4-1-1992

ANALYSIS OF LEAD IN SOILS ADJACENT TO INTERSTATE 275 IN TAMPA, FLORIDA

Mark R. Hafen
University of South Florida

Graduate Council
University of South Florida
Tampa, Florida

CERTIFICATE OF APPROVAL

MASTERS THESIS

This is to certify that the Master's Thesis of

Mark R. Hafen

with a major in Geography has been approved by the Examining Committee on April 1, 1992 as satisfactory for the Thesis requirement for the Master of Arts degree.

Thesis Committee:

Major Professor: Robert Brinkmann, Ph.D.

Member: Robert T. Aangeenbrug, Ph.D.

Member: Mark B. Lindberg, Ph.D.

ANALYSIS OF LEAD IN SOILS ADJACENT TO INTERSTATE 275 IN TAMPA, FLORIDA

by

Mark R. Hafen

A thesis submitted in partial fulfillment of
the requirements for the degree of Master of Arts
in the Department of Geography
in the University of South Florida

May 1992

Major Professor: Robert Brinkmann, Ph.D.

ACKNOWLEDGEMENTS

I would like to thank Geralyn Flick, Karen Lowman, Johannah Anderson, and Dale Nabors for their assistance in the collection of soil samples. I would also like to thank Bruce Antolik for arranging for laboratory space, Benjamin Needleman and James Poehlman for assistance in the lab, and Charles Norris of the Department of Chemistry for operating the atomic absorption unit. Finally, I would like to thank my Committee members, Dr. Mark Lindberg and Dr. Robert Aangeenbrug, for their help and encouragement and my Committee Chair, Dr. Robert Brinkmann, for his patience and guidance throughout this study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ANALYSIS OF LEAD IN SOILS ADJACENT TO INTERSTATE 275
IN TAMPA, FLORIDA

by

Mark R. Hafen

An Abstract

Of a thesis submitted in partial fulfillment of the
requirements for the degree of Master of Arts
in the Department of Geography
in the University of South Florida

May 1992

Major Professor: Robert Brinkmann, Ph.D.

Analysis of two hundred and twenty-four soil samples collected at logarithmic intervals on perpendicular transects adjacent to Interstate Highway 275 in Tampa, Florida revealed that thirty-five percent of the samples contained health-threatening levels of lead (greater than 500 ppm), although the pattern of contamination was not predictable. Twenty-two of the thirty-two transect locations extended toward residential areas and, of these, twenty contained soil lead values dangerous to humans. This analysis also revealed that soil lead does not decrease logarithmically with distance from the highway, as shown in other studies. Soil lead at 3, 9, 27, 81, 243, 729, and 2187 cm distances averaged 316, 305, 303, 403, 444, 295, and 212 ppm respectively.

Abstract approved: ______________________________
Major Professor, Robert Brinkmann, Ph.D.
Assistant Professor, Department of Geography

____
Date of Approval

CHAPTER 1
INTRODUCTION

Lead is a pervasive health problem in urban areas. Elevated blood lead levels and lead poisoning, especially among children, are considered the most common environmentally caused health problems in the United States (Centers for Disease Control, 1985; and U.S. Senate Committee on Environment and Public Works, 1990a). In urban areas, the most prevalent sources of lead are chips and dust from lead based paints; drinking water, from lead solders and pipes; and soils, primarily from automobile exhaust.

Production of lead based paints was limited in 1972, but dust and chips from deteriorating paint in older dwellings remain a cause of lead poisoning. Similarly, most lead was eliminated from gasolines by 1986. However, the lead particulates from years of leaded fuels have accumulated in roadside soils. This lead stays in the surficial soil layer and, through the actions of wind and water, becomes part of lawn and garden soils and household dusts in homes near roads. Through a variety of pathways, this lead is ingested by humans, resulting in elevated blood lead levels which result in health problems such as anemia and kidney failure, as well as reduced I.Q. levels in children.

Although there is an abundance of research on lead in soils from many urban areas, few studies of soil lead contamination have been performed in Florida. In Tampa, Brooks and Doyle (1991) found high levels of lead in sediments in Tampa Bay. Brinkmann (1990a and 1990b) recently began research on the distribution of lead in lawn and garden soils of Tampa. No studies of roadside soil lead have been undertaken in Tampa.

The potential for elevated levels of roadside soil lead in Tampa is greatest near high volume traffic arteries. Many such highways are adjacent to residential and recreational land use areas, providing a potential source of lead poisoning to people in these areas. Therefore, a study was undertaken to analyze the lead content of the soils of one major highway in Tampa -- Interstate 275 -- to determine the potential lead hazard to people living near the highway right of way.

In this thesis, the results of the analysis of lead in the soils adjacent to Interstate 275 (I-275) are reported. The chief aims of the research are to measure the lead content of the soils in the I-275 right of way, determine the potential lead hazard to people living near the highway, and add to the database begun by Brinkmann (1990a and 1990b) on the total lead budget for Tampa.

In addition, several objectives are identified as part of this research. These objectives center primarily on determining the relationship of soil lead with distance from

the edge of I-275 and comparing the findings with those from other studies. 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; and Muskett and Jones, 1980) and that the pattern of lead accumulation in the soil is correlated with traffic density (Ward et al., 1974), soil properties (Zimdahl and Skogerboe, 1977), and climatic factors such as winds and turbulence (Oke, 1978; Rao et al., 1979; and Eskridge and Rao, 1983). It is an objective of this study to determine if these relationships hold true for the soils adjacent to I-275 in Tampa and to assess the relevance of other factors, such as traffic density, ground slope, and roadside turbulence, in contributing to the pattern of soil lead distribution.

Analysis of the soils near I-275 began in November 1991. Two hundred twenty-four soil samples were collected from the upper three centimeters of solum between interchanges at logarithmic intervals along thirty-two transects perpendicular to the highway. Lead was extracted from one gram soil samples by heating them in acid solution. Lead content was measured using atomic absorption spectroscopy. The resulting database was analyzed with respect to the soil lead/distance relationship and the overall pattern of soil lead contamination in the study area using exploratory data analysis (EDA) (Tukey, 1977) and other statistical techniques.

The body and results of the study are reported in this thesis in the five chapters which follow. Chapter 2 is a review of the literature relevant to the study of lead contamination. The chapter begins with a brief history of the health hazards lead has presented to humans from antiquity to the present. This is followed by a section which details studies on the effects of lead on human health, the symptoms of lead poisoning, and the debate over what are safe levels of lead in the environment. Two sections follow which identify the pathways of lead from natural and humanly created sources into the environment and finally into flora, fauna, and humans. The final sections of Chapter 2 focus on lead in soils and, specifically, the accumulation of lead in roadside soils. The intent of this chapter is to provide a basis for the argument that there is a need to study roadside soil lead in Tampa and that potential lead health hazards can be identified based upon results of the I-275 soil analysis and the work of previous researchers.

The third chapter outlines the methods used to conduct the analysis of lead in soils adjacent to I-275. Chapter 3 begins with a description of the study area with respect to climate, soils, vegetation, and locational factors. In the three sections which follow, the soil sampling strategy and the methods of soil sample collection, preparation, and lead extraction are explained. An important aspect of the sampling strategy is the development of an exponential

sampling distance plan for the transects based upon the expected soil lead/distance relationship. The chapter ends with a review of the statistical techniques utilized in the analysis of the soil lead data.

The results of the lead extraction procedures are discussed in Chapter 4. The data are presented first in terms of the general soil lead database and then by individual transect. The data are also aggregated by sample distance from the highway in order to examine the overall soil lead/distance relationship for the I-275 study area.

Chapter 5 expands upon the results presented in Chapter 4 with more detailed analyses and explanations for the patterns of soil lead distribution observed. The chapter opens with an assessment of the effectiveness of the soil sampling plan in relation to the observed results. Following are analyses of the soil lead patterns with regard to average daily traffic, transect slope, highway turbulence, and soil organic matter content. The final aspect of the data that is examined is the identification of locations along I-275 with lead contaminated soils and how these locations relate to human land use near the highway.

The final chapter summarizes the conclusions reached from the analyses in Chapter 5 regarding both the effectiveness of the soil sampling strategy and the pattern of soil lead distribution observed along I-275. Further research is also suggested to augment and improve upon the findings of this study.

CHAPTER 2
LITERATURE REVIEW

Lead (Pb) is a common element found naturally in soils, rocks, and water. Throughout history, humans have extracted lead from the earth's crust and have brought about its dissemination into the environment at levels that are hazardous to humans, plants, and animals. These hazards have been addressed by the scientific community only recently, yet lead toxicity has been suspected and documented for millennia.

In order to assess the scope of the problem of modern lead contamination, it is necessary to examine the history of human lead use and the historic and current documentation regarding the effects of lead exposure on humans. This includes identifying lead sources and the transport mechanisms which bring lead into contact with people. Specifically, the accumulation and behavior of lead in soils is examined, with particular emphasis on soils adjacent to roads, where, over the years, automobile exhaust has provided a source of lead particulates.

The results of this examination form the basis for the research at hand, that is the analysis of lead in soils adjacent to Interstate Highway 275 (I-275) in Tampa, Florida. I-275 is a major traffic artery located in Hillsborough County, Florida, predominantly within the Tampa

city limits. This highway is adjacent to many residential areas throughout Tampa and is a potential line source of lead particulates for the soils of its right of way. These soils, in turn, may be a source of lead in the garden soils and household dusts of the residential areas bordering the highway right of way, posing a health hazard to people, especially children, in these areas. By examining both the history of lead toxicity and the current body of research on lead contamination, one gains an understanding of the need to study the soils of I-275 to ascertain the potential health hazard to people near the highway.

History of Lead as a Health Hazard

Although lead poisoning and lead contamination have been controversial issues recently, lead toxicity from exposure has been documented throughout history. Lead poisoning is considered a disease of the Industrial Revolution. However, symptoms of lead poisoning were known, described, and documented for at least 5000 years prior to that period (Lessler, 1988). The Romans, Egyptians, Greeks, and other historic cultures all left records indicating lead miners and others who worked with lead, such as metallurgists and potters, developed ailments that resulted in illness and premature death (Lessler, 1988). The ancient Egyptians were the first to document the maladies associated with constant exposure to lead that were suffered by the slaves in their mines (Nriagu, 1983). Later, it was noted by

the Greek Hippocrates (460-377 BC) that animals pastured near lead mines soon became sick and died. He also described symptoms of lead poisoning among humans who regularly worked with lead, noting appetite loss, colic, pallor, weight loss, fatigue, irritability, and nervous spasms. These are the same symptoms observed today in individuals with lead toxicity (Nriagu, 1978b; and Lessler, 1988). However, there are no records of attempts to remedy or prevent these symptoms by elimination of exposure to lead, other than to avoid pasturing animals near lead mines.

During the Middle Ages in Europe, there was a marked increase in the use of lead and lead-containing products. Writings of physicians from this period indicate an awareness of sources and symptoms of lead poisoning. For example, foods and wines fortified with sapa, a sweet syrup formed from lead acetate [$Pb(C_2H_3O_2)_2$] by boiling acidic wine in lead-lined vessels, were found to induce symptoms of lead poisoning. As a result, adulteration of wines with sapa was outlawed by the French, Spanish and Germans in the 1400's (Lessler, 1988). Although sapa is no longer added to wines, lead still appears in wines due to lead-foil cork covers which leave lead residue on corks and the mouths of wine bottles. Recent U.S. government tests found that lead levels in some poured wines are higher than the maximum level allowed in drinking water (Anonymous, 1992b).

From the 18th century on, there was a tremendous expansion in the fabrication of metals and in the number of

industries using lead and lead products in Europe and in Colonial America (Lessler, 1988). This occurred despite growing evidence of lead's toxicity. For example, in the 1700's an Italian physician, B. Ramizzini, linked diseases shared by potters, guilders, glass makers, and metal workers with lead poisoning. However, the use of lead in these occupations continued despite obvious deleterious health effects. Eventually some uses of lead were curtailed for health reasons. In the North American colonies, lead pounds and presses were used to make apple cider and lead pipes and vessel covers were used in rum production. However, after the connection was made between extensive sickness (lead poisoning) and the consumption of these beverages (Aronson, 1983), use of lead-containing equipment for rum and cider production was prohibited by law.

Lead was used in other products including glazed earthenware, pewter, lead pipe, lead shot, lead type for printing, lead pigments for paints, food and other household products. It was sometimes added to red pepper; lead acetate and lead oxide (PbO) were used to sweeten and whiten bread; and a PbO product for putty was used in the process of installing windows and was sometimes added to snuff. The result was rampant lead intoxication in Colonial America. Not surprisingly, accusations of witchcraft arose due to the aberrant behavior exhibited by individuals with lead neuropathy (Green, 1985; and Lessler, 1988).

In the late 1890's, childhood lead poisoning related to contamination in housing was documented in Australia (U.S. Senate Committee on Environment and Public Works, 1990a). This was attributed to accumulation of lead in house dusts from lead-based paints and other sources. In the early twentieth century, in Point Pirie, Australia, a high number of workers at a primary lead smelter suffered from lead poisoning. This prompted the formation of a Royal Commission on Plumbism (lead poisoning), which resulted in the adoption of dust-supression measures at the smelter (Body et al., 1991).

By the 20th century, when occupational health was recognized as an important government issue, the United States and several European nations began passing legislation protecting workers from toxic environments. As evidence mounted regarding the hazards of lead and other toxic substances, the need for the protection of the public became more important (Woolley, 1984). In the U.S., the Occupational Health Act of 1970 created the National Institutes of Occupational Safety and Health (NIOSH), which enforce regulations governing the clean up of toxic wastes and which first set limits of acceptable levels of lead in food, water, and air. The levels were revised downward as evidence of the detrimental effects of lower levels of lead exposure were observed in children (Johnson and Mason, 1984). Further legislative actions resulted in the removal or reduction of lead from paints and as an antiknock

additive to gasolines, because these products were identified as two major sources of lead particulate compounds in household dusts and soils (U.S. Senate Committee on Environment and Public Works, 1990a).

Currently, debate is ongoing in the United States as to the extent of the effects of lead exposure on children and adults and the legislative actions that should be taken to further combat the problem. In testimony surrounding two U.S. Senate bills to reduce environmental lead contamination and exposure, witnesses referred to the results of studies which detailed pathways and levels of lead exposure in the environment, homes, and industries. Using these studies, witnesses identified the toxic symptoms and overall health hazards of lead exposure and made recommendations for clean up of contaminated sites and prevention of additional health problems (U.S. Senate Committee on Environment and the Public Works, 1990a and 1990b).

A salient aspect of the testimony before the Senate concerns the effects of lead on human metabolic functions, particularly in children. It is therefore important to review some of the studies discussed before the Senate to understand how ingested lead impacts the human body. Of particular note are the differences in the symptoms between adults and children. Children absorb a higher percentage of the lead they ingest and have more severe health effects than adults. This is an important consideration in analyzing the potential lead hazard near the I-275 corridor in Tampa.

The presence of children close to the highway emphasizes the need to assess the concentration and distribution of soil lead near the highway.

<u>How Lead Affects the Human System</u>

Although many heavy metals are required in trace levels for cellular metabolic activity, larger quantities of these substances are generally toxic (Wood and Goldberg, 1977). Lead is not needed in human metabolic functions. When ingested, it concentrates in several different types of body cells and becomes toxic. Ingested lead is absorbed gastrointestinally and is distributed initially to soft tissues such as the liver and kidneys. It is subsequently distributed through the bloodstream to other organs, sometimes replacing calcium in metabolic functions. The resulting symptoms are anemia, renal dysfunction, and the impairment of the central nervous system. (Nriagu, 1978a and 1978b; Tierney et al., 1979; Committee on Lead in the Human Environment, 1980; Lessler, 1988; and Anonymous, 1992c). Although continued exposure to lead results in health problems in adults, 80-90% of the lead they ingest is excreted. That lead which remains may be stored in the bones where it does little harm unless released again into the bloodstream by illness or bone fracture (Lin-Fu, 1972; and Chisolm et al., 1975).

In contrast, children absorb a higher percentage of the lead they ingest and thus have health effects of a greater

magnitude than adults. A controversial study by Needleman et al. (1979) connected childhood lead poisoning with poor school performance and a concomitant lowering of IQ levels. The authors found that the children showed the major physical symptoms of lead poisoning, such as anemia and renal dysfunction. They also exhibited increased attention deficits, hyperactivity, and neurotoxicity. These children had a six times greater risk of a reading disability and a seven times greater risk of not completing high school than those children without lead poisoning.

Critical Blood Lead Levels. The results of the Needleman et al. (1979) study fueled debate and led to additional research into lead toxicity in children (U.S. Senate Committee on Environment and Public Works, 1990a). In 1985, the Centers for Disease Control (CDC) issued a bulletin on lead poisoning prevention in children based, in part, on the 1979 Needleman et al. study. In this statement, the CDC outlined the pathways by which lead particulates become part of the home environment and are then ingested by children. The CDC urged testing of children for blood lead content and identified critical levels of lead contamination in blood. In 1973, blood lead levels over 40 micrograms per deciliter (ug dl^{-1}) were considered health-threatening. However, these levels were revised downward to 25 ug dl^{-1} in 1981, and then to 10 ug dl^{-1} in 1991 (Behm, 1991). Levels as low as 10-15 ug dl^{-1} have been linked to symptoms of

childhood lead poisoning by researchers such as Needleman (U.S. Senate Committee on Environment and Public Works, 1990a). Despite attacks on the methodology and conclusions of the Needleman et al. study by the lead industry and by other researchers (Palca, 1991), the U.S. Congress, the CDC, and many environmental groups have concluded that lead poisoning is the most common environmental disease of young children and must be curtailed (CDC, 1985; and U.S. Senate Committee on Environment and Public Works, 1990a).

Safe Environmental Levels. Debate continues, however, concerning the levels of lead in air, water, soil, and household dust which are considered safe. Members of the U.S. Senate Committee on Environment and Public Works (1990a) noted that there is currently no consistent standard for lead in soils. The Committee has therefore mandated the establishment of such standards within eighteen months of the enactment of the bill to amend the Toxic Substances Control Act proposed in 1990 (U.S. Senate Committee on Environment and Public Works, 1990b). Some argue that it is difficult to derive any standard value for lead in soil or dust based on existing scientific evidence (Thornton, 1986).

However, there are some similarities in proposed guidelines. The CDC (1985) proposed that soil lead levels of 500-1000 parts per million (ppm) place children at risk and require mitigation. Chaney and Mielke (1986) argued that continued exposure to levels of 500-1000 ppm elevates blood

lead levels to 25 ug dl^{-1}. They proposed that the soil lead standard should be lower, although they gave no specific guidelines. In contrast, Davies and Wixson (1986) argued that natural soil lead levels vary and that one standard is therefore inappropriate. However, Davies and Wixson consider the presence of higher levels of soil lead in urban areas to be normal. Thus instead of acknowledging the need to reduce lead deposition in urban areas, they argue for a higher threshold (2000 ppm), one which others have already demonstrated will result in elevated blood lead levels in children (CDC, 1985; Chaney and Mielke, 1986; and U.S. Senate Committee on Environment and Public Works, 1990a). It appears likely, however, that a soil lead threshold of 500 ppm or lower will be adopted. The U.S. Environmental Protection Agency already considers soil with lead levels above 500 ppm to be hazardous waste (Anonymous, 1992a).

Although there is controversy over establishing guidelines for safe levels of lead in the environment, there is less argument concerning the sources of ingested lead. Point, line, and areal sources have been identified, as well as the transport mechanisms which bring them into contact with humans. The following section reviews important studies in which lead sources and pathways are detailed. Of principal interest are the ways lead particulates in soils and paint dust become part of the home environment and threaten adults and children. Lead in soils near highways, through the actions of wind, water, and other mechanisms,

becomes part of household dust and accumulates in lawn and garden soils, providing an easily accessible source of lead to children in these areas. The I-275 corridor in Tampa could be such a source of lawn, garden, and household lead. Understanding the processes by which lead moves from source to residential destination helps clarify the potential hazard to people near this traffic artery.

Lead Sources, Transport, and Destinations

In order to understand the pathways by which lead enters the human environment, it is necessary to establish both natural and human sources of lead. Wood and Goldberg (1977) assert that identifying the sources and geographic locations of toxic metals is an important aspect of determining how human activities bring about their transport. They note that human action provides new sources of toxic elements by moving them out of the geocycles and making them available to the biological cycles. Mogollon et al. (1990) agree with these assertions, stating that:

> "The anthropogenic input of heavy metals into the environment exceeds those for radioactive and organic wastes; and therefore has produced significant change in global biochemical cycles." (p. 277)

In testimony before the U.S. Senate, Ellen Silbergeld of the Environmental Defense Fund pointed out that human exploitation of lead over the past 5000 years has transferred over 300 million metric tons from beneath the

earth's crust to the air, water, and surface soils of the planet (U.S. Senate Committee on Environment and Public Works, 1990a). The transfer of toxic lead has prompted calls for systems analysis techniques to study the movement of lead from natural and humanly created sources into the work place, the environment, and to the human population (Committee on Lead in the Human Environment, 1980).

Natural Sources. Lead occurs naturally in soils as a trace element. Turner et al. (1985) concluded that humanly deposited lead did not account for the total amount of lead in the soils they studied and that some portion must therefore occur naturally. Swaine and Mitchell (1960) concluded that the total content of trace elements in any soil are related to the chemistry of its parent material. The presence of lead in surface rocks is generally attributed to transport from the earth's crust via volcanic exhalation. This lead appears most abundantly in rocks of sedimentary origin derived from volcanic parent material (Czarowski and Gworek, 1990). Higher background levels of lead in soils are found in areas of naturally occurring lead mineralization and are termed 'geochemical hotspots' (Thornton et al., 1985; and Davies and Ballinger, 1990).

Lead Mining. Most lead reaches the surface of the earth through mining extraction, where it is then used in industrial processes. No lead is mined in Florida, but use

of lead in industrial processes and in gasolines adds it to the local environment.

The primary lead mining areas of the world are in Broken Hill and Mt. Isa, Australia; Black Mountain, South Africa; Kazakhstan, (of the former USSR); Trepca, Yugoslavia (Serbia); and southeast Missouri and Coeur d'Alene, Idaho, United States. Other major lead mining areas are in Western Canada, Mexico, Peru, Morocco, Romania, Bulgaria, eastern Russia, North Korea, and China (Hurlbut and Klein, 1977; and Espenshade, 1990).

In the recent and ancient past, areas of Northern England and Wales, Greece, and North Africa were mined for lead. Studies of England and Wales by Davies and Ballinger (1990), of North Wales by Fuge et al. (1989), and of a Greek island by Kelepertsis and Bibou (1991) revealed that high levels of soil lead are evident in these areas even though mining ceased decades ago. Through the actions of wind and water, lead in spoil piles and discharge from mine drainage adits continues to settle in the surface soils near these old mines. Studies of active lead mines and smelters reveal that soil lead deposition is actively occurring in the soils near these locations (Lessler, 1988; and Body et al., 1991).

<u>Industrial Sources of Lead</u>. Lead smelting and other industrial activities release lead into the atmosphere. Consumption of coal and other fossil fuels release lead particulates into the air which precipitate onto surficial

soils (Lessler, 1988). The manufacture of lead-acid batteries also produces lead-based pollutants which enter soil and air near the production facilities (Schalscha et al., 1987; and U.S. Senate Committee on Environment and Public Works, 1990a). Atmospheric depositions are identified in peat profiles and have been correlated with periods of industrial activity (Lee and Tallis, 1973; and Turner et al., 1985). River sediments in low relief areas also show accumulations of lead pollution from industrial, domestic, and agricultural sources upstream (Mogollon et al., 1990).

Lead from Auto Exhaust. Other human uses of lead, besides manufacturing processes, contribute to lead deposition in the environment. Researchers studying humanly created lead sources have identified two major factors in human exposure to lead: lead particulates from automobile exhaust and dust and chips from leaded paints (Tierney et al., 1979; Committee on Lead in the Human Environment, 1980; Culbard et al., 1988; U.S. Senate Committee on Environment and Public Works, 1990a; Behm, 1991; Body et al., 1991; and Anonymous, 1992c). The processes by which lead from auto emissions enter the human environment are of most concern to the study of I-275 in Tampa.

In 1970, Bove′ and Siebenberg measured atmospheric lead particulate levels at a site in New York City at various elevations above a street during times of differing traffic density. The lead levels in the air were positively

correlated with the traffic levels of the street below. Chow (1970) found a correlation between lead accumulation in roadside soils and lead particulates of automobile exhaust. He compared the lead isotope composition of surface soil samples with subsurface samples and with lead additives in gasoline. He found that the isotopic composition of surface lead was identical with that of gasoline lead for that region, whereas the subsurface lead composition differed. He concluded that excess lead in the surface soil is attributable to automobile exhaust.

A study by Solomon and Hartford (1976) in Urbana-Champaign, Illinois attributes lead in soils adjacent to houses and in household dust samples to high airborne lead around homes which did not use leaded paints. The degree of contamination was related to house proximity to streets and to auto exhaust. Lead in household dusts occurred in the same proportion as the iron-rich, auto exhaust-related fraction of airborne and soil lead.

Huntzicker et al. (1975) modeled the flow of automobile-emitted lead through the Los Angeles basin and estimated that 12 metric tons/day of exhausted lead was deposited over the land area of the basin. Another 6 tons/day was blown out of the basin and accounted for the major portion of atmospheric lead deposited in downwind locations, as well as more than half the anthropogenic lead input to the Los Angeles coastal waters. Nriagu (1978a) determined that contemporary atmospheric lead in the 1970's

was derived 70% from antiknock lead additives in gasoline. The air mass acts as an efficient transport mechanism for lead particulates. This is evidenced by similarities in the patterns of lead concentration in the atmosphere with levels in nearby soils (Muskett and Jones, 1980).

Lead Accumulation and Persistence. Although the production of lead based paint was limited in 1972 by the Lead Paint Poison Prevention Act and 90% of lead in gasoline was removed between 1975 and 1986, lead is persistent in the environment and continues to show up in air, soil, and dust samples (U.S. Senate Committee on Environment and Public Works, 1990a). Lessler (1988) noted that most anthropogenically deposited lead remains in the environment for centuries due to the metal's non-degradable nature. Results of other studies show the accumulation and retention of atmospherically and hydrologically deposited lead in soils and sediments.

In a high-elevation forest, Friedland and Johnson (1985) found lead accumulated in the O, E, and B soil horizons. The outflow from the profile was only 1/60 of lead input. Lead also accumulates on external portions of vegetation, such as bark, twigs, and tree root bark, with little absorption into internal wood. It is estimated that the mean residence time of lead on the forest floor is approximately 500 years. Turner et al. (1985) estimated a mean residence time of 220 years for lead in the forest

floor of pine barrens, with virtually all lead being retained in the O horizon (75%) and the B and C horizons (25%). Near a point source of pollution, Esser et al. (1991) found similar organic horizon accumulations of trace elements including lead. In addition, lead is found in greater than background levels in bottom sediments of Tampa Bay (Brooks and Doyle, 1991) and in salt marsh sediments in the United Kingdom (Rae, 1989).

Lead also accumulates in urban soils and house dusts. Thornton et al. (1985) conducted a national survey in 53 United Kingdom towns and cities and found elevated concentrations of lead (as well as cadmium, copper, and zinc) in urban dusts and soils compared with agricultural soils. The lead in the house dust is correlated with lead levels in associated garden soils, as over 20% of the weight of the internal house dusts are made up of these soil particles. Culbard et al. (1988) concluded that lead concentrations in house dusts sampled in England, Scotland, and Wales are positively correlated with 1) lead concentrations in garden soils; 2) the area of exposed soil surrounding the house; 3) the presence of high lead-containing paints used inside the house; and 4) instances of recent redecoration. Thus lead accumulates in urban soils and house dusts even without an industrial point source that discharges lead particulates.

This accumulation of lead in soils is of concern because of possible uptake by flora, fauna, and humans,

especially children. Therefore, a review of studies of lead uptake follows.

Lead Uptake in Flora, Fauna, and Humans

The human factor must be analyzed to identify heavy metal pathways to biota, especially those related to lead, which appears to have more anthropogenic sources than natural sources in the modern landscape. Ignoring effects of human actions can lead to erroneous conclusions regarding "natural" accumulations. For example, Graf (1985) found that mercury, naturally occurring as HgS (cinnabar) in surface rock, is transported by water action and transformed by reduction to elemental Hg. The Hg is sorbed on to sedimentary materials and forms complexes with organic materials, which are then sorbed or ingested by biota. This led to the conclusion of a natural accumulation of toxic mercury in flora and fauna. However, the author admittedly ignored the effects of human land management and humanly induced climatic changes on this process, which accelerated the initial input of Hg into the system. Thus, similar to accumulation of mercury, it is important to view lead uptake and accumulation within the context of humanly altered or created transport mechanisms.

Lead in Vegetation. Lead can accumulate in vegetation through aerial deposition. Ward et al. (1974) observed concentration of lead in tree bark and leaves along a road

in New Zealand and correlated these accumulations with traffic density and prevailing wind. They concluded that Pb absorption in tree bark is superficial and that Pb is removed as the outer bark peels off, enriching the surface soil below. The Pb levels observed in the leaves were five times greater than background levels. However, the lead present in leaves is not all easily removed particulate matter and is believed to be absorbed both aerially and indirectly via the root system.

In examining lead uptake in plants, it is important to separate externally deposited lead from lead ingested from the soil. In several early studies, grasses near a roadside source of lead showed contamination patterns similar to those of the soils in the same area. However, in their procedures, the authors did not wash cut grass blades to remove superficial deposits. Thus it was not possible to separate the internal and external lead burdens (Chow, 1970; and Muskett and Jones, 1980). In other studies, researchers separated internal and external lead in grass by removing externally deposited (and unabsorbed) lead. Ratcliffe and Beeby (1980) found dead and decaying roadside grasses absorbed more Pb than living grasses. This they attributed to a breakdown of the epidermal layers, especially the cuticle, which results in increased water permeability of these layers and thus greater internal access to higher levels of lead-containing compounds. They also concluded that lead was transferred to dying parts of the plant and

that these older parts were exposed to lead contamination for longer time periods.

Some researchers have argued that vegetation does not effectively assimilate Pb from soil, and instead conclude that higher lead concentrations from twigs, bark, and leaves represent lead <u>on</u> vegetation rather than lead <u>in</u> vegetation (Friedland and Johnson, 1985). Kelepertsis and Bibou (1991) documented accumulated levels of lead in the plants near the Thasos Island (Greece) mining area, but did not compare them to background levels to determine if there was an increase in lead uptake corresponding to elevated soil lead. Moir and Thornton (1989) found lead in vegetable crops from domestic gardens that exceeds background levels, but falls below the statutory limit of 1 ug g^{-1} for saleable food in the UK. Elliott et al. (1986) noted that because of the strong retention of Pb by soils, phytotoxic effects from lead uptake are rare. This appears to hold true, as none of the studies cited herein record any lead toxicity in vegetation.

Whether aerially deposited or assimilated from the soil, lead in vegetation does play a part in the overall patterns of lead accumulation in areas near sources such as roads. This is an important consideration in the study of the I-275 corridor. The types and extent of vegetation present on the highway right of way affect the accumulation of lead and represent one of many factors that need to be considered when analyzing soil lead.

Vegetation and Lead Toxicity. Despite the accumulation of high levels of lead in vegetation, lead toxicity is not a problem. Similarly, this same vegetation is not a threat to fauna. Brams et al. (1989) found that only non-harmful amounts of soil Pb and cadmium (Cd) were retained in goat tissues via the ingestion of hay from adulterated fields, even though the hay itself showed an accumulation. The relative quantities of Pb and Cd transferred along the agricultural food chain is minimal and does not present a threat to humans consuming meats from animals fed with lead adulterated vegetation. In non-domestic animals, a study by Hegstrom and West (1989) shows that some heavy metals, including lead, accumulate in the organs of small mammals residing in forests amended with sewage sludge. The levels of heavy metals are higher in insectivorous small mammals but are neither biologically important nor considered toxic.

Invertebrates and Lead Toxicity. Invertebrate accumulation of lead may pose a threat to wildfowl. Ash and Lee (1980) examined several species of earthworms from roadside soils and found that worms accumulate lead and cadmium and survive in conditions of considerable metal pollution. Lead levels are significantly higher in specimens from sites with higher traffic density. Metal loads found in fecal materials and soils are much less than in the earthworm tissues, indicating retention of Pb and Cd by the worms. Some levels in the invertebrates in roadside sites

are above those known to be fatal to wildfowl and thus they present a threat in the food chain to consuming birds. Some fungi are also capable of surviving considerable absorption of heavy metals and other non-nutrient metals (Siegel et al., 1990). However, it is unclear if they present a lead hazard in the food chain.

Sources of Lead Toxicity in Humans. Intake of lead via food is not considered a major threat to humans. Rather, direct intake via ingestion of paint chips, soils, and dusts is the greatest threat to environmental health, especially to children (Body et al., 1991). Victor Kimm of the U.S. Environmental Protection Agency identifies three principal sources of exposure to lead: 1) deteriorated lead-based paints; 2) drinking water; and 3) soil contamination from gasoline and paint deposition (U.S. Senate Committee on Environment and Public Works, 1990a). Lead in dust, carried to the mouth by hands or on objects placed in the mouth, may contribute around one-half the total lead intake by children (Thornton et al., 1985). Testimony before the U.S. Senate Committee on Environment and Public Works (1990a) by both Vernon Houk of the CDC and Needleman cited pica, the purposeful ingestion of soils by children, as the major pathway of lead ingestion in early childhood. Thus it is clear that lead contaminated soils, and house dusts partially composed of particles from these soils, represent a more serious lead poisoning threat to human children than any other source.

If soils contribute to lead poisoning, then it is important to understand the processes by which lead becomes a part of and remains in soils. In the section which follows, the processes by which lead attenuates in surficial soils and the conditions which affect soil lead mobility are described.

Behavior of Lead in Soils

The adverse effects of heavy metals are inseparably related to a soil's ability to adsorb and retain such elements (Elliott et al., 1986). The persistence of lead in soils makes it an unyielding hazard. Evidence of lead's longevity in the environment is discussed in reviews of the studies of old lead mining areas (Davies and Ballinger, 1990; and Kelepertsis and Bibou, 1991) and in research of forest floor soils (Friedland and Johnson, 1985; and Turner et al., 1985). These studies and other research corroborates that lead has certain properties in soils, namely:

1. Lead is sorbed preferentially and in greater quantities by soils in comparison to other heavy metals.

2. Lead stays fixed to the surface layers of soils.

3. Migration of lead in soils, downward or otherwise, is minimal.

4. Mobility of lead tends to be linked to specific conditions within the soil, such as grain size, pH, organic matter content, cation exchange capacity (CEC), and/or carbonate content.

Lead Adsorption by Soils. Harter (1983) studied the effect of adjusting soil pH on the adsorption of lead (Pb), copper (Cu), zinc (Zn), and nickel (Ni). Although responses to pH adjustments vary widely over a variety of soils, in all cases adsorption is in the order Pb > Cu > Zn > Ni. Similarly, in a study of northwest Indiana sandy soils, which are contaminated with aerially deposited Pb, Cu, Zn, and Cd, Miller et al. (1983) report that metal adsorption is higher for Pb and Cu than for Zn and Cd. The higher sorption of lead and copper is attributed to competition for a limited number of high energy adsorption sites on soil particles to which Pb and Cu ions are preferentially attracted. Elliott et al. (1986) also found strong preferences for lead and copper among a variety of soils. Lead and copper in soils near a smelting facility remain fixed in the surface layers, even when pH reduction increased the mobility of cadmium and zinc. In observing the lead retention capacity of some clay materials, Yong et al. (1990) noted that Pb is retained more strongly than other metals and its retention is influenced by soil constituents such as clay minerals, carbonates, organic matter, oxides, and amorphous material.

Czarowska and Gworek (1990) reported that natural, background values for lead in soil are higher in the A horizon when compared to the B, C, or E horizon, regardless of soil type. Tierney et al. (1979) reported a soil lead background level range of 2-200 milligrams per kilogram (mg

kg^{-1}), with a worldwide mean of approximately 16 mg kg^{-1}. Others cite similar background ranges and means (Motto et al., 1970). The preferential adsorption of lead deposited aerially and hydrologically results in a pattern of surficial accumulation in the O and A horizons above these background levels. In the Miller et al. study (1983), soil cores leached with a dilute metal solution adsorb almost all the added metal. Determination of total heavy metals in sections of the soil cores show enrichment of all metals, including lead, in samples taken from the litter layer and from depths of 0-2.5 centimeters (cm). Total lead in the litter layer ranges from 570-772 micrograms Pb per gram of soil (ug Pb g^{-1}). At greater depths, lead decreases to levels ranging from 316-383 ug Pb g^{-1} and drops to nearly constant (less than 10 ug Pb g^{-1}) levels below 10-15 cm.

The organic horizon overlying mineral soils in a high-elevation forest in Vermont also retains most of the lead atmospherically deposited on it, with estimated lead accumulations of 20 kilograms per hectare (kg ha^{-1}) or 219 mg kg^{-1} in this layer (Friedland and Johnson, 1985). The total soil Pb near a car battery plant is highest in the 0-5 cm depth and significant to depths from 5-15 cm (Schalscha et al., 1987). At a distance of 0.3 kilometers (km) from the battery plant, soil lead levels as high as 983 mg kg^{-1} are reported in the 0-5 cm depth and drop to 204 mg kg^{-1} at the 5-15 cm level.

Lead Migration in Soils. The accumulation of lead in the upper soil horizons is accompanied by a lack of migration within the soil profile. Turjoman and Fuller (1987) observed that lead in solid waste leachate remains in calcareous desert soils and does not appear in effluent at the base of soil columns, indicating a lack of lead mobility within the soil profile. Miller et al. (1983) expected that the sandy soils they studied, which are low in clay, very permeable, and thus apt to facilitate movement of metals out of the profile, would show significant translocation of lead when treated with an acid solution. However, the acid treatments did not cause significant downward migration of lead or any other metals.

In the Vermont forest soils studied by Friedland and Johnson (1985), mineral soil concentrations of lead are an order of magnitude less than those of the forest floor (organic horizon). The authors attribute lead in the lower horizons to soil processes on parent material rather than to migration of atmospherically deposited lead from the organic layer. In contrast, Turner et al. (1985) asserted that "considerable amounts" of the lead accumulating in forest floor organic matter leach through to mineral soils below. They estimated a total lead input to the watershed study area of 140 g Pb ha^{-1} yr^{-1}, 25% of which (35 g Pb ha^{-1} yr^{-1}) enter mineral soils. However, 75% of lead remains in surface layers and little or no lead moves deeper than 2 meters (m) in the mineral soil. In addition, only 2.3% of incoming lead

is transported out of the watershed. The authors qualified their estimate of lead in the mineral horizons with evidence that anthropogenically deposited lead is not the only source of lead in these soils. Thus it is important when computing a lead budget for a study area to account for naturally occurring lead either through establishment of a background level or identification of the lead content of the soil parent materials.

Lead Fixation Mechanisms. Immobilization of lead in the upper soil horizons is attributed to several mechanisms which prevent migration to greater depths. Soil pH, microorganisms, precipitation, sorption or ion-exchange interactions with clays, or fixation by organic matter in the surface layers can prevent downward migration of lead (Zimdahl and Skogerboe, 1977). Soil pH and texture, clay mineral type and concentration, percentage of organic matter, concentrations and types of soil anions and cations, and soil drainage have been measured in relation to lead fixation and migration to determine which conditions favor attenuation and which promote movement.

However, most researchers find it difficult and impractical to isolate one mechanism due to variations in results. For example, Harter (1983) noted that, in other studies he reviewed, lead retention is not strongly correlated to soil pH because the soils that were examined possess widely divergent characteristics. He was able to

conclude in his study that the amount of lead that is retained in any soil is strongly influenced by the soil pH, but a rapid increase in soil retentiveness occurs only in soils of pH greater than 7.0. The magnitude of retentiveness is not consistent between soil types. Harter found it impossible to explain differences in adsorption between samples on the basis of cation exchange capacities or total organic matter.

Other researchers have had limited success in explaining metal retention and mobility based on individual or groups of factors. In Saudi Arabian soils studied by Turjoman and Fuller (1987), the longevity of Pb occlusion is directly related to the migration and/or desorption of CO_3^{2-} (carbonates). This process is directly related to the formation of $PbCO_3$ compounds which form when lead replaces Ca^{2+} in $CaCO_3$, thereby binding the lead. These results are in agreement with those of Harter (1983), who observed that lead carbonates, lead hydroxides [$Pb(OH)_2$], or lead bicarbonates [$Pb_3(CO_3)_2(OH)_2$] remain stable in soil, but may become soluble at high pH (greater than 6.0), with lost lead cations adsorbed to high energy sites on soil particles.

pH and Lead. Despite the variations in the results achieved in the above research, the importance of pH to lead retention is an integral part of most studies of soil lead. The amount of added Pb retained by clay materials, for example, is directly related to the acid input to the clays

(Yong et al., 1990). Almost all clays tested by Yong et al. exhibit full capability in retention of added Pb at low amounts of acid input. As acid input increases, lowering the clay pH, the amount of Pb retained tends to decrease. At pH values >5.0, 100% of applied lead is retained in the clays; at values below 5.0, the amounts decrease rapidly. The addition of acid to the clays eventually reduces the clay buffer capacity, causing the pH to fall below that of the lead precipitate and thereby reducing the amount of lead retained. Similarly, when high concentrations of lead are applied to the clay, the buffer capacities of the clays decrease because of the reduction in the number of sorption sites on the clay particles. This results in a lower percentage of lead retention than with application of lower concentrations of lead.

Lead, Organic Matter, and CEC. Buffer capacities are directly correlated with cation exchange capacities and carbonate content of the clays. For clayey soils, these results have a direct bearing on their ability to retain lead. In sandy soils, the ability to retain lead is linked to pH and organic matter content (Miller et al., 1983). Simulation of acid rainfall on sandy soils does not appear to result in metal solubilization. However, tests over longer time spans or with rainfall of differing pH were not attempted. The authors attribute the binding of heavy metals in nonleachable forms in these soils to higher levels of

organic matter in the litter and in the top few centimeters of the A horizon. They point out that continued deposition eventually results in leaching from the A horizon. When elevated concentrations of Pb are reached, the ability to sorb additional amounts of lead decreases due to the filling of exchange sites in the soils.

Lead, therefore, remains immobile in soils with high organic matter content despite a drop in pH. However, Turner et al. (1985) reported that some Pb is transported with mobile organic matter. Data indicate that lead is removed from the forest floor in association with dissolved organic matter and concomitant acidic pH, perhaps occurring in solution as organo-lead complexes, inorganic complexes, and aqueous Pb^{2+} ions.

Lead adsorption is relatively constant following the removal of organic matter from organic soils (Elliott et al., 1986), suggesting that there are substantial inorganic exchange sites for adsorption of lead as well. When accompanied by a reduction in cation exchange capacity (CEC), however, removal of organic matter reduces adsorption of lead.

In all cases, though, adsorption follows a pH dependent trend in that lower pH results in less adsorption. Zimdahl and Skogerboe (1977) show that pH, CEC, clay, and organic matter are important factors in lead fixation in soils. Because CEC is predominantly controlled by clay and organic matter content, pH and CEC are considered of primary

importance. Lead forms complexes with organic matter from soil and a high correlation coefficient (.925) was found between bulk concentrations of organic carbon and CEC values in the soils Zimdahl and Skogerboe analyzed. This verified the influence of organic matter on cation exchange capacity. These results suggest that the majority of the Pb immobilized by soil is associated with organic matter that is concentrated near the soil surface.

Release of Lead from Soils. With the realization that pH, organic matter content, CEC, and other factors can interact differently in the lead adsorption and fixation processes, the long-term effect of continuous deposition of lead must be considered. Miller et al. (1983) noted that continuous deposition of heavy metals results in metal leaching from the A soil horizon and that land clearing, profile disruption, and acid rainfall in urbanized areas also increases migration. The ability of any soil to retain lead is not unlimited. Continued deposition or changes in outside factors result in the release of lead into other parts of the environment. Stagliani et al. (1991) call these potential toxic releases "chemical time bombs" or CTB's. The risk of CTB's is assessed by estimating changes in a system's vulnerability over time based upon:

1. identification of key factors influencing the mobility of pollutants and how they are linked to soils and sediments (such as CEC, pH, organic matter).

2. determination of environmental conditions which give soils and sediments their properties.

3. scenarios of how the conditions could change.

4. assessment of the effect of changing environmental conditions on storage capacities.

This concept, as well as other known methods of lead release into the environment (e.g. wind action), has important implications for increased exposure to lead for humans in urban environments. For example, larger lead particulates which settle close to highways and roads (linear pollution sources) become fixed in the surface soil and are not often considered a threat to humans. However, changing conditions could make these particles suddenly more mobile and bring them into contact with humans.

Further investigation, then, of the distribution of lead deposited along roadsides and the role these distribution patterns play in lead contamination and lead poisoning is necessary to determine the potential toxic threat to humans. Identifying these patterns also provides a basis for comparison for the results of the analysis of the soils of I-275 in Tampa. Since little or no research of this type has been performed in Florida, it will be important to analyze any differences between the findings of previous researchers and the results obtained in this study to understand the potential lead health hazard near I-275.

Lead Accumulation in Roadside Soils

The patterns of accumulation of lead in soils correspond with patterns and concentrations of airborne lead. Bove′ and Siebenberg (1970) demonstrated correlations with carbon monoxide and lead and traffic and lead in the atmosphere above a high traffic area in New York City. It is estimated that gasoline additives account for 16% of total lead usage and contribute heavily to the atmospheric lead content (Tierney et al., 1979). Similarly, Ward et al. (1974) estimate consumption of lead alkyls in the United States result in emissions of 180,000 tons in the atmosphere. However, both these studies are based upon data obtained prior to the reduction of lead in gasoline. Nevertheless, heavy lead emissions into the atmosphere occurred for decades and the patterns of lead concentration in the air are closely reflected by lead levels in soils (Muskett and Jones, 1980).

The use over many decades of tetraalkylleads as antiknock additives in gasoline resulted in persistent accumulations of lead in roadside soils. Blais and Marshall (1986) found that tetraalkyleads, though toxic, are relatively unstable in the environment and degrade abiotically into trialkylleads, dialkyleads and finally to inorganic lead (Pb^{2+}). These ionic leads form stable compounds in soils, as discussed earlier, while retaining much of the toxicity of their progenitors and are the major

health hazard associated with street dusts, contaminated soils, and storm runoff.

Lead and Distance from Roads. Lead content of soils adjacent to highways has been measured as a function of both distance from the road and depth in the soil (Agrawal et al., 1980). Lead contamination decreases with distance from the highway. Large particles (greater than 10 micrometers) settle rapidly and close to the road edge, while smaller particles remain airborne and settle further away (Huntzicker et al., 1975; and Tierney et al., 1979). The smallest particles remain airborne for the longest period of time, settle furthest from the source, and are more soluble and more easily removed from the soil surface layer by wind and runoff (Wheeler and Rolfe, 1979).

The patterns of lead distribution in soils vary with factors such as traffic volume and prevailing wind. Motto et al. (1970) found that average soil lead levels increase with traffic use and remain fixed in surficial soil. Wheeler and Rolfe (1979) found 99% of deposited lead is contained within 100 m of highways and that the distribution can be summarized as follows:

$$Y = Bkg + A_1e^{-k_1D} + A_2e^{-k_2D}$$

where Y is soil lead concentration in ppm; Bkg is background level of lead in soil in ppm; A is a concentration at pavement edge (1) and at a distance (2) in ppm; k_1 and k_2

are constants relating to two different size classes of particles in units of 1/m; and D is distance from the road edge in meters (m). This model summarizes, but does little to predict, distribution of lead from line sources. Not taken into consideration are factors such as wind velocity and traffic volume. Chow (1970), Ward et al. (1974), and Schalscha et al. (1987) all reported that lead deposition distributions are influenced by the direction of prevailing winds. Motto et al. (1970), Collins (1989), and Francek (1991) each found that patterns of lead concentration are positively correlated with traffic volume.

Despite a 90% reduction in the lead content of gasoline since 1975 and a corresponding reduction in lead emissions, the cumulative effects of lead deposited in soils near roads are a matter of record and are a potential source of lead dusts in homes adjacent to them and to users of the roadways. The Committee on Lead in the Human Environment (1980), the Centers for Disease Control (1985), Bornschein et al. (1986), and Chaney and Mielke (1986) all outlined the processes by which lead dusts are deposited in urban soils and become part of the urban home environment. Of particular concern is the inadvertent ingestion of these dusts by children at play and the transport of the dusts to the interior of the home by pets, adherence to clothing and skin, and wind action. The gradual accumulation of lead in the bodies of the residents of these contaminated areas results in elevated blood lead levels and a high frequency

of lead poisoning symptoms (U.S. Senate Committee on Environment and Public Works, 1990a).

A number of studies of soil lead contamination were performed and comprehensive soil lead studies were completed in cities such as Cincinnati, Baltimore, Washington, DC (U.S. Senate Committee on Environment and Public Works, 1990a), Toronto (Rinne et al., 1986), and Milwaukee (Brinkmann, 1989). Despite this body of research, few studies of lead contamination in Florida have been undertaken. Brooks and Doyle (1991) found lead in sediments in Tampa Bay to be the highest of 51 sites in the Gulf of Mexico area. Brinkmann (1990a and 1990b) recently began research on lead contamination in lawn and garden soils in Tampa, Florida. This is the only comprehensive research of soil lead that has been undertaken in the Tampa Bay area (personal interview, Thomas Cardinale, Hillsborough County Environmental Protection Commission, 1991). Lead pollution in soils near high traffic volume roads is one source of lead dust in urban yards and homes (Davies and Wixson, 1986; and Chaney and Mielke, 1986). Therefore, an assessment of lead distribution adjacent to highways in Tampa would add to the data base begun by Brinkmann of patterns of lead contamination and distribution for the area.

The aims of this study are to:

1. Measure the lead content of the soils adjacent to Interstate Highway 275 in Tampa.

2. Analyze the distribution of the lead concentration.

3. Conclude from measurement and analysis if there is a health threat to residents near I-275.

Based upon the literature reviewed above, there is a high probability that lead has accumulated in the soils near I-275 and poses a health hazard to those exposed to highway soils or dusts and to residents in the neighborhoods near the highway.

CHAPTER 3
METHODOLOGY

In this chapter, the field, laboratory, and statistical methodologies used in the project are discussed. The chapter opens with a description of the study area to provide details of the geographic setting and conditions which affect selection of techniques and methods. Three sections follow which detail 1) field sampling strategies, 2) methods of soil lead extraction and measurement, and 3) compilation and analysis of the data. While many of the methods used are similar to those employed by others in previous research, some variations have been undertaken in order to assess their viability for future work.

Study Area

The study area is the right of way on both sides of Interstate Highway 275 (I-275) in Hillsborough County, Florida (population 834,000) (Shermyen, 1991). I-275 is located in west central Hillsborough County and lies predominantly within the city limits of Tampa (population 280,000) (Shermyen, 1991)(FIGURE 1).

West central Hillsborough County is characterized 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

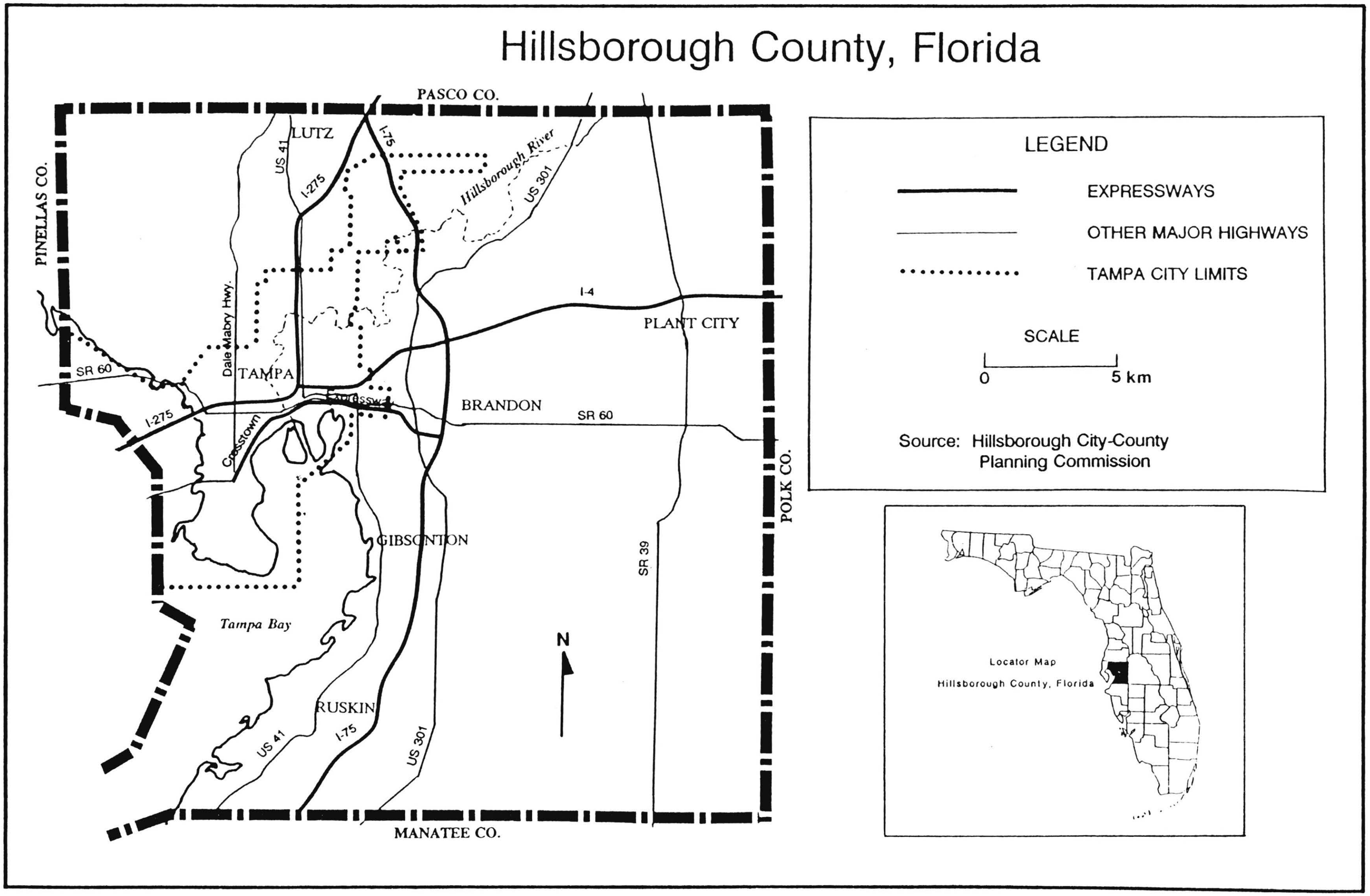


FIGURE 1 Hillsborough County, Florida.

numerous permanent lakes in the north. Elevations range from sea level to about six meters (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 transported by sea waters that covered the area several times during the Pleistocene Epoch (Soil Conservation Service, 1989). The general distribution of soil types in Hillsborough County are found in FIGURE 2. The soils in the study area include Urban land-Tavares, Urban land-Candler, and Urban land-Myakka-Smyrna. All are sandy soils. Most of the areas bearing these classifications are modified for urban use and therefore do not represent the original soil type. This is especially true for the soils adjacent to I-275, which are products of human alteration and construction. It is suggested that these soils still be classified by standard soil classifications, as products of anthropogenic pedogenesis, as they still undergo soil processes such as humus accumulation, structure formation, gleying, decalcification, and acidification, just as soils on natural substrates (Blume, 1989).

The portion of I-275 south of the I-4 interchange was completed in 1958 and was originally part of I-4; the portion north of I-4 was completed in the mid 1960's

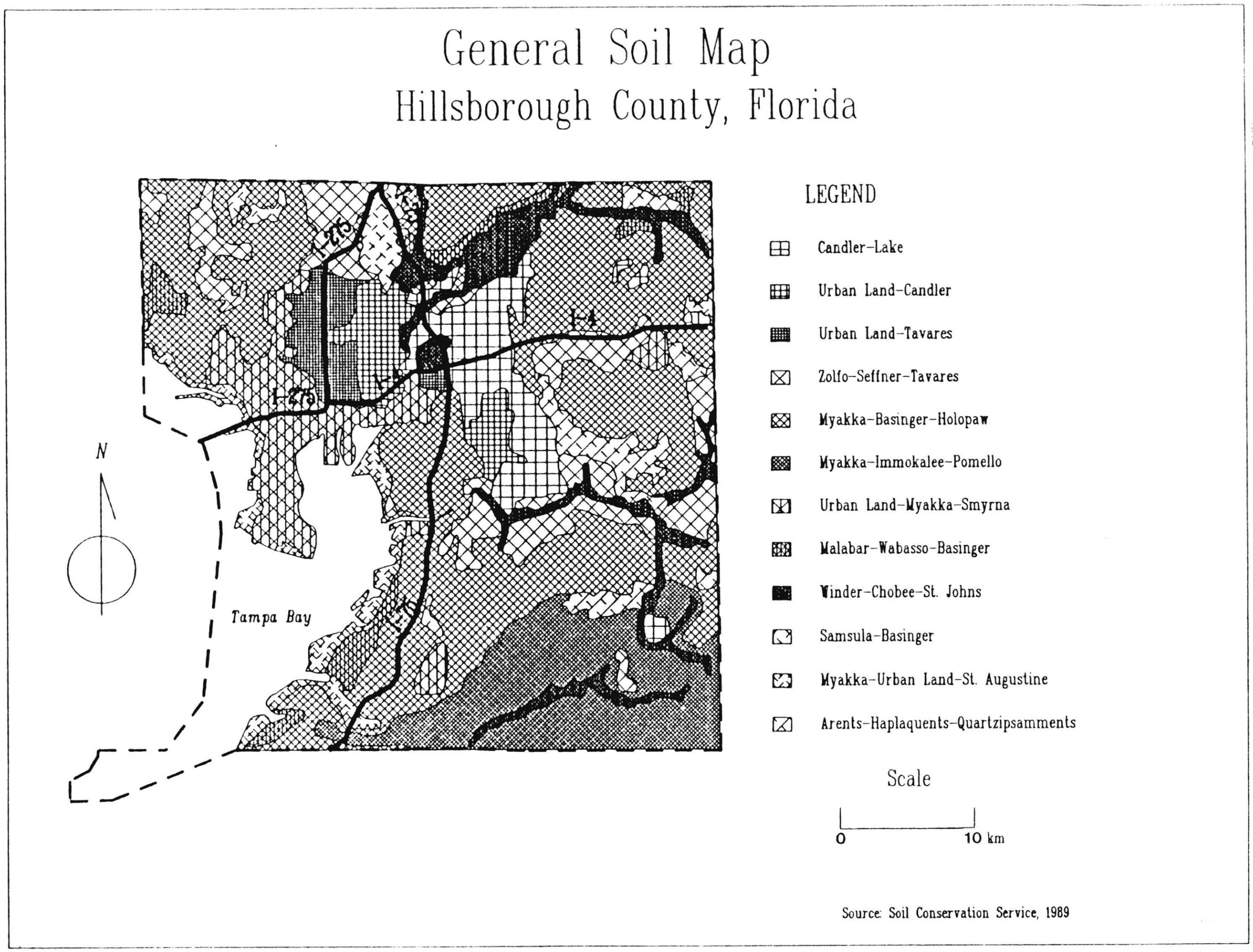


FIGURE 2 General soil types of Hillsborough County, Florida.

(telephone interview, James E. Hanch, Florida Department of Transportation, July 1991). Thus, in terms of soil processes, time is not a relevant factor for the soils adjacent to I-275. However, in terms of aerial deposition of lead, the nearly thirty-year period between the construction of the first part of the highway and the elimination of regular leaded gasoline in Florida is significant.

The climate of Hillsborough County is humid subtropical with warm, wet summers and mild, dry winters. The annual average monthly mean temperature is 22.3°C (72.2°F), ranging from 16.0°C in January to 27.8°C in August. The mean number of days with a temperature of 0°C is 0 for all months and consequently the soils in this area never freeze (Soil Conservation Service, 1989). The sixty year average annual rainfall is 134.6 cm (53 inches). However, from 1951 to 1980 the area averaged 118.7 cm per year, and 107.7 cm per year from 1987 to 1990 due to drought conditions (Soil Conservation Service, 1989; and Southwest Florida Water Management District, 1990). Sixty percent of the annual rainfall occurs in the period from June through September, with the remainder spread evenly over the other eight months.

The annual precipitation and rainfall patterns are the most important climatic aspects controlling the soil properties in the study area. Moisture is involved in most physical, chemical and biochemical processes that occur in the soil. The amount of moisture delivered to the soil

surface influences weathering and leaching, while temperature influences the rate of chemical and biochemical processes. The concomitance of warm temperatures with greatest rainfall in the summer months in Hillsborough County increases the production of above-ground organic matter and produces higher rates of organic matter decomposition (Birkeland, 1984). Previous researchers have identified higher organic matter content as a major factor in lead fixation in soils (Zimdahl and Skogerboe, 1977; and Friedland and Johnson, 1985). Increased organic matter in soils correlates with higher cation exchange capacity (CEC), which promotes adsorption of lead cations (Pb^{2+}). In sandy soils, such as are found in the study area, lead retention is linked to lower pH and higher levels of organic matter (Miller et al., 1983). Organic matter can also aid in the transport of lead if the organic matter itself becomes mobile (Turner et al., 1985). Thus it is likely that the climate of the study area contributes to the retention of lead in the surficial soils around I-275.

The I-275 corridor is located in west central Tampa and is bordered by residential, commercial, and recreational land use areas for most of its length. The study area (FIGURE 3) consists of the portion of the I-275 corridor extending from the Bearss Avenue interchange in the north to the State Route 60 (SR 60) interchange in the south (19.4 kilometers [km]). The Bearss Avenue interchange is the northern-most exit before I-275 joins I-75 at the

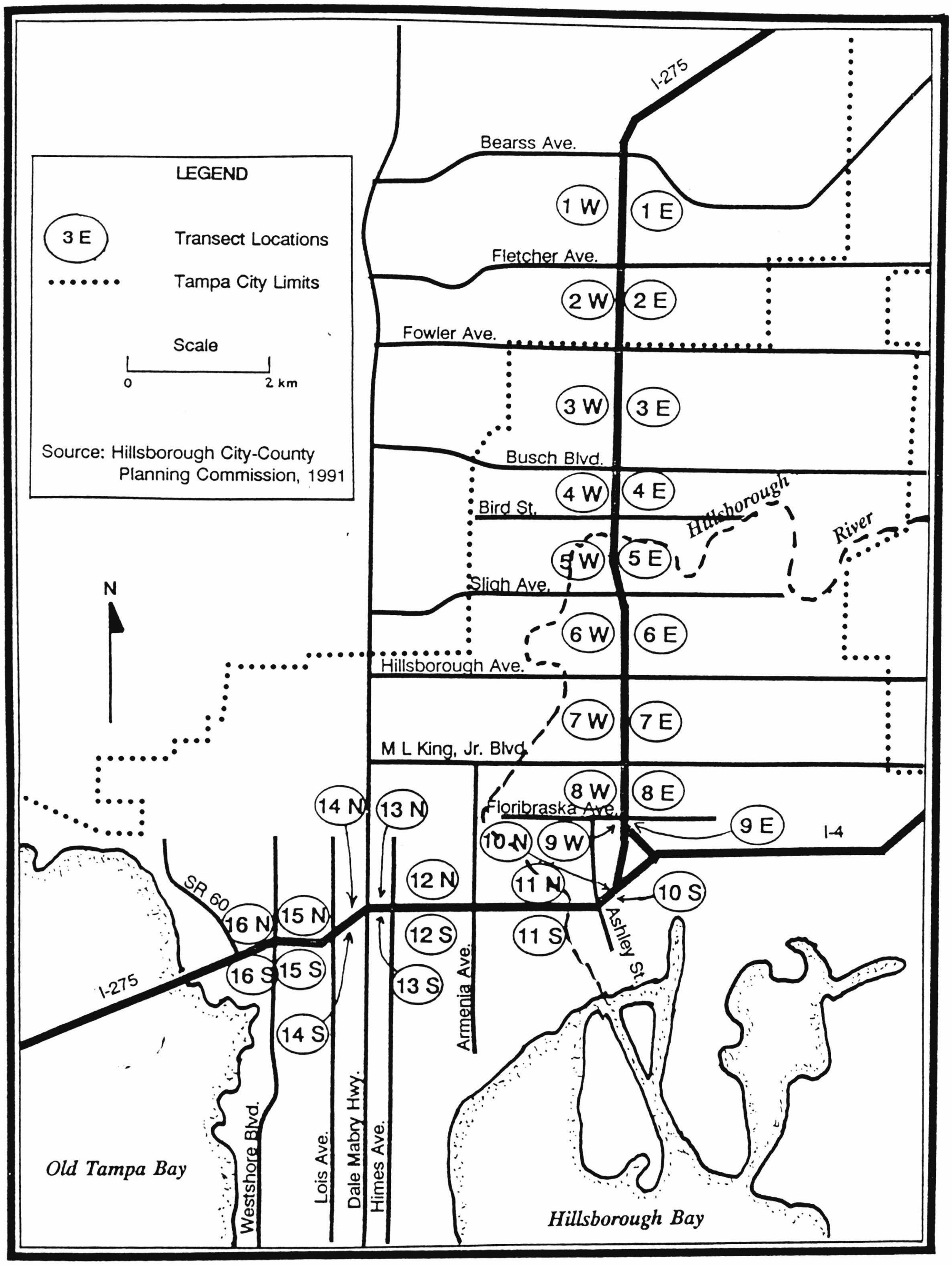


FIGURE 3 Transect locations, soil lead study area, I-275 corridor in Hillsborough County, Florida.

Hillsborough-Pasco County border. The land adjacent to the corridor north of Bearss Avenue is relatively undeveloped. In the south, the State Route 60 exit is the last before I-275 crosses Tampa Bay. There is no residential or recreational land use west of the State Route 60 exit, but some commercial development lies along this stretch of I-275 before it reaches the bay.

The right of way of I-275 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 (ROW) were landscaped in recent years, mainly with rows of long needle pine trees near some residential areas and clusters of palm trees around most overpasses. The elimination and addition of several entrance and exit ramps and widening of the highway in various places in the past five years also resulted in new landscaping and disruption of the soils.

Because of the nature of aerial lead deposits and the dimensions of the right of way, several techniques were utilized to standardize the soil sampling procedure. A discussion of the soil sampling plan follows.

Sampling Plan

Soil samples were taken at point locations along transects perpendicular to the highway. Sampling along transects was utilized by Wheeler and Rolfe (1979), Muskett and Jones (1980), and Agrawal et al. (1980) in studies of

soil lead contamination. Lounsbury and Aldrich (1986) also discuss the use of transects as an effective method of determining relationships between phenomena, such as heavy metals in soils, and linear sources such as roads.

Transects were established at the approximate midpoint between interchanges as measured in miles by automobile odometer. In several cases, overpasses or other obstructions at the midpoint location made it necessary to relocate transects. The next available location beyond the midpoint in the direction of the traffic flow was then selected and the alternative distances noted. Midpoint locations for the transects were selected because they provide a typical or average reading of lead in highway soils, as opposed to locations near exit or entrance ramps which, because of acceleration, deceleration, and idle zones, have higher lead levels than straightaway areas (Francek, 1991). Therefore, the midpoints between interchanges offer the least chance of highly elevated values due to these types of traffic patterns.

Previous research has shown that lead levels decrease rapidly with distance from the road edge (Motto et al., 1970; Solomon and Hartford, 1976; Agrawal et al., 1980; Muskett and Jones, 1980; Wheeler and Rolfe, 1979; and Culbard et al., 1988). In these studies, samples were taken at equal distance intervals from the road edge. For example, Wheeler and Rolfe (1980) began sampling at 30 cm and continued at 1, 5, 10, 15, 20, 25, 30, 40, 50, 100, and

200 m from the road. Others began at further distances (Muskett and Jones, 50 cm; Chow, 7.6 m; Motto et al., 25 feet of 7.62 m) and continued at equally spaced intervals. Log transformations of distances and lead levels were necessary to produce a smooth lead/distance relationship curve. All of these researchers concluded that lead levels decreased exponentially with distance from the highway.

In this study, exponential sampling intervals were utilized 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. Distances between samples were at intervals of 3, 9, 27, 81, 243, 729, and 2187 cm from the edge of the highway. Because the highway right of way width varies, the most distant sample on each transect was taken either at 2187 cm or, if shorter, at the ROW fence line.

Soil Sample Collection

Soil samples were collected November 29 and 30, 1991 from thirty-one transect locations. Samples were also collected January 25, 1992 from a thirty-second transect to complete the sample set. At each transect location, soil samples were taken at seven points from the upper 3 cm of solum using a plastic spatula. Sampling was not done at greater depths because previous research has determined that 75% of lead remains fixed in surface soil layers and does

not migrate (Miller et al., 1983; Turner et al., 1985; and Turjoman and Fuller, 1987). Even background levels of lead are higher in the upper (A) soil horizon compared to lower horizons (Czarowska and Gworek, 1990).

Sample locations, as established above, were determined using a tape measure anchored at the road's edge. Because the slopes varied greatly among transect sites (from 5% to 50%), distances were measured horizontally on a plane from the road edge using a line level and plumb bob with the tape measure to assure conformity of sample site distances. Samples were placed in pre-marked plastic sample bags and returned to the University of South Florida (USF) Hydrology and Physical Geography Laboratory for preparation.

At each site, a map was drawn noting the location of the transect in relation to interchanges. A slope estimate was calculated at each site and notes were kept regarding the distance of the last sample and any unusual phenomena in the area or at a specific sample site. Photographs of each transect location were also taken for future reference.

Soil Preparation and Lead Extraction

To prepare them for extraction, soil samples were first air-dried in the USF Hydrology and Physical Geography Laboratory. The samples were placed on a layer of paper towels and then covered with another layer to avoid contamination. Once dry, the soil samples were returned to their original sample bags. The remaining soil preparation

procedures were accomplished in the USF Department of Geology Sedimentology Laboratory. Each sample was ground using a mortar and pestle to break up soil peds, taking care not to disrupt the integrity of soil particles through excessive grinding. Samples were then sieved through a 1 mm mesh screen to obtain a more homogeneous grain distribution (Gilbert and Doctor, 1985).

One gram samples of the <1 mm fraction from each soil sample were weighed and placed in Kjeldahl extraction flasks with approximately 2 ml of hydrogen peroxide (H_2O_2) and 20 ml of 1:1 nitric acid (HNO_3). The hydrogen peroxide oxidizes organic material and liberates trace metals bound to this fraction (Blais and Marshall, 1986), while the nitric acid begins the removal of lead from soil particles. The flasks were then heated on a micro-Kjeldahl unit at approximately 120°C until one-half the mixture remained. Next, 10 ml of 1:1 hydrochloric acid (HCl) was added to the flasks. The flasks were heated again until one-half of the mixture remained, then removed and allowed to cool for several minutes. Fifteen ml of distilled water was added to each aliquot and the contents of each Kjeldahl flask were filtered into 50 ml volumetric flasks. After filtration, the volumetric flasks were brought to volume with distilled water. Laboratory procedures were completed twice on every fifth sample in order to maintain quality assurance (Davies, 1989). The above procedures, similar to those outlined by McGrath and Cunliffe (1985), aggressively remove lead from

the soil and place it into an acid solution suitable for measurement by atomic absorption spectroscopy (AAS).

Measurement by AAS was performed in the USF Department of Chemistry Laboratory using an acetylene gas atomic absorption unit. Readings of sample aliquots (in units of absorbance) were compared to readings for pre-mixed lead standards and a zero standard. A curve was used to translate absorbance into values of lead in parts per million for each aliquot. The use of AAS is effective in detecting lead at the 0.1 ug ml^{-1} level (Hamilton, 1980) and has proven more effective than other methods such as ion chromatography (Basta and Tabatabai, 1990).

The soil lead data obtained from the above procedures were then subjected to statistical, spatial, and qualitative analyses. The methods utilized are discussed below.

Statistical Treatment

The soil lead levels were treated analytically in four ways: 1) general data (entire database); 2) transect data (comparison of values within a transect); 3) location specific (comparison of transect locations); and 4) distance specific (comparison of samples from all transects at similar distances from the road edge). All statistical analyses were performed using The Student Edition of MINITAB (Schaefer and Anderson, 1989).

General Data. The values in the database represent values of a single variable: soil lead level. Therefore univariate statistical methods were utilized (Sinclair, 1980). The data were first compiled and sorted by ascending value. From this table of values, a frequency histogram was drawn to show the frequency distribution of the lead values. The arithmetic mean, median, standard deviation, and minimum and maximum values were then calculated. These values provide measures of the range and central tendency of the data. Comparison of the mean and median values indicates the degree of skewness in the distribution; in positively skewed distributions, the median is a more precise measure of central tendency than the mean (Davies, 1989). The data were then transformed to their base ten logarithm (normalized) before statistical analysis (Davies, 1989).

Once the data were normalized, the mean, median, variance, and standard deviation of the data were calculated using techniques suggested by Pfaffenberger and Patterson (1977), Sinclair (1980), and Davies (1989). The results of these calculations provide information for interpretation of anomalous values versus background values of lead, as well as the expected frequency of values in populations obtained with similar sampling strategies. In addition, an R-mode (Pearson) correlation coefficient was calculated to determine the strength of the relationship between soil lead levels and distance from the highway. This measure of the lead/distance relationship is important for comparing the

results of this study with those of previous researchers who have found a significant negative correlation between lead values and distance from highways (Motto et al., 1970; Wheeler and Rolfe, 1979; and Agrawal et al., 1980)

Transect Data. The distribution of values within each transect with relation to distance from the highway was graphed. This was performed to assess whether the exponential sampling methodology produced a curve, representing the relationship between soil lead level and distance from the highway, which mirrored the exponential decline in lead with distance shown in previous research. Motto et al. (1970) and Wheeler and Rolfe (1979) produced exponential curves showing rapid decreases in lead values with distance from the road edge from samples taken at set distance intervals up to 200 m from the highway. Variation in lead values beyond 40 m is minimal, with soil lead levels approaching background values.

However, both studies assume a smooth relationship curve between soil lead and distance between samples that are as much as 18 m apart. Neither study attempts to measure variability in soil lead values closest to the highway, which should start high and drop rapidly with distance. In this study, the exponential sampling strategy provides a more intensive examination of lead levels in the area most likely to have higher values and greater variation. Plotting of these data demonstrates whether there is any variation in

the pattern of lead deposition at distances closer to the highway.

Location Specific Data. The data of individual transect locations were compared to examine similarities in patterns of lead distribution among the transects. This analysis was used to 1) identify transect locations with unusually high or low values; 2) identify similarities in patterns of soil lead distribution among transect locations; and 3) assist in identifying conditions which may influence lead values and their distribution.

Transects were compared based on their locations (north, south, east or west) relative to I-275 to determine if there is any relationship due, for example, to prevailing wind direction. Values for transect locations north of the I-4 interchange (the portion of the highway completed in the mid-1960's) were compared to those from the older, southern portion of I-275 to examine any relationship between the relative ages of these sections of the highway and the distribution of lead values. Other significant locational attributes were also noted to establish their possible role in the soil lead distributions observed at each transect location.

Distance Specific Data. The values at each of the specific sample site distances (3 cm, 9 cm, etc.) were grouped, normalized, and treated with the same statistical

methods as the general database. This provides an assessment of the characteristics (range and central tendency) of each set of samples collected at the established distances from the edge of the highway. The measures of central tendency for each distance group also provide values representing a composite transect for the entire study area. The distance specific lead values were plotted using box and whisker graphs which show the variations with distance in the ranges and measures of central tendency of each data group (Tukey, 1977).

CHAPTER 4
RESULTS

The results of the soil sampling, lead extraction, and data handling procedures are presented in this chapter. A total of 224 soil samples were collected from the I-275 right of way and analyzed for their lead content. Twenty percent of the samples were tested twice as a quality assurance measure. The results of the soil lead analyses are presented first as a general database, then by individual transect and transect groups, and finally by distance specific locations.

General Data

The soil lead values for the 224 samples are contained in TABLE 1. Values are rounded to the nearest multiple of 20. This is considered to be the equipment and procedural sensitivity limit for measurement of lead by atomic absorption spectroscopy (Slavin, 1978). Twenty percent of the samples (a total of 44) were tested twice for quality assurance. An F-test of the normalized original and replicated values for the 44 samples determined that the variances of the two sets of data are indistinguishable at a 90% confidence interval. A t-test of the means of the two sets of data yielded a t-value of -0.031 at 90% confidence. The critical value for t is 1.293 at 86 degrees of freedom.

TABLE 1 Transect locations and lead levels for soil samples taken from the I-275 right of way. Transects are located between interchanges on either side of the highway. Seven soil samples were taken at each transect. Lead values are in ppm, followed by the base ten logarithm.

TRANSECT	SAMPLE #	LEAD (PPM)	LOG VALUE
1 East (Bearss-Fletcher)	1	2420	3.3838
	2	180	2.2553
	3	120	2.0792
	4	160	2.2041
	5	120	2.0792
	6	240	2.3802
	7	60	1.7782
2 East (Fletcher-Fowler)	1	1100	3.0414
	2	1100	3.0414
	3	920	2.9638
	4	740	2.8692
	5	840	2.9243
	6	400	2.6021
	7	100	2.0000
3 East (Fowler-Busch)	1	100	2.0000
	2	40	1.6021
	3	60	1.7782
	4	280	2.4472
	5	480	2.6812
	6	440	2.6435
	7	200	2.3010
4 East (Busch-Bird)	1	720	2.8573
	2	300	2.4771
	3	240	2.3802
	4	1000	3.0000
	5	360	2.5563
	6	420	2.6233
	7	60	1.7782
5 East (Bird-Sligh)	1	600	2.7782
	2	480	2.6812
	3	480	2.6812
	4	500	2.6990
	5	660	2.8195
	6	160	2.2041
	7	100	2.0000

TABLE 1 (cont'd)

TRANSECT	SAMPLE #	LEAD (PPM)	LOG VALUE
6 East (Sligh-Hillsborough)	1	420	2.6233
	2	240	2.3802
	3	320	2.5052
	4	300	2.4771
	5	840	2.9243
	6	220	2.3424
	7	340	2.5315
7 East (Hillsborough-ML King)	1	360	2.5563
	2	580	2.7634
	3	280	2.4472
	4	420	2.6233
	5	820	2.9138
	6	160	2.2041
	7	220	2.3424
8 East (ML King-Floribraska)	1	500	2.6990
	2	600	2.7782
	3	520	2.7160
	4	1040	3.0170
	5	500	2.6990
	6	380	2.5798
	7	80	1.9031
9 East (Floribraska-I-4)	1	2460	3.3909
	2	3360	3.5263
	3	1400	3.1461
	4	1260	3.1004
	5	960	2.9823
	6	300	2.4771
	7	280	2.4472
10 South (I-4-Scott/Ashley/Tpa)	1	500	2.6990
	2	300	2.4771
	3	420	2.6233
	4	960	2.9823
	5	800	2.9031
	6	1140	3.0569
	7	440	2.6435
11 South (Scott/Ashley/Tampa-Howard/Armenia)	1	120	2.0792
	2	120	2.0792
	3	320	2.5052
	4	580	2.7634
	5	1040	3.0170
	6	200	2.3010
	7	400	2.6021

TABLE 1 (cont'd)

TRANSECT	SAMPLE #	LEAD (PPM)	LOG VALUE
12 South (Howard/Armenia-Himes)	1	120	2.0792
	2	100	2.0000
	3	160	2.2041
	4	180	2.2553
	5	1080	3.0334
	6	1140	3.0569
	7	1480	3.1703
13 South (Himes-Dale Mabry)	1	500	2.6990
	2	240	2.3802
	3	360	2.5563
	4	220	2.3424
	5	240	2.3802
	6	100	2.0000
	7	60	1.7782
14 South (Dale Mabry-Lois)	1	60	1.7782
	2	540	2.7324
	3	500	2.6990
	4	540	2.7324
	5	520	2.7160
	6	420	2.6233
	7	440	2.6435
15 South (Lois-Westshore)	1	420	2.6233
	2	840	2.9243
	3	3240	3.5106
	4	1360	3.1335
	5	920	2.9638
	6	160	2.2041
	7	140	2.1461
16 South (Westshore-SR 60)	1	40	1.6021
	2	40	1.6021
	3	100	2.0000
	4	40	1.6021
	5	420	2.6233
	6	40	1.6021
	7	100	2.0000
1 West (Bearss-Fletcher)	1	120	2.0792
	2	120	2.0792
	3	60	1.7782
	4	180	2.2553
	5	320	2.5052
	6	160	2.2041
	7	80	1.9031

TABLE 1 (cont'd)

TRANSECT	SAMPLE #	LEAD (PPM)	LOG VALUE
2 West (Fletcher-Fowler)	1	180	2.2553
	2	120	2.0792
	3	60	1.7782
	4	60	1.7782
	5	300	2.4771
	6	300	2.4771
	7	160	2.2041
3 West (Fowler-Busch)	1	800	2.9031
	2	800	2.9031
	3	520	2.7160
	4	300	2.4771
	5	460	2.6628
	6	120	2.0792
	7	160	2.2041
4 West (Busch-Bird)	1	1960	3.2923
	2	1140	3.0569
	3	1500	3.1761
	4	1140	3.0569
	5	580	2.7634
	6	720	2.8573
	7	400	2.6021
5 West (Bird-Sligh)	1	540	2.7324
	2	660	2.8195
	3	640	2.8062
	4	1020	3.0086
	5	860	2.9345
	6	760	2.8808
	7	140	2.1461
6 West (Sligh-Hillsborough)	1	600	2.7782
	2	280	2.4472
	3	340	2.5315
	4	520	2.7160
	5	540	2.7324
	6	220	2.3424
	7	360	2.5563
7 West (Hillsborough-ML King)	1	280	2.4472
	2	620	2.7924
	3	840	2.9243
	4	1020	3.0086
	5	760	2.8808
	6	520	2.7160
	7	160	2.2041

TABLE 1 (cont'd)

TRANSECT	SAMPLE #	LEAD (PPM)	LOG VALUE
8 West (ML King-Floribraska)	1	360	2.5563
	2	360	2.5563
	3	920	2.9638
	4	660	2.8195
	5	360	2.5563
	6	580	2.7634
	7	940	2.9731
9 West (Floribraska-I-4)	1	240	2.3802
	2	240	2.3802
	3	240	2.3802
	4	580	2.7734
	5	280	2.4472
	6	300	2.4771
	7	280	2.4472
10 North (I-4-Scott/Ashley/Tpa)	1	160	2.2041
	2	280	2.4472
	3	340	2.5315
	4	460	2.6628
	5	100	2.0000
	6	360	2.5563
	7	120	2.0792
11 North (Scott/Ashley/Tampa- (Howard/Armenia)	1	120	2.0792
	2	180	2.2553
	3	580	2.7634
	4	180	2.2553
	5	460	2.6628
	6	600	2.7782
	7	340	2.5315
12 North (Howard/Armenia-Himes)	1	160	2.2041
	2	460	2.6628
	3	100	2.0000
	4	200	2.3010
	5	540	2.7324
	6	460	2.6628
	7	460	2.6628
13 North (Himes-Dale Mabry)	1	60	1.7782
	2	160	2.2041
	3	160	2.2041
	4	180	2.2553
	5	200	2.3010
	6	180	2.2553
	7	240	2.3802

TABLE 1 (cont'd)

TRANSECT	SAMPLE #	LEAD (PPM)	LOG VALUE
14 North (Dale Mabry-Lois)	1	700	2.8451
	2	780	2.8921
	3	180	2.2553
	4	1860	3.2695
	5	400	2.6021
	6	620	2.7924
	7	160	2.2041
15 North (Lois-Westshore)	1	360	2.5563
	2	100	2.0000
	3	60	1.7782
	4	520	2.7160
	5	280	2.4472
	6	320	2.5052
	7	540	2.7324
16 North (Westshore-SR 60)	1	100	2.0000
	2	160	2.2041
	3	100	2.0000
	4	60	1.7782
	5	60	1.7782
	6	60	1.7782
	7	340	2.5315

Since the calculated t-value falls below the critical value, the means of the two sets of values are also indistinguishable, indicating successful replication in the lead extraction and measurement procedures.

Lead values range from a minimum of 40 ppm to a maximum of 3360 ppm, with a mean of 473, median of 350, and standard deviation of 478. FIGURE 4 contains a frequency histogram of the soil lead values. The raw data are not normally distributed. Instead, the distribution of values is positively skewed, with a clustering of lower values and a spread to very high values. This indicates that the median of 350 ppm is a better measure of the central tendency of the samples than the arithmetic mean (Davies, 1989). The data were then normalized to their base ten logarithms. FIGURE 5 shows the distribution of these values. The transformed data more closely approximate a normal distribution. The mean value of the normalized data is 317 ppm, just slightly less than the median (350) and less than the arithmetic mean (473) of the raw data. The standard deviation is 482. Over one third of the samples in the study area are at 500 ppm or above, levels considered to be hazardous waste by the EPA (Anonymous, 1992a) and dangerous to humans, especially children (CDC, 1985; and Chaney and Mielke, 1986).

To determine the strength of the relationship between soil lead level and distance from the highway, a sample correlation analysis was performed on both the raw and

Histogram of Pb(ppm)   N = 224
Each * represents 2 obs.

Midpoint	Count	
0	20	**********
200	75	**************************************
400	50	*************************
600	34	*****************
800	16	********
1000	12	******
1200	7	****
1400	3	**
1600	1	*
1800	1	*
2000	1	*
2200	0	
2400	2	*
2600	0	
2800	0	
3000	0	
3200	1	*
3400	1	*

FIGURE 4 Frequency histogram of soil lead values (raw data).

Histogram of Pblogten   N = 224

Midpoint	Count	
1.650	5	*****
1.800	13	*************
1.950	14	**************
2.100	13	*************
2.250	28	****************************
2.400	22	**********************
2.550	38	**************************************
2.700	36	************************************
2.850	25	*************************
3.000	19	*******************
3.150	5	*****
3.300	2	**
3.450	3	***
3.600	1	*

FIGURE 5 Frequency histogram of soil lead values (normalized data).

normalized data. The Pearson product-moment correlation coefficient was calculated for the two variables distance and lead. This coefficient measures the degree of linear association between two variables. For the raw data, r = -.193, indicating a weak negative relationship between the two factors; that is, as distances increase, soil lead levels decrease. The r-value for the normalized data is -.197, again indicating a weak negative correlation between distance and soil lead. Motto et al. (1970) and Wheeler and Rolfe (1979) found stronger negative relationships between soil lead levels and the distance of soil samples from the road edge. Results in this study indicate that other factors may be modifying that relationship.

One factor that can influence soil lead levels is wind direction. A positive correlation between lead levels and wind direction from sources of contamination has been documented, with higher levels of soil lead found downwind from both point and line sources of lead (Chow, 1970; Ward et al., 1974; and Schalscha et al. 1987). Therefore, the data were grouped by direction of the transect location in relation to the highway (north or south of I-275 in the lower portion of the study area, east or west in the upper portion) and the mean, median, and standard deviation were calculated. The results for the raw data are shown in TABLE 2 and for the normalized data in TABLE 3. In both cases, the large, overlapping ranges encompassed by the standard deviations for the samples in each directional category

TABLE 2 Mean, median, and standard deviation (STD) of soil lead levels (raw data in ppm) related to direction from I-275.

DIRECTION	# SAMPLES	MEAN	MEDIAN	STD
north	49	318	200	294.4
south	49	494	400	549.0
east	63	561	400	596.4
west	63	490	360	370.2

TABLE 3 Mean, median, and standard deviation (STD) of soil lead levels (normalized data in ppm) related to direction from I-275.

DIRECTION	# SAMPLES	MEAN	MEDIAN	STD
north	49	234	200	283.1
south	49	297	400	574.3
east	63	369	400	579.8
west	63	366	360	461.7

indicate that there is not a discernible relationship between direction and soil lead level and, therefore, that wind direction does not play an important role in the distribution of soil lead levels. Chow (1970) observed that the effect of wind on lead levels tends to diminish with distance from the highway. Similarly, Ward et al. (1987) completed their study in areas immediately adjacent to roads and thus did not garner results for which there was a need to account for the diminishing effect of distance. Therefore it is not surprising that no strong relationship was found between direction from the highway and mean soil lead levels. However, it is interesting that the measures of central tendency in both of the above tables indicate lower values in the southern portion of the study area (north-south transects) than in the north (east-west transects).

This would not be expected as the lower portion of the highway is older and thus the soils adjacent to it would have had a longer time period in which to adsorb lead particulates from automobile exhaust. The influence of other factors is suggested and is more evident in examination of the data by transect location and by sample site grouping.

Transect Data

Transect site locations are shown in FIGURE 2 and are discussed individually beginning in the northern portion of the study area. Data for the samples from each transect are displayed in TABLE 1.

Site 1. The first transects are located on the east and west sides of I-275 between the highway exits at Bearss Avenue to the north and Fletcher Avenue to the south. Both the East and West sites fall on the approximate midpoints between the two interchanges. At the West location, vegetation consists predominantly of grass, with some pine trees 2-3 m from the highway near the right of way fence line. The slope of this transect is approximately 5%. Lead values range from 60 ppm at the 27 cm distance to 320 ppm at 243 cm.

At Site 1 East, vegetation is predominantly grass; there are no trees or shrubs within the area or along the fence line. The transect slope is approximately 5%. The seventh soil sample on the East transect was taken at the fence line, 1830 cm from the road edge. The fence separates

the highway right of way from a miniature golf course and a gasoline-powered go-kart track. It was suspected that lead levels on this transect, especially near the fence line, might be elevated due to two potential sources of lead particulates. Soil lead values range from 60 ppm at the fence to 2420 ppm at 3 cm. However, excluding the sample closest to the road, the values range only from 60-240 ppm. There does not appear to be an overall elevation of soil lead values as a result of the go-kart track (TABLE 1).

Site 2. The second set of transects are located between Fletcher Avenue and Fowler Avenue. The West transect falls at the midpoint between interchanges; the East transect is located 0.1 miles north of the midpoint because I-275 spans a secondary road with an overpass at the midpoint. Vegetation on the West transect is mainly grass to the fence line; the fence itself is relatively free of any undergrowth. The transect slope is approximately 50%. Soil lead values range from 60 ppm, at both the third and fourth sample site distances, to 300 ppm at both the fifth and sixth sites.

At the East site, the transect descends from the highway at about a 30% slope through grassy vegetation. The seventh soil sample was taken at the fence line at 1830 cm. There is considerable undergrowth of shrubs and vines at the fence, which separates the ROW from a residential cul-de-sac. Lead values at the East site are relatively

high, ranging from 100 ppm at 1830 cm to 1100 ppm at both the 3 and 9 cm sites (TABLE 1).

Site 3. The transects of Site 3 are located between Fowler Avenue and Busch Boulevard. The West transect is 0.2 miles south of the midpoint due to a secondary road overpass, while the East transect is at the midpoint between the two interchanges. The West transect extends from the road edge to 1661 cm at the ROW fence line. Vegetation is predominantly grassy and there is an undergrowth of mostly dead grasses at the fence. The slope of the transect is 50%. Lead values for the soil samples range from 120-800 ppm, with the highest value occurring at each of the two samples closest to the road edge. Values decline steadily with distance from the road except for an increase from 300 ppm at 81 cm to 460 ppm at 243 cm.

The East transect extends 1400 cm through grassy vegetation to the ROW fence, which is almost completely covered with vines, shrubs and grassy undergrowth, producing a substantial layer of organic matter above the soil at the fence. The transect slope is approximately 50%. Lead levels are lowest at 9 cm from the road (40 ppm) and highest at 243 and 729 cm (480 ppm and 440 ppm respectively) (TABLE 1).

Site 4. The fourth set of transects both lie at the midpoints between Busch Boulevard and Bird Street. The grassy vegetation of the highway ROW on the West transect changes abruptly at the fence line (2130 cm) to trees, shrubs and tall grasses. The transect slopes at about 10%.

Lead values at these sample sites are generally high, ranging from 400 ppm at the ROW fence to 1960 ppm at the highway's edge, with six of the seven soil samples above 500 ppm and four above 1000 ppm.

The Site 4 East transect lies on a gentler slope (approximately 10%) than the West but traverses the same generally grassy vegetation up to the ROW fence, where a large stand of shrubs and trees separates the ROW from a residential street. Soil lead levels range from 60-1000 ppm. Highest values are found at 81 cm (1000 ppm) and 3 cm (720 ppm) while the lowest value is at the fence line (1700 cm) (TABLE 1).

Site 5. The Site 5 transects are located between Bird Street and Sligh Avenue, both at the approximate midpoints. The West transect site contains less vegetation cover than previous sites, with areas of bare soil on the sloping portion of the transect (approximately 40% slope). The base of the slope at the ROW fence (1580 cm) has slightly more ground cover than the rest of the site and the fence is host to vines and a small palm tree. Lead values are highest (1020 ppm) at 81 cm and drop to 140 ppm at the fence. However, soil lead exceeds 500 ppm at every sample site except for the fence line site.

The East transect of Site 5 descends at a 40% slope from the road edge through more dense grass cover than the West site. Bare soil was not as evident. This transect crosses a culvert at about 900-1000 cm from the road, and

the seventh soil sample was taken near some recently planted pine trees at 2187 cm on a slight upward slope from the culvert. Soil lead values of 500, 600, and 660 ppm are present at the fourth, first, and fifth sample points respectively; all other values are below 500 ppm and the lowest value is 100 ppm at the seventh sample site (TABLE 1).

Site 6. The sixth transect sites are located between Sligh Avenue and Hillsborough Avenue. The West transect is 0.1 miles south of the midpoint between interchanges and the East site is 0.1 miles north of the midpoint due to a secondary road overpass. The West transect extends 2170 cm from the highway's edge to the ROW fence line at a 30% slope. This transect crosses a drainage culvert and the site contains grassy vegetation with frequent spots of bare soil. The portion of the transect west of the culvert slopes upward at about 5-10%. The highest soil lead value is 600 ppm at 3 cm from the road. Values decrease to 340 ppm at 27 cm, but increase at 81 cm and 243 cm, where soil lead is 520 and 540 ppm respectively. After 243 cm, lead values again descend, with the lowest value (220 ppm) at 729 cm.

Site 6 East extends 1750 cm at a 50% slope to the ROW fence line and also crosses a drainage culvert. Grassy vegetation covers the area and there are small shrubs growing inside the culvert. Several small trees (pine and palm) are attempting establishment at the base of the fence. The lowest soil lead value for this site is 220 ppm at 729

cm from the road edge. The highest is 840 at 243 cm. This is the only value of the seven to exceed 500 ppm (TABLE 1).

<u>Site 7.</u> The transects of Site 7 are between Hillsborough Avenue and Martin Luther King, Jr. Boulevard (ML King). Again, due to a secondary road overpass, the West site is 0.1 miles south and the East site 0.1 miles north of the midpoint between the interchanges. The West transect extends 1920 cm to the ROW fence line at a slope of 50%. Grass cover is the predominant vegetation but there are many areas of bare soil, several recently planted pine trees about 0.5 m from the fence, and shrubs and other undergrowth in a drainage culvert about halfway between the highway and the fence. Soil lead at Site 7 West ranges from 160 ppm at the ROW fence line to 1020 ppm at 81 cm. Soil lead levels at the 9, 27, 243, and 729 cm sites all exceed 500 ppm.

There is little variation in vegetation at Site 7 East, with grassy cover throughout the site and no trees or shrubs at the fence line or in the drainage culvert 1000 cm from the highway. The transect extends a total of 1390 cm at a 40% slope. The lowest soil lead value, 160 ppm, is found at 729 cm. The highest, 820 ppm, is found at 243 cm. One other site (9 cm) exceeds 500 ppm (TABLE 1).

<u>Site 8.</u> The eighth set of transects are located between ML King and Floribraska Avenue. Both fall at the midpoint between interchanges. The West transect of Site 8 descends at a slope of approximately 50% to the ROW fence line at 1500 cm from the road edge. The fence is about 60 cm from a

drainage culvert. Vegetation east of the culvert is primarily grass with a large number of areas of bare soil. Between the culvert and the fence are shrubs and small trees. There is a significant layer of organic material at the base of the fence where soil sample 7 was collected. There is also a spill of what appears to be blue paint on the vegetation and soils between the culvert and the fence within one meter of the transect. Soil lead levels range from 360 ppm at the 3, 9, and 243 cm sample sites to 940 ppm at the fence. Three other soil samples exceed 500 ppm lead.

The East transect of Site 8 is nearly level, with an approximate slope of 5%. Vegetation is primarily grass except for a stand of recently planted trees near the 2187 cm sample site. The sample site with the lowest soil lead value for the transect (80 ppm) is also at 2187 cm. Five of the remaining six sample sites have lead levels exceeding 500 ppm, with the maximum value of 1040 ppm occurring at the 81 cm site (TABLE 1).

Site 9. The Site 9 transects are located between Floribraska Avenue and the I-4 interchange. The West transect is at the midpoint, while the East transect is 0.1 miles north of the midpoint due to an obstruction. The West site slopes at approximately 50% and the transect extends 1500 cm from the highway to the ROW fence. Vegetation is primarily grass with several areas of bare soil. However, there is a variety of palms, grasses and vines along the fence and a 5-6 cm litter layer at the base of the fence.

Lead values in the soils range from 240 ppm at each of the first three sample sites to 580 ppm at the fourth sample site, the only value to exceed 500 ppm.

On the East side, the transect slope is 50% and the fence line is 1500 cm from the road edge. Several areas of bare soil within the grassy cover on the slope appear to have been recently disturbed. There is some undergrowth of vines and grasses at the fence line. This transect contains some of the highest soil lead values in the study area. The low value of 280 ppm is at the fence line. The first five samples sites have soil lead values of 2460, 3360, 1400, 1260, and 960 ppm respectively (TABLE 1). This transect borders a residential area and is near the intersection of two neighborhood streets.

<u>Site 10.</u> Site 10 lies south of the I-4 interchange and east of the Scott/Ashley/Tampa Streets (S/A/T) exit. It is at this point that I-275 extends in an east-west direction instead of north-south. The North transect is slightly beyond the midpoint between interchanges due to an exit ramp to Florida Avenue from the I-4 interchange. The South transect falls at the midpoint between interchanges. The North transect site has very sparse grassy vegetation with large areas of bare soil and many whole and partial sea shells among the vegetation and soils. The ROW fence line is on the north side of the Florida Avenue exit ramp, but is beyond the 2187 cm distance set for the seventh soil sample. Therefore, the seventh soil sample was taken 1650 cm from

the highway at the road edge of the exit ramp. Lead values ranged from 120-460 ppm, with the maximum value occurring at 81 cm and the minimum occurring at 1650 cm (TABLE 1).

The South transect extends 2040 cm to the ROW fence at a 50% slope. Vegetation is grassy, with vines and shrubs at the fence line. Three large metal billboard structures are within 3 m of the fence. Lead values here range from 300 ppm at 9 cm from the highway to 1140 ppm at 729 cm. Values also exceed 500 ppm at the 3, 81, and 243 cm sample sites. It should be noted that samples were taken at this site two months after samples were collected from the other thirty-one transects and within 24 hours after a heavy rainfall.

Site 11. The transects for Site 11 are located between the S/A/T exit and the Howard/Armenia Avenues (H/A) exit, both at the midpoint between interchanges. The North transect extends 1260 cm from I-275 to the ROW fence at about a 30% slope. Vegetation is grassy with several small pine trees near the transect line. Lead levels range from 120 ppm at the sample site closest to the highway to 600 ppm at 729 cm from the road.

The South transect extends 1190 cm from I-275 at approximately a 15% slope to the ROW fence line. Vegetation is grassy except for taller weeds and vines at the fence. There was more trash and litter at this site than at any other. Lead values at this site range from 120 ppm at the two sample sites closest to I-275 to 580 ppm at 81 cm and 1040 ppm at 243 cm from the highway. The latter two sites

are the only ones with soil lead values greater than 500 ppm (TABLE 1).

<u>Site 12.</u> The twelfth set of transects are located between the H/A and Himes Avenue exits at the midpoints between the interchanges. The North transect site contains mainly grassy vegetation with a few small pine trees near the transect line. The slope is 30% and the seventh sample site is 1660 cm from I-275 at the fence line. Soil lead values range from 100-540 ppm. The maximum value is 243 cm from the highway and is the only sample site with lead exceeding 500 ppm, although three other sites have soil lead of 460 ppm.

Site 12 South slopes at approximately 10% and extends 1300 cm to the ROW fence line. Vegetation is thick grass with one small pine tree near the transect line. This site has unusually high lead values at the most distant sample sites from I-275. The first four soil samples have lead values ranging only from 100-180 ppm. However, the 243, 729, and 1300 cm sites have lead of 1080, 1140, and 1480 ppm respectively (TABLE 1). The fence line separates the ROW from a residential street, although, this is true of most of the sites in the study.

<u>Site 13.</u> Site 13, between the Himes Avenue and Dale Mabry Highway exits, is unusual. The overpasses for these two interchanges are only 0.2-0.3 miles apart. Thus, although the transect locations in both directions are at the midpoints, they fall in unique areas. The North transect

slopes steeply (50%) from the highway to the ROW fence line 1960 cm away. The fence line separates the ROW from an abandoned parking lot and there is considerable undergrowth at the fence as well as several large trees. The Litter layer at the fence sample site is 5-6 cm thick. The transect also crosses a drainage culvert. Lead values here ranged only from 60-240 ppm, the minimum occurring closest to I-275 and the maximum at the ROW fence.

The South transect falls in a triangular area that is bordered by I-275, Dale Mabry Highway, and the entrance ramp from Dale Mabry to I-275. The center of this area is landscaped with palms, pine trees and manicured shrubs through which the line of the transect extended, sloping at about 15%. However, none of the soil sample sites fall within this landscaped area; the 729 cm site lies before the landscaping and 2187 cm lies beyond it. Lead values range from 60 ppm at 2187 cm from I-275 to 500 ppm at 3 cm (TABLE 1).

Site 14. The Site 14 transects are located at the midpoints between the Dale Mabry Highway and Lois Avenue exits. The North transect extends 1880 cm from I-275 to the ROW fence line at approximately a 40% slope. The grassy vegetation of the site is sparse until about 1200 cm from the road edge, where it becomes thicker. The fence line has considerable undergrowth of tall grasses and small shrubs and lies within two meters of a telephone pole and guy wire. Lead levels range from 160 ppm at the fence line to 1860 ppm

at 81 cm from I-275. The 3, 9, and 729 cm sites have soil lead values of 700, 780, and 620 ppm.

The ROW fence at the South transect site separates it from a commercial/warehouse area. Less than a meter north of the fence is a very large drainage culvert (2 m across and 1-2 m deep) that is barely visible for all the vegetation growing within its confines. Vegetation in the rest of the area is primarily grass. The transect extends 1780 cm from the road edge to the edge of the culvert at a 15% slope. Lead values at this site range from 60 ppm at the highway's edge to 540 ppm at 9 and 81 cm from the road. The 27 and 243 cm sample sites also exceed 500 ppm.

Site 15. The transects for Site 15 are between the Lois Avenue and Westshore Boulevard exits; both are at the midpoint between the interchanges. The North site appears to have been recently disturbed. The grass cover is very thick and the soils compacted. The transect extends only 840 cm from the highway to the ROW fence at about a 10% slope. There is a light upward slope before the fence. The site borders an office complex parking lot. Soil lead values range from 60 ppm to 540 ppm, with the maximum value occurring at the fence line and a similar value (520 ppm) occurring at 81 cm from the road edge.

The South transect extends only 800 cm from I-275 to the ROW fence. The slope from the highway is about 5%, but there is a 10% upward slope to the ROW fence (and a residential street) beginning at about 500 cm from the

highway. The vegetation is mostly grass. Soil lead levels have an extensive range at this site. The two lowest values, 140 and 160 ppm, occur at 729 and 800 cm sampling distances. From there, values increase substantially. Soil lead of 3240 ppm is found in the third transect sample, with values of 840, 1360, and 920 ppm at the second, fourth, and fifth sample points, respectively (TABLE 1).

Site 16. Site 16 is in an area of recent construction and landscaping due to highway modifications between the Westshore Boulevard and SR 60 exits. Both transects are at the midpoints between interchanges. The North transect extends 1500 cm from I-275 to the ROW fence, which separates the site from an office complex with an artificial pond within 1 m of the fence. The soils near the fence are moist and dark in color and the soils close to the road are compacted. Within in ROW, grass cover is thick throughout the site. There is a drainage depression about 1400 cm from the road edge. The vegetation within the depression appears to be hydric and is coated with a white powder. Lead values at this transect site are quite low, ranging from 60 ppm at three sample points to 340 ppm at the fence line (TABLE 1).

The South transect site is separated by the ROW fence from the Westshore Mall parking lot (within 2 m). The transect extends 1910 cm from I-275 at approximately a 5% slope. The grass cover is thick throughout the site and there is a row of pine trees planted near the fence. The soils near the road are compacted. This area was formerly

part of an exit ramp to Westshore Boulevard that was removed in recent construction. Overall, soil lead values are low here. The minimum value of 40 ppm occurs at the 3, 9, 81, and 729 cm sample sites. The maximum value of 420 ppm occurs at the 243 cm site (TABLE 1).

<u>Treatment of Transect Data.</u> The data within each transect were plotted on graphs to show the relationship between soil lead and distance from the highway at each location. These graphs are shown in FIGURE 6. Both axes of these graphs are in logarithmic scale. The exponential soil sampling procedure that was utilized did not produce the smooth, descending, curvilinear relationship between lead level and distance that has been observed in other research (Wheeler and Rolfe, 1979; and Agrawal et al., 1980). Most notably, there is not a rapid decline in lead values after the first sample site nearest the highway. Instead, lead values in the first three sample sites nearest the highway vary considerably. The relationship between lead levels and distance at these sites is difficult to discern in graphs with non-transformed distance scales because of the proximity of the first three sample distances. Therefore, the distance scales have been logarithmically converted in order to better display the lead/distance relationships in this study.

Roughly two thirds of the transect graphs show an

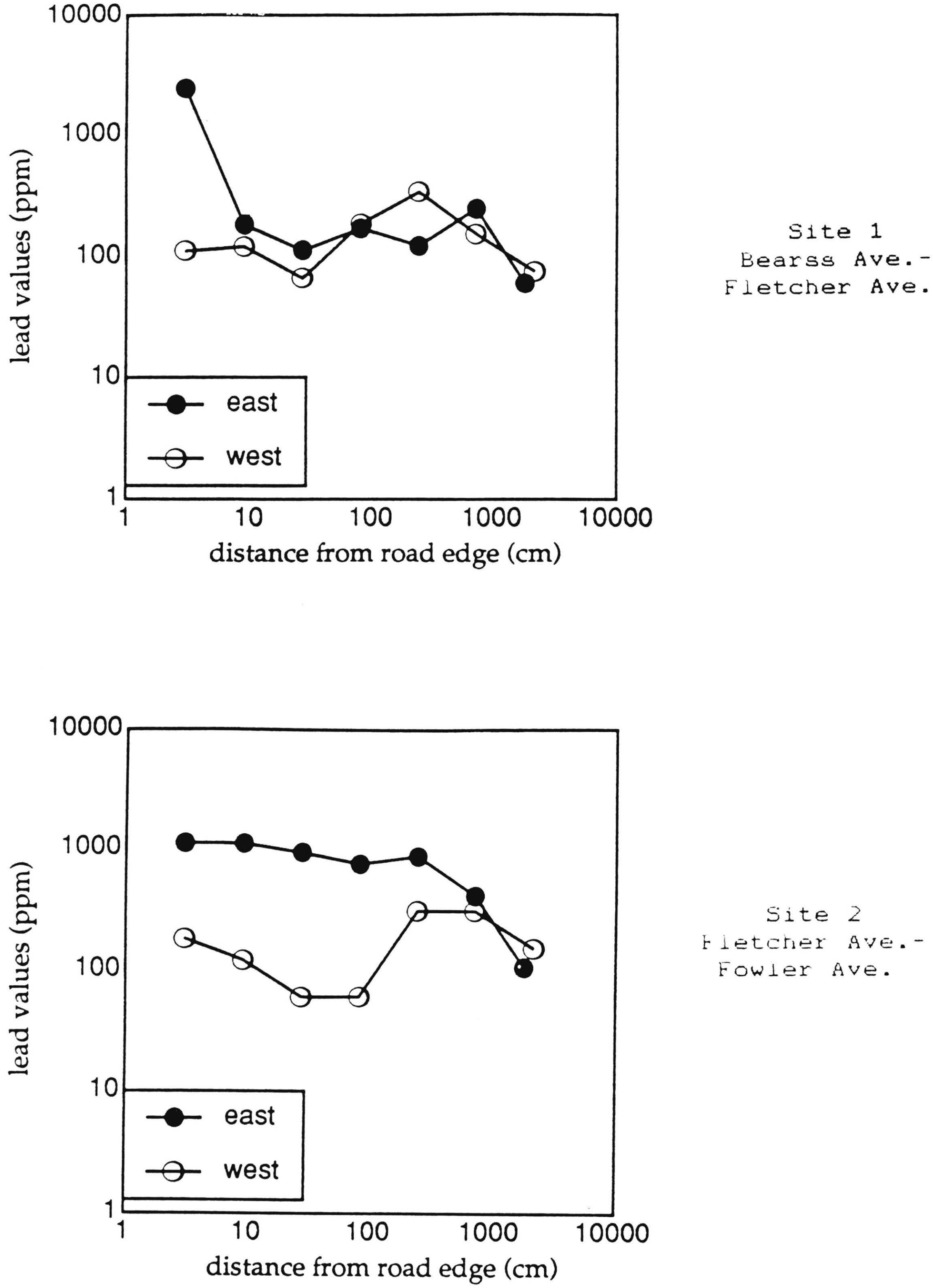
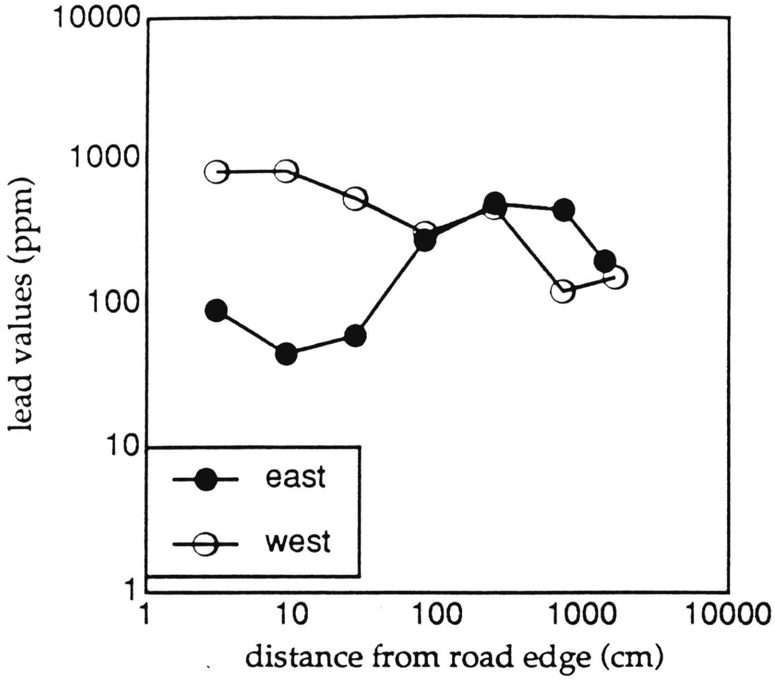
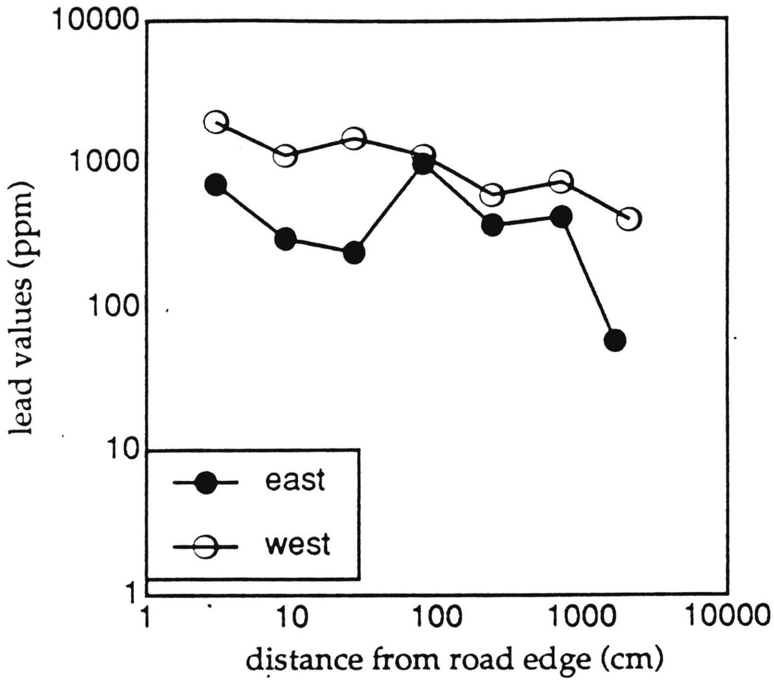


FIGURE 6 Relationship of soil lead values with distance from the highway for soil samples on transects adjacent to I-275.

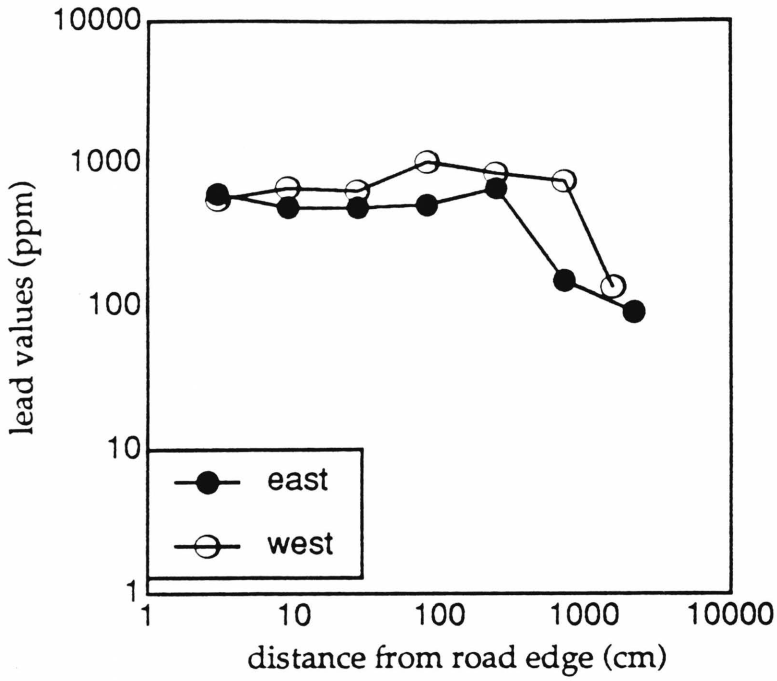


Site 3
Fowler Ave.-
Busch Blvd.

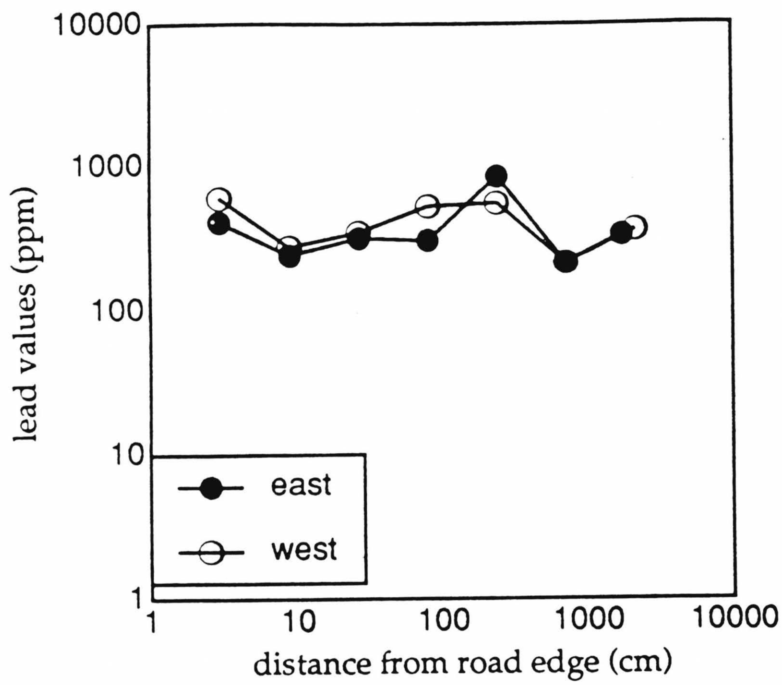


Site 4
Busch Blvd.-
Bird St.

FIGURE 6 (cont'd)

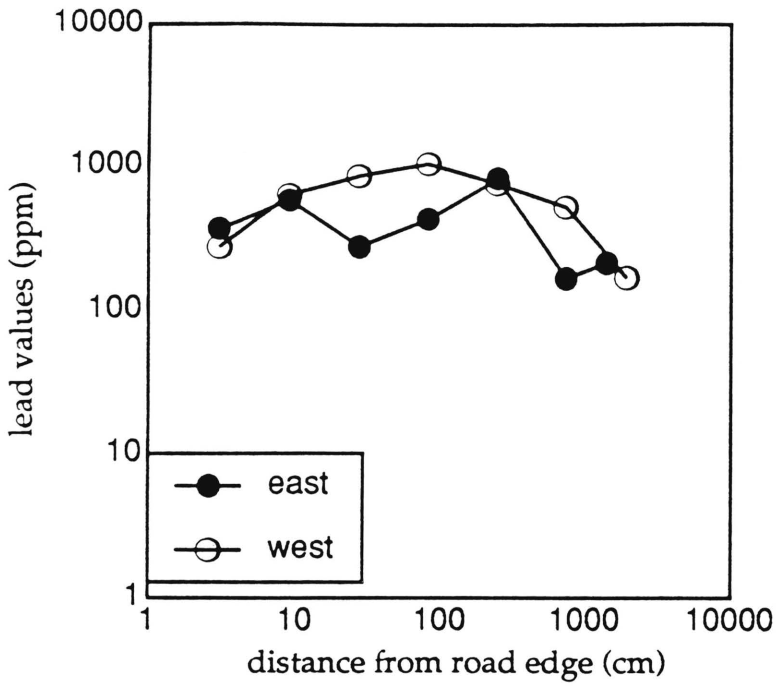


Site 5
Bird St.-
Sligh Ave.

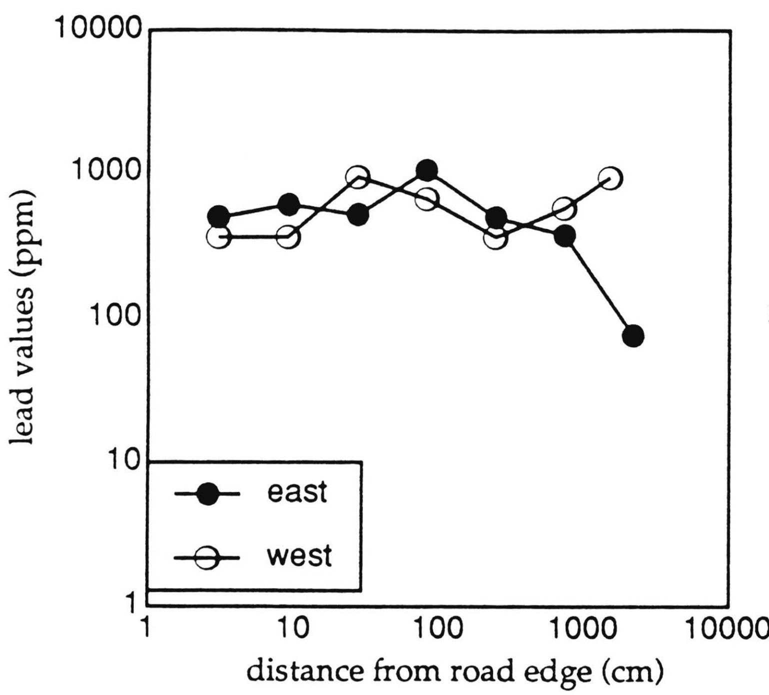


Site 6
Sligh Ave.-
Hillsborough Ave.

FIGURE 6 (cont'd)

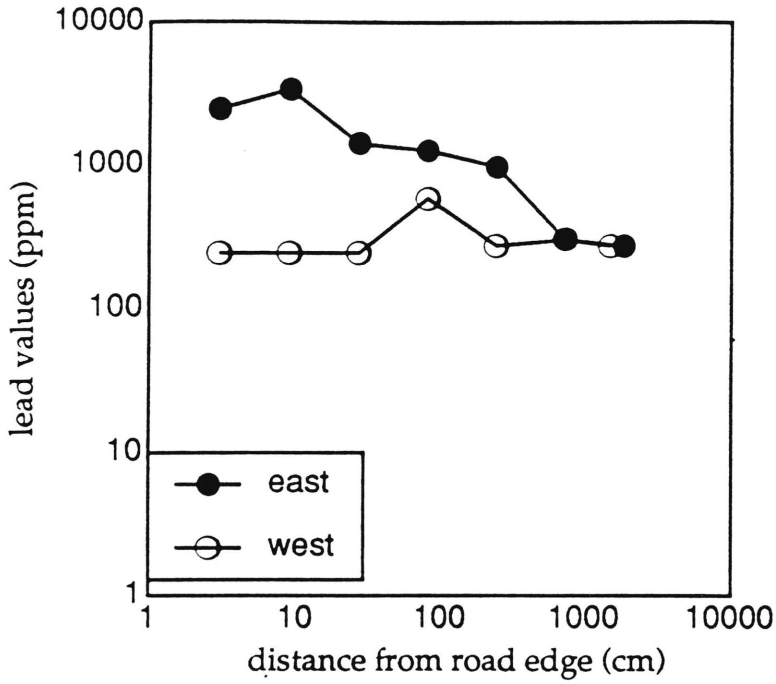


Site 7
Hillsborough Ave.-
M.L. King, Jr. Blvd.

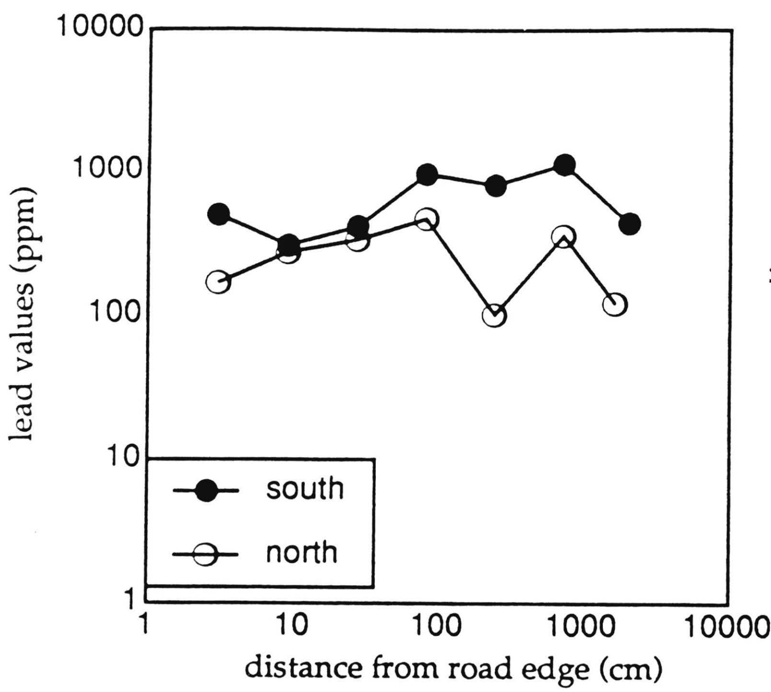


Site 8
M.L. King, Jr. Blvd.-
Floribraska Ave.

FIGURE 6 (cont'd)

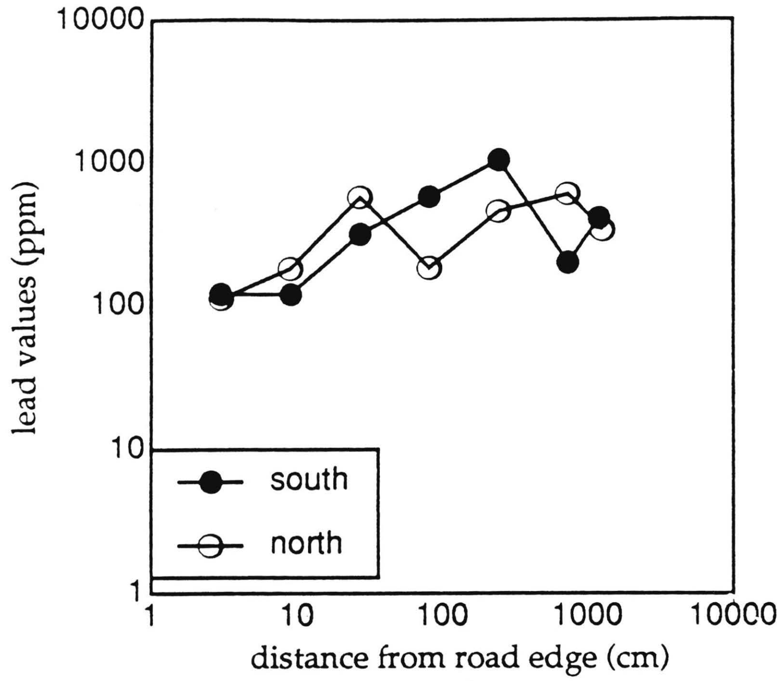


Site 9
Floribraska Ave.-
I-4

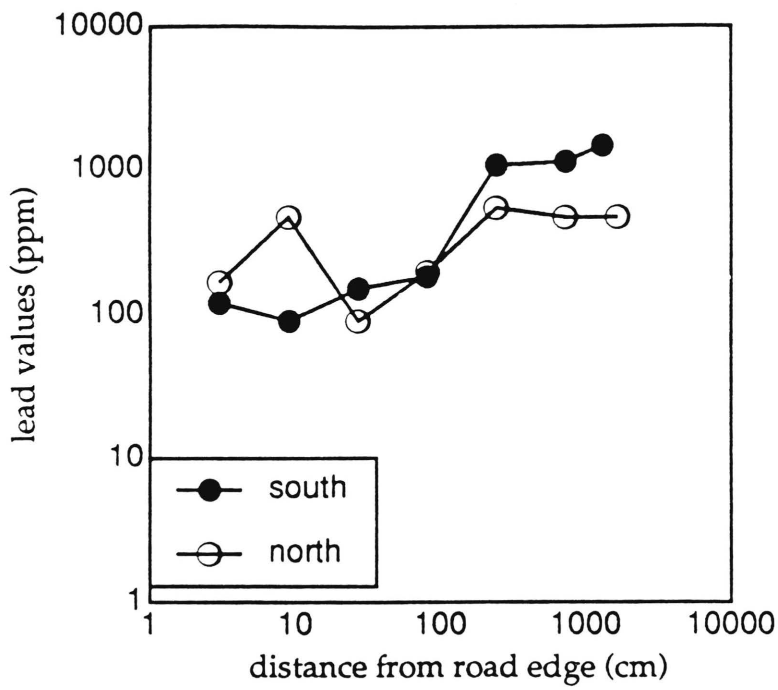


Site 10
I-4-
Scott/Ashley/Tampa

FIGURE 6 (cont'd)

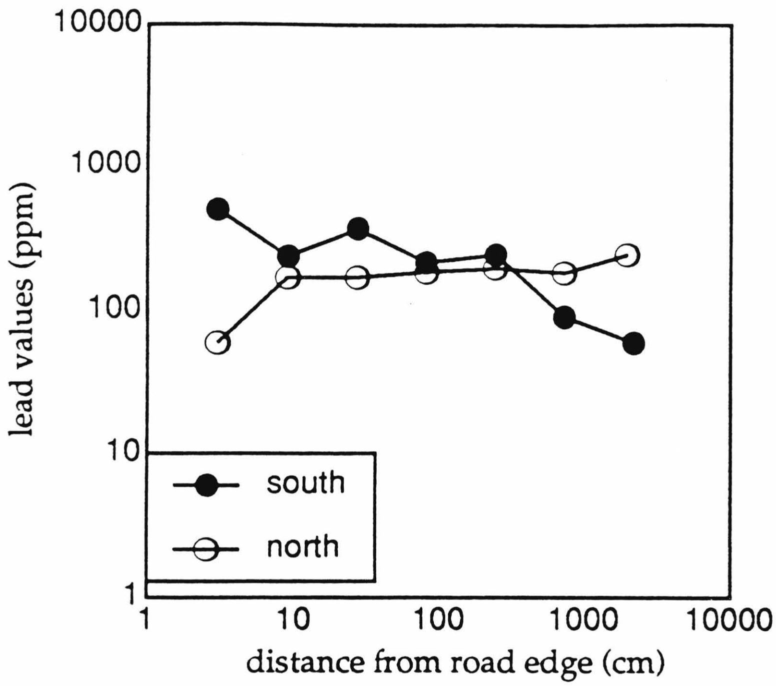


Site 11
Scott/Ashley/Tampa-
Howard/Armenia

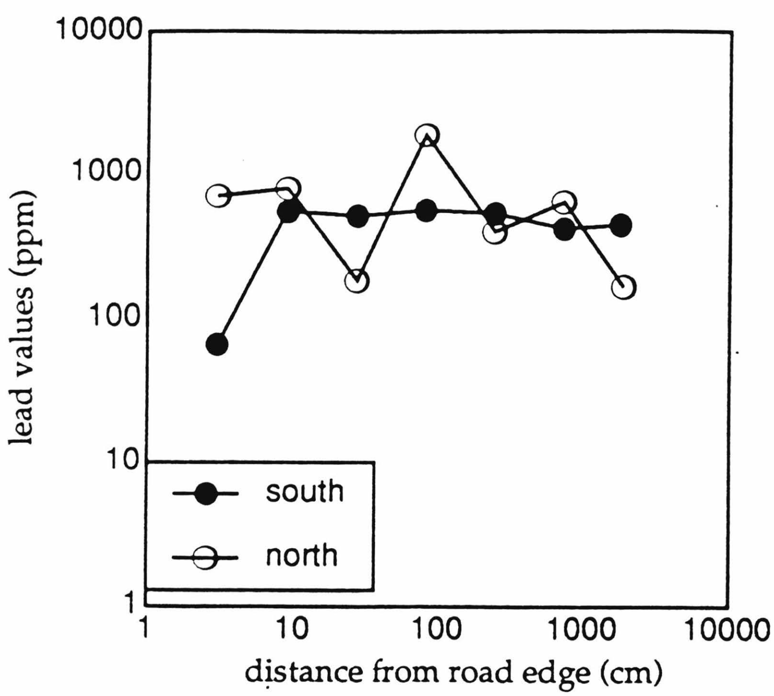


Site 12
Howard/Armenia-
Himes Ave.

FIGURE 6 (cont'd)

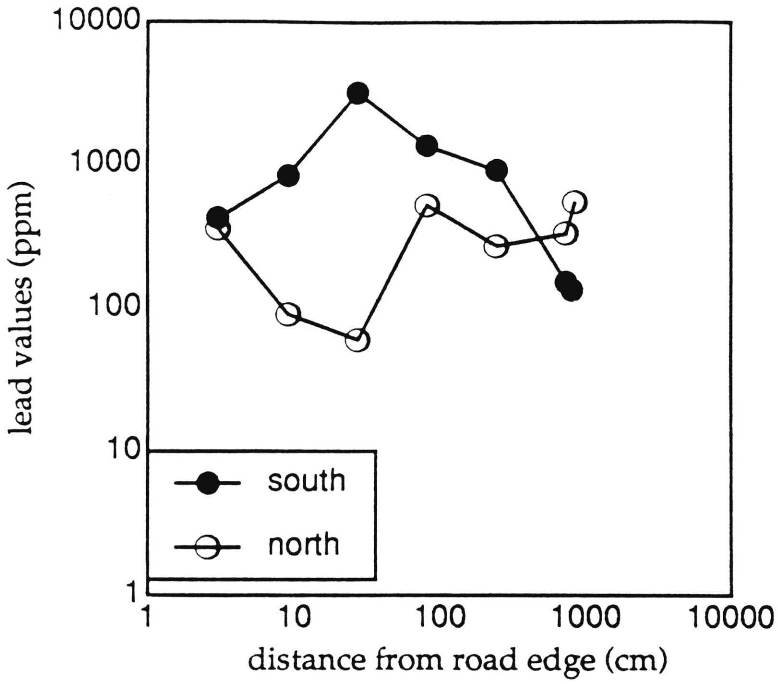


Site 13
Himes Ave.-
Dale Mabry Hwy.

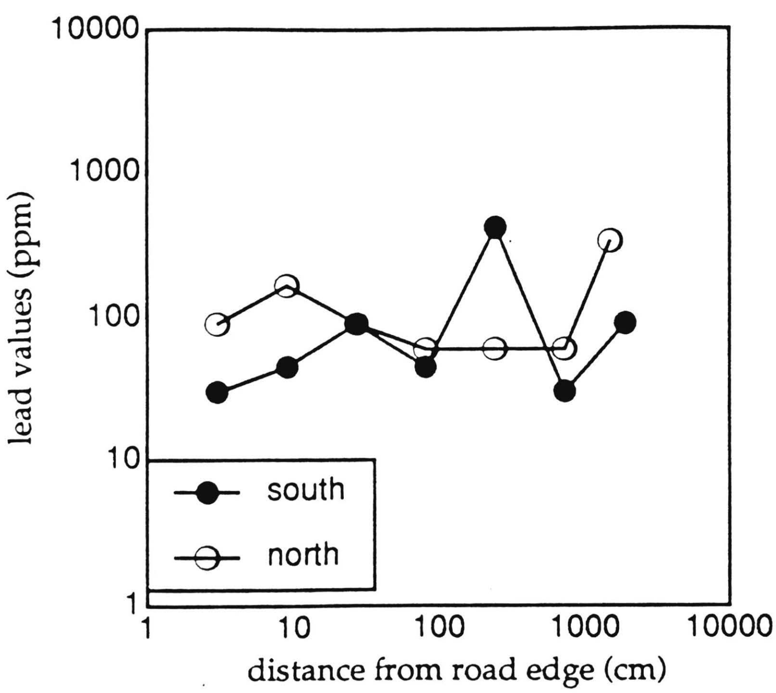


Site 14
Dale Mabry Hwy.-
Lois Ave.

FIGURE 6 (cont'd)



Site 15
Lois Ave.-
Westshore Blvd.



Site 16
Westshore Blvd.-
State Route 60

FIGURE 6 (cont'd)

increase in lead values at either the 81, 243, or 729 cm sample distances from the road edge before lead values again decrease. This is in contrast to the findings of other researchers that lead values decrease rapidly and steadily with distance from the highway (Chow, 1970; Motto et al., 1970; Wheeler and Rolfe, 1979; Muskett and Jones, 1980; Agrawal et al., 1980; and Culbard et al., 1988). There has been no trend reported of a zone of increased soil lead values at any distance from the road edge. However, previous researchers have also not taken samples as close to the road edge or at the narrow intervals utilized here. Nevertheless, in this study, it is difficult to identify a common trait among the transect locations which accounts for such a rise in soil lead with distance.

There is a marked divergence in the ranges and the overall soil lead values among the transects. For example the soil lead levels at one transect (16 South) ranged from 40-420 ppm, while another (9 East) ranged from 280-3360 ppm. 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 Site 16 South (Westshore-SR 60), where an overpass was widened, an exit ramp removed, and the entire area replanted with sod in the past year. The disturbing of the soils and the likely addition of fresh soil during landscaping probably accounts for the lower values at this site. Several other sites are modified by recent

construction and landscaping and have similar low ranges of soil lead values (16 North and 12 South). However, this factor alone does not explain all the transects with lower lead values.

It is useful to examine which transects contain sample sites with lead values greater than or equal to 500 ppm. TABLE 4 displays the number of contaminated sample sites at each transect location (total of seven sample sites per transect). There are clearly some locations with significant accumulations of soil lead away from the highway's edge, 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 the Westshore-SR 60 location, where, as discussed earlier, recent construction has disturbed the soils and vegetation.

TABLE 4 Number of sample sites at each transect location with soil lead values greater than or equal to 500 ppm.

West	TRANSECT	East
0	Bearss-Fletcher	1
0	Fletcher-Fowler	5
3	Fowler-Busch	0
6	Busch-Bird	2
6	Bird-Sligh	3
3	Sligh-Hillsborough	1
5	Hillsborough-ML King	2
4	ML King-Floribraska	5
1	Floribraska-I-4	5
North		South
0	I-4-Scott/Ashley/Tampa	4
2	Scott/Ashley/Tampa-Howard/Armenia	2
1	Howard/Armenia-Himes	3
0	Himes-Dale Mabry	1
4	Dale Mabry-Lois	4
2	Lois-Westshore	4
0	Westshore-SR 60	0

Distance Specific Data

In order to observe aggregate patterns in the relationship between soil lead values and distance from the highway, the data were grouped by the 3, 9, 27, 81, 243, 729, and >800 cm sample site distances and normalized. This enabled the calculation of aggregate range and central tendency characteristics for each sample site distance throughout the study area. The results are shown in TABLE 5. The mean values range from 212 ppm at the most distant sampling sites to 444 ppm at the fifth sampling sites from the road's edge (243 cm). The mean values of the 3, 9, and 27 cm sampling distances show little variation, with values of 316, 305, and 303 ppm respectively. The lack of variation in the mean values among these sites is not surprising since they are all very close to the edge of the highway and very close to one another. However, a distinct increase in the mean values occurs at the fourth and fifth sampling

TABLE 5 Mean, median, standard deviation (STD), and maximum (MAX) value of soil lead levels (normalized data in ppm) grouped by distance from I-275.

DISTANCE	# SAMPLES	MEAN	MEDIAN	STD	MAX
3 cm	32	316	360	596.6	2460
9 cm	32	305	290	501.0	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

distances before the mean values decline. The relationship is shown in FIGURE 7. Although the increase in mean lead values is not dramatic, based on previous research, a steady decline in the mean values with distance from the highway was expected.

At the same distance intervals where the soil lead level means increase, the maximum soil lead value for each group decreases (FIGURE 7). Thus there is not an incidence

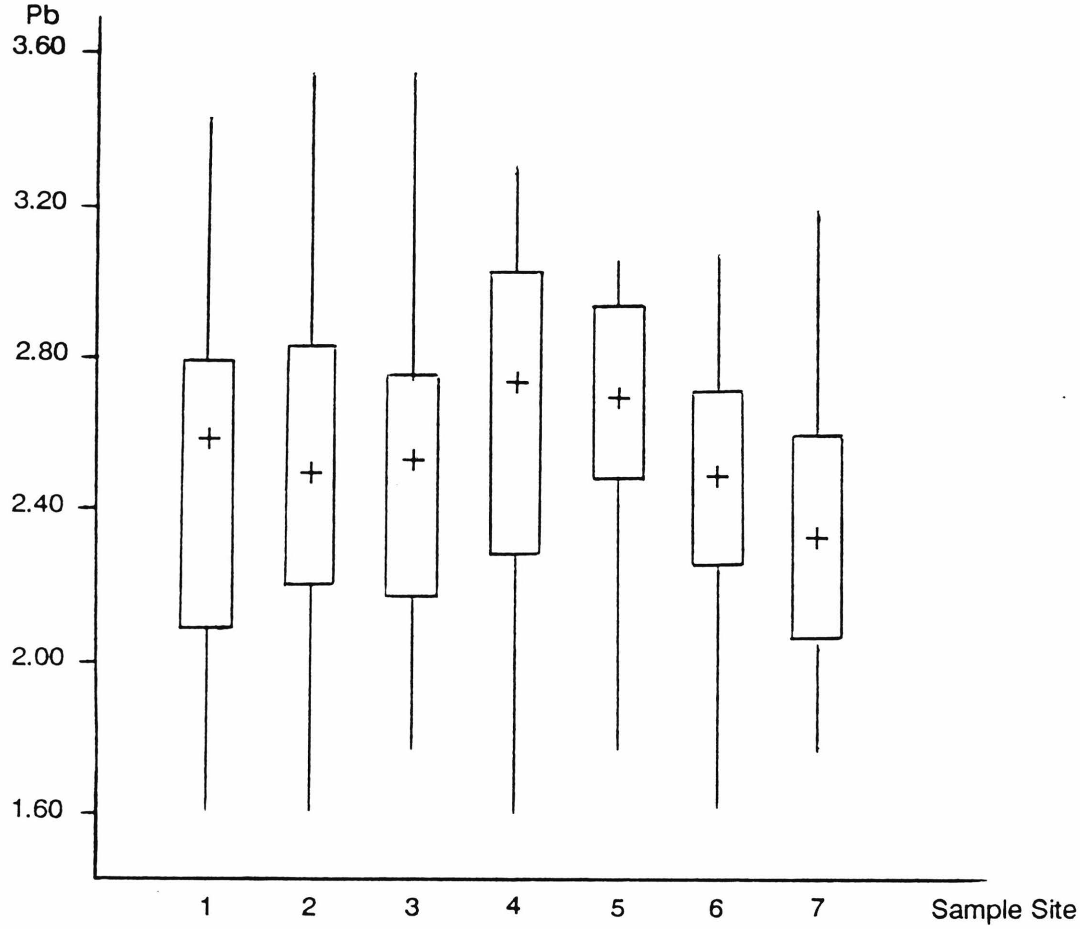


FIGURE 7 Ranges and median lead values (normalized) grouped by sample site. The median values of the fourth and fifth sampling distances are higher than those closer to the highway. Maximum values decline as the median values rise.

of anomalously high values at the fourth and fifth sampling distances to account for the unexpected increase in mean values. Rather, the soil lead values from approximately one to seven meters from the edge of I-275 are slightly higher overall than those closer to the road. If the soil lead values observed at the highway's edge are considered typical, then the values at greater distances are anomalous because they are higher on the whole. However, it is possible that the values closer to the road are actually lower than would be expected and are therefore the anomaly. These and other relationships between soil lead levels and distance in this study bear further discussion as many of the results obtained were not expected.

CHAPTER 5
DISCUSSION

In this chapter, various aspects of the results of this research are discussed. Emphasis is on the effectiveness of the methodologies employed in the study and on explanations for the relationship between soil lead and distance from the highway. Several factors are analyzed regarding their affects on soil lead distribution, including transect slope, traffic density, roadside turbulence, and organic matter content of the soil. The potential lead hazard to people living near I-275 is also discussed, based on the extent of the soil lead contamination which exists along the highway.

Methods

Most of the methods employed in this study have been used by other researchers in investigations of soil lead levels near roads. However, modifications of these procedures for this study, especially in the sampling strategy, produced data which in many ways are dissimilar to those from previous research.

Transect Sampling. Transect sampling was utilized in previous research to sample soils near highways for their lead content and to determine the relationship between distance and soil lead levels (Chow, 1970; Motto et al.,

1970; Wheeler and Rolfe, 1979; and Muskett and Jones, 1980). However, the number of transects utilized in this study exceeds that of other studies. Muskett and Jones (1980) sampled from only three transects in their study area; Chow (1970) drew samples from two transects on each of two different highways; and Motto et al. (1970) drew samples from thirteen transects along a highway.

The conclusions reached in these previous studies were drawn from fewer samples. In contrast, Wheeler and Rolfe (1979) established twelve transects on either side of four roads and took six soil samples at each distance point on the transect. However, they averaged the lead values by sampling location for each highway (twenty-four transects per highway), which precluded investigation of sources of variation in soil lead in their area of study. In this study, soil samples were drawn from thirty-two transects along I-275 in Hillsborough County, providing a larger database than previous research. A comparison of ranges of values and other factors for this study compared to previous research is shown in TABLE 6.

The number of transects and samples does not account for all the variability in the ranges of lead values among the studies. Location of the highway (urban vs. rural) and average daily traffic counts also affected the ranges of values in these studies, although the relationship is not clear. The two highways in Chow's study are located near Washington, DC, and have average daily traffic counts of

TABLE 6 Comparison of ranges of Pb values (ppm) versus number of sample transects, number of values reported, range of daily traffic volume, and urban or rural location of study area in five studies of roadside soil lead.

RESEARCHERS	Chow (1970)	Motto et al. (1970)	Wheeler & Rolfe (1979)	Muskett & Jones (1980)	Current (1992)
RANGE OF VALUES	39-403	30-442	8-1225	48-1769	40-3360
# TRANSECTS	4	13	96	3	32
# VALUES REPORTED	12	65	48	27	224
TRAFFIC VOLUME	24,000-56,000	12,800-54,700	550-8100	40,000	25,607-80,048
URBAN OR RURAL	Urban	Rural to Urban	Rural	Urban	Urban

24,000 and 56,000. Motto el al. took samples from segments of a highway in northeastern New Jersey with daily traffic volumes ranging from 12,800 to 54,700 vehicles. Wheeler and Rolfe studied four rural highways in central Illinois with average daily traffic of 550, 1500, 2300, and 8100 respectively. Muskett and Jones sampled soils near a West London highway with daily traffic of 40,000 vehicles. Traffic counts from the highway in the urban area of this study ranged from 25,607 to 80,048. Maximum values in the ranges of each study do not correlate with traffic volume or number of transects, indicating other factors affect the range of lead values. However, the large number of transects from which samples are drawn in this study raises opportunities to explore regional and transect location factors which influence the distribution and range of the lead values.

Exponential Distance Intervals. The exponential sample distance intervals that were used in this study did not produce the smooth relationship curve between distance and soil lead levels that was expected. This is due in large part to 1) the close proximity of the 3, 9, and 27 cm sampling distances; and 2) the unexpected increases in lead values away from the highway. In the 3, 9, and 27 cm sample distances, there was a rather large range in lead values compared to other distances. These are shown in TABLE 7. Yet the geometric mean lead values at these three distances were virtually the same, indicating that in the aggregate, there is no difference in soil lead values within 27 cm of I-275. This is not surprising, considering the short distance from the highway that is covered by the three samples. However, in the previous research reviewed, 30 cm was the closest distance from the highway that transect sampling was begun (Wheeler and Rolfe, 1979). Muskett and Jones (1980) began sampling at 50 cm, while Chow (1970) and Motto et al. (1970) began sampling at 760 cm and 762 cm (25 feet) respectively.

TABLE 7 Ranges and geometric mean soil lead values (ppm) at transect sample site distances.

DISTANCE	RANGE	MEAN
3 cm	40-2460	316
9 cm	40-3360	305
27 cm	60-3240	321
81 cm	40-1960	403
243 cm	60-1080	444
729 cm	40-1140	295
>800 cm	60-1480	212

Thus while little variation in the aggregate was found in the 3-27 cm distance range, the results in this range provide a basis for comparison to the values at greater distances and to the rise in mean soil lead values at these distances. In addition, the range of values obtained in the 3-27 cm distance is very interesting from a micro-study point of view since there are a wide variety of lead values in an area where lead deposition was expected to be consistently high.

Database

The pattern of soil lead distribution is examined in two ways. First, a comparison of lead values with traffic density patterns is made to examine the relationship between average daily traffic and the distribution of lead among transect locations. Second, the overall lead/distance relationship is analyzed with regard to slope, roadside turbulence, and organic matter content of the soils.

Traffic Density. Accumulation of lead in roadside soils is positively correlated with traffic density (Ward et al., 1974; and Ash and Lee, 1980). Sites with elevated lead levels generally correlate to segments of highways with higher average daily traffic. To test this relationship along I-275, the 1991 average daily traffic counts (ADT) for the highway between Bearss Avenue and SR 60 were obtained from the Florida Department of Transportation (FDOT). Counts

were taken between most interchanges and are shown by corresponding highway segment in TABLE 8. ADT's were not taken for three interchange segments and lead values at these locations were left out of the correlation analyses.

TABLE 8 Average Daily Traffic counts (ADT's) between interchanges on I-275 from the Florida Department of Transportation (FDOT). Counts were not taken between three sets of interchanges.

Southbound	TRANSECT	Northbound
25,607	Bearss-Fletcher	26,379
37,608	Fletcher-Fowler	36,788
48,535	Fowler-Busch	48,193
55,740	Busch-Bird	55,919
64,306	Bird-Sligh	62,851
63,632	Sligh-Hillsborough	64,906
65,124	Hillsborough-ML King	63,532
61,258	ML King-Floribraska	63,276
61,497	Floribraska-I-4	65,360
Westbound		Eastbound
80,048	I-4-Scott/Ashley/Tampa	75,522
NA	Scott/Ashley/Tampa-Howard/Armenia	NA
74,863	Howard/Armenia-Himes	77,556
NA	Himes-Dale Mabry	NA
65,369	Dale Mabry-Lois	62,661
NA	Lois-Westshore	NA
47,793	Westshore-SR 60	50,379

The correlation coefficient for ADT and normalized soil lead values is r=.295, indicating a positive relationship in which approximately 9% of the variability in soil lead is accounted for by ADT. Coefficients were also calculated for ADT and 1) maximum normalized value at each transect (r=.181); 2) mean normalized lead value at each transect (r=.283); and 3) number of values greater than or equal to 500 ppm at each transect (r=.299). There is a consistent positive relationship between traffic density and soil lead along I-275. However, since ADT is not the only factor

related to soil lead deposition, the strength of the correlation is not high. Also, the patterns of lead deposition along the highway have developed over several decades. The use of 1991 ADT's does not accurately reflect the historical traffic patterns responsible for soil lead accumulation since the construction of the highway.

Soil Lead and Distance. Among the most important aspects of the soil lead level data are the lead value/distance relationship; the number of samples above background levels; and, more importantly, the number of samples at or above 500 ppm. First, let us consider the relationship of lead values with distance. As seen earlier, there is a weak negative relationship between lead levels and distance in the I-275 study area. Graphs of this relationship (FIGURES 6 and 7) did not reveal a rapid decline in lead with distance from the highway, nor a smooth, exponentially declining curve. Instead, the individual transects displayed variably rising and falling lead levels with distance from the road edge.

In the aggregate, the mean values of the sampling distances were fairly constant at the closest sampling sites, increased at 81 and 243 cm from the highway, and declined somewhat at the furthest sampling points. This does not totally conflict with the results of previous research. Neither Chow (1970), Motto et al. (1970), Muskett and Jones (1979), nor Wheeler and Rolfe (1980) analyzed soil samples

from as close to the road edge as was done in this study. Wheeler and Rolfe began sampling at 30 cm and continued at 1, 5, 10, 15, 20, 25, 30, 40, 50, 100, and 200 m from the road. Others began at further distances (Muskett and Jones, 50 cm; Chow, 7.6 m; Motto et al., 25 feet or 7.62 m) and continued sampling at distances greater than those used here. In this study, the proximity of residential zones to the I-275 right of way and the potential for interference of lead from paint sources precluded going beyond 27 m.

Little variation in lead levels was found at distances greater than 40 m in any of the studies cited above, with soil lead approaching background levels at these distances. However, all of these researchers reported a rapid decline in lead between their first and subsequent samples. Even if the first three sample distances of this study are ignored, there is still not the same rapid decline in lead levels that would have been expected between 81, 243, 729, and the furthest sampling distance (range 800-2187 cm). This is a different relationship than was expected and is not adequately explained by variations in the sampling strategy or other methodological considerations. Several analyses follow which offer partial explanation for the lead/distance relationship observed.

Slope. An unknown factor in previous research which may be instrumental in explaining some of the variations in this study is the slope of each soil sample transect. Slopes were

not accounted for in published results by Chow (1970), Motto et al. (1970), Wheeler and Rolfe (1979), or Muskett and Jones (1980). Approximate slopes were calculated for each of the transect sites adjacent to I-275 and are shown in TABLE 9. Eighteen of the thirty-two transects are located on ground sloping at 30-50%. It is possible that due to soil erosion, deposited lead is being carried further down these steep slopes, causing a general increase in lead values at the 81, 243, and 729 cm distances and a less than expected decline in values at the furthest distance, a zone of deposition at the base of the slope. Air drainage patterns associated with slope also affect the dispersal of lead particulates. If previous researchers did not sample on steeply sloping ground, their results would not reflect these phenomena.

TABLE 9 Approximate slopes at each transect location.

West	TRANSECT	East
5%	Bearss-Fletcher	5%
50%	Fletcher-Fowler	30%
50%	Fowler-Busch	50%
10%	Busch-Bird	10%
40%	Bird-Sligh	40%
30%	Sligh-Hillsborough	50%
50%	Hillsborough-ML King	40%
50%	ML King-Floribraska	5%
50%	Floribraska-I-4	50%
North		South
40%	I-4-Scott/Ashley/Tampa	50%
30%	Scott/Ashley/Tampa-Howard/Armenia	15%
15%	Howard/Armenia-Himes	10%
50%	Himes-Dale Mabry	15%
40%	Dale Mabry-Lois	15%
10%	Lois-Westshore	5%
5%	Westshore-SR 60	5%

The median and range of soil lead values for each category of slope are graphed in FIGURE 8. In general, the median lead values increase with increasing steepness until slope reaches 50%. There is a positive correlation coefficient between slope and soil lead of r=.162. The ranges of values narrow at first with increasing slope, then expand. This produces inverse curves for the minimum and maximum values as they relate to slope.

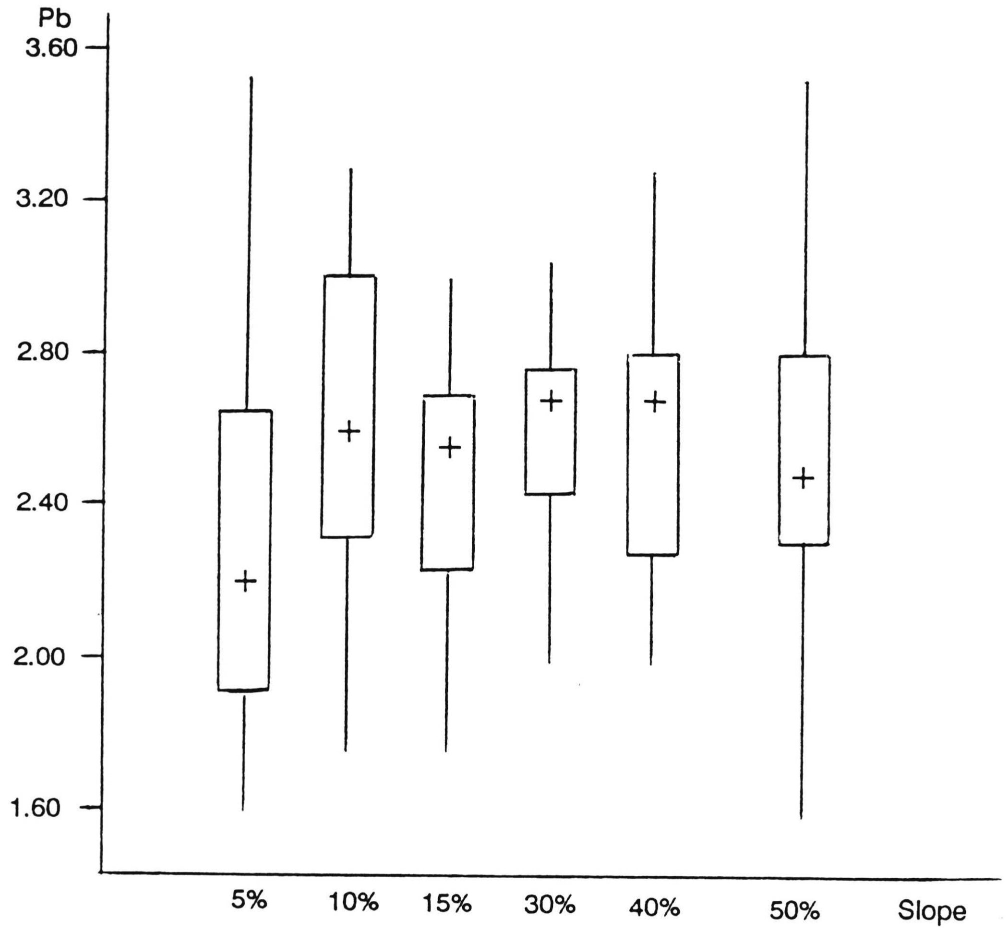


FIGURE 8 Soil lead values (normalized) related to transect slope (expressed as a percent). Median values for each slope appear in the box as a '+'. Minimum and maximum values are at the ends of the whiskers extending from each box.

For the I-275 soil lead data, the high mean lead value at 243 cm and the less than rapid decline in mean values thereafter are related to slope. The lead values for all samples taken at 243 cm and 729 cm are graphed in relation to slope in FIGURES 9 and 10 respectively. For the data at 243 cm, there is a general increase in median soil lead values with increasing slope except at 50%. The correlation coefficient between slope and soil lead is r=.172. For the 729 cm data, there is a similar pattern, although the graphed relationship is not as smooth. Correlation is stronger at r=.245. The data at 243 cm and 729 cm correlate with each other at r=.366.

There is, then, a relationship between soil lead values and slope, but it is difficult to determine whether this is caused by soil erosion, aerial deposition patterns, or some combination of phenomena. For example, the air drainage patterns associated with slope contribute to the pattern of dispersal of lead particulates. In nocturnal drainage flows, pollutants released at ground level spread through the entire depth of the drainage layer and are effectively diffused at shallow slopes (Nappo et al., 1989). At steeper slopes, wind speeds, turbulence, and boundary layer depth increase with downslope distance. Suspended particulates are not well diffused and are carried further away from the road edge before they are deposited. This process could contribute to the higher mean soil lead values at the 243 and 729 cm sampling distances and the increasing median

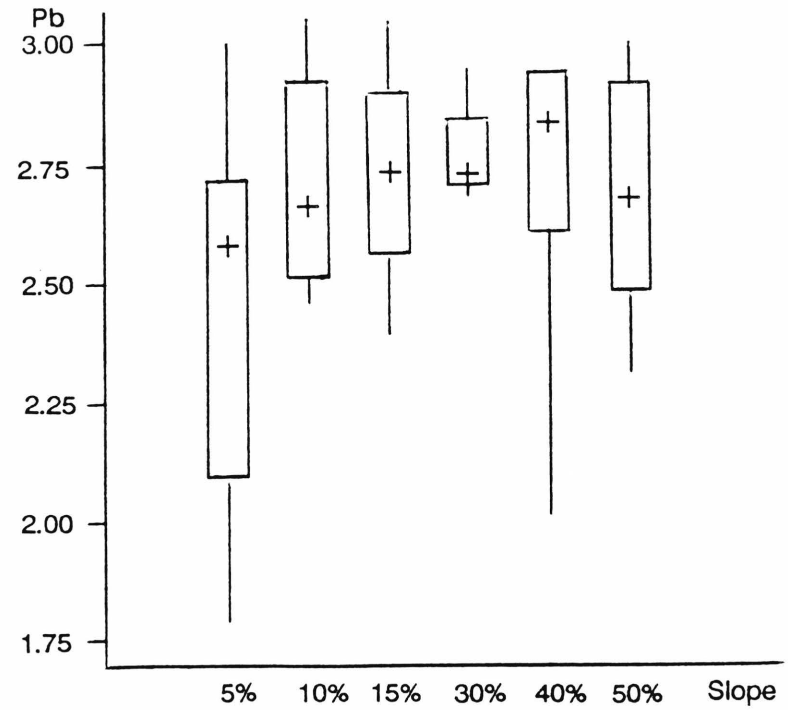


FIGURE 9 Soil lead values (normalized) for samples taken at 243 cm from the road edge in relation to slope (expressed as a percent).

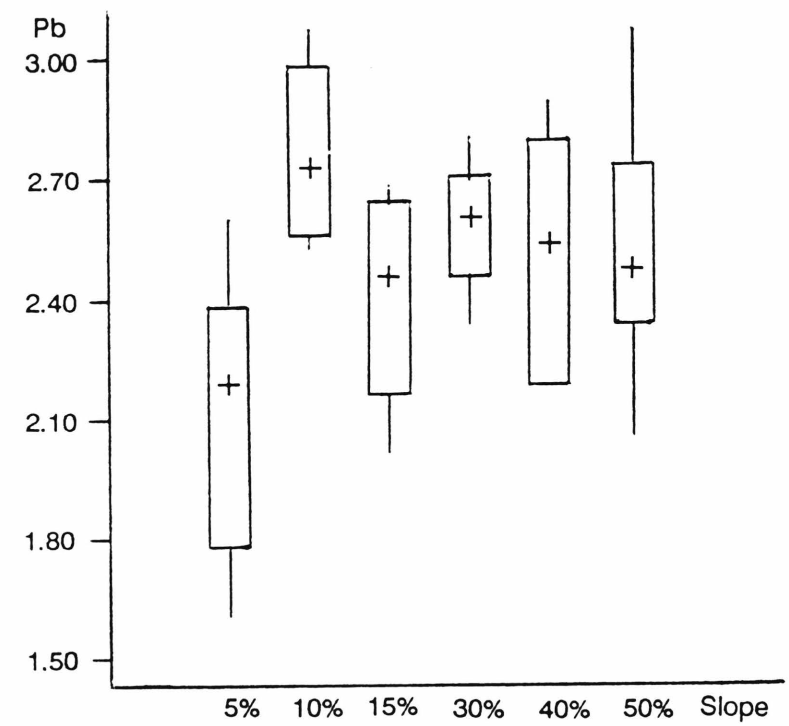


FIGURE 10 Soil lead values (normalized) for samples taken at 729 cm from the road edge in relation to slope (expressed as a percent).

values in relation to slope. However, air drainage is a nocturnal process and does not fully account for the aerial deposition of lead particles.

Other climatic and traffic generated processes act alone or in conjunction with slope and air drainage patterns to determine the patterns of particulate deposition. Convection and ambient winds over the highway right of way also determine dispersal of lead emissions. These processes are in turn modified by vehicle generated turbulence, which can both nullify and augment natural climatic factors. This phenomena is discussed in the following section.

<u>Roadside Turbulence</u>. Locally generated turbulence plays a role in the transport and diffusion of lead from automobiles. Gravitational settling and precipitation washout remove lead particulates from the air after emission. In the absence of turbulence, the distribution of deposited lead particles is affected only by atmospheric stability components such as ambient wind and air drainage patterns. Turbulence modifies ambient wind velocities and affects the patterns of lead particulate distribution.

Roadside turbulence can be generated by a combination of factors including vehicle-induced drag and waste heat emissions from vehicles on the roadway (Eskridge and Rao, 1983). Turbulent winds generated by these factors keep lead particulates aloft long enough that many do not settle immediately adjacent to the highway. This is especially true

for particles less than 10 microns in diameter (Oke, 1978). Gravitational settling is responsible for removing most particulate matter greater than 1 micron in diameter from the air. Particles greater than 10 microns settle close to their source in a matter of minutes and are not held in suspension for long even by strong turbulence. However, smaller particles are affected by turbulent diffusion, which slows their descent and governs the rate at which lead and other pollutants are delivered to the surface (Oke, 1978).

Turbulence is enhanced when the shear between ambient wind and traffic flow is intense, such as when prevailing wind is perpendicular to the traffic flow (Eskridge and Rao, 1983). The wind component, however, becomes less important as the speed of the vehicles increases (Chock, 1978). The aerodynamic drag from moving vehicles distorts the ambient wind profiles (Rao et al., 1979). Traffic generated eddies extend from 4-8 m from the road edge. There is a maximum distance from the highway up to which both atmospheric stability and traffic flow govern lead dispersal and after which only atmospheric stability (convection, ambient winds, etc.) determines dispersal (Rao et al., 1979).

The effects of vehicle induced turbulence may explain in part why mean lead values along I-275 are lower at the 3, 9, and 27 cm sampling distances than at the 81 and 243 cm sites. Lead particles greater than 10 microns settle close to the road edge and elevate the mean soil lead values at the closer sampling sites. Smaller and presumably more

numerous lead particles are transported by turbulence to greater distances, elevating mean soil lead levels at these sites. Beyond 729 cm, turbulent eddies no longer affect transport and the remaining lead particles (smallest in size and fewer in number) settle at the furthest sampling distances (Wheeler and Rolfe, 1979).

Further analysis of the microclimate near I-275 is needed to clarify the effects of turbulence on soil lead distribution. Vertical temperature profiles, slope, and air drainage patterns along the highway influence the characteristics of traffic generated eddies (Geiger, 1965; and Oke, 1978). Measurement of microclimatic factors, as suggested by Unwin (1980), will assist in turbulence modeling for the study area (Xiang, 1988) and further explain the soil lead patterns observed near I-275.

Organic Matter. Another factor which may influence the pattern of soil lead levels observed in the study area is the amount of organic matter in the soils that were sampled. Organic matter content of soils is positively correlated with soils' ability to retain lead (Zimdahl and Skogerboe, 1977; Elliott et al., 1986). Lead can also be transported by mobile organic matter (Turner et al., 1985). On twenty-five of the thirty-two sampling transects adjacent to I-275, the seventh soil sample was taken at the right of way fence line. This area, unlike the other sites, invariably contained a visible organic litter layer and/or a

substantial amount of organic matter in the upper soil layer, due to vegetative growth on and around the fences and possibly due to deposition from erosion and runoff. Bonding of lead with organic matter can partially explain the less than rapid decline in lead values at these farthest transect sampling distances. In addition, most of the right of way areas away from the road edge are covered with grassy vegetation, which also provides litter and organic material to these soils.

However, it is interesting to note that the areas immediately adjacent to the road edge, where the first three soil samples were obtained on each transect (3, 9, and 27 cm), generally had the least amount of vegetation and consisted primarily of bare sand, pieces of asphalt and concrete, rocks, stones, and omnipresent cigarette butts. The lack of organic matter content at these sample sites, coupled with the greater amount of vegetative matter farther out on the transects, helps explain why their mean lead levels are lower than those away from the highway.

<u>Extent of Contamination</u>

In order to further analyze the soil lead data base for I-275, it is necessary to establish a background lead threshold to which the sample values can be compared. Background soil lead levels vary greatly throughout the world. Background levels range from 2-200 ppm and average about 16 ppm worldwide (Motto et al., 1970; and Tierney et

al., 1979). However, such a worldwide average cannot be used as a standard in a specific location. For example:

> "From an examination of available literature, it would appear that the native lead content of soils is quite low, probably less than 50 p.p.m. Published values for the average lead content of soils are of the order of 15 p.p.m. Lead content is higher in surface soils and will vary with the geological source of the parent material." (Motto et al., 1970, p. 231)

Davies (1980b) concurs, and notes:

> "Published compendia of the trace element content of soils are useful to get a general impression of values likely to be encountered and this is particularly helpful when seeking an analytical method of sufficient sensitivity...However, these compilations do not provide a secure basis to decide whether a particular soil is in fact contaminated." (p. 296)

Thus, unless a clearly uncontaminated control sample can be obtained, comparison of sampled lead values to background values is difficult.

Davies (1980b) suggests that in a sampled frequency distribution which is not unimodal (such as the data obtained from the soils adjacent to I-275), per cent cumulative frequencies should be plotted against trace element content. Sharp changes in the slope of the curve that is created by the plot indicate the change from one population to the other and may be taken as the threshold or background value. The cumulative frequency plot for the soil lead values adjacent to I-275 is shown in FIGURE 11.

The first sharp change in slope occurs at the break between the 41-60 and 61-80 ppm class intervals. Therefore, the range 0-60 ppm is taken as the background range of lead values, with any content greater than 60 ppm being anomalous

for this group of soil samples (Davies, 1980b). Davies is careful to distinguish between terms such as 'anomalous' and 'contaminated.' Davies does not consider soils with high lead levels to be necessarily contaminated, as some areas of the world possess high background values of soil lead due to the nature of the parent materials responsible for soil formation (Thornton et al., 1985; Czarowski and Gworek, 1990; and Davies and Ballinger, 1990). Thus soil lead levels

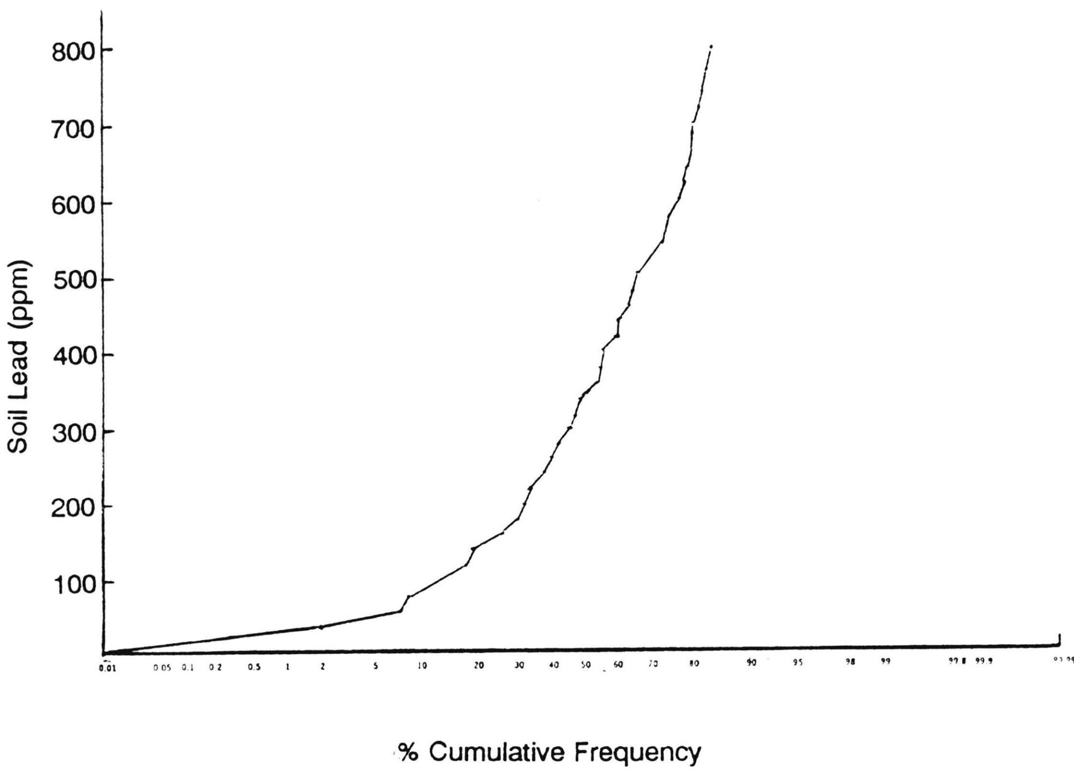


FIGURE 11 Percent cumulative frequencies vs. soil lead content for soil samples in the I-275 study area. The marked change in slope between the 41-60 and 61-80 ppm class intervals indicates the break between background soil lead levels and anomalous values.

exceeding 500 ppm may be neither anomalous nor contaminated by Davies' definition. However, this does not change the lead levels at which adverse health effects take place in humans. Based on the above analysis, more than 90% of the soil samples obtained in this study are above normally expected values (anomalous). Similarly, around 35% of the soil lead values are at 500 ppm or greater. Whether naturally occurring or a result of pollutant dispersal, the 500 ppm level is generally considered the hazardous threshold for soil lead (CDC, 1985; Chaney and Mielke, 1986; U.S. Senate Committee on Environment and Public Works, 1990a; and Anonymous, 1992a). In this study, since a 'normal' soil lead range of 0-60 ppm has been established, it is safe to say that levels of 500 ppm are not only anomalous, but also indicate contamination.

However, it may be inappropriate to classify all the soils of this study area as contaminated based on the presence of sample sites with excessive lead values. There is a great deal of variability in the distribution of soil lead, even within a small area (Chaney and Mielke, 1986). Both variability in the source of the lead and the results of human activities which disturb surficial soils affect the concentration of lead. Studies have shown extreme variations between sample locations in relatively small areas; variability of surface soil concentrations of lead are such that the maximum of the soil lead range extends to at least

ten times the mean value for the area (Chaney et al., 1984). This holds true for the soils of the I-275 study area, where the geometric mean soil lead value for the data is 317 ppm, with a maximum value of 3360 ppm. Chaney et al. (1984) and Duggan et al. (1985) found this variation in lead levels in playground and garden soils. However, because of the accessibility of these soils to children, the risk of direct ingestion of the soils with exceptionally high lead values is great. Access to the soils immediately adjacent to I-275 is somewhat limited. However, given that lead from these soils becomes part of residential household dust, there is still ample reason for concern (Tierney et al., 1979; Committee on Lead in the Human Environment, 1980; Culbard et al., 1988; U.S. Senate Committee on Environment and Public Works, 1990a; Behm, 1991; and Anonymous, 1992c).

Exposure to lead levels of 500 ppm or greater in soil or household dust can elevate blood lead levels, especially in susceptible populations, such as children with inadequate diets and other conditions which characterize the urban poor. Chaney and Mielke (1986) compiled data from nineteen studies linking various levels of soil lead to elevated blood lead levels in children. Exposure to soil lead levels of 1000 ppm elevate blood lead levels anywhere from 2.0 to 9.0 ug dl^{-1}. Elevations in blood lead occur with exposure to soil lead levels in the 150-500 ppm range. Based on this compendium of results, Chaney and Mielke concluded that:

> "Soils with 500 mg Pb/kg contribute to increased Pb-B in children, but seldom cause Pb-B to exceed 25 ug/dl in the absence of pica. Soil/dust-Pb especially contribute to the urban disadvantaged child who is the most susceptible, most exposed individual for Pb." (p. 372)

However, it is important to remember that blood lead levels of 10-15 ug dl^{-1} disrupt a child's ability to concentrate and learn and impair coordination and growth. Levels from 25-30 ug dl^{-1} disrupt a child's ability to use vitamin D (needed for growing healthy bones) and damage hearing. Adults also experience hearing loss, as well as increased hypertension at these blood lead levels (Behm, 1991). Thus, the lead levels found in the soils adjacent to I-275 are sufficiently high and pervasive enough to be considered hazardous, on the whole. Therefore, an examination of the lead levels of individual sample transects and their locations with respect to land use follows in order to assess the extent of the soil lead hazard to humans.

Soil Lead and Land Use. TABLE 10 depicts the sample transects and number of soil samples at each with lead levels greater than or equal to 500 ppm as they relate to types of land use adjacent to the I-275 right of way. This is a rough analysis and in no way comprehensively examines officially zoned land uses for the entire length of the I-275 study area, but rather is based on field observations of what type of land use each transect faces: residential, commercial, parks/recreation, or other (empty lots, other roads, institutional buildings). The greatest concern is the

TABLE 10 Transect sites, number of sample sites per transect with lead values greater than or equal to 500 ppm, and adjacent land use (R=residential, C=commercial, P=park/recreation, O=other).

Land Use	West	TRANSECT	East	Land Use
R	0	Bearss-Fletcher	1	P
O	0	Fletcher-Fowler	5	R
R	3	Fowler-Busch	0	R
R	6	Busch-Bird	2	R
R	6	Bird-Sligh	3	R
R	3	Sligh-Hillsborough	1	R
R/P	5	Hillsborough-ML King	2	R
R	4	ML King-Floribraska	5	R
R	1	Floribraska-I-4	5	R
	North		South	
O	0	I-4-Scott/Ashley/Tampa	4	C/O
R	2	S./A./T.-Howard/Armenia	2	R
R	1	Howard/Armenia-Himes	3	R
O	0	Himes-Dale Mabry	1	O
R	4	Dale Mabry-Lois	4	C
C	2	Lois-Westshore	4	R
C	0	Westshore-SR 60	0	C

potential for soil lead from the I-275 right of way to be ingested by people living near the highway.

Twenty-two of the thirty-two transects extend from the road edge toward residential areas; twenty of the twenty-two contain one or more sample sites with soil lead values of 500 ppm or greater. Lead dust from automobile emissions comprises a substantial fraction of indoor residential lead dust (Solomon and Hartford, 1976). Houses close to main roads tend to have higher concentrations of lead in house dust than those set back from the road or adjoining minor roads (Culbard et al., 1988). The pathways for this lead dust to enter homes are varied, but there is a strong correlation between lead in house dust and lead in lawn and garden soils in urban areas (Thornton et al., 1985). Lead in soil that also becomes part of house dust is the predominant

source of lead ingested by children (Bornschein et al., 1986; and Body et al., 1991).

An increase in exterior surface dust lead from 0 to 1000 ppm around homes results in an indirectly mediated increase in blood lead levels of 6.2 ug dl^{-1}. Therefore, it is likely that a portion of the residences immediately adjacent to the I-275 right of way (and some homes and yards are only a few meters from the right of way fence line) have elevated levels of lawn and garden soil lead and have elevated levels of interior house dust lead. Subsequently, the adults and children in these homes are likely to have increased blood lead levels as a result of the lead in the highway right of way soils. Further examination of specific homes, lawns, and gardens is necessary to substantiate this claim, as well as further sampling and analysis of highway right of way soils and comprehensive testing of blood lead levels; however, all the elements necessary to produce a lead contamination problem in people, especially children, living near I-275 are present.

CHAPTER 6
CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

The results of this study have provided new information on lead patterns in relation to highways, as well as variations in existing information regarding soil lead and distance. The conclusions reached from this research, along with other research on soil lead in Tampa (Brinkmann, 1990a and 1990b), provide justification for further soil lead research in the area and will lay the groundwork for computation of a total lead budget for Tampa.

Conclusions

The use of exponential sampling intervals did not prove to be worthwhile for the purpose of producing a smooth curve representing the relationship of lead with distance. The proximity of the initial soil sampling sites to one another and the variation in the distances of the last transect sample added variables that made analysis of the soil lead data and comparison to other research more complex. However, this method did provide some interesting data regarding lead in soils within 27 cm of the road edge, an area that has not been analyzed in previous research. The absence of a strong relationship between soil lead and distance from the road edge also complicated data analysis within the framework of the sampling plan, since the exponential sampling technique

was created with the specific expectation that soil lead would decline exponentially with distance.

Perhaps the most interesting result of this study is the relationship between soil lead and distance from I-275. The pattern of soil lead with distance does not match the results of previous researchers. Although soil lead tends to decline with distance from I-275, the relationship is not as strong as some others have found. On the whole, there is not a dramatic decline in soil lead with distance from the road edge up to 2187 cm. There are several possible reasons for this variation. One could be related to the slopes of the rights of way where samples were taken. Processes of erosion and deposition, or possibly changes in the pattern of aerial lead deposition due to the slope, may be responsible for accumulations of lead at distances from the highway where declines are expected.

In addition, variations in the amount of organic matter in the soils affect soil lead adsorption and may contribute to the pattern of lead values observed in the soils near the highway. Other aspects not considered may be differences in climatic factors in this area when compared to most other areas that have been studied. Most soil lead research has been done in northern North American cities, such as Toronto, Milwaukee, Baltimore, and Cincinnati. Little or no research on soil lead has been completed in the Sun Belt in general, or in Florida in particular. Thus unique aspects of

the climate of this area may also contribute to the pattern of soil lead accumulation observed near I-275.

There is a relationship between average daily traffic and lead. The 1991 traffic density counts for I-275 correlate positively with mean, maximum, and overall soil lead values, but do not account for more than 9% of the variation in soil lead in the study area. An historical analysis, using older ADT's that correspond to the historical deposition of lead, might provide a higher correlation between traffic and soil lead.

Despite the unexplained variations and unique patterns observed, there are lead contaminated soils in the right of way adjacent to I-275. Levels as high as 3360 ppm are present, over one-third of the soils sampled exceed the threshold of 500 ppm considered hazardous to humans, and the distribution of contaminated sites is pervasive enough to distribute the potential hazard over most of the study area. Factors which could link these contaminated soils to elevated blood lead levels in people living near the highway are present (such as proximity to the road, human and climatic transport mechanisms, etc.).

Interestingly, the choice of transect locations at or near the midpoints between interchanges was designed to avoid areas that are known to produce higher soil lead levels, such as idle zones and entrance and exit ramps. Based on the data obtained, the likelihood of even higher values near highway interchanges is great and this increases

the potential hazard to the residential areas bordering I-275.

Furthermore, other factors could exacerbate the problem. With the reduction of lead in gasoline, aerial deposition of lead to highway soils has slowed substantially. This is fortunate since the capacity of any soil to adsorb lead is limited. The problem of lead contamination in humans would be far worse were it not for the fixation of lead particulates in soil. However, climatic and other changes could increase the mobilization of lead from soils. Increased acid raid, for example, could lower soil pH and increase the migration of lead downward in the soil or out of the soil profile altogether via runoff, potentially increasing the lead content of surface waters and distributing the lead over a wider area by transporting it to areas away from the highway.

<u>Further Research</u>

There are many opportunities for further research on lead in Hillsborough County, Tampa, and the surrounding area, as well as in the I-275 corridor. Some suggestions follow.

Within the I-275 study area, further research is needed to expand the soil lead database and to further assess the range and distribution of lead along the highway right of way. A more comprehensive sampling of soils from the entire corridor, utilizing a stratified random sampling network,

would provide a more accurate view of lead in the area than the transect system employed in this study. However, such an approach would be a large undertaking and would require substantial funding and personnel. In that event, analysis of the soils near the highway interchange areas could be added to the data already obtained for the midpoints between interchanges. This combination of data would provide a fairly complete picture from which more definitive conclusions could be drawn regarding the distribution of lead in the soils near I-275.

In addition, micro-studies regarding the effects of slope on the distribution of lead would also clarify the results obtained from current research. Specifically, studies which would be designed to relate soil lead with slope or which analyzed the movement of lead-containing soils in relation to slope would be invaluable in explaining the role (if any) that slope plays in the pattern of soil lead accumulation. Measurement of microclimatic factors such as turbulence and air drainage would also be of benefit in determining the roadside soil lead patterns.

Studies similar to the one of I-275 soils are also needed for other major roads in Tampa and Hillsborough County, such as I-4 and the Crosstown Expressway. Both of these roads, like I-275, are elevated limited access highways which are adjacent to residential neighborhoods. However, it would be interesting to analyze differences in the patterns of soil lead values adjacent to these roads in

comparison to I-275, since most major regional factors such as climate would remain constant. The role of micro-level factors could then be more easily established.

Outside the highway rights of way, there is an immediate need to assess the extent of lead contamination in lawn and garden soils in the neighborhoods which border I-275 and other major highways. Primarily, this would identify any link between lead in residential soils and contaminated highway soils, but would also establish the extent of the soil lead hazard to people living near the road. Brinkmann (1990a and 1990b) has already begun sampling lawn and garden soils in Tampa, but in order to directly address the lead hazard that has been proposed as a result of this study, a systematic and comprehensive analysis of the soil lead in the neighborhoods close to I-275 is warranted.

If a pervasive soil lead problem is identified, the next steps would involve measurement of lead in household dusts, screening of blood lead levels, and finally, a comprehensive effort to ameliorate lead contamination in Tampa.

LIST OF REFERENCES

Agrawal, Y.K.; Raj, K.P.S.; Densai, S.J.; Patel, S.G.; and Merh, S.S. 1980. Effect of Lead from Motor-Vehicle Exhausts on Plant and Soil Along a Major Thoroughfare in Baroda City. International Journal of Environmental Studies 14:313-315.

Anonymous. 1992a. Composted Sludge May Lessen Dangers Lead Poses, USDA Says. The Florida Specifier 14(1):21,23.

Anonymous. 1992b. Unleaded Wine. University of California at Berkely Wellness Letter 8(5):3.

Anonymous. 1992c. Lead Threat to Kids Exceeds City's Fears. The Milwaukee Journal January 10:1,12.

Anonymous. 1992d. Stunning Alarm on Lead Peril. The Milwaukee Journal January 13: A6.

Aronson, S.M. 1983. Lead and the Demon Rum in Colonial America. Rhode Island Medical Journal 16:37-40.

Ash, C.P.J., and Lee, D.L. 1980. Lead, Cadmium, Copper and Iron in Earthworms from Roadside Sites. Environmental Pollution (Series A) 22(1):59-67.

Basta, N.T., and Tabatabai, M.A. 1990. Ion Chromatograph Determination of Total Metals in Soils. Soil Science Society of America Journal 54(5):1289-1297.

Behm, D. 1991. Are We Robbing Our Children's Future? The Milwaukee Journal Sept. 8:A1.

Birkeland, P.W. 1984. Soils and Geomorphology. New York: Oxford University Press.

Blais, J.S., and Marshall, W.D. 1986. Determination of Alkyllead Salts in Runoff, Soils, and Street Dusts Containing High Levels of Lead. Journal of Environmental Quality 15(3):254-260.

Blume, H.P. 1989. Classification of Soils in Urban Agglomerations. Catena 16:269-275.

Body, P.E.; Inglis, G.; Dolan, P.R.; and Mulcahy, D.E. 1991. Environmental Lead: A Review. Critical Reviews in Environmental Control 20(5-6):299-310.

Bornschein, R.L.; Succop, P.A.; Krafft, K.M.; Clark, C.S.; Peace, B.; and Hammond, P.B. 1986. Exterior Surface Dust Lead, Interior House Dust Lead and Childhood Lead Exposure in an Urban Environment. In Trace Substances in Environmental Health, ed. D.D. Hemphill, pp. 322-332. Columbia, MO: University of Missouri-Columbia.

Bove', J.L., and Siebenberg, S. 1970. Airborne Lead and Carbon Monoxide at 45th Street, New York City. Science 167:986-987.

Brams, E.; Anthony, W.; and Weatherspoon, L. 1989. Biological Monitoring of an Agricultural Food Chain: Soil Cadmium and Lead in Ruminant Tissues. Journal of Environmental Quality 18(3):317-323.

Brinkmann, R. 1989. Spatial Distribution of Soil Lead Pollution in Milwaukee County, Wisconsin. Doctoral Dissertation, University of Wisconsin-Milwaukee.

Brinkmann, R. 1990a. Analysis of Lead Pollution in Soils of Tampa, Florida. Research and Creative Scholarship Grant Proposal, University of South Florida, Tampa.

Brinkmann, R. 1990b. Analysis of Lead Pollution Data of Soils of Tampa, Florida. Research Grant Proposal, Association of American Geographers.

Brooks, G.R., and Doyle, L.J. 1991. Distribution of Sediments and Sedimentary Contaminants in Tampa Bay. In Proceedings, Tampa Bay Area Scientific Information Symposium 2, February 27-March 1, 1991, eds. S.F. Treat and P.A. Clark, pp. 399-413. Tampa, FL: TEXT.

Centers for Disease Control. 1985. Preventing Lead Poisoning in Young Children: A Statement by the Centers for Disease Control. Atlanta: U.S. Dept. of Health and Human Services.

Chaney, R.L., and Mielke, H.W. 1986. Standards for Soil Lead Limitations in the United States. In Trace Substances in Environmental Health, ed. D.D. Hemphill, pp. 357-377. Columbia, MO: University of Missouri-Columbia.

Chaney, R.L.; Sterrett, S.B.; and Mielke, H.W. 1984. In Proceedings of the Symposium on Heavy Metals in Urban Gardens, ed. J.R. Preer, pp. 37-84. Washington, DC: University of the District of Columbia.

Chisolm, J.J.; Barrett, M.B.; Mellits, A.B.; and Mellits, E.D. 1975. Dose Effect and Dose Response Relationships for Lead in Children. Journal of Pediatrics 87:1152-1160.

Chock, D.P. 1978. An Advection-Diffusion Model for Pollutant Dispersion Near Roadways. Journal of Applied Meteorology 17:976-989.

Chow, T.J. 1970. Lead Accumulation in Roadside Soil and Grass. Nature 225:295-296.

Collins, J.A. 1989. Lead Soil and Vegetables Throughout a Catchment with Mixed Landuse and Low-to-Moderate Traffic Density. New Zealand Geographer 45(1):36-41.

Committee on Lead in the Human Environment. 1980. Lead in the Human Environment. Washington, DC: National Academy of Sciences.

Culbard, E.B.; Thornton, I.; Watt, J.; Wheatley, M.; Moorcroft, S.; and Thompson, M. 1988. Metal Contamination in British Urban Dusts and Soils. Journal of Environmental Quality 17(2):226-234.

Czarowska, K., and Gworek, B. 1990. Geochemical Background Values for Trace Elements in Arable Soils Developed from Sedimentary Rocks of Glacial Origin. Environmental Geochemistry and Health 12(4):289-290.

Davies, B.E., ed. 1980a. Applied Soil Trace Elements. Chichester, England: John Wiley & Sons.

Davies, B.E. 1980b. Trace Element Pollution. In Applied Soil Trace Elements, ed. B.E. Davies, pp. 287-351. Chichester, England: John Wiley & Sons.

Davies, B.E. 1989. Data Handling and Pattern Recognition for Metal Contaminated Soils. Environmental Geochemistry and Health 11(3/4):137-143.

Davies, B.E., and Ballinger, R.C. 1990. Heavy Metals in Soils in North Somerset, England, with Special Reference to Contamination from Base Metal Mining in the Mendrips. Environmental Geochemistry and Health 12(4):291-300.

Davies, B.E., and Wixson, B.G. 1986. Lead in Soil - How Clean is Clean? In Trace Substances in Environmental Health, ed. D.D. Hemphill, pp. 233-241. Columbia, MO: University of Missouri-Columbia.

Delwiche, C.C., and Likens, G.E. 1977. Biological Response to Fossil Fuel Combustion Products. In Global Chemical Cycles and Their Alterations by Man, ed. W. Stumm, pp. 73-78. Berlin: Dahlem Konferenzen.

Duggan, M.J.; Inskip, M.J.; Rundle, S.A.; and Moorcroft, J.S. 1985. Lead in Playground Dust and on the Hands of Schoolchildren. Science in the Total Environment 44:65-79.

DuRose, R.A. 1992. NIOSH Issues Alert on Lead at Bridge Demolition Sites. The Florida Specifier 14(2):10.

Elliot, H.A.; Liberati, M.R.; and Huang, C.P. 1986. Competitive Adsorption of Heavy Metals by Soils. Journal of Environmental Quality 15(3):214-219.

Eskridge, R.E., and Rao, S.T. 1983. Measurement and Prediction of Traffic-Induced Turbulence and Velocity Fields Near Roadways. Journal of Climate and Applied Meteorology 22:1431-1443.

Espenshade, E.B., ed. 1990. Goode's World Atlas, 18th Edition. Chicago: Rand McNally.

Esser, K.B.; Helmke, P.A.; and Bockheim, J.G. 1991. Trace Element Contamination of Soils in the Indiana Dunes. Journal of Environmental Quality 20(1):492-496.

Francek, M.A. 1991. Soil Lead Levels in Mt. Pleasant, Michigan: An Assessment of Risk in A Rural Environment. Paper presented at 87th Annual Conference of the Association of American Geographers, Miami, FL.

Friedland, A.J., and Johnson, A.H. 1985. Lead Distribution and Fluxes in a High-Elevation Forest in Northern Vermont. Journal of Environmental Quality 14(3):332-336.

Fuge, R.; Paveley, C.F.; and Holdham, M.T. 1989. Heavy Metal Contamination in the Tanat Valley, North Wales. Environmental Geochemistry and Health 11(3/4):127-135.

Geiger, R. 1965. The Climate Near the Ground. Cambridge, MA: Harvard University Press.

Gilbert, R.O., and Doctor, P.G. 1985. Determining the Number and Size of Soil Aliquots for Assessing Particulate Contaminant Concentrations. Journal of Environmental Quality 14(2):286-292.

Graf, W.L. 1985. Mercury Transport in Stream Sediments of the Colorado Plateau. Annals of the Association of American Geographers 75(4):552-565.

Green, D.W. 1985. The Saturnine Curse: A History of Lead Poisoning. Southern Medical Journal 78:48-51.

Hamilton, E.I. 1980. Analysis for Trace Elements II: Instrumental Analysis. In Applied Soil Trace Elements, ed. B.E. Davies, pp. 69-130. Chichester, England: John Wiley and Sons.

Harter, R.D. 1983. Effect of Soil pH on Adsorption of Lead, Copper, Zinc, and Nickel. Soil Science Society of America Journal 47(1):47-51.

Hegstrom, L.J., and West, S.D. 1989. Heavy Metal Accumulation in Small Mammals following Sewage Sludge Application to Forests. Journal of Environmental Quality 18(3):345-349.

Hilts, P.J. 1991. White House Shuns Key Role on Lead Exposure. The St. Petersburg Times August 23.

Huntzicker, J.J.; Friedlander, S.K.; and Davidson, C.I. 1975. Material Balance for Automobile-Emitted Lead in Los Angeles Basin. Environmental Science and Technology 9(5):448-457.

Hurlbut, C.S. Jr., and Klein, C. 1977. Manual of Mineralogy (after James D. Dana). New York: John Wiley & Sons.

Johnson, B.L., and Mason, R.W. 1984. A Review of Public Health Regulations on Lead. Neurotoxicology 5:1-22.

Kelepertsis, A.E., and Bibou, A. 1991. Heavy Metal Contamination of Soils at Old Mining Sites on Thasos Island, Greece. Environmental Geochemistry and Health 13:23-28.

Lee, J.A., and Tallis, J.H. 1973. Regional and Historical Aspects of Lead Pollution in Britain. Nature 25:216-218.

Lessler, M.A. 1988. Lead and Lead Poisoning from Antiquity to Modern Times. Ohio Journal of Science 88(3):78-84.

Lin-Fu, J.S. 1972. Undue Absorption of Lead Among Children. A New Look at an Old Problem. New England Journal of Medicine 286:702-710.

Lounsbury, J.F., and Aldrich, F.T. 1986. Introduction to Geographic Field Methods and Techniques. Columbus, OH: Charles E. Merrill Publishing Co.

McGrath, S.P., and Cunliffe, C.H. 1985. A Simplified Method for the Extraction of the Metals Fe, Zn, Cu, Ni, Cd, Pb, Cr, Co, and Mn from Soils and Sewage Sludges. Journal of Scientific Food Agriculture 36:794-798.

Miller, W.P.; McFee, W.W.; and Kelly, J.M. 1983. Mobility and Retention of Heavy Metals in Sandy Soils. Journal of Environmental Quality 12(4):579-584.

Mogollon, J.L.; Ramirez, A.J.; Guillen, R.B.; and Bifano, C. 1990. Heavy Metals and Organic Carbon in Sediments from the Tuy River Basin, Venezuela. Environmental Geochemistry and Health 12(4):277-287.

Moir, A.M., and Thornton, I. 1989. Lead and Cadmium in Urban Allotment and Garden Soils and Vegetables in the United Kingdom. Environmental Geochemistry and Health 11(3/4):113-119.

Motto, J.L.; Daines, R.H.; Chilko, D.M.; and Motto, C.K. 1970. Lead in Soils and Plants: Its Relationship to Traffic Volume and Proximity to Highways. Environmental Science and Technology 4(3):231-237.

Muskett, C.J., and Jones, M.P. 1980. The Dispersal of Lead, Cadmium and Nickel from Motor Vehicles and Effects on Roadside Invertebrate Macrofauna. Environmental Pollution (Series A) 23(3):231-242.

Nappo, C.J.; Rao, K.S.; and Herwehe, J.A. 1989. Pollutant Transport and Diffusion in Katabatic Flows. Journal of Applied Meteorology 28:617-625.

Needleman, H.L.; Gunnoe, C.; Levitson, A.; Reed, R.; Peresie, H.; Maher, C.; and Barrett, P. 1979. Deficits in Psychological and Classroom Performance of Children with Elevated Dentine Lead Levels. New England Journal of Medicine 300(13):689-695.

Nriagu, J.O. 1978a. The Biogeochemistry of Lead in the Environment: Part A. Ecological Cycles. Amsterdam: Elsevier/North-Holland Biomedical Press.

Nriagu, J.O. 1978b. The Biogeochemistry of Lead in the Environment: Part B. Biological Effects. Amsterdam: Elsevier/North-Holland Biomedical Press.

Nriagu, J.O. 1983. Lead and Lead Poisoning in Antiquity. New York: John Wiley and Sons.

Oke, T.R. 1978. Boundary Layer Climates. London: Methuen & Co. Ltd.

Palca, P. 1991. Get-the-Lead-Out Guru Challenged. Science 253:842-844.

Petrucci, R.H., and Wismer, R.K. 1983. General Chemistry with Qualitative Analysis. New York: Macmillan Publishing Co.

Pfaffenberger, R.C., and Patterson, J.H. 1977. Statistical Methods for Business and Economics. Homewood, IL: Richard D. Irwin, Inc.

Rae, J.E. 1989. Copper, Lead and Zinc in Salt Marsh Sediments of the Severn Estuary, UK: The Potential for Their Early Diagnetic Mobility. Environmental Geochemistry and Health 11(3/4):121-126.

Rao, S.T.; Sedefian, L.; and Czapski, U.H. 1979. Characteristics of Turbulence and Dispersion of Pollutants Near Major Highways. Journal of Applied Meteorology 18:283-293.

Ratcliffe, D., and Beeby, A. 1980. Differential Accumulation of Lead in Living and Decaying Grass on Roadside Verges. Environmental Pollution (Series A) 23(4):279-286.

Rinne, R.J.; Linzon, S.N.; and Stokes, P.M. 1986. Clean-up of Lead Contaminated Sites - the Ontario Experience. In Trace Substances in Environmental Health, ed. D.D. Hemphill, pp. 308-321. Columbia, MO: University of Missouri-Columbia.

Schaefer, R.L., and Anderson, R.B. 1989. The Student Edition of MINITAB. Reading, MA: Addison-Wesley Publishing Co.

Schalscha, E.B.; Morales, M.; and Pratt, P.F. 1987. Lead and Molybdenum in Soils and Forage near an Atmospheric Source. Journal of Environmental Quality 16(4):313-315.

Shermyen, A.H., ed. 1991. Florida Statistical Abstract. Gainesville, FL: University Press of Florida.

Siegel, S.M.; Galun, M.; and Siegel, B.Z. 1990. Filamentous Fungi as Metal Biosorbents: A Review. Water, Air, and Soil Pollution 53(3-4):335-344.

Sinclair, A.J. 1980. Statistical Analysis of Trace Element Data. In Appled Soil Trace Elements, ed. B.E. Davies, pp. 131-153. Chichester, England: John Wiley and Sons.

Slavin, M. 1978. Atomic Absorption Spectroscopy. New York: John Wiley and Sons.

Soil Conservation Service. 1989. Soil Survey of Hillsborough County, Florida. Washington, DC: U.S. Government Printing Office.

Solomon, R.L., and Hartford, J.W. 1976. Lead and Cadmium in Dusts and Soils in a Small Urban Community. Environmental Science and Technology 10(8):773-777.

Southwest Florida Water Management District. 1990. Where Has All the Water Gone? Understanding the Water Shortage. Hydroscope 21(2):6-11.

Stigliani, W.M.; Doelman, P.; Salomons, W.; Schulin, R.; Smidt, G.R.B.; and Van der Zee, S.E.A.T.M. 1991. Chemical Time Bombs: Predicting the Unpredictable. Environment 33(4):4-9, 26-30.

Swaine, D.J., and Mitchell, R.L. 1960. Trace-Element Distribution in Soil Profiles. Journal of Soil Science 11(2):347-368.

Thornton, I. 1986. Lead in United Kingdom Soils and Dusts in Relation to Environmental Standards and Guidelines. In Trace Substances in Environmental Health, ed. D.D. Hemphill, pp. 298-307. Columbia, MO: University of Missouri-Columbia.

Thornton, I.; Culbard, E.; Moorcroft, S.; Watt, J.; Wheatley, M.; Thompson, M.; and Thomas, J.F.A. 1985. Metals in Urban Dusts and Soils. Environmental Technology Letters 6:137-144.

Tierney, D.R.; Blackwood, T.R.; and Briggs, T.M. 1979. Status Assessment of Toxic Chemicals: Lead. Cincinnati: U.S. Environmental Protection Agency.

Tukey, J.W. 1977. Exploratory Data Analysis. Reading, MA: Addison-Wesley Publishing Co.

Turjoman, A.M., and Fuller, W.H. 1987. Behavior of Lead as a Migrating Pollutant in Saudi Arabian Soils. Arid Soil Research and Rehabilitation 1(1):31-45.

Turner, R.S.; Johnson, A.H.; and Wang, D. 1985. Biogeochemistry of Lead in McDonalds Branch Watershed, New Jersey Pine Barrens. Journal of Environmental Quality 14(3):305-314.

Unwin, D.M. 1980. Microclimate Measurement for Ecologists. London: Academic Press Inc. Ltd.

U.S. Senate Committee on Environment and Public Works. 1990a. Health Effects of Lead Exposure. Hearing before the Subcommittee on Toxic Substances, Environmental Oversight, Research and Development. Washington, DC: U.S. Government Printing Office.

U.S. Senate Committee on Environment and Public Works. 1990b. The Lead Ban Act of 1990 and the Lead Exposure Reduction Act of 1990. Hearing before the Subcommittee on Toxic Substances, Environmental Oversight, Research and Development. Washington, DC: U.S. Government Printing Office.

Ward, N.I.; Brooks, R.R.; and Reeves, R.D. 1974. Effect of Lead from Motor-Vehicle Exhausts on Trees Along a Major Thoroughfare in Palmerston North, New Zealand. Environmental Pollution 6(2):149-158.

Wheeler, G.L.; and Rolfe, G.L. 1979. The Relationship Between Daily Traffic Volume and the Distribution of Lead in Roadside Soil and Vegetation. Environmental Pollution 18(4):265-274.

Wood, J.M., and Goldberg, E.D. 1977. Impact of Metals on the Biosphere. In Global Chemical Cycles and Their Alterations by Man, ed. W. Stumm, pp. 137-153. Berlin: Dahlem Konferenzen.

Woolley, D.E. 1984. A Perspective of Lead Poisoning in Antiquity and the Present. Neurotoxicology 5:353-362.

Xiang, K.Z. 1988. A Model for the Evaluation of Ground-Level Pollutant Concentration. Journal of Applied Meteorology 27:336-340.

Yong, R.N.; Warkentin, B.P.; Phadungchewit, Y.; and Galvez, R. 1990. Buffer Capacity and Lead Retention in Some Clay Materials. Water, Air, and Soil Pollution 53(1-2):53-68.

Zimdahl, R.L., and Skogerboe, R.K. 1977. Behavior of Lead in Soil. Environmental Science and Technology 11(13): 1202-1207.