Importance of Considering Soil-Lead in Property Site Assessments[1]

G. Fred Lee, Ph.D., P.E. Anne Jones-Lee, Ph.D.
President Vice President

G. Fred Lee & Associates
27298 E. El Macero Drive
El Macero, CA 95618
Tel (530) 753-9630 • Fax (530) 753-9956

ABSTRACT

Lead is becoming recognized as an important contaminant in surface soils on urban properties. Lead in soil is of concern for several reasons. Soil is a potential source of lead for children who consume the soil as part of their play activities. Erosion can carry soils to surface waters; some forms of lead are toxic to aquatic life. The cost of remediation (removal) of soil-lead can be high, and can exceed the value of the property. It is therefore important to include detailed investigation of the concentrations of lead present in the surface soils in a property transfer site assessment. The US EPA allows 1,000 mg Pb/kg soil (dry wt) to remain in the surface soils at "Superfund" sites; the state of California Department of Health Services (DHS) has established 174 mg Pb/kg as a level that can be present in soil in residential areas. The DHS concentration was computed based on the assumption that children who play in the soil and ingest about 0.1 g/day of soil and the goal of maintaining blood-lead levels below the DHS standard of 5 µg/dL. Many soils in urban centers contain concentrations of lead above the DHS level owing largely to the use of lead as an anti-knock additive to gasoline.

This paper summarizes what is known about lead as a soil contaminant, the significance of soil-lead residues to public health and water quality, and areas that are likely to have elevated concentrations of lead in soil, focusing on how these issues relate to site assessments for property transfer. It also provides guidance on approaches that should be considered in evaluating the public health and water quality significance of soil lead levels as part of property site assessments.

INTRODUCTION

The key issue driving site assessment associated with the transfer of property is the potential for properties' having been contaminated by chemicals that could be hazardous to public health or the environment, or detrimental to groundwater quality. Recent advances in the understanding of the public health significance of lead for children have increased the attention given to soil-lead residues in properly conducted property site assessments. It has been found that soils in many urban areas contain lead in concentrations that are being judged by some regulatory agencies to represent significant threats to the health of children who play in the soils. Soil-lead residues are also becoming a focus of regulatory programs for non-point-source runoff to surface waters as contributing to exceedances of water quality standards. Lenders are becoming concerned about the potential costs of remediating lead-contaminated

[1] Presented at National Ground Water Association Conference, "Environmental Site Assessments: Case Studies and Strategies," Orlando, FL, August 1992.

soils since the costs can significantly diminish the value of the property. Representatives of the Bank of America, for example, have labeled soil-lead residues "the due diligence issue for the 1990's" (Forslund and Henry, 1991).

This paper reviews the significance of soil-lead residues in affecting public health, and surface and groundwater quality as it relates to property transfer site assessments.

PUBLIC HEALTH SIGNIFICANCE OF LEAD

The US Department of Health and Human Services Public Health Service (US DHHS) published a "Toxicological Profile for Lead," that describes modes and potential impacts of people's exposure to lead (US DHHS, 1991). Lead has been known to be hazardous to people for thousands of years; some have conjectured that lead poisoning (from wine contaminated by lead from wine containers) contributed to the fall of the Roman Empire. Lead poisoning in adults due to workplace exposure has been recognized for many years as have the hazards of toxicity of lead in paint, to children. It has not been until recent years, however, that the particular potential significance of lead in soil to the health of children has become better understood and acknowledged.

The US Public Health Service (US PHS) Centers for Disease Control stated (CDC, 1991),

> *"Lead poisoning remains the most common and societally devastating environmental diseases of young children."*

They pointed out that the neurobehavior effects of lead can be permanent and that blood-lead concentrations of 10 µg/dL (micrograms per deciliter (100 milliters)) in young children may result in lowered intelligence and other developmental consequences. The CDC (1991) described its current understanding of the general significance of ranges of blood-lead concentrations in children as follows:

Significance of Lead Levels in Children's Blood
(CDC, 1991)

Blood Lead Concentration (µg/dL)	Comment
≤ 9	Child Not Considered Lead-Poisoned
10 - 14	Initiate Child Lead-Poisoning Prevention Activities
15 - 19	If Persistent, Reduce Lead Input

There is controversy about what constitutes a "safe" blood-lead level for children (e.g., Ernhart and Scarr, 1992). What were once thought to be "safe" concentrations of lead in the blood of children are now recognized to be detrimental to children's health. V. Houk, Assistant Surgeon General and Director of the National Center for Environmental Health and Injury Control of the Centers for Disease Control (CDC) stated (Houk, 1992), *"Before the mid-1960s, a lead level in children in the United States below 60 micrograms per deciliter (μg/dL) in whole blood was not considered dangerous enough to require intervention. Subsequent research noted adverse health effects on humans with lower blood levels; in 1985, the threshold was lowered to 25 μg/dL and more recently to as low as 10 μg/dL." "This threshold* [10μg/dL] *was selected not because lower levels are without consequences, but for practical reasons of dealing with current blood lead levels in the general population."*

A review of the CDC (1991) evaluation shows that there is substantial evidence of harm to children's health associated with blood-lead levels of 10 μg/dL. There is also evidence that harm occurs in some children associated with blood-lead levels below 10 μg/dL. The California Department of Health Services (DHS) has established 5 μg/dL as an acceptable blood-lead level for children. In a major study being conducted at this time, DHS has found that 67% of the 544 children studied in Oakland, CA had blood-lead levels ≥10 μg/dL; 32% of the 199 children studied in Los Angeles, CA and 14% of the 382 children studied in Sacramento, CA had blood-lead levels ≥10 μg/dL (DHS, 1991). Those study populations were not designed to be "representative" of the cities overall, but rather of populations most likely receiving elevated lead exposure. Similar results are being found for children in other urban areas in the US and in other countries. *Rachel's Hazardous Waste News* cited US Department of Health and Human Services statistics as showing that 88% of American children 5 years old or younger have blood-lead levels of ≥10 μg/dL (RHWN, 1990). Such findings are causing widespread concern among public health officials, and considerable attention is being given to this issue in the popular press (e.g., *Newsweek*, Waldman, 1991; *The Washington Post*, Young, 1990).

The national concern about this problem prompted the development of a national organization (Alliance to End Childhood Lead Poisoning), headquartered in Washington, D.C., specifically focused on issues of lead and children's health. The Alliance has published layperson-oriented public information booklets (AECLP, 1987). It also organized "The First Comprehensive National Conference on Preventing Childhood Lead Poisoning" in October 1991 and published proceedings of that conference (AECLP, 1991). Other public-interest groups are also focusing attention on the environmental lead issue (e.g., Environmental Research Foundation (RHWN, 1990, 1991, 1992); US Consumer Product Safety Commission (US CPSC, 1989, 1990); Citizen's Clearinghouse for Hazardous Wastes (Lester, 1992); National Environment Journal (Anonymous, 1992a)).

In the summer of 1991, the US EPA specified the maximum contaminant level goal for lead in drinking water to be "zero" and a proposed national primary drinking water standard (maximum contaminant level - MCL) for lead of 0.005 mg Pb/L (US EPA, 1991b,c) for the protection of children's health; that MCL represents a 10-fold reduction in the MCL for lead. The establishment of the new MCL and the associated monitoring for compliance with that standard is causing widespread concern among water utilities (Frey, 1992). This concern arises from the fact that drinking water standards are applicable to water as drawn from the consumer's tap, and that one source of lead in drinking water is household plumbing including lead-containing solder (Murrell, 1991).

While the focus of much of the public health concern about lead is children, there is also concern about the exposure of adults to lead. Allison (1992) reported in the *Harvard Health Letter*,

"Lead is stored in the bones and may be released by osteoporosis or events such as pregnancy or lactation." and that lead freed from bone can target red blood cells, the central nervous system, the kidneys, and a fetus.

The significance of lead has become recognized as extremely important in children's health and welfare. It also appears quite possible that what are considered today to be "acceptable" levels of lead in children's blood will be found in the future to have adverse impacts as well.

SOIL-LEAD RESIDUES AS A SOURCE OF LEAD IN PEOPLE

While children obtain lead from a variety of sources including food, water, household dust, and lead-based paint, the source of greatest concern with respect to site assessment for property transfer is soil-lead residues. Bolger *et al*. (1991) reported Food and Drug Administration (FDA) figures' showing that as of the late 1980's, about 1% of the baseline dietary exposure to lead for a 2-yr-old child is from soil; 75% of the dietary exposure was reportedly from dust. Chaney *et al*. (1984) discussed the potential for heavy metal exposure from urban gardens and soils and suggested precautions to reduce exposure from those sources.

It is becoming increasingly recognized that as part of their play activities children ingest potentially significant quantities of soil. From information derived from environmental risk assessments for Superfund sites, the US EPA has estimated that a child in the age range of 1 to 6 yrs consumes about 200 mg of soil per day in his/her routine play activity (US EPA, 1989). Ingestion rates can be substantially higher among some children, especially associated with "pica" exposure, the direct ingestion of soil. Chaney *et al*. (1988) attributed ingestion of up to 100 mg soil/day to "hand-to-mouth play" and ingestion of as much as 10 g soil/day associated with pica exposure. Soil ingestion rates of 0.1 to 1 g/day are commonly used for estimating children's exposure to soil-associated contaminants.

Considerable controversy exists today on what constitutes a "safe" concentration of lead in soil for the protection of children's health and welfare. The relationship between soil-lead residue levels and blood-lead levels has received considerable attention over the years (Davies and Wixson, 1988; SEGH, 1991; Chaney and Mielke, 1986). At this time that relationship remains poorly understood and poorly defined. It is clear, as would be expected, that factors other than the concentration of total lead in the soil govern or influence the amount of lead in the blood of exposed people. One of the key issues that is being investigated at this time is the factors influencing the amount of lead in soil that is absorbed from the intestinal tract into the bloodstream. Of particular focus is the physiological chemistry of ingested lead as it proceeds through the stomach and small intestine. The low pH of the human stomach ($\approx$ pH 1) would be expected to cause the dissolution of most, but not all, forms of lead. Mielke and Heneghan (1991) discussed a variety of gut physiological processes and conditions, and factors affecting those processes and conditions that can affect lead bioavailability, including type of food eaten, frequency of eating, and nutritional status. They noted the complex nature of the gastrointestinal tract and mechanisms by which that system attempts to reduce lead absorption.

Davis *et al*. (1992) reported the results of a study of the behavior and bioavailability of various forms of lead in New Zealand white rabbits. They found that 6% of the total lead fed to the rabbits solubilized in their small intestine. The residence time typical of the gastrointestinal tract must be considered when estimating contaminant availability, they noted, and the toxicity of ingested Pb depends on the bioavailability of the lead. They indicated that while studies with Pb salts showed bioavailability of 30% or more of ingested lead, such estimates are not appropriate for evaluating the bioavailability of lead associated with soils since solid forms of lead in soils are much less soluble than metal salts. Davis *et al*. (1992) reported that soil mineralogy is a critical parameter controlling the forms of lead present and hence the net bioavailability of the lead. This finding, which would be expected based on what is generally known about the behavior and impacts of chemical contaminants, helps explain the variable blood-lead levels in individuals exposed to the same soil-lead concentrations.

While Davis *et al*. (1992) discussed the solubilization of lead in the digestive system, Chaney *et al.* (1988) noted that part of the lead that is dissolved in the stomach adsorbs onto solid fractions of the ingested material residues (e.g., food, soil) further-on in the digestive system in the small intestine. This sorption alters the bioavailability of the lead for absorption into the bloodstream.

The "Lead in Soil Task Force" of the Society for Environmental Geochemistry and Health (SEGH) has been working for a number of years to establish guidelines for lead residues in soil for the protection of children's health. SEGH has published a number of monographs containing collections of papers devoted to various aspects of this topic (Davies and Wixson, 1988; SEGH, 1991). Davies and Wixson (1986, 1988), Wixson (1988, 1989, 1991), and Wixson and Davies (1991) have been particularly active in developing information pertinent to guidelines for soil-lead residues. Wixson and Davies (1991) pointed out that to propose a single-value upper concentration limit or guideline for lead that would protect young children was unrealistic owing to uncertainties about what constitutes a "safe" blood-lead level, the variability of exposure to myriad forms/sources of lead in various soils and dusts, and the differences in bioavailability among forms of lead in soil. They offered a mathematical representation (model) for deriving a target soil/dust lead "guideline" that incorporates a number of these factors. However, one of the major factors in the model is the relationship between the soil-lead concentration and the blood-lead level of the exposed population, represented by "δ." That is a relationship that must be defined on a highly site-specific basis because of the many factors noted above and identified by Wixson and Davies known to influence it and that are not sufficiently well-understood to be quantified. Thus while the model presented by Wixson and Davies (1991) is an important step in defining the parameters that need to be considered, the reliability of the guidelines generated by it depends on the reliability of the values selected for the variables included in it. At this time, insufficient information is available to enable this model to be widely used. A SEGH conference will be held in early August 1992 devoted to lead and other chemical contaminants in soils (SEGH, 1992); the proceedings of that conference should provide additional information on the current state of knowledge on the public health implications of lead residues in soils.

The US EPA (1991a) has developed a strategy for reducing lead exposures for the protection of public health. The strategy recognizes the potential significance of lead residues in urban soil and also that comparatively little is known about its actual public health significance. Studies are reportedly under-way in Boston, Baltimore, and Cincinnati to develop needed information.

APPROACHES TO REGULATION OF SOIL-LEAD RESIDUES

The California Code of Regulations (CCR, 1990) indicated that background soil-lead in the western US is about 18 mg/kg (dry wt.) (All soil-lead concentrations reported in this paper are on a dry-weight basis.) According to Longest (1991),

> *"Currently, the US EPA recommends a soil cleanup level of 500 - 1000 ppm* [mg Pb/kg soil] *total lead for Superfund sites which are characterized as residential property. The objective of the Superfund guidance is to develop a cleanup level for lead in soil which would reduce children's blood lead levels to below 10 μg/dL at that specific Superfund site."*

On the other hand, California Department of Health Services (DHS) has established that for residential areas, the concentration of lead in soils can be no greater than 174 mg Pb/kg (DHS, 1989; Sedman, 1989; Reynolds *et al*., 1990; Hadley and Sedman, 1990). The DHS value was estimated, based on the assumption that children consume 100 mg soil/day, to be a level that would not cause the blood-lead level of exposed children to be greater than 5 µg/dL. Soil-lead limits for (West) Germany and the European Economic Community (EEC) have been reported to be 100 mg Pb/kg soil, and for the United Kingdom, 450 mg Pb/kg soil. Those values are more in line with the California DHS limitation than those of the US EPA.

The California DHS has determined that a "safe" soil-lead level for adult exposure is 3700 mg Pb/kg soil. The difference between the "safe" exposure levels for adults and children reflects the comparatively greater absorption of lead through the intestinal tract of children. The difference in absorption appears to be related to differences in the metabolism of calcium; children absorb a greater percentage of their dietary calcium and lead than do adults (Weis and LaVelle, 1991). Even though the California DHS established 3700 mg Pb/kg as a "safe" level for adult exposure, it requires that soil-lead residues at state superfund sites be clean-up to 950 mg Pb/kg soil for commercial and industrial (i.e., non-residential) reuse of the property. DHS also requires that areas containing soil-lead >174 mg Pb/kg be covered with a low-lead soil veneer 1 to 2-ft thick and that a deed/use restriction be placed on the property to preclude use of the property for residential development or other purposes that would bring children in contact with the soil. The 950 mg Pb/kg limitation was instituted not because of intrinsic hazards but because of the DHS's arbitrary designation of materials containing greater than 1000 mg Pb/kg as "hazardous waste" (CCR, 1990).

Having dual soil-lead standards for state superfund site clean-up in California (i.e., 174 mg/kg for residential areas and 950 mg/kg for commercial/industrial areas) is leading to problems in remediation and redevelopment of superfund sites. As discussed by Lee and Jones (1991b,c), responsible parties for superfund sites may make decisions to only remediate those parts of the site that contain greater than 950 mg Pb/kg, to meet the 950 mg/kg level (rather than to 174 mg/kg) in order to save clean-up costs. (Typical costs to remediate (i.e., remove) soils that contain 950 mg Pb/kg to achieve the 174 mg/kg residential standard are on the order of $500,000/acre-ft of soil removed.) However, with the considerable pressure for inner city superfund sites to be redeveloped for residential purposes, e.g., for low-income housing, the dual standard can lead to situations in which areas meeting residential standards for lead are adjacent to and not isolated from areas containing lead concentrations as high as 950 mg/kg. Since deed restrictions associated with the commercial/industrial clean-up levels are implemented by municipalities, and since the lead that is present in the soils will represent a potential source of lead exposure for as long as it remains there (i.e., forever), there is considerable concern about the degree of protection of the health and welfare of children in such areas that can in fact be achieved with this approach (Lee and Jones, 1991b,c).

CONCENTRATIONS OF LEAD IN URBAN RESIDENTIAL SOILS

There have been numerous studies to define the concentrations of lead in urban residential soils. Mielke and his co-workers have conducted studies on the soil-lead concentrations in several Minnesota cities, Baltimore, and New Orleans (Mielke, 1984, 1991; Reagan and Mielke, 1991; Mielke *et al*., 1983, 1984, 1985, 1988, 1991). Other investigators (see Davies and Wixson, 1988; Davies, 1988; Stokes, 1988; Simms, 1988; SEGH, 1991; Jayne, 1992) have reported that many urban soils in residential areas frequently contain lead residues greater than 200 mg Pb/kg. Some such soils have been found to contain lead in excess of 1000 mg Pb/kg.

The California DHS (1991) reported that the median household soil-lead level associated with the 358 residences in its Oakland, CA study area was 880 mg Pb/kg; the range in concentration measured was 50 to 88,000 mg Pb/kg. For the 343 household areas studied in Los Angeles, the median household soil-lead level was 190 mg Pb/kg with a range of 30 to 2000 mg Pb/kg. For the 232 household areas studied in Sacramento, the median household soil-lead level was 230 mg Pb/kg with a range of 26 to 2700 mg Pb/kg. It is clear from the numerous studies that have been conducted that lead commonly occurs in urban residential soils in concentrations above those that are considered detrimental to children's health, especially if the California DHS value of 174 mg Pb/kg is used as a guideline for the assessment. This finding, coupled with its potential public health significance for children, makes the evaluation of soil-lead residues one of the most important aspects of a property site assessment for potentially hazardous chemicals.

ORIGIN OF URBAN SOIL-LEAD RESIDUES

The principal sources of lead residues in urban residential soils are lead-based paint chips, alkyl-lead used as an anti-knock agent in gasoline, and in some areas, industrial emissions. DHS (1991) reported that house paint containing lead is the most common cause of childhood lead poisoning. DHS (1991) stated,

> *"As lead paint deteriorates, chalks, or is removed during home remodeling, lead enters house dust and soil, which may then be ingested during normal hand-to-mouth activity. Ingestion of small amounts of dust contaminated with lead paint can result in adverse health effects. Ingestion of only a few thumbnail size chips of lead paint can cause severe lead poisoning."*

DHS (1991) reported that some of the household paint chips it has sampled have been found to contain more than 300,000 mg Pb/kg. This demonstrates that lead-based paint is an extremely potent source of lead. Lead that becomes associated with soils remains there indefinitely, although as noted below, soil erosion associated with stormwater runoff can result in some transport of lead from properties.

While lead-based paint has been recognized as a potentially significant source of lead in urban soils, increasing recognition is being given to alkyl-lead-derived lead residues as an important source. In the 1960's and early 1970's, numerous studies were conducted on the fate, dispersion, and persistence of lead from alkyl-lead used in gasoline (e.g., Cannon and Bowles, 1962; US PHS, 1965; Atkins and Kruger, 1968; Singer and Hanson, 1969; Daines *et al*., 1970; Lagerwerff and Specht, 1970; Motto *et al*., 1970; Page and Ganje, 1970; Page *et al*., 1971). In the 1950's and 1960's, a gallon of gasoline contained about 2 g of lead; some gasoline formulations contained more than 4 g Pb/gal. During the time of intensive use of alkyl-lead in gasoline, significant concentrations of lead were found in the air. Lead was emitted as a particulate aerosol from the automobile exhaust; it was found that the concentrations of lead in air decreased exponentially with distance from the roadway, with most of the lead being deposited in the soil within a few hundred meters of the roadway. Concentrations of lead in soils near highways were frequently found to exceed several hundred mg Pb/kg. Some of the lead emitted from autos was carried for long distances in the upper atmosphere.

The pioneering work of Patterson and his co-workers on environmental pollution by lead showed that atmospheric lead derived from alkyl-lead sources was accumulating in the Greenland snowpack and in the deep-ocean sediments (Patterson, 1965; Murozumi *et al*., 1965). In the early 1960's Patterson repeatedly tried to gain attention for the fact that lead was accumulating in human tissue in much higher amounts than had been occurring prior to widespread use of lead. He reported that the concentrations of lead in humans in the 1960's was about 100 times what it was projected to have been before the industrial revolution (Patterson, 1965). From the studies conducted on this topic, it is clear that the use of alkyl-lead as an anti-knock agent in gasoline has contributed to the excessive levels of lead in soils of urban areas.

While through regulatory action the use of alkyl-lead as an anti-knock agent in gasoline has been greatly reduced, eliminated in some areas, and will be eliminated in all areas of the US in the near future, its use has left appreciable lead residues in surface soils near highways especially in urban areas; these residues still represent a threat to children's health. This issue has not been, and is not now being, adequately addressed by regulatory agencies. Some urban soils contain greater concentrations of lead than lead-contaminated soils at Superfund sites that require remediation. In the opinion of the authors the reason for this paradox is that urban soil-lead is such a massive and ubiquitous problem that regulatory agencies are choosing not to address it because of funding limitations. However, this problem will not simply go away; the lead in the soils is particulate and relatively immobile and subject to transport basically only through erosion. Because of the large amount of work being devoted today to the issues of lead-poisoning of children, however, there can be little doubt that within a few years attention will be given to addressing the problems of soil-lead residues in urban areas.

WATER QUALITY SIGNIFICANCE OF LEAD

While it has been known for many years that lead can be toxic to aquatic life, the critical concentration of lead in water for the protection of aquatic life has been, and continues to be, poorly understood. A review of the impacts of lead on aquatic life has been presented by the US Department of Interior Fish and Wildlife Service (Eisler, 1988).

It has been well-known for many years that particulate forms of lead are not toxic and that the toxicity of lead is significantly lower in hard water (water containing high levels of calcium and magnesium) than in soft water. Lee and Jones (1992a) reviewed the factors affecting the availability of lead in soils. A review of USDA Research presented in *Biocycle* reported that the work of Chaney of the US Department of Agriculture's Agricultural Research Service showed that the addition of composted sewage sludge to soils binds lead in the soil and reduces its mobility (Anonymous, 1991).

The US EPA "Red Book" of water quality criteria (US EPA, 1976) recognized the differences in availability and toxicity of lead forms that could not be distinguished by chemical analytical procedures, and recommended that a 96-hr aquatic life bioassays be used to establish critical concentrations of lead on a site-specific basis. The US EPA (1976) reported that the concentration of soluble lead that caused 50% mortality of the test organisms in 96 hours (96-hr LC50) was typically on the order of several mg Pb/L to several hundred mg Pb/L. The agency recommended that an application factor of 0.01 be used to convert the acute-lethal concentration of soluble lead (96-hr LC50) determined in an aquatic organism bioassay for a particular water to a "chronic exposure safe concentration" for that water.

In revised criteria, the US EPA (1985, 1987) recommended that for soft water (hardness of 50 mg/L $CaCO_3$) the maximum allowable 4-day average total lead concentration, not to be exceeded more than once in 3 yr, was 1.3 μg Pb/L. For hard waters (hardness of 200 mg/L $CaCO_3$), the value was 7.7 mg Pb/L. These are the criteria values that are being used by the US EPA today and that have been adopted by many states as water quality standards. According to the US EPA (1976), Kopp and Kroner (1967) reported that the mean concentration of total lead in 1500 samples of stream waters from across the US was 23 μg Pb/L. Those measurements were made at a time when there was extensive use of lead as an anti-knock compound in gasoline. It is likely, therefore, that since this use has decreased significantly in recent years, concentrations of lead in stream waters would also have decreased from those reported by Kopp and Kroner. Peterson (1973) reported on lead concentrations in the water and sediments of a number of Wisconsin lakes in the mid-1960's. He found that typically the total lead concentrations in the lake waters were less than 1 to 2 µg Pb/L. The concentrations of lead in surface sediments of those lakes were often on the order of 100 mg Pb/kg, with the sediments of some urban lakes (such as Lake Monona in Madison) containing lead in excess of 400 mg Pb/kg. Some of the street runoff in Madison contained more than 2000 µg Pb/L total lead. As discussed by Lee and Jones (1991e), Pitt and Field (1990) reported that the median concentration of total lead in urban stormwater runoff from across the US was 150 µg Pb/L.

Hodgkins (1992) reported that 93% of the urban runoff samples recently collected from the city of Sacramento, CA had lead concentrations in excess of the California water quality objective (standard) for lead (numerically equal to the US EPA criteria). Lee and Jones (1991d) cited the results of a USGS 1982 study on the American River that runs through the city of Sacramento; the USGS data showed that the lead concentrations in the American River above the city routinely exceeded the US EPA criteria for lead. The lead concentration in the river almost doubled after it passed through the city. There were no known wastewater inputs to that part of the river to cause the doubling of concentration; the increased concentration of lead was caused by non-point-sources. With the reduction in the use of alkyl-lead in gasoline, soil-lead from historical use of alkyl-lead additives and from other sources is becoming the dominant source of lead in stormwater runoff from urban and commercial properties, and a potentially dominant source from industrial properties.

It is evident, therefore, that the concentrations of lead in urban runoff and in receiving waters across the US exceed the US EPA numeric criteria. The high concentrations in urban stormwater runoff reflect the high levels of lead in the environment of urban areas, part of which is derived from soil-lead residues. While until recently regulatory agencies have not addressed non-point-sources of heavy metals such as urban and rural stormwater runoff, the US EPA's current program for control of contaminants in urban stormwater runoff initiated in November 1991 is beginning to address this issue. Within a few years, exceedances of US EPA ambient water quality criteria such as for lead will be considered violations of NPDES permits for non-point-source discharges/runoff and will be subject to regulatory enforcement action. As projected now, cities will eventually have to control violations of ambient water quality standards caused by stormwater runoff. Because of the manner in which stormwater regulations have been developed, it is likely that industrial and commercial stormwater runoff will have to be in compliance with state standards much sooner than cities. Many commercial and industrial establishments that have made no previous use of lead to cause elevated soil-lead residues will find that the residential-type sources of lead will cause them to be in violation of lead standards. This could cause commercial and industrial establishments to have to remediate or manage lead-soil residues on their properties to prevent transport of lead from the properties, activities that could affect transfers of industrial and commercial properties. Further, even with complete control of soil-lead residues from commercial and industrial properties, cities will likely find that the lead in stormwater runoff from residential areas will continue to cause exceedances of lead standards in receiving waters. The issue of exceedance of water quality standards may, in the end, be a stronger driving force to cause clean-up of lead residues in urban residential soils than the human/children health issue.

There is some uncertainty as to whether US EPA water quality criteria and state standards as they exist today will, in fact, be applied to regulating contaminants in stormwater runoff. As discussed by Lee and Jones (1991e), the way in which the US EPA water quality criteria were developed and are being implemented cause state standards based on those criteria to significantly overestimate the water quality impacts of stormwater-associated contaminants. Concentrations of contaminants in stormwater runoff can greatly exceed the numeric water quality standards without adverse impacts on beneficial uses of waters receiving the runoff. Further information on this topic is provided by Lee and Jones (1991f). It has been the experience of the authors that soil-lead residues in stormwater runoff would rarely be expected to adversely affect the beneficial uses of the surface waters into which the stormwaters enter. It is hoped that the US EPA and/or the states will develop stormwater quality criteria to properly assess the real impacts that soil-lead residues could have on designated beneficial uses of receiving waters. If that is done, the actual water quality significance of soil-lead residues would be put into proper perspective. If such criteria are not developed, meeting the unnecessarily and overly protective water quality criteria and standards in receiving water could control the soil-lead residue management/remediation. For now, those conducting property site assessments should alert their clients to the possibility that soil-lead residues that may be present in property runoff may soon have to be viewed in terms of their role in causing exceedances of state water quality standards in receiving waters.

POTENTIAL LIABILITIES ASSOCIATED WITH REMEDIATION OF SOIL-LEAD

At this time the only economically viable method of remediation of lead-contaminated soils is the removal of the soil. The soil removed is typically taken to a landfill for burial. If the soil is classified as a "non-hazardous" waste (e.g., in California, if the lead concentration is below 1000 mg Pb/kg and the concentrations of lead leached in the California extraction procedure or the US EPA TCLP are less 5 mg Pb/L) it may be disposed of in a municipal solid waste landfill at a cost of about \$20 to \$50/ton. If the soil is classified as a "hazardous waste" (e.g., in California, if the lead concentration is above 1000 mg Pb/kg) it would have to be taken to a RCRA "hazardous waste" landfill. For "hazardous waste"-designated soils removed from Sacramento, CA, this would cost about \$300/ton of soil removed.

There is controversy about the appropriateness of depositing lead-containing soils in municipal landfills. Recently the governor of Louisiana filed suit against the US EPA in order to prevent the transport of 30,000 to 40,000 yd^3 of lead-containing soils from Texas for deposition in a Louisiana municipal solid waste landfill (Anonymous, 1992b). While the soil in question passed the US EPA TCLP limit of 5 mg Pb/L, the state of Louisiana justifiably feels that the lead could pollute groundwater in the vicinity of the landfill.

Industrial Economics, Inc. (1991) prepared a report on potential human exposure from lead in municipal solid waste for the Lead Industries Association in which it was claimed that lead in municipal solid waste landfills does not represent a threat to groundwater quality. However, a critical review of the information presented in the report shows that that conclusion is not reliable or supported by the technical information cited as providing the basis for that conclusion. The Industrial Economics, Inc. (1991) report significantly underestimated the typical concentrations of lead in municipal landfill leachate. While the US EPA (1988) was cited as a source of information on lead concentrations in municipal landfill leachate, a critical review of that report and other information on the characteristics of landfill leachate (e.g., Lee and Jones, 1991a) shows that the concentrations are frequently much higher than those reported by Industrial Economics, Inc. and typically are on the order of 0.5 mg Pb/L. Therefore, the concentrations of lead in leachate from many municipal landfills are at least a factor of 10 above the US EPA drinking water standard of 50 μg Pb/L, and a factor of 100 above the proposed MCL of 5 μg Pb/L. While lead tends to sorb and/or precipitate in many soils and therefore tends to have relatively low mobility in groundwater systems, there are some systems such as non-calcareous quartz sands in which lead would be expected to be highly mobile. Thus lead in municipal landfill leachate can be a significant threat to groundwater quality.

Some commercial firms are manipulating their lead-paint removal products (such as paint-stripping tape) by addition of sodium hydroxide or other chemicals in order to add sufficient alkalinity so that the lead paint removed by the product will "pass" the TCLP test. "Passing" that test makes the material eligible for disposal in a municipal solid waste landfill rather than in a "hazardous waste" landfill. While the hydroxide helps the material pass the TCLP test, it would be neutralized by the large amount of acidity typical of municipal landfill leachate. Thus, the product would have little or no ability to reduce the hazard of the lead to groundwater. As discussed by Lee and Jones (1991a) the US EPA's TCLP is not reliable for the classification of the hazards of contaminants such as lead in soils or wastes. Materials that "pass" that test can readily cause highly significant groundwater pollution problems.

Increasing concern is being expressed about the liability of responsible parties for materials placed in municipal solid waste landfills. As discussed by Lee and Jones (1991g, 1992b) so-called "modern" lined, dry-tomb landfills of the type being developed today will not prevent groundwater pollution by landfill leachate. At best such systems only postpone the occurrence of pollution. In the past, unless the landfill became a federal or state superfund site, little attention was given to pollution of groundwater by municipal landfill leachate. However, this situation is changing. For example, the Minnesota Pollution Control Agency has indicated that those who have placed large amounts of lead-containing materials in municipal solid waste landfills could have to remove the materials from the landfill.

On behalf of the US EPA, Franklin Associates, Ltd. (1989) reviewed the amounts of lead disposed of in municipal solid wastes. They concluded that in 1986 approximately 214,000 tons of lead were disposed of in municipal landfills in the US. The principal source of that lead was lead-acid batteries that contributed about 65% of the total lead. Consumer electronics accounted for approximately 27% of the lead discarded in municipal solid waste in 1986. The Franklin Associates, Ltd. (1989) review did not consider the amount of lead added to municipal solid waste landfills in soils such as from street-sweepings. The significance of soil-lead residues as a source of the approximately 0.5 mg Pb/L in municipal landfill leachate is unknown at this time.

While the pollution of groundwaters by leachate from non-superfund municipal landfills (classical sanitary landfills) is receiving limited attention at this time, there is growing recognition that essentially all municipal solid waste landfills are polluting groundwater with landfill leachate. Ultimately a large national program similar in many respects to the superfund program will have to be undertaken to stop the continued pollution of groundwater by landfill leachate and to attempt to clean up the groundwater already polluted. When that occurs, those who have contributed waste to a landfill will become responsible parties to share the costs of groundwater quality clean-up and protection. Lead will be one of the elements of concern in groundwater pollution near landfills. Those sites from which lead in leachate is migrating through the groundwater system will likely be examined to determine whether large amounts of lead-containing materials including soils were deposited in the landfill. Those who deposited lead-containing soils and other lead-bearing material in large amounts into those landfills will likely be required to pay a significant part of the site remediation costs. This is analogous to what is done today at superfund sites.

It will be important for those who advise on lead-soil clean-up procedures to critically examine the characteristics of the municipal landfills potentially available for materials disposal to determine whether there is a significant potential for that landfill to pollute groundwater that could be used for domestic purposes at any time in the future. All landfills of the type being developed today will eventually fail to prevent leachate transport from the landfill to area strata. Landfills that are properly sited in areas not hydraulically connected to groundwater of importance to the public could be acceptable for disposal of lead-containing materials. Lee and Jones (1991h) provided guidance on approaches that should be used to evaluate whether an existing or proposed landfill has a high potential to represent a significant threat to groundwater quality. From the perspective of management of soil-lead, consideration should be given in a landfill evaluation to whether the geological strata of the aquifer system connected with the landfill would permit lead transport to adjacent properties that could be detrimental to domestic water supply use of the groundwater.

It is therefore concluded that the disposal of lead-containing soils in municipal solid waste landfills carries with it a potential for long-term liability for harm to public health and environmental quality and for financial responsibility for eventual site remediation. These liabilities should be considered in any site remediation follow-up to a site assessment.

CONCLUSIONS

The following conclusions can be drawn from this review regarding the concerns about soil-lead residues in property transfer site assessments.

- As greater understanding is developed about the significance of lead in children, the blood-lead levels considered "safe" continue to be lowered. This has caused regulators and public interest groups to focus attention on the sources of lead that cause elevated blood-lead levels.

- It is likely that as additional information is gathered on the public health significance of lead to children and adults that what are now considered to be acceptable blood-lead levels will be lowered further.

- Soil-lead residues, especially in urban residential areas, represent a potentially significant threat to the public health and welfare of children.

- The California Department of Health Services has adopted 174 mg Pb/kg as an accepted "safe" soil-lead residue for residential soils. Judging by that standard, soils in many urban residential, commercial/industrial, and some rural areas have what would be considered to be excessive amounts of lead.

- The costs to "remediate" (remove) lead-contaminated soils can be sufficiently great to cause significant decrease in property values.

- Property site assessments should include an evaluation of concentrations of soil-lead residues and their potential significance.

* * *

- The US EPA's water quality criteria and standards equivalent to them for lead are sufficiently low, and the concentrations of lead in most urban stormwaters sufficiently high, that the numeric standards are frequently exceeded in waters receiving stormwater runoff.

- The US EPA's and state regulatory agencies' recent efforts to control exceedances of water quality standards caused by non-point-sources will call attention to soil-lead residues as a source of lead in stormwater runoff.

- Site assessments for industrial/commercial and residential properties should include an evaluation of whether soil-lead residues could cause exceedance of water quality standards in receiving waters.

- It is possible that the development of stormwater quality criteria and standards that more properly account for the availability of soil-lead residues in water and sediments will provide a better perspective on the actual water quality significance of soil-lead residues.

* * *

- The remediation of soil-lead residues typically involves removal of the soil and its deposition in a landfill.

- In many instances the procedures used to judge the hazards that lead-containing materials such as soils represent to public health and the environment (such as the US EPA's TCLP test) are unreliable.

- Soil-lead residues that have been judged satisfactory by those approaches, for deposition in municipal landfills can at some locations represent significant threats to groundwater quality.

- The disposal of lead-contaminated soil in municipal landfills of the type being developed today carries with it the potential for long-term liability for harm to public health and environmental quality and for financial responsibility for eventual site remediation.

- Site-specific evaluation of potential sites for disposal of lead-contaminated soils should be made to determine whether the lead could contribute significantly to the groundwater pollution potential of the landfill leachate.

* * *

- Lending institutions should require that property-transfer site assessments should reliably determine the potential significance of soil-lead residues as they may affect future use of the property and its value.

- Further research needs to be done to more reliably determine the bioavailability of lead to humans and aquatic life in order to develop more reliable site-specific criteria/standards for judging the public health and water quality significance of soil-lead residues.

REFERENCES

AECLP (Alliance to End Childhood Lead Poisoning), "What Everyone Should Know about Lead Poisoning," Booklet 15 pp., AECLP, Washington, D.C. (1987).

AECLP (Alliance to End Childhood Lead Poisoning), "Preventing Childhood Lead Poisoning," The First Comprehensive National Conference Final Report, AECLP, Washington, D.C. (1991).

Allison, M., "Lead Poisoning - Not Just for Kids," Harvard Health Letter 17(7):6-8, May (1992).

Anonymous, "Sludge Compost 'Binds' Lead in Contaminated Soil," Biocycle (1991).

Anonymous, "Lead in the Environment," The National Environmental Journal, p. 18, January/February (1992a).

Anonymous, "Government Officials Battle to Keep Dallas Soil Out of Magnolia," Contaminated Soil Report 1(3):1,6, April (1992b).

Atkins, P., and Kruger, P., "The Natural Removal of Lead Pollutants from a Suburban Atmosphere," Technical Report No. 98, Department of Civil Engineering, Stanford University, Stanford, CA, 220 pp. August (1968).

Bolger, P, Carrington, C., Capar, S., and Adams, M., "Reductions in Dietary Lead Exposure in the United States," IN: Proc. Symposium on Bioavailability and Dietary Exposure of Lead, SEGH Monograph, Chemical Speciation and Bioavailability 3(3/4):31-36, December (1991).

Cannon, H., and Bowles, J., "Contamination of Vegetation by Tetraethyl Lead," Science 137:765-766 (1962).

CCR (California Code of Regulations), Title 22, Division 4 - Environmental Health, Chapter 30 - Minimum Standards for Management of Hazardous and Extremely Hazardous Wastes, Article 11 - Criteria for Identification of Hazardous and Extremely Hazardous Wastes, §66693-66747 April (1990).

CDC (Centers for Disease Control), "Preventing Lead Poisoning in Young Children," Statement by the Centers for Disease Control, Atlanta, 5 pp. October (1991).

Chaney, R., and Mielke, H., "Standards for Soil Lead Limitations in the United States," IN: Proc. XX Annual Conference on Trace Substances in Environmental Health, University of Missouri, Columbia, pp. 357-377 (1986).

Chaney, R., Sterrett, S., and Mielke, H., "The Potential for Heavy Metal Exposure from Urban Gardens and Soils," IN: Preer, J. (ed), Proc. Symposium Heavy Metals in Urban Gardens, Univ. Dist. Columbia Extension Service, Washington, D.C. pp. 37-84 (1984).

Chaney, R., Mielke, H., and Sterrett, S., "Speciation, Mobility and Bioavailability of Soil Lead," IN: Davies, B., and Wixson, B. (eds), Lead in Soil: Issues and Guidelines, Environmental Geochemistry and Health Monograph Series 4, Supplement to Volume 9 of *Environmental Geochemistry and Health*, Science Reviews Limited, Northwood, U.K. pp. 105-129 (1988).

Daines, R., Motto, H., and Chilko, D., "Atmospheric Lead: Its Relationship to Traffic Volume and Proximity to Highways," Environ. Sci. & Technol. 4(4):318-322 (1970).

Davies, B., "Lead in Soils: Its Sources and Typical Concentration," IN: Davies, B., and Wixson, B. (eds), Lead in Soil: Issues and Guidelines, Environmental Geochemistry and Health Monograph Series 4, Supplement to Volume 9 of *Environmental Geochemistry and Health*, Science Reviews Limited, Northwood, U.K. pp. 65-72 (1988).

Davies, B., and Wixson, B., "Lead in Soil - How Clean is Clean?" IN: Proc. XX Annual Conference on Trace Substances in Environmental Health, University of Missouri, Columbia, pp. 233-241 (1986).

Davies, B., and Wixson, B. (eds), Lead in Soil: Issues and Guidelines, Environmental Geochemistry and Health Monograph Series 4, Supplement to Volume 9 of *Environmental Geochemistry and Health*, Science Reviews Limited, Northwood, U.K. (1988).

Davis, A., Ruby, M., and Bergstrom, P., "Bioavailability of Arsenic and Lead in Soils from the Butte, Montana, Mining District," Environ. Sci. & Technol. 26(3):461-468 (1992).

DHS (California Department of Health Services), Memorandum from DHS Toxic Substances Control Program to B. Kilgore, Waste Management Engineer Site Mitigation, Regarding Southern Pacific Sacramento Station, October 18 (1989).

DHS (California Department of Health Services), "Childhood Lead Poisoning Prevention," Report of DHS, Berkeley, CA, 8 pp., June 6 (1991).

Eisler, R., "Lead Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review," Biological Report 85(1.14), US Dept. Interior Fish and Wildlife Service, Laurel, MD, 134 pp. (1988).

Ernhart, C., and Scarr, S., "Lead Study Challenge," (Letters), Science 255:783, February 14 (1992).

Forslund, B., and Henry, E., "Lead - The Due Diligence Issue for the 1990's?" IN: Proc. 1991 Environmental Site Assessments Case Studies and Strategies: The Conference, National Ground Water Association, Dublin, OH, pp. 597-608 (1991).

Franklin Associates, Ltd., "Characterization of Products Containing Lead and Cadmium in Municipal Solid Waste in the United States, 1970 to 2000," Final Report Executive Summary, EPA/530-SW-89-015C, US EPA Office of Solid Waste, Washington, D.C., January (1989).

Frey, M., "Meeting the Monitoring Challenges of the Lead and Copper Rule," Journ. Am. Water Works Assn. 84(7):12 (1992).

Hadley, P., and Sedman, R., "A Health-Based Approach for Sampling Shallow Soils at Hazardous Waste Sites Using the $AAL_{soil\ contract}$ Criterion," Environmental Health Perspectives 84:203-207 (1990).

Hodgkins, F., "Impact of the State Water Resources Control Board's California Inland Surface Waters Plan on the County and City of Sacramento," Presentation to the Environmental Leadership Seminar on Water Quality, University Extension, University of California, Davis, May 14 (1992).

Houk, V. Assistant Surgeon General and Director National Center for Environmental Health and Injury Control, CDC, "Assessing Environmental Risk -- Scientifically Defensible or Fantasy?" Presentation to American Chemical Society, San Francisco, CA, April 8 (1992).

Industrial Economics, Inc., "Potential Human Exposures from Lead in Municipal Solid Waste," Report for Lead Industries Association, Inc., New York, by Industrial Economics, Inc., Cambridge, MA, May 21 (1991).

Jayne, J., Professor, Department of Chemistry, San Francisco State University, San Francisco, Personal Communication to G. Fred Lee (1992).

Kopp, J., and Kroner, R., "Trace Metals in Waters of the United States," Federal Water Pollution Control Administration, US Department of the Interior, Cincinnati, OH (1967).

Lagerwerff, J., and Specht, A., "Contamination of Roadside Soil and Vegetation with Cadmium, Nickel, Lead, and Zinc," Environ. Sci. & Technol. 4(7):583-586 (1970).

Lee, G. F., and Jones, R. A., "Groundwater Pollution by Municipal Landfills: Leachate Composition, Detection, and Water Quality Significance," Proc. National Water Well Association's Fifth National Outdoor Action Conference, Las Vegas, NV, pp. 257-271, May (1991a).

Lee, G. F., and Jones, R. A., "Evaluation of Adequacy of Site Remediation for Redevelopment: Site Assessment at Remediated, Redeveloped 'Superfund' Sites," Proc. National Water Well Association's Site Assessments Conference, Columbus, OH, pp. 823-837, July (1991b).

Lee, G. F., and Jones, R. A., "Redevelopment of Remediated Superfund Sites: Problems with Current Approaches in Providing Long-Term Public Health Protection," Proc. American Society of Civil Engineers National Environmental Engineering 1991 Conference, Reno, NV, July (1991c).

Lee, G. F., and Jones, R. A., "Summary of Current Water Quality Issues for the American River, Sacramento, CA: Implications for Stormwater Runoff Contaminant Control Programs," Presented at American River Conference, Sacramento, CA, June (1991d).

Lee, G. F., and Jones, R. A., "Suggested Approach for Assessing Water Quality Impacts of Urban Stormwater Drainage," IN: Symposium Proceedings on Urban Hydrology, American Water Resources Association Technical Publication Series TPS-91-4, AWRA, Bethesda, MD pp. 139-151 (1991e).

Lee, G. F., and Jones, R. A., "Comments on US EPA's November 19, 1991 Proposed Rule for Compliance with Water Quality Standards Regulations Governing State Development of Numeric Water Quality Standards for Toxic Chemicals," Submitted by G. Fred Lee & Associated, El Macero, CA, to the US EPA, Washington, D. C., December (1991f).

Lee, G. F., and Jones, R. A., "Landfills and Groundwater Quality," Guest Editorial, Journ. Ground Water 29:482-486 (1991g).

Lee, G. F., and Jones, R. A., "Review of Proposed Landfills: Questions That Should Be Answered," Report of G. Fred Lee & Associates, El Macero, CA (1991h).

Lee, G. F., and Jones, R. A., "Evaluation of the Public Health and Water Quality Significance of Lead Residues in Soil: The Need for Better Understanding of Biogeochemistry of Lead," Presented at American Chemical Society National Meeting, Geochemistry Division, March (1992a).

Lee, G. F., and Jones, R. A., "Municipal Solid Waste Management in Lined, 'Dry Tomb' Landfills: A Technologically Flawed Approach for Protection of Groundwater Quality," Report of G. Fred Lee & Associates, El Macero, CA (1992b).

Lester, S., "Mislead Science: The Dangers of Lead," Everyone's Backyard, Citizen's Clearinghouse for Hazardous Wastes, June (1992).

Longest, H., Director, Office of Emergency and Remedial Response, US EPA, Washington, D.C., Personal Communication to G. Fred Lee, September 16 (1991).

Mielke, H., Statement at the Hearing before the Committee on Environment and Public Works United States Senate, 89th Congress, Second Session on S. 2609, Bill to Amend the Clean Air Act with Regard to Mobile Source Emission Control, June 22 (1984).

Mielke, H., "Lead in Residential Soils: Background and Preliminary Results of New Orleans," Water, Air & Soil Pollut. 57-58:111-119 (1991).

Mielke, H., and Heneghan, J., "Selected Chemical and Physical Properties of Soils and Gut Physiological Processes That Influence Lead Bioavailability," IN: Proc. Symposium on Bioavailability and Dietary Exposure of Lead, SEGH Monograph, Chemical Speciation and Bioavailability 3(3/4):129-134, December (1991).

Mielke, H., Anderson, J., Berry, K., Mielke, P., Chaney, R., and Leech, M., "Lead Concentrations in Inner-City Soils as a Factor in the Child Lead Problem," Am. Journ. Public Health 73(12):1366-1369 (1983).

Mielke, H., Blake, B., Burroughs, S., and Hassinger, N., "Urban Lead Levels in Minneapolis: The Case of the Hmong Children," Environmental Res. 34:64-76 (1984).

Mielke, H., Burroughs, S., Wade, R., Yarrow, T., and Mielke, P., "Urban Lead in Minnesota: Soil Transect Results of Four Cities," Journ. Minnesota Academy of Science 50:19-24 (1985).

Mielke, H., Adams, J., Reagan, P., Mielke, P., "Soil-Dust Lead and Childhood Lead Exposure as a Function of City Size and Community Traffic Flow: The Case for Lead Abatement in Minnesota," IN: Davies, B., and Wixson, B. (eds), Lead in Soil: Issues and Guidelines, Environmental Geochemistry and Health Monograph Series 4, Supplement to Volume 9 of *Environmental Geochemistry and Health*, Science Reviews Limited, Northwood, U.K. pp. 253-271 (1988).

Mielke, H., Adams, J., Huff, B., Pepersack, J., Reagan, P., Stoppel, D., and Mielke, P., "Dust Control as a Means of Reducing Inner-City Childhood Pb Exposure," Accepted for publication IN: Proc. XXV Annual Conference Trace Substances in Environmental Health, University of Missouri, Columbia (1991).

Motto, H., Daines, R., Chilko, D., and Motto, C., "Lead in Soils and Plants: Its Relationship to Traffic Volume and Proximity to Highways," Environ. Sci. & Technol. 4(3):231-237 (1970).

Murozumi, M., Chow, T., and Patterson, C., "Concentrations of Common Lead in Greenland Snows," IN: Marine Geochemistry, Proc. of Symposium, University of RI Occasional Publication No. 3, University of RI, Kingston, pp. 213-215 (1965).

Murrell, N., "Impact of Lead and Other Metallic Solders on Water Quality," Project Summary, EPA/600/S2-90/056, US EPA Risk Reduction Engineering Laboratory, Cincinnati, OH, February (1991).

Page, A., and Ganje, T., "Accumulations of Lead in Soils for Regions of High and Low Motor Vehicle Traffic Density," Environ. Sci. & Technol. 4(2):140-142 (1970).

Page, A., Ganje, T., and Joshi, M., "Lead Quantities in Plants, Soil, and Air near Some Major Highways in Southern California," Hilgardia (Journ. of Agricultural Science, California Agricultural Experiment Station) 41(1):1-31, July (1971).

Patterson, C., "Contaminated and Natural Lead Environments of Man," Arch. Environ. Health 11:344-360 (1965).

Peterson, J., A Study of Lead in Lake Sediments, Ph.D. Thesis, University of Wisconsin, Madison, Madison, WI, 247 pp. (1973).

Pitt, R., and Field, R., "Hazardous and Toxic Wastes Associated with Urban Stormwater Runoff," IN: Proc. Sixteenth Annual RREL Hazardous Waste Research Symposium, US EPA Office of Research and Development, EPA/600/9-90-037, pp. 274-289 (1990).

Reagan, P., and Mielke, H., "The Monetized Costs of Childhood Pb Exposure: An Estimate for Three Minnesota Cities," IN: Proc. XXIV Annual Conference Trace Substances in Environmental Health, University of Missouri, Columbia, Supplement to Vol. 13 (1991) of Environmental Geochemistry and Health, pp. 105-118 (1991).

Reynolds, S., Hadley, P., and Sedman, R., "A Health-Based Approach for Evaluating Soil at Depth Contaminated by Hazardous Waste: Utilizing the $AAL_{soil\ contact}$ Criterion," Risk Analysis 10(4):571-574 (1990).

RHWN (Rachel's Hazardous Waste News), "Lead--Part 1. A Hopeful New Year's Resolution for a Nation That Has Poisoned Its Children," RHWN No. 213, Environmental Research Foundation, Washington, D.C., December 26 (1990).

RHWN (Rachel's Hazardous Waste News), "Lead--Part 2. Learning from a National Scourge," RHWN No. 214, Environmental Research Foundation, Washington, D.C., January 3 (1991).

RHWN (Rachel's Hazardous Waste News), "Forty Years of Environmental Racism," RHWN No. 294, Environmental Research Foundation, Washington, D.C., July 15 (1992).

Sedman, R., "The Development of Applied Action Levels for Soil Contact: A Scenario for the Exposure of Humans to Soil in a Residential Setting," Environmental Health Perspectives 79:291-313 (1989).

SEGH (Society for Environmental Geochemistry and Health), Proc. Symposium on Bioavailability and Dietary Exposure of Lead, SEGH Monograph, 185 pp., Chemical Speciation and Bioavailability 3(3/4), December (1991).

SEGH (Society for Environmental Geochemistry and Health), International Conference on Lead and Other Trace Substances, August (1992).

Simms, D., "Lead in Soil: The Unanswered Questions," IN: Davies, B., and Wixson, B. (eds), Lead in Soil: Issues and Guidelines, Environmental Geochemistry and Health Monograph Series 4, Supplement to Volume 9 of *Environmental Geochemistry and Health*, Science Reviews Limited, Northwood, U.K. pp. 27-47 (1988).

Singer, M., and Hanson, L., "Lead Accumulation in Soils near Highways in the Twin Cities Metropolitan Area," Soil Sci. Soc. Amer. Proc. 33:152-153 (1969).

Stokes, P., "Lead in Soils: Canadian Case Studies and Perspectives," IN: Davies, B., and Wixson, B. (eds), Lead in Soil: Issues and Guidelines, Environmental Geochemistry and Health Monograph Series 4, Supplement to Volume 9 of *Environmental Geochemistry and Health*, Science Reviews Limited, Northwood, U.K. pp. 7-25 (1988).

US CPSC (US Consumer Product Safety Commission), "CPSC Warns about Hazards of 'Do-It-Yourself' Removal of Lead-Based Paint," Consumer Product Safety Alert, US Consumer Produce Safety Commission, Washington, D.C., US Gov't. Printing Office, Washington, D.C., 1 p. February (1989).

US CPSC (US Consumer Product Safety Commission), "What You Should Know about Lead-Based Paint in Your Home," Consumer Product Safety Alert, US Consumer Produce Safety Commission, Washington, D.C., US Gov't Printing Office, Washington, D.C., 4 pp. September (1990).

US DHHS (US Department of Health and Human Services, Public Health Service), "Draft Toxicological Profile for Lead," Prepared by Clement International Corp. for US DHHS Public Health Service Agency for Toxic Substances and Disease Registry, October (1991).

US EPA, "Quality Criteria for Water," EPA/400/9-76-023, US EPA, Washington, D.C., July (1976).

US EPA, "Ambient Water Quality Criteria for Lead - 1984," EPA 440/5-84-027, US EPA Office of Water Regulations and Standards, Criteria and Standards Division, Washington, D.C., January (1985).

US EPA, "Quality Criteria for Water 1986," EPA/44/5-86-001, US EPA Office of Water Regulations and Standards, Washington, D.C., May (1987).

US EPA, "Summary of Data on Municipal Solid Waste Landfill Leachate Characteristics," Draft Background Document, EPA/530-SW-88-038, US EPA Office of Solid Waste, July (1988).

US EPA, "Risk Assessment Guidance for Superfund, Volume 1, Human Health Evaluation Manual (Part A)," Interim Final Report, EPA/540/1-89-002, US EPA Office of Emergency and Remedial Response, Washington, D.C. (1989).

US EPA, "US EPA Strategy for Reducing Lead Exposures," US EPA, Washington, D.C., 39 pp., February 21 (1991a).

US EPA, "Drinking Water Regulations; Maximum Contaminant Level Goals and National Primary Drinking Water Regulations for Lead and Copper," Final Rule, 40 CFR Parts 141 and 142, Federal Register 56(110):26460-26564 June 7 (1991b).

US EPA, "Drinking Water Regulations; Maximum Contaminant Level Goals and National Primary Drinking Water Regulations for Lead and Copper," Final Rule; Correction, 40 CFR Parts 141 and 142, Federal Register 56(135):32113 July 15 (1991c).

US PHS (US Public Health Service), "Survey of Lead in the Atmosphere of Three Urban Communities," Public Health Service Publication No. 999-AP-12, US Gov't. Printing Office, Washington, D.C. (1965).

Waldman, S., "Lead and Your Kids," Newsweek, July 15 (1991).

Weis, C. and LaVelle, J., "Characteristics to Consider When Choosing an Animal Model for the Study of Lead Bioavailability," IN: Proc. Symposium on Bioavailability and Dietary Exposure of Lead, SEGH Monograph, Chemical Speciation and Bioavailability 3(3/4):113-119, December (1991).

Wixson, B., "Lead in Soil: Issues and Guidelines Conference Summary," IN: Proc. XXII Annual Conference on Trace Substances in Environmental Health, University of Missouri, Columbia, pp. 349-356 (1988).

Wixson, B., "Status Report on the Society for Environmental Geochemistry and Health Task Force on Lead in Soil," IN: Proc. XXIII Annual Conference on Trace Substances in Environmental Health, University of Missouri, Columbia, pp. 93-99 (1989).

Wixson, B., "The SEGH Task Force Approach to the Assessment of Lead in Soil," IN: Proc. XXIV Annual Conference on Trace Substances in Environmental Health, University of Missouri, Columbia, Supplement to Vol. 13 (1991) of Environmental Geochemistry and Health, pp. 11-20 (1991).

Wixson, B., and Davies, B., "Lead in Soil Guidelines," Presented at 25th Annual Conference on Trace Substances in Environmental Health, May (1991) in press for publication.

Young, S., "A National Recipe for Stupidity," Washington Post, Public Health Outposts, April 8 (1990).