using practice-based evidence. While Rhode Island Department of Health (RIDOH) lead-soil sampling regulations are based on the best available scientific evidence (i.e., environmental availability and human exposure modeling), until this study, no one had evaluated these regulations using actual field data. This study was conducted at the request of the Rhode Island Department of Health with funding from the National Institutes of Health/National Institute of Environmental Health Sciences P42 Superfund Research Program Grant. This study had four research questions:

1. What was the distribution of lead concentration in soil at the surface and at depths of six- and twelve-inches found on residential properties adjacent to municipal water towers?
2. What was the distribution of lead concentration in soil at 50-foot incremental distances from the center of municipal water towers?
3. What percentage of residential properties were misclassified as “lead free” or “lead safe” using RIDOH sampling protocols?

4. Is the Rhode Island Department of Health (RIDOH) or the Rhode Island Department of Environmental Management (RIDEM) sampling protocols more efficacious at determining the extent of lead contamination on residential properties?

In the following sections, the case study will be presented followed by background information on environmental availability and human exposure to lead as well as pertinent state and federal regulations.

1.1. Case study

Prior to 1978, the exterior of Rhode Island's municipal water towers was painted with lead-containing paint. Most of these large elevated tanks were not well maintained. Over time, this lead-containing paint either flaked-off or was mechanically removed. As a result, this lead may have deposited on adjacent residential properties. In September 2003, officials in a small Rhode Island town notified residents that its 70 year-old water tower was going to be replaced. Contractors were in the process of evaluating this site for potential lead-soil contamination per RIDEM regulations. For the purposes of this study, this tower is referred to as Site 19 (Fig. 1). In January 2004, RIDEM notified town officials that the tank site and residential properties surrounding the tower had a “soil-lead hazard” (i.e., lead concentrations >400 mg/kg). Four months later, town officials notified residents of RIDEM's findings.

Residents were outraged at the town's delayed notification (Russell, 2004). They were equally angered at the absence of a physical barrier to



Fig. 1. Topographical map for site 19 municipal water tower. Map courtesy of Rhode Island Department of Environmental Management.

restrict public access to the site. Since remediation was estimated to take a number of years, they stated that their quality of life would be negatively impacted by restricting or eliminating outdoor activities, and by being unable to open windows and doors. Additionally, they feared losing tenants and/or the ability to sell their property. They voiced concerns about their health and the health of their children. The relationship between town officials and the residents quickly became adversarial.

The residents formed the Site 19 Tank Neighborhood Association, hired an environmental lawyer and an independent lead inspector to collect soil samples. Using RIDOH sampling criteria, their inspector identified additional areas of contamination contiguous to areas previously identified as not contaminated by contractors using RIDEM sampling criteria. As a result, residents questioned the efficacy of contractors' soil sampling procedures, noting in particular that a lower number of soil samples had been taken from adjacent residential properties than the number of samples taken on town-owned property that immediately surrounded the tower. While these discrepancies in lead-soil concentrations were more likely due to spatial variability, residents challenged the differences between RIDOH and RIDEM requirements for collecting and analyzing samples (R. Vanderslice, personal communication, May 9, 2012). When the residents proposed legislation to force RIDEM to use RIDOH sampling regulations, RIDOH requested researchers to evaluate the efficacy of these regulations in determining the extent of lead contamination on residential properties.

By the time this study commenced in 2012, RIDEM had analyzed soil samples for lead at other municipal water tower sites in Rhode Island (Staff, 2004). As a result, soil samples were pooled from 31 residential properties adjacent to six municipal water towers located in rural Newport and Washington Counties (Fig. 2).

1.2. Environmental availability and human exposure

Rhode Island Department of Health (RIDOH) lead-soil sampling criteria were based on the best available scientific evidence with respect to environmental availability and human exposure modeling. Lead is pervasive and persistent in the environment. Environmental persistence of lead is affected by air and sea temperatures, wind speeds, variation in precipitation patterns and secondary effects of climate change (McMichael and Martins, 2002) and soil acidification (Navratil et al., 2004). Over time, lead-containing paint deteriorates and eventually lands on the ground. Once deposited, lead adheres to soil particles and remains in the upper layer of soil (Agency for Toxic Substances and Disease Registry, 2007). The environmental availability of lead

in soil varies from 49% to 100%, depending upon the source of contamination, the presence of other contaminants (i.e., phosphates, iron oxides, organic matter), and soil characteristics such as pH, clay content, and cation exchange capacity (Pauget et al., 2012; Smith et al., 2010). Typically, contamination is remediated by removing and replacing the soil.

Deteriorating lead paint and lead contaminated dust and soil are the primary sources of elevated blood lead levels in children in the United States. For every 1000 mg/kg increase in lead-soil contamination, blood lead levels can rise 1 µg/dL to 5 µg/dL (Levin et al., 2008). Lead has been shown to have neurobehavioral and neurodevelopmental consequences in animal models and human population studies. These effects are well documented and have been reviewed elsewhere (Wigle et al., 2007). Luo et al. (2012) estimated the average bioavailability of lead to be 49%. In adults, the bioavailability of lead through ingestion varies: 2% to 10% with food, and 60% to 80% without food present in the stomach. Dietary calcium and phosphate decrease lead's bioavailability (Zia et al., 2011).

The United States Environmental Protection Agency's (USEPA) Integrated Exposure Uptake Biokinetic (IEUBK) Model assesses the risk of an elevated blood lead level in a child younger than seven years who is exposed to environmental lead from multiple sources (U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, 2002, 2009). This model estimates that 30% of the lead that is present in soil and dust is absorbed by children under the age of seven. Depending on age, a child's lead intake is estimated to be 85 mg/day to 135 mg/day, apportioned 45% from soil and 55% from dust; these absorption values change depending upon site-specific conditions. The IEUBK Model was predicated on a child having ≤5% probability of >10 µg/dL blood lead level. This model was validated by Hogan et al. (1998). It should be noted that neither RIDOH regulations nor the IEUBK model has been updated with respect to the recently lowered Centers for Disease Control and Prevention (CDC) reference blood lead level of 5 µg/dL for children 1 to 5 years old (Centers for Disease Control and Prevention, 2012a, 2012b).

1.3. State and federal regulations

The Rhode Island Department of Health (2010), the Rhode Island Department of Environmental Management (2011) and the U.S. Environmental Protection Agency (2010) each have regulations that address lead contamination in residential soil. However, there are differences in terms used and the degree to which sampling methods

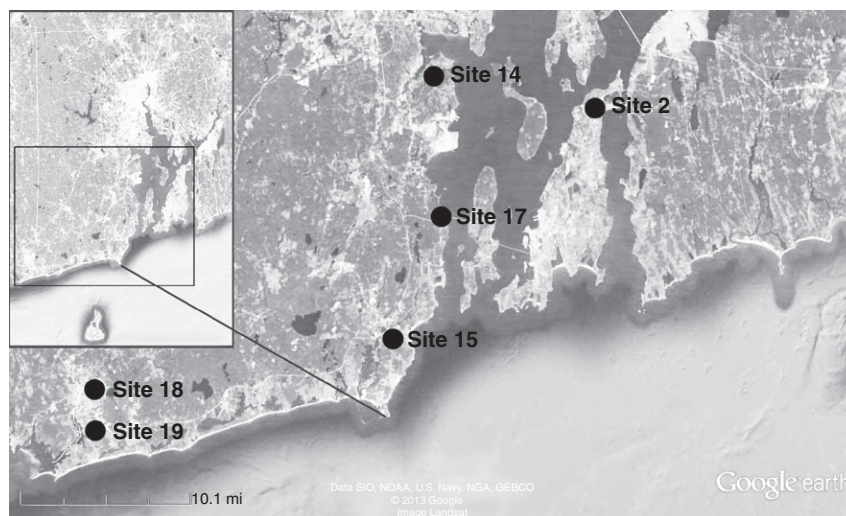


Fig. 2. Locations of municipal water towers in Newport and Washington Counties. State of Rhode Island (inset).

and remediation techniques are prescribed by their respective regulations (Table 1).

1. RIDOH's definition "lead free" equates to a lead-soil concentration of <150 mg/kg in a sample taken from a depth of 2 cm. Additionally, RIDOH has a "lead safe" category of 150 mg/kg to 400 mg/kg in a sample taken from a depth of 2 cm.
2. RIDEM's "residential direct exposure" equates to RIDOH's "lead free" definition. RIDEM defines a lead-soil concentration >400 mg/kg to be a "soil-lead hazard". Samples are taken at incremental six-inch depths until the sample concentration is <150 mg/kg to depth of 24-inches (Rhode Island Department of Environmental Management, 2002).
3. USEPA defines a "significant environmental lead hazard" as equal to 400 mg/kg in exposed bare surface soil, or >1000 mg/kg at any depth. USEPA does not address lead soil concentrations <400 mg/kg.

2. Materials and methods

According to RIDEM regulations, the environmental engineering contractor was responsible for evaluating a contaminated site. Each initial site evaluation began by sampling in a grid pattern that extended outside the water tower support leg footings. Based on the results of these initial samples, additional samples were collected distally to this perimeter in order to document the extent of the lead contamination on adjacent residential properties. All samples were collected by employees of environmental engineering contractors and analyzed by an EPA-accredited laboratory (U.S. Environmental Protection Agency, 2012). Sample collection and analyses as well as quality control/quality assurance followed USEPA Soil Sampling Standard Operating Procedures (1994) and USEPA Method 6010B: Inductively Coupled Plasma-Atomic Emission Spectrometry (U.S. Environmental Protection Agency, 2007). All samples were analyzed for total lead. Once the sampling and analyses were completed, the environmental engineering contractor filed a site investigation report for RIDEM review.

RIDEM requires post-remediation sampling only when contaminated soil is excavated (i.e., if the contaminated soil remains in place and subsequently capped, post-remediation sampling is not required). According to RIDEM policy, at least one soil sample must be taken from each 625 square foot area. Additional samples are taken every 25 linear feet from the sidewall of the excavation and analyzed incrementally at five-foot depths, minimally. If the sample lead concentration is >150 mg/kg, then further excavation is required until the sample concentration is <150 mg/kg at depth of 24 in. (Rhode Island Department of Environmental Management, 2002).

For this study, researchers interviewed key government personnel; reviewed written accounts of events including public town meetings with residents; reviewed current national and state departmental policies, regulations and practices; and extracted and compiled lead data from environmental soil sampling. All of these data were publicly available through the RIDEM in Providence, Rhode Island. Residents were not interviewed due to pending litigation. Data gathered by the Site 19 Tank Neighborhood Association's independent lead inspector and available from RIDEM were included in this study. As stated previously, data were pooled from 31 residential properties adjacent to six municipal water towers. Researchers met with RIDOH and RIDEM officials to review the study's preliminary findings and discuss the study's recommendations. Institutional Review Board was not warranted as these environmental sampling data were publicly and freely available. Regardless, researchers assigned each residential property an identification number.

Data were extracted from site investigation reports, illustrated site maps and remedial closure reports prepared by contractors and on file at RIDEM. Illustrated site maps denoted the physical locations of all core samples. For each location, lead concentration (mg) in soil (kg), sample distance, and sample depth were transcribed onto an electronic spreadsheet. An estimate of distance was measured from the center of the water tower to the center of each sample location marked on the map to the nearest 1/16-inch using an 18-inch stainless steel ruler. Subsequently, distances were rounded to the nearest foot, scaled, and then

Table 1

Regulatory terms and requirements for sampling and soil remediation by government agency.

Sources: Rhode Island Department of Health (2010); Rhode Island Department of Environmental Management (2011); U.S. Environmental Protection Agency (2010).

Terms	Health 23–24.6	DEM DEM-DSR-01-93	USEPA 40CFR745.227
Lead free	<150 mg/kg @ depth 2 cm	None	None
Lead safe	≥150 mg/kg to 400 mg/kg or 1000 mg/kg @ depth 2 cm if there is NO bare surface soil and soil remains covered	Residential Direct Exposure	None
Soil lead hazard	>400 mg/kg to 1000 mg/kg @ depth 2 cm for bare surface soil or >1000 mg/kg if there is NO bare surface soil	Same as USEPA	≥400 mg/kg for bare surface soil in play areas
Residential direct exposure Sampling procedures	None XRF spectrum analysis or soil samples @depth 2 cm ≥1 sample within 3 ft of each side of structure and each ancillary structure in areas with bare soil; or if paved/covered, sample outside each side paved/covered area or allow composite sample with equal amounts from individual samples from same side of structures BUT analyze separately if composite sample >1000 mg/kg Sample analyzed by USEPA recognized laboratory (USEPA, 2012)USEPA Soil Sampling Operating Procedure and Method 6010 for total lead, Method 1311 for TCLP. Quantitative Methodology with 150 mg/kg + 25% accuracy, + 10% precision	≥150 mg/kg @ depth 24 in. Method 1 Soil Objective approved by Director for each hazardous substance at a contaminated site	None Sample collected by USEPA certified persons (inspector, risk assessor)

grouped into 50-foot increments. Core samples were identified by sample reference number. Some, but not all core samples were analyzed at more than one depth. All sample depths were noted and stratified into three groups for data analyses: surface, six inches, and twelve inches. Univariate statistical analyses of these data were conducted using Excel© 2010.

3. Results

Only lead-soil samples collected from clearly identified residential properties were included in this study. Thirty-one residential properties adjacent to six water tower sites located in rural Newport (1) and rural Washington (5) counties were included in this study (Supplemental Material Table 1). Data were available for 498 core soil samples collected from these residential properties. In addition to surface analysis, 348 of these soil samples were analyzed for corresponding lead contamination at 6-inch and/or 12-inch depths (Supplemental Material Table 2).

3.1. Distribution, depth and distance

3.1.1. What was the distribution of lead concentration in soil at the surface and at depths of six- and twelve-inches found on residential properties adjacent to municipal water towers in Rhode Island?

Approximately 26% of the residential properties had one or more samples with lead soil concentration >1000 mg/kg. More than half (52%) of the residential properties had one or more samples exceeding a lead-soil concentration of 400 mg/kg. Seven properties (22%) had one or more samples with lead soil concentrations between 150 and 400 mg/kg. Eight properties (26%) had lead soil concentrations <150 mg/kg. (Table 2). The distribution of lead concentrations for each water tower site by sampling depths is summarized in Table 3.

3.1.2. What was the distribution of lead concentration in soil at 50-foot incremental distances from the center of municipal water towers?

Overall, lead-soil concentration was inversely related to distance. A few lead concentrations >400 mg/kg were detected more than 400 ft from the center of the water tower. Most likely, prevailing winds and tower height (120 ft) were two significant contributing factors. Surface sample concentrations were highest at distances closest to the center of the water tower, particularly for lead concentrations of 150 mg/kg to 400 mg/kg. Among samples analyzed at a depth of six inches, there was persistent lead contamination >400 mg/kg at a distance of 200-feet and more (Fig. 3). Historical contamination and/or ground that was previously disturbed or moved may account for this persistence. Other confounding factors include natural sources of lead, bulk density of the soil and stone content (Desaules, 2012). Lead concentrations >400 mg/kg at the 12-inch depth were more frequently found at distances less than 50 ft from the center of the water tower (Fig. 4). The small number of samples analyzed at this depth limited further analyses.

Table 2
Distribution of properties per site by highest lead concentration.

Site	Lead concentration			
	<150 mg/kg	150 to 400 mg/kg	>400 mg/kg	>1000 mg/kg
2	0	1	1	0
14	4	2	1	0
15	1	0	0	0
17	3	1	0	0
18	0	0	1	4
19	0	3	5	4
Total	8	7	8	8

Table 3
Distribution of lead concentrations by sampling depth and water tower site.

Depth (inches)	Surface			6"			12"		
	<150	150 to 400	>400	<150	150 to 400	>400	<150	150 to 400	>400
Lead concentration (mg/kg)									
Samples per site									
Site 2	25	8	1	24	6	0	12	0	0
Site 14	58	8	1	66	0	0	66	0	0
Site 15	7	0	0	0	0	0	0	0	0
Site 17	27	1	0	27	0	0	27	1	0
Site 18	47	29	34	1	2	3	63	15	19
Site 19	208	30	31	12	0	0	9	0	0
Total samples	372	76	67	130	8	3	177	16	19

3.2. Efficacy of current RIDOH lead-soil sampling criteria

3.2.1. What percentage of residential properties were misclassified as “lead free” or “lead safe” under RIDOH regulations?

Soil samples for the eight properties deemed “lead free” were examined. While all lead-soil concentrations were <150 mg/kg, the total number of samples per property was too few to state with any confidence whether these properties deemed “lead free” were in fact, “lead free” (Table 4).

To determine misclassification for “lead safe” properties, each surface sample concentration was compared to its corresponding 6-inch and 12-inch sample concentration (Table 5). If the surface sample was <400 mg/kg lead-soil concentration and the corresponding 6- and/or 12-inch sample lead-soil concentration was >400 mg/kg, then the sample was considered misclassified. Using this definition, four properties (13%) were identified as having one or more misclassified samples. This misclassification was especially true with regard to those properties with the highest lead contamination (>1000 mg/kg) at 6- and/or 12-inch depths.

3.2.2. Is the Rhode Island Department of Health (RIDOH) or the Rhode Island Department of Environmental Management (RIDEM) sampling criteria more efficacious at identifying lead-soil contamination on residential properties?

While no property was misclassified in terms of remediation, this analysis would suggest that core samples only analyzed at the surface

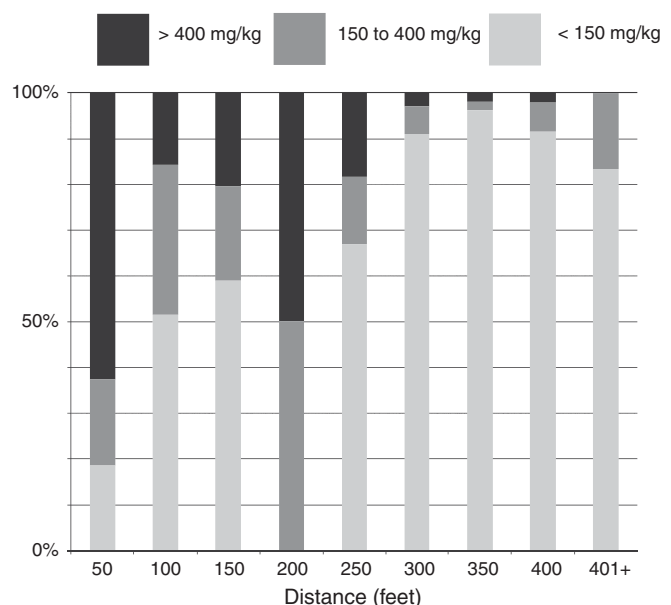


Fig. 3. Percentage of samples and distribution of lead concentrations in soil at depth six inches by distance from center of water tower.

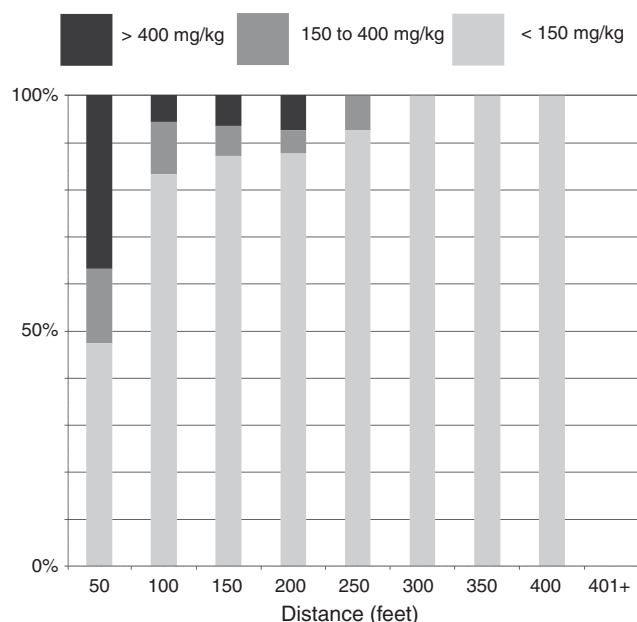


Fig. 4. Percentage of samples and distribution of lead concentrations in soil at depth 12-inches by distance from the center of water tower.

depth per RIDOH regulations is insufficient to classify a property as “lead safe”. While residents were concerned as to whether RIDEM soil sampling method missed contamination, the opposite was true; rather, RIDOH method of only sampling the surface, missed deeper soil contamination.

3.3. Post remediation sample concentrations

As previously stated, RIDEM requires all post-remediation sample concentrations to be <150 mg/kg to a depth of 24 in. (Rhode Island Department of Environmental Management, 2002). Post-remediation lead-soil concentrations from 12 residential properties at Site 19 were available for examination. About 4% of the 1373 post-remediation samples were >150 mg/kg, with more than 1% of these samples having concentrations >400 mg/kg (Supplemental Material Table 3). These findings are of concern in that the extent of lead contamination may have been deeper than initially determined. Following further remediation, lead-soil concentrations ranged from non-detectable to 65 mg/kg (C and E Engineering, 2012). These final lead-soil concentrations indicate that the remediation was sufficient to achieve concentrations lower than the 150 mg/kg level required by RIDOH.

Table 4
Highest lead concentration detected in surface samples on residential properties determined initially to be lead free.^a

Site	Property	Number of samples	Lead concentration (mg/kg)
14	14-2	1	30
14	14-4	4	39
14	14-5	1	120
14	14-7	2	66
15	15-1	7	39
17	17-2	5	120
17	17-3	5	54
17	17-4	8	120

^a Lead Free < 150 mg/kg (Ref. RIDOH, 2010).

3.4. Limitations

Only one-third of all water tower sites in Rhode Island had lead-soil data from identifiable residential properties. Two sites had no samples collected on residential property while residential properties could not be identified from eleven water tower site maps. Clearly classifying properties would allow future data analyses. RIDEM reported that a few of the homeowners denied access to their properties while others blocked contractors from taking core samples deeper than “surface” samples (T.M. Fleury, personal communication, July 27, 2012). There was no written documentation as to which properties were not sampled due to these circumstances. This documentation would have added to the overall perspective of this study. There was no documentation regarding historical use. Post-remediation sampling data were available for only twelve properties.

There were differences noted among the sampling grids employed by contractor, site and property with respect to distance and depth. There were inconsistencies in designating sample locations when compared to each map legend; GIS coordinates were not provided. For this study, using a ruler to estimate the distances from the center of each water tower consistent with the maps' scale introduced inaccuracy as well. Problems in determining exact sample location were minimized by defining distances in 50-foot increments.

Only 40% to 44% of samples with surface lead-soil concentrations <400 mg/kg were also analyzed at depths of 6-inches and/or 12-inches, respectively. When available, data from other sites will be analyzed to confirm findings and improve the ability to draw more meaningful and generalized conclusions.

Factors that likely influenced distal deposition of lead were prevailing winds and the height of each water tower. These factors may account for lead found at distances >200 ft. Information was not provided on confounding factors including past and existing structures, prior use of lead-containing materials, and lead-contaminated soil brought onsite. Additionally, no documentation was provided with regard to historical sources of lead such as paint and gasoline. In this study, lead soil concentrations exceeded those found in urban Lubbock TX surface soil by Brown et al. (2008). There, researchers found peak concentrations of 90 mg/kg to 174 mg/kg in a city founded in 1890; Newport and Washington counties were founded in 1703 and 1729, respectively. By comparison, older urban communities such as Baltimore, MD and New Orleans, LA have significantly higher lead surface soil concentrations (Mielke et al., 1983, 2008) than Newport and Washington counties that are considered rural. While the potential for misclassification of RI urban properties may be less due to overall higher lead concentrations, soil sampling at depth is strongly recommended. Milillo et al. (2012) found a combination of surface and sub-surface samples were the most accurate approach for lead-soil distributions.

4. Discussion

RIDOH regulations were evidence-based (i.e., environmental availability of lead in soil, and USEPA's IEUBK Model). While RIDOH found no historical instance of elevated blood lead levels among children who lived in the area of Site 19, this provided little comfort to residents who believed their health and the health of their children were threatened. Their lives were disrupted for *nine* years. When residents questioned the efficacy of soil sampling procedures, noting differences between RIDOH and RIDEM regulations, RIDOH officials requested evaluation of the efficacy of their lead-soil regulations. This study suggests that RIDOH regulations as currently written may be insufficient to detect lead contamination when samples are taken only from surface soil.

When there is more than one regulatory agency responsible for developing policies and regulations, overlaps, gaps and contradictions serve as sources of confusion that become major points of contention for impacted communities. These inconsistencies obfuscate regulatory transparency and erode the public's trust in the regulatory process. Efforts

Table 5
Possibility of misclassification of properties based on individual samples.

Site	Property	Depth (inches)	Distribution of samples by lead concentration in soil (mg/kg)			Samples potentially misclassified
			<150	150 to <400	≥400	
2	2-1	Surface	5	1	0	–
		6	6	0	0	0
		12	0	0	0	0
	2-2	Surface	20	7	1	–
		6	18	6	0	2
		12	12	0	0	0
14	14-1	Surface	29	2	0	
		6	31	0	0	0
		12	30	0	0	0
	14-2	Surface	1	0	0	–
		6	1	0	0	0
		12	1	0	0	0
	14-3	Surface	16	3	0	–
		6	19	0	0	0
		12	19	0	0	0
	14-4	Surface	4	0	0	–
		6	4	0	0	0
		12	4	0	0	0
	14-5	Surface	1	0	0	–
		6	1	0	0	0
		12	1	0	0	0
	14-6	Surface	5	3	1	–
		6	9	0	0	0
		12	9	0	0	0
	14-7	Surface	2	0	0	–
		6	2	0	0	0
		12	2	0	0	0
15	15-1	Surface	7	0	0	–
		6	0	0	0	NA
		12	0	0	0	NA
17	17-1	Surface	8	1	0	–
		6	9	0	0	0
		12	1	1	0	1
	17-2	Surface	5	0	0	–
		6	5	0	0	0
		12	5	0	0	0
	17-3	Surface	5	0	0	–
		6	5	0	0	0
		12	5	0	0	0
	17-4	Surface	8	0	0	–
		6	8	0	0	0
		12	8	0	0	0
18	181	Surface	12	2	9	–
		6	0	0	0	NA
		12	10	1	6	0
	18-2	Surface	8	17	16	–
		6	1	3	2	0
		12	33	6	10	10
	18-3	Surface	11	2	1	–
		6	0	0	0	NA
		12	1	2	1	1
	18-4	Surface	10	0	1	–
		6	0	0	0	NA
		12	1	0	0	0
	18-5	Surface	4	7	4	–
		6	0	0	0	NA
		12	5	3	1	0
19	19-1	Surface	14	1	0	–
		6	0	0	0	NA
		12	0	0	0	NA
	19-2	Surface	14	4	3	–
		6	1	0	0	0
		12	1	0	0	0

Table 5 (continued).

Site	Property	Depth (inches)	Distribution of samples by lead concentration in soil (mg/kg)			Samples potentially misclassified
			<150	150 to <400	≥400	
19-3	Surface	6	24	3	10	–
		6	4	0	0	0
		12	0	0	0	NA
19-4	Surface	6	21	7	1	–
		6	4	0	0	0
		12	0	0	0	NA
19-5	Surface	6	10	1	2	–
		6	1	0	0	0
		12	1	0	0	0
19-6	Surface	6	5	3	5	–
		6	2	0	0	0
		12	1	0	0	0
19-7	Surface	6	11	2	0	–
		6	0	0	0	NA
		12	0	0	0	NA
19-8	Surface	6	0	0	0	–
		6	0	0	0	NA
		12	0	0	0	NA
19-9	Surface	6	36	6	9	–
		6	0	0	0	NA
		12	1	0	0	0
19-10	Surface	6	10	0	0	–
		6	0	0	0	NA
		12	1	0	0	0
19-11	Surface	6	16	3	0	–
		6	0	0	0	NA
		12	1	0	0	0
19-12	Surface	6	21	0	0	–
		6	0	0	0	NA
		12	1	0	0	0

BOLD = Properties Potentially Misclassified.

should be initiated to unify regulatory terms, establish minimal sampling guidelines, and update RIDOH and RIDEM regulations to reflect lowered CDC reference blood lead value for children 1 to 5 years old (5 µg/dL). The following recommendations were made:

1. Use terms and definitions consistently or, at a minimum, cross-reference terms and definitions used in by cognizant state agencies whenever possible. Consider not using the term “lead free”, as this can be interpreted as meaning “no or zero lead”.
2. Update state regulations and USEPA IEUBK Model to reflect lowered CDC reference blood lead level (5 µg/dL).
3. Standardize map legends and whenever possible use different symbols, not colors. Use geo-mapping (GIS coordinates) to document sample locations. Indicate prevailing wind direction(s). [Milillo et al. \(2012\)](#) have proposed a novel approach using geostatistical techniques for modeling and mapping spatial distributions irrespective of property lines to delineate the extent of lead-soil contamination.
4. Provide historical use information in site investigation reports where available (e.g., age of existing structures).
5. Develop minimal sampling guidelines for residential properties that prescribe depths, distances, frequencies and locations relative to the contamination source. These guidelines could include:
 - a. Conducting a (statistical) power analysis to determine the minimal number of core samples necessary to decrease the probability of property misclassification (false negatives).
 - b. Analyzing each core sample at more than one depth (i.e., surface; 6 in., and 12 in., minimally).
 - c. Describing conditions under which core sample analysis at depths more than 12 in. would be recommended or required.
 - d. Collecting core samples at 50-foot incremental distances, minimally. Additional data are needed to determine whether a 200-foot radius from the contamination source is a sufficient sampling distance. Prevailing winds and tower height should be taken into account.

6. Sample additional residential properties adjacent to other municipal water towers. These additional data would improve the ability to draw more meaningful and generalized conclusions with regard to similar situations.
7. Educate town and tribal council members in the proper procedures to follow in situations where residential property has been potentially contaminated by municipal and/or industrial/commercial sources, including effective risk communication strategies for engaging community members/groups. Using a map-based interactive approach in community engagement has been shown to be an effective tool (Milillo et al., 2012).

4.1. Update

By 2007, the old Site 19 water tower had been replaced and the contaminated soil immediately surrounding the tank had been removed from town property. In September 2008, the town purchased a portion of one property and paid the owner damages. By December 2009, the town had yet to reach an out of court settlement with five of the nine residents (Dupuis, 2009). It took three years for contractors to remove brush, trees and ground. Following soil replacement, samples were collected to ensure these properties were “lead free”. The Closure Report for this site was submitted to RIDEM for their review in July 2012 (C & E Engineering, 2012).

As a result of this study, RIDOH officials met with residents to follow-up on their proposal to force RIDEM to use RIDOH sampling regulations. Officials reassured residents that no property was misclassified with respect to remediation. However, RIDOH's regulatory requirement of only sampling the surface missed deeper soil contamination that was identified using RIDEM regulations. The study's recommendations will be considered in an upcoming regulatory review.

5. Conclusions

A state-based approach was used to address lead-soil contamination, a worldwide problem. This study analyzed lead-soil sampling data from 31 residential properties adjacent to six RI municipal water towers. Approximately 25% of the residential properties had one or more samples with lead soil concentration >1000 mg/kg. More than half of the residential properties had one or more samples exceeding a lead-soil concentration of 400 mg/kg. Overall, contamination was inversely related to distance from the water towers. Most likely, prevailing winds and tower height were contributing factors.

While no residential properties were misclassified with respect to remediation, analysis indicated the potential for misclassifying properties as “lead safe” was approximately 13% if only RIDOH surface soil sampling was conducted. The total number of samples from properties designated as “lead free” was too few to draw any conclusions. Five post-remediation lead soil concentrations suggest the extent of lead contamination may have been deeper than initially determined. Additional data from other sites are needed to confirm findings and improve the ability to draw more meaningful and generalized conclusions.

Modifications to current RIDOH soil sampling regulations are recommended, as is congruency across state environmental regulations. A USEPA IEUBK Model reflecting recently lowered CDC reference blood lead level of 5 µg/dL for children 1 to 5 years old is strongly recommended.

This study amplifies the need to incorporate translational and evaluation research in environmental health regulatory policy. While scientific research informed the initial development of these RIDOH regulations, practice-based evidence did not support its efficacy in the context of real world practice.

Abbreviations

IEUBK	Integrated Exposure Uptake Biokinetic (Model)
RIDEM	Rhode Island Department of Environmental Management
RIDOH	Rhode Island Department of Health
USEPA	U.S. Environmental Protection Agency

Conflict of interest declaration

Kim Boekelheide has additional grant support from NIEHS, USEPA and the American Chemistry Council. Dr. Boekelheide is an occasional consultant for chemical and pharmaceutical companies, including Dow Chemical, Akros Pfizer, Zafgen and Bristol Myers Squibb. Additionally, he owns stock in and is a consultant for CytoSolv, an early stage biotechnology company developing a wound healing therapeutic based on growth factors. These activities are unrelated to the current work but are mentioned in the interest of full disclosure. Marcella Thompson and Andrea Burdon declare no conflicts of interest.

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