Management of Hazardous Waste from Highway Maintenance Operations

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16. ABSTRACT

This report consists of three phases. Phase one is a review of existing information on all aspects of highway maintenance waste management. A survey was conducted with the state transportation-highway departments in the US and its territories and Canada. The information obtained in response to the questionnaire, such as quantity of specific waste material and their concentration of specific hazardous material and the method of treatment of disposal was placed in a computer software database for easy accessability.

Phase two is the characterization of the highway maintenance waste. The waste consisting of road sweepings, vactor sludges, and ditch diggings were found to be contaminated with hazardous substances. Three pollution indicators, total petroleum hydrocarbons (TPH), polycyclic aromatic hydrocarbons (PAH), and the Microtox solid-phase bioassay toxicity test (MSPT) were used to define the waste. The geometric mean and range for all three parameters were determined for each waste category. Road sweepings were categorized into three age groups: recently collected, recently stored, and aged material. The recently collected material had the highest level of pollutional parameters. Road sweepings were sieved into three fractions. The smallest particle size fraction was found to have the largest concentration of the pollutional parameters.

Based on the waste characterization, the following full scale treatment technologies are suggested to render the highway maintenance waste non-toxic: land farming or bioenvelope, solids washing and rotary kiln incineration. As a pretreatment rotary screening is recommended. The treated solids can be disposed of in sanitary landfills or used as road fill.

17. KEY WORDS
Highway maintenance waste characterization, Highway pollution, Total Petroleum Hydrocarbons, Polycyclic Aromatic Hydrocarbons, Microtox Solid-Phase Bioassay Test

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MANAGEMENT OF HAZARDOUS WASTE FROM HIGHWAY MAINTENANCE OPERATIONS

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DISCLAIMER

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SUMMARY

Highway maintenance operations consisting of road sweeping, drain or vactor and ditch cleaning generate wastes contaminated with hazardous substances. These wastes are currently being stored at highway maintenance yards due to the reluctancy of municipal landfills to accept them. The difficulty in disposing the above mentioned wastes led to a three phase study in highway maintenance waste management.

Phase one consisted of a literature review of all aspects of highway waste management. A second part of this phase consisted of a survey of waste management practices used by the various state and U.S. territorial transportation/highway agencies. Findings from the survey were entered into a computer database. It was found that a majority of the respondents did not recognize the possible presence of hazardous substances in their highway maintenance wastes. The most common method of disposing their wastes was by burial at landfills. Certain types of equipment maintenance wastes, such as motor oil, were recycled while with others the residuals found in the containers were returned to the vendors.

Phase two consisted of characterizing the road sweepings, vactor sludges, and ditch spoils. The wastes were characterized relative to three hazardous waste parameters which were: total petroleum hydrocarbon (TPH) content, polycyclic aromatic hydrocarbons (PAH) content and the Microtox solid-phase bioassay toxicity test (MSPT). Fresh as well as weathered samples were subjected to the above mentioned tests. It was found that each of the above targeted parameters had a wide concentration range in each type of waste. This indicates that the location where the waste was generated was as important as the type of waste. Weathered road sweepings compared to fresh road sweepings had a lower TPH concentration, lower incidence of individual (PAH), and a lower toxicity. This shows that natural

processes such as biodegradation vaporization, photolysis, and leaching occurred. The small size fraction of particles had a higher TPH content than the coarser fractions.

Based on the findings from the waste characterization investigation, phase three of the study was undertaken. This phase reviewed the applicable treatment technology used to render the waste non-hazardous. Upon completion of the review those technologies in current full scale operation and are simple to assemble, operate, shut down, and are cost effective were recommended. A sizing or particle size separation treatment method, i.e. mechanical screens, is highly recommended. This is to be followed by one of the following three treatment technologies: rotary kiln incineration, solids washing, biological treatment, or land farming/bioenvelope.

CONCLUSIONS

Phase One

The most important element of this phase was a hazardous waste management survey. This survey was conducted to gain a better insight of the types of material in highway maintenance waste being generated and the means of their disposal. The following can be concluded from the survey.

1. A majority of the respondents to the survey questionnaire did not recognize the presence of hazardous substances in their highway maintenance wastes.

2. The most common method of disposing their wastes was by burial at sanitary landfills. Certain types of equipment maintenance wastes were recycled, while with others the residual in the container were returned to the vendor.

Phase Two

Characterization of the highway maintenance wastes found along roadsides and in maintenance yards provided information which permitted the following conclusions.

1. Each of the targeted pollutional parameters, total petroleum hydrocarbons (TPH), polycyclic aromatic hydrocarbons (PAH), and Microtox solid phase toxicity test (MSPT) had a wide concentration range in each type of waste. This indicates that the location of the waste was as important as the type of waste.
2. Weathered road sweepings compared to fresh road sweepings had a lower TPH concentration, lower incidence of individual PAHs, and a high Microtox toxicity EC50 value. This shows that natural process such as vaporization, biodegradation, leaching, and photolysis were underway.
3. The smaller particle size fraction had a higher TPH concentration than the coarser fractions.

Phase Three

Based on the conclusions arrived at in the previous two phases, the following technologies are suggested in cleaning up the highway maintenance wastes described in this study.

1. Sizing or particle size separation is a required pretreatment. Only those contaminated size fractions which do not meet regulatory requirements need be treated for removal of hazardous substances.
2. The treatment systems should be current full scale units with prior evaluation in their capability of destroying or detoxifying hazardous organic material and stabilize or remove the inorganic hazardous substances.
3. The three full scale methods recommended for treatment of the stored piles of highway maintenance wastes are: land farming (bio-envelope), solids washing, and rotary kiln incineration.
4. Bench scale treatment process should not be totally discounted. Their progress to full scale operation should be followed to see if they are cost effective, simple in operation and maintenance, and degree of efficiency in cleanup of the hazardous materials in the waste pile.

CHAPTER 1 INTRODUCTION

Highways play an important role in meeting a variety of this nations societal needs. Such needs include: movement of people to and from home and the work place, to recreational areas, and shopping areas. In addition highways serve as major arteries in the movement of raw and finished products of industry, commerce, and agriculture. The intensive use of these roads require their continuous maintenance to insure safe travel.

Pavement, bridge, and guard rail repair are the most apparent maintenance activities. Removal of debris, litter, and the residual sand and gravel after ice and snow treatment are equally important highway maintenance activities. In many instances these solid materials become contaminated with a variety of highway pollutants. The contaminated solids are removed in the course of maintaining the highway system through such activities as road sweepings, vactor sludge removal, ditch digging/cleaning, and bridge and road surface rehabilitation. The above mentioned activities generate waste materials that must be collected, stored, and eventually disposed.

In the United States the disposal of highway maintenance waste has come under close environmental scrutiny by federal, state and local regulatory agencies. These wastes have been recognized in themselves as being potentially hazardous or serve as surfaces onto which hazardous substances can adsorb and/or absorb (1),(2),(3).

The inorganic and organic substances that make these wastes hazardous come from a variety of non-point and point sources. Non-point sources consist of the deposition of airborne and fugitive dust particulates onto which incompletely combusted and uncombusted petroleum hydrocarbons, polycyclic aromatic hydrocarbons, and condensed volatilized metals are adsorbed. Vehicle parts wear and corrosion of auto bodies, tire wear, and brake lining wear also contribute to the heavy metal particulate load. Leaking brake fluids, antifreeze, transmission fluids and lubricating oils and greases result in the deposition of these substances on particulates and directly on road surfaces. A point sources of highway maintenance waste can result in sand blasting the old paint prior to repainting a bridge. The spent blasting sand may contain hazardous heavy metals in the paint flakes which has been removed. Another point source is from maintenance equipment wastes. These wastes consist of used lubricating oil, worn tires, discarded auto batteries, spent equipment parts cleaners, equipment wash and rinse waters and discarded paint. Road repair and construction which include road pavement debris and discarded striping paint containers is yet another point source.

The disposal of point and non-point highway maintenance waste by landfill is the most common method, however it is becoming less attractive due to liability insurance and hazardous substance monitoring costs. Consequently, these wastes have accumulated and are stored at highway department maintenance yards awaiting an economic means of safe disposal. The accumulation of waste has contributed in part for a request by an increasingly number of state executive agencies or committees from their respective state department of transportation to formulate a waste management plan. Currently a limited number of states have established guidelines for handling and disposing these wastes (4), while others are in the process of formulating such guidelines.

OBJECTIVES

To assist the Washington State Department of Transportation in formulating guidelines for disposing highway maintenance wastes which may contain hazardous substances, this study was undertaken. The study is divided into the three following segments: information resource, waste characterization, and applicable remedial treatment technology. The objective of the information resource segment is to compile existing information dealing with the identification, characterization, handling, treatment and disposal of highway maintenance wastes. This segment consists of placing state transportation departments information into a computer database. The second segment objective is to characterize the waste found at select locations throughout the State of Washington for targeted hazardous substances. The objective of the third segment is to recommend those remedial technologies best suited to destroy or convert the hazardous substances into a non-hazardous form.

CHAPTER 2 INFORMATION RESOURCE SYSTEM

Research Approach

Information review. A review of the existing literature and internal reports showed that interest in water pollution from street surfaces began in the middle 1960's (5). Numerous investigations continued for the next 13 years dealing primarily with the characterization of this non-point source runoff in respect to total, suspended and settleable solids, total biodegradable organic material (BOD), total oxidizable organic material (COD), and the phosphorus and nitrogen nutrients (6),(7). Information relative to the levels of heavy metals and toxic organics were virtually non-existent. More recent published studies on highway runoff quality, their environmental impact, and control was summarized by Hvitved, et al (8). The sources and levels of heavy metals in highway runoff, highway dust, and road sweeping have been reported by numerous investigators beginning in 1973 (1), (9), (10), and (11). The primary focus of most of the studies were on the levels of the following heavy metals: lead, cadmium, copper, zinc, iron, nickel, and chromium in the above mentioned waste source. Meager information is available regarding the types, classes and/or specific organic compounds in highway wastes. Studies have been conducted in England and Japan starting in the late 1970's concerning the presences of polycylic(polynucleated) aromatics (12) (13) (14).

Hazardous waste management survey. To gain a better insite of the types of material in highway maintenance waste currently being generated and the means of their disposal a highway waste survey was conducted. A questionnaire was sent to all highway/transportation departments in the United States, Guam and Puerto Rico, and the Canadian Provinces requesting information pertaining to the hazardous waste management practices. To assist them in their response the types of wastes were divided into six categories which were: road sweepings, ditch diggings (spoils), vactor sludges, equipment maintenance, bridge maintenance, and an others category. Information concerning the segregation of the various types of waste during storage prior to treatment and/or disposal was requested. Questions concerning each type of waste were asked dealing with quantity handled annually and the type and concentration of specific groups of hazard substances. The final question dealt with the type of method used to treat and/or dispose the waste. The information from the responses were compiled and entered into a computer database. This was done for easy retrieval of specific information. The database software was distributed to those agencies responding to the questionnaire and is available to others upon request.

Table 1 is a summary of the information obtained from the waste survey.

Table 1. Summary of Information From Waste Survey

Type	Composition	Disposal method
I. Road Sweepings (19)	Unknown (17) Petroleum hydrocarbons (3)	Landfill (12) Roadside or road fill (7) screened and reused
II. Vactor Sludge (9)	Unknown (9)	Landfill (8) Roadfill (1)
III. Ditch Spoils (11)	Unknown (11)	Roadfill (9) Road cover (4)
IV. Equipment Maintenance (29)		
A. Parts Cleaner (17)	Non-chlorinated solvent (6) Chlorinated solvent (3) Mixed Chlorinated & non-Chlorinated (3) Biodegradable (1)	Recycle (8) Incinerated (6) Landfill (sludge) (3) Biological treatment (1)
B. Waste Oil (17)	Petroleum Hydrocarbons	Recycle (10) Landfill (2) Incinerated (6)
C. Antifreeze (4)	Ethylene glycol (base) (4)	Recycled (2) Biological treated (POTW)
D. Batteries (2)	Lead (2)	Reclaimed (2)
E. Brakeliners and Clutches (1)	Asbestos (1)	Landfill (1)
V. Bridge Maintenance (10)	Lead (9)	Solidification (1)
A. Blasting Sand/Paint Flakes (10)	Unknown	Landfill (7) Road cover and fill (1)
VI. Misc.		
A. Road & Sign Paint and Paint Solvents (21)	Lead and other heavy metals (10) Non-Chlorinated solvents (12) Mixed Chlorinated and non-chlorinated solvents (2)	Incineration (9) Recycled (5) Landfill (3)

Type	Composition	Disposal method
B.Testing Lab Waste (3)	Chlorinated Solvents (2) Heavy Metals (1)	Recycle (3) Incineration (1)
C. Contaminated soil due to leaking underground storage Tanks (5)	Motor fuels (BETX) (5)	Soil encapsulation (1) Fill material (2) Landfill (3)
D.Pesticides (3)	Sulfumeturon (1) 2,4,5 Silvex (1) Unknown (1)	Incineration (2) Residue returned to vendor (1)

Findings of Surveys

Road sweepings were the most prevalent type of highway maintenance waste responded to in the survey. Most respondents were unaware if the waste was hazardous or not. Though the presence of petroleum hydrocarbons in the road sweeping waste was recognized by several respondents. The most common method of disposing road sweepings was by placing the material into secure or municipal landfills. Seven of the respondents indicated that the sweepings were reused. Sizing was practiced by several of the state transportation departments. The large and medium sized screenings were mixed with chemical deicers then used for traction on snow and ice covered roads. Maintenance division in some state departments of transportation used the road sweeping as fill material in road construction.

Information on vactor sludges, another type of highway maintenance waste, was requested. Vactor sludges are solids which settle out in drains and catchment basins from road runoff during periods of precipitation and road surface washing. Unlike road sweepings, the vactor sludges contain finer grain material. The sludges are similar to a mixture of clays and organic material found in road sweepings. All of the respondents were unaware of the nature of the materials in the sludge. All assumed that the wet sludge were safe enough to landfill. Several maintenance divisions air dried the sludge and disposed of it along with the stored piled road sweepings.

Ditch spoils or ditch diggings are another type of waste generated in maintaining highway systems. In the course of time ditches adjacent to road shoulders will fill up with deposited solids from road surface runoff and overland wash from highway right of ways and adjacent agricultural lands. Periodically the ditches must be cleaned of deposited solids so that the ditches can convey runoff/overland wash waters. The respondents to the survey indicated that they were unaware of the hazardous potential of these spoils. The removed ditch spoils were used as road fill by most. However, four of the respondents indicated that the spoils are used as road or embankment cover.

Wastes from the maintenance of equipment used in highway maintenance were the major point source of pollution. These wastes were divided into five categories. Spent parts cleaners and used crankcase (motor) oil were the major waste materials generated in equipment/vehicle maintenance according to the survey respondents. Most of the parts cleaners were non-chlorinated solvents. A few solvents were of the chlorinated type while others were a mixture of chlorinated and non-chlorinated organic compound. One respondent indicated that a biodegradable parts cleaner was used. The most common method of treating the spent solvents was to contract for their removal by a licensed hauler or recycler, who in turn would sell the waste to a facility for solvent recovery. Another method used for spent parts cleaner disposal was through incineration. Sludges which settle out from spent parts cleaner solutions were removed and usually incinerated, though several respondents disposed their waste in landfills. The spent biodegradable parts cleaner was sent to a sewage treatment plant for disposal by one of the respondents.

Spent crankcase (motor) oil is another waste generated in significant amount in equipment maintenance. Ten of the 17 respondents had their used crankcase oil collected by licensed haulers or recyclers who in turn delivered the material to a reprocessing facility. The used oil not recycled was incinerated. The waste crankcase oil was mixed with fuel oil and used as a fuel in furnaces or industrial type boilers. Two respondents were able to dispose their waste oil in a municipal landfill. This type of disposal was very rare and most often this is not permitted. Another waste or spent material maintenance equipment was antifreeze. On occasion this solution must be drained from vehicles and replaced with a fresh solution. The waste antifreeze solutions were usually ethylene or propylene glycol based solutions. The respondents had the spent antifreeze removed by licensed based solutions. The respondents had the spent antifreeze removed by licensed haulers for recycling. Waste antifreeze, when sufficiently diluted, can be biodegraded. This had led several respondents to send the waste antifreeze to the municipal sewage treatment plant for biodegradation.

Worn equipment parts is the final category in the equipment maintenance classification. This category includes such items as discarded "dead" lead-acid storage batteries, worn brakeliners, worn clutch plates and discarded spark plugs. Except for discarded lead-acid storage batteries which are reclaimed, discarded parts were disposed of in landfills.

Another of highway maintenance waste results from bridge maintenance operations. These wastes contain heavy metals in paint flakes and residual amounts of paint in paint containers. In repainting bridges, loose paint and rust are removed by sandblasting. Lead and some cadmium-based paints were used in painting bridge surfaces. Spent sand blast contain heavy metal paint flakes which must be disposed of. The most common method of disposal was burial in a landfill. However, one respondent used the spent sands as a roadfill and road cover. Paint residues remaining in paint containers and spent paint solvents are usually incinerated. However, one respondent disposed of their waste by solidification.

The final type of waste was classified as miscellaneous. These highway maintenance wastes were generated in small quantities. One such waste was residual paint and paint solvents used in road sign painting and in road stripe (surface) painting. The paint residuals contain heavy metals as lead and chromium as well as non-chlorinated paint carriers (solvents). The paint solvents, thinners, and cleaners as well as metal surface cleaners were chlorinated and non-chlorinated solvents. About half of the respondents disposed the paints and solvent residual by incineration. Others were able to send the old paint cans containing residual paints to the vendor from whom they were purchased, who in turn arranged for their disposal. A few respondents disposed the paints and paint solvent in a sanitary landfill.

Another category of miscellaneous waste were those generated by the transportation departments testing laboratory. The quantity of these wastes were small. They consist of chlorinated solvents and heavy metals. The solvents were either recycled by collecting the pure solvent after distillation or the solvents were incinerated. One respondent who reported generating heavy metal waste disposed the waste by soil encapsulation.

Only three departments indicated they had procedures for residual pesticide disposal. However, all departments which practice weed control on road medians and right-of-ways had some protocols for dealing with residual pesticide disposal. Residual herbicides used to control broadleaf and woody stem herbicides are disposed of by incineration or containers with residual herbicide were returned to the vendor for disposal. With implementation of the underground storage tank program under Resource Conservation and Recovery Act (RCRA), all owners of underground storage tanks were required to inspect the tanks and remove those which were leaking. Where leaking underground storage tanks were found, the surrounding soil may be contaminated with motor fuels. Five of the respondents encountered such a situation. Three sent the contaminated soil to a landfill for disposal while two used the soil as road fill.

CHAPTER 3 CHARACTERIZATION OF HIGHWAY MAINTENANCE WASTE

The current practice in the State of Washington is to collect the road sweepings, vactor sludges and ditch spoils in small piles and to store the material in convenient locations along roadsides. After a sufficiently large amount of material accumulates it is then removed to the closest Department of Transportation maintenance yard where the material is stored. The above mentioned waste collected from county roads are stored at the respective county's highway maintenance yards. The waste piles stored at the maintenance yards are extremely heterogeneous in particle size and chemical composition. Particle size range from coarse gravels to very fine clay particles. A large variety of chemical compounds makeup these wastes. The quantity of each substance is highly variable. Almost every conceivable organic and inorganic compound found in the environment are found in the above mentioned waste. Previous research efforts have focused on the identity of the hazardous substance by sampling directly from the highway environment (15) (16) rather than stored material.

The study described herein investigated the hazardous materials in the piles of collected waste along roadsides and that stored at the maintenance yards. Because of the complex nature of the chemical substances present and the heterogeneity of the waste, indicator groups of hazardous compounds or their toxic response were analyzed and quantified. The indicators measured were total petroleum hydrocarbons, (TPH) polycyclic aromatic hydrocarbons, (PAH) and Microtox solid phase toxicity bioassay (MSPT). Each measures one of the four hazardous waste categories.

Research Approach

Site selection. Samples were collected from waste piles located at Washington State Department of Transportation maintenance sites, along interstate and state highways and at the Spokane County Maintenance yard. Figure 1 is a map of the State of Washington showing the sample site locations. Samples were taken from three types of waste materials; road sweepings, vactor sludges, and ditch spoils. The waste piles ranged in size from a few cubic yards to several thousand cubic yards. The type of waste material, origin of waste, and age of waste pile were among the information recorded. Samples were taken from piles of varying ages to investigate the weathering effect on the contaminant concentrations. This ranged from sampling "fresh" roadside piles to well weathered piles locate at highway department maintenance sites.

Sample collection. Samples from waste piles were collected by Mr. Craig Martin of Washington State University and Mr. Edwin Hannus of the Washington Department of Transportation. Samples were obtained by digging into the sides of the waste piles and removing subsamples. Samples were taken below the pile surface. Subsamples were then blended and a composite sample was taken. The samples were placed in cleaned glass containers, iced, and transported back to the laboratory. Samples were then refrigerated at 4° C until processed.

Methods of analysis. *TOTAL PETROLEUM HYDROCARBON (TPH).* A wide variety of petroleum hydrocarbon compounds may be present in road sweepings, vactor sludges, and ditch spoils. These compounds are primary the higher boiling semi-volatile and non-volatile compounds e.g. those found in motor oils, lubricating greases, and asphalts. The presence of volatile petroleum hydrocarbon would be rare due to their rapid evaporation from particulate surfaces and road surfaces.

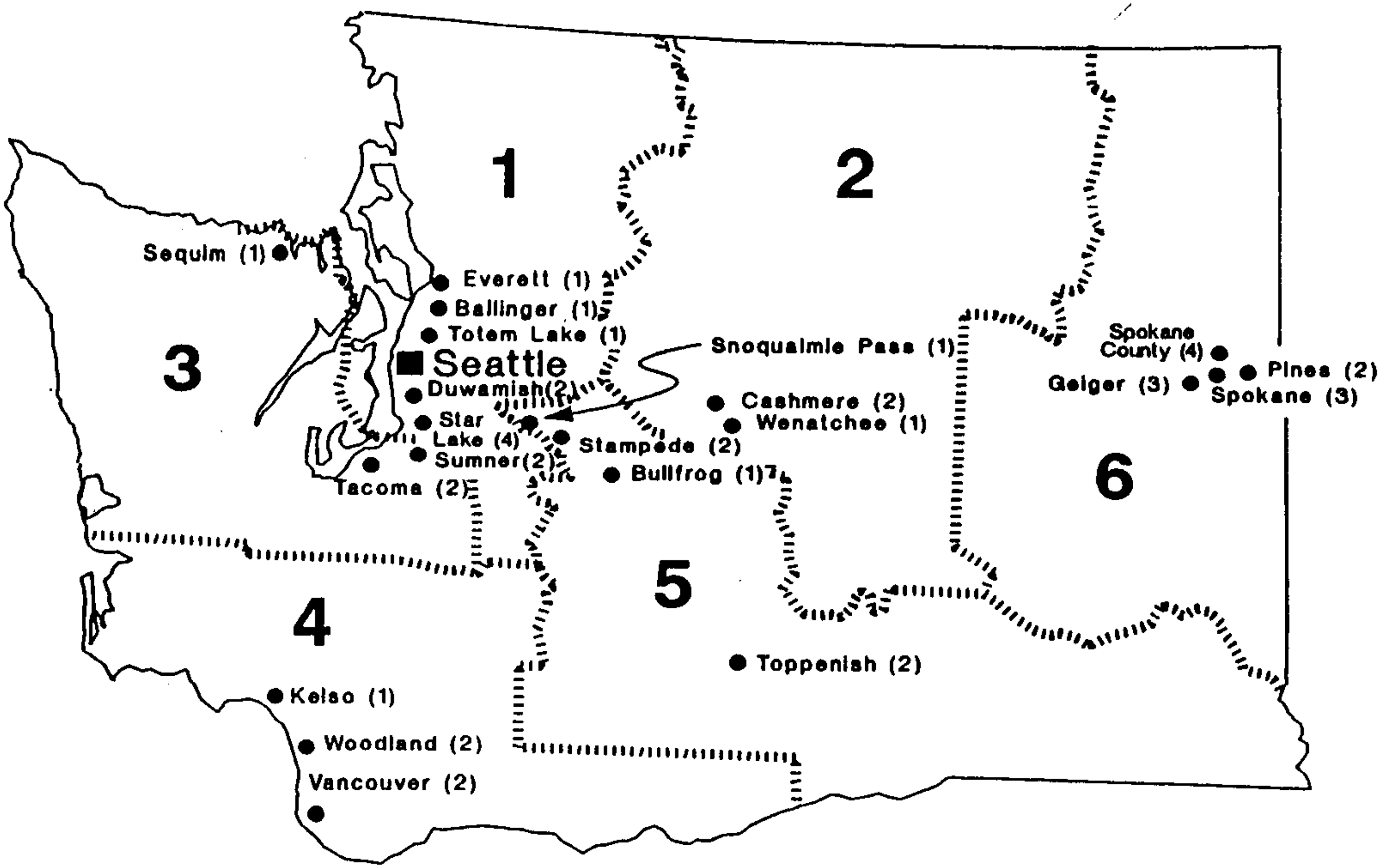


Fig.1 Sampling Site Locations

A search for analytical methods to quantify the amount of total petroleum hydrocarbons revealed two methods. One, a gas chromatographic technique, the other an infrared spectrophotometric method. The gas chromatographic technique was most applicable for the analysis of volatile and the lower and mid boiling semi-volatile petroleum hydrocarbon compounds (17). The infrared spectrophotometric method, though not as specific for individual hydrocarbons as the gas chromatographic techniques, was capable of detecting and quantifying all hydrocarbon compounds regardless of their volatility (18). Both methods are adaptation of EPA approved methods.

The infrared spectrophotometric method is a combination of EPA method 418.1 and Standard Method 5520E (18) (19). This procedure is valid for a TPH concentration range of 5 mg/kg to approximately 10,000 mg/kg petroleum contaminated soils.

Sample Preparation. Petroleum hydrocarbons were desorbed from the samples using a Soxhlet extraction process which is described in Standard Methods 5520E, "Extraction Method for Sludge Samples" (19). Though this method was developed for oil and grease analysis of sludges and slurries, it can be used to extract petroleum hydrocarbons from road sweepings, vactor sludges and ditch spoils. The extracting solvent used was 1,1,2-trichloro, 1,2,2 trifluoroethane, (Freon 113) because of its solvency properties and its non-response to infrared absorption in the 3.4μm wavelength band. Extraction was followed by a silica gel cleanup. The silica gel cleanup process was used to remove non-petroleum hydrocarbons (polar organics such as humic material). Sodium sulfate was used to remove water which interferes with the analysis.

TPH Analysis. A Foxboro, Inc. MIRAN 1A CVF, an attenuated total reflection infrared analyzer, was used in the analysis. This instrument measured the absorbance of radiation by the extract at a wavelength of 3.42 μm. The carbon hydrogen stretching bonds of hydrocarbons absorb radiation at this wavelength and thus absorbance can be measured. A EPA recommended standard consisting of a mixture of n-hexadecane, isooctane, and chlorobenzene was used to prepare standard calibration curves. Benzene, hexane, heptene, used motor oil, and lube oils were used as comparative standards. TPH concentrations given in this paper were based on the EPA standard. Data from the analyses are found in the Appendix.

POLYCYCLIC AROMATIC HYDROCARBON (PAH) ANALYSIS. Polycyclic aromatic hydrocarbons (PAHs) or polynuclear aromatic (PNAs) are of interest in highway pollution control. All members of this group of organic compounds are very toxic. Those having four or more nucleated or condensed rings are the most toxic chemicals known. These compounds are formed during the combustion of solid and liquid fuels, eg. gasoline and diesel fuel. PAHs have been found in vehicle exhaust, road dusts, and road runoff in Japan and England (12), (13). Since road dusts are found in road sweepings, vactor sludges and ditch spoils, the PAHs are an important parameter to be monitored.

The two methods used for measuring PAH or PNA compounds singly or in mixtures are by gas chromatography (GC) and by high performance liquid chromatography (HPLC). Of the two chromatographic techniques, gas chromatography is most commonly used (12) (17) and (20).

Sample Preparation. Prior to the gas chromatographic analysis for the PAHs, the samples were air dried for 24 hours, then sieved. The particle size fraction that passed through a 2 millimeter screen was sampled then extracted for PAHs. The sample was extracted using the Soxhlet extraction protocol described in Method 3540 of EPA Test Methods SW846 (21). Methylene chloride was used as the extractant. The extract after being concentrated was cleaned-up on silica gel using method 3630 of EPA test methods SW846 (22). The cleaned up extracted was concentrated according to method 3630 prior to being analyzed by gas chromatography.

PAH Analysis. EPA method 8100 of SW846 protocol was used to identify and quantify individual PAHs (17). Liquid samples of 2 ul were injected into a Varian 3600 gas chromatograph equipped with a photoionization detector. A 15m x 0.53 mm J&W DB5 megabore column coupled with a 30m x 0.53 mm J&W 1701 megabore columns used to separate the various polycyclic aromatic hydrocarbons. The gas chromatographic coupled column was held at 33°C for 3 min., then temperature programmed in several steps; 3°C/min. to 48°C, 15°C/min. to 115°C, 4°C/min. to 280°C then held at 280°C for 10 minutes. The injector and detector were maintained at 280°C. Helium was used as the carrier gas at a flow of 700 gauge units. A standard mixture of PAHs was used to calibrate the instrument. A three point calibration curve was used for quantification. Relative retention time using toluene as the internal standard was used for identification of individual PAHs. The PAH gas chromatographic data are found in the Appendix.

MICROTOX SOLID-PHASE TOXICITY ASSAY. As previously mentioned, road sweepings, vactor sludges, and ditch spoils may contain a large number of inorganic and organic hazardous/toxic chemical compounds. The toxicity of the waste will depend on the nature of the chemical species as well as their availability. They may be present in the free state or bound to the solid surface. In addition, the toxicity of a specific chemical species can be magnified by the presence of other hazardous chemicals through synergism. A search was conducted to find a method which can determine the toxicity of the road maintenance waste. Several methods were examined. The one selected was the Microtox solid phase bioassay test (23). This toxicity bioassay test is a simple and rapid screening technique. It employes the change in intensity of the bioluminescence of the marine microorganism. Photobacterium phosphorium as a measure of toxicity. The test procedure utilizes the direct contact between the solid particles and the luminescent microorganisms. This allows free and bound hazardous/toxic substances to interact with the test microorganism. Using a serial dilution technique the percent or quantity of sample to cause a decrease in 50% of the bioluminescence, EC50, can be determined. Work by Becker et. al. in comparing sediment bioassay and alternatives to benthic micro-invertebrate examination at a marine superfund site found the Microtox solid phase bioassay test (MSPT) was comparable to those tests using micro-invertebrates (24).

A Microbics Corp. Microtoxic model 500 analyzer with a portable data collection and reduction system was used to measure the bioluminescences and collect the resulting data (25). Special protocols were followed in performing the solid-phase test (26).

The data was statistically analyzed and reported using the Microtox version 6 software. A three-tenths gram of a sieved sample containing particle sized up to 2 millimeter and less was brought in contact with an aqueous solution of the luminescent microorganisms. A seven tube serial dilution technique was used to determine the EC50 value of the samples. The results of the toxicity bioassay for each sample is found in the Appendix.

Quality control. Quality control consisted of using blanks, spiked blanks, matrix spikes and background samples. Quality control was used solely in the TPH analysis. The purpose of the quality control was to determine the accuracy and sensitivity of the TPH analytical procedure.

Particle size distribution. Experiments were conducted to determine particle size distribution of the waste materials and the concentration of TPH in each particle size fraction. The samples were air dried for 36 hours then sieved into three particle size fraction by mechanical sieving. The three particle size fractions used in this study were as follows:

> 2mm:	Coarse fraction consisting of gravel and large debris.
< 2mm to > 250 um:	Medium fraction consisting mostly of small gravel, sand, and small debris.
< 250 um:	Fine fraction consisting of silt, clay and minute debris.

Samples from each of the particle size categories were analyzed for TPH as previously described.

FINDINGS

Sample description. A total of 41 samples were collected of which 26 were road sweepings, 7 were vactor sludge, 4 ditch spoils and 4 were either mixtures of two or more of the above classes of waste material or were of an unknown class. Those in the unknown classification were not collected by Washington State University personnel.

At the time of sample collection, information was obtained which allowed categorization by the relative waste pile age. Waste pile age was determined using information obtained from local Washington State Department of Transportation personnel and by visual inspection of the waste piles. Visually, the age of the piles could be estimated by the degree of decay of vegetative matter. Although this was a qualitative method of age estimation, the observations indicated that waste materials could be separated into three road sweeping categories and two vactor sludge groups.

The freshest of the road sweepings groups were those that were found in small piles along the highway. These piles were typically less than a few weeks old. The second category of road sweepings were piles that had recently been deposited at highway maintenance sites. These piles, while generally older than the piles found along the highway, were not more than a few months old. The last category were well weathered road sweeping piles found at the highway maintenance sites. These piles were typically over six months old.

The vactor sludges were classified as either wet (fresh) or dry (aged) waste piles. Wet sludges contained free water while the dry sludges had been allowed to drain and dry. Ditch spoils were not classified by age since only four samples were collected.

Total petroleum hydrocarbons quality control. Results from the analysis of TPH in blank shown in table 2A. Although detectable TPH was found in two of the blanks, the concentrations were low enough causing no interference with the sample analysis. Contamination of the blanks probably occurred during the Soxhlet extraction. Blanks were spiked with the EPA recommended standard to determine the recovery efficiency of the analytical procedure. Tables 2B shows the % recovery of the spiked blanks. The data in Table 2B shows acceptable percent recovery from spike solvent blanks.

Several samples were spiked with the EPA recommended standard to further demonstrate the effectiveness of the extraction and analytical procedures. Table 2C shows the % recovery of the spiked samples. The recoveries were poorer than those determined for the spiked blank analysis. This was attributed in part to the heterogeneity of the sample. In addition, there was an extra transfer step in the spiked sample procedure that did not occur with the spiked blank analysis.

TABLE 2A TPH Solvent Background

BLANK #	TPH CONC (mg/100ml)	EXTRACT VOL (mls)	BLANK TPH (mg)
1	0.59	94	0.55
2	0.52	75	0.39
3	0.10	79	0.08

TABLE 2B SPIKE BLANK RECOVERY

SPIKE BLANK #	SPIKE (mg TPH)	TPH CONC (mg TPH/100ml)	EXTRACT VOL (mls)	% RECOVERY (mls)
1	160	180	76	86
2	100	136	83	113
3	54	73	81	110
4	216	257	78	119

TABLE 2C SPIKE SAMPLE RECOVERY

SPIKE BLANK #	SPIKE (mg TPH)	SAMPLE TPH ON SPIKE (mg TPH/kg)	SAMPLE TPH PLUS SPIKE (mls)	% RECOVERY (mls)
43	100	8082	12184	72
44	100	16966	21408	79
1	107	4157	8095	66
29	116	2467	7204	48

TABLE 2D BACKGROUND SAMPLES

BACKGROUND SAMPLE	TPH CONCENTRATION (mg TPH/kg)
Tacoma "A"	17
Tacoma "B"	19
Pullman "A"	16
Pullman "B"	16

Table 2D shows the results of analysis of two background samples. Background samples were used to demonstrate the ability of the procedure (silica gel cleanup) to remove non petroleum hydrocarbon interferences. Sample "TACOMA" was taken from a garden plot in Tacoma, WA. Sample "PULLMAN" was collected from a landscaped area on the Washington State University campus. "A" & "B" represent duplicate analysis. As the sampling sites were located well away from high traffic volume areas they were not influenced from pollutants from the highway environment. The samples were observed to contain a significant amount of humic material. The low TPH concentrations of these samples demonstrates the ability of the silica gel to remove this interference. The quality control laboratory work was done to insure the precision and accuracy of the analytical results generated.

TPH concentration of waste types. Samples were analyzed in duplicate while selected samples were analyzed in greater replication. The results were averaged. Table 3 shows the range and mean values of the TPH concentration for samples of each waste type. Both arithmetic and geometric means were determined. This analysis was conducted on a wet weight basis and moisture content was not accounted for. Wet weight analysis was used since drying would result in the loss of volatile organic compounds. Analytical data for TPH analysis of each sample can be found in the Appendix.

The results indicated that vactor sludges had a higher TPH arithmetic and geometric means than road sweepings which in turn were greater in the TPH content than ditch spoils. It was apparent from the results that TPH concentrations of the waste materials vary greatly. Since a wide range of TPH concentrations was found in the waste materials, the geometric mean is a more accurate estimate of the average value.

Effects of waste pile weathering on TPH concentrations. The effect of weathering is shown in Table 4. The mean and concentration range of samples in the weathering categories of road sweepings and vactor sludges are reported in Table 4.

The results suggest that weathering of road sweepings waste piles reduce the concentrations of TPH's. These results were expected since the natural processes, such as vaporization, biodegradation, leaching, and photolysis would reduce the concentration of contaminants over time. The effect of weathering was not obvious in vactor sludge samples. This could be attributed to the greater range of moisture contents in the vactor sludges causing the TPH analysis conducted on a wet basis to be misleading.

TABLE 3 TPH CONCENTRATIONS IN WASTE CATEGORIES

Waste Type	TPH Concentration [mg (TPH/Kg]		
	Arithmetic Mean	Geometric Mean	Range
Road Sweepings	2524	1054	2-16966
Vactor Sludge	2884	1788	251-2541
Ditch Spoils	954	664	214-2541

TABLE 4
EFFECTS OF WASTE PILE WEATHERING ON TPH CONCENTRATIONS

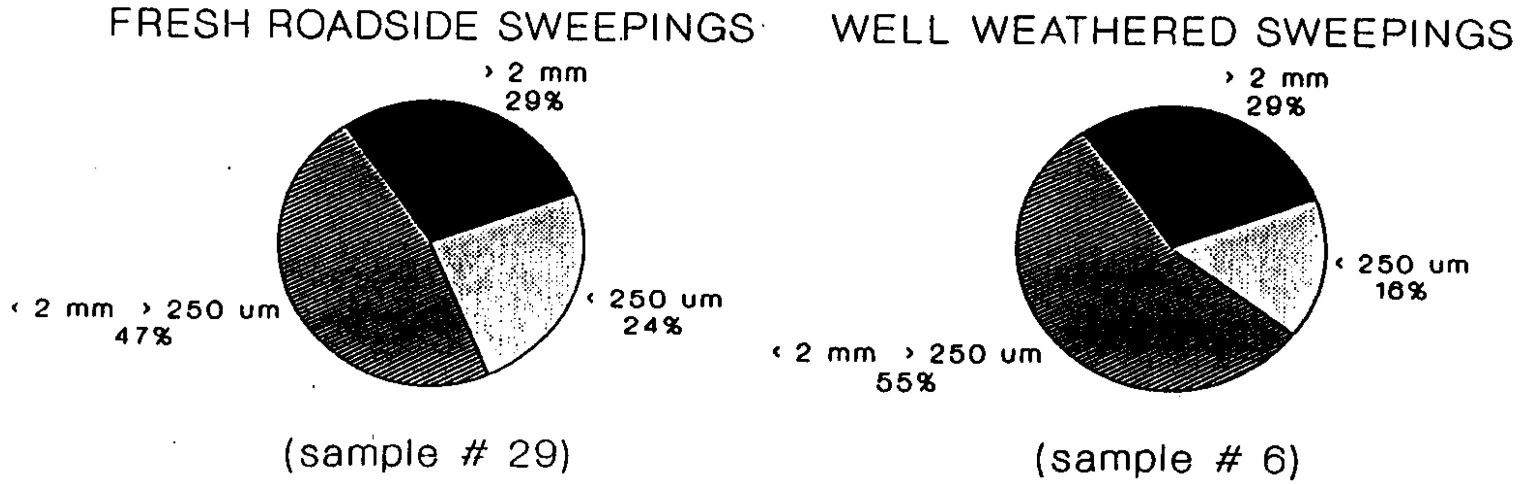
Waste Type	Number of Samples	TPH Concentration (mg/Kg)		
		Arithmetic Mean	Geometric Mean	Range
Fresh Roadside Sweepings	5	3307	3215	2410-4157
Fresh Sweepings at Maintenance Site	9	4560	2870	825-16966
Well Weathered Sweepings	12	671	312	2-2009
Wet Vactor Sludge	5	2503	1604	251-5787
Dry Vactor Sludge	3	1070	2412	553-7690

Particle Size Analysis. Figure 2 shows the particle size distribution of typical samples from fresh sweepings and well weathered sweepings piles. The percentage of the fine fraction (<250 um fraction) in the fresh road sweepings was found to be consistently higher than the weathered sweepings samples. This was attributed to the fine fractions in the older piles being lost by wind or carried off by precipitation runoff water.

Figure 3 shows the concentrations of TPH in the three particle size fractions for the two samples indicated above. Each sample is a representative of its waste category. This figure shows that upon weathering the TPH concentration in the two coarser fraction was reduced. This analysis was conducted on a dry sample weight basis. Additional particle size TPH data can be found in the Appendix.

Figure 4 illustrates that TPH is more concentrated in the finer fractions. This is a common finding with contaminated soils. Sorption of organic compounds is highest by clay mineral particles. These particles are found in the <250 um fraction. Figure 4 further emphasizes the importance of particle size on TPH concentration. In the two samples shown, the coarse fraction (>2 mm) makes up almost 1/3 of the sample (by weight), yet the TPH contribution is only 5% and 6% of the total sample.

FIGURE 2. PARTICLE SIZE DISTRIBUTION WEIGHT % OF PARTICLE SIZE FRACTIONS



(sample # 29)

(sample # 6)

FIGURE 3. TPH CONCENTRATION OF PARTICLE SIZE FRACTIONS

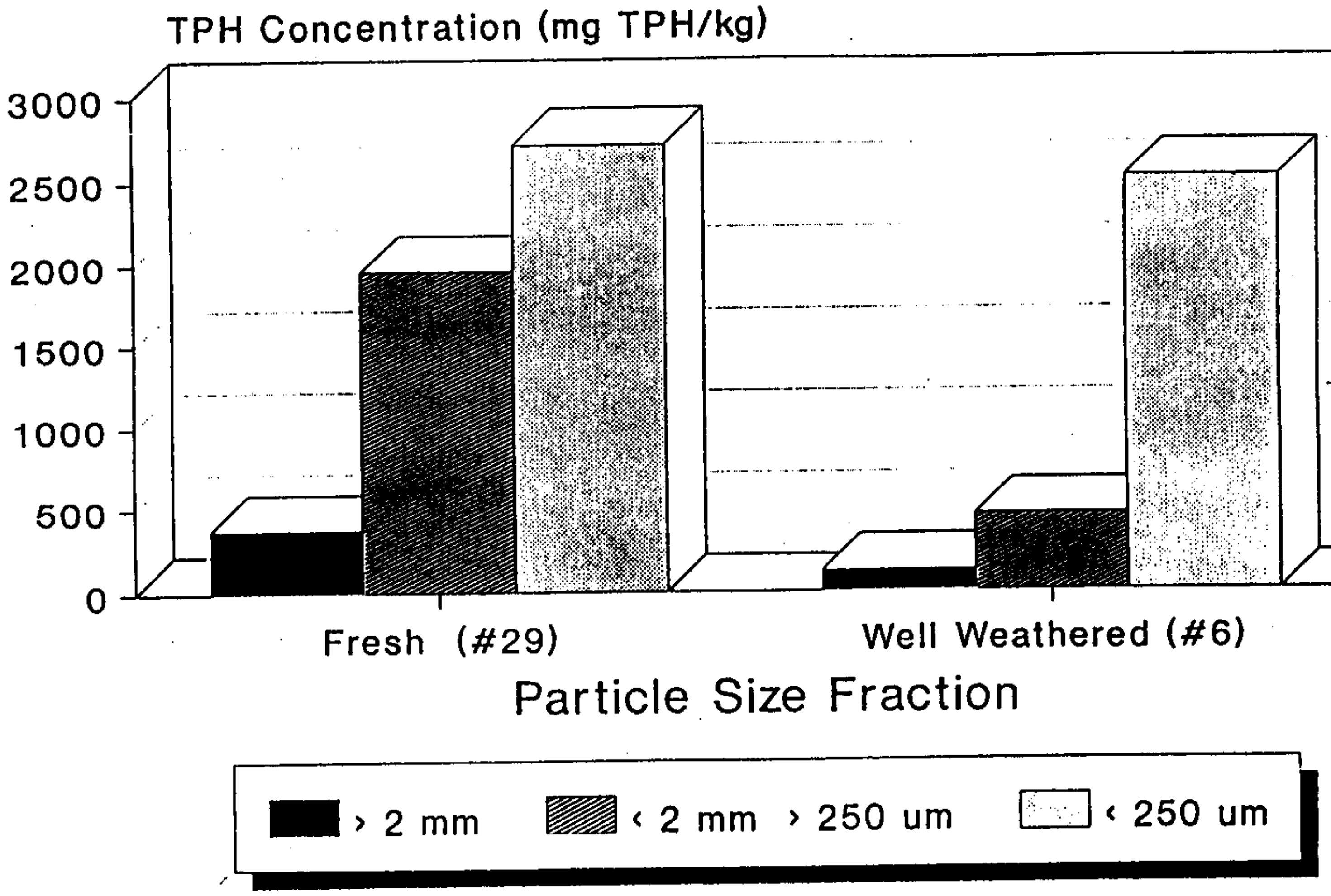
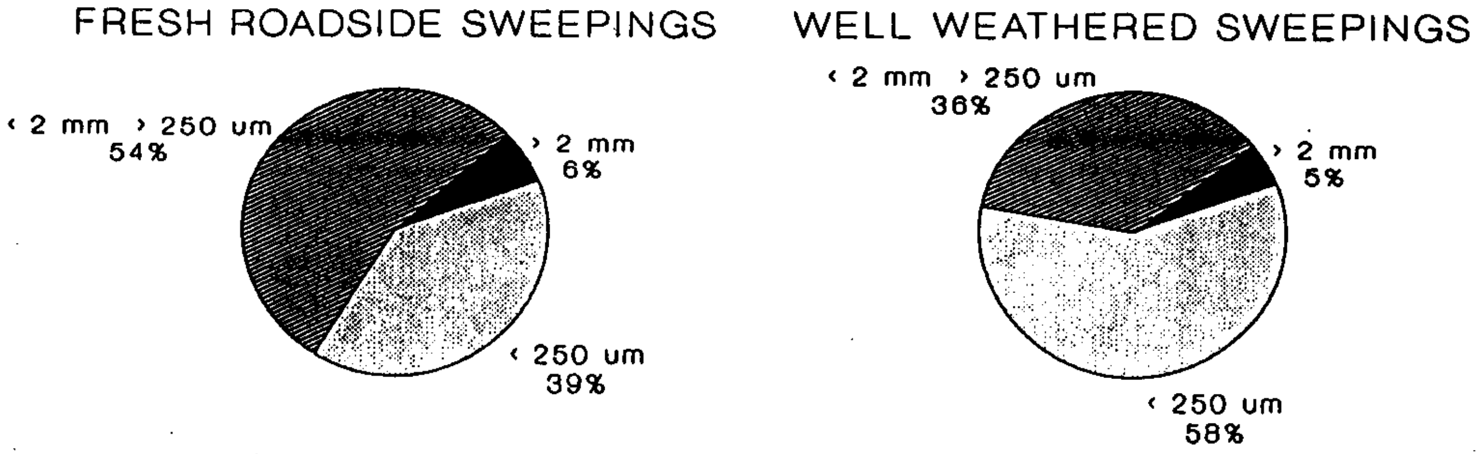


FIGURE 4. % CONTRIBUTION OF SAMPLE TPH CONCENTRATION BY PARTICLE SIZE FRACTIONS


FRESH ROADSIDE SWEEPINGS

WELL WEATHERED SWEEPINGS

(sample # 29)

(sample # 6)

PAH/PNA in Highway Waste Types. Polycyclic aromatic hydrocarbons (PAHs) or Polynuclear aromatic hydrocarbons (PNAs) constitute a class of hazardous organic compounds containing fused or condensed aromatic rings. The four and greater number condensed rings compounds are extremely carcinogenic. Sixty three PAH/PNA compounds have been isolated and identified. However, gas chromatography using the EPA recommended method 8100 in SW846 manual can detect and quantify sixteen individual PAH/PNA compounds. Using a more sophisticated gas chromatographic method 63 PAHs can be identified and quantified (14). The higher boiling point semi-volatile and non-volatile PAHs/PNAs must be detected by some other technique such as high performance liquid chromatography (HPLC) (27). The HPLC technique has certain disadvantages notably the lack of positive identification and sensitivity. Another technique in the developmental stage is an immunoassay method for total PAHs/PNAs.

Using EPA Method 8100, the incidence of PAH/PNAs in the various types of samples is shown in table 5.

INCIDENCE IN WASTE CATEGORIES. The highest incidence of PAH/PNAs was found in fresh road sweepings. Only half as much were present in the weathered road sweepings. This loss can be attributed to the same phenomena that caused the reduction in the TPH content of weathered sweepings. Half of the ditch spoils contained PAH/PNAs. This value is biased as only four samples were analyzed. This may also be true for the wet vactor sludges.

Table 6 summarized the data for the individual PAH/PNA compounds found in the Appendix.

Table 6 doesn't contain individual PAH/PNA data for dried vactor sludges as none were detected. The summarized information reveal that in only one sample of fresh road sweepings were the more volatile three condensed ring PAH/PNAs

Table 5 Incidence of PAHs in Waste Types

Waste Type	Occurrence of PAHs Percent
Fresh Road Sweepings	47
Well Weathered Sweepings	23
Wet Vactor Sludges	33
Dried Vactor Sludges	0
Ditch Spoils	50

TABLE 6 PAH CONCENTRATION IN HIGHWAY MAINTENANCE WASTES

PAH	Road Sweepings				Wet Vactor Sludge (ug/kg)		Ditch Spoils (ug/kg)	
	Fresh (ug/kg)		Weathered (ug/kg)					
	Arth. Av.	Range	Arth. Av.	Range	Arth. Av.	Range	Arth. Av.	Range
Acenaphthylene	448	448						
Acenaphthene	335	335						
Fluorene	530	530						
Phenathrene	2178	2178	385	350-420	363	363		
Anthracene	433	395-475	393	369-415	369	369	655	655
Fluoranthene	564	389-995	605	605				
Pyrene	728	397-1980	454	375-575	413	395-430	415	415
Benzo (a) anthracene	560	395-875	400	375-425				
Chrysene	350	350					375	375
Benzo (b) fluoranthene	433	410-465	508	410-605	375	375	856	856
Benzo (k) fluoranthene	393	375-410	399	375-438	475	475	395	395
Benzo (a) pyrene	406	352-467					350	350
Dibenzo (a,h) anthracene	387	387					350	350
Benzo (g,h,i) perylene							368	368

NOTE: Minimum detectable quantity for each PAHs = 330 ug/kg based on a 25 gram sample.

PAH/PNAs present.

PAH CONCENTRATIONS IN WASTE TYPES. The fresh road sweeping results were within the range found by Takada et al (12) in road dust on National Road Route 20 in Japan, but significantly less than that found in heavily trafficked roads in Tokyo, Japan. The three and four ring PAH/PNAs were the predominant forms found in this study as well as that found in the Japanese study. However, the fresh road sweepings results in Table 6 were significantly less compared to that found by Butler et al. (13) in a study of PAH/PNAs in surface soils in the vicinity of heavy vehicular traffic near the Midlands in England and that by the Blumer, et al. (12),(13), (14) in a correlation study of highway traffic and cancer incidence. Weathered road sweepings showed a 41 percent reduction in the total PAH/PNA concentration and in the number of individual PAH/PNA members. The greatest loss was in the three membered ring compounds PAHs/PNAs due to biodegradation. This was also observed by McKenna (28), Coover and Sims (29), Heitkemp, et al. (30) and by Sims, et al. (31) where they saw a reduction in the number of PAH/PNA members.

Wet vactor sludge and ditch spoils were found to contain PAHs/PNAs. Since the number of samples of these compounds was small, this would result in the bias of the quantified results, though PAHs/PNAs are present particularly in ditch spoils. This is confirmed by the work of Takada, et al. (12), Butler, et al. (14), and Blumer (28). Those PAHs/PNAs, which were detected in road vactor sludge, were slightly above detectable levels.

Microtox Toxicity Bioassay of Waste Types. The term used to measure the toxicity of a particular waste is the effective concentration 50 or EC50. This term can be defined as the percent of the sample required to cause a 50% reduction in the activity of Photobacterium phosphorium as measured by a reduction in the enzyme induced bioluminescence produced by the microorganism. The activity of the test microorganism is influenced by the presence of the toxic type of hazardous substances. The substances may be organic or heavy metals or mixtures of both. Many of the organics will disappear due to the various phenomena associated with weathering, ie. photolysis, vaporization, biodegradation, and leaching. The heavy metals are less likely to disappear as they are strongly adsorbed onto the particulate material or are part of the particle matrix. The final factor influencing the toxicity measurements are the presence of bactericides and bacteriostatic compounds produced by the indigenous soil microorganisms. Some of the more potent antibiotics are produced by several soil bacteria. It is not unusual for a microbial active soil free of hazardous substances to show a degree of toxicity. The factors just alluded to should be considered in reviewing the toxicity data in Table 7.

Table 7 summarized the microtoxicity data found in the Appendix. Arithmetic and geometric means are presented. Due to the wide range of values for all types of wastes the geometric mean was used for comparing data. The fresh road sweepings had a higher toxicity than the weathered sweepings. A reduction of 22.8% in toxicity between the fresh and weathered road sweepings were observed. The dried vactor sludge showed greater toxicity than the wet sludge due in large part to the high water content of the wet sludge. The geometric mean of the various types of waste did not differ too greatly in magnitude from each other. This can be attributed to the non-weathered toxic substances present.

Table 7 Effect of Weathering on Toxicity Bioassay Analysis

Waste Type	Effective Concentration, EC50		
	Arithmetic Mean	Geometric Mean	Range
Fresh Road Sweepings	13.21	8.95	1.04-40.8
Well Weathered Sweepings	24.65	12.88	4.60-100.00
Wet Vactor Sludges	13.00	10.40	3.55-35.00
Dried Vactor Sludges	9.49	8.97	6.96-14.30
Ditch Spoils	11.36	10.47	4.71-15.80

Relationship between TPH-PAHs/PNAs Microtox Toxicity test data. Individual sample TPH, PAH/PNAs concentrations and microtoxic toxicity test data appearing in the Appendix and average values in Table 4, 5, and 6 were compared. No relationship was found among the three parameters in the waste types. Sample having a high TPH did not necessarily have a high PAH/PNAs content and/or a low EC50 toxicity value. Nor was there found a relationship between the PAHs/PNA content and the EC50 toxicity test data.

Comparing the three parameters of weathered road sweepings to that of fresh road sweepings revealed a relationship does exist. The fresh sweeping had higher TPH, PAHs/PNAs and microtox toxicity values than weathered sweepings. This can be attributed to the loss of organic hazardous substances.

CHAPTER 4 WASTE CLEANUP & TREATMENT TECHNOLOGY SELECTION

As previously mentioned, the wastes generated by highway maintenance activities can be classified into one of three categories. Sweepings after removal from road surfaces are collected in small piles. These piles are periodically removed and taken to highway maintenance yards where they are combined with other sweeping. Wet vactor sludges are taken to the maintenance yard where they are allowed to dry. The dried sludge is added to the existing pile of waste material. Excess ditch spoils may also find their way onto the maintenance yards waste pile. Visual inspection of the waste piles reveal that materials are extremely heterogeneous. The solids range from material as large as plastic bottles to fine grained clay particles. The chemical composition similarly consists of a wide variety of hazardous and non-hazardous inorganic and organic compounds. In order to determine the most applicable treatment systems and their estimated cost, the following information must be known: quantity of waste, initial contaminant concentration, residual or targeted contaminant concentration after treatment, quantity of cleaned up waste, method of disposal of the cleaned up waste, special waste handling procedures, permitting, pretreatment, utility/fuel rates, labor costs and special site related costs. That which follows is a brief description of the treatment processes and the associated operation and maintenance costs for all systems except rotary kiln treatment. Rotary kiln treatment includes capital, operational and maintenance costs.

SIZE CLASSIFICATION

As mentioned in the waste characterization section of this report, 5 to 6 percent of the TPHs are found in the greater than 2 mm fraction. Due to this low contaminant concentration a size classification or particle size pretreatment is recommended. The particle size range separation will depend on the final or targeted contaminant concentrations desired. Size classification will reduce the amount of waste to be treated, thereby effecting the cost of treatment.

Mechanical vibrating screens. Several size separation treatment methods are available. One is the mechanical vibrating screen. The apparatus consists of a series of rectangular screens stacked in descending screen size openings. The screens are placed in frames with the frames set at an incline in the apparatus. Waste is applied to the head of the top screen while the screens are vibrating. The solid particles smaller than the screen openings fall through to the next lower screen. The solids that are retained on the screen travel down to the bottom of the screen where they are collected. Typical vibrating screens are used to separate particles ranging from 1/8 inch to 6 inches in diameter. Although separating efficiencies can be as high as 95% some fine size particles mechanically adhere on large size particles. These fine grain particles may contain high levels of the hazardous contaminants which are carried on the large size particles. To overcome the problem of mechanical adhesion, the solid waste can be suspended in water thereby removing the fine particles. Another approach is to spray the solids with a high pressure jet of water as the solids move down the screen. Where water is used to separate the mechanically adhered particles, provisions must be made to collect and treat the carrier or wash water before reuse or disposal.

Wedge bar screen. Another type of size separation apparatus is the wedge bar screen. The wedge bar screen consists of a series of vertical bars with knife edges. The bars are placed in the apparatus to give a curved surface. The dry solids must be suspended in water prior to size separation. As the aqueous suspension of waste solids flows tangentially over the screen's surface, centrifugal force results. The water and solids having a diameter smaller than the bars space openings will fall through the openings. The water and solids are collected. The solids are separated using conventional sedimentation treatment units. The spacing between the bars can be varied which makes this unit more flexible in its use. The wedge bar can be modified where a high pressure water spray is applied. This action brakes up the clumps of waste and mechanically removes adhered small particles from the large particles. The wedge bar is less efficient in particle removed than the vibrating screen. Comparative costs have shown that the capital cost of the wedge bar screen is greater than the vibrating screen.

Hydroclassifiers. Another type of size separation treatment system is the hydroclassifier. Hydroclassifiers are separation units used in the separation of sand and gravels from slurries according to their densities. Hydroclassifiers are rectangular tanks with "V" shaped bottoms. The slurry is fed into the head end of the tank. As the slurry flows to the opposite end of the tank solids settle out according to the particle size resulting from the different settling velocities. The settling velocity is dependent on the specific density of the solid particles and the tank flow through rate. Solids with lower specific density progressively settle out along the length of the tank. Splitter gates are used to selectively assist in the removal of specific gravity solids. Inorganic solids ranging from 3/8 inch to about 75 micron can be separated. If solids greater than 3/8 inch are present, pre-screenings is required. A major disadvantage with hydroclassifier is the inability to handle slurries with high solids concentration.

Other types. Other types of size separation treatments units are available. All required the use of slurries or suspensions containing a settleable solids content of less than 30%. They work best using a more homogeneous composition of solid material. This is due to the difference in the size-density relationship between organic and inorganic solids.

Because of the extreme heterogeneity of the road maintenance waste solids in composition and particle size, the mechanical vibrating screens would be most suited for classification of the road sweepings, vactor sludges, or ditch spoils singly or in combination. Cost estimates reveal that at the vibrating screen treatment unit has the least capital and operational costs. However, if abrasive material is present there may be undue wear on the screen. This would result in more than normal screen replacement.

SOLIDS CLEANUP

Highway maintenance wastes contain a vast number of semi-volatile and non-volatile organic compounds. Because of the diversity of compounds a non-selective treatment method for complete destruction or detoxification is required. The choice of treatment technology may be influenced by state and/or federal regulations. The following treatment methods will be described and their merits discussed: thermal destruction treatment, chemical oxidation, solvent extraction, soil (solids) washing, and bioremediation.

Cost considerations. An attempt was made to determine capital and operational costs for each of the above technologies. Cost estimates using the Mean Guide (32), the Dodge Guide (33), and EPA's Remedial Action Cost Compendium (34) were consulted. In addition, the use of cost estimating software as G.A. Rich's Cost Estimating Spread Sheet for Pollution (35), EPA's cost of Remedial Action CORA (36), and EPA's VISITT (37) were used. It was concluded that a relative cost ranking system would be used due to the large non-comparative site specific factors, i.e. location, quantity of the material to be treated at each location, and variability in composition of material through the waste pile. Since the maintenance yards storing the waste are found in widely scattered locations throughout the state, it would be desirable that the treatment system be mobile. In addition the treatment technology must be relatively simple with a short start up and shut down time.

Thermal destruction treatment. There are two types of thermal systems used to destroy or recover the hazardous organic compounds in solid wastes. The low temperature systems operate at a temperature of 450 to 810° F. There are several types of low temperature thermal units, however they are all designed to treat volatile and low boiling semi-volatile organic compounds. These compounds are not generally found to accumulate in highway maintenance waste, i.e. road sweepings, vactor sludges, and ditch spoils. Because of the preponderance of middle and high boiling semi-volatile and non-volatile compounds in the highway maintenance waste, low temperature thermal systems will not be considered.

High temperature thermal systems that operate at 1400 to 1800°F are capable of destroying all types of organic material found in highway maintenance wastes. Rotary kiln incinerators are highly versatile and can be transported from site to site. This type of incinerator operates on batch feeding using either a ram or screen type feeder with typical feed rates of 1300 to 1400 lbs/day. Most rotary kiln incinerators have a dual chamber. In the primary chamber the operating temperature is about 1400°F. Here is where some of the organic compounds are destroyed while others are volatilized. The more volatile heavy metals, e.g. lead, cadmium, and mercury are also volatilized. The gases from the primary chamber are sent to a secondary chamber where the refractory organics e.g. PAHs/PNAs and Dioxins are destroyed and the non-volatile heavy metals are calcined into a more stable form. Due to the large heat sink capacity of the inert material in the highway maintenance waste and the highly variable heat value of the waste, auxiliary heating would be required. Fuel oil is generally used to supply the added fuel to sustain the combustion temperatures. As the waste moves through the kiln, the organic material will be destroyed and the solid material or ash will collect at the bottom of the kiln and drop into a hopper. Here the hot ash is cooled by water. The cooled solids can be disposed in landfills or used as roadfill provided the total and leachable heavy metal meets federal and state regulations. The gases from the combustion of the organics will require further treatment for the removal of fly ash, condensed heavy metal vapors and acidic compounds by conventional air quality abatement devices. All devices ie. kiln, stack gas cleanups, solids or ash disposal or reuse, and hot ash quenching equipment must be taken into account in cost estimating. Cost is not only site specific but depends on the volume of waste and the characteristics of the waste being treated. Using the CORA (36) estimating cost software for estimating cost of a small rotary kiln incinerator, certain assumptions were made. The maximum capacity of the kiln was 5,600 lbs/hr. processing 1000 lbs/hr. The waste was a mixed solid waste having an assumed heat value of 500 BTU/lb and a moisture content of 10%. The primary combustion chamber was held at a temperature of 1600°F with an average air temperature of 55°F. To maintain these chamber temperatures, 89 gallons of fuel oil per hour, 10,500 lbs of air and 144 kw per hour of total power would be required. The maximum time that this treatment unit would be at any one site would be two weeks. The total cost (capital and operational, maintenance costs) would be $1,500,000 to treat 1000 lbs of waste/hour. Cost will vary with change in any of the assumed specified values. Leasing of a mobile rotary kiln incinerator rather than purchase of the incinerator would be an option to be considered. However, in the long run it would not be cost effective as the waste generation is continuous and non-ending.

Chemical oxidation. Another method of destroying hazardous organic compounds is through the use of high energy oxidants. The two most investigated oxidants for complete or partially destroying organic compounds are ozone and hydrogen peroxide. Total destruction of all organic compounds does not occur. Partially oxidized organic compound in many cases can be biologically degraded by microorganisms.

Of the two oxidants, ozone is the most reactive and as a gas must be generated on-site. A water medium is required for ozone to react with solid organics. The treatment consists of either the solids are slurried and ozone bubbled into the aqueous suspension or an aqueous solution of ozone is added to the dry solids. The contact time between the organic material and ozone is very limited as ozone rapidly decomposes in water. The other oxidant, hydrogen peroxide has been used to a greater extent than ozone as a chemical oxidation. However, it is a weaker oxidant than the ozone. Hydrogen peroxide oxidation totally destroys less organic compounds than ozone, but produces more partially oxidized organics.

Commercial hydrogen peroxide is available in aqueous solution ranging from 3 to 50 percent. It has been observed that both chemical oxidants work most effectively with slurried homogeneous wastes and where the chemical characteristics of the feed is constant. The equipment used for chemical oxidation consist of chemical storage and make up tanks, chemical feeders, contact tank with agitators, settling tanks, treated solid dewatering device, and spent water holding tanks. To reduce the size of the chemical feeders a concentrated solution of oxidants must be used and the solid waste slurried. Numerous bench scale studies using hydrogen peroxide in the treatment of refractory wastewaters and slurries have been performed (38) (39). However, full scale or pilot plant scale operation information is not available. As a result capital cost for such treatment system is not available. In conversations with Dr. R. Watts (40), he has estimated that operational costs to be $50 to $150 per ton to treat road sweepings. The major operational cost being hydrogen peroxide solution. The amount of hydrogen peroxide used will depend on the peroxide demand of the highway maintenance waste plus other factors such as quantity of waste to be treated.

Ozone has been used as an oxidant primarily for the treatment of hazardous organic compounds in wastewater. Due to ozone's high oxidative potential, the equipment required must be fabricated from more costly materials than that used for hydrogen peroxide. Operation cost for ozone can be as high as one and half times the cost of hydrogen peroxide treatment.

In considering the use of chemical oxidation for the treatment of highway maintenance waste solids, all liquid wastewaters which result will require treatment. These liquid waste waters may contain partially oxidized and refractory organics and leached heavy metals. The degree of additional treatment required will depend on the permitted concentration of specific pollutants that may be discharged. Provisions must be provided for the disposal of the treated solids.

Solvent extraction. Several full scale solvent extraction systems are currently being used for the removal of organics form soil and sludges. Basically, these systems use a hydrophobic organic solvent for the removal of organic and metallorganic compounds from contaminated solids. Several methods require the slurrying of the solids prior to extraction. The extracting solvent is sent countercurrent to the movement of the slurry or solids. The contaminant enriched solvent is redistilled and used over. The still bottom comprising about 1 to 5 percent of the volume of extracting solvent and containing the contaminant is incinerated or encapsulated. The extracted solids are relatively free of contaminants and can be used as fill or taken to a sanitary landfill as cover.

A variety of solvent extraction modifications are available. One uses a dual solvent extraction system. This method uses a special solvent pair, one for extracting the other for concentrating the contaminants allowing for an extremely efficient and versatile solids decontamination. No cost estimate is available for a trailer mounted commercial full scale system. The mobile unit should be able to treat 100 to 500 lbs of solids per hour. Another system designed primarily to extract organics from soil can also remove metals if they are in the form of sulfides or carbonates. This system can operate at two and a half tons per hour at a cost of

$130.00 to $900/ton. With this system, the solids are continuously extracted with the solvent in a countercurrent process. The contaminants dissolve in the solvent. The contaminated solvent is reclaimed by distillation in a closed loop circuit. The cleaned solids are removed to a closed loop drain system when any excess solvent is removed from the solids leaving them clean and dry.

The final solvent extraction method described uses a triethylamine solvent. This solvent is biodegradable working best with slurries. The operational cost for this system is between $100 to $400 per ton.

Solids washing. Soil or solids washing is a method developed in the Netherlands and used extensively in Europe. This method consists of bringing the contaminated solids in contact with an aqueous surfactant (detergent) solution. The contaminants are removed from the particle surface in a series of washings. The solids in the water suspension are allowed to settle after each washing step. After the final washing step, the solids are rinsed free of surfactant. The solids are dewatered, dried and used as a fill material or disposed of into a sanitary landfill. The spent contaminated enriched wash waters are treated to destroy the organic material by biological treatment, while the inorganics are removed by precipitation or fixation. The water is then recycled back into the system as make up water for the surfactant solution. In the short time that this cleanup method has been introduced in this country, several modified washing methods have been introduced. Most modifications require size classification pretreatment, e.g. vibrating mechanical screens.

One solids washing method takes the contaminated solids and slurries it with an aqueous solution of surfactant and surfactant aids in a clarifier. The slurry is sent through a shearing device and sized using a vibrating mechanical screen. The screen has a spray system to remove mechanically adsorbed particulates from large rocks and debris. The screened material is sent to a second clarifier where jet mixers (venturi) provide the scrubbing action and suspension. The treated slurry goes through a series of hydrocyclones for liquid solids separation. The solids are dewatered, dried and disposed. The liquids are sent through a biological filter. The estimated operational costs are from $7.00 to $30.00 per ton.

Another solids washing method utilizes a washing process used in mining and enhanced oil recovery. A series of size fractionation and chemical hydration steps are used to accomplish this separation. The second step in this process involves the dissolution of certain contaminants into the washing solution and the dispersion of other contaminants into the solution. The cleaned solids are separated from the wash solution through a series of steps until the residual moisture content of the solids is reduced to 3 to 15%. The cleaned soil can be used for fill or disposed into a sanitary landfill. Estimated operational costs for this system is from $60 to $120/ton.

Several pilot studies have been conducted showing the applicability of solid washing cleanup methodology for remediation of contaminated soils (41). A study recently concluded at the Burlington Northern Railroad Company's Minnesota maintenance facility showed the applicability of this technology in cleaning up lubrication oil, greases and other TPH contaminated soils (42).

Bioremediation. Bioremediation is a process whereby microorganisms detoxify or destroy hazardous organic substances. All such technologies require oxygen in some form, moisture, microbial nutrients, and environmental modifiers, and in many instances an innoculum and heat. There are four types of such system: the bioreactor, bioenvelope, land farming and composting.

BIOREACTORS. The initial step in using bioreactors is to place the sized and slurried solids into the bioreactor vessel. Environmental modifiers and microbial innoculum are added if needed. Microbial nutrients are added in all cases. The slurry plus additives are agitated causing the mixture to become aerated and causing an even distribution of additives throughout the vessel. Microbial degradation is allowed to continue until contaminant levels meet or exceed regulatory guidelines. The operational cost for this type of biodegradation is from $40 to $100/ton.

BIOENVELOPE. The bioenvelope method consists of spreading the sized contaminated solids on a geomembrane liner. The microbial innoculum, environmental modifiers, microbial nutrients, and water is tilled into the contaminated solids. A second geomembrane supported by a framework covers the contaminated material. Oxygen is supplied either by pumping air into a system through perforated pipes buried in the contaminated solids or by having inlet fans under the top liner blowing air over the contaminated solids. The exhaust or off gas from the system may have to be collected and sent through an activated carbon adsorber if any hazardous volatile organics are present. The estimated cost of this type of treatment is $25 to $100/cubic yard.

LAND FARMING. Land farming is a modification of the bioenvelope method. Land farming involves the controlled application of the contaminated solids into the upper soil zone. The contaminated solids, microbial nutrients and a supplemental easily biodegradable material are tilled into the soil to a depth of about 6 inches. Water and a microbial innoculum are added as needed. Physical, chemical, and biological processes take place. The land farming area can be left open where the weather conditions permit such an operation. The estimated cost of the open system is $15 to $35 per cubic yard. Where adverse weather can be encountered e.g. cold temperature and/or rain the system can be enclosed, similar to the bioenvelope. In total enclosed systems, an air distribution system, a vapor recovery system must be provided. In both the open and closed systems, additional water and nutrients must be included. The estimated cost for the closed system is $50 to $100 per cubic yard.

COMPOSTING. The final bioremediation method is composting. The contaminated solids are prepared by size classification. The large solids as stones and other non-reactive material are removed prior to composting. The contaminated material is mixed with actively composting material to give the desired carbon to nitrogen ratio for optimal composting conditions. The contaminated solids and the active compost are mixed and placed on prepared beds for composting. Air is pulled through the compost pile via a perforated pipe in the compost pile. The temperature in the pile is controlled by the rate of the air flow through the compost. Moisture is added and environmental modifiers are added as required. After 4 to 8 weeks the compost materials are removed. A part of the inoculum material is used as the active compost to be mixed with a new batch of untreated contaminated solids. The remainder of the compost is placed in a curing pile to allow biodegradation of the more refractory hazardous organic compounds. The estimated operational costs for composting is from $32 to $100 per cubic yard.

Factors affecting remediation selection. A limitation that all biological treatment technologies posses is that they are slower in achieving the specified degree of remediation than other treatment technologies. Any factors which impede biological activity such as the presence of toxic amounts of heavy metals limits the use of this technology. On the positive side, the capital cost of most bioremediation are considerably less than any other system.

The cleanup methods described in this section were selected for the simplicity, mobility or ease of construction and applicability to treat a variety of organic and inorganic compounds. Other treatment technologies are available however, they are still in the developmental stage hence cost of operation is not available. Capital costs, except for the rotary kiln incinerator, are highly variable and size specific. Therefore these costs, although major, were not given. These costs can be obtained from vendors once the quantity of waste in the piles is determined. Another factor to be considered is the cost of leasing equipment vs. outright purchase. A summary of the various types of waste clean-up and treatment technologies with their operational costs, advantages, and disadvantages are found in table 8.

Table 8 Waste Clean-Up and Treatment Technologies

PROCESS	COST*	QUANTITY	ADVANTAGES**	DISADVANTAGES**
Thermal Destruction (rotary kiln incineration)	$1,500,000	1000 LBS/HR	Removes a variety of waste products	Not very mobile, High capital and O/M cost
Chemical Oxidation	$50-$100	Ton	Quick Method	Not yet a full scale process, Post treatment required, Moderate O/M cost
Solvent Extraction (Organics Removal)	$130-$900	Ton	Removes most organic compounds and some metals, solvent recyclable	Moderate O/M cost
Solvent Extraction (Triethylamine)	$100-$400	Ton	Solvent is biodegradable	Moderate O/M cost
Solids Washing	$7-$30	Ton	Proven Technology, Low O/M cost	Multi-step Process
Solids Washing and drying	$60-$120	Ton	Cleaned soil can be used as fill	Moderate O/M cost
Bioremediation	$40-$100	Ton	Enclosed system, low O/M cost	Slow method
Bioenvelope	$25-$100	Ton	Enclosed system, low O/M cost	Not a mobile system, slow method
Land Farming (Open)	$15-$35	Cubic Yard	Simple system, low O/M cost	Takes a lot of space, not a mobile operation, slow method
Land Farming (Closed)	$50-$100	Cubic Yard	Faster process than open system with more control on process	More complex system, not mobile, higher cost than open system, slow method
Composting	$32-$100	Cubic Yard	Simple, cheap system Low O/M cost	Slow method, not mobile

*All costs are operational costs, except for thermal destruction which includes capital and first years operation costs.
**O/M cost are operational and maintenance costs.

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Appendix. Site Description and Analytical Results.

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 1　　Sample type: Road Sweepings

Sample Date: 06/26/90　　District No.: 6

Sample Pile Location: Spokane, Sprague Ave. & I-90 Interchange

Origin of Material: Collected along I-90 in Spokane

Misc. Remarks: Fresh sweepings found along highway

Results of Analysis:

Total Petroleum Hydrocarbon (TPH)
(wet basis) (mg/kg) Run 1: 4134

Run 2: 4180

Average: 4157

Polynuclear Aromatics (PNA/PAH)
(ug/kg)

Naphthalene: 330 U
Acenaphthylene: 330 U
Acenaphthene: 330 U
Fluorene: 330 U
Phenathrene: 410 J
Anthracene: 395 J
Fluoranthrene: 421 J
Pyrene: 432 J
Benzo(a)anthracene: 330 U
Chrysene: 330 U
Benzo(b)fluoranthene: 425 J
Benzo(k)fluoranthene: 330 U
Benzo(a)pyrene: 330 U
Indeno(1,2,3-cd)pyrene: 330 U
Dibenzo(a,h)anthracene: 330 U
Benzo(g,h,i)perylene: 330 U

Microtox-Toxicity (%)

EC50: 4.39 (2.6 to 7.4)
TU50: 22.8 (13.5 to 38.4)

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 2 Sample type:Road Sweepings

Sample Date: 06/26/90 District No.: 6

Sample Pile Location: Spokane-Pines St. Maintenance Yard

Origin of Material: From pile along I-90 (East Spokane)

Misc. Remarks: Weathered road sweepings at disposal site

Results of Analysis:

Total Petroleum Hydrocarbon (TPH)
(wet basis) (mg/kg) Run 1: 939

Run 2: 902

Average: 921

Polynuclear Aromatics (PNA/PAH)
(ug/kg)

Naphthalene: 330 U
Acenaphthylene: 330 U
Acenaphthene: 330 U
Fluorene: 330 U
Phenathrene: 330 U
Anthracene: 350 J
Fluoranthene: 330 U
Pyrene: 330 U
Benzo(a)anthracene: 330 U
Chrysene: 330 U
Benzo(b)fluoranthene: 410 J
Benzo(k)fluoranthene: 330 U
benzo(a)pyrene: 330 U
Indeno(1,2,3-cd)pyrene: 330 U
Dibenzo(a,h)anthracene: 330 U
Benzo(g,h,i)perylene: 330 U

Microtox-Toxicity (%)
EC50: 7.3 (3.2 to 16.9)
TU50: 13.6 (6.0 to 31.4)

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 3

Sample type: Mixture of road sweepings and vactor sludge

Sample Date: 06/26/90

District No.: 6

Sample Pile Location: Spokane-Pine St. maintenance yard

Origin of Material: Pile from along I-90 (East Spokane)

Misc. Remarks: Pile next to large pile (sample no.2)

Results of Analysis:

Total Petroleum Hydrocarbon (TPH)
(wet basis) (mg/kg)

Run 1: 312

Run 2: 684

Average: 498

Polynuclear Aromatics (PNA/PAH)
(ug/kg)

Naphthalene:	330 U
Acenaphthylene:	330 U
Acenaphthene:	330 U
Fluorene:	330 U
Phenathrene:	330 U
Anthracene:	395 J
Fluoranthene:	330 U
Pyrene:	375 J
Benzo(a)anthracene:	425 J
Chrysene:	330 U
Benzo(b)fluoranthene:	330 U
Benzo(k)fluoranthene:	375 J
benzo(a)pyrene:	330 U
Indeno(1,2,3-cd)pyrene:	330 U
Dibenzo(a,h)anthracene:	330 U
Benzo(g,h,i)perylene:	330 U

Microtox-Toxicity (%)

EC50: 4.6 (2.3 to 8.8)
TU50: 21.7 (11.3 to 41.9)

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 4 Sample type: Road sweepings

Sample Date: 06/26/90 District No.: 6

Sample Pile Location: Spokane WA. Highway 195 Exit and I-90

Origin of Material: Collected from small pile along I-90

Misc. Remarks: Fresh sweepings found along the roadside

Results of Analysis:

Total Petroleum Hydrocarbon (TPH)
(wet basis) (mg/kg) Run 1: 3520

Run 2: 3170

Average: 3345

Polynuclear Aromatics (PNA/PAH)
(ug/kg)

Naphthalene:	330 U
Acenaphthylene:	330 U
Acenaphthene:	330 U
Fluorene:	330 U
Phenathrene:	330 U
Anthracene:	330 U
Fluoranthene:	330 U
Pyrene:	330 U
Benzo(a)anthracene:	330 U
Chrysene:	330 U
Benzo(b)fluoranthene:	410 J
Benzo(k)fluoranthene:	330 U
Benzo(a)pyrene:	330 U
Indeno(1,2,3-cd)pyrene:	330 U
Dibenzo(a,h)anthracene:	330 U
Benzo(g,h,i)perylene:	330 U

Microtox-Toxicity (%)

EC50: 40.8 (2.0 to 930)
TU50: 2.45 (0.11 to 55.8)

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 5　　Sample Type: Road sweepings

Sample Date: 06/26/90　　District No. 6

Sample Pile Location: Spokane, I-90 & Hamilton Ave. Interchange

Origin of Material: Along I-90 in central Spokane

Misc. Remarks: Fresh road sweepings in a pile along the highway

Results of Analysis:

Total Petroleum Hydrocarbon (TPH)
(wet basis) (mg/kg) Run 1: 2356
Run 2: 2466
Average: 2411

Polynuclear Aromatics (PNA/PAH)
(ug/kg)

Naphthalene:	330 U
Acenaphthylene:	330 U
Acenaphthene:	330 U
Fluorene:	330 U
Phenathrene:	350 J
Anthracene:	475 J
Fluoranthene:	450 J
Pyrene:	330 U
Benzo(a)anthracene:	410 J
Chrysene:	350 J
Benzo(b)fluoranthene:	465 J
Benzo(k)fluoranthene:	330 U
benzo(a)pyrene:	350 J
Indeno(1,2,3-cd)pyrene:	330 U
Dibenzo(a,h)anthracene:	330 U
Benzo(g,h,i)perylene:	330 U

Microtox-Toxicity (%)
EC50: 9.5 (3.1 to 28.7)
TU50: 10.55 (3.48 to 32.00)

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 6 Sample type: Road sweepings

Sample Date: 06/26/90 District No.: 6

Sample Pile Location: Spokane WA. Geiger Maintenance Yard

Origin of Material: Collected along I-90 (West of Spokane)

Misc. Remarks: Large well weathered pile

Results of Analysis:

Total Petroleum Hydrocarbon (TPH)
(wet basis) (mg/kg)

Run 1:	937
Run 2:	900
Average:	919

Polynuclear Aromatics (PNA/PAH)
(ug/kg)

Naphthalene:	330 U
Acenaphthylene:	330 U
Acenaphthene:	330 U
Fluorene:	330 U
Phenathrene:	420 J
Anthracene:	330 U
Fluoranthene:	397 J
Pyrene:	415 J
Benzo(a)anthracene:	375 J
Chrysene:	330 U
Benzo(b)fluoranthene:	330 U
Benzo(k)fluoranthene:	383 J
benzo(a)pyrene:	330 U
Indeno(1,2,3-cd)pyrene:	330 U
Dibenzo(a,h)anthracene:	330 U
Benzo(g,h,i)perylene:	330 U

Microtox-Toxicity (%)

EC50:3.5 (2.75 to 4.46)
TU50:28.6 (22.4 to 36.3)

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 7 Sample type: Ditch spoils

Sample Date: 07/10/90 District No.: 4

Sample Pile Location: Vancouver WA. 139th Ave. Stockpile

Origin of Material: Along I-5 (north of Vancouver)

Misc. Remarks: Collected during a construction project.

Results of Analysis:

Total Petroleum Hydrocarbon (TPH)
(wet basis) (mg/kg) Run 1: 272

Run 2: 438

Average: 355

Polynuclear Aromatics (PNA/PAH)
(ug/kg)

Naphthalene:	330 U
Acenaphthylene:	330 U
Acenaphthene:	330 U
Fluorene:	330 U
Phenathrene:	330 U
Anthracene:	330 U
Fluoranthene:	330 U
Pyrene:	330 U
Benzo(a)anthracene:	330 U
Chrysene:	330 U
Benzo(b)fluoranthene:	330 U
Benzo(k)fluoranthene:	330 U
benzo(a)pyrene:	330 U
Indeno(1,2,3-cd)pyrene:	330 U
Dibenzo(a,h)anthracene:	330 U
Benzo(g,h,i)perylene:	330 U

Microtox-Toxicity (%)

EC50: 4.71 (4.18 to 5.30)
TU50: 21.2 (18.85 to 23.93)

SAMPLE DESCRIPTION AND ANYSIS SUMMARY

Sample No.: 8 Sample Type: Ditch spoils

Sample Date: 07/09/90 District No.: 4

Sample Pile Location: Vancouver WA., 139th Av. Stockpile

Origin of Material: From pile along I-5 north of Vancouver

Misc. Remarks:

Results of Analysis:

Total Petroleum Hydrocarbon (TPH)
(wet basis) (mg/kg) Run 1: 350

Run 2: 559

Average: 455

Polynuclear Aromatics (PNA/PAH)
(ug/kg)

Naphthalene:	330 U
Acenaphthylene:	330 U
Acenaphthene:	330 U
Fluorene:	330 U
Phenathrene:	363 J
Anthracene:	330 U
Fluoranthene:	425 J
Pyrene:	430 J
Benzo(a)anthracene:	330 U
Chrysene:	330 U
Benzo(b)fluoranthene:	350 U
Benzo(k)fluoranthene:	475
Benzo(a)pyrene:	330 U
Indeno(1,2,3-cd)pyrene:	330 U
Dibenzo(a,h)anthracene:	330 U
Benzo(g,h,i)perylene:	330 U

Microtox-Toxicity (%)

EC50: 15.8 (0.1 to 248.2)
TU50: 6.3 (0.0 to 99)

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 9 Sample type: Road sweeping

Sample Date: 07/09/90 District No.: 4

Sample Pile Location: Washougal WA. Maintenance Yard

Origin of Material: Sweepings from Hwy 14 near Washougal

Misc. Remarks: Reminants of a road sweepings pile

Results of Analysis:

Total Petroleum Hydrocarbon (TPH) (wet basis) (mg/kg)

Run 1:	18363
Run 2:	17150
Average:	17757

Polynuclear Aromatics (PNA/PAH) (ug/kg)

Naphthalene:	330 U
Acenaphthylene:	330 U
Acenaphthene:	330 U
Fluorene:	330 U
Phenathrene:	350 J
Anthracene:	369 J
Fluoranthene:	330 U
Pyrene:	450 J
Benzo(a)anthracene:	330 U
Chrysene:	330 U
Benzo(b)fluoranthene:	330 U
Benzo(k)fluoranthene:	438 J
Benzo(a)pyrene:	330 U
Indeno(1,2,3-cd)pyrene:	330 U
Dibenzo(a,h)anthracene:	330 U
Benzo(g,h,i)perylene:	330 U

Microtox-Toxicity (%)

EC50: 65.6 (34.6 to 124.2)
TU50: 1.52 (0.8 to 2.9)

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 11 Sample type: Vactor sludge

Sample Date: 07/12/90 District No.: Spokane County

Sample Pile Location: Spokane County District 4 maintenance yard

Origin of Material: Dry well in east Spokane County

Misc. Remarks: Sample taken upslope from sample #10

Results of Analysis:

Total Petroleum Hydrocarbon (TPH)
(wet basis) (mg/kg) Run 1: 1612

Run 2: 3012

Average: 2312

Polynuclear Aromatics (PNA/PAH)
(ug/kg)

Naphthalene:	330 U
Acenaphthylene:	330 U
Acenaphthene:	330 U
Fluorene:	330 U
Phenathrene:	330 U
Anthracene:	330 U
Fluoranthene:	330 U
Pyrene:	330 U
Benzo(a)anthracene:	330 U
Chrysene:	330 U
Benzo(b)fluoranthene:	330 U
Benzo(k)fluoranthene:	330 U
Benzo(a)pyrene:	330 U
Indeno(1,2,3-cd)pyrene:	330 U
Dibenzo(a,h)anthracene:	330 U
Benzo(g,h,i)perylene:	330 U

Microtox-Toxicity (%)

EC50: 14.2 (0.7 to 302.9)
TU50: 7.1 (0.3 to 151.4)

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 12 Sample Type: Road Sweepings

Sample Date: 07/12/90 District No.: Spokane County

Sample Pile Location: Spokane County District #1 Maintenance Site

Origin of Material: North Spokane County

Misc. Remarks: Fresh sweepings with vegetation

Results of Analysis

Total Petroleum Hydrocarbon (TPH)
(wet basis) (mg/kg) Run 1: 1200

Run 2: 769

Average: 985

Polynuclear Aromatics (PNA/PAH)
(ug/kg):

Naphthalene: 330 U
Acenaphthylene: 330 U
Acenaphthene: 330 U
Fluorene: 330 U
Phenathrene: 330 U
Anthracene: 330 U
Fluoranthene: 330 U
Pyrene: 330 U
Benzo(a)anthracene: 330 U
Chrysene: 330 U
Benzo(b)fluoranthene: 330 U
Benzo(k)fluoranthene: 330 U
benzo(a)pyrene: 467 J
Indeno(1,2,3-cd)pyrene: 330 U
Dibenzo(a,h)anthracene: 330 U
Benzo(g,h,i)perylene: 330 U

Microtox-Toxicity (%)

EC50: 4.04 (3.4 to 4.8)
TU50: 24.8 (20.8 to 29.3)

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 13
Sample Type: Road Sweepings

Sample Date:07/12/92
District No.: Spokane County

Sample Pile Location: Spokane County District #4 Maintenance Site

Origin of Material: East Spokane County

Misc. Remarks: Fresh sweepings upslope of sample #11

Results of Analysis

Total Petroleum Hydrocarbon (TPH)
(wet basis) (mg/kg) Run 1: 4071

Run 2: 3965

Average: 4018

Polynuclear Aromatics (PNA/PAH)
(ug/kg):

Naphthalene: 330 U
Acenaphthylene: 330 U
Acenaphthene: 330 U
Fluorene: 330 U
Phenathrene: 330 U
Anthracene: 330 U
Fluoranthene: 330 U
Pyrene: 330 U
Benzo(a)anthracene: 330 U
Chrysene: 330 U
Benzo(b)fluoranthene: 330 U
Benzo(k)fluoranthene: 330 U
benzo(a)pyrene: 330 U
Indeno(1,2,3-cd)pyrene: 330 U
Dibenzo(a,h)anthracene: 330 U
Benzo(g,h,i)perylene: 330 U

Microtox-Toxicity (%)

EC50: 7.35 (3.60 to 15.01)
TU50: 13.60 (16.66 to 22.75)

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 14

Sample Type: Ditch Spoils

Sample Date: 07/09/92

District No.: 4

Sample Pile Location: Kelso WA., I-5 southbound Milepost 42

Origin of Material: Ditches along I-5 in the Kelso area

Misc. Remarks:

Results of Analysis

Total Petroleum Hydrocarbon (TPH) (wet basis) (mg/kg)

Run 1:	2451
Run 2:	2630
Average:	2540

Polynuclear Aromatics (PNA/PAH) (ug/kg):

Naphthalene:	330 U
Acenaphthylene:	330 U
Acenaphthene:	330 U
Fluorene:	330 U
Phenathrene:	330 U
Anthracene:	369 J
Fluoranthene:	330 U
Pyrene:	395 J
Benzo(a)anthracene:	330 U
Chrysene:	330 U
Benzo(b)fluoranthene:	375 J
Benzo(k)fluoranthene:	330 U
benzo(a)pyrene:	330 U
Indeno(1,2,3-cd)pyrene:	330 U
Dibenzo(a,h)anthracene:	330 U
Benzo(g,h,i)perylene:	330 U

Microtox-Toxicity (%)

EC50: 13.31 (1.81 to 97.30)
TU50: 7.51 (1.02 to 55.22)

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 15 Sample Type: Vactor Sludge

Sample Date: 07/30/90 District No.: 1

Sample Pile Location: Star Lake Maintenance Site, So. King County

Origin of Material: I-5, South King County

Misc. Remarks:

Results of Analysis

Total Petroleum Hydrocarbon (TPH)
(wet basis) (mg/kg)

Run 1:	5209
Run 2:	6365
Average:	5787

Polynuclear Aromatics (PNA/PAH)
(ug/kg):

Naphthalene:	330 U
Acenaphthylene:	330 U
Acenaphthene:	330 U
Fluorene:	330 U
Phenathrene:	330 U
Anthracene:	655
Fluoranthene:	330 U
Pyrene:	415 J
Benzo(a)anthracene:	330 U
Chrysene:	375 J
Benzo(b)fluoranthene:	856
Benzo(k)fluoranthene:	395 J
Benzo(a)pyrene:	350 J
Indeno(1,2,3-cd)pyrene:	330 U
Dibenzo(a,h)anthracene:	350 J
Benzo(g,h,i)perylene:	368 J

Microtox-Toxicity (%)

EC50: 9.1 (0.05 to 1697)
TU50: 11.0 (0,05 to 2000)

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 16	Sample Type: Road Sweepings
Sample Date: 07/30/90	District No.: 1

Sample Pile Location: Star Lake Maintenance Site, So. King County

Origin of Material: Collected along I-5 in So. King County

Misc. Remarks:

Results of Analysis

Total Petroleum Hydrocarbon (TPH) (wet basis) (mg/kg)

Run 1:	1145
Run 2:	2873
Average:	2009

Polynuclear Aromatics (PNA/PAH) (ug/kg):

Naphthalene:	330 U
Acenaphthylene:	330 U
Acenaphthene:	330 U
Fluorene:	330 U
Phenathrene:	330 U
Anthracene:	330 U
Fluoranthene:	330 U
Pyrene:	330 U
Benzo(a)anthracene:	330 U
Chrysene:	330 U
Benzo(b)fluoranthene:	330 U
Benzo(k)fluoranthene:	330 U
benzo(a)pyrene:	330 U
Indeno(1,2,3-cd)pyrene:	330 U
Dibenzo(a,h)anthracene:	330 U
Benzo(g,h,i)perylene:	330 U

Microtox-Toxicity (%)

EC50: 2.75 (2.49 to 3.03)
TU50: 36.4 (33.00 to 40.01)

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 17 Sample Type: Road Sweepings

Sample Date: 07/30/90 District No.: 1

Sample Pile Location: Duwamish Landfill, So. Seattle WA.

Origin of Material: Highways in the So. Seattle area

Misc. Remarks:

Results of Analysis

Total Petroleum Hydrocarbon (TPH) (wet basis) (mg/kg)

Run 1:	3033
Run 2:	2659
Average:	2846

Polynuclear Aromatics (PNA/PAH) (ug/kg):

Naphthalene:	330 U
Acenaphthylene:	330 U
Acenaphthene:	330 U
Fluorene:	330 U
Phenathrene:	330 U
Anthracene:	415 J
Fluoranthene:	365 J
Pyrene:	575 J
Benzo(a)anthracene:	330 U
Chrysene:	330 U
Benzo(b)fluoranthene:	605 J
Benzo(k)fluoranthene:	330 U
benzo(a)pyrene:	330 U
Indeno(1,2,3-cd)pyrene:	330 U
Dibenzo(a,h)anthracene:	330 U
Benzo(g,h,i)perylene:	330 U

Microtox-Toxicity (%)

EC50: 58.93 (1.04 to 3328.00)
TU50: 1.70 (0.30 to 95.80)

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 18	Sample Type: Road Sweepings
Sample Date: 07/30/90	District No.: 1

Sample Pile Location: South bound Hwy 167 near Sumner WA.

Origin of Material: Collected from Hwy 167 and nearby roads

Misc. Remarks:

Results of Analysis

Total Petroleum Hydrocarbon (TPH) (wet basis) (mg/kg)

Run 1:	4552
Run 2:	3748
Average:	4150

Polynuclear Aromatics (PNA/PAH) (ug/kg):

Naphthalene:	330 U
Acenaphthylene:	330 U
Acenaphthene:	330 U
Fluorene:	330 U
Phenathrene:	330 U
Anthracene:	428 J
Fluoranthene:	389 J
Pyrene:	397 J
Benzo(a)anthracene:	330 U
Chrysene:	330 U
Benzo(b)fluoranthene:	330 U
Benzo(k)fluoranthene:	330 U
benzo(a)pyrene:	330 U
Indeno(1,2,3-cd)pyrene:	330 U
Dibenzo(a,h)anthracene:	330 U
Benzo(g,h,i)perylene:	330 U

Microtox-Toxicity (%)

EC50: 19.68 (5.39 to 71.84)
TU50: 5.08 (1.39 to 18.56)

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 19	Sample Type: Road Sweepings
Sample Date: 07/30/90	District No.: 1

Sample Pile Location: South bound Hwy 167 near Sumner WA.

Origin of Material: Collected from Hwy 167 and nearby roads

Misc. Remarks: Collected from a weathered pile near sample #18

Results of Analysis

Total Petroleum Hydrocarbon (TPH) (wet basis) (mg/kg)

Run 1:	1109
Run 2:	1519
Average:	1314

Polynuclear Aromatics (PNA/PAH) (ug/kg):

Naphthalene:	330	U
Acenaphthylene:	448	J
Acenaphthene:	355	J
Fluorene:	330	U
Phenathrene:	2178	
Anthracene:	330	U
Fluoranthene:	995	
Pyrene:	1980	
Benzo(a)anthracene:	875	
Chrysene:	330	U
Benzo(b)fluoranthene:	330	U
Benzo(k)fluoranthene:	330	U
benzo(a)pyrene:	405	J
Indeno(1,2,3-cd)pyrene:	330	U
Dibenzo(a,h)anthracene:	330	U
Benzo(g,h,i)perylene:	330	U

Microtox-Toxicity (%)

EC50: 12.0 (0.07 to 1993)
TU50: 8.4 (0,05 to 1384)

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 20

Sample Type: Road Sweepings

Sample Date: 08/01/90

District No.: 2

Sample Pile Location: I-90 Snoqualmie Pass Exit 47

Origin of Material: Collected from I-90 at the Pass

Misc. Remarks: Collected from a small pile

Results of Analysis

Total Petroleum Hydrocarbon (TPH) (wet basis) (mg/kg)

Run 1:	845
Run 2:	806
Average:	826

Polynuclear Aromatics (PNA/PAH) (ug/kg):

Naphthalene:	330 U
Acenaphthylene:	330 U
Acenaphthene:	330 U
Fluorene:	330 U
Phenathrene:	330 U
Anthracene:	330 U
Fluoranthene:	330 U
Pyrene:	330 U
Benzo(a)anthracene:	330 U
Chrysene:	330 U
Benzo(b)fluoranthene:	330 U
Benzo(k)fluoranthene:	330 U
Benzo(a)pyrene:	330 U
Indeno(1,2,3-cd)pyrene:	330 U
Dibenzo(a,h)anthracene:	330 U
Benzo(g,h,i)perylene:	330 U

Microtox-Toxicity (%)

EC50: 9.45 (5.68 to 15.73)
TU50: 10.58 (6.36 to 17.60)

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 21 Sample Type: Road Sweeping

Sample Date: 08/01/90 District No.: 2

Sample Pile Location: I-90 Exit 62 to Stampede Pass

Origin of Material: Area arround Exit 62

Misc. Remarks: Sample was taken from the west large pile

Results of Analysis

Total Petroleum Hydrocarbon (TPH)
(wet basis) (mg/kg) Run 1: 195

Run 2: 190

Average: 193

Polynuclear Aromatics (PNA/PAH)
(ug/kg):

Naphthalene:	330 U
Acenaphthylene:	330 U
Acenaphthene:	330 U
Fluorene:	330 U
Phenathrene:	330 U
Anthracene:	330 U
Fluoranthene:	330 U
Pyrene:	330 U
Benzo(a)anthracene:	330 U
Chrysene:	330 U
Benzo(b)fluoranthene:	330 U
Benzo(k)fluoranthene:	330 U
Benzo(a)pyrene:	330 U
Indeno(1,2,3-cd)pyrene:	330 U
Dibenzo(a,h)anthracene:	330 U
Benzo(g,h,i)perylene:	330 U

Microtox-Toxicity (%)

EC50: 4.42 (3.32 to 5.89)
TU50: 22.6 (16.98 to 30.11)

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 22 Sample Type: Road Sweepings

Sample Date: 08/01/90 District No.: 2

Sample Pile Location: I-90 Exit 62 to Stampede Pass

Origin of Material: Roads in the vacinity of Exit 62

Misc. Remarks: Sample taken the east large pile

Results of Analysis

Total Petroleum Hydrocarbon (TPH)
(wet basis) (mg/kg)

Run 1:	< 5
Run 2:	< 5
Average:	< 5

Polynuclear Aromatics (PNA/PAH)
(ug/kg):

Naphthalene:	330 U
Acenaphthylene:	330 U
Acenaphthene:	330 U
Fluorene:	330 U
Phenathrene:	330 U
Anthracene:	330 U
Fluoranthene:	330 U
Pyrene:	330 U
Benzo(a)anthracene:	330 U
Chrysene:	330 U
Benzo(b)fluoranthene:	330 U
Benzo(k)fluoranthene:	330 U
Benzo(a)pyrene:	330 U
Indeno(1,2,3-cd)pyrene:	330 U
Dibenzo(a,h)anthracene:	330 U
Benzo(g,h,i)perylene:	330 U

Microtox-Toxicity (%)

EC50: 5.20 (2.59 to 10.44)
TU50: 19.2 (9.6 to 38.7)

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 23 Sample Type: Vactor Sludge

Sample Date: 08/01/90 District No.: 2

Sample Pile Location: I-90 Exit 62 to Stampede Pass

Origin of Material: From roads in the vacinity of Exit 62

Misc. Remarks: Sludge from the catchment basin at Easton

Results of Analysis

Total Petroleum Hydrocarbon (TPH)
(wet basis) (mg/kg)

Run 1:	10271
Run 2:	6563
Average:	8417

Polynuclear Aromatics (PNA/PAH)
(ug/kg):

Naphthalene:	330 U
Acenaphthylene:	330 U
Acenaphthene:	330 U
Fluorene:	330 U
Phenathrene:	330 U
Anthracene:	330 U
Fluoranthene:	330 U
Pyrene:	330 U
Benzo(a)anthracene:	330 U
Chrysene:	330 U
Benzo(b)fluoranthene:	330 U
Benzo(k)fluoranthene:	330 U
Benzo(a)pyrene:	330 U
Indeno(1,2,3-cd)pyrene:	330 U
Dibenzo(a,h)anthracene:	330 U
Benzo(g,h,i)perylene:	330 U

Microtox-Toxicity (%)

EC50:	100
TU50:	<0.01

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 24 Sample Type: Road Sweeping

Sample Date: 08/01/90 District No.: 2

Sample Pile Location: Bullfrog Maintenance Yard near I-90

Origin of Material: A mixture of road sweepings and sludge

Misc. Remarks: Material was well weathered

Results of Analysis

Total Petroleum Hydrocarbon (TPH)
(wet basis) (mg/kg) Run 1: 535

Run 2: 178

Average: 357

Polynuclear Aromatics (PNA/PAH)
(ug/kg):

Naphthalene:	330 U
Acenaphthylene:	330 U
Acenaphthene:	330 U
Fluorene:	330 U
Phenathrene:	330 U
Anthracene:	330 U
Fluoranthene:	330 U
Pyrene:	330 U
Benzo(a)anthracene:	330 U
Chrysene:	330 U
Benzo(b)fluoranthene:	330 U
Benzo(k)fluoranthene:	330 U
Benzo(a)pyrene:	330 U
Indeno(1,2,3-cd)pyrene:	330 U
Dibenzo(a,h)anthracene:	330 U
Benzo(g,h,i)perylene:	330 U

Microtox-Toxicity (%)

EC50: 7.58 (3.46 to 16.62)
TU50: 13.19 (6.02 to 28.91)

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 26 25
Sample Type: Road Sweepings

Sample Date: 10/31/90
District No.: 5

Sample Pile Location: Hwy 2, Milepost 105 east of Cashmere WA.

Origin of Material: From Hwy 2

Misc. Remarks: Sample from a large pile at the milepost

Results of Analysis

Total Petroleum Hydrocarbon (TPH)
(wet basis) (mg/kg)

Run 1:	-
Run 2:	224
Average:	224

Polynuclear Aromatics (PNA/PAH)
(ug/kg):

Naphthalene:	330 U
Acenaphthylene:	330 U
Acenaphthene:	330 U
Fluorene:	330 U
Phenathrene:	330 U
Anthracene:	330 U
Fluoranthene:	330 U
Pyrene:	330 U
Benzo(a)anthracene:	330 U
Chrysene:	330 U
Benzo(b)fluoranthene:	330 U
Benzo(k)fluoranthene:	330 U
Benzo(a)pyrene:	330 U
Indeno(1,2,3-cd)pyrene:	330 U
Dibenzo(a,h)anthracene:	330 U
Benzo(g,h,i)perylene:	330 U

Microtox-Toxicity (%)

EC50: 6.20 (1.86 to 20.61)
TU50: 16.14 (4.85 to 33.69)

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 27 Sample Type: Road Sweepings

Sample Date: 10/31/90 District No.: 5

Sample Pile Location: Hwy 2, Milepost 105 near Cahmere WA.

Origin of Material: Sweepings from Hwy 2

Misc. Remarks: Sample taken the small pile at the milepost

Results of Analysis

Total Petroleum Hydrocarbon (TPH) (wet basis) (mg/kg)

Run 1:	72
Run 2:	7
Average:	40

Polynuclear Aromatics (PNA/PAH) (ug/kg):

Naphthalene:	330 U
Acenaphthylene:	330 U
Acenaphthene:	330 U
Fluorene:	330 U
Phenathrene:	330 U
Anthracene:	330 U
Fluoranthene:	330 U
Pyrene:	330 U
Benzo(a)anthracene:	330 U
Chrysene:	330 U
Benzo(b)fluoranthene:	330 U
Benzo(k)fluoranthene:	330 U
Benzo(a)pyrene:	330 U
Indeno(1,2,3-cd)pyrene:	330 U
Dibenzo(a,h)anthracene:	330 U
Benzo(g,h,i)perylene:	330 U

Microtox-Toxicity (%)

EC50: 7.70 (3.01 to 19.69)
TU50: 12.99 (5.08 to 33.23)

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 28 Sample Type: Unknown

Sample Date: 10/31/90 District No.: 5

Sample Pile Location: Hwy 2, Milepost 105 near Cashmere WA.

Origin of Material: From Hwy 2

Misc. Remarks: From a pile of probable unused traction material

Results of Analysis

Total Petroleum Hydrocarbon (TPH)
(wet basis) (mg/kg) Run 1: <5

Run 2: <5

Average: <5

Polynuclear Aromatics (PNA/PAH)
(ug/kg):

Naphthalene: 330 U
Acenaphthylene: 330 U
Acenaphthene: 330 U
Fluorene: 330 U
Phenathrene: 330 U
Anthracene: 330 U
Fluoranthene: 330 U
Pyrene: 330 U
Benzo(a)anthracene: 330 U
Chrysene: 330 U
Benzo(b)fluoranthene: 330 U
Benzo(k)fluoranthene: 330 U
Benzo(a)pyrene: 330 U
Indeno(1,2,3-cd)pyrene: 330 U
Dibenzo(a,h)anthracene: 330 U
Benzo(g,h,i)perylene: 330 U

Microtox-Toxicity (%)

EC50: 16.12 (1.69 to 153.76)
TU50: 6.0 (0.65 to 59.15)

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 29 Sample Type: Road Sweepings

Sample Date: District No.:

Sample Pile Location:

Origin of Material: From I-5 between Portland Ave. & SR 512

Misc. Remarks: Collected by E. Hannus of WSDOT

Results of Analysis

Total Petroleum Hydrocarbon (TPH)
(wet basis) (mg/kg) Run 1: 2798

Run 2: 2161

Average: 2480

Polynuclear Aromatics (PNA/PAH)
(ug/kg):

Naphthalene:	330 U
Acenaphthylene:	330 U
Acenaphthene:	330 U
Fluorene:	330 U
Phenathrene:	330 U
Anthracene:	330 U
Fluoranthene:	330 U
Pyrene:	330 U
Benzo(a)anthracene:	330 U
Chrysene:	330 U
Benzo(b)fluoranthene:	330 U
Benzo(k)fluoranthene:	330 U
Benzo(a)pyrene:	330 U
Indeno(1,2,3-cd)pyrene:	330 U
Dibenzo(a,h)anthracene:	330 U
Benzo(g,h,i)perylene:	330 U

Microtox-Toxicity (%)

EC50: 33.8 (0.28 to 4140.86)
TU50: 2.94 (0.02 to 362.42)

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 30 Sample Type: Vactor Sludge

Sample Date: 8/20/90 District No.:

Sample Pile Location: Collected from the Narrows Bridge

Origin of Material:

Misc. Remarks: Collected by E. Hannus of WSDOT

Results of Analysis

Total Petroleum Hydrocarbon (TPH)
(wet basis) (mg/kg)

Run 1:	3175
Run 2:	3281
Average:	3228

Polynuclear Aromatics (PNA/PAH)
(ug/kg):

Naphthalene:	330 U
Acenaphthylene:	330 U
Acenaphthene:	330 U
Fluorene:	330 U
Phenathrene:	330 U
Anthracene:	330 U
Fluoranthene:	330 U
Pyrene:	330 U
Benzo(a)anthracene:	330 U
Chrysene:	330 U
Benzo(b)fluoranthene:	330 U
Benzo(k)fluoranthene:	330 U
Benzo(a)pyrene:	330 U
Indeno(1,2,3-cd)pyrene:	330 U
Dibenzo(a,h)anthracene:	330 U
Benzo(g,h,i)perylene:	330 U

Microtox-Toxicity (%)

EC50: 7.31 (2.68 to 19.94)
TU50: 13.69 (5.02 to 37.35)

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 31 Sample Type: Road Sweeping

Sample Date: 11/28/90 District No.:

Sample Pile Location: From roads in the Toppanish area

Origin of Material:

Misc. Remarks: Collected by E. Hannus of WSDOT

Results of Analysis

Total Petroleum Hydrocarbon (TPH)
(wet basis) (mg/kg)

	Run 1:	2398
	Run 2:	2186
	Average:	2292

Polynuclear Aromatics (PNA/PAH)
(ug/kg):

Naphthalene:	330 U
Acenaphthylene:	330 U
Acenaphthene:	330 U
Fluorene:	330 U
Phenathrene:	330 U
Anthracene:	330 U
Fluoranthene:	330 U
Pyrene:	330 U
Benzo(a)anthracene:	330 U
Chrysene:	330 U
Benzo(b)fluoranthene:	330 U
Benzo(k)fluoranthene:	330 U
Benzo(a)pyrene:	330 U
Indeno(1,2,3-cd)pyrene:	330 U
Dibenzo(a,h)anthracene:	330 U
Benzo(g,h,i)perylene:	330 U

Microtox-Toxicity (%)

EC50: 18.86 (4.38 to 81.22)
TU50: 5.3 (1.2 to 22.6)

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 32   Sample Type: Vactor Sludge

Sample Date: 6/26/90   District No.: 6

Sample Pile Location: Spokane WA. Geiger Maintenance Yard

Origin of Material:

Misc. Remarks: Small pile of dried sludge

Results of Analysis

Total Petroleum Hydrocarbon (TPH)
(wet basis) (mg/kg) Run 1: 404

Run 2: 702

Average: 553

Polynuclear Aromatics (PNA/PAH)
(ug/kg):

Naphthalene: 330 U
Acenaphthylene: 330 U
Acenaphthene: 330 U
Fluorene: 330 U
Phenathrene: 330 U
Anthracene: 330 U
Fluoranthene: 330 U
Pyrene: 330 U
Benzo(a)anthracene: 330 U
Chrysene: 330 U
Benzo(b)fluoranthene: 330 U
Benzo(k)fluoranthene: 330 U
Benzo(a)pyrene: 330 U
Indeno(1,2,3-cd)pyrene: 330 U
Dibenzo(a,h)anthracene: 330 U
Benzo(g,h,i)perylene: 330 U

Microtox-Toxicity (%)

EC50: 6.96 (1.81 to 26.72)
TU50: 14.37 (3.74 to 55.17)

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 33

Sample Type: Vactor Sludge

Sample Date: Unknown

District No.:

Sample Pile Location: Sequim WA.

Origin of Material: From Hwy 214 the old Blynn Hwy

Misc. Remarks: Collected by E.Hannus of the WSDOT

Results of Analysis

Total Petroleum Hydrocarbon (TPH)
(wet basis) (mg/kg)

Run 1:	175
Run 2:	328
Average:	251

Polynuclear Aromatics (PNA/PAH)
(ug/kg):

Naphthalene:	330 U
Acenaphthylene:	330 U
Acenaphthene:	330 U
Fluorene:	330 U
Phenathrene:	330 U
Anthracene:	330 U
Fluoranthene:	330 U
Pyrene:	330 U
Benzo(a)anthracene:	330 U
Chrysene:	330 U
Benzo(b)fluoranthene:	330 U
Benzo(k)fluoranthene:	330 U
Benzo(a)pyrene:	330 U
Indeno(1,2,3-cd)pyrene:	330 U
Dibenzo(a,h)anthracene:	330 U
Benzo(g,h,i)perylene:	330 U

Microtox-Toxicity (%)

EC50: 3.55 (2.76 to 4.57)
TU50: 28.15 (21.88 to 36.22)

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 34 Sample Type: Vactor Sludge

Sample Date: 11/29/90 District No.:

Sample Pile Location: Toppanish WA.

Origin of Material: Unknown

Misc. Remarks: Collected by E. Hannus of the WSDOT

Results of Analysis

Total Petroleum Hydrocarbon (TPH)
(wet basis) (mg/kg)

Run 1:	1161
Run 2:	874
Average:	1018

Polynuclear Aromatics (PNA/PAH)
(ug/kg):

Naphthalene:	330 U
Acenaphthylene:	330 U
Acenaphthene:	330 U
Fluorene:	330 U
Phenathrene:	330 U
Anthracene:	330 U
Fluoranthene:	330 U
Pyrene:	330 U
Benzo(a)anthracene:	330 U
Chrysene:	330 U
Benzo(b)fluoranthene:	330 U
Benzo(k)fluoranthene:	330 U
Benzo(a)pyrene:	330 U
Indeno(1,2,3-cd)pyrene:	330 U
Dibenzo(a,h)anthracene:	330 U
Benzo(g,h,i)perylene:	330 U

Microtox-Toxicity (%)

EC50: 35.24 (0.46 to 2653.81)
TU50: 2.84 (0.04 to 213.70)

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 37 Sample Type: Road Sweepings

Sample Date: 01/06/91 District No.: 1

Sample Pile Location: Star Lake Maintenance Site, So. King County

Origin of Material:

Misc. Remarks: Collected by E. Hannus of the WSDOT

Results of Analysis

Total Petroleum Hydrocarbon (TPH)
(wet basis) (mg/kg) Run 1: 2

Run 2: 2

Average: 2

Polynuclear Aromatics (PNA/PAH)
(ug/kg):

Naphthalene:	330 U
Acenaphthylene:	330 U
Acenaphthene:	330 U
Fluorene:	330 U
Phenathrene:	330 U
Anthracene:	330 U
Fluoranthene:	330 U
Pyrene:	330 U
Benzo(a)anthracene:	330 U
Chrysene:	330 U
Benzo(b)fluoranthene:	330 U
Benzo(k)fluoranthene:	330 U
Benzo(a)pyrene:	330 U
Indeno(1,2,3-cd)pyrene:	330 U
Dibenzo(a,h)anthracene:	330 U
Benzo(g,h,i)perylene:	330 U

Microtox-Toxicity (%)

EC50: 3.62 (0.31 to 42.79)
TU50: 27.65 (2.34 to 327.03)

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 38

Sample Type: Ditch Spoils

Sample Date: 01/06/91

District No.: 1

Sample Pile Location: Star Lake Maintenance Site, So, King County

Origin of Material: Unknown

Misc. Remarks: Collected by E, Hannus of the WSDOT

Results of Analysis

Total Petroleum Hydrocarbon (TPH) (wet basis) (mg/kg)

Run 1:	673
Run 2:	303
Average:	488

Polynuclear Aromatics (PNA/PAH) (ug/kg):

Naphthalene:	330 U
Acenaphthylene:	330 U
Acenaphthene:	330 U
Fluorene:	330 U
Phenathrene:	330 U
Anthracene:	330 U
Fluoranthene:	330 U
Pyrene:	330 U
Benzo(a)anthracene:	330 U
Chrysene:	330 U
Benzo(b)fluoranthene:	330 U
Benzo(k)fluoranthene:	330 U
Benzo(a)pyrene:	330 U
Indeno(1,2,3-cd)pyrene:	330 U
Dibenzo(a,h)anthracene:	330 U
Benzo(g,h,i)perylene:	330 U

Microtox-Toxicity (%)

EC50: 11.62 (3.89 to 34.77)
TU50: 8.61 (2.88 to 25.76)

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 39 Sample Type: Road Sweeping

Sample Date: 01/07/91 District No.: 1

Sample Pile Location: Seattle WA., Duwamish area

Origin of Material:

Misc. Remarks: Collected by E. Hannus of the WSDOT

Results of Analysis

Total Petroleum Hydrocarbon (TPH)
(wet basis) (mg/kg)

	Run 1:	814
	Run 2:	836
	Average:	825

Polynuclear Aromatics (PNA/PAH)
(ug/kg):

Naphthalene:	330 U
Acenaphthylene:	330 U
Acenaphthene:	330 U
Fluorene:	330 U
Phenathrene:	330 U
Anthracene:	330 U
Fluoranthene:	330 U
Pyrene:	330 U
Benzo(a)anthracene:	330 U
Chrysene:	330 U
Benzo(b)fluoranthene:	330 U
Benzo(k)fluoranthene:	330 U
Benzo(a)pyrene:	330 U
Indeno(1,2,3-cd)pyrene:	330 U
Dibenzo(a,h)anthracene:	330 U
Benzo(g,h,i)perylene:	330 U

Microtox-Toxicity (%)

EC50: 1.04 (0.89 to 1.20)
TU50: 96.58 (83.2 to 112.06)

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 40 Sample Type: Road Sweepings

Sample Date: 01/26/91 District No.: 1

Sample Pile Location: Ballinger WA.

Origin of Material:

Misc. Remarks: Collected by E. Hannus of the WSDOT

Results of Analysis

Total Petroleum Hydrocarbon (TPH)
(wet basis) (mg/kg) Run 1: 4951

Run 2: 4288

Average: 4620

Polynuclear Aromatics (PNA/PAH)
(ug/kg):

Naphthalene:	330 U
Acenaphthylene:	330 U
Acenaphthene:	330 U
Fluorene:	530 J
Phenathrene:	330 U
Anthracene:	330 U
Fluoranthene:	330 U
Pyrene:	420 J
Benzo(a)anthracene:	395 J
Chrysene:	330 U
Benzo(b)fluoranthene:	330 U
Benzo(k)fluoranthene:	405 J
Benzo(a)pyrene:	375 J
Indeno(1,2,3-cd)pyrene:	330 U
Dibenzo(a,h)anthracene:	330 U
Benzo(g,h,i)perylene:	330 U

Microtox-Toxicity (%)

EC50: 29.70 (0.01 to 239.20)
TU50: 3.37 (0.1 to 271.47)

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 41

Sample Type: Road Sweepings

Sample Date: 01/26/91

District No.: 1

Sample Pile Location: From small pile at Ballinger

Origin of Material:

Misc. Remarks: Collected by E. Hannus of the WSDOT

Results of Analysis

Total Petroleum Hydrocarbon (TPH)
(wet basis) (mg/kg) Run 1: 4597

Run 2: 4567

Average: 4582

Polynuclear Aromatics (PNA/PAH)
(ug/kg):

Naphthalene: 330 U
Acenaphthylene: 330 U
Acenaphthene: 330 U
Fluorene: 367 J
Phenathrene: 330 U
Anthracene: 330 U
Fluoranthene: 330 U
Pyrene: 410 J
Benzo(a)anthracene: 505 J
Chrysene: 330 U
Benzo(b)fluoranthene: 330 U
Benzo(k)fluoranthene: 375 J
Benzo(a)pyrene: 435 J
Indeno(1,2,3-cd)pyrene: 330 U
Dibenzo(a,h)anthracene: 387 J
Benzo(g,h,i)perylene: 330 U

Microtox-Toxicity (%)

EC50: 5.92 (3.82 to 9.17)
TU50: 16.89 (10.90 to 26.17)

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 42 Sample Type: Unknown

Sample Date: 01/28/91 District No.: 1

Sample Pile Location: Smith Island, Everett WA.

Origin of Material: Unknown

Misc. Remarks: Sample #1 collected by E. Hannus of the WSDOT

Results of Analysis

Total Petroleum Hydrocarbon (TPH)
(wet basis) (mg/kg)

Run 1:	1180
Run 2:	1262
Average:	1221

Polynuclear Aromatics (PNA/PAH)
(ug/kg):

Naphthalene:	330 U
Acenaphthylene:	330 U
Acenaphthene:	330 U
Fluorene:	330 U
Phenathrene:	330 U
Anthracene:	330 U
Fluoranthene:	330 U
Pyrene:	330 U
Benzo(a)anthracene:	330 U
Chrysene:	330 U
Benzo(b)fluoranthene:	330 U
Benzo(k)fluoranthene:	330 U
Benzo(a)pyrene:	330 U
Indeno(1,2,3-cd)pyrene:	330 U
Dibenzo(a,h)anthracene:	330 U
Benzo(g,h,i)perylene:	330 U

Microtox-Toxicity (%)

EC50: 15.97 (1.17 to 217.58)
TU50: 6.26 (0.45 to 85.32)

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 43

Sample Type: Unknown

Sample Date: 01/28/91

District No.: 1

Sample Pile Location: Smith Island, Everett, WA.

Origin of Material: Unknown

Misc. Remarks: Sample #2 collected by E. Hannus of the WSDOT

Results of Analysis

Total Petroleum Hydrocarbon (TPH)
(wet basis) (mg/kg) Run 1: 1385

Run 2: 1092

Average: 1239

Polynuclear Aromatics (PNA/PAH)
(ug/kg):

Naphthalene: 330 U
Acenaphthylene: 330 U
Acenaphthene: 330 U
Fluorene: 330 U
Phenathrene: 330 U
Anthracene: 330 U
Fluoranthene: 330 U
Pyrene: 330 U
Benzo(a)anthracene: 330 U
Chrysene: 330 U
Benzo(b)fluoranthene: 330 U
Benzo(k)fluoranthene: 330 U
Benzo(a)pyrene: 330 U
Indeno(1,2,3-cd)pyrene: 330 U
Dibenzo(a,h)anthracene: 330 U
Benzo(g,h,i)perylene: 330 U

Microtox-Toxicity (%)

EC50: 10.38 (5.34 to 20 70)
TU50: 9.65 (4.97 to 18.74)

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 44
Sample Type: Road Sweeping
Sample Date: 02/04/91
District No.: 1

Sample Pile Location: Totem Lake, Kirkland,WA.

Origin of Material: Unknown

Misc. Remarks: Sample from jar #1 collected by E.Hannus of WSDOT

Results of Analysis

Total Petroleum Hydrocarbon (TPH)
(wet basis) (mg/kg) Run 1: 2874

Run 2: 3579

Average: 3227

Polynuclear Aromatics (PNA/PAH)
(ug/kg):

Naphthalene: 330 U
Acenaphthylene: 330 U
Acenaphthene: 330 U
Fluorene: 330 U
Phenathrene: 330 U
Anthracene: 330 U
Fluoranthene: 330 U
Pyrene: 330 U
Benzo(a)anthracene: 330 U
Chrysene: 330 U
Benzo(b)fluoranthene: 330 U
Benzo(k)fluoranthene: 330 U
Benzo(a)pyrene: 330 U
Indeno(1,2,3-cd)pyrene: 330 U
Dibenzo(a,h)anthracene: 330 U
Benzo(g,h,i)perylene: 330 U

Microtox-Toxicity (%)

EC50: 15.70 (9.01 to 27.35)
TU50: 6.37 (3.66 to 11.10)

SAMPLE DESCRIPTION AND ANALYSIS SUMMARY

Sample No.: 45 Sample Type: Road Sweepings

Sample Date: 02/04/91 District No.: 1

Sample Pile Location: Totem Lake, Kirkland WA.

Origin of Material: Unknown

Misc. Remarks: Sample from jar #2 collected by E.Hannus

Results of Analysis

Total Petroleum Hydrocarbon (TPH)
(wet basis) (mg/kg) Run 1: 3369

Run 2: 3044

Average: 3207

Polynuclear Aromatics (PNA/PAH)
(ug/kg):

Naphthalene:	330 U
Acenaphthylene:	330 U
Acenaphthene:	330 U
Fluorene:	330 U
Phenathrene:	330 U
Anthracene:	330 U
Fluoranthene:	330 U
Pyrene:	330 U
Benzo(a)anthracene:	330 U
Chrysene:	330 U
Benzo(b)fluoranthene:	330 U
Benzo(k)fluoranthene:	330 U
Benzo(a)pyrene:	330 U
Indeno(1,2,3-cd)pyrene:	330 U
Dibenzo(a,h)anthracene:	330 U
Benzo(g,h,i)perylene:	330 U

Microtox-Toxicity (%)

EC50: 7.98 (5.42 to 11.74)
TU50: 12.54 (8.52 to 18.46)

Sample No.: 1A **Sample Type:** Road Sweepings

Sample Date: 06/26/90 **District No.:** 6

Sample Pile Location: I-90 Sprague Ave Interchange, Spokane

Origin of Material: From sweeping along I-90

Misc. Remarks: Fresh sweepings found along highway

Results of Analysis:

Total Petroleum Hydrocarbon (TPH) in Particle Size Fractions

Particle Size	TPH Concentration (mg/kg of dry weight)
>2 mm	611
<2 mm to >250 mm	1468
<250 mm	1808

Sample No.: 5A **Sample Type:** Road Sweepings

Sample Date: 06/26/90 **District No.:** 6

Sample Pile Location: I-90 Hamilton Ave Interchange, Spokane

Origin of Material: Sweepings along I-90 Central Spokane

Misc. Remarks: Fresh road sweepings from pile

Results of Analysis:

Total Petroleum Hydrocarbon (TPH) in Particle Size Fractions

Particle Size	TPH Concentration (mg/kg of dry weight)
>2 mm	663
<2 mm to >250 mm	1242
<250 mm	2339

Sample No.: 7A **Sample Type:** Ditch Spoils

Sample Date: 07/10/90 **District No.:** 6

Sample Pile Location: I-5, 139th Ave Stockpile, Vancouver

Origin of Material: Along I-5 north of Vancouver

Misc. Remarks: Appears fresher than sample #*

Results of Analysis:

Total Petroleum Hydrocarbon (TPH) in Particle Size Fractions

Particle Size	TPH Concentration (mg/kg of dry weight)
>2 mm	22
<2 mm to >250 mm	7
<250 mm	17

Sample No.: 10A **Sample Type:** Vactor Sludge

Sample Date: 07/12/90 **District No.:** Spokane County

Sample Pile Location: Sopkane Cty. Dist. 4 Maintenance yard

Origin of Material: Flora pit downside

Misc. Remarks:

Results of Analysis: Site used for vactor sludge disposal

Total Petroleum Hydrocarbon (TPH) in Particle Size Fractions

Particle Size	TPH Concentration (mg/kg of dry weight)
>2 mm	15556
<2 mm to >250 mm	12125
<250 mm	9361

Sample No.: 14a **Sample Type:** Ditch Spoils

Sample Date: 07/09/90 **District No.:** 4

Sample Pile Location: Southbound I-5 Milepost 42, Kelso WA

Origin of Material: From ditches in the Kelso area

Misc. Remarks: Collected by E. Hannus of the WSDOT

Results of Analysis:

Total Petroleum Hydrocarbon (TPH) in Particle Size Fractions

Particle Size	TPH Concentration (mg/kg of dry weight)
>2 mm	367
<2 mm to >250 mm	417
<250 mm	586

Sample No.: 15 a **Sample Type:** Vactor Sludge

Sample Date: 07/30/92 **District No.:** 1

Sample Pile Location: Star Lake Maintenance Yard

Origin of Material: South King County

Misc. Remarks:

Results of Analysis:

Total Petroleum Hydrocarbon (TPH) in Particle Size Fractions

Particle Size	TPH Concentration (mg/kg of dry weight)
>2 mm	2300
<2 mm to >250 mm	3393
<250 mm	2711

Sample No.: 25a **Sample Type:** Road Sweepings

Sample Date: 10/31/90 **District No.:** 5

Sample Pile Location: Hwy 28 Milepost B-5, Wenatchee, WA

Origin of Material: Road sweeping pile bed removed May 1990

Misc. Remarks:

Results of Analysis:

Total Petroleum Hydrocarbon (TPH) in Particle Size Fractions

Particle Size	TPH Concentration (mg/kg of dry weight)
>2 mm	19
<2 mm to >250 mm	201
<250 mm	1237

Sample No.: 29a **Sample Type:** Road Sweepings

Sample Date: Unknown **District No.:** Unknown

Sample Pile Location: I-5

Origin of Material: Along I-5 between Portland Ave & SR 512

Misc. Remarks: Collected by E. Hannus of the WSDOT

Results of Analysis:

Total Petroleum Hydrocarbon (TPH) in Particle Size Fractions

Particle Size	TPH Concentration (mg/kg of dry weight)
>2 mm	371
<2 mm to >250 mm	1958
<250 mm	2717

Sample No.: 35a **Sample Type:** Vactor Sludge

Sample Date: 06/26/90 **District No.:** 6

Sample Pile Location: Geiger Maintenance Yard, Spokane WA

Origin of Material: Sprague Lake Rest Area catchment basin

Misc. Remarks: Taken immediately after dumping

Results of Analysis:

Total Petroleum Hydrocarbon (TPH) in Particle Size Fractions

Particle Size	TPH Concentration (mg/kg of dry weight)
>2 mm	279
<2 mm to >250 mm	1172
<250 mm	2712

Sample No.: **Sample Type:**

Sample Date: **District No.:**

Sample Pile Location:

Origin of Material:

Misc. Remarks:

Results of Analysis:

Total Petroleum Hydrocarbon (TPH) in Particle Size Fractions

Particle Size	TPH Concentration (mg/kg of dry weight)
>2 mm	
<2 mm to >250 mm	
<250 mm	