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Heavy Metal Contamination in the Brownfield Soils of Cleveland

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The results esults of a survey of heavy metal contamination at Cleveland area brownfields and public spaces are presented. Soils were analyzed using a 24 h, 1N HCl extraction procedure. The study was conducted to seek brownfield soils that manifest properties of "old" sequestered contamination and to develop a better understanding of the nature and extent of heavy metal burdens at brownfield sites in the Greater Cleveland area. The results indicated that Cleveland brownfields commonly yield soil burdens well above remediation triggers for residential soils and often yield values above industrial remediation triggers. It was also discovered that public areas in the vicinity of brownfields commonly have heavy metal contamination significantly above background levels and occasionally above residential remediation triggers. These results indicate that brownfields redevelopment initiatives should proceed with caution. The appropriate remediation goals or restrictions must be imposed to control urban exposure to heavy metal contamination.

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INTRODUCTION

This article presents the results of a survey of heavy metal soil contamination in brownfields of the Greater Cleveland area. However, before presenting study details, it is necessary to explain the original motivation and multiple agenda of the survey. This will help clarify questions about the design of the field sampling program and the laboratory procedures used to quantify contamination.

Brownfields are abandoned or underutilized industrial properties for which concerns about environmental problems are assumed to increase the difficulty of redevelopment. However, brownfield problems extend beyond industrial property lines. The communities that developed around these sites relied on the industrial revenue to sustain their quality of life. As the profitability of these industries failed, the consequences rippled through the surrounding neighborhoods. Community infrastructures decayed and property values declined. The skilled workforce moved elsewhere. This, in turn, made industrial redevelopment more challenging, and new industries often went elsewhere. This is a well-known syndrome in the industrial cities of the Northeast and Midwest, but it is a pattern that can be repeated anywhere. The total number of brownfield sites in the United States is unknown, but it has been estimated to exceed 500,000. The U.S. Environmental Protection Agency (EPA) began a brownfield initiative in 1993 under authority provided in the Comprehensive Environmental Response Compensation, and Liability Act of 1980 (CERCLA — P.L.96-510). Currently, 44 states have voluntary cleanup or redevelopment initiatives for brownfields.

The problems of “old contamination” and lingering environmental liability are significant challenges to brownfield redevelopment in the Greater Cleveland area. However, after investigating over 100 of these sites, it became clear that contamination is certainly not the only barrier. The buildings of these sites tend to be huge, dilapidated multiple-story brick structures configured for a style of manufacturing that is no longer viable (see Figure 1). The sites are clustered along a rail system that once moved Cleveland steel from foundry to fabrication but now isolates these areas from the modern highway system. The sites are also isolated from the evolving commercial centers and often are surrounded by Cleveland’s least prosperous residential neighborhoods. Redevelopment poses logistic, economic, social, ethical, and political challenges that would be daunting even without environmental compromise.

The concept of “old contamination” refers to a specific class of contamination often found at brownfield sites. Generally, these sites were contaminated by industrial activities that predate modern environmental regulations (i.e., pre-1970) by decades. These vast time periods (over 100 years at some sites) are selective for particular types of contamination. If the pollutant was biodegradable, volatile, or water soluble, it would not have persisted at the point of contamination. Mobile contaminants escaped long ago to exact their impact elsewhere in the environment. This is not the case with “old contamination”. Often, old contamination pollutants

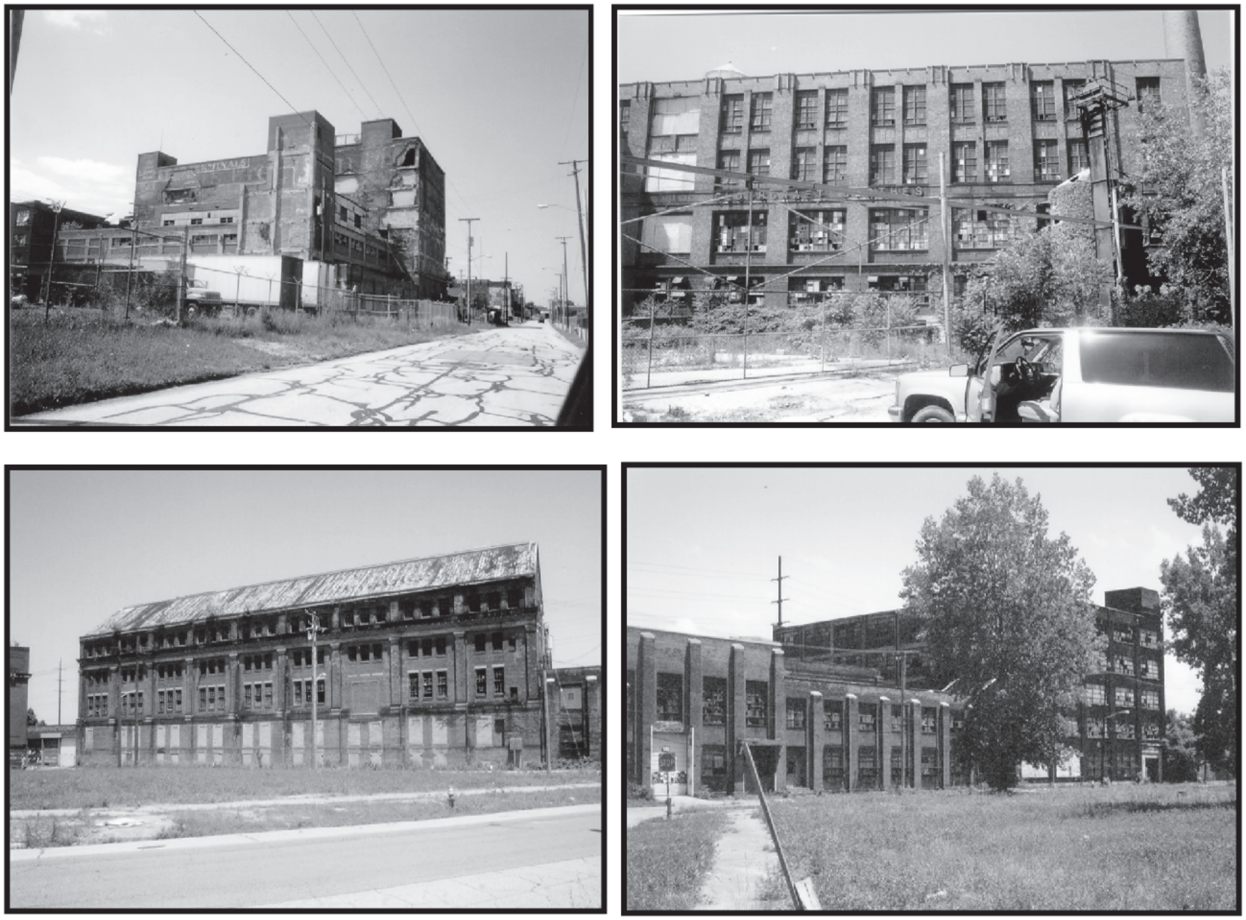

FIGURE 1

Typical brownfield structures of the Greater Cleveland area.

are strongly partitioned onto (or otherwise associated with) the soil and have "aged" in ways that have reinforced immobilization. The mass burdens can be much more difficult to remove than equal amounts of "young contamination". There are several reasons for this, but the dominant phenomena appear to be mass migration into aggregates by solid state or micropore diffusion and/or deposition of younger minerals that encapsulated the sorbed mass and shelter it from the soil's environmental interface.

Sequestered "old contamination" lead was discovered in Cleveland brownfield soils in a survey conducted by Pfaff in 1996. Pfaff (1996) harvested soils from an area around a lead smelter and evaluated extraction procedures by which the high levels of lead contamination could be quantified. After determining the effectiveness of extraction protocols based on a variety of extracting solutions (H_2O, Na_2SO_4, NaCl, $CaCl_2$, EDTA, HNO_3 HCl, and HF), examining the kinetics of laboratory scale extractions, and quantifying the impact of chemical heterogeneity, Pfaff measured reproducible soil burdens that were believed to be accurate (Pfaff, 1996; Pfaff and Jennings, 1996). However, when Krumholz (1996) experimented with electrokinetically enhanced processes for remediating these soils, he was able to extract between 110 and 120% of the measured lead burden. Subsequent analysis and aggregate mass transport modeling (Jennings and Mansharamani, 1999; Ma and Jennings, 2000) revealed that the larger aggregate particles in the soil contained both a surface burden that was easily removed by extraction and a sequestered burden that was buried deep in the aggregate matrix and was not accessible to extraction, over conventional laboratory time scales. It appeared that this mass had slowly diffused into the soil over a long period of time by processes that could be reversed but were difficult to accelerate. These sequestered burdens can be measured by techniques such as hydrofluoric acid dissolution, but this is a dangerous and difficult procedure that must be conducted in a "bomb" at high temperature using large sample volumes to accommodate chemical heterogeneity. The difficulties and dangers of accomplishing this makes the test undesirable for routine soil testing and HF dissolution does not translate into a useful remediation process. The development of methods for quantifying sequestered contamination based on electrokinetically enhanced extractions are currently underway (Deng and Jennings, 2001).

Ongoing research into the mechanisms of and remediation processes for sequestered contamination provided the motivation for this brownfield soil survey. Research had been proceeding using soils collected by Pfaff in 1996, but supplies of these were nearly exhausted. In addition, Pfaff (1996) concentrated on lead contamination in an area that had been influenced by particulate deposition from Cleveland's notorious Master Metals, Inc. site (Jennings and Kuhlman, 1997), which was reported to have released the highest airborne lead levels ever measured in Ohio (2300% above national air quality standards). Because of this, and other local Cleveland sources, lead contamination was of particular interest. However, lead is not representative of all heavy metal contamination, so an effort was launched to acquire soils with a wider range of heavy metal contaminants (Cd, Cr, Cu, Ni, Zn, . . .). The survey described here was designed to accomplish this. The survey was initially designed to identify brownfield soils that were contaminated with a variety of heavy metals, that had a grain size structure conducive to the formation of sequestered contamination, and that could be collected in large volume for remediation process research. As the brownfield soil burden results began to emerge, the original goals expanded to include a more general assessment of the magnitude and distribution of heavy metal soil contamination in and around Cleveland area brownfields.

Site Selection

Brownfield sampling sites were identified from a street survey of historic industrial areas of Greater Cleveland. Locations were sought where venerable industrial buildings were abandoned or greatly underutilized (e.g., minor activity on the ground level of a multiple story building with abandoned upper stories), where soils could be sampled without creating access issues, and where large-scale samples (>100 kg) could be acquired if preliminary screening indicated that the soil would be a desirable candidate for future research. Each sampling site was located with a GARMIN GPS 38 global positioning system (GPS) (GARMIN, 1996), and mapped in the field using DeLorme 3-D TopoQuads topographic mapping software (DeLorme, 1999). Each site was also photographed and a site description was prepared to ensure that the exact location could be revisited if desired. The site mapping software was used to help identify desirable sampling locations and to help achieve a reasonable spatial distribution of samples. The locations of brownfields sampled are illustrated in Figure 2. This area does not define the extent of brownfields in greater Cleveland, but it does cover the industrial strip along the environmentally infamous Cuyahoga River that includes the LTV Ltd. steel foundries, the industrial strip that parallels the river along its eastern valley rim, and the industrial neighborhood east of the river along the Lake Erie shoreline. It is significant to note how closely these sites are associated with the rail system (see Figures 2 and 3). In retrospect this should have been anticipated, but the association was not recognized until midway through the sampling program and would probably not have been identified if not for the site mapping software used. In the later stages of the survey, these old (nearly abandoned) railway corridors were used to identify additional brownfield clusters and to improve the spatial distribution of sites.

As brownfield soil contamination results began to emerge, it became apparent that some context was required for interpreting the data. To help accomplish this a “background” sampling program was initiated to sample soils from public spaces in and around the brownfields study area. These locations were also selected by street survey and GPS mapping. Selected locations included public parks, recre-

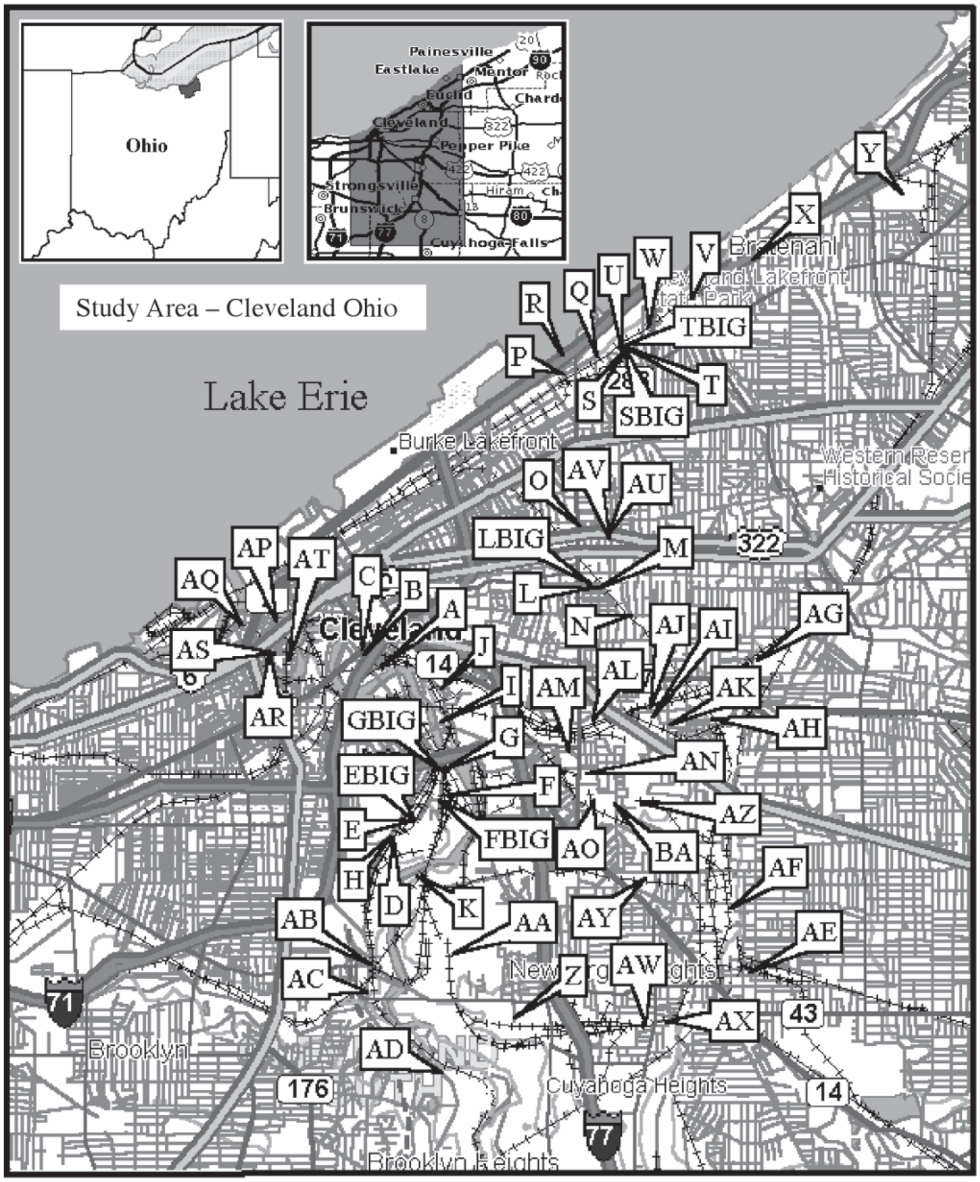

FIGURE 2

Study area map indicating brownfield locations sampled.

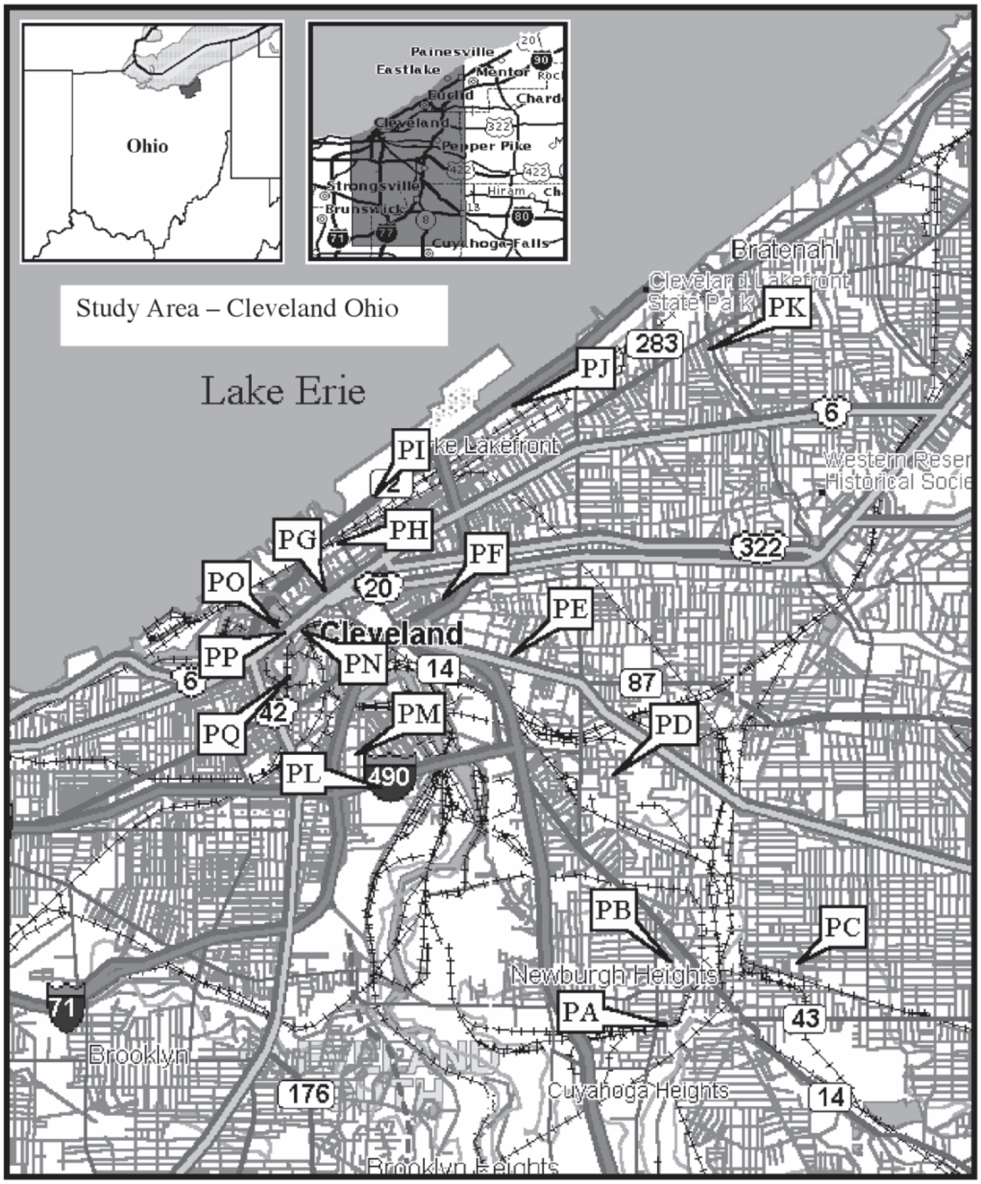

FIGURE 3

Study location map indicating public areas sampled.

ational fields, schoolyards, and city gardens. Efforts were made to identify locations that had not been recently disturbed, but this was not always possible because of Cleveland's ongoing efforts to improve public spaces. The sites included in this background survey are illustrated on Figure 3

SOIL SAMPLING AND ANALYSIS

Once desirable sampling locations were identified, soils were sampled by collecting approximately 2 to 3 kg of soil from a single point at each site. Bare, near-surface soils (i.e., soils at depths of less than 6 in [15 cm]) were sampled. Near-surface samples were used because particulate deposition was believed to be one of the most significant avenues of contamination, because the persistence of near-surface contamination is selective for highly insoluble pollutants, and because near-surface heavy metal soil contamination poses one of the greatest threats to public health. A single location was sampled (as opposed to collecting numerous or composite samples) to identify locations where larger volume samples could subsequently be acquired. No effort was made to quantify the spatial distribution of contamination at each site.

Near-surface soils from public areas were sampled by a modified procedure. Because the goal was to quantify the general urban ambient contamination levels, composite samples of approximately 1 to 2 kg were assembled in 100-g increments. At most locations samples were acquired from bare soil patches or through sparse surface vegetation.

Samples were transported to the laboratory in plastic containers and prepared for analysis using the U.S. Soil Conservation Service standard "air-dry" procedure (U.S. Dept. of Agriculture, 1982). Large rocks, vegetable matter, and debris were removed by hand. The soil was then rolled to break up large clods and sieved using a Meinzer vibrating sieve shaker and Hubbard plastic sieves. All material retained on a number 10 sieve was rejected. The remainder was returned to its container and stored at room temperature.

Soil heavy metal burdens were quantified by using the 1 N HCl, 24 h extraction procedure described by Pfaff (1996). All glassware was acid washed using 6 N nitric acid to remove possible contamination from previous use. This was of particular concern due to the high concentrations of metals generated by these extractions, but no evidence of significant "blank" contamination was ever detected. Extractions were conducted by adding 5 g of soil to a 250-ml Erlenmeyer flask, adding 200 ml of 1 N HCl, capping the flask with a gas vent stopper, placing the flask on a New Brunswick G2 orbital shaker, and shaking with agitation sufficient to maintain suspension for 24 h. After 24 h of extraction the shaker was shut off and the flask contents were allowed to settle for one h. The contents were then filtered through Fisherbrand P2 fine filter paper and stored in full 120-ml bottles for further analysis. Chemical analysis was generally completed within 24 h of filtration.

At least three replicates were extracted and analyzed for each sample. Reagent/method blanks were carried through all steps of analysis for each set of extractions.

The heavy metal concentrations of extraction solutions were measured using flame atomic adsorption spectrometry. The Varian Spectra AA 250 used was equipped for graphite furnace analysis, but the levels of contamination proved to be far above its analytical range. Often, dilution was required to quantify results by Flame AA. In nearly all cases dilution was accomplished using a SIPS (Sample Introduction Pump System) attachment. The SIPS makes standard dilutions from a single reference stock concentration to calibrate the AA. The system also attempts to dilute unknown samples to concentrations that are within the bounds of its calibration curve if the full-strength measurement falls out of range. The SIPS makes these dilutions by adjusting the sample injection rate and adding makeup volume from a dilution water reservoir. Volumetric accuracy limits this to a dilution factor of about 50. Whenever a dilution larger than this was required, it was accomplished by hand. Once the concentration of a metal in the extraction solution was known, the soil's mass burden (mg/kg) was calculated from the known extraction volume and known soil mass. All soils were analyzed for Cd, Cr, Cu, Ni, Pb, Zn, and Fe. Iron was included to serve as a possible indicator of the industrial history of the soil.

Because this was a screening survey conducted to identify brownfield soils with specific heavy metal contamination properties, limited additional soil characterization was performed. The rationale was that all soils identified for large volume sampling would have to be re characterized after large volume samples were collected. Therefore, the decision was made to process a greater number of field samples rather than to generate additional detail about each soil. However, to identify the potential for "sequestering", something must also be known about the grain size distribution of the soil. Grain size information was generated using conventional sieve analysis to physically separate soil fractions and a Coulter LS 250 particle size analyzer to quantify detailed particle size distributions. This information plus results from extractions conducted on grain size fractions was used as an indicator of sequestered contamination. The actual degree of sequestering in these soils remains the subject of ongoing research.

It should be noted that the extraction procedure used here may not be as aggressive as U.S. EPA Method 3050B that uses a smaller sample (1 g) refluxed in 1:1 HNO_3, and 30% H_2O_2. Our experience has indicated that the method 3050B sample size of 1 g is too small to accommodate chemical heterogeneity in many soils, that the repeated additions of small reactant volumes followed by heating/drying allows volume errors to accumulate, and that if the extraction is too aggressive it overestimates the realistic environmental availability of contamination. The acid extraction method used has been developed both as a screening tool and as one step in a procedure designed to distinguish readily available contamination from that strongly sequestered within the soil. The results of the procedure have been verified using alternative extractants (HNO_3, EDTA, HF), extended extraction times, sequential extractions, and extractions with and without soil pulverization. However, the reader is cautioned that the extraction method used here may underestimate the "total" metal burden. Care must be used when comparing these results to reported background concentrations or remediation trigger levels, all of which are based on a variety of quantification techniques. The method used here would not be the appropriate measure on which to base regulatory action.

LEVELS OF CONCERN FOR METAL CONTAMINATED SOILS

In addition to generating data on brownfield soil contamination levels, an effort was made to develop a basis for interpreting these results. This is not simple because, with the possible exception of lead, there are not widely accepted standards for concentrations that represent unacceptable levels of contamination.

One method of interpreting soil contamination values is to compare observed concentrations to background levels. This was a common method of setting remediation goals prior to risk-based remediation and is often used to establish lower limits on remediation obligations. However, determining background concentrations is not straightforward, particularly for pollutants such as heavy metals that are naturally occurring in many soils and have been released as air pollutants on regional scales. For example, it is nearly impossible to distinguish between natural and anthropogenic lead sources in near surface soils. In the struggle to quantify background levels, some states such as New York and Massachusetts have introduced the concept of an "urban" and "rural" background. The idea is that there is a level of urban soil content that is higher than the rural background, but that should not be attributed to any specific contamination site. Although this is undoubtedly true, this also compromises the concept of background and raises the threshold (or lowers the bar?) on environmental quality in urban communities. Clearly, there may be levels of contamination in urban areas that result more from the regional volume of activity than from any one source. However, it does not seem appropriate to characterize this anthropogenic pollution as "background" and does not seem necessary unless one mandates remediation down to background levels.

Measuring background contamination levels can also pose daunting sampling challenges. Is there an Ohio background level for lead, and, if so, how many samples would be required to measure it accurately? Should this be measured regionally or locally? These are difficult questions to answer, but some guidance is available. Several states have published guidance background values for many pollutants. There have also been independent projects conducted to estimate these values. Therefore, the data of Table 1 were assembled to assist in interpreting the results of this survey. The primary sources of data were guidance documents produced by state remediation or brownfield redevelopment programs. Many of the values were extracted from a complex context without which they are dangerous to use, but this table does present a snapshot of current heavy metal background assessment. References have been provided for each table entry. The final row of Table 1 presents the values used as background guidance for the Greater Cleveland area.

Background concentration levels are helpful in interpreting soil contamination measurements, but must be used cautiously when determining remediation implications. When values are "high enough" above background, remediation should be considered (may be required), but the magnitude of "high enough" is the object of considerable debate. Background values vary, so small increases above background may be *de minimus* anthropogenic contamination or naturally occurring

TABLE 1
Background Guidance Values for Heavy Metals in Soils (All Values in mg/kg)

Location	Reference	Cd	Cr(3)	Cu	Ni	Pb	Zn
Delaware	DDNREC	3	0.4	50	30	41	8
Massachusetts	MDEP	3	39		31	99	340
New York	NY DEC	1	10	25	13	4 to 61	20
Ohio	OEPA	1.25	22		33	37	90
Ohio(1)	Holmgren et al., 1993	0.36	-	26.2	27.1	18.2	82.1
Ohio Farm Soil	Logan and Miller, 1983	0.20	12	19	18	19	75
Texas	Texas NRCC	-	30	15	10	15	30
Eastern US	NY DEC	0.1 to 1	1.5 to 40	1 to 50	0.5 to 25	4 to 61	9 to 50
Quebec	Murray et al., 2000	1.5	-	50	50	50	100
US Northeast	Frink, 1996	1.0	36.0	-	13.0	14.0	36.0
US Northeast(2)	Holmgren et al., 1993	0.24	-	61,30	25	10,16	59,87,41
US Southeast(2)	Holmgren et al., 1993	0.08,0.57	-	8,57	10	11, 7,17	16,44
US North Central(2)	Holmgren et al., 1993	0.36, 0.24	-	21,9,16	25,14	10,16	64,87,41
US South Central(2)	Holmgren et al., 1993	0.26, 0.24 0.12, 0.64	-	9,16,31, 17	19,40, 21,14	7,18, 8,11	16,81, 25,50,60
US Northwest(2)	Holmgren et al., 1993	0.3	-	21,34	25,38	8,36, 10	83
US Southwest (2)	Holmgren et al., 1993	1.2, 0.28 0.30	-	53,28, 17,	94,21	8,36, 15,11	106,81, 50
USA	Holmgren et al., 1993	0.27	-	29.6	23.9	12.3	56.5
world	Alloway, 1995	0.53	-	24 to 55	20	<20	10 to 300
world	Bear, 1964	0.2	200	70	100	16	80
Cleveland(4)	This study	1	20	20	20	20	75

(1) Holmgren et al. (1993) reported state averages for 34 states. Results are included here as regional summaries.
(2) Multiple numbers are for geographical regions with significant areas in the indicated regions.
(3) All values appear to be total Cr with the exception of Delaware values that refer to Cr (III).
(4) Values adopted as the background reference for this study.

material. Most states have struggled with the issue of how far above background is allowable before remediation is required, or, conversely, if remediation is required, how close to background the remediation goal should be set. This issue is compounded by the fact that most states have introduced some element of risk-based remediation goal assessment into their remediation and brownfield redevelopment programs. In theory, the potential impacts of contamination are identified, the risks of these impacts are assessed, and then appropriate remediation goals are set to reduce risks to acceptable levels. However, truly comprehensive risk-based analysis is extremely difficult to accomplish without either a great deal of information or a great deal of guesswork. Concerns have been expressed that this type of analysis can be used to justify leaving too much contamination in place.

To help eliminate uncertainty and to ensure remediation to acceptable levels, many states are developing quantitative guidance values for risk-based remediation analysis. These numbers take several forms, but often they can be interpreted as "trigger values" that automatically trip some level of remedial response. Some states suggest values only as guidelines, others provide values as optional minimums that can be supplanted with sufficiently detailed risk assessment. When guidance is provided, many states distinguish between residential soils and commercial/industrial soils with the lowest trigger values specified for residential soils. Table 2 presents a summary of remediation trigger values. Readers are cautioned that these numbers have been taken out of context, and there is usually a great deal of context imposed on their use. The origins of these numbers are not always clear, and there is considerable variability and debate about the values. A reference has been provided for each table entry. The final row of Table 2 represents the trigger value guidance used for evaluating Greater Cleveland brownfield soil contamination.

It is interesting to note that the remediation trigger reported for Cr(III) at industrial sites in Virginia and U.S. EPA Region III (3,100,000 mg/kg) is not physically possible because this is 3.1 kg/kg! This value was listed for Virginia because the state defaults to U.S. Region III values. This value was listed for U.S. EPA Region III because EPA staff confirmed that it was correct. When asked, U.S. EPA III staff explained that the number was based on a risk calculation using data from a rat feeding study to which a safety factor of 1000 was applied (Alvarado, 2001). This illustrates the potential problems of risk-based analysis because it leads to a trigger value that is not physically possible. Under this criterion, no amount of Cr(III) would require remediation.

As a final observation about the numbers of Tables 1 and 2, the "natural background" and "remediation trigger" approach seems to be much more logical than attempting to define "rural" and "urban" backgrounds. The latter introduces conceptual problems and implies issues of environmental justice. The remediation trigger approach avoids this by accepting that there is room between the levels of naturally occurring materials in soils and the concentrations of anthropogenic pollutions that are high enough to warrant remediation.

TABLE 2
Remediation Triggers of Residential (R) and Commercial/Industrial (I) Soil Contamination (All Values in mg/kg)

Location	Ref.	Cd (R)	Cd (I)	Cr [5] (R)	Cr [5] (I)	Cu (R)	Cu (I)	Ni (R)	Ni (I)	Pb (R)	Pb (I)	Zn (R)	Zn (I)
Delaware[1]	DDNREC	4	38	12000 35	310000 35	310	8200	160	650	400	1000	2300	2300
Florida	FDEP	75	1300	210	420	110	76000	110	28000	400	920	23000	560000
Georgia	GDNR	39	39	1200	-	1500	1500	420	420	400		2800	
Indiana [2]	IDEM	7.5	77	10000 38	10000 120	580	1700	950	2700	81	230	10000	10000
Louisiana	LDEQ	3.7	94	11000 22	280000 560	300	7500	150	3700	400	1700	2200	56000
Massachusetts	MDEP	60	90	1000 40	2000 200	-	-	300	500	300	600	2500	3000
New Jersey	NJDEP	1	100	-	-	600	600	250	2400	400	600	1500	1500
New York [3]	NYDEC	1 or SB	1 or SB	10 or SB	10 or SB	25 or SB	25 or SB	13 or SB	13 or SB	61 or SB	500 or SB	20 or SB	20 or SB
Oregon	ODEQ	100	1000	1000	1500	10000	80000	5000	40000	200	2000	-	-
Pennsylvania	PDEP	47	210	190000 94	190000 420	8200	100000	4400	56000	500	1000	66000	190000
Rhode Island	RIDEM	39	1000	1400 390	10000 10000	3100	10000	1000	10000	150	500	6000	10000
Virginia[4]	VDEQ	39	1000	120000 2300	3100000 6100	3100	82000	1600	41000	-	-	23000	610000
Washington	WDOE	2	10	100	500	-	-	-	-	250	1000	-	-
Wisconsin	WDNR	8	510	14	200	-	-	-	-	50	500	-	-
US EPA Region III [6]	EPA-III	39	1000	120000 2300	3100000 6100	3100	82000	1600	41000	-	-	23000	610000
US EPA	TSCA Section 403	-	-	-	-	-	-	-	-	400	1200	-	-
Quebec[7]	Murray et al., 2000	20	20	-	-	500	500	500	500	1000	1000	1000	1000
Cleveland[8]	This study	1	10	20	120	300	600	150	420	400	1200	1500	10000

SB – Site Background. (R) - residential soil, (I) – commercial/industrial soil.
(1) Delaware identifies use classes as "unrestricted" and "restricted".
(2) Default Closure Levels.
(3) New York did not distinguish between Residential and Commercial/Industrial soil.
(4) Defaults to current US EPA Region III risk-based concentration values.
(5) Where two values are indicated, states have specified values for both Cr (III) (upper) and Cr (VI) (lower). Where only one value is indicated, speciation has not been specified.
(6) "Risk-Based Concentrations" from Table 5/8/2001.
(7) Quebec triggers do not distinguish between residential and commercial/industrial soil.
(8) Values adopted as the remediation trigger guidelines for this study.

BROWNFIELD FIELD SURVEY RESULTS

Figures 4 through 9 present the results for heavy metal analysis at the brownfield sites illustrated on Figure 2. Note that contamination burdens have been graphed on a log scale so the spikes on these bar graphs indicate orders of magnitude changes in contamination. Each value is the average of at least three replicate extractions from a single sample taken at a large site. Results for all Figure 2 sites have been graphed. Not all columns have been labeled, but sites are illustrated in alphabetical order so missing labels can easily be inferred. A horizontal bar has been added to each figure indicating the background contamination level adopted from Table 1. Lines have also been added to each figure representing the residential

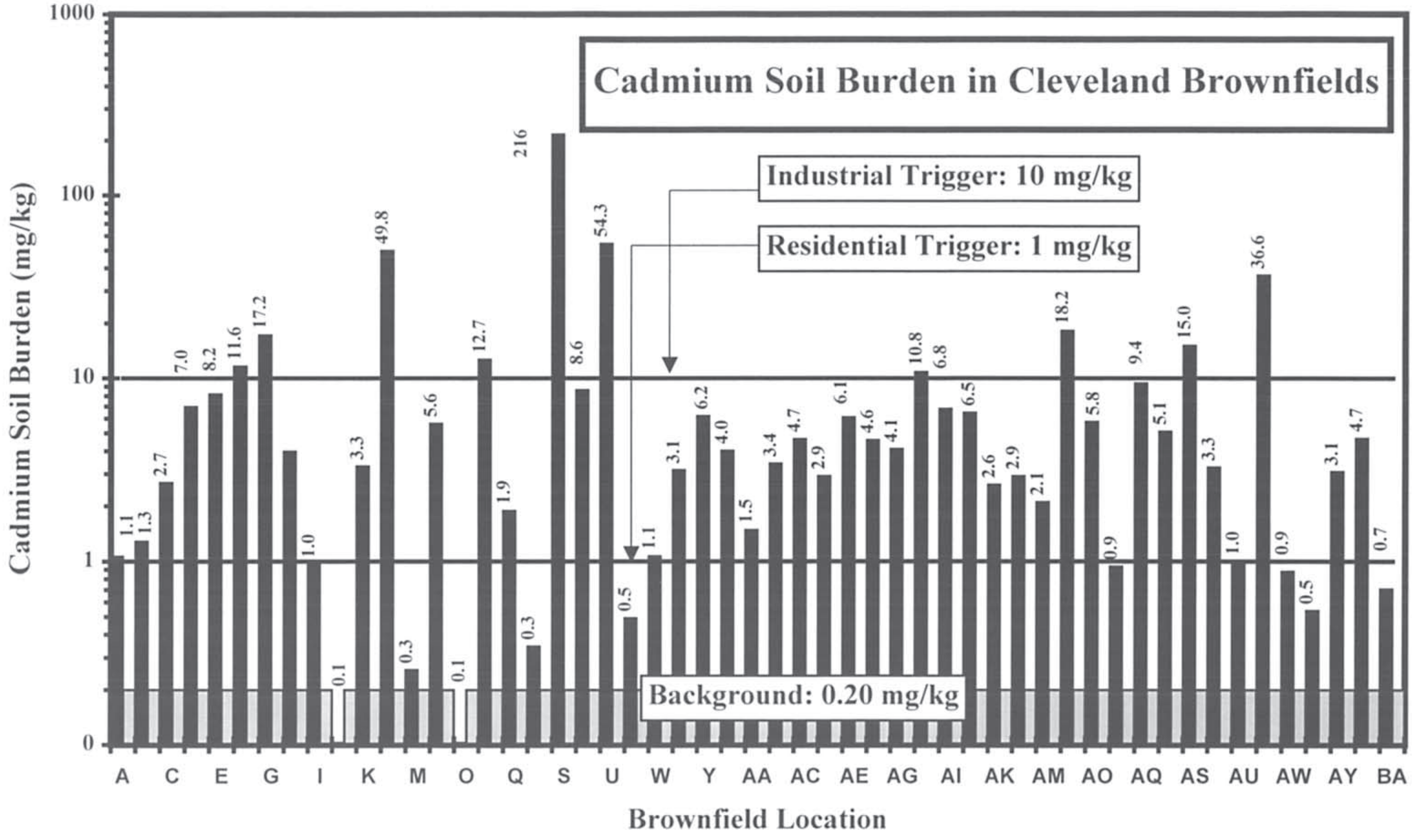

FIGURE 4

Cadmium soil burdens (mg/kg) in Greater Cleveland area brownfields.

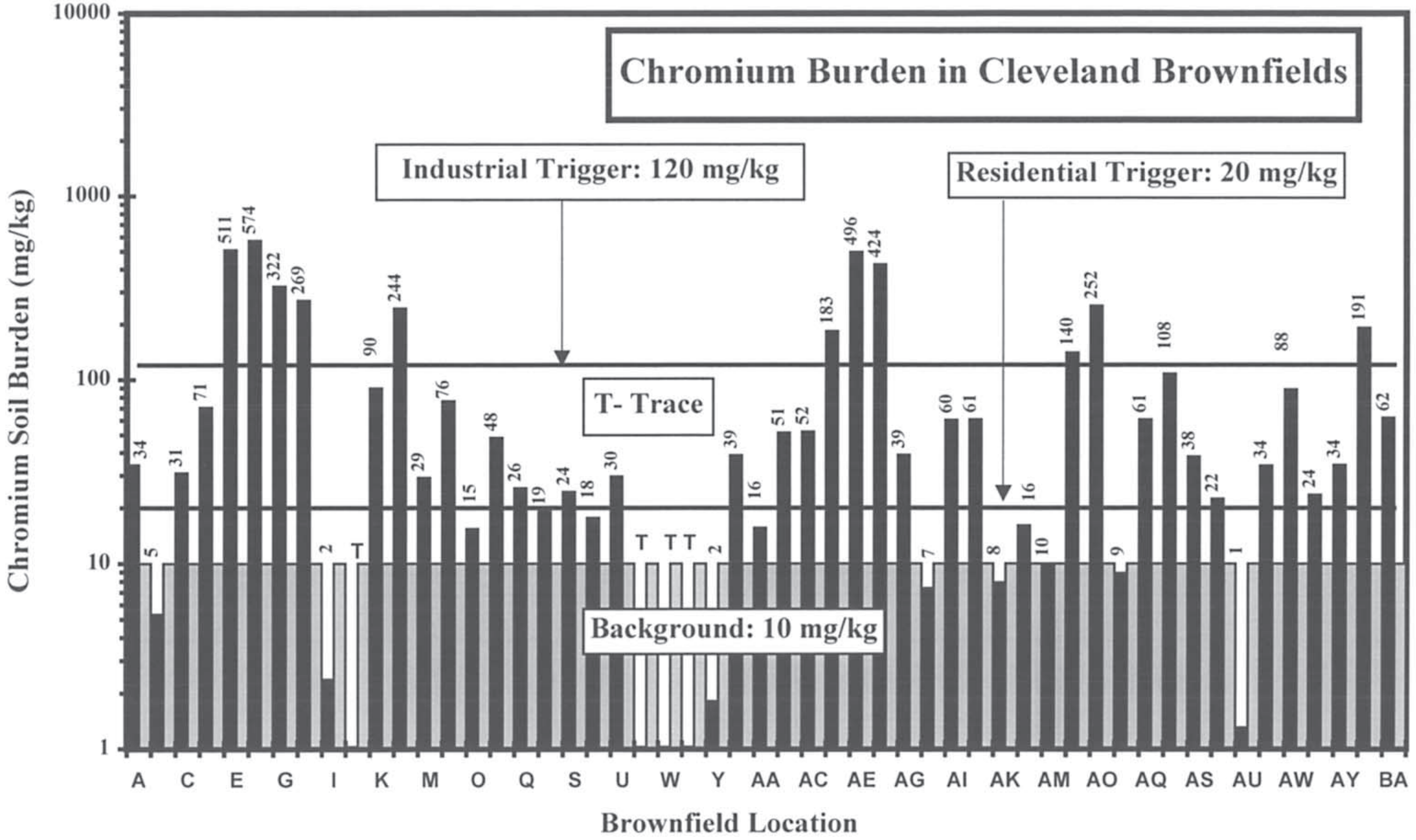

FIGURE 5

Chromium soil burdens (mg/kg) in Greater Cleveland area brownfields.

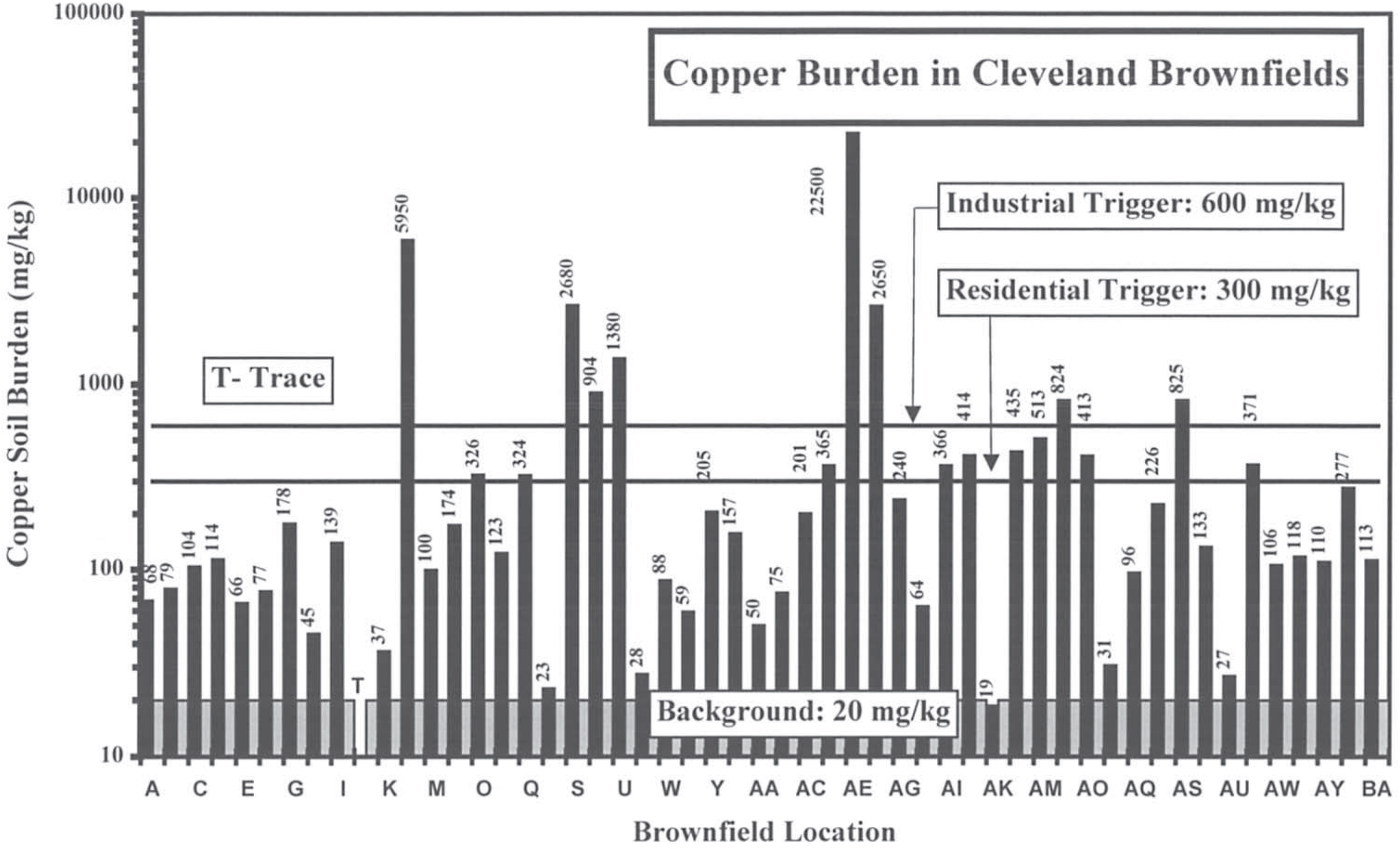

FIGURE 6

Copper soil burdens (mg/kg) in Greater Cleveland area brownfields.

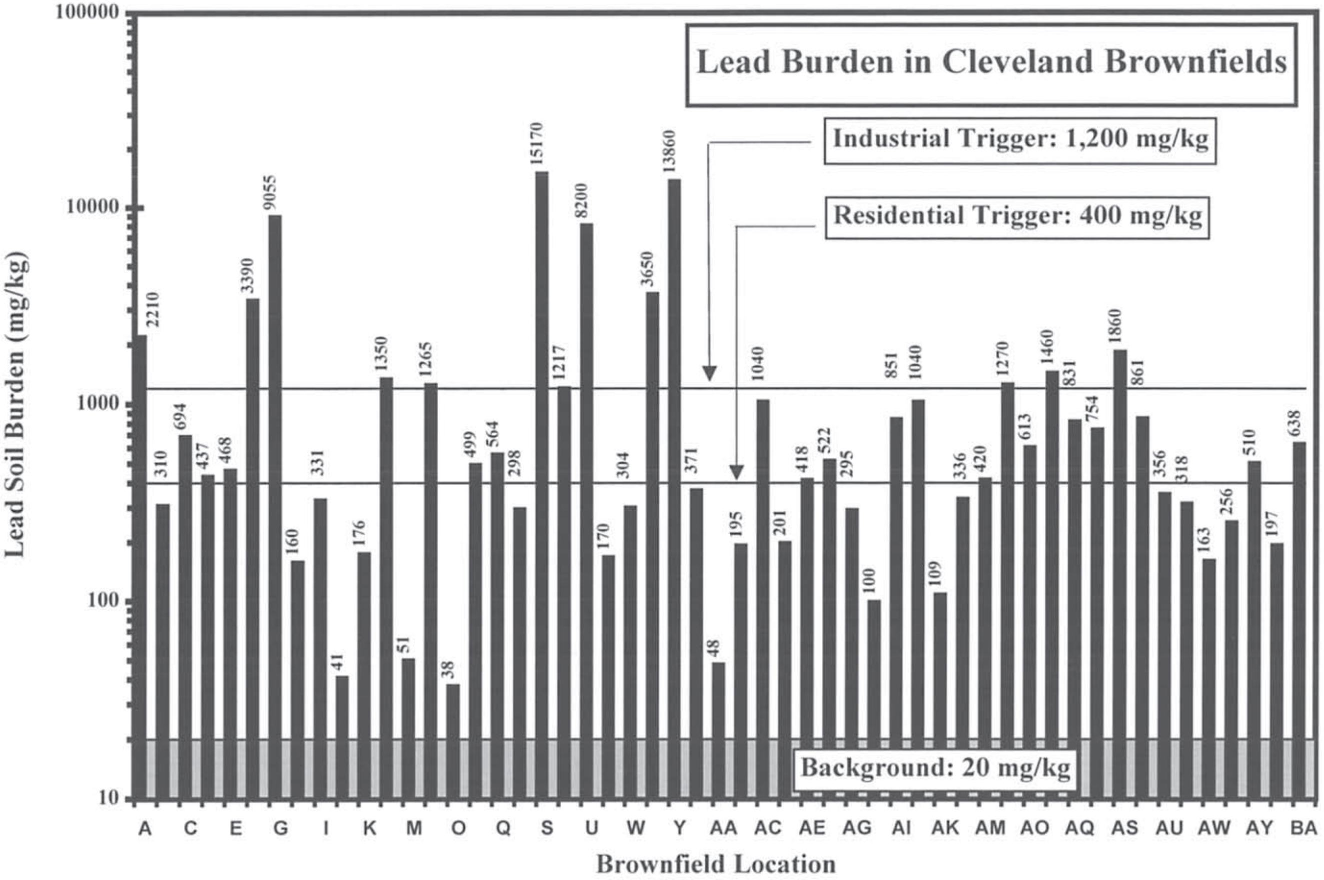

FIGURE 7

Lead soil burdens (mg/kg) in Greater Cleveland area brownfields.

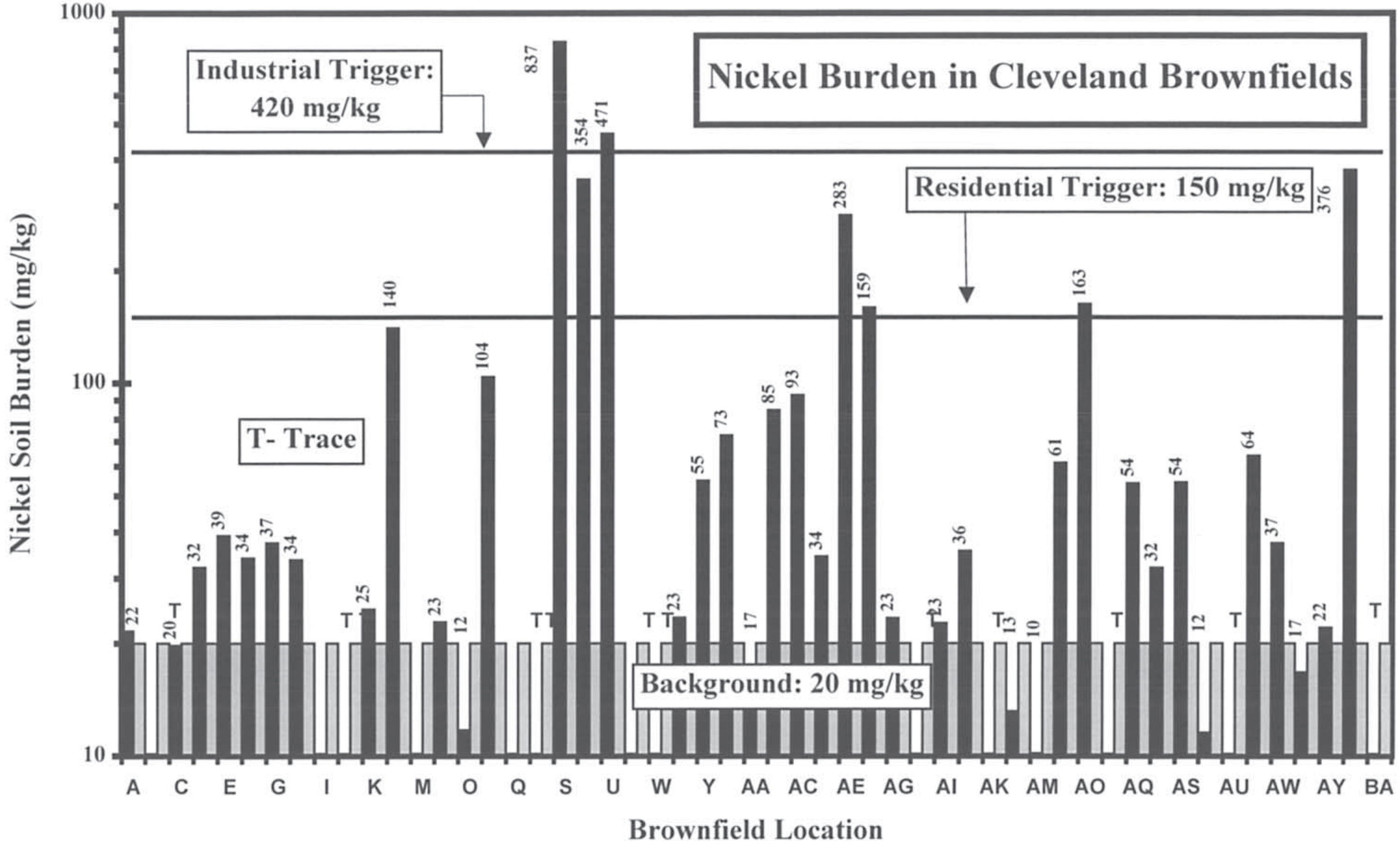

FIGURE 8

Nickel soil burdens (mg/kg) in Greater Cleveland area brownfields.

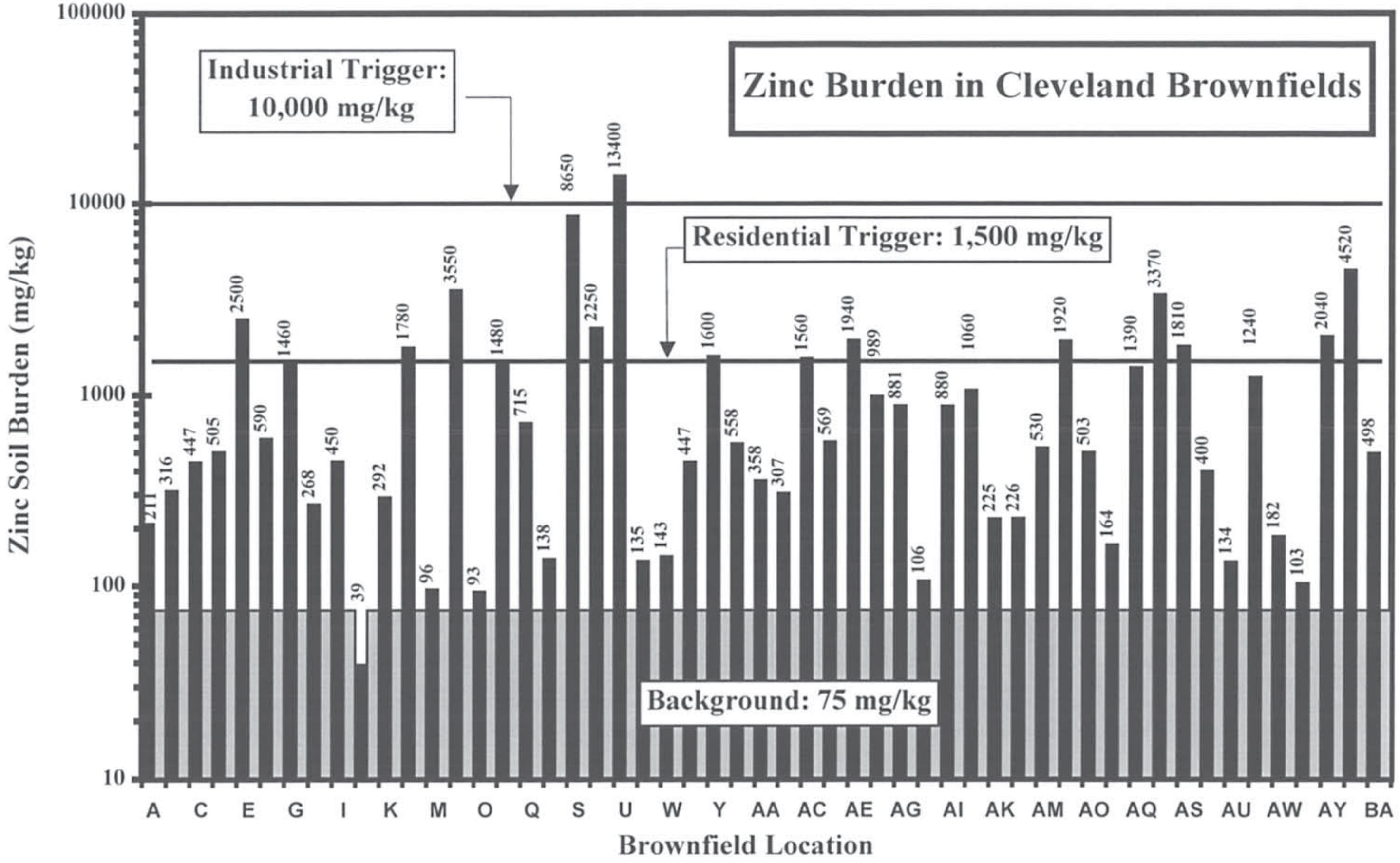

FIGURE 9

Zinc soil burdens (mg/kg) in Greater Cleveland area brownfields.

and industrial contamination trigger values adopted from Table 2. Trigger values have been included for framework reference only, but spikes that exceed the upper trigger line indicate locations where remediation would be desirable.

Figures 10 through 15 present heavy metal soil burden results for the public spaces of Figure 3. Because the concentration values were substantially lower, these have been graphed on arithmetic scales. The Table 1 background reference and Table 2 residential remediation triggers have also been indicated on these diagrams. Industrial triggers have been omitted because they are not appropriate for these locations. Although none of these sites are “residential”, all are areas where residential-like exposures such as children playing on the ground are likely. Although the remediation trigger values are included for reference only, spikes above these lines indicate locations where either remediation or limited public access would be desirable.

The possibility that much of this heavy metal contamination might share a common industrial source was evaluated. If this were true, high concentrations of one metal might serve as an indicator of high concentrations of the others. Conversely, low concentrations of an element might indicate low total mass burdens. Although this would introduce the danger of missing important data, if such correlations existed they might be useful in improving the pace of soil screening studies by identifying the most likely candidates for more exhaustive analysis. This hypothesis was tested by examining metal/metal correlations for binary combinations of all metals analyzed. Although iron is of limited environmental concern, it was included because it might indicate the degree to which industrial activity had impacted the soil.

The results of metal/metal correlation analysis are presented in Tables 3 and 4. The highlighted cells of these tables indicate correlations that have been illustrated. For the brownfield sites studied, the analysis was inconclusive. The most dramatic contamination values appear to be isolated, independent, element-specific events. None seemed to correlate well with iron. The highest correlation ($R^2 = 0.65$) was for Cd/Ni. Although there is some reason to expect these to occur together (e.g., use of Ni-Cd power cells), Figure 16 illustrates that the correlation is dominated by a single extreme point

The observed correlations were considerably stronger for the heavy metal concentrations in public area soils. Figure 17 illustrates the nature of the best ($R^2 > 0.8$) Cr/Ni and Pb/Cu correlations observed. The dependability, explanation for, and potential applications of these observations are the subject of ongoing research.

SUMMARY AND CONCLUSIONS

The most obvious conclusion about Cleveland’s brownfield soils is that contamination burdens of Cd, Cr, Cu, and Pb that is well above remediation trigger values

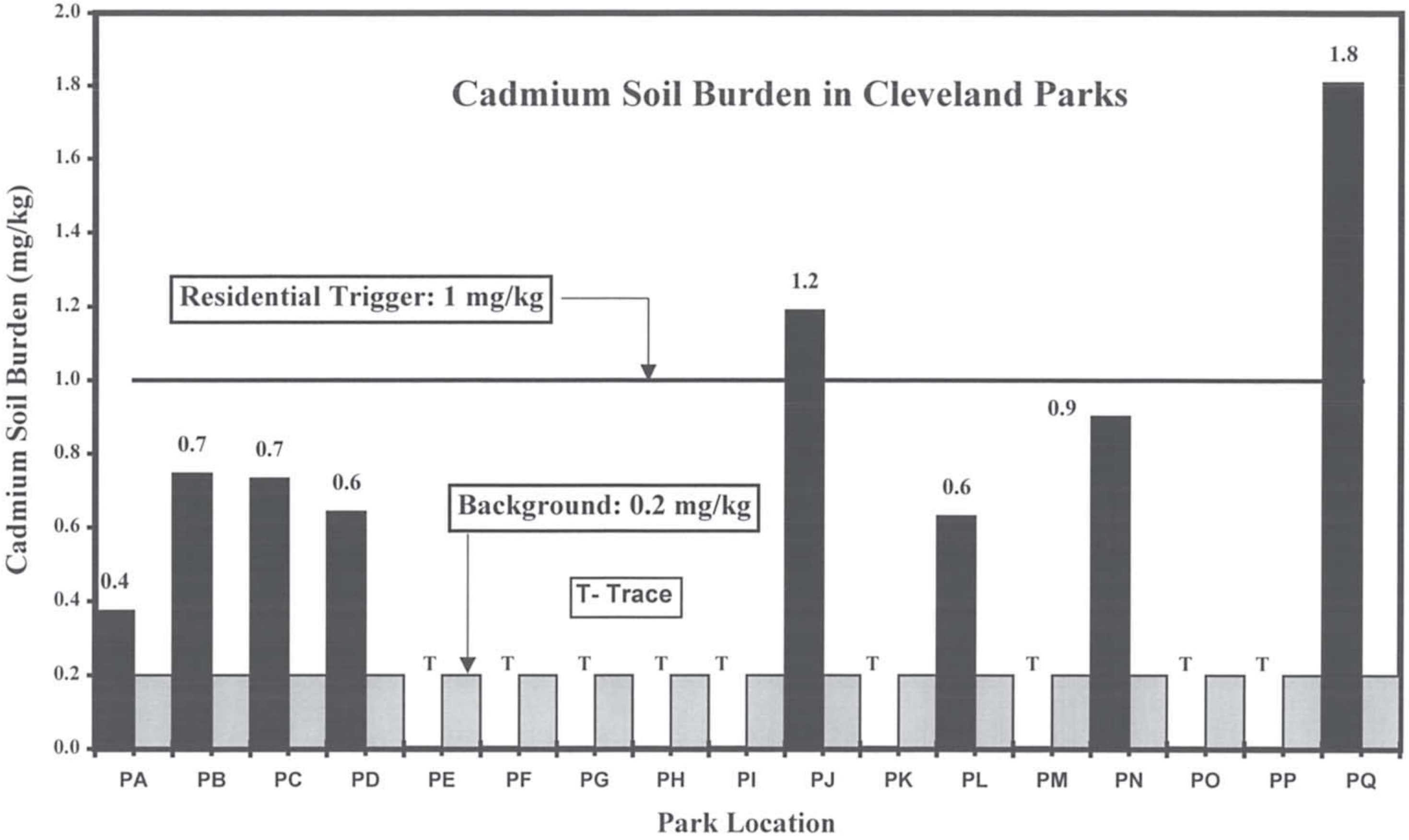

FIGURE 10

Cadmium soil burdens (mg/kg) in Greater Cleveland public areas.

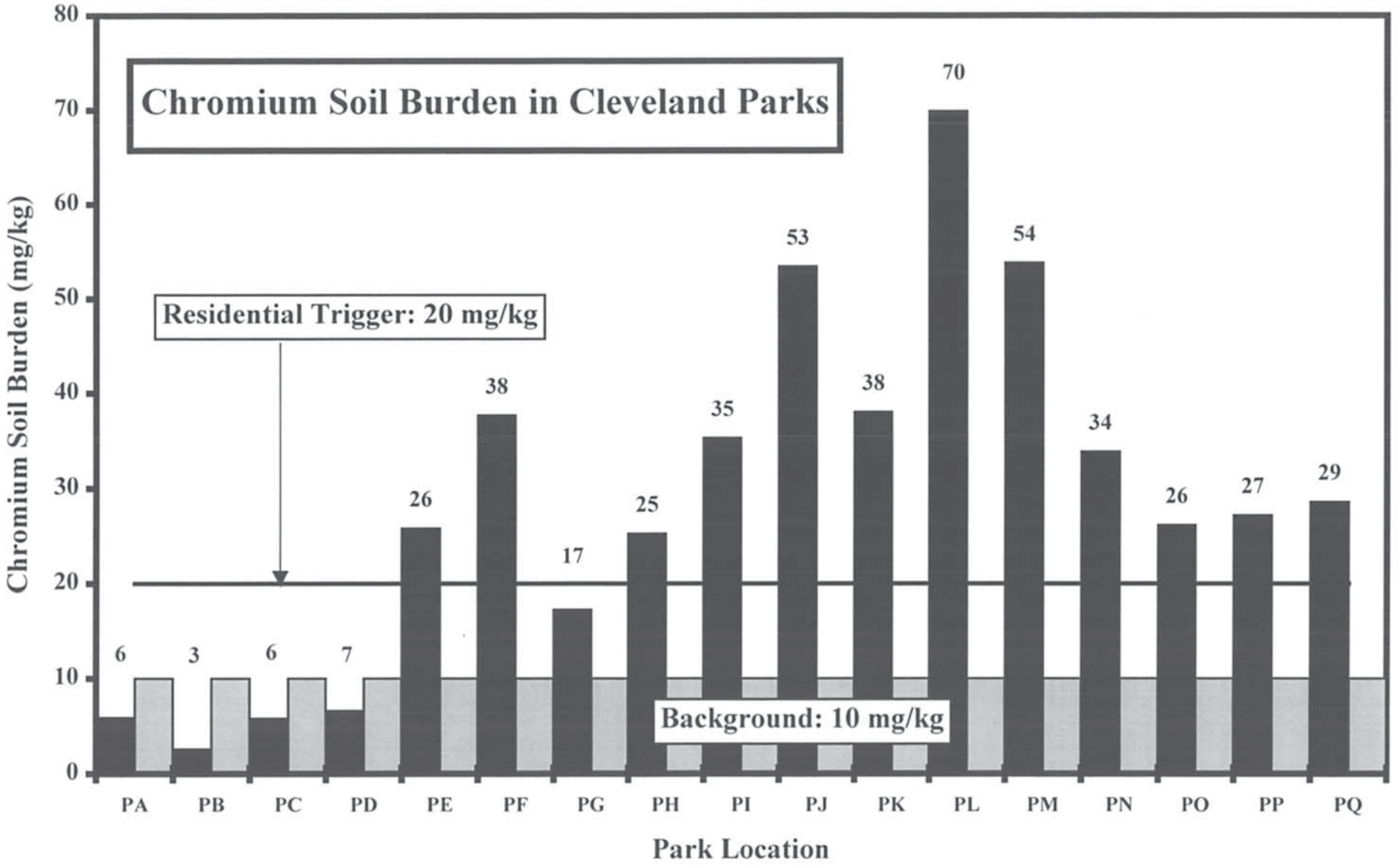

FIGURE 11

Chromium soil burdens (mg/kg) in Greater Cleveland public areas.

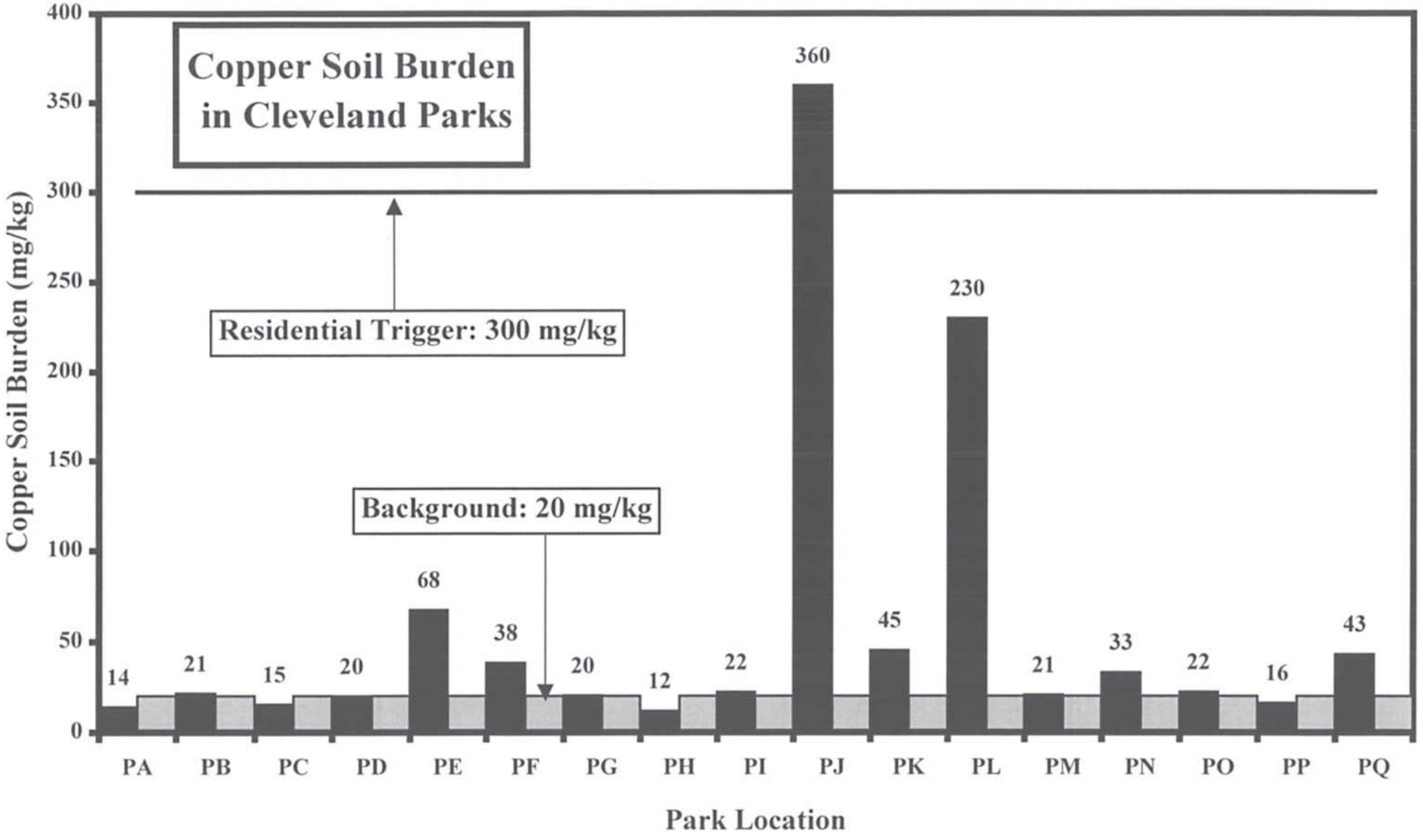

FIGURE 12

Copper soil burdens (mg/kg) in Greater Cleveland public areas.

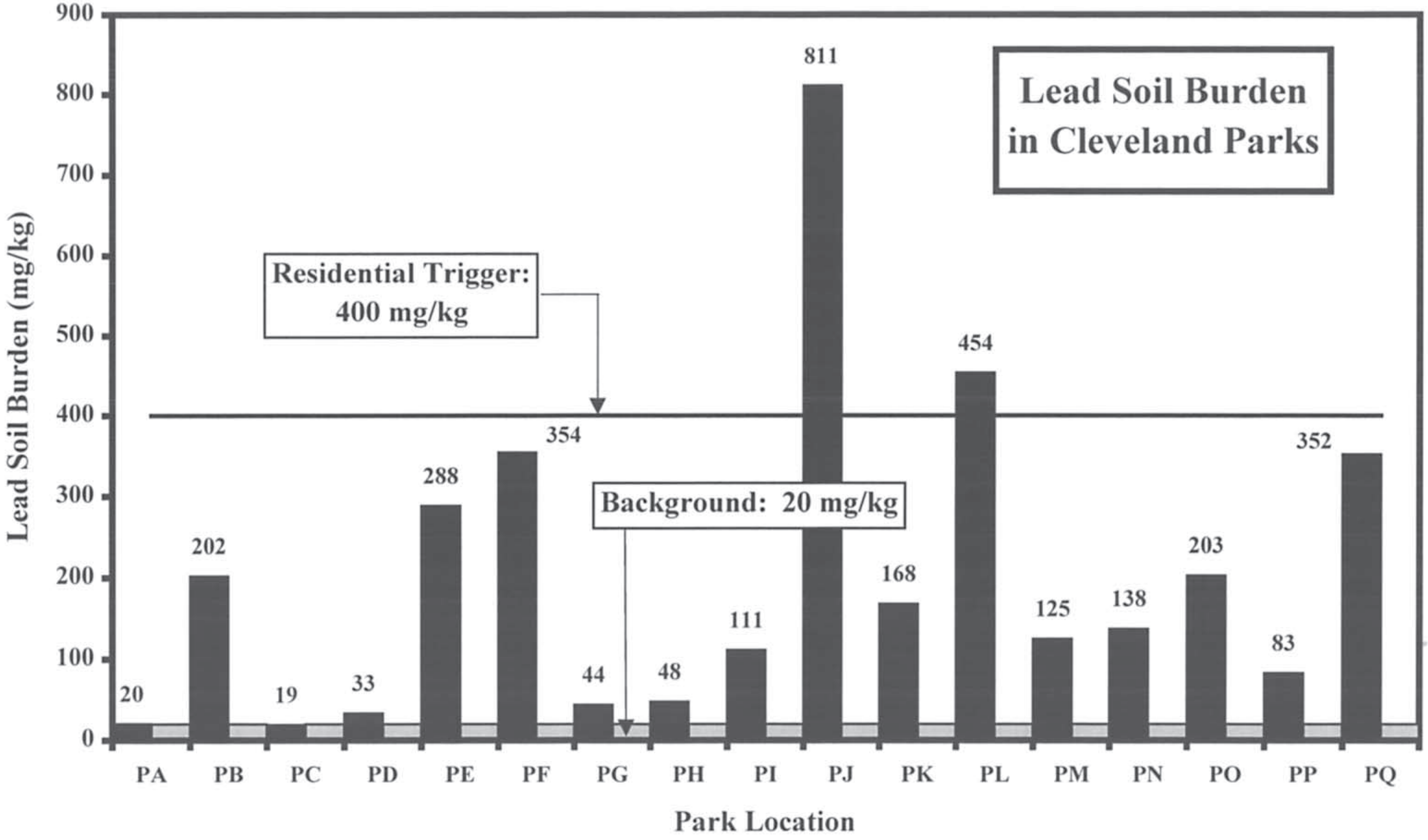

FIGURE 13

Lead soil burdens (mg/kg) in Greater Cleveland public areas.

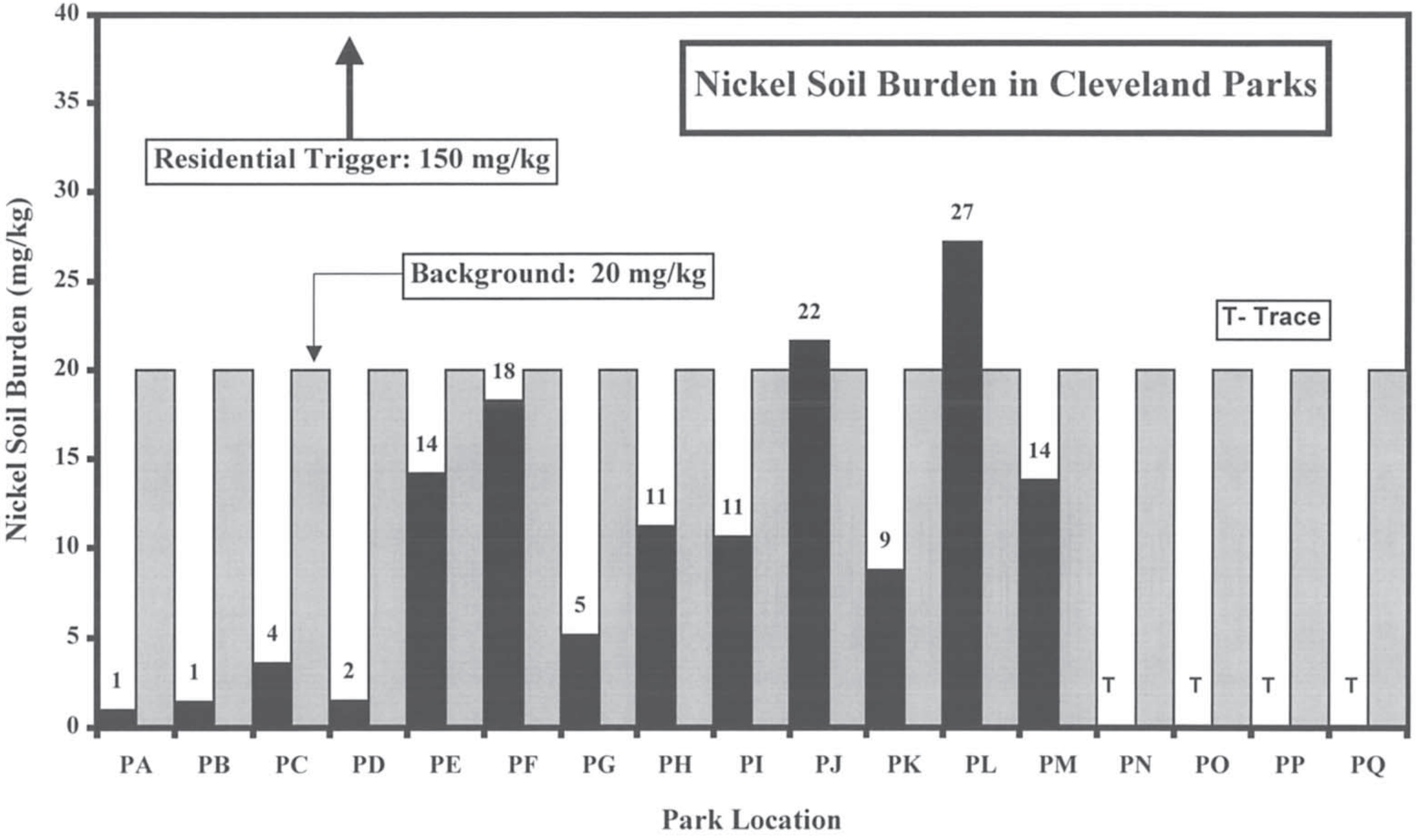

FIGURE 14

Nickel soil burdens (mg/kg) in Greater Cleveland public areas.

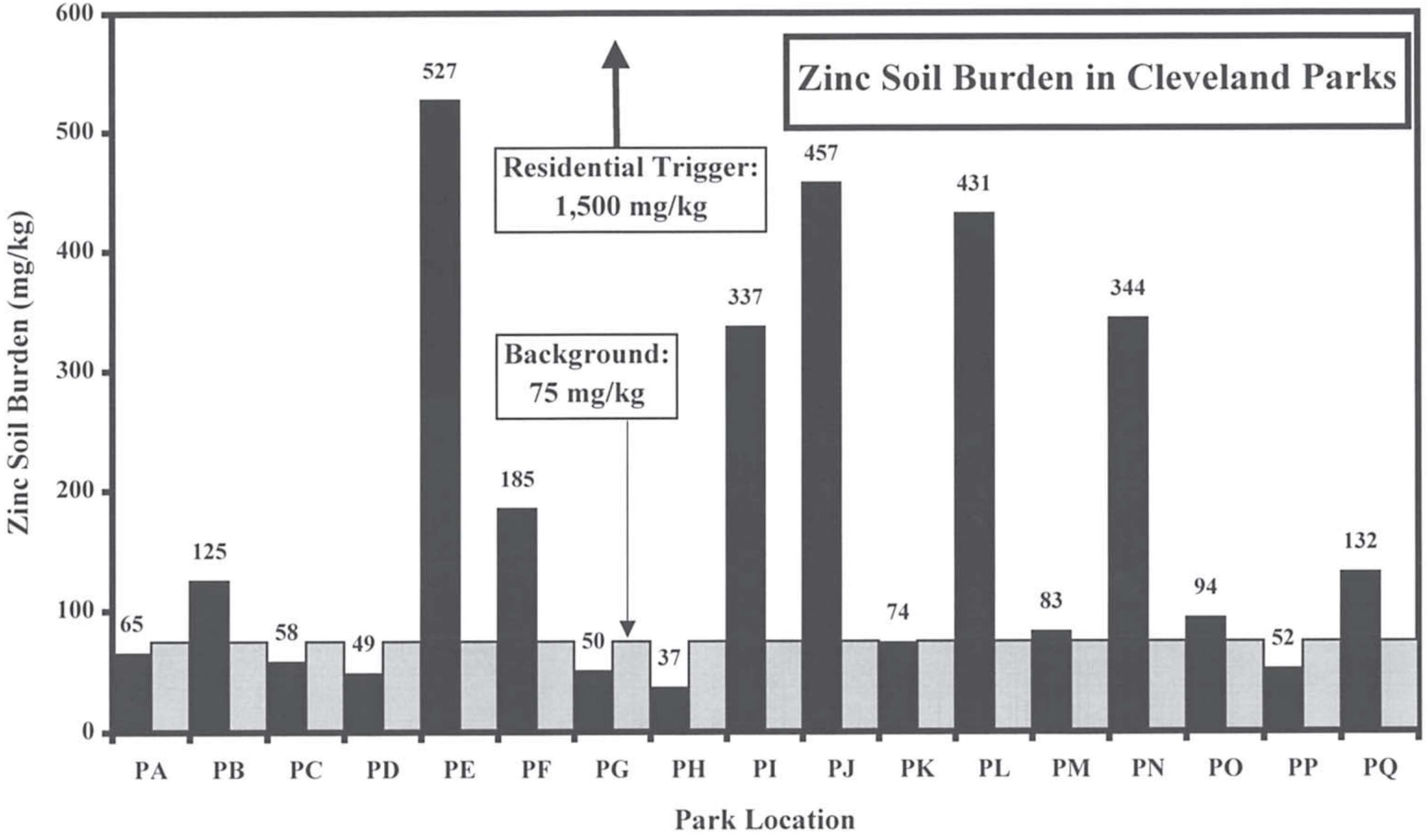

FIGURE 15

Zinc soil burdens (mg/kg) in Greater Cleveland public areas.

TABLE 3
Heavy Metal Burden Correlation Coefficients (R^2) for Cleveland Area Brownfields

Metal	Pb	Cu	Cr	Zn	Cd	Ni	Fe
Pb	1.0000	0.0009	0.0002	0.3575	0.4571	0.3291	0.0509
Cu	0.0009	1.0000	0.2024	0.0217	0.0181	0.1073	0.0142
Cr	0.0002	0.2024	1.0000	0.0005	0.0000	0.0163	0.0770
Zn	0.3575	0.0217	0.0005	1.0000	0.4188	0.5044	0.1097
Cd	0.4571	0.0181	0.0000	0.4188	1.0000	0.6547	0.0461
Ni	0.3291	0.1073	0.0163	0.5044	0.6547	1.0000	0.2452
Fe	0.0509	0.0142	0.0770	0.1097	0.0461	0.2452	1.0000

TABLE 4
Heavy Metal Burden Correlation Coefficients (R^2) for Cleveland Public Areas

Metal	Pb	Cu	Cr	Zn	Cd	Ni	Fe
Pb	1.0000	0.8016	0.3898	0.4503	0.1963	0.6002	0.1935
Cu	0.8016	1.0000	0.3969	0.4348	0.1525	0.5235	0.2906
Cr	0.3898	0.3969	1.0000	0.2916	0.0000	0.8472	0.1635
Zn	0.4503	0.4348	0.2916	1.0000	0.0367	0.5015	0.2772
Cd	0.1963	0.1525	0.0000	0.0367	1.0000	0.0025	0.1986
Ni	0.6002	0.5235	0.8472	0.5015	0.0025	1.0000	0.3782
Fe	0.1935	0.2906	0.1635	0.2772	0.1986	0.3782	1.0000

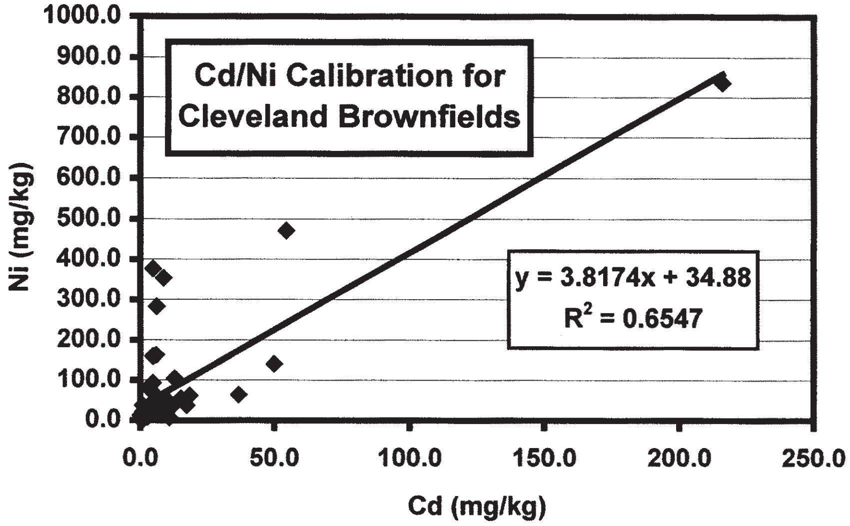

FIGURE 16

Cadmium/nickel soil burden correlation for Cleveland area brownfields.

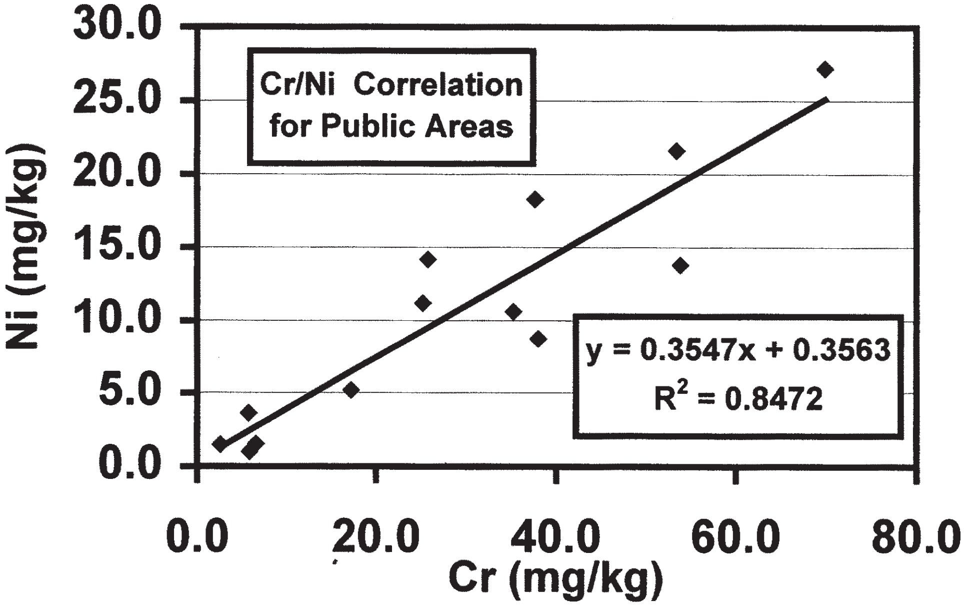

FIGURE 17

Chromium/nickel soil burden correlation for Cleveland public areas.

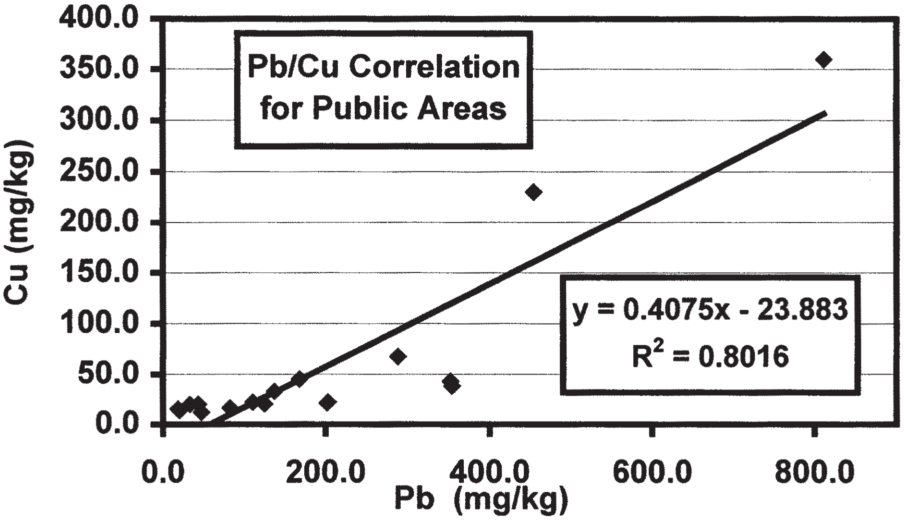

FIGURE 18

Lead/copper soil burden correlation for Cleveland public areas.

are common. Problems associated with Ni and Zn appear to be less severe. In interpreting these results it is important to consider that the values are for a single sample taken from a readily accessible location at each site and do not necessarily represent either the worst or average contamination condition. Given a more thorough site investigation, it is very likely that higher levels of contamination would have been detected at "hot spots". A second important conclusion is that restoring these areas to below industrial remediation trigger concentrations might be attainable, but restoration to residential property standards would be a greater challenge. With the possible exception of nickel, one should expect any of these sites to yield substantial multicomponent remediation obligations that would have to be satisfied before they would be appropriate for residential use. This is important because many of the sites appear to be isolated from the flow of industrial revival and seem to offer more redevelopment opportunities as residential real estate. However, this opportunity and the growing pressure to promote redevelopment in these areas should not be allowed to unduly increase urban heavy metal exposures.

The results of the metal/metal correlation analysis indicates that "pollution profiling" for heavy metal contamination at brownfield sites will probably not work. Any site may contain very high values of any heavy metal independently of other metals of concern. It would be dangerous to make assumptions about metal contamination burdens without actually measuring them.

It should be noted that, because of the nature of the screening tests applied to these soils, the reported values probably underestimate the soil's total mass burdens. Analysis of the kinetics of the 24 h, 1N HCl extraction indicated that this process should recover in excess of 95% of the surface-associated metal burden, and that extending the extraction to 48 h makes a negligible improvement in the results. However, it is accepted that this method may underestimate the burden that would be measured by a longer, more aggressive extraction. It has also been demonstrated that extractions can miss a sequestered fraction of the mass burden if sequestering exists, and sequestered burdens as high as 20% have been measured in Cleveland area soils. The 24 h extraction results were ideal for the purposes of this survey, but care must be taken in assuming that these define the total magnitude of the remediation problem.

The results of the analysis of Cleveland public areas showed that, with the exception of nickel and copper, nearly all sites yielded values substantially above an uncontaminated background. As expected, these soils show evidence of Cleveland’s industrial history. Of the 17 areas tested, 2 exceeded the residential remediation trigger for cadmium, 12 exceeded the chromium trigger, 1 exceeded the copper trigger, 2 exceeded the nickel trigger, and 2 exceeded the lead trigger. None exceeded the zinc trigger. The lead and chrome values appear to be most problematic. The lead results are of concern because lead exposure is known to be unusually high in Cleveland children, and because the observed values exceed the national EPA standard.

The chromium results are of concern because this appears to be a more extensive problem, and because this result was unexpected. However, additional work is required to determine speciation (which governs toxicity) before the true danger can be evaluated. Table 2 illustrates that there is also considerable uncertainty in defining appropriate chrome remediation triggers. Apparently, the values illustrated in Figure 11 would not be of regulatory concern in many states.

A more comprehensive risk assessment should also be conducted before discounting the potential problems of other contaminants. Although the contamination burdens fall below remediation triggers, the cumulative impact of exposures to multiple heavy metals should also be considered.

Although some of the public area concentrations were unexpected, the possibility that such values might be encountered had been anticipated. Because of the nature of these areas, the study team believed that there would be a public health obligation to be satisfied if high values were detected. The plan was to reanalyze all existing samples that indicated high metal contamination to verify that results did not originate from laboratory error. In a parallel task, sites of concern would be revisited to collect additional discrete and composite samples. If extended analysis confirms high levels of contamination, the data will be delivered to the City of Cleveland Safety Director for appropriate action with a request that the team be informed about the official disposition of the matter. This process is currently underway.

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