

Lead, Arsenic, and Polycyclic Aromatic Hydrocarbons in Soil and House Dust in the Communities Surrounding the Sydney, Nova Scotia, Tar Ponds

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This study evaluated lead, arsenic, and polycyclic aromatic hydrocarbon (PAH) contamination in the residential communities adjacent to the Sydney, Nova Scotia, tar ponds, the area considered Canada's worst contaminated site. The tar pond remediation policy has been limited to the site and some residential properties. We compared background concentrations in 91 soil samples taken 5–20 km from the coke oven site with those in soil samples from the three communities surrounding the tar ponds: Whitney Pier, Ashby, and North End. These surrounding communities were statistically different from background regarding arsenic, lead, and PAHs. Twenty percent of the background soil samples and 95% of the tar pond soil samples were above the Canadian health-risk-based soil guidelines for arsenic (12 ppm), and 5% of the background samples and 80% of the tar pond soil samples were above the Canadian guidelines for lead (140 ppm). Regarding dust lead and arsenic loading, the results provide no evidence that Whitney Pier is significantly different than Ashby and North End. Children in these communities are predicted to have a 1–15% chance of blood lead > 10 µg/dL. The results suggest that lead and arsenic found in the homes originate outside. The lead content of paint in the homes was not evaluated, but consideration of painted wood at the doorway did not confound the results of the study. The results indicate that the residential environment has been adversely affected by PAHs, lead, and arsenic and should be considered for remediation. *Key words:* arsenic, community, environmental justice, house dust, lead, PAHs, polycyclic aromatic hydrocarbons, soil, Sydney, tar ponds, tracking. *Environ Health Perspect* 112:35–41 (2004). doi:10.1289/ehp.6423 available via <http://dx.doi.org/> [Online 16 October 2003]

A steel plant and coke ovens in Sydney, Nova Scotia, Canada, operated from 1901 through 1988 (Barlow and May 2000) (Figure 1). The coke oven area contained 400 coke ovens, four blast furnaces, and 10 open-hearth furnaces. The coal tar produced in making coke was released into Muggah Creek and created the tar ponds (Furimsky 2002; Tay et al. 2003). The release of the coal tar also resulted in the contamination of the groundwater. The coke ovens and steel plant deposited several million tons of particulate matter on the industrial site and surrounding community (CBCL Ltd. 1999; Furimsky 2002). Based on the analysis of the coal used in the coking operation, the particulate matter would have deposited significant levels of lead, arsenic, polycyclic aromatic hydrocarbons (PAHs), and other contaminants (Furimsky 2002). Air sampling done while the coke ovens were operational showed significant levels of PAHs in the ambient air (Atwell et al. 1982). In September 1998, a memorandum of understanding was signed between the Government of Canada, Government of Nova Scotia, and Cape Breton Regional Municipality stating that the Muggah Creek estuary is recognized as Canada's worst contaminated site and should be considered a national issue (CBCL Ltd. 1999).

Health research in Sydney, Nova Scotia, has found an increase in cancer incidence (Guernsey et al. 2000), cancer mortality (Band et al. 2003; Health Canada 1999), and

congenital anomalies (Dodds and Seviour 2001) compared with the rest of Nova Scotia and Canada. Adolescents living near the tar ponds have expressed environmental and health related concerns about themselves and their families (Covell and O'Leary 2002). The health research suggests that the environmental contaminants released during the coke and steel operations may play a significant role.

For several years, the community has expressed the need for the contamination around the site to be evaluated to address their concerns about potential health risks. Sampling for contaminants has focused primarily on an area called "north of the coke ovens" (NOCO) in Whitney Pier, where lead, arsenic, and PAHs have been found (JDAC Environmental Ltd. 2001a) and remediation has been recommended for several residential properties (JDAC Environmental Ltd. 2001b). The reason for focusing on Whitney Pier NOCO is that it is predominantly downwind of the coke oven site. The other neighborhoods in close proximity, Whitney Pier (outside NOCO), Ashby, and North End, have not been considered adversely affected, and the residents have not been considered to face increased health risks. There has been no evaluation of contaminants in house dust in Sydney. House dust is the primary exposure route for children (Manton et al. 2000).

Our study addressed three fundamental questions: *a*) Is there a significant difference in

soil contaminant concentrations in background samples collected 5, 10, 15, and 20 km from the coke oven site and samples collected from the communities surrounding the tar ponds? *b*) Are contaminant levels in Whitney Pier significantly different from those in Ashby and North End (Figure 1)? *c*) Are the environmental contaminants found in the soil also moving into the homes in the three communities surrounding the tar ponds?

Materials and Methods

Household dust and soil samples were analyzed for the presence of lead and arsenic in all three locations. The Government of Canada collected and analyzed soil samples for PAHs and metals in residential soil (Government of Canada. Unpublished data), and residents provided us with their results to be used in the analysis. For background data, we used the Government of Canada "Far A Field" study (Fraser and Small 2001), in which soil samples were collected from 5, 10, 15, and 20 km upwind of the coke oven site and analyzed for lead, arsenic, and PAHs.

Recruitment and household survey of residents. We chose 15 homes in each community within a three-block radius of the site to ensure coverage of the study area (Figure 1). We conducted a survey in each household to document the age, construction, and condition of the doorway; smoking status; cleaning of the doorway and floor; and other possible sources of lead and arsenic. Homes that had undergone major renovations in the last 2 years were excluded from the study.

Soil sampling. Discrete soil samples were collected from the top 5 cm of soil, placed in a plastic bag, and sealed. If bare areas were

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available in the yard, we chose these sites to collect the sample. If grass was present, the top organic layer was removed and the soil sample was taken from the top 5 cm of soil. The soil samples were taken from the middle of the yard to avoid potential contamination from other sources; areas in close proximity to the house or garage were avoided to mitigate confounding from these sources, most notably paint. We collected some composite soil samples. The same sampling procedure was followed, and equal amounts of soil were thoroughly mixed in the sample bag before sending the sample for analysis. Soil samples were sent to the Environmental Services Laboratory (Sydney, Nova Scotia, Canada) for lead and arsenic analysis following U.S. Environmental Protection Agency (EPA) methods (U.S. EPA 1994a, 1994b, 1996).

Our sampling strategy involved using Government of Canada data from the communities surrounding the tar ponds (Government of Canada. Unpublished data); in addition, we collected soil samples to provide coverage of all the geographic areas indicated in Figure 1. Precise locations of samples taken are not provided, to maintain the anonymity of the participants.

In Whitney Pier (NOCO), residents provided data for 13 Government of Canada samples for lead, arsenic, PAHs, and other contaminants. In Whitney Pier (outside

NOCO), residents provided data for 17 Government of Canada samples, and 3 residential soil samples were collected; these were analyzed for lead and arsenic ($n = 20$). In Ashby, residents provided data for 3 Government of Canada samples, and 6 residential soil samples were collected and analyzed for lead and arsenic ($n = 9$). In addition, 1 soil sample was taken from beneath a 100-year-old home to provide some indication of background concentrations for lead and arsenic before the deposition of the contaminants. In North End, residents provided data for 6 Government of Canada samples, and 6 residential soil samples were collected and analyzed for lead and arsenic ($n = 12$). One soil sample was taken from beneath a home in North End, directly adjacent to the tar ponds, at water level, and analyzed for lead and arsenic to provide information on contamination from groundwater.

The soil samples collected by the Government of Canada were used in developing Spearman correlation coefficients between lead, arsenic, and PAHs, and were used for predicting the level of PAH loading in dust ($n = 33$). Prediction of the PAH dust loading in the homes was made by presuming that the correlation of lead to PAHs holds for both soil and indoor dust. The prediction of PAH loading in dust was made using the following equation:

$$\text{PAH dust loading} = (\text{GM Pb dust loading} \times \text{GM PAH soil}) \div (\text{GM Pb soil}),$$

where GM is the geometric mean.

We collected 1 soil sample from outside Sydney to provide an indication of background lead and arsenic. In addition, background data consisted of 91 shallow soil samples analyzed for lead, arsenic, and PAHs collected upwind of the tar ponds at distances of 5 km ($n = 6$), 10 km ($n = 25$), 15 km ($n = 11$), and 20 km ($n = 50$) (Fraser and Small 2001). The soil results were also compared with typical background urban concentrations in Canada and the Canadian Council of Ministers of the Environment (CCME 1997) soil quality guidelines for arsenic (12 ppm), lead (140 ppm), and PAHs.

House dust sampling. For indoor dust, we compared 15 homes in Whitney Pier with 30 control homes, 15 in Ashby and 15 in North End (Figure 1). In Whitney Pier, the samples were taken from both NOCO and outside NOCO, north of the steel plant site. Homes were chosen in the sampling areas in order to provide a geographically representative sample. Our sampling was designed to compare lead and arsenic concentrations from the main entrance with those from the kitchen floor to determine if the contaminants were entering the home from outdoors and to show movement of the contaminants into the home.

The dust sampling method generally followed the wipe methods of Lanphear et al. (1995) and Sterling et al. (1999). For the kitchen floor, we used a 50 × 40 cm template

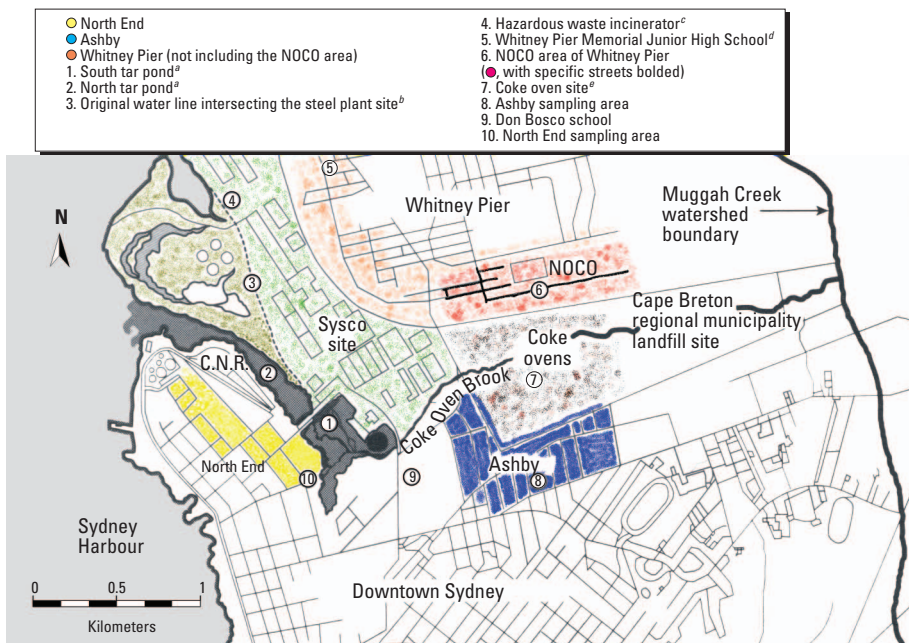


Figure 1. Sydney, Nova Scotia, tar ponds and surrounding area (adapted from Barlow and May 2000). The soil and dust sampling took place in the three communities: North End, Ashby, and Whitney Pier. In Whitney Pier, the NOCO area (red with bolded streets) has been partitioned off from Whitney Pier as a whole by the authorities. In this study we tested the assumption that the NOCO area is different from Ashby and North End with respect to soil and house dust levels of lead and arsenic.

^aThe tar ponds are reported to contain 700,000 tons of coal tar, of which 50,000 tons are contaminated with PCBs; however, the amount of coal tar may greatly exceed this estimate (Furimsky 2002). ^bThe infill material is predominantly slag piles. ^cThe hazardous waste incinerator was built in 1992 to burn the coal tar waste in the tar ponds. ^dSituated approximately 600 m uphill from the waste incinerator. ^eFour hundred coke ovens processed coke for the steel mill.

Table 1. Comparison of lead and arsenic in soil in the background Far A Field (FAR) study (Fraser and Small 2001) sampled at 5, 10, 15, and 20 km from the coke ovens site and the three communities surrounding the tar ponds (TAR): Whitney Pier, Ashby, and North End.

	FAR As (ppm)	TAR As (ppm)	FAR Pb (ppm)	TAR Pb (ppm)
No.	91	55	91	55
GM	6.5	50 ^a	32	297 ^a
Median	6.0	52 ^a	29	340 ^a
Mode	4.0	18 ^{a,b}	18	230 ^{a,b}
SD	9	56	40	309
Percentiles				
1	2	5	2	52
10	3	18 ^a	15	92
20	4	25 ^a	18	132
30	4	34 ^a	21	230 ^a
40	6	43 ^a	24	275 ^a
50	6	52 ^a	29	340 ^a
60	8	61 ^a	35	410 ^a
70	9	80 ^a	44	448 ^a
80	11	92 ^a	65	505 ^a
90	16 ^a	140 ^a	110	669 ^a
100	65 ^a	280 ^a	200 ^a	1,700 ^a

^aValues exceed the CCME health-risk-based guidelines for lead (140 ppm) and arsenic (12 ppm) (CCME 1997). ^bMultiple modes exist; the smallest value is shown.

to give an area of 0.2 m². For the doorway floor, the sample was taken the length of the door (~70 cm) and approximately 20 cm into the doorway. The same approximate area was wiped with alcohol swabs at each doorway, but each was marked and measured with a tape measure. Premoistened alcohol wipes were used to sample dust in each home. The samples were collected by wiping the floor in small circles one direction for the entire template area, and then the same procedure was repeated in the opposite direction. All alcohol wipes were immediately placed in a plastic bag and sealed after dust collection. All sample bags were labeled with the code and delivered to the Environmental Services Laboratory in Sydney for analysis. The wipe samples were analyzed using U.S. EPA methods for lead and arsenic (U.S. EPA 1994a, 1994b, 1996), and all of the wipes for each home were digested in the analysis. All of the sampling took place over 6 days at the end of August 2002. The lead content of paint in the homes was not measured.

To determine the floor loading, we subtracted the mass value in the blank wipe from the mass value in the wipe and then divided by the area of floor wiped. For some arsenic samples within the interior of the home, the result was not zero but was reported as less than a certain value; in these cases, this value was subtracted from the blank and used in calculating the concentration. In addition, the loading was corrected for cleaning by dividing the contaminant loading by the number of days since the floor was cleaned.

In addition to the floor wipes, one wipe sample was taken from an outside wall in Whitney Pier (outside NOCO) facing the steel plant site. This wipe was taken to determine the presence or absence of lead and arsenic in the wind-blown dust.

Statistical analysis. To test the alternate hypothesis that environmental contamination in Whitney Pier is significantly different from Ashby and North End, the contaminant concentrations of lead and arsenic in the soil and dust loading were compared using nonparametric statistics because of the nonnormal distribution. We used Mann-Whitney tests for two-way comparisons and the Kruskal-Wallis test for analyses involving more than two groups. To test the alternate hypothesis that the communities adjacent to the tar ponds were significantly different than background, we used the Mann-Whitney and Kruskal-Wallis tests. The data were also compared descriptively and with respect to the distributions for lead and arsenic.

To test the alternate hypothesis that lead and arsenic originated from outside the home and moved (tracked or blown) into the home, three analyses were used. First, we used Mann-Whitney and Kruskal-Wallis tests to compare

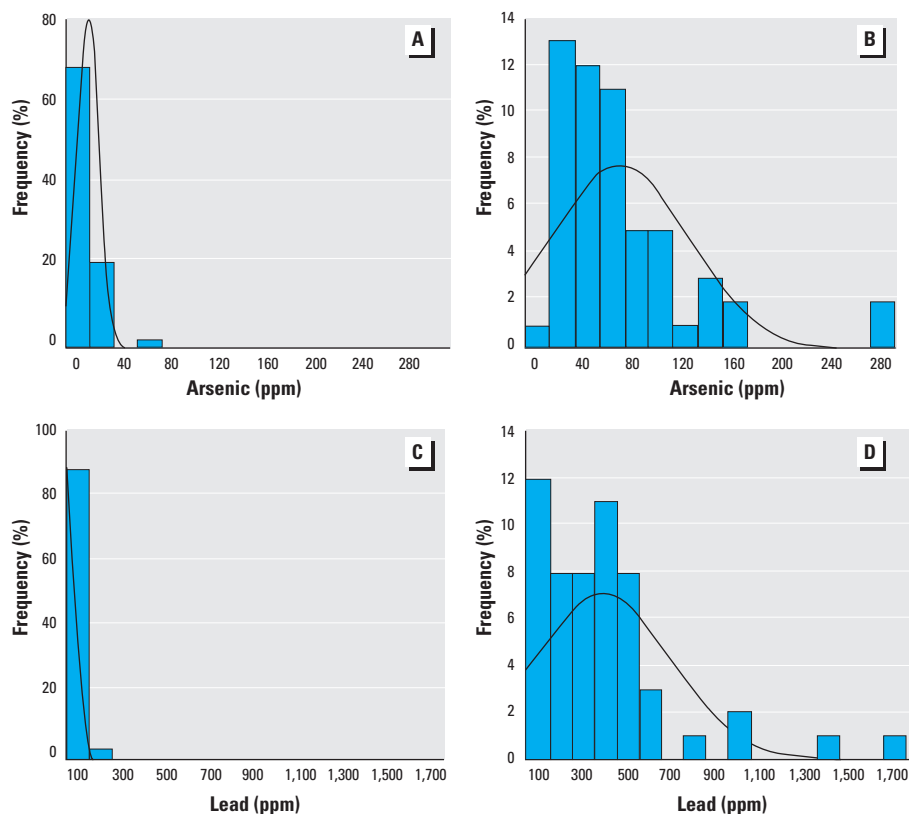


Figure 2. Comparison of the distribution of soil lead and arsenic concentrations from the background (Fraser and Small 2001) and the three communities surrounding the tar ponds. (A) Background soil arsenic concentrations (SD = 9.03; mean = 9 ppm; $n = 91$). (B) Soil arsenic concentrations in the communities adjacent the tar ponds (SD = 56.28; mean = 67 ppm; $n = 55$). (C) Background soil lead concentrations (SD = 39.59; mean = 44 ppm; $n = 91$). (D) Soil lead concentrations in the communities adjacent the tar ponds (SD = 308.87; mean = 388 ppm; $n = 91$). The curve shows the sample distribution, and the peak represents the mean concentration.

Table 2. Lead and arsenic samples in the communities adjacent the tar ponds.

Location/data source	Sample type	Lead (mg/kg or ppm)	Arsenic (mg/kg or ppm)	Lead:arsenic ratio
Whitney Pier (NOCO)				
Government of Canada ^a (GM; $n = 14$)	Discrete	299	44	4.4
Control locations				
Whitney Pier (outside NOCO)				
Government of Canada (GM; $n = 17$)	Composite/discrete	450	94	4.7
BH 15	Discrete	589	135	4.4
BH 16	Discrete	242	52.2	4.6
BH 17	Discrete	192	33.5	5.7
Ashby				
BH 5 (under house above grade)	Discrete	37.4	9	4.7
Government of Canada (GM; $n = 3$)	Composite	241	60	4
BH 1	Discrete	429	21.7	19.8
BH 2	Discrete	232	42.7	5.4
BH 3	Discrete	422	157	2.7
BH 4	Discrete	607	59.2	10.3
BH 6	Discrete	78	17.6	4.4
BH 7	Composite	136	21.6	6.3
North End				
BH13 (under house beside tar ponds)	Discrete	297	36.5	8.1
Government of Canada (GM; $n = 6$)	Composite/discrete	653	74	4.2
BH 8	Discrete	497	52.8	9.4
BH 9	Discrete	92.3	4.7	19.6
BH 10	Composite	506	40.9	12.4
BH 11	Discrete	322	29.4	11
BH 12	Discrete	107	24.7	4.3
BH 14	Discrete	131	48.5	2.7
20 km outside Sydney				
BH 18	Discrete	9.1	2	4.6

BH, borehole.

^aGovernment of Canada sample results were provided by residents.

loading in the doorway and kitchen, along with relative contaminant loading in each location. Second, we calculated Spearman correlation coefficients for the ratio of lead to arsenic at the doorway and kitchen. Third, Spearman correlation coefficients were calculated for the loading of lead and arsenic individually in the doorway and the kitchen.

Smoking, painted wood at the door, and the use of slag in building the driveway were evaluated as potential confounding factors; homes were aggregated on this basis. Kruskal-Wallis and Mann-Whitney tests were used to evaluate the confounding variables. With respect to wood at the doorway, we used the ratio of lead to arsenic in addition to loading of contaminants. We assumed that if the wood contributed lead from paint, then this should be reflected in the ratio of lead to arsenic. The homes were stratified if wood was present. There was no attempt to stratify the data on the basis of the age of the paint or the state of the doorway material. Some doorways were constructed with a metal plate on plastic. These were compared with doorways

in which the metal doorplate was sitting on wood; generally, approximately 4 cm of wood (a 2-inch strip) was visible beneath the metal plate, and in a few cases, the entire door plate was constructed of wood.

Results

Soil. Table 1 and Figure 2 show the comparison of soil lead and arsenic concentrations taken from the background locations and the communities surrounding the tar ponds. With respect to arsenic, 80% of the background soil samples and 5% of the soil samples adjacent to the tar ponds were below the Canadian health-risk-based arsenic soil guidelines (12 ppm) (CCME 1997). With respect to lead, 95% of the background soil samples and 20% of the soil samples adjacent to the tar ponds were below the Canadian lead health-risk-based soil guidelines (140 ppm) (CCME 1997). Table 2 presents the results of our soil sampling in the communities.

For each PAH, the GM is greater in the communities surrounding the tar ponds than in the background soils (Table 3). The GM

of benzo[*k*]fluoranthene, benzo[*a*]anthracene, benzo[*b*]fluoranthene, and benzo[*a*]pyrene (BaP) are above the Canadian soil quality guidelines (CCME 2002) in communities adjacent to the tar ponds. The Spearman correlation coefficients were statistically significant for soil arsenic and soil lead, naphthalene, 1-methylnaphthalene, and 2-methylnaphthalene; for soil lead, only acenaphthene and acenaphthylene were not statistically significant (data not shown). This suggests that lead can be used as a surrogate for PAH contamination.

The Mann-Whitney test suggests a statistically significant difference between the communities adjacent to the tar ponds and the background soils for lead, arsenic, and each PAH (Table 4). The Kruskal-Wallis test suggests no evidence that the communities adjacent to the tar ponds are different with respect to lead and arsenic (Table 4). The Mann-Whitney test suggests no evidence that Whitney Pier (NOCO) is significantly different from Whitney Pier (non-NOCO), Ashby, or North End for lead and arsenic (Table 4). Thus, the alternate hypothesis that Whitney

Table 3. Comparison of soil PAHs in the background Far A Field (FAR) study (Fraser and Small 2001) and the communities adjacent to the tar ponds (TAR).

Compound	Site	No.	Canadian soil quality guidelines (ppm) ^a	Soil contamination ^b				TAR GM: FAR GM ratio	Prediction of dust loading (pg/cm ²)
				Minimum (ppm)	Maximum (ppm)	GM ^c (ppm)	SD		
Naphthalene	FAR	90	0.6	0.05	0.66	0.053	8.4	150	
	TAR	33		0.05	3.00	0.45			
Perylene	FAR	90		0.05	0.60	0.053	4.7	85	
	TAR	33		0.05	1.10	0.25			
1-Methylnaphthalene	FAR	90		0.05	0.23	0.053	7.7	136	
	TAR	33		0.05	2.70	0.40			
2-Methylnaphthalene	FAR	90		0.05	0.28	0.053	8.5	151	
	TAR	33		0.05	3.50	0.45			
Acenaphthylene	FAR	90		0.05	0.05	0.05	2.2	36	
	TAR	33		0.05	0.38	0.11			
Acenaphthene	FAR	90		0.05	0.63	0.051	2.4	42	
	TAR	33		0.05	1.10	0.12			
Fluorene	FAR	90		0.05	0.85	0.052	4.1	71	
	TAR	33		0.05	1.20	0.21			
Phenanthrene	FAR	90	5.0	0.05	6.60	0.062	39	819	
	TAR	33		0.17	21.00	2.4			
Anthracene	FAR	90		0.05	1.40	0.053	11	194	
	TAR	33		0.05	3.50	0.58			
Fluoranthene	FAR	90		0.05	4.30	0.066	53	1,137	
	TAR	33		0.24	23.00	3.4			
Pyrene	FAR	90	10	0.05	3.50	0.062	42	887	
	TAR	33		0.20	18.00	2.6			
Benzo[<i>a</i>]anthracene	FAR	90	1	0.05	4.50	0.058	25	497	
	TAR	33		0.08	7.70	1.5			
Chrysene	FAR	90		0.05	1.60	0.06	27	550	
	TAR	33		0.15	9.10	1.6			
Benzo[<i>b</i>]fluoranthene	FAR	89	1	0.05	0.64	0.055	19	358	
	TAR	33		0.08	5.70	1.07			
Benzo[<i>k</i>]fluoranthene	FAR	89	1	0.05	0.64	0.059	19	362	
	TAR	33		0.08	5.70	1.1			
BaP	FAR	89	0.7	0.05	0.69	0.055	23	415	
	TAR	33		0.07	5.70	1.2			
Indeno[1,2,3- <i>c,d</i>]pyrene	FAR	90	1	0.05	0.81	0.054	13	231	
	TAR	33		0.05	3.40	0.7			
Dibenz[<i>a,h</i>]anthracene	FAR	90	1	0.05	0.22	0.051	2.8	48	
	TAR	33		0.05	0.70	0.14			
Benzo[<i>g,h,i</i>]perylene	FAR	90		0.05	0.67	0.054	10	180	
	TAR	33		0.05	2.50	0.53			

^aData from CCME (2002). ^bThe detection limit for PAH samples was 0.05 ppb in the FAR samples. ^cIn calculating the GM, we used the detection limit instead of zero.

Pier NOCO is significantly different from the control locations was rejected.

The soil sample taken beneath a 100-year-old home (slightly raised above grade) in Ashby [bore hole (BH) 5: lead, 37.4 ppm; arsenic, 9 ppm] was similar to the concentrations observed in the data in the background sample locations (Table 2). In contrast, the soil sample taken beneath the home in North End, directly adjacent to the tar ponds, suggests contamination from groundwater (BH 13: lead, 297 ppm; arsenic, 37 ppm) (Table 2).

Dust. Table 5 presents the loading of lead and arsenic for the doorway and kitchen floor in Whitney Pier and the two control locations (Ashby and North End). The range of lead loading was similar, especially in Whitney Pier and North End. The Kruskal-Wallis test suggests that the communities are not significantly different from one another, and the Mann-Whitney test provides no evidence that Whitney Pier is different from the control locations (Table 6). With respect to dust contamination in the homes, the alternate hypothesis was rejected: there is no evidence to suggest that Whitney Pier is significantly different from the control locations.

The alternate hypothesis that contaminants are entering the homes from outside was accepted. The doorway concentrations are roughly an order of magnitude higher than the interior concentrations (Table 5). Values in the Kruskal-Wallis and Mann-Whitney tests comparing doorway and interior contaminant

loading were both < 0.0009 , suggesting that the doorway and interior are significantly different. The Spearman correlation coefficients are positive for the ratio of lead to arsenic loading at the doorway and inside for all data and for each community considered individually; statistical significance at 99% confidence level was achieved for all data combined and at 95% confidence for the North End data (Table 7). The lead at the door is positively correlated with lead in the kitchen for all data and for every community. Arsenic at the door was not positively correlated with kitchen arsenic based on all data combined or on those from Whitney Pier or North End. However, arsenic loading was positively correlated with lead in the kitchen for all data, Whitney Pier, and Ashby, suggesting tracking. When the time since the floors were cleaned was taken into account, the conclusions did not change (Table 7).

In addition, the one wipe sample taken from the outside wall of a home facing the steel plant site was found to contain $0.07 \mu\text{g Pb}/\text{cm}^2$ and $0.008 \mu\text{g As}/\text{cm}^2$. This indicates that the dust blowing around the community is contaminated with lead and arsenic and is perhaps an additional source for entry of the contaminants into the homes.

Predictions of indoor PAH were based on lead because PAHs and lead were significantly correlated in the soil. The GM of lead contaminant loading at the door ($0.1 \mu\text{g}/\text{cm}^2$) and the GM of each PAH and lead in the soil were used to predict PAH dust loading (Table 3).

Confounding by wood at doorways, smoking, and slag. The results indicate that wood at the doorway is not a significant confounder for the presence of lead contamination in this study (Table 8). Paint chips were noted in only two locations. If wood was contributing lead at the doorway, this should result in a change in the ratio of lead to arsenic. Considering this ratio, the statistical analysis suggests that the presence of wood at the doorway does not make a statistically significant difference in the levels of contaminants found in house dust.

For arsenic loading, there is no evidence to suggest that wood at the doorway is a confounder. For lead loading, the statistical evaluation indicates that there is some difference between the homes. However, the homes with high lead also had high arsenic loading, suggesting that dust is the source. When we ignored the highest lead loading in each community in the analysis, there was no statistically significant difference between the homes with or without wood present.

Environmental tobacco smoke contains approximately $1.5 \mu\text{mol}$ of lead and arsenic per gram of environmental tobacco smoke and thus was evaluated for confounding (Benner et al. 1989). In all cases, we did not find cigarette smoking to be a confounding factor for the presence of lead and arsenic in house dust (Table 9). Similar results were found for the presence of slag in the driveway construction (data not shown).

Discussion

The Muggah Creek estuary is considered Canada's worst contaminated site. Deposition modeling predicted that the coke ovens and steel plant had a maximum total particulate matter deposition rate of $387 \text{ g}/\text{m}^2/\text{year}$ and PAH deposition rate of $10 \text{ g}/\text{m}^2/\text{year}$ (CBCL Ltd. 1999). Furimsky (2002) suggested that the particulate matter would have contained arsenic, lead, cadmium, chromium, and zinc and resulted in a 20-cm layer of contaminated material. Deposition modeling predicted that contaminants released from coke and steel production would have deposited in Whitney Pier, Ashby, and North End (CBCL Ltd. 1999).

Our study results are consistent with the prediction that arsenic, lead, and PAHs were deposited in the three communities surrounding the tar ponds. The soil concentrations of

Table 4. Statistical tests to determine if hypothesis 1 [the tar pond (TAR) communities are significantly different from the background Far A Field (FAR) study (Fraser and Small 2001) with respect to lead, arsenic, and PAHs] and hypothesis 2 [the Whitney Pier (WP) is significantly different from Ashby and North End with respect to lead and arsenic soil contamination] should be rejected.

Test	Arsenic	Lead	PAHs
Mann-Whitney: FAR (5 km, $n = 7$) and TAR ($n = 55$)	$< 0.002^a$	< 0.0009	$< 0.0009^b$
Mann-Whitney: FAR (10 km, $n = 30$) and TAR ($n = 55$)	< 0.0009	< 0.0009	
Mann-Whitney: FAR (15 km, $n = 13$) and TAR ($n = 55$)	< 0.0009	< 0.0009	
Mann-Whitney: FAR (15 km, $n = 58$) and TAR ($n = 55$)	< 0.0009	< 0.0009	
Kruskal-Wallis: All sites	< 0.0009	< 0.0009	
Kruskal-Wallis: TAR	0.16	0.21	
Mann-Whitney: WP NOCO and WP non-NOCO	0.033 ^c	0.05	
Mann-Whitney: WP NOCO and Ashby	0.78	0.88	
Mann-Whitney: WP NOCO and North End	0.63	0.16	

^aEach TAR was significantly different than the FAR samples taken from 5 km; 0.002 was the largest asymptote of significance. The same was done for each comparison between TAR and FAR samples. ^bFor each individual PAH listed in Table 3, there was a significant difference between the three TAR communities together and the FAR samples taken from 5–20 km away. ^cThe Mann-Whitney test suggests that the two groups are statistically different, but the WP non-NOCO had a higher mean rank (20) than the WP NOCO mean rank (13).

Table 5. Comparison (mean \pm SD and GM, or range) of Whitney Pier (WP) and the control communities Ashby and North End.

Location	Door lead ($\mu\text{g}/\text{cm}^2$)	Inside lead ($\mu\text{g}/\text{cm}^2$)	Door arsenic ($\mu\text{g}/\text{cm}^2$)	Inside arsenic ($\mu\text{g}/\text{cm}^2$)
WP [mean \pm SD (GM ^a)]	0.16 ± 0.31 (0.06)	0.0036 ± 0.0045	0.019 ± 0.05 (0.005)	0.00088 ± 0.0015 (0.0004)
Ashby [mean \pm SD (GM)]	0.15 ± 0.21 (0.079)	0.013 ± 0.023	0.0062 ± 0.0072 (0.004)	0.00086 ± 0.0010
North End [mean \pm SD (GM)]	0.32 ± 0.40 (0.16)	0.014 ± 0.022 (0.0076)	0.008 ± 0.0093 (0.0052)	0.0012 ± 0.0013 (0.00066)
WP (range)	0.02–1.41	0–0.014	0.007–0.19	0.0005–0.0058
Ashby (range)	0.026–0.83	0–0.034	0.001–0.028	0–0.0036
North End (range)	0.02–1.44	0.001–0.087	0.0013–0.037	0.0002–0.0039

^aGM could not be calculated where the data set contained a zero.

lead, arsenic, and PAHs are similar in the three communities surrounding the tar ponds but are significantly different from those from the background locations 5–20 km from the coke ovens (Figure 2, Tables 1 and 3). The surface soil sample result from beneath the 100-year-old home in Ashby (lead, 37 ppm; arsenic, 9 ppm) provides an indication of the degree of contamination as a result of the particulate

matter that deposited on the community (Table 2).

Our results are consistent with the ambient air PAH levels during the site operation: averages in Whitney Pier, 37 ng/m³ PAH; Ashby, 31 ng/m³ PAH; and the background location 4 km from the site, 3.48 ng/m³ PAH (Atwell et al. 1982). High-molecular-weight PAHs have been observed from coke oven

emissions and electric arc furnaces (Yang et al. 1998). Our results are supported by Paul Moore, project manager of the Sydney Tar Ponds for Health Canada, who stated that results from 250 soil samples indicate that contamination consistent with the chemicals found in NOCO spreads approximately 3 km from the site (MacDonald 2003). Given the range of concentrations, there are hotspots in each community, as would be expected from deposition of contamination.

From the comparison of the household dust, we found no evidence to suggest that Whitney Pier is significantly different from Ashby and North End with respect to lead and arsenic loading (Table 5). The dust analysis indicates that the source of lead and arsenic in the homes originates outside the homes (Table 7). In this study, we did not measure lead in house paint; however, consideration of painted wood at the door did not confound the results. Our results are consistent with the findings that indoor dust lead loading can be accounted for largely by outside sources, particularly in summer (Adgate et al. 1998; Yiin et al. 2000). Further, arsenic does not appear to be present in paint above detection limits using X-ray fluorescence analysis and through indirect evaluation of dust and soil and therefore originates outside (Adgate et al. 1998; Black 1997; Burger and Gochfeld 2000; Wolz et al. 2003).

The Spearman correlation coefficients between lead, arsenic, and PAHs were statistically significant, suggesting that the contaminants are from a common source. Positive correlations have been observed between lead and PAHs, indicating a common source (Mielke et al. 2001). Because the house dust contaminants are derived from outside, it is likely that the PAH levels predicted in house dust (Table 3), as well as other contaminants found in the soils, will also be present in house dust. Chuang et al. (1995) found that PAHs are tracked into the home from soil, and a similar PAH profile was found in entry-way soil, pathway soil, and house dust; the highest loading was for the 4- and 5-ring PAHs: fluoranthene, pyrene, benzofluoranthene, and BaP. In our study, these had among the highest predicted indoor loadings. The lowest loadings were for acenaphthylene (36 pg/cm²) and acenaphthene (42 pg/cm²). These PAHs were not significantly correlated with lead, perhaps because acenaphthylene is reactive in soil (Chuang et al. 1995).

The wipe method has been shown to consistently explain blood lead levels (Lanphear et al. 1995; Sterling et al. 1999). Manton et al. (2000) showed that blood lead is dominated by lead derived from the hands, which in turn appears to derive from floors. Polissar et al. (1990) found that hand-to-mouth activity was the primary source of arsenic exposure. The likelihood that children will have elevated

Table 6. Results of statistical tests to determine if we should reject the alternative hypothesis that Whitney Pier is significantly different from Ashby and North End with respect to dust contamination.

Variables	Kruskal-Wallis All	Mann-Whitney		
		Whitney Pier vs. Ashby	Whitney Pier vs. North End	Ashby vs. North End
Door lead	0.14	0.33	0.078	0.17
Door arsenic	0.78	0.72	0.80	0.46
Inside lead	0.015 ^a	0.13	0.004 ^a	0.16
Inside arsenic	0.407	0.63	0.11	0.73

^aThe low asymptote of significance is driven by the inside loading of lead in North End.

Table 7. Spearman correlation coefficients used to evaluate tracking of lead and arsenic.

	Spearman correlation (loading)	Spearman correlation (loading/day) ^a
All data		
Ratio Pb:As (door with inside)	0.48 (0.001)*	0.50 (0.001)*
Pb door with As door	0.53 (0.00)*	0.59 (0.00)*
Pb door with Pb inside	0.48 (0.001)*	0.30 (0.047)**
As door with As inside	-0.11 (0.48)	-0.10 (0.51)
Pb inside with As inside	0.083 (0.59)	0.18 (0.24)
Whitney Pier		
Ratio Pb:As (door with inside)	0.49 (0.062)	0.49 (0.061)
Pb door with As door	0.64 (0.01)*	0.74 (0.002)*
Pb door with Pb inside	0.34 (0.22)	-0.16 (0.57)
As door with As inside	-0.12 (0.68)	-0.40 (0.15)
Pb inside with As inside	0.12 (0.67)	0.23 (0.40)
Ashby		
Ratio Pb:As (door with inside)	0.35 (0.25)	0.35 (0.25)
Pb door with As door	0.29 (0.29)	0.33 (0.23)
Pb door with Pb inside	0.37 (0.17)	0.27 (0.33)
As door with As inside	0.062 (0.83)	0.21 (0.45)
Pb inside vs. As inside	0.21 (0.45)	0.004 (0.99)
North End		
Ratio Pb:As (door with inside)	0.55 (0.044)**	0.54 (0.045)**
Pb door with As door	0.59 (0.020)**	0.72 (0.002)*
Pb door with Pb inside	0.45 (0.11)	0.46 (0.10)
As door with As inside	-0.22 (0.45)	-0.095 (0.75)
Pb inside with As inside	-0.33 (0.25)	0.26 (0.37)

^aConcentration data were divided by the number of days since cleaning. *Statistically significant at 99%. **Statistically significant at 95%.

Table 8. Statistical test to evaluate confounding by wood present at the doorway.

Variables (wood and no wood)	Kruskal-Wallis All 6 groups	Mann-Whitney			
		All 3 groups	Whitney Pier	Ashby	North End
Ratio (Pb:As)	0.32	0.42	0.70	0.64	0.15
Door (As)	0.55	0.61	0.19	0.73	0.36
Door (Pb)	0.044	0.026	0.089	0.028	0.60
Delete high (Pb)	0.116	0.23	0.24	0.086	0.82

Table 9. Statistical analysis to evaluate confounding by smoking.

Variables (smoking vs. nonsmoking homes)	Kruskal-Wallis All 6 groups	Mann-Whitney			
		All 3 groups	Whitney Pier	Ashby	North End
Door (Pb)	0.45	0.35	0.72	0.49	0.42
Door (As)	0.65	0.62	0.26	0.35	0.64
Inside (Pb)	0.08	0.45	0.78	0.56	0.09
Inside (As)	0.38	0.55	0.89	0.69	0.12

blood lead levels can be estimated from Lanphear et al.'s (1998) pooled analysis of epidemiologic studies. Considering the dust lead levels in the kitchen, which is perhaps a good indicator of children's play areas, Lanphear et al.'s (1998) results suggest that the likelihood of a child having elevated blood lead (i.e., > 10 µg/dL) ranges from 1 to 15%. In addition, residential soil is a viable pathway for a child to become acutely exposed and harmed (Calabrese et al. 1997).

The results of the present study are most relevant to the evaluation of congenital anomalies after closure of the site (Dodds and Seviour 2001). A small (25%) but statistically significant increase in the rate of major congenital anomalies in Sydney compared with all of Nova Scotia and a consistently increased rate ratio for each congenital anomaly category was observed from 1988 through 1998.

At this time, authorities have stated that the residents in the three communities surrounding the tar ponds do not have an increased health risk. This has largely been based on assumptions of typical urban concentrations (JDAC Environmental Ltd. 2001b). For example, soil arsenic was referenced against a concentration of 72 ppm As, rather than the Canadian health-risk-based guidelines of 12 ppm As (CCME 1997). Typical Canadian urban arsenic concentrations are < 10 ppm As, with most values between 4 and 6 ppm (CCME 1997). For lead, an urban background concentration of 320 ppm was used rather than the CCME guidelines of 140 ppm Pb (CCME 1997); by comparison, urban concentrations in Calgary, Alberta, Canada, are approximately 20 ppm. For BaP, an urban background of 1.2 ppm was used rather than the guideline of 0.7 ppm BaP; the GM for BaP was approximately 18 times higher than background urban concentrations (0.17–0.22 ppm BaP) [Agency for Toxic Substances and Disease Registry (ATSDR) 1995], and approximately 10 times higher than the mean of 60 old urban park soils from Ontario, Canada (0.113 ppm BaP) (CCME 1997). Our results suggest that the three communities surrounding the tar ponds should be considered at increased health risk from lead, arsenic, and PAHs found in the soils and dust, and they should be remediated as part of the tar pond policy.

Conclusion

The soil in the communities adjacent to the tar ponds is significantly different from background regarding lead, arsenic, and PAH concentrations. There is no evidence to suggest

that Whitney Pier is significantly different from Ashby and North End in the concentrations of these toxicants. Soil levels for lead, arsenic, and some PAHs are above Canadian guidelines in the three communities. The contaminants are present on house floors at loading levels that may cause harm to young children. The residential communities surrounding the Sydney tar ponds have increased health risks from the contaminants and should be included in the tar pond remediation policy, which currently includes only the tar ponds, coke ovens, and a small number of residential properties.

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