Report on

Proposed Soil Lead Management Criteria as Part of Caltrans Highway Construction and Maintenance

Prepared for

California Department of Transportation
Environmental Program

Submitted to

Robert Bein, William Frost & Associates
Irvine, Ca

Prepared By

G. Fred Lee, PhD, DEE, G. Fred Lee & Associates
El Macero, Ca

Scott Taylor, PE, Robert Bein, William Frost and Associates
Irvine, CA

June 5, 1998

1.0 Executive Summary

Lead has accumulated in soils adjacent to highways above natural levels due to historic use of lead antiknock compounds in gasoline, the use of lead tire weights, lead in paint, and ambient levels of lead in crude oil/gasoline. Federal and state regulatory agencies have developed criteria and standards designed to protect public health and the environment from the potential hazards associated with elevated concentrations of lead in soil, drinking water and surface waters. This report presents a review of information related to regulating lead in near highway surface soils relative to the State Water Resources Control Board's proposed restrictions in the draft Caltrans Statewide Storm Water Permit.

1.1 Regulatory Approach

The US EPA RCRA regulations that govern wastes containing lead are directed to the disposal of the waste in a municipal landfill. The regulations are designed to protect ground water supplies from pollution by landfill leachate. The US EPA regulations specify a maximum concentration of lead that may be leached under specified conditions before the waste is classified as a hazardous waste. The US EPA Toxicity Characteristic Leaching Procedure (TCLP) for designation of a lead containing waste as a hazardous waste is based on a leachable lead concentration of 5 mg/L (5,000 µg/L). Leachable lead values at or above this level cause a waste to be classified as a hazardous waste. No hazardous waste threshold value is specified by the US EPA for total lead in soil. The US EPA does not have a drinking water Maximum Contaminant Level (MCL) criterion for lead, but does designate a drinking water "action" level of 15 µg/L. Concentrations of lead in drinking water above this amount are considered hazardous to children's health.

The California Department of Health Services (DHS) developed a hazardous waste classification system governing the deposition of waste in landfills that is more restrictive than the US EPA requirements. This system was codified in 1984 under Title 22 as the Waste Extraction Test (WET), and it determines the total leachable concentration of certain constituents such as lead in a waste. The WET Soluble Threshold Limiting Concentration (STLC) for lead is 5 mg/L (5,000 µg/L). The DHS limit for total lead as a hazardous waste is 1,000 mg/kg, known as the Total Threshold Limiting Concentration (TTLC). The California Environmental Protection Agency Department of Toxic Substances Control (DTSC) regulates hazardous wastes in California. In the early 1990's the regulatory authority for hazardous waste management in California was shifted to DTSC. The DTSC is currently revising the hazardous waste classification system under the Regulatory Structure Update (RSU). The proposed revisions include changing the TTLC and STLC for lead in waste soils, which would raise the TTLC to 6,000 mg/kg and eliminate the use of the STLC as a classification approach. The proposed revisions would also create a new special hazardous waste classification for lead of 1,000 mg/kg, based on potential impacts to earthworm reproduction. DTSC's proposed approach would allow the special waste to be placed in a municipal landfill.

1.2 Public Health Threat

Lead may be a public health threat in two primary ways: 1) through surface water contamination of domestic water supplies above the US EPA "action level," and 2) through accumulation in soils to a level that could cause harm through ingestion by children or absorption by pregnant women, to an unborn child. For the purposes of using near highway soils as "clean fill" in highway construction, it is proposed that "clean" soil may be broadly defined as soil with a total lead concentration of 400 mg/kg or less based on US EPA guidance relative to unrestricted soil contact by children.

It is rare that the lead level in the source water for a domestic water supply is a problem in instances when excessive lead has been found at a residential or commercial use service point. Dissolved lead at the consumer level is primarily derived from lead pipes, lead solder used in connections of copper pipe, and lead in plumbing fixtures or pumps. Lead in wastes can be a source of groundwater pollution at significant distances from the source in relatively rare cases. Typically, lead in most aquifer systems is either precipitated or sorbed to the aquifer solids, and, therefore, its transport from a source is normally limited. The types of situations of particular concern for long distance transport of lead polluted groundwaters are those associated with cavernous limestone or fractured rock aquifer systems.

Lead may also be a threat to children who ingest soil containing lead, or to unborn children if sufficient lead is absorbed by the mother to cause elevated blood lead concentrations in the fetus. The US EPA has determined that Superfund site soils containing total lead above about 700 mg/kg to 1,500 mg/kg may be a hazard to unborn children if sufficient quantities are dispersed in a residential area where the lead is carried into a home through tracking or airborne dust.

The DTSC has issued variances to Caltrans governing the use of near highway surface soils as construction fill in new or redeveloped/maintained highways. Soils containing lead (meeting the current TTLC threshold of 1,000 mg/kg) may be buried in the fill with a protective soil cover. This provision is designed to protect public health and the environment to eliminate significant surface water or dust borne transport of surface soil lead from new or reconstructed highways. Also, the existing DI WET (distilled water) leachable lead value of 500 µg/L contained within the existing variances is designed to protect groundwater quality.

With respect to storm water runoff water quality impacts, based on recent monitoring data, runoff from Caltrans highways may exceed US EPA worst case based water quality criteria for the protection of aquatic life from lead toxicity. However, reducing highway shoulder surface soil total lead values below 1,575 mg/kg is not required to protect aquatic life, since lead in highway storm water runoff is primarily controlled by constituents derived from the paved surface.

Lead concentrations in storm water runoff have fallen dramatically since the early 1970's when the use of lead as an additive to gasoline began to be discontinued. However, the lead concentrations in highway storm water runoff have become relatively constant during the last decade.

1.3 Summary of Soil Testing Information

In the spring of 1998, Caltrans undertook a study to determine the lead content and other characteristics of near highway surface soils. Kinnetic Laboratories, Inc. (KLI, 1998a) took core samples at 68 locations throughout the state. The average total lead concentration of the 68 samples was 131 mg/kg, with the average value for the top 6 inches of soil at 252 mg/kg. This data is consistent with the expectation that soils adjacent to highways contain elevated concentrations of lead. Average surface soils in California contain about 30 mg/kg of total lead.

The KLI data show that about 4% (three cores) exceeded a total lead value of 1,575 mg/kg. Further, only two cores (as an average over 2 feet of depth) exceeded the US EPA TCLP hazardous wastes threshold of 5 mg/L. About 10 cores or 15% exceeded the DI WET value of 500 µg/L.

The KLI data show that high total lead does not correlate with high DI WET dissolved lead. There is also no clear relationship between leached dissolved lead and total hardness or total organic carbon (TOC).

A study of the variability of total lead and leachable lead in near highway surface soils shows that the coefficient of variation (standard deviation divided by the mean times 100) is typically 60% to 90% for samples taken near each other, or in a typical construction site work area covering about 750 feet along an existing highway by 20 feet wide. These results indicate that there is moderate variability in the concentrations of total lead and leachable lead in near highway surface soils.

1.4 Permit Issues

A detailed set of requirements relative to the handling of soils containing lead is included in the draft Caltrans storm water permit. Several of the SWRCB draft permit language requirements are not consistent with the recent data collected by Caltrans and other investigators. Given the leaching characteristics of near highway surface soils, the US EPA TCLP threshold of 5 mg/L of leachable lead using the DI WET procedure would not be expected to be attained. The DI WET testing of Caltrans highway surface soils has been found to leach less than the US EPA allowed 5 mg/L for TCLP extractable lead, which governs the placement of waste containing lead in a municipal landfill. The placement of near highway surface soil in a construction fill typically represents less of a threat to groundwater than many municipal solid waste landfills. This is due to the limited areas of groundwater that could be impacted by leaching lead from the highway fill that could impact a domestic water supply, as compared to many municipal landfills. The appropriate DI WET extractable lead threshold value should be established as 5 mg/L. This value would be protective of ground water quality at all but those situations where the highway construction fill is underlain by cavernous limestone or fractured rock aquifer systems.

Further, a review of a significant number of near highway surface soil investigations shows that there is no relationship between soil pH and the DI WET leachable lead. Use of soil pH to a value lower than about a pH 4.5 is not a valid criterion for restricting the placement of soils containing lead in highway construction fill. Neither is there technical justification for a DI WET criterion of 150 µg/L governing the placement of near highway surface soils in construction fill. The current DTSC variance value of 500 µg/L DI WET leachable lead is protective of groundwater resources and is conservative compared to the US EPA TCLP criteria for leachable lead from wastes. The SWRCB should defer the Caltrans statewide storm water permit conditions to the existing DTSC variance for the regulations governing the use of near highway surface soils containing lead in highway construction fill for the interim time period during which DTSC promulgates new hazardous waste management criteria.

Table of Contents

Table of Figures

2.0 Introduction

On April 22, 1998, the State Water Resources Control Board (SWRCB) issued a draft Caltrans permit "National Pollutant Discharge Elimination System (NPDES) Permit State Wide Storm Water Permit and Waste Discharge Requirements for the State of California, Department of Transportation." This draft permit establishes special requirements for Caltrans associated with "Construction Program Management" which requires that 30 days prior to advertisement for bids, Caltrans shall notify the appropriate Regional Board of the proposed project in order that the Board may determine "*...the need for development of a lead soils management plan described in provision H.5.w.*" Section H.5. sets forth several requirements that govern situations where Caltrans may disturb and reuse soil containing lead in construction projects. These requirements include:

- "Material exceeding the following criteria may not be reused in Caltrans construction projects and must be transported and disposed of in accordance with applicable state and/or federal requirements, including hazardous waste requirements.

- *"a. Soils containing more than 150 µg/l and less than 500 µg/l* [DI water] *extractable lead..."* may be used as construction fill under certain prescribed conditions, providing the total lead concentration does not exceed 1,575 mg/kg. Note: DI water is deionized water ("distilled water").

  "b. Soils containing more than 500 µg/l but less than 50 mg/l [DI water] *extractable lead…" "…or more than 1575 mg/kg total lead but less than 4150 mg/kg total lead..." may be used as construction fill provided that the fill is located under a pavement structure.*

  "c. Soils containing lead with a pH less than 6.0 may only be used as fill under a pavement structure..."

The draft permit contains several pages of conditions, or BMPs, that Caltrans must satisfy in order to use soils containing lead under the above-listed restrictions as construction fill.

2.1 Report Organization

This report is organized into six primary sections: 1) executive summary, 2) introduction, 3) review of criteria for soils containing lead and their classifications, 4) discussion of lead as a pollutant, including the regulation of lead as it relates to soils as wastes and near highway surface; 5) discussion of the recommended approach for regulation of soils containing lead; and 6) discussion of the water quality characteristics of Caltrans storm water runoff with respect to lead.

2.2 Background

The historic use of lead as an antiknock gasoline additive coupled with use of lead tire weights and lead-based paint has caused surface soils near highways to contain elevated concentrations of lead. Some near highway surface soils contain lead at sufficient concentrations to represent a potential threat to public health and the environment through toxicity to humans, aquatic life and wildlife. Federal and state regulatory agencies have developed criteria, standards, and guidelines designed to protect public health and the environment from the potential hazards associated with elevated concentrations of lead in soil, drinking water and surface waters. Elevated lead may impact the use of an area and aquatic life related beneficial uses of waterbodies. There are four areas of concern with respect to managing soils containing lead near highways. These include:

- The ingestion of the soil by children who could increase their blood lead levels sufficiently to be a health hazard.

- The exposure of adults to elevated concentrations of soil lead that cause increased blood lead levels in unborn children. Exposure associated with working in contact with the soils, or through inhalation/ingestion of dust particles containing lead.

- The transport of lead in the soils to surface waters, where the lead would be a threat to the use of these waters for domestic water supply or aquatic life propagation.

- The leaching of lead to a groundwater aquifer by infiltration from precipitation that is used or could be used for domestic water supply purposes; or that is a threat to aquatic life where the lead contained in groundwater enters surface water systems.

A discussion of the key issues to consider in controlling the hazards posed by near highway surface soil lead to public health and the environment associated with highway construction and/or maintenance is presented below. Lee and Jones (1982a) reviewed issues related to constituents leaching from highway soil fill for the National Research Council Transportation Research Board. The discussions presented herein represent a synthesis of their work, as well as that of others, pertinent to this topic.

3.0 Regulatory Approach to Managing Soils Containing Lead

Both the US EPA and the California Department of Toxic Substances Control (DTSC) have developed regulatory approaches for managing lead in soils that become waste. Those approaches, relative to the SWRCB proposed soil lead management restrictions in the Caltrans statewide storm water permit, are discussed below.

US EPA Regulatory Approach. As part of implementing the Resource Conservation and Recovery Act (RCRA), the US EPA has developed regulations governing the management of wastes containing lead with respect to their disposal in a municipal landfill (US EPA Subtitle D and California Class III) or a hazardous waste landfill (US EPA Subtitle C and California Class I). These regulations focus on the leaching character of the lead from the waste under conditions that are designed to simulate, to some degree, the environment of a municipal landfill. A dilute acetic acid solution is used to leach the waste. This solution is assumed to be similar to the leaching characteristics of municipal landfill leachate. This leaching procedure, originally called EP Tox test, has become the US EPA's Toxicity Characteristic Leaching Procedure (TCLP) leaching test. If the lead leached under the conditions of this test exceeds 5 mg/L, the waste is classified as a hazardous waste, cannot be placed in a municipal landfill, and must be deposited in a hazardous waste landfill.

The 5 mg/L maximum leachable lead concentration allowed in the TCLP test is derived from the former 50 µg/L lead drinking water action level and a 100-fold attenuation/dilution factor. It was assumed by the US EPA that when waste containing lead is placed in a municipal landfill, the leachate leaving the landfill would be attenuated by the soil base of the landfill and diluted by the groundwater aquifer. The attenuation/dilution factor of 100 should account for the movement of lead from the point where the leachate leaves the landfill, and enters the groundwater system, until the groundwater containing lead would be consumed as part of a groundwater-based domestic water supply. For most situations, the attenuation/dilution factor of 100 is overprotective.

There are limited situations, however, where the factor of 100 may not be protective, especially situations associated with landfills overlying fractured rock or cavernous limestone aquifer systems. Under these conditions, it is possible that landfill leachate with lead concentrations of 5 mg/L could pollute a nearby domestic water supply well with lead above the drinking water action level.

The US EPA has not promulgated a maximum contaminant level (MCL) for lead. The drinking water "standard" for lead has always been based on an "action level" which, for all practical purposes, is implemented the same as an MCL. Several years ago the US EPA promulgated a new lead drinking water action level of 15 µg/L. The US EPA, however, did not change the maximum allowable TCLP leachable lead to 1.5 mg/L, which is the value that would be derived from the 100-fold attenuation/dilution factor. The Agency has maintained the allowable TCLP leachable lead at 5 mg/L. The US EPA is allowing a much larger attenuation factor in classifying a waste containing lead as a hazardous waste than it uses for other constituents regulated by the TCLP. With few exceptions as noted above, this approach is highly protective of groundwater-based water supplies, as well as those situations where the groundwater becomes part of a surface water system.

Department of Health Services/Department of Toxic Substances Control. In the early 1980's the Department of Health Services (DHS) developed a California-only hazardous waste classification approach in which citric acid was used in a TCLP-like leaching procedure rather than acetic acid as the leaching solution. The California hazardous waste leaching test was promulgated in 1984 under Title 22 as the Waste Extraction Test (WET). DHS has continued to use the US EPA's hundred-fold attenuation/dilution factor, as the amount of allowable leaching for characterizing waste with respect to its deposition in a municipal landfill versus a hazardous waste landfill. For lead, the Soluble Threshold Limiting Concentration (STLC) was established as 5 mg/L.

Recently, DTSC has proposed to drop the WET procedure in favor of the TCLP test for classifying waste as hazardous waste in California. This DTSC Regulatory Structure Update (RSU) is part of an over two-year effort devoted to revisions of the approach used to classify hazardous waste. Under this proposal, California will follow the approach of all other states, and only use the TCLP test to determine whether a waste containing lead or other regulated constituents can be placed in a municipal landfill versus a hazardous waste landfill.

The DTSC proposed revised hazardous waste classification is currently under review. DTSC recently issued a call for comments on the scope of an EIR devoted to the revisions of the hazardous waste classification approach that leads to a California-only hazardous waste stream. On May 18, 1998, DTSC announced that it is significantly revising the proposed hazardous waste classification approach project and would issue a new call for comments on the scope of the EIR for the revised project. The scope is expected to be revised in June 1998. If adopted, the revised classification approach should be in place in February 1999. However, significant and controversial changes in approach are expected.

In 1984, DHS adopted a total lead hazardous waste classification of 1,000 mg/kg as the Total Threshold Limiting Concentration (TTLC). The DTSC, as part of the RSU, has reviewed this value and concluded that it can be raised to 6,000 mg/kg and still be protective. The US EPA has not adopted a total lead content of waste as a basis for determining whether a waste containing lead can be placed in a municipal landfill. The current US EPA requirements are still based on the 5 mg/L concentration for TCLP leachable lead.

As part of the RSU, DTSC has proposed a revised approach for defining a California hazardous waste. In this revised approach, "ecological" considerations are incorporated into the originally proposed definition in which a total lead concentration above 700 mg/kg would cause a waste to be classified as a "special" hazardous waste. DTSC proposes that special hazardous waste can be placed in a municipal landfill provided that the municipal landfill owner obtains a change in its waste discharge requirements from its Regional Board that allows hazardous waste in a Class III landfill. DTSC has proposed that this special hazardous waste classification would be such that once a special hazardous waste is placed in a municipal landfill, it is no longer classified as a hazardous waste.

There is considerable uncertainty as to whether this approach is workable because of the additional administrative burden associated with obtaining revised waste discharge requirements, and the potential for significant public opposition to allowing a "hazardous" waste to be placed in a municipal landfill. Many of the current municipal landfill owners indicated, as part of the permitting of the landfill, that no hazardous waste would be deposited in the landfill. It could be difficult for municipal landfill operators to reverse their previous position as DTSC has proposed. The net result is that the special hazardous waste may have to be managed as a regular hazardous waste where it is deposited in a hazardous waste landfill, rather than in a municipal landfill as proposed by DTSC. The difference in cost is about \$300 to \$400/yd^3 of waste.

The DTSC proposed 700 mg/kg total lead special hazardous waste classification is based on the potential impact of soil containing lead on earthworm reproduction. Based on limited studies conducted in the Netherlands using synthetic soils with 100 percent toxic/available forms of lead added to these soils, it was found that earthworm reproduction was impaired at lead concentrations above about 500 mg/kg. DTSC initially adjusted the 500 mg/kg to 700 mg/kg. Recently DTSC has adjusted the 700 mg/kg to 1,000 mg/kg as the critical concentration of total lead in a waste that would cause the waste to be classified as a special hazardous waste.

There is considerable controversy about the appropriateness of DTSC using the impairment of earthworm reproduction as a basis for establishing a special hazardous waste classification. Further, the appropriateness of using the limited Dutch studies as the basis for establishing a hazardous waste classification in California is being seriously questioned. In addition, numerous studies have shown that lead in soils derived from leaded gasoline residues is largely inert, i.e. in a nontoxic, non-available form under normal environmental conditions. The fact that the Dutch studies used toxic/available forms of lead in the synthetic soil studies could cause these studies to significantly overestimate the toxicity of lead derived from gasoline residues to earthworms.

The DHS (1984) Statement of Reasons covering the proposed adoption of the provisions that generated a California-only hazardous waste stream, that led to the 1,000 mg/kg TTLC total lead hazardous waste classification value, indicates that *"the TTLC level for lead is 20 times lower than the recommended 'highly contaminated' level,"* based on a DHS 1979 study. Concern was expressed about the potential impact of lead on children's health. At that time there was limited understanding of the relationship between lead concentrations in soils and adverse impacts on children who play on these contaminated soils. As discussed in Section 4, there is considerable new information available today on the threat that lead in soils represents to children's health. The DTSC is proposing that the current 1,000 mg/kg total lead hazardous waste classification be continued despite the shift in purpose from protecting children from exposure to lead to protecting earthworm reproduction. The proposed revised approach for implementing this hazardous waste classification is through the management of a special hazardous waste in a municipal landfill.

In summary, there is a normally conservative, well-established federal procedure (TCLP) for determining whether a waste containing lead may be placed in a municipal versus hazardous waste landfill. However, the California hazardous waste classification approach is in a state of considerable uncertainty. There are significant pressures and justifications for DTSC to abandon the development of California-only hazardous waste, including its newly-proposed special hazardous waste, in favor of using the same approach as other states of classifying waste as hazardous waste based on the federal procedure. The uncertainty as to the future of California's approach for classifying waste as a hazardous waste is of considerable importance to SWRCB's development of a Caltrans statewide storm water permit which significantly restricts how Caltrans can use soils containing lead as construction fill.

4.0 Lead as a Pollutant

This section discusses lead as a domestic water supply pollutant, the hazards of lead if ingested by children, the protection of groundwater quality and the potential for surface water pollution by lead. The appropriateness of the existing DTSC variance relative to these issues is also discussed.

4.1 Lead as a Domestic Water Supply Pollutant

Lead is a well-known pollutant in domestic water supplies. Lead at the faucet is primarily derived from the use of lead pipe, lead solder used in connecting copper pipe, lead in the faucet metal, or in some cases, lead in a groundwater well pump. It is rare that the source of the excessive lead in the water at a residential faucet is the source water for the water supply. While there are examples of groundwater being polluted by lead, such as near Superfund sites, rarely does this pollution extend for considerable distances from the site. This is because lead readily precipitates out of solution. This is particularly true in calcareous (limestone-hard water) areas. Further, lead tends to sorb (attach) to aquifer solids, significantly limiting its mobility compared to conservative/non-reactive constituents such as sodium and chloride. Therefore, while leachate plumes near landfills may extend for considerable distances for conservative chemicals, rarely does the lead move for any significant distance down gradient.

Geological areas of particular concern for lead and other constituent pollution in groundwater are aquifer systems that are composed of fractured rock and/or cavernous limestone. Even cavernous limestone areas would tend to remove lead through precipitation reactions, and thereby reduce its mobility compared to conservative/non-reactive chemicals. There are, however, fractured rock aquifer systems where there could be limited removal of lead by physical/chemical reactions compared to the removal that would occur in a sand, silt, or clay aquifer system.

In addition to the physical/chemical reactions that limit the mobility of lead in most groundwater systems, there is also significant lateral and vertical dilution due to dispersion of the lead in the landfill leachate or percolate water as it enters the groundwater system. Further, dilution can occur due to the addition of waters arising from the percolation of precipitation along the plume path. The dilution that occurs along the plume path limits the distance lead can travel

Another factor that often significantly reduces the concentration of lead pumped from a groundwater plume is that most water supply wells are screened to intercept much greater vertical distances of an aquifer than would typically be associated with a leachate or percolate derived plume near the origin of the plume. Near the plume origin, the typical water supply well would also pump low lead waters that would underlie the plume, thereby diluting the lead concentration that is received at the pump discharge point. At some distance from the plume origin, the lead concentration would be significantly reduced due to physical/chemical reactions and dilution/dispersion.

In summary, lead has been found to be a pollutant impairing the use of groundwater for domestic water supply purposes because of the health hazard it represents to children near the pollutant source. Despite this fact, it is highly unusual that the elevated lead present in groundwater near a pollution source is transported for any considerable distance at concentrations above drinking water action levels.

4.2 Prevention of Soil Lead Ingestion

The accumulation of lead residues in areas where children could be exposed to the soils containing lead represents a health hazard to children through the possible ingestion of the soil and resultant increased blood lead levels.

Soil Lead as a Threat to Children. Lee and Jones-Lee (1992, 1997), have discussed the current information on the threat that lead in soils represents to children's health. The US EPA (1994) concluded that soil lead concentrations below 400 mg/kg are not a threat to the health of children who play in these soils. The Agency further recommended that for soils with concentrations of total lead between 400 and 2,000 mg/kg, restrictions should be implemented to reduce children's exposure to the bare soil. Above 2,000 mg/kg soil lead, the US EPA recommends that a public notice of lead contaminated soils should be issued and the conditions should be monitored. The Agency also recommended that interim controls to reduce children's access to the lead contaminated soils be implemented. Above 5,000 mg/kg, the US EPA recommended the removal and replacement of the soils or the establishment of permanent barriers to prevent children's access to them.

Based on this information, there is a small potential for lead contaminated surface soils associated with highway construction/maintenance to be a threat to children's health. This would occur through airborne dust or waterborne erosion transport of particulate soil lead from the highway shoulder area to areas where children would have access to the soil. It would be unusual, however, for such transport mechanisms to lead to soil lead concentrations in children's play areas that would exceed the US EPA's 1994 guidance for the protection of children's health. This assessment is premised on Caltrans or other agencies not transporting near highway surface soils containing lead above 400 mg/kg to areas where children would play in contact with these soils.

Lead as a Threat to Unborn Children. A new area of concern in managing near highway surface soils during construction and maintenance is a potential for airborne transport of the soil containing elevated lead to residential areas. The US EPA (1996) has reported on an interim approach for assessing the risks associated with adult exposure to lead in soil. The Agency has concluded that when lead above about 700 to 1,500 mg/kg is present in soils that enter a home, either through dust or foot traffic, there is a risk to the fetuses of pregnant women. Pregnant women could absorb sufficient lead which would cause, through placental transfer, the blood lead levels of the fetus to be elevated above hazardous levels. This issue was not considered by DTSC in establishing its revised recommended hazardous waste classification approach for lead.

Limiting the surface soil lead in residential areas to the 700 to 1,500 mg/kg range is being recommended at US EPA Superfund sites where lead contamination is of concern. This approach is not being used in other areas. There are questions about whether the form of lead, such as associated with lead mining/smelting upon which this information is based, is in the same form as the soil lead derived from leaded gasoline. They are likely to be in significantly different forms and therefore their availability for absorption through ingestion or inhalation could be influenced.

Regulation of Near Highway Surface Soil Lead. The SWRCB proposed Caltrans statewide storm water NPDES permit places additional restrictions on the reuse of surface soils in highway construction. These restrictions are based on the total concentration of lead as well as the deionized water leachable amount of lead present in the soils beyond those set forth by the US EPA and the Cal EPA DTSC. The draft Caltrans statewide storm water permit allows soils containing lead with total lead less than 1,575 mg/kg to be used as construction fill. However, at least a clean soil cover of one to two foot thickness, depending on the slope of the surface soil, must be maintained above the soils containing lead in the constructed roadway.

The draft permit allows soils containing lead with up to 4,150 mg/kg total lead to be used as construction fill provided that soils above 1,575 mg/kg are located under a pavement structure. These provisions are, for practical purposes, equivalent to the existing DTSC variances granted to Caltrans. The proposed conditions for the use of near highway surface soils as construction fill, where the elevated lead soil is to be covered and maintained, should eliminate surface water or dustborne transport of soil lead from the new highway/reconstructed area to areas where children and/or pregnant women would be exposed. The existing variance, or the proposed SWRCB restrictions on controlling the wash-off or windblown transport of any stockpiles of surface soils containing elevated lead, is appropriate to protect the children that play in the soils and unborn children exposed to elevated lead.

It is concluded that near highway soil lead with concentrations above approximately 1,575 mg/kg can, and where possible should, be used as construction fill where there will be at least one foot of clean soil maintained above the fill area. While the 1,575 mg/kg is above what could be hazardous levels for children or fetuses, the likelihood of these soils being transported from the highway and accumulating hazardous levels of lead in the surface soils of children-accessible areas is remote. Therefore, requiring the use of near highway surface soils with concentrations of lead above 1,575 mg/kg as construction fill is appropriate.

4.3 Protection of Groundwater Quality

The primary thrust of the SWRCB proposed Caltrans statewide NPDES permit soil lead restrictions is directed toward preventing the pollution of groundwater. The issue is therefore one of determining whether the existing variance value is protective of groundwater. At this time Caltrans has been unable to review the rationale for the 150 µg/L DI water soluble lead criterion. This is the basis for determining that a near highway soil containing lead must be buried in the fill below at least one foot of clean fill. The 150 µg/L value is ten times the US EPA's 15 µg/L drinking water action level for lead. This is a ten-fold attenuation/dilution factor to protect groundwater from receiving excessive lead, compared to the drinking water action level. As with municipal landfills, it would be indeed rare, if ever, that there would only be a ten-fold decrease in the concentration of lead from where water percolating through highway fill enters an aquifer until the groundwater is used for domestic water supply purposes. The only types of geologic area where this low an attenuation/dilution factor might possibly be justified, would be a fractured rock or cavernous limestone area in which domestic water supply wells obtain water from the fractures or solution pathways that are primarily fed by the percolate through the fill.

Percolation associated with highway fill is significantly different than percolation associated with municipal landfills, in terms of the potential area of underlying groundwater that could be impacted by leachate/percolation that could in turn impact a domestic water supply well. Landfills can be hundreds of acres in size where the leachate leaving the landfill can and sometimes does contain 0.5 mg/L (500 μg/L) of lead that is derived from the waste placed in the landfill (Jones-Lee and Lee, 1993; and Lee and Jones-Lee 1998). This situation can lead to the potential for contaminating a large number of fractures with lead concentrations that are excessive when compared with drinking water action levels. However, for highway fill, only a small part of the total fill would typically contain the elevated lead derived from the near highway surface soils. There is little possibility that the pockets of fill could contribute lead at sufficient concentrations as the percolate enters the fractures, and to a sufficient areal extent, to cause a municipal or homeowner's well in a fractured bedrock system to exceed the drinking water action level.

It is concluded that, except for areas as noted above, use of the 150 μg/L DI water leachable lead concentration in near highway soils is overprotective. The existing DTSC variance value of 500 μg/L DI water leachable lead is protective of groundwater quality associated with the use of lead-containing soils for highway construction.

The basic issue that needs to be addressed is what is an acceptable amount of DI water leachable lead that would be generally protective of groundwater quality, associated with the use of near highway soils containing lead in highway construction fill. In order to establish this value, it is necessary to consider the hydrogeologic characteristics of the area underlying the construction area. Areas that are composed of sand, silt, or clays can have much larger DI water leachable concentrations than areas that are underlain by fractured rock or cavernous limestone aquifer systems.

In the mid 1980s, the US EPA, as part of promulgating the revisions to the former EP Tox test (current TCLP test), proposed that a site-specific hazard evaluation be used to determine the allowable attenuation/dilution factor that would be protective of a domestic water supply well. This approach would consider the hydrogeology of the area, as well as the aqueous environmental chemistry of the constituents of concern in the aquifer system of concern. This approach is similar to that recommended by Lee and Jones (1981, 1982b), where a site-specific hazard assessment is conducted to determine whether the leaching of a constituent from waste represents a potential threat to public health and/or the environment. The alternative to this approach is that used by the US EPA and DTSC of assuming that an attenuation/dilution factor of 100 is applicable to all landfill sites.

The US EPA, as part of promulgating the TCLP, abandoned the site-specific approach in favor of the administratively simpler method of assuming an attenuation/dilution factor of 100 for all sites. For most situations, this can represent an unnecessary financial burden to the public. However, it may not be protective for landfills located above certain types of geological strata.

The SWRCB staff have proposed that soils containing between 500 µg/L and 50 mg/L of DI water leachable lead can be used as fill, provided that the fill is located under a Caltrans maintained pavement structure. The purpose of this requirement is apparently to restrict moisture from interacting with the soil and thereby leaching lead from it. Based on the information available, it is unlikely that near highway soil lead would be leachable to a value approaching 50 mg/L. However, it is possible, based on the information available (see discussion presented below), that some near highway soil lead could be DI water leachable to about 5 mg/L (5,000 µg/L) and still be protective of groundwater.

The basic question becomes one of whether there is need for Caltrans to restrict the deposition of near highway surface soils with a DI water leachable lead concentration of greater than 500 µg/L to areas under pavement. There is need to evaluate whether an attenuation/dilution factor of 330 would not be adequate to dilute - attenuate lead leached from near highway soils when placed in highway construction fill under conditions where percolation of precipitation could contact the elevated fill containing lead. The 330 value is based on the assumption that the maximum DI water leachable lead is 5 mg/L (5,000 µg/L) and the drinking water action level is 15 µg/L. From the information available, it appears that an attenuation/dilution factor of 330 would be protective in most situations, except possibly where fractured bedrock and/or cavernous limestone underlies the highway construction fill area.

The US EPA concluded, as part of promulgating the TCLP, that an attenuation/dilution factor of 330 is protective from landfill derived lead in municipal solid waste leachate. The characteristics of municipal solid waste leachate would tend to promote the transport of lead in aquifer systems to a greater extent through complexation and colloid transport than would occur in the leaching of near highway soil lead present in highway fill. The potential of lead leaching from highway fill soil would generally represent significantly less threat to cause groundwater pollution than from a large municipal landfill. Therefore, it is not necessary for Caltrans to restrict the placement of soils containing lead with DI water leachable lead above 500 µg/L to areas under a pavement structure in order to protect groundwater quality except as noted. The same restrictions placed on the use as soils with DI water leachable lead above 150 µg/L should apply to both municipal landfill and near highway sites, i.e. it should be allowable to place soils containing lead in areas where percolating precipitation could interact with these soils.

Based on the data recently developed by Kinnetic Laboratories Inc. (KLI) (1998a) for Caltrans, there is no technical need for continuing the use of the DI water leaching procedure to determine whether a near highway surface soil needs to be restricted in its reuse as highway construction fill if the recommended 1,575 mg/kg total lead value is used as the cutoff point above which the soil needs to be covered with at least one foot of clean soil. In the highway soil lead leaching studies that Caltrans has recently completed, none of the soils leached lead greater than 5 mg/L using the DI water procedure. Therefore, except where fractured rock or cavernous limestone underlies the highway construction area, the DI water leaching procedure is not necessary to protect public health or the environment. This conclusion assumes that all near highway surface soils with a concentration of total lead greater than 1,575 mg/kg will be buried under at least one foot of clean soil when reused in highway construction or maintenance activities.

Currently, soils containing lead are regulated by DTSC as a hazardous waste, based in part on the WET procedure where, if the citric acid leachable lead exceeds 5 mg/L, the soil must be placed in a hazardous waste landfill. DTSC, as part of the RSU, has recommended that the WET procedure no longer be used. If this recommendation is adopted, California will assume the same approach as the other states of defining a hazardous waste based on the US EPA TCLP criteria. A review of the KLI (1998a) data shows that only two (less than 3%) of the near highway soil samples tested had concentrations of TCLP leachable lead above the 5 mg/L limit. Therefore, adopting the recommended approach of limiting the total lead in the surface soils after highway construction/maintenance to less than 1,575 mg/kg would, in general, not leave a hazardous waste on the surface based on the US EPA TCLP definition.

Since there are few near highway surface soils that have concentrations of total lead above 1,575 mg/kg, Caltrans, as part of highway construction and maintenance, can proceed with using the surface soils from areas where there was an existing highway without making special provisions for their burial as construction fill. Only in those areas where the near highway surface soil lead exceeds 1,575 mg/kg, should Caltrans need to take special precautions in managing the near highway surface soils as part of highway construction or maintenance activities. However, Caltrans must identify the underlying geology of the project site to determine if fractured rock or cavernous limestone is present. Information of this type is available in the project geotechnical evaluation. In cases where these formations are found, soils containing lead above a TCLP value of 5 mg/L should not be used on the site.

Groundwater Table Position Restriction. The SWRCB has proposed to limit the placement of soils containing lead to five feet above the highest groundwater table. This value is similar to the requirements set forth in the US EPA Subtitle D regulations and the SWRCB Chapter 15 regulations governing the landfilling of municipal solid wastes. The purpose of this requirement is to prevent groundwater from entering the landfill and thereby serving as an additional source of moisture which would generate additional leachate over that which would be generated by percolation of precipitation through the cover of the landfill. For “dry tomb” type landfills, siting a landfill so that the bottom of the wastes are at least five feet above the highest water table is an appropriate approach for minimizing leachate generation.

Highway construction normally takes place in areas where the groundwater table is well below the bottom of the construction, where elevated lead soil fill could be placed in accord with SWRCB proposed restrictions. However, there are some areas of California where shallow water tables could restrict placing elevated lead soil fill near the bottom of the excavation based on the proposed permit requirements and the current DTSC variance. It would be desirable to use any surface soil fill with elevated lead as fill independent of the position of the groundwater table. It is concluded, based on the leaching characteristics of near highway soil lead, that placing soil with elevated lead above or below the water table will not significantly change the *de minimus* threat that the leachable lead from this soil represents to the public health or the environment.

While the SWRCB and the DTSC can remove the restriction on the placement of near highway surface soils containing elevated lead relative to the position of the groundwater table and still be protective of groundwater quality, for now Caltrans will conform to the existing variance requirements of placing all reused near highway surface soils above the groundwater table in construction fill until this matter can be further reviewed by DTSC.

pH 6.0 Restriction. The SWRCB proposed that elevated soils containing lead with a soil pH of less than 6.0 used as construction fill must be placed under a pavement structure. The DTSC variance provides this restriction for soils with a pH of less than 5.0. The purpose of these requirements seems to be to restrict moisture contact with the acidic soils containing lead. Examination of the KLI (1998a) data on the characteristics of near Caltrans highway surface soils shows that 16 samples of the 262 soil samples analyzed had a pH of less than 6.0. Four of these samples had a pH of less than 5.0. Similarly, the data developed by Geocon (1997/1998) showed that nine of the soil samples taken near a California highway had a pH of less than 6.0. Examination of the two data sets shows that there is no relationship between soil pH and DI water leachable lead. pH in the range found, i.e. greater than 4.0, is not a dominant factor in controlling lead released from near Caltrans highway soils.

These results are similar to those reported by Legiec (1997) who found that the leaching of lead from soils where the lead was primarily derived from its former use as a gasoline additive was essentially independent of pH for soils above pH 5.0 and below pH 11.0. Serrano-Belles and Laharne (1997) found that the leaching of lead from near highway soils was dependent on the buffer capacity of the soil. When the soil pH was less than about 4.0, the lead was readily leachable. Van Benschoten *et al*. (1997) concluded from a study of soil washing of several lead contaminated soils, that a pH of 3.0 was necessary to solubilize appreciable lead. Howard and Sova (1993) found similar results, but also concluded that sodium chloride used for deicing tended to promote lead leaching. Soil pH in the range of 4.0 or less did tend to leach greater lead from these type of soils. It is concluded that near highway soil pH less than 6.0 be removed as a criterion for determining the placement of elevated soils containing lead in highway construction fill.

4.4 Potential Surface Water Pollution

An issue that needs to be considered is whether leaving soils with a total lead concentration up to the recommended 1,575 mg/kg criterion at the surface after highway construction could represent a significant threat to domestic surface water supplies or aquatic life. This is the same problem that exists now throughout the country where soils near highways and urban streets contain elevated concentrations of lead that have been primarily derived from the former use of lead as a gasoline additive. Studies conducted throughout the US have shown that the lead concentration in highway and urban street storm water runoff exceeds US EPA water quality criteria of about 1 to 5 µg/L for potential impacts to aquatic life through toxicity

(Lee and Jones 1991) (Barrett, 1995). Therefore, under the worst case conditions for which the criteria were developed to be protective, there is a potential for lead in storm water runoff from highways to cause adverse impacts to aquatic life in essentially undiluted storm water runoff. Ordinarily, however, storm water runoff from highways which contains elevated lead in the runoff waters is significantly diluted with low lead waters in the receiving waters for the runoff. It is indeed rare that the principle source of water to a waterbody for which there is aquatic life is from highway area runoff.

The US EPA (1997) Region 9 has recommended, as part of implementing the California Toxics Rule, that lead be regulated based on its dissolved form in ambient waters. There is, however, concern by the US Department of Interior Fish and Wildlife Service and the US Department of Commerce National Marine Fishery Service (USDI/USDC 1998) that particulate forms of lead may be adverse to endangered species of aquatic life and terrestrial life that are dependent on aquatic life as food. How lead will be regulated with respect to total versus dissolved lead under the California Toxics Rule, which is scheduled to be promulgated this summer, remains to be determined.

The 1995-1998 Caltrans highway storm water runoff water quality monitoring data obtained throughout the state has been reviewed for the purpose of determining whether the dissolved lead in the runoff exceeds the US EPA water quality criteria for protection of aquatic life in fresh or marine waters. The Caltrans highway storm water runoff monitoring data, obtained over the past several years, shows that about half of the 90 data points for dissolved lead are above the criterion value. Essentially all of the total lead data points are above the criterion value. Therefore, storm water runoff from Caltrans highways frequently exceeds the US EPA water quality national criterion for both total and soluble lead. This is a problem that will need to be addressed throughout California by all urban area and highway storm water runoff water quality managers and the regulatory agencies. In order to eliminate exceedances of the current water quality criterion/standard, Caltrans and urban storm water runoff water quality managers would need to construct, operate, and maintain advanced wastewater treatment works that would remove lead from the storm water runoff.

There is considerable controversy, however, about the appropriateness of having the public spend funds for implementation of the advanced wastewater treatment technology needed to remove lead from urban area and highway storm water runoff such that it meets the current lead water quality criterion/standard. As reviewed by Lee and Jones-Lee (1997) a number of studies have shown that the lead and other heavy metals in residential urban area and highway storm water runoff are in non-toxic, non-available forms. The work of Peterson (1973) and his colleagues at the University of Wisconsin, Madison in the late 1960s, as well as the studies conducted by Dr. G. Fred Lee and his associates in the 1970s on the chemical characteristics and toxicity of US waterway sediments, and more recent work by various storm water dischargers in the 1990s, all lead to the conclusion that the lead in urban area street and highway storm water runoff, as well as the lead that accumulates in sediments derived from this type of runoff, is predominantly in a non-toxic, non-available form. If the lead in urban storm water runoff or aquatic sediments receiving urban area storm water runoff was in toxic forms, then the various investigators would have found this lead to be an important cause of toxicity to various forms of aquatic life.

Toxicity in urban area storm water runoff has, in general, been found to be due to organophosphate pesticides used for residential and commercial purposes and not due to heavy metals. Further, toxicity in aquatic sediments is primarily due to ammonia and hydrogen sulfide (Lee and Jones-Lee, 1996). There may be some situations such as associated with low pH, low alkalinity, low TOC, and suspended solid waters where lead in urban area and highway storm water runoff could be converted in part to a toxic available form; however, these situations would be rare in California.

Therefore, the exceedance of a US EPA water quality criterion, and a state standard based on this criterion for lead in urban area and highway storm water runoff, is an administrative exceedance related to the overly protective nature of applying the US EPA worst case criteria values to urban area and highway storm water runoff for most receiving waters for such runoff. Based on the information available today, it is highly likely that site specific studies of the water quality significance of the exceedance of the US EPA water quality criterion and state water quality standard for lead would show that highway storm water runoff lead discharge limits can be appreciably raised from the current US EPA worst case criterion value and still be protective of receiving water beneficial uses. These results are in accord with the aqueous environmental chemistry of lead and its toxicology.

The regulation of storm water runoff from paved and unpaved highway right-of-way surfaces is an issue that will be resolved over the next five to ten years through the Best Management Practices (BMP) ratcheting-down process that is now in effect to ultimately achieve appropriate water quality standards. When this matter has been resolved, it would be appropriate to revisit the need for Caltrans to change its approach for managing near highway surface soils that contain elevated lead at the recommended concentration of 1,575 mg/kg in order to comply with the regulatory requirements that are ultimately adopted for managing the highway and urban area street storm water runoff lead-caused violations of current water quality standards. This could be done with the five-year renewal of the Caltrans' statewide storm water permit.

There is no technical basis for the SWRCB to impose special restrictions on Caltrans' statewide storm water permit which limit the surface soil lead to values less than 1,575 mg/kg based on the potential for this lead to be adverse to aquatic life. Such an approach would not be advised since there would be no significant impact from highway area storm water runoff on the beneficial use of receiving waters. The impacts on the receiving water beneficial uses will be controlled primarily by the constituents in the paved surface runoff. It is, therefore, recommended that the SWRCB not impose any special management requirements for near highway soils that contain elevated lead below 1,575 mg/kg as part of issuing the Caltrans statewide storm water permit that is currently under review.

Covering near highway soil reused as construction fill with soil that contains significantly lower concentrations of lead should also eliminate any potential for surface water problems for either domestic water supplies or aquatic life.

4.5 Appropriateness of Continuing Current DTSC Soil Lead Variances

Currently Caltrans' management of near highway surface soils containing elevated lead concentrations is governed by existing DTSC variances. These variances require the determination of the total lead in the soil. If the total lead exceeds the TTLC hazardous waste classification of 1,000 mg/kg, then the soil is considered a hazardous waste and must be managed as a California hazardous waste except as allowed in the DTSC variances. If the total soil lead exceeds 1,000 mg/kg, further testing is required to determine if the soil meets the requirements of the variances.

If the soil contains total lead between 50 and 1,000 mg/kg, the standard WET is used to determine the soluble lead. If the soluble lead exceeds the STLC of 5 mg/L, further testing is required. If the soluble lead is less than 5 mg/L, the soil would be considered non-hazardous and can be used without restrictions. The current DTSC lead variances contain the following requirements:

Category 1:

If total lead is less than 1,575 mg/kg and the DI-WET lead is less than 0.5 mg/L (500 µg/L), soil may be reused with the following restrictions:

1. Soil must be placed at least 5 feet above the maximum height of the water table, and
2. Covered with at least 1 foot of clean soil.

DI WET leachable lead is the same as DI water leachable lead referred to in this report.

Category 2:

If total lead is greater than 1,575 mg/kg but less than 4,150 mg/kg or the DI-WET is greater than 0.5 mg/L (500 µg/L), soil may be reused with the following restrictions:

1. Soil must be placed at least 5 feet above the maximum water table height, and
2. Contaminated soil must be covered with pavement or similar impervious cap.

Category 3:

If soil is hazardous due to lead and exhibits a pH under 5.0, soil shall only be used as fill material under the paved portion of the roadway.

The SWRCB currently proposed soil lead restrictions in the draft statewide permit are largely based on the existing DTSC Caltrans soil lead variances with some important exceptions. First, the SWRCB raised the pH restriction from the DTSC 5.0 to 6.0. As discussed herein, from the information available from the KLI (1998) data and from the literature, it is concluded that there is no technical justification to raise the soil pH restriction from 5.0 to 6.0. In fact, the pH 5.0 DTSC restriction can be lowered to about pH 4.5 and not appreciably effect near highway soil lead leaching.

Based on the review of the information, it is concluded that the DTSC variance limitation of 1,575 mg/kg total lead, where near highway soils containing soil lead above this amount must be buried under one foot of clean surface soil, is protective (likely significantly overprotective) in preventing significant airborne and waterborne transport of soluble and particulate lead from the surface of a new or reconstructed highway shoulder area. It is recommended that the 1,575 mg/kg concentration be used to establish special management requirements for the use of new highway surface soils as construction fill. No restrictions are recommended for the placement of this fill other than it be under at least one to two feet of clean or low lead soil, dependent on the slope of the surface soils as recommended in the SWRCB proposed Caltrans statewide storm water permit.

The SWRCB proposed DI water leachable lead, for the Caltrans statewide permit of 150 µg/L near highway surface soils for construction fill, is far more restrictive than the current DTSC variance value of 500 µg/L DI water leachable lead that is used to trigger the need to place near highway surface soils in construction fill below at least one foot of clean soil. There is no technical justification for the SWRCB to change the DTSC DI water leachable lead from 500 µg/L to 150 µg/L. Further, as discussed herein, the 500 µg/L DI water leachable lead value is significantly overprotective in essentially all situations except possibly where the highway construction is underlain by fractured rock or cavernous limestone. It is recommended that both of these values not be used as a general requirement limiting the placement of near highway surface soils as construction fill in new highways or their maintenance.

Since DTSC has proposed to terminate the use of the WET classification approach for hazardous waste and replace it with the US EPA TCLP test, it is recommended that the WET restrictions be removed in the future. Instead, only the TCLP would be used to determine whether a near highway soil total lead would cause the soil to be classified as a hazardous waste associated with new highway development or maintenance.

The variance restrictions limiting the concentrations of total lead that can be used in highway construction fill to 4,175 mg/kg should be removed. Total lead in soils in any concentration above 1,575 mg/kg that is not a TCLP defined hazardous waste should be allowed to be used as fill provided that it is covered with at least one to two feet of clean soil.

4.5.1 Caltrans Construction Projects

Caltrans undertakes on the average about 256 improvement projects each year in the pursuit of its mission to provide transportation facilities for California. Of this total number of projects, about 60% or 154 projects involve disturbance of the soils in the median, shoulder, or soils that have historically been in these areas. These projects typically involve the installation of a High Occupancy Vehicle (HOV) lane, auxiliary lane, general widening or similar construction. Earthwork generally involves minor cut and fill operations to establish the pavement subgrade elevation and the new design grading daylight point. The average pavement structural section is about 2 feet thick; consequently, for the general case of a roadway widening, a 2 foot 'cut' is required for the new construction.

In a review of Caltrans projects statewide for the past nine years, it was determined that on average, 13,900,000 yd^3 of material are moved per year. Using the estimate that 60% of such projects include disturbance of soil near the median or shoulder equates to a total volume of 8,340,000 yd^3/year of soils that may contain elevated concentrations of lead. It is further estimated that about 50% of the earth moved in projects disturbing median or shoulder area soils is within the top 2 feet, or historically has been within the top 2 feet of the construction area and is within about 10 feet of the existing or historical shoulder, where lead in soils is reported to be highest. As a result, about 4,170,000 yd^3/year is moved in Caltrans construction projects that is within the top 2 feet of soil and within about 10 feet of the existing or historical shoulder areas that have highest probability of containing elevated concentrations of lead.

5.0 Recommended Approach for Regulating Near Highway Surface Soil Lead in Caltrans Highway Construction and Maintenance Projects

Overall, the existing DTSC variances and the proposed SWRCB permit language are highly conservative compared to that needed to protect surface and groundwaters from pollution by lead. Except possibly for construction projects overlying fractured bedrock aquifer, there is little likelihood that the use of near highway surface soils in highway construction fill without restriction can lead to surface or groundwater pollution. Even for fractured bedrock systems where there could be a conduit fracture(s) from the area where elevated lead has been deposited in the fill to a nearby domestic water supply well, the likelihood that the user of such a well would pump water which would contain excessive lead compared to drinking water action levels is remote.

Near highway surface soils containing elevated lead can be reused as fill in highway construction/maintenance. It is recommended that the SWRCB refer to the existing DTSC variances in the Caltrans Storm Water Permit. These regulations are sufficiently conservative to protect surface and groundwater resources in the interim timeframe wherein DTSC promulgates new hazardous waste criteria. This approach would also relieve the Board of the position of specifying BMPs, a deviation from previous policy, as well as the provisions of SB 1320 requiring peer review of any new SWRCB policy.

In order to address concerns about surface water and airborne transport of lead from new or reconstructed highway shoulder areas, it is recommended that any near highway surface soils with lead above 1,575 mg/kg be deposited in fill under certain conditions. At least one foot of clean soil where final grade slope is less than one (1) vertical foot in two (2) horizontal feet; and two (2) feet of clean cover soil (soil with less than 400 mg/kg total lead) in areas where the final grade slope is greater than one (1) vertical foot in two (2) horizontal feet is necessary, provided that Caltrans incorporates and maintains BMP measures for slope stability/erosion protection for all slopes.

All near highway surface soils should be tested on a representative basis for TCLP leachable lead using the Caltrans Sampling Protocol (Caltrans Noise, Air, and Hazardous Waste Management Office, 1997). If the TCLP leachable lead is greater than 5 mg/L, then the soil containing this lead should be transported to a hazardous waste landfill. If DTSC adopts a total lead special hazardous waste classification value such as the proposed 1,000 mg/kg, then this value should become the value that is used as the criterion to determine the need to restrict the placement of near highway surface soils in highway construction fill. In the absence of such a value or through a revised Caltrans near highway surface soil lead variance, it is recommended that 1,575 mg/kg be used as the criterion to determine the need to place near highway surface soils under appropriate clean cover soil within the construction fill.

In order to eliminate the ambiguity about what constitutes a clean soil for covering construction fill with elevated soil lead, it is suggested that soils with a total lead concentration less than 400 mg/kg can be used as "lead clean soils." This value is suggested based on the US EPA's recommendations that soils with total lead less than 400 mg/kg are considered safe for unrestricted child contact. This value would be significantly overprotective for conditions where there could be erosion of the new or reconstructed highway surface soils that could be transported to a nearby residential area and accumulate in an area where children would play in contact with the soils.

Adoption of these suggested requirements will be highly protective of surface water quality and children's health due to the hazards of near highway surface soil with elevated lead being potentially transported from a new or reconstructed highway project.

In conclusion, it would appear prudent for the SWRCB to maintain the current DTSC variance until the DTSC has promulgated the new regulations. Such an approach would minimize confusion and overlap of regulation, satisfy the requirements of SB 1320, avoid the pitfalls associated with including the language in the permit rather than another document such as the SWMP, and maintain current SWRCB policy relative to the inclusion of specific BMPs in an NPDES permit.

6.0 Water Quality Characteristics of Caltrans Highway Storm Water Runoff

Beginning in the mid 1990s the Caltrans districts initiated highway storm water runoff water quality monitoring programs. The data from 1995 through that available in 1998 has been examined with reference to information on lead in storm water runoff from Caltrans highways. Presented below is a review of this information.

Total and Dissolved Lead. Approximately 90 data points were available for the three primary study areas (SCA-Southern California area, CV-Central Valley, and SF-San Francisco). Figure 1 presents the data for total lead and dissolved lead in Caltrans highway storm water runoff in these areas. Examination of this figure shows that generally, with the exception of five points, the concentrations of total lead were less than 200 µg/L. About 95% of the samples had a total lead concentration less than 200 µg/L. Further, this figure shows that, with the exception of three data points, the dissolved lead concentrations in highway storm water runoff were less than 50 µg/L. About 95% of the samples had a total lead concentration less than 50 µg/L. As discussed herein, the US EPA worst case water quality criterion for protection of aquatic life due to lead toxicity is about 1 to 5 µg/L for fresh and marine waters. Therefore, both total and dissolved lead in Caltrans highway storm water runoff could frequently contribute to exceedance of water quality standards (objectives) at the point of discharge if these standards are numerically equal to the US EPA worst case water quality criteria, and no mixing zones allowed for the storm water runoff to mix with the receiving waters. However, there is substantial evidence that both the dissolved and total lead in urban area highway storm water runoff is in non-toxic/non-available form. This exceedance of the worst case criterion is likely to be an administrative exceedance related to the overly protective nature of the criteria when applied to most waterbodies.

In order to examine the relationship between total and dissolved lead in Caltrans highway storm water runoff, the data presented in Figure 1 has been replotted in Figure 2 with the three high dissolved lead values removed from the data set. Examination of this figure shows that, with the exception of a couple of points, there could be two somewhat distinct relationships between total and dissolved lead where the 1996-1997 data set is somewhat different than the Southern California 1997-1998 data set. The 1996-1997 data set (small diamonds) includes some data obtained from Southern California. The squares which cluster above about 0.15 to 0.2 mg/L total lead represent points that were obtained from sampling the first flush of storm water runoff from a highway area. There is need for additional review of this data and the procedures by which the data were obtained to better understand the relationship between total and dissolved lead in highway storm water runoff. It is apparent from the data, that a high total lead does not necessarily lead to high dissolved lead in the storm water runoff for the State of California. This would be expected since there are a variety of factors, some of which may be regional, that influence this relationship.

Total Lead Versus Suspended Solids. One of the areas of interest is whether there is a relationship between the total lead in highway storm water runoff and the total suspended solids in this runoff. The issue of concern is whether lead is a relatively constant proportion of the total suspended solids in highway storm water runoff. Figure 3 examines this issue for the Caltrans highway storm water runoff water quality monitoring data set available. There are several high outlier values for suspended solids and total lead shown in this figure. Figure 4 presents that same data with the total suspended solids data above 1,000 mg/kg removed from the data set. Examination of Figures 3 and 4 shows that total lead is not a constant fraction of the suspended solids in Caltrans highway storm water runoff. However, the Southern California 1995-1998 data shows that if some of the higher suspended solids values are removed from the data set, the data tends to show a general relationship between total suspended solids and total lead.

Total Lead Versus Turbidity. There was a limited data set for the relationship between turbidity and total lead. This is shown in Figure 5. As might be expected, increasing turbidity is associated with increasing total lead. However, the data set is too limited to determine whether this relationship would hold over a larger data set.

6.1 Changes in Lead Concentrations in Highway Storm Water Runoff

Lead in urban area streets, highway storm water runoff, and near highway deposition on soils associated with atmospheric transport from highway vehicular traffic is primarily derived from lead used in gasoline and other motor vehicle fuels. It is also derived from lead used in vehicular tire weights used for balancing tires, paint striping, and lead paint used on structures such as bridges. Archibald and Wallberg (1997) have conducted a review of the sources of lead in the City and County of Sacramento urban storm water runoff. They were unable to define distinct lead sources that, through control, would likely lead to the elimination of the excessive lead in airborne transport and in storm water runoff from urban area streets and highways.

Until the early 1970s, the concentrations of lead in storm water runoff from highways were much higher than they are today. It was about that time that there were significant decreases in the amount of lead added to gasoline as an antiknock compound. Since then there has been a decrease in the total lead concentration in urban area and highway storm water runoff. SCCWRP (1987) reported that the lead content of storm water runoff in the Los Angeles River during 1971-1972 was 910 and 980 µg/L for two different storms; while in 1979-1980 the lead content was found to be 74, 210, and 180 µg/L for three different storms. In 1986-1987, the monitoring of a single storm showed a lead content of 164 µg/L.

Barrett *et al*. (1998) have reported on the chemical characteristics of highway runoff from an expressway located in Austin, Texas. Samples were collected between 1993 and 1995. The median event mean concentration of total lead in storm water runoff ranged from 15 to 53 µg/L. The highest concentrations in storm water runoff from the highway test section were found to be correlated with high traffic densities, indicating that vehicular traffic was the primary source of the lead. The Caltrans storm water runoff total lead data obtained in the past several years, with few exceptions, tends to be significantly higher than the concentrations found in the Austin, Texas storm water runoff. These differences may be related to the more frequent rainfall events that occur in Austin compared to most of California.

Peterson (1973) conducted a Ph.D. dissertation, under the supervision of Dr. G. Fred Lee, devoted to a study of lead in storm water runoff in the Madison, Wisconsin area. He found, in the late 1960s, that storm water runoff from urban streets contained up to 2,200 µg/L total lead. The Wisconsin lakes, which receive urban area and/or highway storm water runoff or atmospheric transport of highway derived lead, had accumulated lead in the sediments to significantly elevated concentrations compared to the concentrations of lead in the lake sediments that were deposited prior to the use of lead as a gasoline additive.

Stephenson and Leonard (1994) reported on the changes in the 1977-1990 California State Mussel Watch Program data for several heavy metals. The program found a 40% decrease in accumulated lead in mussels deployed in cages for the purpose of monitoring the bioaccumulatable chemical constituents in the vicinity of the deployment area. They attributed the lead decrease to increased wastewater treatment and decreased use of leaded gasoline. They found that lead had decreased linearly with time in 7 of 20 stations monitored through 1991. One of the stations showed an increase in lead since 1985. They noted that many of the mussel watch stations showed no clear temporal trends in the lead content of mussels. They were unable to explain the differences between the seven stations where there was a linear decrease with lead over time and the 13 stations which either showed no change or an increase in lead since the mid 1980s.

O'Connor and Beliaeff (1995) presented a summary of NOAA's national Mussel Watch Project data covering the period 1986-1993. This study included several stations along the

California coast. While nationally, the lead content of mussels in coastal waters did not change significantly during this period, several of the California coastal mussel watch stations showed statistically significant decreases in the lead content of deployed mussels. Other California stations showed no change in the lead concentrations that accumulate in mussels that are deployed to assess the bioaccumulatable constituents that are a potential threat to public health and the environment.

The observation by some investigators that mussels deployed at certain locations show decreasing temporal trends in the lead content, while mussels deployed at other locations showed no change or even an upward trend over time, reflects the complexity of the situation governing the availability of bioaccumulatable lead in a caged mussel environment. Depending on the physiographic and hydrologic characteristics of an area, mussels deployed at a particular location will be exposed to a mixture of historic lead stirred into the water column from the sediments as well as current inputs of lead into the water column from the watershed. Under the conditions where the current inputs are the controlling source of bioaccumulatable lead, it would be expected that, during the 1970s and 1980s, there would have been a significant decrease in the lead content of deployed mussels. However, where the predominant source of lead is lead resuspended into the water column from the sediments, and there is a low sediment deposition rate in the area, then it would be expected that there would be little or no change over time in the lead content of mussels.

It can be concluded that the rapid decrease in the concentrations of lead in storm water runoff, domestic wastewater, and some industrial wastewaters in the early to mid 1970s was apparently due to the decreased use of lead as a gasoline additive and increased wastewater source control and treatment. The situation today is likely at a new steady state with respect to lead inputs to the aquatic environment associated with highway storm water runoff and airborne transport to near highway soils. There is still sufficient lead used to cause highway storm water runoff and soils near highways to contain significantly elevated concentrations of lead compared to runoff from areas where limited vehicular traffic occurs.

The continued use of lead as tire weights and as a reflective material in striping paint, coupled with the naturally occurring lead in gasoline, is apparently the source of the elevated lead in current highway and urban street storm water runoff. Refined petroleum products such as gasoline typically contain from 10 to 15 mg/L of total lead. This is lead that is apparently present in crude oil. The US EPA allows unleaded gasoline to contain up to 15 mg/L total lead. At the time that lead was added to gasoline as an anti-knock compound, its concentration was about 250 mg/L. The current lead in gasoline is apparently a major source of lead in urban area street and highway storm water runoff. It, coupled with the other sources, primarily through atmospheric transport, is the primary source of lead that is being added to surface soils near highways. These soils, however, contain lead that has been deposited there since the surface soils were developed as part of highway construction.

Mahmood (1997) reviewed the information on lead contamination of soils near highways, where he indicated that most of the roadway traffic contributions of lead were within 150 meters of the roadway. A number of investigators have found that there is an exponential decrease in the atmospheric transported lead from highways that accumulates in adjacent soils.

Mahmood concluded that, in general, lead is "immobile" due to its strong affinity for soils. He recommended that a better understanding of the fate and mobility of lead is needed to manage soil lead associated problems.

6.1.1 Lead Content of Near Highway Surface Soils

In the spring of 1998, Caltrans undertook a study to determine the lead content and other characteristics of near highway surface soils. Kinnetic Laboratories Inc. (1998a) took core samples from 23 areas near Caltrans highways from throughout the state. The KLI study plan and characteristics of the Caltrans highways where the near highway soil cores were taken has been presented by KLI (1998b).

A total of 68 cores were divided into four depth strata (0 to 6 inches; 6 to 12 inches; 12 to 18 inches; and 18 to 24 inches) for a total of 262 samples. The average total lead concentration of all samples was 131 mg/kg, with the top 0 to 6 inch strata averaging 252 mg/kg total lead. The 6 to 12 inch strata had an average total lead concentration of 58 mg/kg, while the 12 to 18 inch strata and 18 to 24 inch strata had average concentrations of 36 and 37 mg/kg total lead, respectively. Dragun and Chiasson (1991) have summarized the concentrations of selected constituents in soils for the US. Based on 75 surface samples of California soils, obtained by Boerngen and Shacklette (1981) of the USGS, the mean concentration of total lead was 29 mg/kg, with a standard deviation of 41 mg/kg. As expected, the KLI data for surface soils near Caltrans highways contain elevated concentrations of lead above the typical background concentrations for areas at significant distances from highways. Further, as expected, the KLI data show that the highest concentration of total lead in soils near highways generally occurs at the surface.

Examination of the KLI data shows that, with the exception of four data points, all of the total lead concentration measurements were below 1,575 mg/kg. About 99% of the samples were below 1575 mg/kg total lead concentration. Based on the recommended approach for managing near highway soil lead in construction projects, the near surface soil samples can, with few exceptions, be placed at any location within the construction fill, including the surface of the fill. There will, however, be some near highway surface soils with total lead that will require special management since the total lead exceeds the recommended criterion of 1,575 mg/kg.

Examination of the TCLP leachable lead from the KLI data set shows that only two samples had TCLP leachable lead above the 5 mg/L, which is the US EPA cut-off point for defining a lead containing waste as a hazardous waste. Therefore, there will be some samples of near highway surface soils with TCLP leachable lead concentrations which would cause the soil to be classified as a hazardous waste under current US EPA regulations.

With respect to the DTSC's proposed revised classification of total soil lead (lead concentration in excess of 1,000 mg/kg in soil is classified as a special hazardous waste) there were seven samples that had total lead in excess of 1,000 mg/kg. According to DTSC's criterion of 1,000 mg/kg, these soils would not be suitable for propagation of earthworms. However, as discussed herein, it is unlikely that the lead in near highway surface soils would have the same effect on earthworm reproduction as the toxic available forms of lead that were used to develop the 1,000 mg/kg value.

KLI also determined the DI water leachable lead from the samples. There were no samples that exceeded the 5 mg/L hazardous waste classification level that the US EPA has adopted for waste that could be placed in a municipal landfill using the acetic acid extraction procedure (TCLP). This would be expected to be more effective in leaching lead than deionized water. A soil that leaches 500 µg/L lead by TCLP is not a hazardous waste. Sixteen samples had DI water leachable lead greater than 500 µg/L. According to the SWRCB proposed restrictions on Caltrans use of elevated lead soils in highway construction, near highway soils that contain DI extractable lead greater than 500 µg/L would have to be placed under a paved area. However, as discussed herein, except possibly for highway construction above fractured rock where the fractured rock would be in contact with the base of the highway fill, this requirement is significantly overprotective.

The KLI data shows that 32 of the samples had DI water extractable lead greater than 150 µg/L. These soils, according to the SWRCB proposed approach for restricting Caltrans use of near highway surface soils as fill in highway construction and maintenance, could be used as highway construction fill provided that they are covered with at least one to two feet of clean soil. However, as discussed herein, this requirement is significantly overprotective in preventing groundwater pollution by leaching of the lead from highway construction fill soils. Imposition of this requirement would mean that about half of the near highway surface soils that are used as construction site fill would have to be placed under one to two feet of clean topsoil, depending on the slope of the surface soils. This would represent an unnecessary financial burden to the public associated with highway development and maintenance that could be used for more appropriate purposes.

Examination of the KLI data shows that, with one exception, only one of the four total lead values that were analyzed from each core's four six inch sampling interval was above 1,000 mg/kg. Similarly, only seven of the 68 cores had two of the sampling intervals with a DI water leachable lead above 150 µg/L. This situation reflects the heterogeneous nature of the lead distribution in the near highway surface soils. The elevated concentrations of total lead and leachable lead are generally restricted to a narrow band of soil. This is of importance in evaluating the potential for preconstruction near highway soils with elevated total or leachable lead to be placed, undiluted by cleaner soils, in the surface of the new highway or reconstructed highway fill area. It would be virtually impossible, based on typical construction techniques, that elevated concentrations of total or leachable lead that are present in the near highway surface soils would be placed undiluted in the surface of the new highway area. This situation provides a significant additional margin of safety with regard to using the 1,575 mg/kg total lead value as a guideline for determining the need to manage near highway surface soil lead so that it would not be at the surface of the reconstructed area.

Examination of the KLI near Caltrans highway soil lead data, with respect to discerning conditions that promote the leaching of lead from the soils, shows that, in general, there is no consistent pattern. High total lead does not necessarily lead to high dissolved lead. There was also no relationship between leached lead concentration and TOC. One of the constituents in soil that is being found to control lead mobility is phosphate. Ruby *et al*. (1994) has reviewed the potential role of phosphates in soils in limiting lead mobility. While the studies were directed toward controlling lead mobility from lead ores, it is likely that the phosphate content of soils may play some role in controlling near highway soil lead mobility. Phosphate was not measured in the KLI studies.

Geocon (1996-98) presented the results of the total lead and its leaching characteristics for 32 sites near Caltrans highways. Based on 980 data points, the total lead concentrations ranged from 50 mg/kg to about 9,290 mg/kg. Only two samples had a total lead above the DTSC variance total lead value of 4,150 mg/kg. All but 17 values were below the 1,575 mg/kg, with 40 samples having total lead concentrations above 1000 mg/kg. Therefore most of the 980 samples tested would not require special handling in highway construction or maintenance based on their total lead content.

Not all of the samples collected were subjected to leaching procedures. Examining the results of the 63 samples subjected to TCLP leaching of the lead from these near highway surface soils showed that nine samples had a TCLP leachable lead greater than 5 mg/L and therefore would be classified as a hazardous waste under current US EPA regulations.
Three hundred twenty one samples were leached with deionized water with 176 data points above the SWRCB proposed limits of 150 µg/L; 40 samples had DI water leachable lead with values above the 500 µg/L DTSC current Caltrans soil lead limit governing the placement of near highway soil with elevated lead. None of the DI water leachable lead was above the US EPA allowed TCLP leachable limit of 5 mg/L. Geocon (1996-98) (380 data points) found similar results as KLI (1998a) in that there was a poor relationship between near highway surface soil total lead and the DI water extractable lead.

Overall, the KLI (1998a) and the Geocon (1996-98) data for total lead and DI water leachable lead are similar in that they show that only a small part of the near highway surface soils would require special management based on total lead, TCLP leachable lead and the 500 µg/L DI water leachable lead. With few exceptions the current Caltrans near highway surface soils can be used as construction fill without requiring special handling.

Review of the KLI and Geocon data shows that the citric acid in the DTSC WET procedure frequently extracts lead above 5 mg/L. Therefore, a soil with this characteristic is technically, based on current DTSC Title 22 regulations, a California hazardous waste. Both sets of data showed that about 60 % of the near highway surface soils leached lead above the STLC 5 mg/L criterion. Based on the large differences between the DI water leaching and the citric acid leaching of lead from near highway surface soils, it is clear that citric acid leaching near highway surface soils is an inappropriate approach for estimating the leaching of lead from highway construction fill as it may relate to estimating the public health and environmental hazard of the lead present in the fill.

The use of citric acid as the leaching solution in the WET was designed to provide a more vigorous leaching environment than the acetic acid leaching solution that the US EPA had selected to simulate the leaching environment of municipal landfills. During the past two years, DTSC as part of the RSU has conducted extensive testing of the relative leaching ability of acetic and citric acids for various types of solid wastes. Based on these studies, DTSC has recommended that the WET procedure no longer be used to classify wastes as hazardous wastes. Instead DTSC has proposed that the acetic acid based TLCP be used for hazardous waste characterization in California.

The acetic acid TCLP is not an appropriate procedure for leaching of soils and other materials that are not managed in municipal landfills. It is for this reason that both WET and TCLP have been modified to replace the acetic acid or citric acid with deionized water as the leaching solution. Deionized water is a far more appropriate leaching solution for estimating the leaching potential of percolating precipitation (rainwater). Both acetic and citric acids leach metals from solids based on increased solubility of metals at lower pH values and most importantly by complexation of the metal by the acid ligand (acetate and citrate). A ligand is a part of a molecule that interacts with metal ions to form complexes.

Rainfall precipitation through highway construction fill will have a low organic complexation ability. The KLI (1998a) data shows, as expected, that the near highway surface soils have a low organic carbon content. The overall average organic carbon content for the KLI data was 0.4%. With few exceptions, the TOC was less than 1%. Such soils have low complexation capacity. Further, rainwater percolating these soils would not be expected to pick up significant amounts of organics that would assist in transporting metals such as lead.

6.1.1.1 Variability of Total Lead and Leachable Lead Results

KLI (1998a) conducted studies to determine the variability of the total lead and leachable lead in near Caltrans highway surface soils. Multiple analysis of the same sample showed that the analytical precision was good with a coefficient of variation (standard deviation divided by the mean times 100) of 7% for total lead analysis. Replicate analysis of DI water leachable lead was 13%; for TCLP leachable lead, the CV was 24%.

Cores were taken within a foot of each other, and a set of cores were also taken over a typical construction site of 750 ft by 20 ft. The results of this analysis had coefficients of variations in the range of 60 to 90%, indicating that the total and leachable lead in the near highway surface soils was moderately variable. These results suggest that a number of samples of near highway surface soils should be taken to characterize the soil lead content. Further, very high total or leachable lead values are typical of small areas and volumes of near highway surface soils.

Figure 1. Dissolved Lead as Function of Total Lead in Stormwater All Data 1996-1998

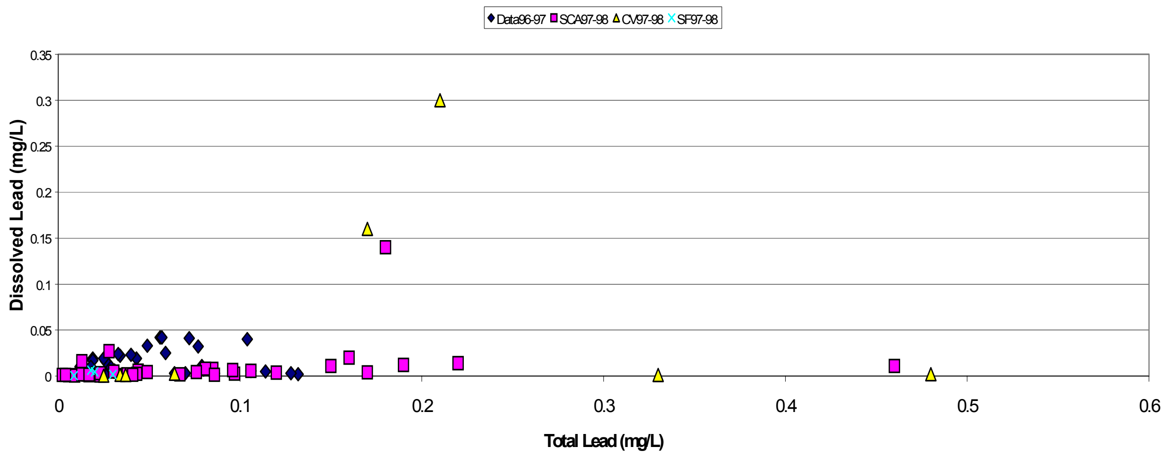


Figure 2. Dissolved Lead as Function of Total Lead in Stormwater (3 High Points Removed) 1996-1998

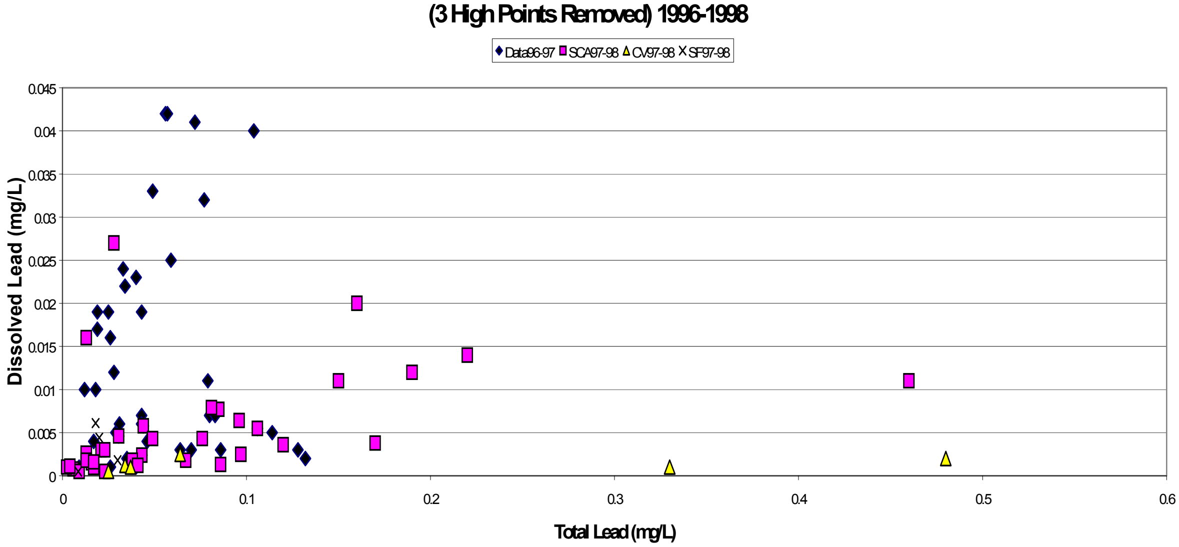


Figure 3. Total Lead as Function of Total Suspended Solids

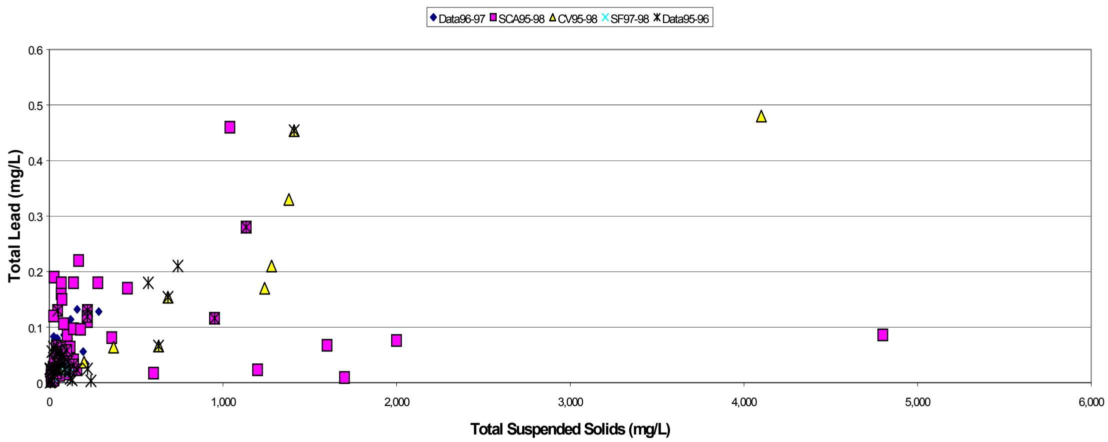


Figure 4. Total Lead as Function of Total Suspended Solids (for Suspended Solids <1000 mg/L)

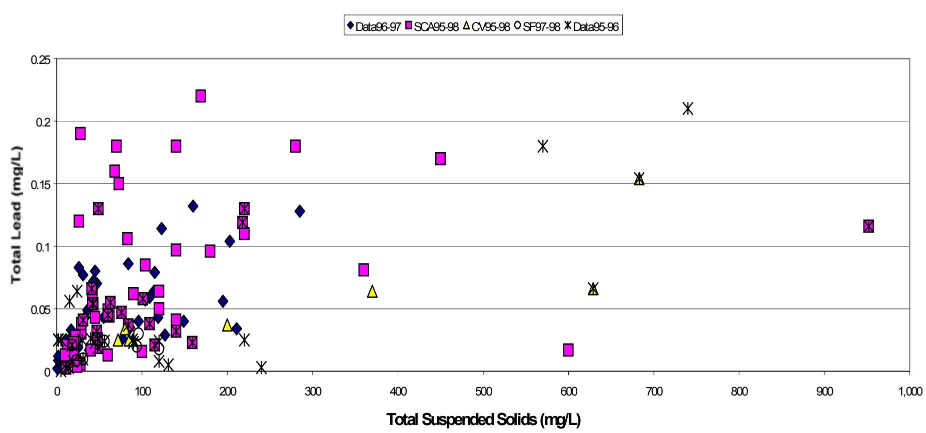
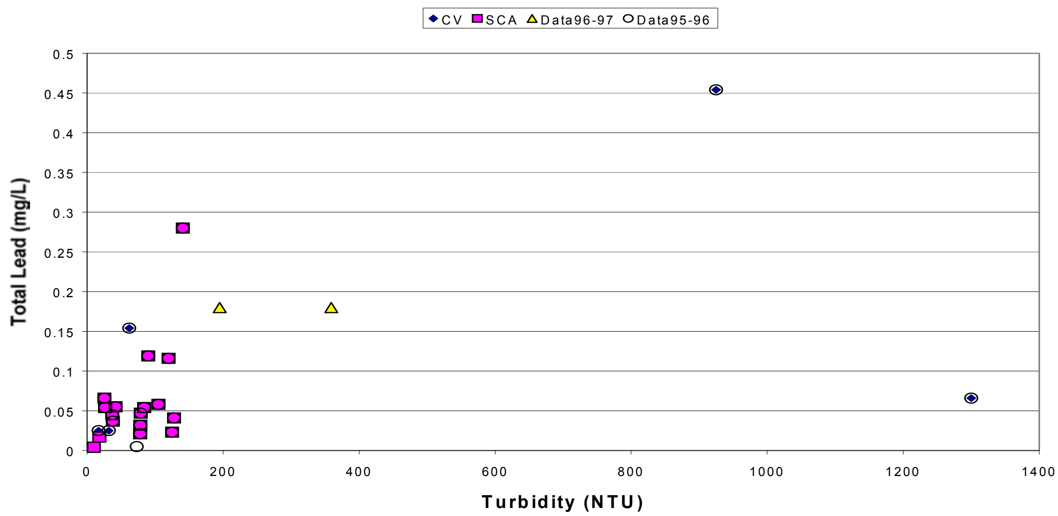


Figure 5. Total Lead as Function of Turbidity



References

Archibald & Wallberg Consultants, "Identification of the Sources of Lead in Sacramento Urban Runoff," Technical Memorandum, Submitted to the Sacramento Stormwater Runoff Program, Sacramento, CA, March (1997).

Barrett, M.E., Irish, Jr., L.B., Malina, Jr., J.F., Charbeneau, R.J., "Characterization of Highway Runoff in Austin, Texas Area," Journal of Environmental Engineering, 124: (No. 2), pp 131-137, (1998).

Barrett, M.E., Malina, J.F., and Randall, J.C., "A Review and Evaluation of Literature Pertaining to the Quantity and Control of Pollution from Highway Runoff and Construction", Center for Research in Water Resources, The University of Texas at Austin, April (1995).

Boerngen, J.G. and Shacklette, H.T., "Chemical Analyses of Soils and Other Surficial Materials of the Conterminous United States," U.S. Geological Survey Open-File Report, (1981).

DHS, Statement of Reasons for Proposed Regulations, "Criteria for Identification of Hazardous and Extremely Hazardous Waste," Department of Health Services, Title 22, Article 11, Sacramento July 20 (1984).

Dragun, J. and Chiasson, A., Elements in North American Soils, Hazardous Materials Control Resources Institute, Greenbelt, MD, (1991).

Geocon Environmental Consultants, submitted a series of site investigation reports to Caltrans on the lead content of soils near highways (1996-1998).

Howard, J.L. and Sova, J.E., "Sequential Extraction Analysis of Lead in Michigan Roadside Soils: Mobilization in the Vadose Zone by Deicing Salts?" Journal of Soil Contamination, 2: (No. 4), 361-378 (1993).

Kinnetic Laboratories, Inc., Technical Report, "Lead Content of Caltrans Highway and Freeway Soils," CTSW-RT-98-32 prepared for Caltrans, Sacramento, CA, May (1998a).

Kinnetic Laboratories Inc. "Study Design and Protocols for Evaluation of Lead Criteria for Caltrans Highway Soils with Respect to Classification as Hazardous Waste and Reuse," Draft Technical Memorandum, Sacramento, CA, March (1998b).

Lee, G.F. and Jones, R.A., "Application of Site-Specific Hazard Assessment Testing to Solid Wastes," In: Hazardous Solid Waste Testing: First Conference, ASTM STP 760, ASTM, pp 331-344 (1981).

Lee, G.F. and Jones, R.A., "Evaluation of Potential Water Quality Problems Associated with Highway Excavation and Fill," In: Leachate Terrain Analysis, National Academy of Sciences, Transportation Research Board Record, 892, pp 1-7 (1982a).

Lee, G.F. and Jones, R.A., "A Risk Assessment Approach for Evaluating the Environmental Significance of Chemical Contaminants in Solid Wastes," In: Environmental Risk Analysis for Chemicals, Van Nostrand, New York, pp 529-549 (1982b).

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, AWRA Technical Publication Series TPS-91-4, AWRA, Bethesda, MD, pp. 139-151 (1991).

Lee, G.F. and Jones-Lee, A., "Importance of Considering Soil-Lead in Property Site Assessments," Presented at National Ground Water Association Conference, Environmental Site Assessments: Case Studies and Strategies, Orlando, FL 23 pp, August (1992).

Jones-Lee, A. and Lee, G.F., "Groundwater Pollution by Municipal Landfills: Leachate Composition, Detection and Water Quality Significance," Proc. Sardinia '93 IV International Landfill Symposium, pp. 1093-1103 (1993).

Lee, G.F. and Jones-Lee, A., "Evaluation of the Water Quality Significance of the Chemical Constituents in Aquatic Sediments: Coupling Sediment Quality Evaluation Results to Significant Water Quality Impacts," In: WEFTEC '96, Surface Water Quality and Ecology I & II, Vol 4, pp 317-328, Proc. Water Environ. Fed. Annual Conference (1996).

Lee, G.F. and Jones-Lee, A., "Lead as a Stormwater Runoff Pollutant," Report, G. Fred Lee & Associates, El Macero, California June (1997).

Lee, G.F. and Jones-Lee, A., "Assessing the Potential of Minimum Subtitle D Lined Landfills to Pollute: Alternative Landfilling Approaches," Proc. of Air and Waste Management Association national meeting, San Diego, CA, June (1998).

Legiec, I.A., "Pb Mobility and Extractant Optimization for Contaminated Soils," Environmental Progress, 16: (No. 2), 88-92 (1997).

Mahmood, R.J., "Review of Lead Contamination in Soils Near Highways," Report to California Department of Transportation Environmental Engineering Program, Sacramento, CA (1997).

O'Connor, T.P. and Beliaeff, B., "Recent Trends in Coastal Environmental Quality: Results from the Mussel Watch Project," National Status and Trends Program, US Department of Commerce National Oceanic and Atmospheric Administration, June (1995).

Peterson, J.O., "A Study of Lead in Lake Sediments," Ph.D. Dissertation, Water Chemistry Program, University of Wisconsin, Madison (1973).

Ruby, M.V., Davis, A. and Nicholson, A., "*In Situ* Formation of Lead Phosphates in Soils as a Method to Immobilize Lead," Environmental Science Technology, 28: (No. 4), 646-654 (1994).

SCCWRP, "Stormwater Runoff in Los Angeles and Ventura Counties," Southern California Coastal Research Project Annual Report, pp 13-18 (1987).

Serrano-Belles, C. and Leharne, S., "Assessing the Potential for Lead Release from Road Dusts and Soils," Environmental Geochemistry and Health, 19: 89-100 (1997).

Stephenson, M.D. and Leonard, G.H., "Evidence for the Decline of Silver and Lead and the Increase of Copper from 1977 to 1990 in the Coastal Marine Waters of California," Marine Pollution Bulletin, 28: (No. 3), 148-153 (1994).

US EPA, "Guidance Manual for the Integrated Exposure Uptake Biokinetic Model for Lead in Children," US Environmental Protection Agency, Office of Solid Waste and Emergency Response, EPA/540R-93/081, Research Triangle Park, NC (1994).

US EPA, "Recommendations of the Technical Review Workgroup for Lead for an Interim Approach to Assessing Risks Associated with Adult Exposures to Lead in Soil," Technical Workgroup for Lead, Washington D.C. (1996).

US EPA, "Water Quality Standards for the State of California," Federal Register 40 CFR Part 131 Proposed Tuesday, August 5 (1997).

USDI/USDC, "Draft Biological/Conference Opinion on the Environmental Protection Agency's Proposed Rule for the Promulgation of Water Quality Standards: Establishment of Numeric Criteria for Priority Toxic Pollutants for the State of California," Draft Report, US Department of Interior Fish and Wildlife Service and US Department of Commerce National Marine Fishery Service, Submitted to US EPA Region 9, San Francisco, CA, April 10 (1998).

Van Benschoten, J.E., Matsumoto, M.R., Young, W.H., "Evaluation and Analysis of Soil Washing for Seven Lead-Contaminated Soils," Journal of Environmental Engineering, 123: (No. 3), 217-224, (1997).