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Analysis of lead in soils adjacent to an interstate highway in Tampa, Florida

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In order to assess the amount and distribution of lead pollution in soils adjacent to a major interstate highway serving the city of Tampa, Florida, a total of 224 samples were collected from 32 transects perpendicular to the roadway. The lead content was measured using atomic absorption spectrophotometry. The highest levels of lead were found at distances of 81, 243, and 729 cm from the road. The results show that there is a weak negative correlation between soil lead and the distance from the roadside, as well as with traffic density. The weakness of the relationship is a result of confounding variables such as turbulence and other microclimatic factors, downslope movement of soils over time, and human action such as construction and highway landscaping. Nevertheless, over one-third of the samples collected in the study area contain more than 500 $\mu g\ g^{-1}$ lead, levels considered to be hazardous by the United States Centers for Disease Control and the Environmental Protection Agency.

Keywords: Lead, ingestion, particulates, soils, hazardous waste, transect, traffic density

Introduction

Lead is a pervasive health problem in urban areas (Mielke *et al.*, 1989; US Senate Committee on Environment and Public Works, 1990; Mushak, 1992). Ingested lead causes elevated blood lead levels and lead poisoning, leading to health problems such as anaemia, renal dysfunction, and reduced IQ levels in children (Needleman *et al.*, 1979; Mushak *et al.*, 1989; Pocock *et al.*, 1994). Diseases from lead ingestion are considered the most common environmentally caused health problems in the United States (Centers for Disease Control, 1985; US Senate Committee on Environment and Public Works, 1990; Mushak, 1992; Anderson, 1995). In urban areas, the most prevalent sources of lead are chips and dust from lead-based paints, lead solder in water pipes, and automobile exhaust particulates in soils.

Lead from automobile exhaust has been identified as a source of lead particulates in roadside soils (Chow, 1970; Muskett and Jones, 1980) and has been identified as a major source of lead particulate compounds in household dusts and soils (Solomon and Hartford, 1976; US Senate Committee on Environment and Public Works, 1990; Page and Chang, 1993; Ewers *et al.*, 1994). As a result, most lead was eliminated from petrol by 1986. However, the lead particulates from years of leaded fuel usage have accumulated in roadside soils, have remained fixed in the surficial soil layer, and through a variety of pathways, have become part of household dusts that are ingested by humans (Centers for Disease Control, 1985; Bornschein *et al.*, 1986; Chaney and Mielke, 1986). For this reason, it is important to study the distribution and amount of lead in soils adjacent to roads in urban areas that were utilized during the time that leaded petrol was in use.

A number of researchers have analysed the lead content of roadside soils as a function of distance from the road. Previous researchers have found that soil lead decreases exponentially with distance from the road edge (Chow, 1970; Motto *et al.*, 1970; Wheeler and Rolfe, 1979; Muskett and Jones, 1980; Burguera and Burguera, 1988) and that the pattern of lead accumulation in the soil is correlated with traffic density (Ward *et al.*, 1974; Rodriguez-Flores and Rodriguez-Castellon, 1982), soil properties (Zimdahl and Skogerboe, 1977), and climatic factors such as winds and turbulence (Oke, 1978; Rao *et al.*, 1979; Eskridge and Rao, 1983; Piron-Frenet *et al.*, 1994).

Tampa, Florida, is an interesting area in which to study the distribution of roadside lead because most of the area's growth occurred in the later half of this century, with a substantial amount of it occurring during and since the reduction and removal of lead from petrol. Interstate Highway 275 (I-275) in Tampa divides many residential and commercial neigh-

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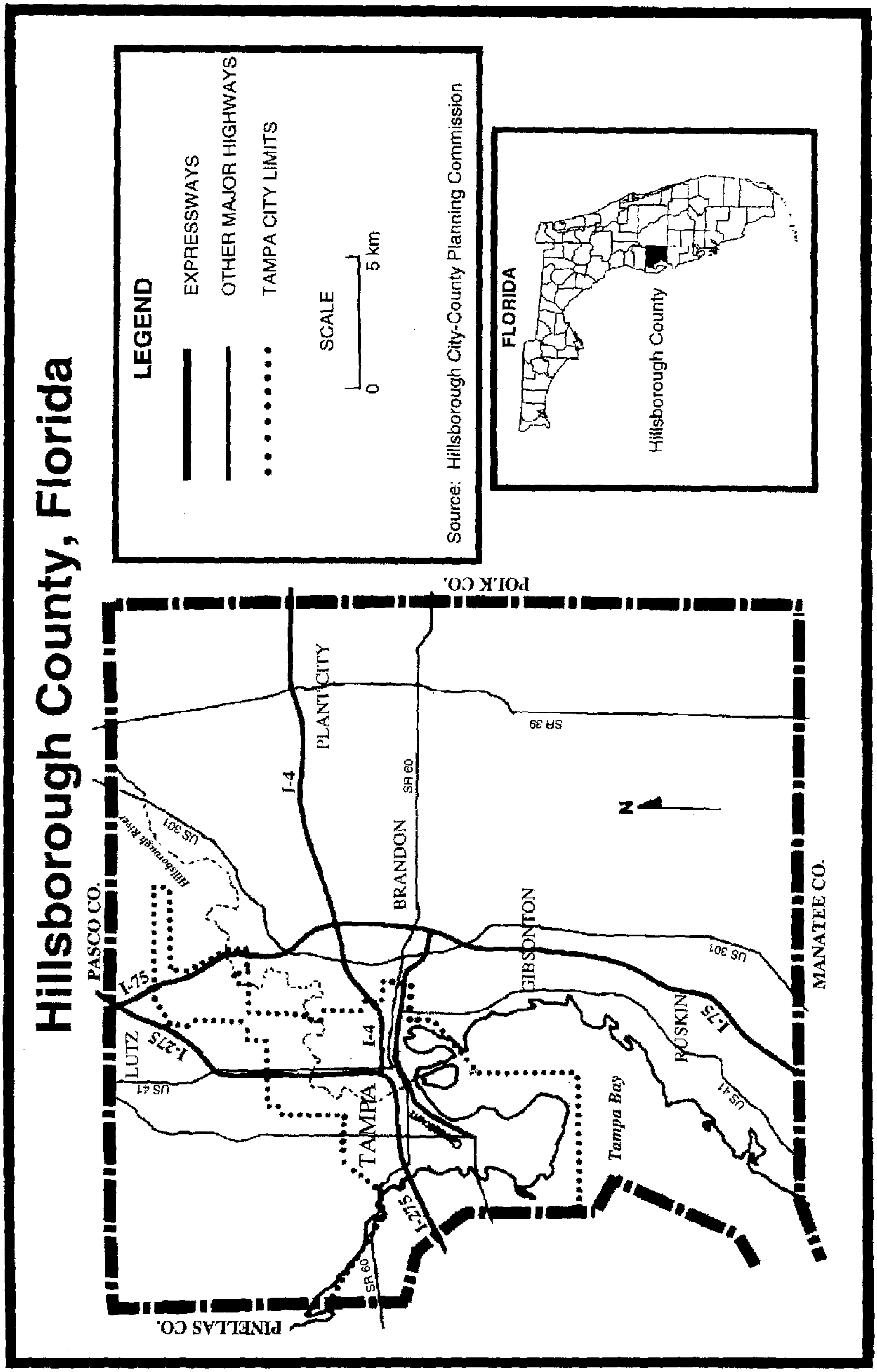

Figure 1 *The location of the City of Tampa in Hillsborough County, Florida.*

bourhoods. Many homes and properties border the highway. Brinkmann (1994) has demonstrated that there is lead contamination in lawn and garden soils in Tampa's older neighbourhoods. It is the purpose of this study to determine if soils along Tampa's major expressway contain levels of lead hazardous to human health which could threaten adjacent neighbourhoods and if the patterns of the lead distribution are similar to those identified in other studies.

Study Area

The study area is the right of way on both sides of I-275 in Hillsborough County, Florida (population 834 000 (Shermyen, 1991)). I-275 is located in west-central Hillsborough county (Figure 1) and lies predominantly within the city limits of Tampa (population 280 000 (Shermyen, 1991)). West-central Hillsborough county is characterised physiographically by nearly level coastal plains near Tampa Bay and by large, nearly level flatwoods away from the bay, punctuated by intermittent ponds, swamps, marshes, and numerous permanent lakes in the northern section of the study area. Elevations range from sea level to about 6 m in Tampa and higher in the northern part of the study area. Surface drainage is toward Old Tampa Bay, Tampa Bay, and Hillsborough Bay *via* the Hillsborough River and other smaller streams (Soil Conservation Service, 1989).

The underlying parent material for soils in Hillsborough County consists mainly of marine quartz sand, clay, and shell fragments. These materials were deposited by seawater that covered the area several times during the Pleistocene epoch (Soil Conservation Service, 1991). The soils adjacent to I-275 are the product of human alteration and construction, but have characteristics similar to surrounding unaltered soils.

I-275 is part of the US interstate highway system and is a limited access, frequently elevated expressway. The construction of I-275 south of the interchange at Interstate Highway 4 (I–4) was completed in 1958 and was originally part of I–4; the portion north of the I–4 interchange was completed in the mid 1960s (Figure 2). The study area consists of the portion of the I-275 corridor extending from the Bearss Avenue interchange in the north to the State Road 60 (SR 60) interchange in the south (19.4 km) and is bordered by residential, commercial, and recreational areas for most of its length.

The I-275 right of way contains mostly grassy vegetation with some shrubs and vines along the fence lines at the edge of the corridor. However, portions of the right of way were landscaped in recent years, mainly with rows of long needle pine trees (*Pinus elliottii*) near some residential areas and clusters of sabal palms (*Sabal palmetto*) around most overpasses. This landscaping, along with the alteration of several entrance and exit ramps and widening of the highway in various places in the past five years, has caused some disruption of the soils.

Methods

Soil samples were taken at point locations along transects perpendicular to the highway (Lounsbury and Aldrich, 1986). Transects were established at the approximate midpoint between interchanges as measured by automobile odometer. In several cases, overpasses or other obstructions at the midpoint location made it necessary to relocate the transect site to the next available location beyond the midpoint in the direction of the traffic flow. Midpoint locations were chosen because they offer the least chance of anomalously high values, as opposed to locations near interchanges which can exhibit higher lead levels from vehicle acceleration, deceleration and idling (Francek, 1992).

Previous research has shown that lead levels decrease rapidly with distance from the road edge (Motto *et al.*, 1970; Solomon and Hartford, 1976; Wheeler and Rolfe, 1979; Agrawal *et al.*, 1980; Muskett and Jones, 1980; Burguera and Burguera, 1988; Culbard *et al.*, 1988). In this study, exponential sampling intervals were utilised in an attempt to determine if this method can provide a better model of the relationship between soil lead levels and distance from the highway without log transformation of the distance scale. Seven samples were taken on each transect at distances of 3, 9, 27, 81, 243, 729, and 2187 cm from the edge of the highway. Because the highway right of way width varied, the most distant sample on each transect was taken either at 2187 cm or, if shorter, at the right of way fence line.

A total of 224 samples were collected from the upper 3 cm of solum using a plastic spatula. These samples were returned to the University of South Florida Hydrology and Physical Geography Laboratory where they were ground using a pestle and mortar and sieved through a 1 mm mesh screen to obtain a more homogeneous grain distribution (Gilbert and Doctor, 1985). The lead was extracted by dual digestion with 1:1 nitric acid and 30% hydrogen peroxide and then 1:1 hydrochloric acid. After cooling and filtration, the lead content in the digestant was measured using atomic absorption spectrophotometry in the University of South Florida Chemistry Laboratory. These methods are similar to those outlined by McGrath and Cunliffe (1985). Laboratory procedures were completed twice on every fifth sample in order to maintain quality assurance (Davies, 1989). An *F*-test, comparing the variances between the original and replicate samples, was completed. The variances between the sample suites were indistinguishable within a 90% confidence

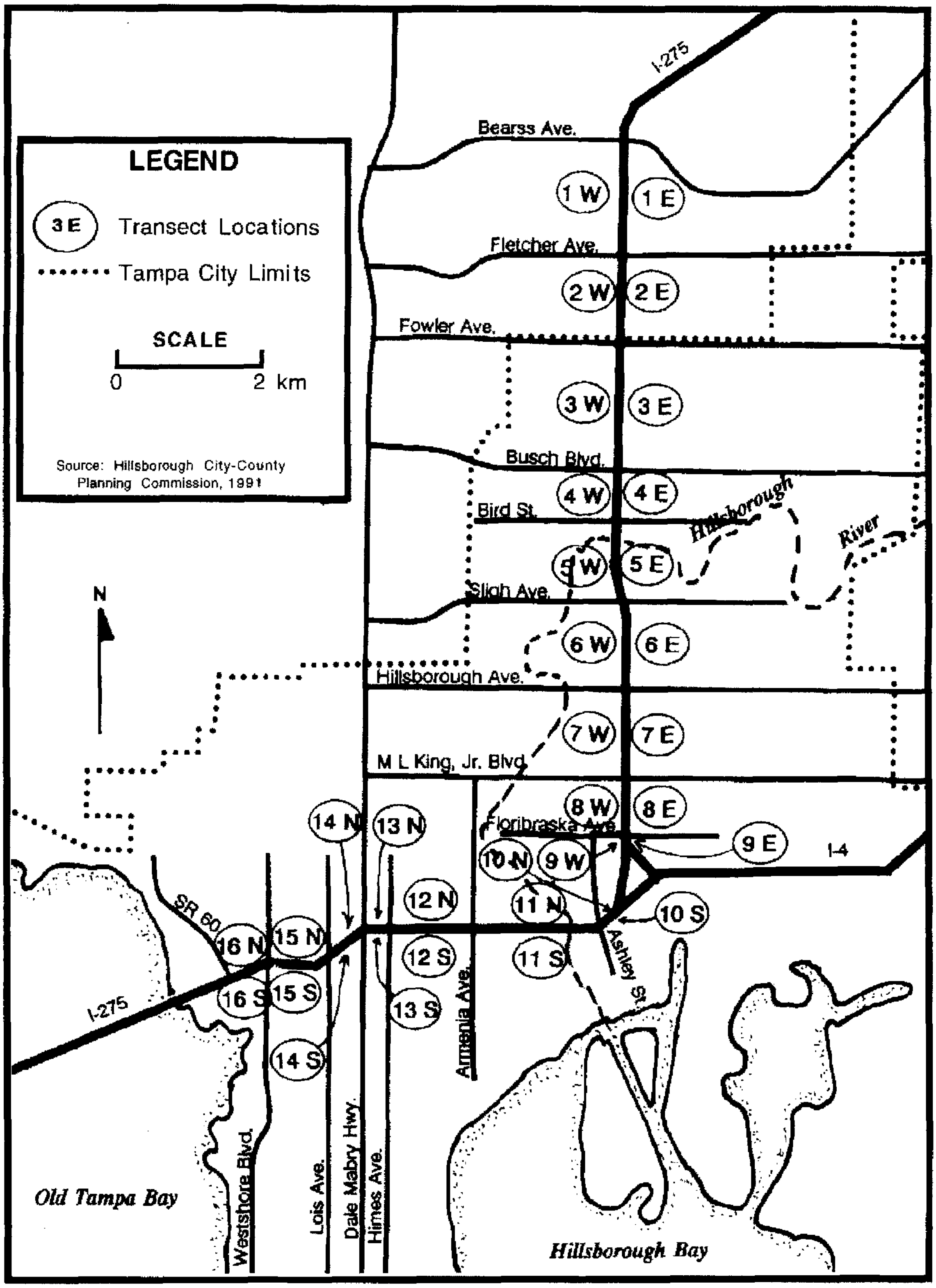

Figure 2 *Map of Interstate Highway 275 showing transect locations.*

interval. A t-test of the means of the two sets of data yielded a t-value less than the critical t at 90% confidence levels. Therefore, the means of the two sets are also indistinguishable. The F-test and t-test results indicate successful replication in the lead extraction and measurement procedures.

Results and Discussion

The soil lead values for the samples are listed in Table 1. Lead values are distributed about a mean of 473 $\mu g\ g^{-1}$, a median of 350 $\mu g\ g^{-1}$, and standard deviation of 478 $\mu g\ g^{-1}$. Using procedures outlined by Davies (1980), background (expected) lead levels for the study area were calculated to be within the range of 0 to 60 μg g^{-1}. Ninety percent of the samples in the study area show lead levels above expected values. Over one-third of the samples have lead levels of 500 μg g^{-1} or greater, levels considered to be hazardous waste by the US Environmental Protection Agency (EPA) and dangerous to humans, especially children (Centers for Disease Control, 1985; Chaney and Mielke, 1986; Wixson and Davies, 1994).

To determine the strength of the relationship between lead levels and distance from the highway, a sample correlation analysis was performed on the normalised data. The Pearson product-moment correlation coefficient was calculated for the distance and lead variables. The r-value for the normalised data is −0.197, indicating a weak negative relationship between soil lead and distance from the highway. Motto *et al.* (1970) and Wheeler and Rolfe (1979) found stronger relationships.

Approximately two-thirds of the transects show lead levels increasing beyond levels at the road edge sites, at either the 81, 243, or 729 cm samples distances. Lead values then decrease at the farthest sampling sites. This is in contrast to the findings of other researchers who demonstrated that lead values decay logarithmically from maximum values closest to the highway (Chow, 1970; Motto *et al.*, 1970; Wheeler and Rolfe, 1979; Muskett and Jones, 1980; Agrawal *et al.*, 1980; Culbard *et al.*, 1988).

There is a marked divergence in the ranges and the overall soil lead values among the transects. For example, soil lead at transect 16 North (Table 1) ranges from 40 to 420 μg g^{-1}, while values at transect 9 East (Table 1) range from 280 to 3360 μg g^{-1}. It is somewhat easier to explain the low end values as anomalies, frequently related to recent construction and landscaping which have disturbed the soils at several sites. This is true of transect 16 South (Figure 2), where an overpass was widened, an exit ramp removed, and the entire area replanted with sod in 1991, prior to sampling. The disruption of the soils and the likely addition of fresh soil during landscaping accounts for the lower values at this and several other sites.

The number of samples per transect with lead values greater than 500 μg g^{-1} are displayed in Table 2.

Table 1 *Actual soil lead values (μg g^{-1}) collected along all transects adjacent to Interstate Highway 275.*

Transect	Sample 1 3 cm	Sample 2 9 cm	Sample 3 27 cm	Sample 4 81 cm	Sample 5 243 cm	Sample 6 729 cm	Sample 7 800+ cm
1 east	2420	180	120	160	120	240	60
1 west	120	120	60	180	320	160	80
2 east	1100	1100	920	740	840	400	100
2 west	180	120	60	60	300	300	160
3 east	100	40	60	280	480	440	200
3 west	800	800	520	300	460	120	160
4 east	720	300	240	1000	360	420	60
4 west	1960	1140	1500	1140	580	720	400
5 east	600	480	480	500	660	160	100
5 west	540	660	640	1020	860	760	140
6 east	420	240	320	300	840	220	340
6 west	600	280	340	520	540	220	360
7 east	360	580	280	420	820	160	220
7 west	280	620	840	1020	760	520	160
8 east	500	600	520	1040	500	380	80
8 west	360	360	920	660	360	580	940
9 east	2460	3360	1400	1260	960	300	280
9 west	240	240	240	580	280	300	280
10 north	500	300	420	960	800	1140	440
10 south	160	280	340	460	100	360	120
11 north	120	120	320	580	1040	200	400
11 south	120	180	580	180	460	600	340
12 north	120	100	160	180	1080	1140	1480
12 south	160	460	100	200	540	460	460
13 north	500	240	360	220	240	100	60
13 south	60	160	160	180	200	180	240
14 north	60	540	500	540	520	420	440
14 south	700	780	180	1860	400	620	160
15 north	420	840	3240	1360	920	160	140
15 south	360	100	60	520	280	320	540
16 north	40	40	100	40	420	40	100
16 south	100	160	100	60	60	60	340

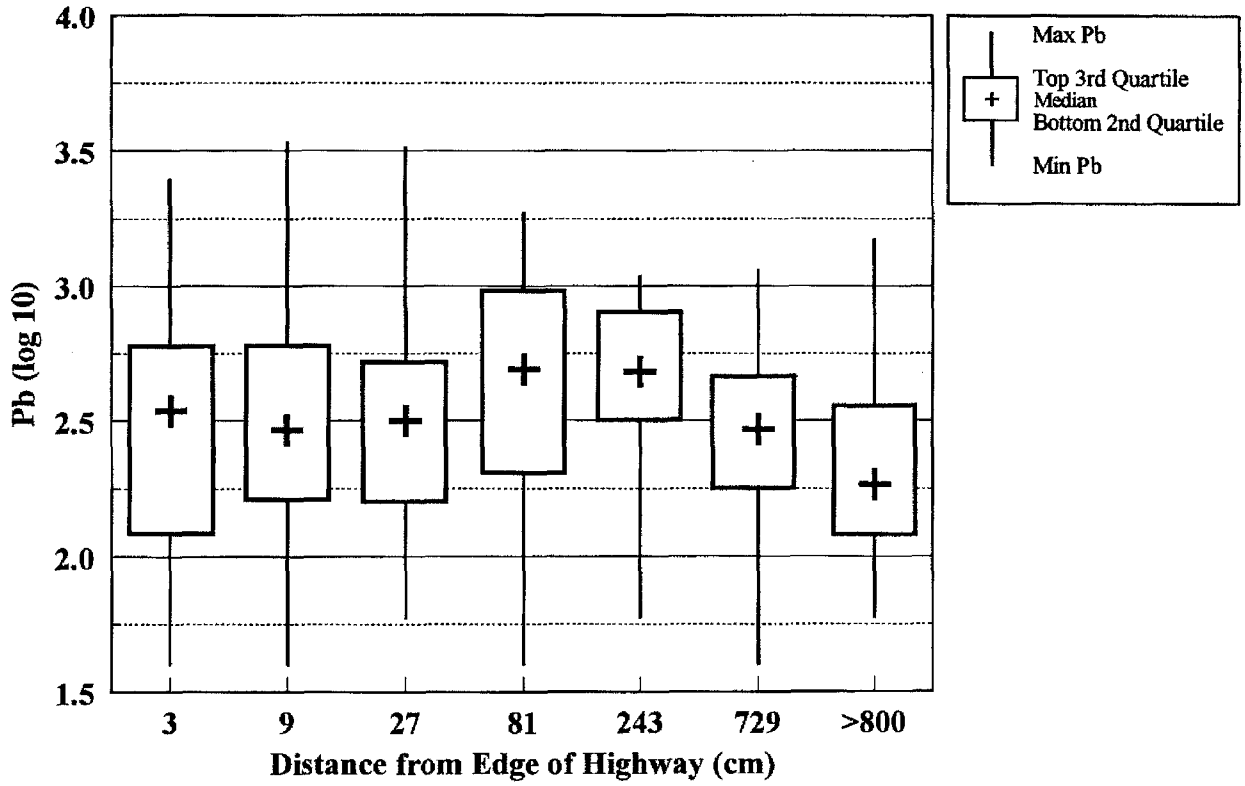

Figure 3 *Box and whisker graph of range and median lead values (log_{10}) grouped by distance from the edge of the highway.*

There are clearly some locations with significant accumulations of soil lead, although it is difficult to discern any pattern to the distribution of these contaminated areas. The only transect pair with no contaminated sample sites is transect 16, where construction disturbed soils and vegetation.

To observe aggregate patterns in the relationship between soil lead and distance, the data were grouped by the 3, 9, 27, 81, 243, and >800 cm distances and normalized (Table 3). The mean values range from 212 $\mu g\ g^{-1}$ at the most distant sampling sites to 444 $\mu g\ g^{-1}$ at 243 cm. The mean values at the 3, 9, and 27 cm sampling distances show little variation. This is not surprising since these sites are all very close together. However, a distinct increase in the mean values occurs at the 81 and 243 cm distances before the mean values decline. The relationship is shown in Figure 3. This increase in the mean values at these distances is significant in that a steady *decrease* was expected, based on previous research.

Table 2 *The number of sample sites per transect with soil lead values of 500 $\mu g\ g^{-1}$ or greater.*

Sites	Transect	Sites
West		East
0	1	1
0	2	5
3	3	0
6	4	2
6	5	3
3	6	1
5	7	2
4	8	5
1	9	5
North		South
0	10	4
2	11	2
1	12	3
0	13	1
4	14	4
2	15	4
0	16	0

The lack of clear patterns in the lead values with respect to distance from the highway indicates the influence of confounding variables with time. This is further evidenced by the rather weak correlation between lead levels and average daily traffic counts (ADT) which are compared for 1977 and 1991 in Table 4. The relationship between lead and traffic was shown to be much stronger in other studies (Ward *et al.*, 1974; Ash and Lee, 1980; Piron-Frenet *et al.*, 1994).

Other variables that were investigated are wind velocity and transect slope. Wind direction has been positively correlated with soil lead levels, with higher levels of soil lead found downwind from both point and line sources of lead (Chow, 1970; Ward *et al.*, 1974; Schalscha *et al.*, 1987; Piron-Frenet *et al.*, 1994). No significant relationship between wind

Table 3 *The normalized mean, median, standard deviation, and maximum soil lead values in μg g^{-1} grouped by distance from Interstate Highway 275.*

Distance	Samples	Mean	Median	σ	Maximum
3 cm	32	316	360	596.6	3460
9 cm	32	305	290	501.1	3360
27 cm	32	303	330	539.1	3240
81 cm	32	403	510	653.0	1860
243 cm	32	444	480	445.7	1080
729 cm	32	295	310	345.1	1140
>800 cm	32	212	210	259.4	1480

Table 4 *Pearson product moment correlation coefficients (r) for soil lead values and average daily traffic counts (ADT) for 1977 and 1991.*

	1977	1991
All soil lead values	0.413	0.295
Maximum lead values at each transect	0.258	0.181
Mean lead value at each transect	0.474	0.283
Number of values at each transect 500 μg g^{-1} or higher	0.452	0.299

velocity and soil lead values was evident in the study area; however, this was based on comparison with general wind patterns for the Tampa area, rather than the microclimatic features which probably control deposition patterns (Oke, 1978; Eskridge and Rao, 1983). Rao *et al.* (1979) found that there is a maximum distance downwind from a roadway up to which both natural turbulence and traffic-generated turbulence will govern the dispersal of pollutants, beyond which only natural turbulence affects the diffusion process. They found that traffic-generated eddies could extend 4–8 m from their source, with their effect more pronounced when the wind direction was parallel to the highway. A more detailed study of these effects would be necessary in the Tampa study to determine their correlation with the pattern of lead distribution.

Correlations were also run between lead parameters and calculated slopes for each transect, revealing weak positive relationships between increasing slope and all lead values ($r = 0.162$) and between slope and values at the 243 cm ($r = 0.172$) and 729 cm ($r = 0.245$) sampling sites on all transects, where the highest mean values occurred. We interpret this as a relation to mass movement of soils downslope, but it could also reflect some aspect of microclimate (e.g. wind turbulence downslope). Again, further study is necessary to determine any relationship with microclimatic parameters.

Conclusions

Lead concentrations within the 224 samples ranges from 40 to 3360 μg g^{-1}, with a geometric mean of 317 μg g^{-1}. Over one-half of the samples contained more than 500 μg g^{-1} of lead – a level considered hazardous by the Centers for Disease Control (1985). There is a weak negative correlation between soil lead and distance from the roadway; as distance from the edge of the highway increases, lead decreases. The weakness of the correlation appears to be related to roadside air turbulence or some other microclimatic feature, mass wasting of sediment with increasing slope (causing higher mean values away from the edge of the highway before the expected exponential decrease), and human factors disrupting the soils such as construction and landscaping. Samples collected closest to the roadway may contain less lead because they fall within an area where small lead particles are transported away from the road by turbulence. The lead is deposited further downslope, causing unexpectedly higher lead values between 81 and 729 cm from the roadway. These results demonstrate that there is no simple logarithmic relationship between distance from the roadway and lead soil after long periods of time without additional deposition.

Hazardous levels of lead were found at most transect locations. Residential areas about twenty transects having one or more sample sites with values at or greater than 500 μg g^{-1}. Individuals living in these areas may be at risk of lead poisoning from lead particulates originating at the roadside. It is suggested that dust samples from homes in these areas be tested for lead to assess the magnitude of the potential threat.

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