FINAL DRAFT REPORT

EVALUATION OF HEALTH AND ENVIRONMENTAL PROBLEMS ASSOCIATED WITH THE USE OF WASTE OIL AS A DUST SUPPRESSANT

PEI ASSOCIATES

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EVALUATION OF HEALTH AND ENVIRONMENTAL PROBLEMS ASSOCIATED WITH THE USE OF WASTE OIL AS A DUST SUPPRESSANT

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EXECUTIVE SUMMARY

The objective of this study was to evaluate the potential for harm to human health or to the environment presented by the use of waste oil as a dust suppressant. This study is one of three funded by the U.S. Environmental Protection Agency, Office of Solid Waste, to assess the environmental impact of common waste oil practices. The practices covered in the other two studies are waste oil storage and use of waste oil as a fuel.

This study is divided into three main parts: 1) the characterization of the use of oil as a dust suppressant, 2) the environmental fate of waste oil contaminants, and 3) a risk assessment. The results indicate that the use of waste oil as a dust suppressant is potentially harmful to human health and the environment. The results of each of these major efforts are summarized.

TECHNOLOGICAL CHARACTERIZATION OF THE USE OF WASTE OIL AS A DUST SUPPRESSANT

The waste oil management system consists of generators, collectors, processors, and reusers. Most road oiling is done by collectors, many of whom also participate in other segments of the industry. For example, these collectors may also reprocess or blend used oils into boiler fuels. Some road oiling is done by local government agencies and private industries, which may

also be generators. Because of the large number of participants and the undocumented nature of the collection/processing segments of the industry, tracing the movement of waste oil is difficult and it is often necessary to make estimates based on numerous interviews.

A state-by-state survey was conducted to determine the extent of road oiling in the United States. Based on results of this survey and on other published data, an estimated 30 to 50 million gallons of waste oil per year is used in commercial road oiling activity in the United States. If road oiling by self-generators is included, an estimated 50 to 80 million gallons of waste oil per year is used for this purpose. Road oiling is most common in the northern Rocky Mountain states, the extreme Southwest, and the Southeast. A moderate amount is also practiced in the Northwest and in northern New England.

The concentrations of potentially hazardous constituents in waste oil used for road oiling vary greatly from sample to sample. Several descriptive statistical methods have been used to summarize the concentrations of metals, chlorinated solvents, and other organics found in waste oil. The data presented in Table I clearly indicate that waste oil used as a road oil may contain high levels of potentially hazardous materials.

ENVIRONMENTAL FATE OF WASTE OIL COMPONENTS

Dispersion models were applied to the movement of waste oil from road surfaces in an effort to quantify the extent of possible contamination of air and surface waters. Evaporation, seepage,

TABLE I. SUMMARY OF RESULTS OF ANALYSES FOR POTENTIALLY HAZARDOUS CONSTITUENTS FOUND IN WASTE OIL[a]

	Total analyzed samples	Samples detecting contaminant		Mean concentration,[b] ppm	Median concentration, ppm	Concentration at 75th percentile,[c] ppm	Concentration at 90th percentile,[d] ppm	Concentration range, ppm	
		Number	Percent					Low	High
Metals									
Arsenic	17	17	100	12	11	14	16	0.4	45
Barium	159	130	79	187	50	200	485	0	3,906
Cadmium	189	87	46	2.9	1.1	1.3	4.0	0	36
Chromium	273	221	81	18	10	12	28	0.1	537
Lead[e]	227	21.3	93.8	398	220	420	1,000	0	3,500
Zinc	232	227	98	561	469	890	1,150	0.7	5,000
Chlorinated solvents									
Dichlorodifluoromethane	78	53	68	361	20	210	860	0	2,200
Trichlorotrifluoroethane	44	25	57	241	<1	33	130	0	550,000
1,1,1-Trichloroethane	146	124	85	253	270	590	1,300	0	110,000
Trichloroethylene	143	108	76	591	60	490	1,049	0	330,000
Tetrachloroethylene	100	89	89	408	120	370	1,200	1	3,900
Total chlorine	62	62	100	3,719	1,400	2,600	6,150	40	459,000
Other organics									
Benzene	56	39	70	115	46	77	160	0	280
Toluene	69	57	83	843	190	490	1,300	0	5,100
Xylene	53	42	79	219	36	270	570	0	139,000
Benz(a)anthracene	17	14	82	88	16	26	35	5	660
Benzo(a)pyrene	19	11	58	59	9	12	33	3.2	405
PCB's	264	86	33	54	9	41	50	0.4	3,150
Naphthalene	15	15	100	389	290	490	580	110	790

[a] The development of these statistical summaries is described in a 1983 report by Bider, et al.

[b] Values reported as "0" were used to calculate average, but values reported as "less than" for any given concentration were omitted.

[c] Seventy-five percent of the analyzed waste oil samples had contaminant concentrations below the given value.

[d] Ninety percent of the analyzed waste oil samples had contaminant concentrations below the given value.

[e] Lead represents data taken only from 1979 to 1983.

and dust transport typically occur simultaneously, but at different rates, depending on environmental conditions. Rainfall runoff, which is of a more intermittent nature, is restricted to periods of heavy rainfall. A reasonable worst-case scenario approach was chosen to describe the conditions that would result in the worst levels of environmental contamination.

Evaporation

The worst-case scenario for evaporation assumes a hot, dry environment under which the rate of evaporation of waste oil components is very rapid. The calculated evaporation rate was then used to predict the concentration of each of the major waste oil components in the air above and downwind of the roadway. Airborne concentrations depend on the contaminant concentration in the waste oil and the rate of evaporation.

Rainfall Runoff

Calculations were made of concentrations of waste oil and its components in streams or roadside ditches. The worst-case scenario has been defined as a situation in which a heavy rainfall washes 100 percent of the oil applied to the road into an adjacent stream or ditch, where it is diluted by rainwater that has drained from an adjacent field. A more reasonable case in which only 5 percent of the oil on the road is removed in the runoff was used for the risk analysis.

Oil concentrations were calculated and used to predict oil depths on the stream surface so that the potential for an oil slick might be evaluated. The previously described worst-case scenario predicted an oil slick for every case evaluated. For

determination of the real potential for an oil slick, a more typical (possibly even a best-case) scenario was developed. In this evaluation heavy rainfalls were still used, but only 5 percent of the oil was assumed to be washed from the road, 10 percent of which is soluble and 90 percent of which is adsorbed onto soil particles (as reported in a 1983 GCA Corporation report). The results predicted a visible oil slick in almost every situation evaluated. Oil slicks pose hazards to aquatic birds and mammals by reducing buoyancy, insulation, and swimming ability. Oil in water also affects the morbidity and mortality of fish, shellfish, algae, and micro-organisms and is generally detrimental to the stream.

Contaminated Dust

Calculations of the maximum 30-day average ambient air concentrations of toxic (threshold) and carcinogenic waste oil contaminants were based on an assumed set of worst-case conditions that include low evaporation and rainfall runoff of waste oil components from the road surface. Conditions typical of the arid southwest were used in all models.

IMPACT AND HEALTH RISKS ASSOCIATED WITH THE USE OF WASTE OIL AS A DUST SUPPRESSENT

Assessments made of the impact and health risk of airborne and waterborne emissions from road-oiling operations consisted of an evaluation of risk associated with exposure to both toxic and carcinogenic waste oil contaminants. For toxic substances, Environmental Exposure Limits (EEL's) were derived from modifications

of Threshold Limit Values for occupational exposure. For carcinogens, reference concentrations were derived by calculating the frequency of excess cancers due to exposure to contaminants in road oil.

Tables II and III present the most significant results obtained by modeling concentrations of threshold and nonthreshold contaminants from evaporative emissions, rainfall runoff, and reentrained dust.

Evaporation

The modeled worst-case concentrations of evaporative emissions from oiled roads were compared with Environmental Exposure Limits (EEL's) to quantify the risk from exposure to these emissions. (See Appendix D.) As shown in Table II, several of the threshold constituents likely to evaporate into the atmosphere, particularly dichlorodifluoromethane and 1-1-1-trichloroethane, can present a significant health hazard. Toluene presents a lesser hazard. All other contaminants modeled pose relatively small risks.

As shown in Table III, all of the carcinogenic constituents modeled present a significant risk well in excess of one chance in 10,000, which is usually considered the highest acceptable risk level. The concentrations modeled, however, represent a worst-case exposure scenario, and lesser risks would be predicted in a typical situation.

Runoff

A risk analysis was performed for road oiling contaminants in a stream adjacent to a sand-based road that had been oiled.

TABLE II. RESULTS OF RISK ASSESSMENT FOR THRESHOLD CONTAMINANTS

Route of entry into environment	Contaminant posing a significant risk	Modeled concentration	Percentage of EEL[a]
Evaporative emissions	Dichlorodifluoromethane	3,598 µg/m³	85
	Toluene	602 µg/m³	19
	1,1,1-Trichloroethane	3,804 µg/m³	232
Rainfall runoff[b]	Barium	550 µg/liter	211
	Cadmium	4.5 µg/liter	95
	Lead	1,130 µg/liter	2,260
	Zinc	1,300 µg/liter	26
	Benzo(a)anthracene	40 µg/liter	5,155
	Naphthalene	660 µg/liter	19
	Toluene	1,360 µg/liter	10
	1,1,1-Trichloroethane	1,470 µg/liter	8
	Xylene	650 µg/liter	19
Reentrained dust	Barium	0.1209 µg/m³	28
	Lead	0.2534 µg/m³	17

[a] Environmental Exposure Limit. See Appendix D.

[b] Represents high-intensity rainfall after heavy oiling of a sand roadbed with 5 percent of the oil removed from the road as runoff.

TABLE III. RESULTS OF RISK ASSESSMENT FOR NONTHRESHOLD CONTAMINANTS

Route of entry into environment	Contaminants posing given risk levels[a]		
	10^{-4}	10^{-5}	10^{-6}
Evaporative emissions	Benzene Tetrachloroethylene 1,1,2-Trichloroethane Trichloroethylene	Benzene Tetrachloroethylene 1,1,2-Trichloroethane Trichloroethylene	Benzene Tetrachloroethylene 1,1,2-Trichloroethane Trichloroethylene
Rainfall runoff			
Sand roadbed, heavy oiling, Nevada rainfall	Arsenic Benzene Benzo(a)pyrene PCB's Tetrachloroethylene 1,1,2-Trichloroethane Trichloroethylene	Arsenic Benzene Benzo(a)pyrene PCB's Tetrachloroethylene 1,1,2-Trichloroethane Trichloroethylene	Arsenic Benzene Benzo(a)pyrene PCB's Tetrachloroethylene 1,1,2-Trichloroethane Trichloroethylene
Sand roadbed, light oiling, Florida rainfall	Arsenic Benzo(a)pyrene PCB's	Arsenic Benzo(a)pyrene PCB's Tetrachloroethylene 1,1,2-Trichloroethane Trichloroethylene	Arsenic Benzene Benzo(a)pyrene PCB's Tetrachloroethylene 1,1,2-Trichloroethane Trichloroethylene
Reentrained dust	Chromium	Arsenic Chromium PCB's	Arsenic Cadmium Chromium PCB's 1,1,2-Trichloroethane

[a] 10^{-4} is a risk level of 1 cancer in 10,000; 10^{-5} is a risk level of 1 cancer in 100,000; and 10^{-6} is a risk level of 1 cancer in 1,000,000.

The sand road was modeled on the basis of maximum rainfalls recorded at Reno, Nevada, and Pensacola, Florida. These two locations represent the extremes in local heavy rainfall intensities that occur in the United States. The range of contaminant concentrations that may occur under worst-case conditions represented by these two locations is the worst that may be expected for the country. For estimation of a reasonable risk case, it was assumed that rainfall runoff removes 5 percent of the oil applied to the road.

Table II presents a comparison of calculated concentrations of threshold contaminants with estimated EEL's. A high-intensity, Nevada-based, heavy rainfall following heavy applications of oil on sand roadbeds is likely to result in waterborne concentrations of lead and benz(a)anthracene, which could be hazardous to human health. A high-intensity, Florida-based, heavy rainfall following light applications of oil on silt or clay roadbeds would not pose a significant risk to human health from waterborne contaminant concentrations.

Table III presents a summary of estimated cancer risks resulting from stream contaminant levels due to runoff. The summary shows that for the first scenario (heavy oiling of a sand roadbed followed by high-intensity Nevada-based rainfall), all the contaminants modeled pose cancer risks greater than one chance in 10,000. The second scenario (light oiling of a sand roadbed followed by a high-intensity Florida rainfall) also resulted in significant risks from arsenic, benzo(a)pyrene and PCB's at the arsenic, benzo(a)pyrene and PCB's at the risk level

of 1 cancer in 10,000. All seven contaminants posed a risk level of 1 cancer per million persons exposed.

For the second scenario (light oiling followed by heavy Florida rainfall) the cancer risk is much less. Only PCB's present a cancer risk greater than one in 10,000; all the other contaminants modeled present a cancer risk of less than one in a million.

Contaminated Dust

The impact of reentrained dust emissions from road oiling operations was estimated for a number of scenarios involving the application of waste oil to different roadbeds. The health effects of waste oil contaminants in reentrained dust were assessed based on the specific worst-case scenario for each contaminant. As shown in Table II, two of the substances (barium and lead) are present in sufficient quantities to cause concern. The remaining substances are present at concentrations equal to or less than 1 percent of the EEL's.

Table III presents the results of an assessment of the impact on air quality and the risk to human health posed by carcinogenic substances in reentrained dust emissions. These results show that the risk of cancer from the chromium concentration is about one chance in 10,000 and that from the arsenic concentration is one chance in 60,000. Cadmium, polychlorinated biphenols (PCB's), and 1,1,2-trichloroethane pose cancer risks between one in 100,000 and one in a million. The risk posed by benzene, trichloroethylene, and tetrachloroethylene concentrations is less than one chance in a million.

SECTION 1

INTRODUCTION

Each year an estimated 30 to 50 million gallons of waste oil is used to oil roads in the United States.[1] These waste oils contain many contaminants, either as a result of their original uses or as a result of their being mixed with other chemical wastes. Among the contaminants found in waste oil are heavy metals, particularly lead; organic solvents such as benzene, xylene, and toluene; and chlorinated organics such as trichloroethane, trichloroethylene, and polychlorinated biphenyls (PCB's). Many contaminants commonly found in this oil are toxic or carcinogenic and therefore potentially hazardous.

The impacts of the use of waste oil as a dust suppressant have not been fully assessed. Three studies have attempted to determine the environmental fate of waste oil applied to roads through laboratory and field investigations.[2,3,4] Although the results of all three of these studies are either study- or site-specific, they indicate that elevated levels of contaminants may enter the environment.

The U.S. Environmental Protection Agency's Office of Solid Waste is currently funding a study to assess the environmental impact of three waste oil practices--its use as a dust suppressant, its use as a fuel, and its storage. Each of three separate

reports completed as part of this study characterize one of these practices and analyze the associated risks.

This report covers the practice of road oiling with waste oil. It provides an estimate of its dispersion and fate in the environment and assesses the resulting risks to human health. The study is divided into three main parts: a technological characterization, environmental dispersion modeling, and risk assessment. The technological characterization (Section 2) describes the use of waste oil as a dust suppressant. Discussions cover road oil application procedures, including surface preparation, spraying equipment, application rates, and the effects of weather and seasonal factors on application procedures. An evaluation of the composition of waste oil applied to roads focuses special attention on concentrations of potentially hazardous constituents.

An evaluation of the environmental fate of waste oil components in the atmosphere and surface waters is presented in Section 3. Dispersion models were developed for evaporation, dust transport, and rainfall runoff and applied to both typical and worst-case scenarios to determine potential levels of environmental contamination.

Section 4 presents a risk analysis, which is a quantitative assessment of the hazard that the use of waste oil as a dust suppressant poses to human health. This analysis is divided into two evaluations: those risks associated with exposure to toxic

waste oil contaminants and those risks associated with carcinogens. For the toxic substances, Environmental Exposure Limits (EEL's) were derived from modifications of Threshold Limit Values for occupational exposure. For carcinogens, derived reference concentrations, based on EPA's carcinogenic potency factors, were used to calculate the frequency of excess cancers from exposure to contaminants released into the environment as a result of the application of waste oils to roadbeds.

REFERENCES FOR SECTION 1

1. Bider, W. L., L. E. Seitter, and R. G. Hunt. Survey of the Oil Industry and Waste Oil Composition. Prepared for the U.S. Environmental Protection Agency under Contract No. 68-02-3173. April 1983.

2. Freestone, F. J. Runoff of Oils From Rural Roads Treated to Suppress Dust. EPA-R2-72-054, 1972.

3. Stephens, R. D., et al. A Study of the Fate of Selected Toxic Materials in Waste Oils Used for Dust Palliation on Logging Roads in the Plumas National Forest. California Department of Health Services, Hazardous Materials Laboratory Section. March 1981.

4. GCA Corporation. Fate of Hazardous and Nonhazardous Wastes in Used Oil Recycling, Fifth Quarterly Report. Prepared under DOE Contract No. DE-AC19-81BC1037. March 1983.

SECTION 2

TECHNOLOGICAL CHARACTERIZATION OF THE USE OF WASTE OIL AS A DUST SUPPRESSANT

This section examines current road oiling practices in the United States. Several issues are addressed, including the waste oil management system, the methods of application, the current extent of road oiling nationally and by state, the composition of the oil, and an overview of the effectiveness of waste oil as a dust suppressant.

2.1 WASTE OIL MANAGEMENT SYSTEM

Understanding the waste oil management system (the generation, collection, processing, and reuse segments of the industry) is not difficult; however, tracing the movement of oil through the various industry segments is far more complex, partially because of the large number of generators and the undocumented nature of the collection/processing segments, and partially because the flow of materials through the system varies tremendously among the different regions and seasonally within each region.

Currently (1982), the Federal Government does not require participants in the waste oil industry to report their collection or reuse activities. Some states have implemented programs for monitoring waste oil transactions, but most of these programs are still in the early stages of development. As a result, much of

the collection, reprocessing, and reuse of waste oils in this country is not documented. The ultimate disposition of the collected oil in most geographic regions is dictated by existing market conditions.

Road oiling constitutes only one part of the overall waste oil management system; however, many of the companies involved in road oiling also participate in other segments of the industry. For example, a collector who oils roads in the summer may also reprocess or blend used oils into boiler fuels during the winter months when the road oiling market is slow.

The road oiling system begins with the generation of either industrial or automotive waste oil. It has been estimated that there are several hundred thousand waste oil generators in the United States.[1] Following a systematic routing procedure, a collector regularly visits each generator and pumps accumulated waste oil into a tank truck. Some collectors are careful to segregate crankcase oils from industrial oils because of their different compositions (discussed later in this section); however, others mix all of their oil in a single tank. Once collected, the waste oil may undergo some reprocessing to remove water or other contaminants, but any processing of oil for the road oiling market is considered rare. Although undocumented, it is believed that road oilers often rid themselves of undesirable heavy tank bottoms from the waste oil storage tanks by thinning them with lighter oils and using this mixture for road oiling. Little information could be obtained regarding the extent of this

practice; however, tank bottoms are believed to comprise up to 10 percent of the waste oil used to control dust.

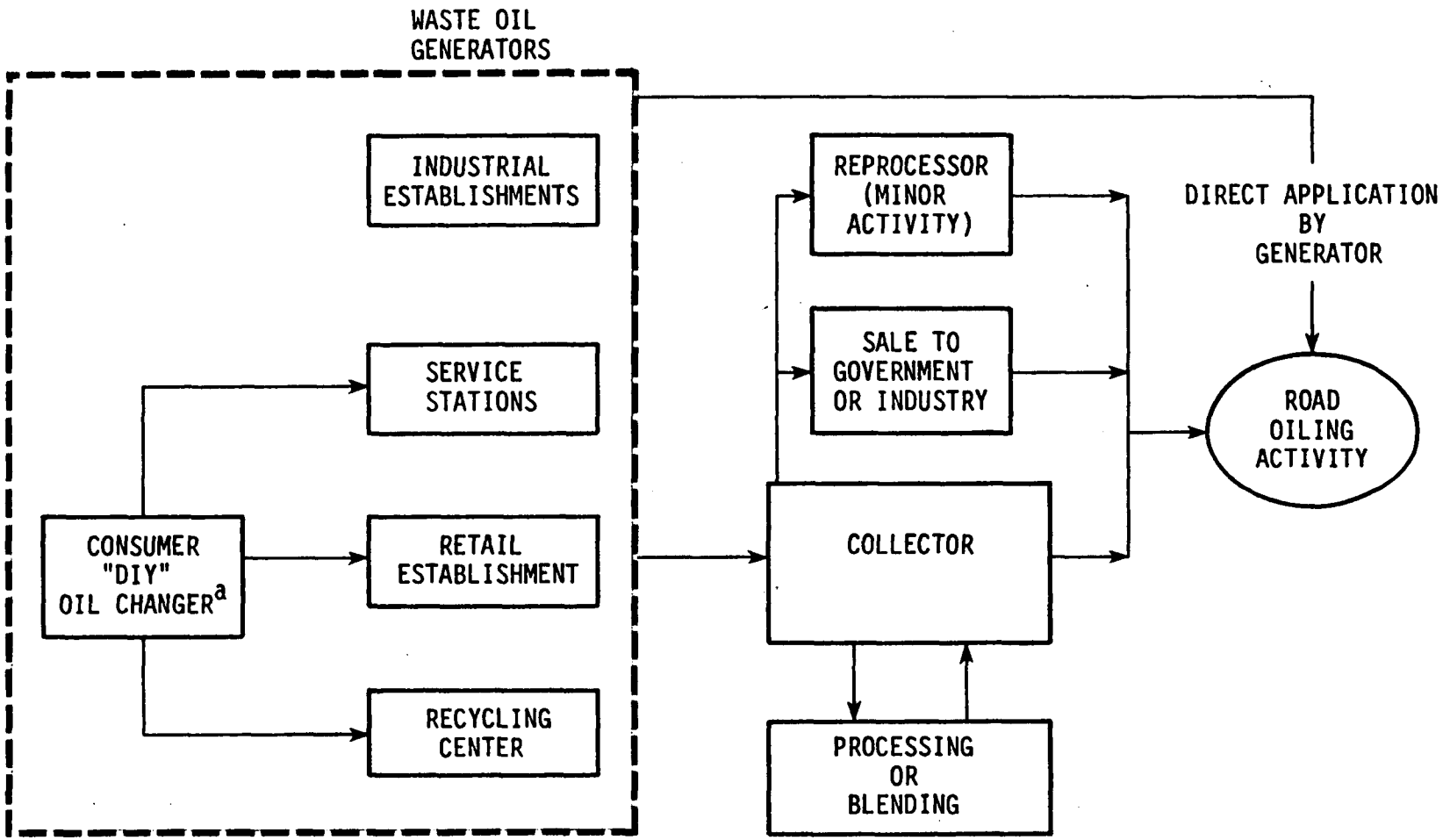
Most road oiling is performed by waste oil collectors who also maintain crews and equipment for this purpose. Small amounts, however, are applied by local government agencies (e.g., county highway departments) that are responsible for the maintenance of unpaved roads. Some roads on private property are oiled by industrial customers who purchase the waste oil and apply it to their own roads. The latter two classes of road oilers are believed to be declining in importance, as most road oiling is now performed by collectors.

In addition to the road-oiling activities just described, several industries generate significant quantities of waste oil, which they accumulate and use to suppress dust on their own private roads. The mining, logging, construction, and agricultural industries are the major groups that fall into this category. The in-house consumption of waste oil by generators cannot be quantified precisely, but this practice may be significant in some regions of the country.

Figure 2-1 identifies the general participants in the waste oil management system and illustrates the flow of oil through the system.

2.2 COMPOSITION OF WASTE OIL APPLIED TO ROADS

The summary of waste oil composition presented in this section is based on a comprehensive waste oil composition document submitted separately to EPA under this same contract.[1] Emphasis



[a] DIY = Do-it-yourselfer.

Figure 2-1. Road oiling activity as a part of the overall waste oil management system, which includes generators, collectors, processors, and users.

is given to the presence of potentially hazardous constituents, and the data focus on the contaminant concentrations selected for use in the dispersion modeling. These data represent statistical summaries of hundreds of waste oil analyses.

2.2.1 Availability of Analytical Data

Prior to the late 1970's, few analytical data characterizing the constituents of waste oils were available. Some limited data quantifying contamination by heavy metals were published, but virtually no data could be found that quantified the presence of other hazardous constituents that are now known to be in waste oils [e.g., chlorinated solvents, polynuclear aromatics (PNA's), and polychlorinated biphenyls (PCB's)].

In the late 1970's and early 1980's, several analytical programs were implemented to characterize waste oil composition. The increase in analytical activity was due largely to an increased awareness of the potential contamination of waste oil with hazardous materials. As of late 1982, the availability of analytical data had increased tremendously compared with just a few years earlier. Nevertheless, the data base still has some limitations. The sources of analyzed waste oil samples are often unidentified, and it is not always known whether an oil sample was obtained from automotive or industrial generators or if it represents a mixture of both types. Also, the planned end-use of the oil is often unknown. Another limitation involves analytical data. The contaminants that are measured usually vary from sample to sample, as do the analytical techniques and the precision of the techniques.

For this study, the most desirable approach was believed to be to summarize the contaminant concentrations in waste oil samples specifically identified as road oils. This would permit conclusions to be drawn regarding the relative probability of significant contamination in automotive versus industrial road oils. Although some data are available on which to base such evaluations, it was determined that a statistical summary of road oils might distort the true probability of contamination because the end-use of many samples was unidentified and because virtually any waste oil sample could be used to suppress dust under certain local conditions. For example, an oil sample identified as a fuel oil supplement may have been taken in the winter when fuel oil demand was high. In the summer, this same oil might be used to control dust. Therefore, the concentrations of the potentially hazardous constituents in waste oil used in the road oiling dispersion modeling are based on analytical data for all of the available waste oil rather than just the data developed specifically for road oils.

2.2.2 Concentrations of Potentially Hazardous Constituents

For purposes of the dispersion modeling (which is covered in Section 3), specific concentration levels had to be selected for each potentially hazardous constituent. There is no clearcut method for selecting the most appropriate statistical parameter. The use of mean or median concentrations can be eliminated because the risks associated with many oils are known to be much higher. On the other hand, the use of the high concentration values may be unreasonable because the concentrations of some

contaminants appear to be extremely high. These high levels are unusual and not representative of most waste oil. For these reasons, the concentration of each potentially hazardous contaminant was determined at the 75th and 90th percentile for use in the dispersion modeling analyses.

The concentrations of each contaminant were summarized by use of several descriptive statistics (Table 2-1). Although the mean, median, and range of concentrations are not used in the dispersion modeling, these data are included to provide a more thorough statistical summary. As shown in Table 2-1, waste oils vary greatly with respect to concentrations of potentially hazardous constituents. Some oils are virtually free of contamination, whereas others contain high levels of one or more constituents of concern. Unfortunately, the presence of a contaminant cannot be predicted easily on the basis of the reported source of the oil. Although crankcase oils differ from industrial oils, the waste oil management system does not assure that additional contamination will not occur during transport and storage of this oil. For example, pure crankcase oils should not contain any PCB's; however, samples identified as crankcase oil have been shown to contain significant PCB concentrations. Although the methods of contamination are not clearly understood, it is believed that PCB's could enter the oil as a result of residues of previously stored oil, negligent or careless mixing practices, or misrepresented oil.

Overall, it is clear that waste oil used to oil roads may contain high levels of potentially hazardous materials. How

TABLE 2-1. SUMMARY OF RESULTS OF ANALYSES FOR POTENTIALLY HAZARDOUS CONSTITUENTS FOUND IN WASTE OIL

	Total analyzed samples	Samples detecting contaminant		Mean concentration,[a] ppm	Median concentration, ppm	Concentration at 75th percentile,[b] ppm	Concentration at 90th percentile,[c] ppm	Concentration range, ppm	
		Number	Percent					Low	High
Metals									
Arsenic	17	17	100	12	11	14	16	0.4	45
Barium	159	130	79	187	50	200	485	0	3,906
Cadmium	189	87	46	2.9	1.1	1.3	4.0	0	36
Chromium	273	221	81	18	10	12	28	0.1	537
Lead[d]	227	21.3	93.8	398	220	420	1000	0	3,500
Zinc	232	227	98	561	469	890	1150	0.7	5,000
Chlorinated solvents									
Dichlorodifluoromethane	78	53	68	361	20	210	860	0	2,200
Trichlorodifluoromethane	44	25	57	241	<1	33	130	0	550,000
1,1,1-Trichloroethane	146	124	85	253	270	590	1300	0	110,000
Trichloroethylene	143	108	76	591	60	490	1049	0	300,000
Tetrachloroethylene	100	89	89	408	120	370	1200	1	3,900
Total chlorine	62	62	100	3719	1400	2600	6150	40	459,000
Other organics									
Benzene	56	39	70	115	46	77	160	0	280
Toluene	69	57	83	843	190	490	1200	0	5,100
Xylene	53	42	79	219	36	270	570	0	139,000
Benz(a)anthracene	17	14	82	88	16	26	35	5	660
Benzo(a)pyrene	19	11	58	59	9	12	33	3.2	405
PCB's	264	86	33	54	9	41	50	0.4	3,150
Naphthalene	15	15	100	389	290	490	580	110	790

[a] Values reported as "0" were used to calculate average, but values reported as "less than" any given concentration were omitted.

[b] 75 percent of the analyzed waste oil samples had contaminant concentrations below the given value.

[c] 90 percent of the analyzed waste oil samples had contaminant concentrations below the given value.

[d] Lead represents data taken only from 1979 to 1983.

Source: The development of these statistical summaries is described in Reference 1.

often this occurs depends on the type of oil, its specific origin, and any additions of materials by the generator or collector. It is unlikely that any given road oil will contain significant levels of all of the materials of concern; however, the probability of a significant concentration of a single hazardous constituent (particularly lead) in road oil is much higher than is the case for waste oil in general.

2.3 EXTENT OF ROAD OILING WITH WASTE OIL

Since the early 1970's, lawmakers, environmentalists, and representatives of government agencies and industry have shown considerable interest in how widespread the practice of road oiling with waste oil is in the United States. Early estimates released in the 1970's were largely theoretical and based upon very limited data. Most of the national estimates made through 1980 were based on a 1969 study Arthur D. Little, Inc., performed for the State of Massachusetts.[2] Estimates of road oiling with waste oil presented by several individuals at a hearing before the Senate Committee on Environmental and Public Works in 1980 indicated the amount to be about 200 million gallons per year.[3] A recently released U.S. Environmental Protection Agency (EPA) study adjusted that value downward to 126 million gallons per year.[4] Despite the apparent accuracy of this number (presented with three significant figures), the authors have expressed a much lower degree of certainty in the data.

Because of the questionable nature of available data and the lack of a regional breakdown in road oiling activity, the authors

of this report carried out a state-by-state survey to reevaluate current road oiling practices. Appropriate governmental and private agencies and industry representatives were contacted in each state to obtain any available information regarding waste oil generation, recovery, and reuse. Several relevant reports (both published and unpublised) that were identified also provided useful data.

The quality of the available data varied considerably. Some states have programs that attempt to monitor the generation, recovery, and reuse of oil. Although these states often maintain reasonably good records on the amount of road oiling that occurs, the existence of a used-oil recycling program does not assure the availability of quantitative data on waste oil usage. Other states have no programs, but information obtained from conversations with state environmental agency personnel and local waste oil collectors provided a basis for estimating road oiling practices.

The results of this survey contributed to an understanding of road oiling practices of both commercial (or large-scale) firms and self-generators. Commercial road oiling could be quantified for each state; however, self-generator road oiling could only be assessed qualitatively. Basically, commercial road oiling activity represents that road oiling activity for which waste oil is collected by haulers who operate clearly identified waste oil businesses. The following are examples of road oiling

activity that may not show up in the quantified estimates for each state:

- Road oiling by individuals who are intermittently involved in the waste oil business
- Infrequent road oiling by waste oil collectors who usually sell their material as a fuel oil
- Small-scale private agreements between generators and users of road oil

The state-by-state survey served as the basis for the estimates presented in Table 2-2. The results of the survey indicate that less than 24 million gallons of waste oil is used in large-scale commercial road oiling per year. This estimate is much lower than even the most recent estimates reported in other documents. The value of 126 million gallons reported in the 1982 EPA report actually represents 95 million gallons of commercial road oiling and 31 million gallons of self-generator road oiling. This lowest previous estimate is nearly four times larger than the estimate based on a state-by-state survey.

Although there are some known omissions in the survey data, it seems unlikely that the magnitude of these omissions would be larger than all of the reported activity (i.e., 24 million gallons per year).

The results of the state survey indicate that road oiling activity accounts for only a small percentage of waste oil usage and disposal. The almost complete absence of road oiling in so many regions may explain the large differences in estimates of national activity. Earlier national estimates assumed an average

TABLE 2-2. SUMMARY OF ROAD OILING PRACTICE BY STATE[a,b]

State	Generated waste oil, 10^3 gallons	Legal status of road oiling	Estimated large-scale road oiling, 10^3 gallons	Road oiling as a Percent of recovered	Road oiling as a Percent of generated	Self-generator oiling activity
Alabama	23,200	No specific regulations	770	33	3	Minor
Alaska	2,270	Agency approval and guidelines	600	60	26	Significant
Arizona	14,500	No specific regulations	1,800	25	12	Significant
Arkansas	16,900	No specific regulations	<10	-	-	Significant
California	119,100	Regulated-manifest system	5,000	10	4	Significant
Colorado	15,400	No specific regulations	1,000	NA[c]	6	Moderate
Connecticut	11,100	No specific regulations	<10	-	-	Insignificant
Delaware	3,230	Prohibited on large scale	<10	-	-	Insignificant
Florida	30,000	No specific regulations	340	10	1	Minor
Georgia	29,700	No specific regulations	1,000	33	3	Minor
Hawaii	2,540	No specific regulations	150	19	6	Significant
Idaho	4,500	No specific regulations	600	44	13	Minor
Illinois	82,900	Permit required	<10	-	-	Significant
Indiana	40,800	Analysis required	100	5	<1	Significant
Iowa	20,200	No specific regulations	1,520	75	8	Significant
Kansas	25,000	Prohibited	<10	-	-	Significant
Kentucky	24,700	No specific regulations	750	20	3	Minor
Louisiana	46,600	No specific regulations	<10	-	-	Minor
Maine	4,800	Analysis required	200	8	4	Insignificant
Maryland	17,000	No specific regulations	<10	-	-	Minor
Massachusetts	20,800	Prohibited	<10	-	-	Insignificant
Michigan	77,100	Analysis required	50	5	<1	Minor
Minnesota	27,600	Prohibited with exceptions	<10	-	-	Significant
Mississippi	15,400	No specific regulations	510	33	3	Minor
Missouri	38,900	Prohibited	<10	-	-	Significant
Montana	6,100	Guidelines provided	610	36	10	Minor
Nebraska	14,500	No specific regulations	30	2	<1	Significant
Nevada	2,700	No specific regulations	<10	-	-	Minor
New Hampshire	2,200	No specific regulations	100	10	1	Insignificant
New Jersey	55,100	Prohibited	<10	-	-	Minor
New Mexico	7,800	No specific regulations	<10	-	-	Moderate
New York	50,200	Prohibited	<10	-	-	Minor
North Carolina	28,900	Permit required	580	NA[c]	2	Moderate
North Dakota	4,700	Agency notification	90	25	2	Significant
Ohio	87,100	No specific regulations	2,200	25	3	Moderate
Oklahoma	32,800	Permits/manifest	330	NA[c]	1	Significant
Oregon	18,400	No specific regulations	700	10	4	Minor
Pennsylvania	93,900	Guidelines for permitting and analysis	470	NA[c]	1	Moderate
Rhode Island	3,200	Prohibited	<10	-	-	Insignificant
South Carolina	12,500	Unknown	<10	-	3	Moderate
South Dakota	4,500	No specific regulations	90	25	2	Significant
Tennessee	29,600	No specific regulations	150	NA[c]	1	Moderate
Texas	125,100	No specific regulations	630	NA[c]	1	Significant
Utah	6,900	Reprocessing required	<10	-	-	Minor
Vermont	1,700	Permits and analysis	60	10	4	Insignificant
Virginia	22,600	No specific regulations	<10	-	-	Minor
Washington	17,200	No specific regulations	1,060	10	6	Minor
Washington, D.C.	1,700	No specific regulations	<10	-	-	Insignificant
West Virginia	15,000	No specific regulations	380	10	3	Minor
Wisconsin	24,400	No specific regulations	1,100	14	5	Significant
Wyoming	4,900	No specific regulations	550	40	11	Minor
Totals	1,388,010[d]		23,520		~2	

[a] Annual estimates for 1981/1982.

[b] Source: Generated waste oil - Reference 5; other columns based on Franklin Associates phone survey.

[c] NA - Not available; waste oil recovery rates for designated states were unavailable.

[d] The waste oil generation data presented in this table do not agree with the estimate independently developed by Franklin Associates (1,148 million gallons) which can be found in Reference 1. The value used in Reference 1 was selected for use in the summary of the waste oil management system because its derivation is documented, whereas the value in this table is not; however, the state-by-state breakdown associated with this value is necessary for the road oiling analysis.

level of road oiling for the entire country, which could have resulted in overstated values for many regions.

Some other factors also may have resulted in high estimates. Probably the most important of these is the recent trend toward burning waste oil as a fuel rather than using it as a dust suppressant. Other factors include the increased marketing of alternative dust control products and a growing awareness on the local level that road oiling can cause some undesirable environmental impacts.[1]

Overall, road oiling with waste oil appears to be regional in nature (Figure 2-2). The practice seems to be the most prevalent in the northern Rocky Mountain states, the extreme Southwest, and the Southeast. Moderate amounts of road oiling activity also occur in the Northwest and in northern New England.

Based upon all available information, an estimated 30 to 50 million gallons of oil is used in commercial road oiling activity each year in the United States. Road oiling activity by self-generators is believed to involve considerably less than this amount, although one source has estimated that self-generators use 31 million gallons of waste oil annually. The latter figure is only an estimated value because these activities are neither monitored nor reported. Total road oiling of all types in the United States almost certainly involves less than 100 million gallons of waste oil per year, and most likely involves between 50 and 80 million gallons.

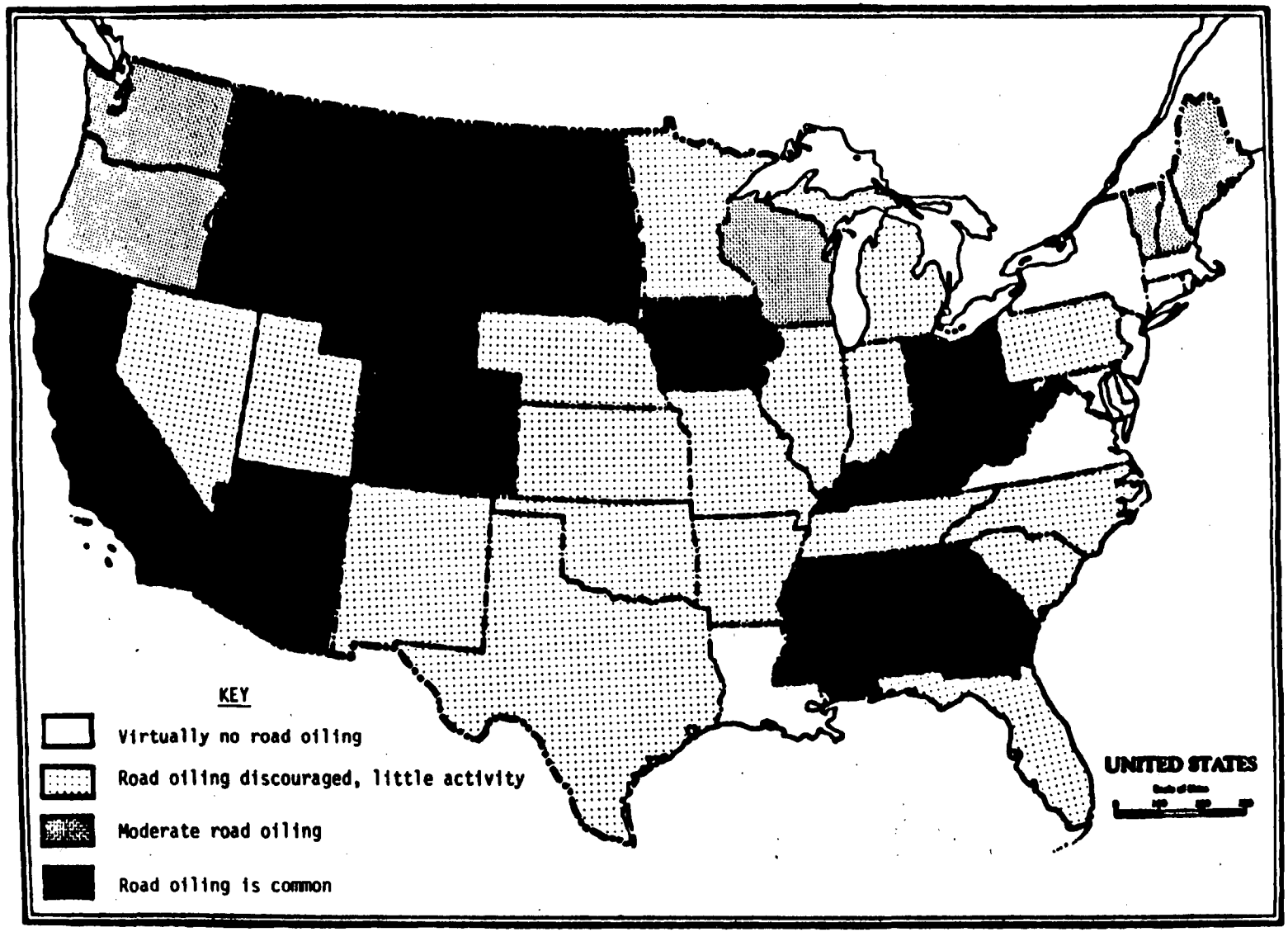


Figure 2-2. The status of commercial road oiling activity in 1981/1982 by state.

2.4 ROAD OIL APPLICATION

The road oiling segment of the waste oil industry is largely unstructured and consists of many independent companies and individuals. Nevertheless, information obtained from state agencies and waste oil firms indicates that road oil application procedures are quite similar everywhere and involve a technology that is many years old. Also, although guidelines have been developed for achieving maximum efficiency, actual applications are sometimes haphazard and usually less precise than those recommended in the guidelines.

Early road oiling activity (in the late 1920's and early 1930's) was considered a form of highway construction. Proper surface preparation, oil application, curing/penetration, and surface coating with coarse sand or gravel were common practices. Although these techniques are still relevant in 1983, they are rarely practiced to the same extent. Road oiling is now primarily surface application, sometimes preceded by routine grading.

The following four subsections discuss recommended application practices for optimal results and common practices in 1982. Several reports and conversations with road oilers provided the basis for the recommended road oiling practices summarized herein.

2.4.1 Surface Preparation

Currently, surface preparation often involves simple grading or sometimes nothing at all.* A road surface that is to be oiled

* Personal communications from various road oilers, county maintenance crews, and state highway departments.

should be relatively free of dust, and the dirt pores should be open to allow adequate penetration of the oil.[6] The shaped surface should be smooth and well-crowned to facilitate drainage. This is important because, if the surface is properly oiled, water will accumulate in any depressions and ultimately contribute to rapid deterioration unless proper drainage occurs.[7] If the road surface is clay, it should be loosened before the oil is applied; this will facilitate penetration.[8]

2.4.2 Weather and Seasonal Factors

Road oil should be applied during warm weather.[8] This is recommended primarily because the viscosity of some oils increases in cold weather. For most waste oils, viscosity should not be a problem at temperatures above 50°F, and it should not be necessary to heat them for road oiling unless the oil is to be used to cut (thin) asphalt for use as a road oil. Under these conditions (which are not common), a heating device may be necessary to prevent the plugging of sprayer orifices and to ensure even application rates.

The surface of the road should be slightly damp to facilitate the binding properties of the oil and dirt.[9] Conditions that are too dusty or too damp produce unsatisfactory results.

Depending on local conditions and the types of oil used, road oil should be applied one to three times per year. Under moderate traffic conditions (about 100 vehicles per day) and fairly dry climatic (summer) conditions, a heavy application is usually required in the spring, followed by another (usually

lighter) application in July or August.[10] Under less-traveled conditions, once-a-year application may be adequate. Heavily traveled roads could require three applications per year, but this requirement would be limited primarily to industrial (e.g., mining or logging) or urban roads.

These frequency guidelines are sometimes followed, but road oiling often does not take place until the need is obvious or until citizens' complaints regarding dust become significant. Quite often, a road will not be oiled until it becomes very dusty; at this point, good oil penetration and bonding to the dirt particles are difficult to achieve. Also, if rainfall should follow the application, the probability of surface runoff of oil and contaminants is greater. Such conditions also decrease the length of time that the oil will effectively control dust. These frequency guidelines do not differentiate between waste oil and virgin oil, but the lower viscosity of waste oil reportedly makes it less effective in suppressing dust. Nevertheless, reported application data for waste oil are within the guidelines, as reported in a later subsection.

2.4.3 Spraying Equipment

Road oiling is based on relatively old technology. The capacities of most distribution vehicles range from 800 to 3000 gallons. These vehicles may or may not have oil heating capabilities. Oil is forced from orifices in the horizontal distribution pipe by means of an engine-driven pump.[8] The distribution pipe is generally situated 8 to 12 inches from the road surface.

Although specific road oiling equipment can be purchased from manufacturers, improvisation is common, particularly among self-generator road oilers such as industries and farmers. With the aid of some basic mechanical skills, trucks, tanks, pipe, and fittings can be assembled into equipment for oiling roads. Many homemade systems use only gravity to spread the oil. For small areas (such as parking lots or short strips of road), hand oiling with a modified watering can is not unusual.

2.4.4 Application Rates

The quantity of oil applied to unpaved roads to suppress dust is reported in gallons per square yard (gal/yd^2). The application rate depends on such factors as soil type, previous road oiling, average vehicle travel, and traffic detour time period.

A distinction is made between application rates for different soil types. The typical recommended rate for sand is 0.75 to 1.0 gal/yd^2.[8] Clay and sand/clay mixtures require lesser amounts, ranging from 0.2 to 0.5 gal/yd^2.[8,11,12,13] One source of information reported that gravel roads required 0.25 gal/yd^2,[8] whereas another source reported an application rate for gravel of 0.33 to 0.50 gal/yd^2.[7] The type of oil used is not always stated in these references, but these rates are consistent with reported rates of waste oil usage.*

If the road to be oiled has never been treated or it has been several years since the last treatment, the application rate

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* Personal communications from road oilers, county maintenance crews, and state highway departments.

would predictably be higher than for a recently oiled surface. It can be assumed that the upper end of the ranges given for each soil type would apply to new road oiling, whereas the lower end of the ranges would often be satisfactory for reapplication. One source recommends that the yearly application in the spring should be fairly heavy (0.5 to 0.7 gal/yd^2), whereas any necessary reapplications in the summer can be reduced to about 0.3 gal/yd^2.[10]

Vehicle travel and available traffic detour time are less critical factors in the determination of application rates, primarily because there is an optimal rate in terms of oil penetration in a given soil type. If a road is more heavily traveled, however, a slightly heavier application would seem appropriate. On the other hand, if traffic can only be delayed for a very short period, a lighter coat would have to be applied.

Some road oiling guidelines specify post-application procedures; these include the sprinkling of coarse gravel or soil on top of the oiled surface to allow traffic to return earlier and to prevent oil "pickup" by vehicles. This practice is unusual when waste oil is used because the relatively low adhesion quality of this oil results in less pickup than that with heavier asphaltic oils.

2.5 EFFECTIVENESS OF WASTE OIL AS A DUST SUPPRESSANT

The overall performance of any dust-control product depends on several local factors, including soil type and composition,

weather, traffic patterns, surface characteristics of the road, and the grade of the road surface.

The surface characteristics of the road are very important. A crusty or dusty surface will inhibit oil penetration and binding, will contribute to pooling of oil on the surface, and could increase the potential for runoff. Under these road surface conditions, oil is also more likely to be picked up by passing vehicles and deposited elsewhere. These mechanisms that move oil off the road surface quickly decrease the stabilization characteristics contributed by the oil.

It is obvious that the weather conditions that follow the application of oil are important in determining performance. A period of heavy rain will wash much of the oil from the surface via flotation, even if some penetration has occurred. In some cases, particularly with sandy soils, oil-coated soil particles will actually float and wash off the road surface.

The crown and slope of the road are also important factors with respect to potential runoff and performance of the oil as a dust suppressant. Waste oils that are fairly thin can run off or down a road without the addition of water to the road, particularly if the road surface is crusted and excessively crowned.

Recently, numerous technical reports and articles have been written that assess the effectiveness of various dust-control products. Very few of these documents include waste oil as an alternative, but virtually all evaluate one or more virgin oil products. These include emulsified oil in water or asphaltic-

based material cut back (or thinned) by a light hydrocarbon solvent. It is unlikely that the performance of waste oil would be equivalent to the measured performance of virgin-oil-based products for controlling dust because used lube oils are much lower in asphaltics than virgin products. This low asphaltic content of used oils minimizes the adhesive characteristics of the oil as a road bed stabilizer and the potential for runoff is greater. The waste oil is more likely to be removed from the road surface as a result of washing and oil flotation, which is ultimately followed by runoff from the typically crowned road surface. This process and other transport mechanisms are discussed in more detail in Section 3.

A few reports have attempted to document waste oil performance as a dust suppressant. Midwest Research Institute (MRI) reported a dust control efficiency of 75 percent.[14] This assumed level of control was based on visual observation rather than actual particulate sampling. It is interesting to note that MRI also reported that monthly oiling was required to maintain the dust control level at 75 percent. Monthly road oiling is undocumented as a common practice; applications once or twice a year are considered the norm in most situations.

The performance of virgin-oil-based dust-control products is reported to be considerably better than used oil. The Arizona Transportation and Traffic Institute carried out a major test program to measure the effectiveness of virgin oil dust suppressants; performance levels were reported to be consistently over 90 percent control and as high as 96 percent.[15] These levels

represented immediate and temporary control; however, the expected decreases in performance are not large. More than 1 year from the time of initial application of a virgin-oil cutback product, the treated surface of a control road was still emitting 75 percent fewer dust particles than the untreated portion of the road.[15] These data on the performance of the virgin-oil products are based on actual particulate sampling with high-volume samplers.

2.5.1 Dust Suppression as a Function of Time

Performance of the dispersion modeling covered in Section 3 necessitated an evaluation of the data on the effectiveness of waste oil as a dust suppressant over time. The following assumptions and basic information requirements were used to develop a worst-case estimate of the decrease in the effectiveness of waste oil as a dust suppressant as a function of time.

- Immediately after a road has been oiled, total particulate control is about 75 percent.[14,16]
- The decrease in control effectiveness depends on the following factors:
  1) Previous oiling that has taken place
  2) Type of road surface
  3) Oil composition
  4) Traffic patterns, including vehicle types and speeds
  5) Weather conditions
  6) Application rate
- A worst-case scenario with respect to the factors listed above would assume the following:
  1) No oiling had previously taken place.
  2) The road surface was crusted, dusty, or hard-packed, and the oil could not penetrate the soil.
  3) The oil contained a large light-hydrocarbon fraction that quickly evaporated.

4) Many large and fast-moving vehicles traveled the road on a daily basis.
5) Dry and windy conditions were prevalent.

- Road oiling, which is performed primarily from May to October, is largely dependent on the immediate need to control dust. Therefore, actual road oiling frequency reasonably can be used to estimate the change in effectiveness of the oil in the control of dust over time. Road oilers report frequencies ranging from once a month to once a year.

- No one has attempted to measure the decrease in the effectiveness of road oil as a dust suppressant as a function of time. Some other dust suppressants lose effectiveness in a nonlinear way, following what can be described as a "backwards S-curve." It is not known if waste oil also follows this pattern. Whether this is the case probably depends on local conditions as well as the oil composition. Because of these uncertainties, it was assumed that dust emissions from an oiled road will increase linearly with time.

- For the worst-case analysis, it was assumed that dust would be controlled at 75 percent efficiency at time zero and decrease linearly to no control at the end of 30 days. It is reasonable to conclude that as long as some oil remained on the road, some dust control would continue; however, for the purposes of this analysis, it was assumed that the adverse local conditions would decrease control to approximately zero after one month. The percent of dust control expected under worst-case conditions over a 30-day period was then estimated (Table 2-3).

TABLE 2-3. CONTROL OF PARTICULATE EMISSIONS FROM AN UNPAVED ROAD TREATED WITH WASTE OIL[a]

Day number	Percent control[b]
0	75.0
1	72.5
2	70.0
3	67.5
4	65.0
5	62.5
10	50.0
15	37.5
20	25.0
25	12.5
30	0

[a] Based on a 75 percent control efficiency reported by Midwest Research Institute at time zero.[14]

[b] Percent control assumes linear decreases from 75 percent at Day 1 to zero control at Day 30. This rate of decrease in effectiveness assumes worst-case local conditions.

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SECTION 3

ENVIRONMENTAL FATE OF WASTE OIL COMPONENTS

This section addresses the movement of waste oil components that have been applied to road surfaces and their fate within the environment. Numerous components of waste oil and contaminants that are frequently mixed with waste oil may be of environmental concern. Among them are heavy metals (including arsenic, barium, cadmium, chromium, lead, and zinc); the freons (including dichlorodifluoromethane and trichlorotrifluoroethane); degreasing solvents (including trichloroethane, trichloroethylene, and tetrachloroethylene); ignitable solvents (such as benzene, toluene, and xylene); polynuclear aromatic hydrocarbons (including benz(a)-anthracene, benzo(a)pyrene, and naphthalene); and PCB's.[1] As discussed in Section 2, concentrations of these substances within waste oil vary widely.

3.1 MECHANISMS OF WASTE OIL MOVEMENT

Waste oil typically leaves the road surface by four major mechanisms: evaporation, seepage, dust transport, and rainfall runoff. Oil that is applied to the road will gradually begin to seep into the road surface. Evaporation of some of the waste oil components also will begin to occur. If the wind is sufficient, the transport of dust particles from the road surface will also

begin at this time. Rainfall runoff is of a more intermittent nature, restricted to those periods in which rainfall levels are sufficient to carry water and oil from the road surface. The processes of evaporation, seepage, and dust transport will typically occur simultaneously, although the rates of the different processes will vary according to environmental conditions.

3.1.1 Evaporation

The rate of evaporation of waste oil and its components is influenced by a number of factors. The concentration of various waste oil components and their physical characteristics will determine the rate of vaporization of each individual component of the waste oil. The vapor pressure of waste oil components is the most important physical parameter that affects evaporation. Influenced by temperature, it increases as the temperature increases. Carbon chain length is often used to estimate evaporation rates, because shorter chain hydrocarbons commonly have higher rates of evaporation than longer hydrocarbon chains. Oil surface area and depth of penetration of oil into the soil are two additional factors that affect the evaporation of oil from road surfaces.

The evaporation of waste oil from rural roads has been estimated in laboratory weathering experiments.[2] The waste oil was placed in a shallow pan or applied to clay, and then placed under infrared lamps in the draft of a fan; surface temperature was adjusted to 100°F. Used crankcase oil underwent a weight loss of 5.97 to 9.05 percent over a 72- to 360-hour evaporation period

(Table 3-1). Oils to which 20 percent No. 6 sludge had been added had significantly higher weight losses. The composition of No. 6 sludge was not given in the reference, but it is apparent that the weight loss of waste oil is greatly affected by its overall composition. The most important result of this study is the significant weight loss that occurs from evaporation.

TABLE 3-1. EVAPORATION OF TWO WASTE OILS[a]

Oil type	Temperature, °F	Time, h	Weight loss, %
b	90	72	5.97
b	100	360	9.05
b	100	360	7.29
c	100	288	18.15
c	100	288	16.43
c,d	100	354	16.13
c,d	100	354	17.07

[a] Source: Reference 2.
[b] Used crankcase oil.
[c] Eighty percent used crankcase oil, 20 percent No. 6 sludge.
[d] Applied to clay.

3.1.2 Seepage

Oil will gradually seep through the road surface into underlying soil. The seepage rate depends primarily on soil permeability and the degree of compaction of the road surface. As oil passes through the soil, it coats the soil particles, and some oil contaminants adsorb onto soil surfaces. The depth of oil

penetration into the road surface depends on the soil type and the amount of oil applied to the road surface. Because the amount of oil applied to the road surface at a given time is generally fairly small, oil will not penetrate deeply into the road surface. Some leaching of oil components will occur from water passing through the oil, but such leaching is detectable only at shallow depths.

Two studies have investigated depth of penetration of oil and organic oil components into road surfaces after road oiling.[2,3] Freestone[2] measured hydrocarbon concentrations with depth on two New Jersey roads (Table 3-2). Significant but variable penetration of oil into the road surface was observed at both 4 and 6 inches. Concentrations at the 6-inch depth ranged from 7.65 to 67.63 mg/kg on one road and from 198.35 to 354.40 mg/kg on the other road. A study of two oiled logging roads in California[3] measured the change in concentration of anthracene, pyrene, benz(a)anthracene, and benzo(a)pyrene with depth and time (Tables 3-3 and 3-4). The Cow Creek site was oiled on Day 1 with waste oil and after Day 21, with MC-70 dust palliative. Very little movement below the 3-inch depth was observed. The North Canyon site was oiled 2 to 3 weeks prior to Day 0. Results were inconsistent with time and depth, and no conclusions were drawn. Even with the sampling difficulties encountered in both road oiling studies, however, it appears that downward migration of organic oil components through road surfaces is minimal.

TABLE 3-2. PENETRATION OF OIL INTO ROAD SURFACE[a]

Station	Hole	Depth, in.	Hydrocarbons, mg/kg
1	1	Surface	6,313.17
		4	18.04
		6	18.53
	2	Surface	12,572.70
		4	26.42
			52.62
	3	Surface	8,254.50
		4	88.72
		6	7.67
	4	Surface	5,880.24
		4	70.71
		6	7.65
	5	Surface	13,441.25
		4	39.95
		6	67.63
	6	Surface	2,555.91
		4	59.87
		8	9.35
		10	12.15
2 Control	1	Surface	347.76
		4	0
		6	0
	2	Surface	131.04
		4	0
	3	Surface	211.83
		4	0
3	1	Surface	1,586.22
		6	354.40
	2	Surface	9,437.94
		4	805.74
		6	198.35
		Surface	6,222.52
		4	276.21
4 Control	1	Surface	142.72
		6	10.04

[a] Source: Reference 2.

TABLE 3-3. POLYNUCLEAR AROMATIC HYDROCARBONS IN ROAD SAMPLES AT VARIOUS DEPTHS - COW CREEK SITE[a]
(ppm)

	Background	Day 1		
		Surface	0-3 inches	3-6 inches
Anthracene	0.0152	7.84	0.72	0.0672
Pyrene	0.2095	113.60	15.0	0.6095
Benz(a)anthracene	0.381	114.92	13.05	0.7168
Benzo(e)pyrene	0.2952	186.85	19.70	1.28
		Day 21		
Anthracene		5.37	0.9039	0.315
Pyrene		97.76	20.56	5.53
Benz(a)anthracene		68.64	18.04	5.04
Benzo(e)pyrene		99.69	27.43	6.42
		Day 41		
Anthracene		22.70	6.5	0.196
Pyrene		157.3	52.8	3.13
Benz(a)anthracene		147.2	57.2	3.33
Benzo(e)pyrene		72.59	29.92	4.64
		Day 71		
Anthracene		7.86	5.6	0.92
Pyrene		69.11	11.95	4.59
Benz(a)anthracene		65.0	9.21	5.59
Benzo(e)pyrene		40.42	8.10	5.6
		Day 133		
Anthracene		2.10	0.396	0.153
Pyrene		33.46	10.42	1.696
Benz(a)anthracene		32.21	4.74	2.90
Benzo(e)pyrene		39.38	6.82	5.25

[a] Source: Reference 3.

TABLE 3-4. POLYNUCLEAR AROMATIC HYDROCARBONS IN ROAD SAMPLES AT VARIOUS DEPTHS - NORTH CANYON SITE[a]
(ppm)

	Background	Day 1		
		Surface	0-3 inches	3-6 inches
Anthracene	0.006	1.95		2.35
Pyrene	0.003	13.0		15.6
Benz(a)anthracene	0.0025	10.5		12.26
Benzo(e)pyrene	0.008	6.5		6.69
Benzo(a)pyrene		5.5		5.13
		Day 21		
Anthracene		9.10	1.97	0.80
Pyrene		76.92	34.48	4.0
Benz(a)anthracene		69.23	37.21	3.7
Benzo(e)pyrene		48.35	49.15	2.0
Benzo(a)pyrene		38.46	32.1	1.6
		Day 41		
Anthracene		0.028		0.022
Pyrene		0.614		0.394
Benz(a)anthracene		0.692		0.347
Benzo(e)pyrene		0.435		0.465
Benzo(a)pyrene		0.384		
		Day 71		
Anthracene		1.69	1.54	0.135
Pyrene		35.60	20.97	2.89
Benz(a)anthracene		32.08	16.4	2.81
Benzo(e)pyrene		55.98	23.81	5.07
		Day 133		
Anthracene		1.67	2.65	2.46
Pyrene		35.28	39.77	37.8
Benz(a)anthracene		40.00	39.8	39.5
Benzo(e)pyrene		87.50	65.6	62.5

[a] Source: Reference 3.

Metals are also expected to remain in the upper levels of the road surface. On two logging roads, lead and zinc concentrations due to road oiling were analyzed for variations with depth and over time.[3] Lead penetration was observed only once (on the 15th day) at the 0 to 3-inch horizon. Zinc penetration was negligible on one road, but variable penetration up to 6 inches was observed on the other road. No concentrations of lead and zinc above 20 parts per million were observed below the road surface.

Because seepage has a minimal impact on the movement of waste oil from an oiled road, it has not been pursued further in this report.

3.1.3 Dust Transport

Dust transport may be an important factor in the removal of adsorbed oil components from the road surface. With an average daily traffic flow of 100 vehicles, it has been estimated that 100 tons of dust per mile per year will be deposited along a 1000-foot-wide corridor with the road at the center.[4] After application of waste oil, dust transport is temporarily reduced to about 25 percent of uncontrolled emissions.[5]

The adsorption of oil components onto airborne dust particles may be an important mechanism of oil component transport from the road surface. The period of time during which dust is suppressed and the amount of oil component removal by runoff, vaporization, and seepage that occurs during this period determine the importance of dust transport as a mechanism of waste

oil component removal from the road surface. No data on concentrations of oil components on airborne road dust were found in the literature. One study was attempted,[3] but vandalism of air sampling equipment invalidated the data.

3.1.4 Rainfall Runoff

Components of oil and waste oil that have been applied to road surfaces may contaminate surface waters. Rainfall and subsequent surface runoff may contain colloidal oil, dissolved oil components, and oil adsorbed onto soil particles. The form of oil (i.e., colloidal, soluble, or adsorbed) depends on the amount of time that has elapsed since road oil application and the characteristics of the road surface. Oil may be washed from the road surface and carried with the water as a surface film or colloids. After oil has seeped into the road, rainfall cannot wash it off as easily or rapidly. If rain seeps into the road, it can displace the oil and cause it to float to the surface, where it can be washed away. Another rainfall removal mechanism involves erosion. Oil components that have adsorbed onto road soil can be carried to surface waters as a result of the soil being washed from road surfaces. After this occurs, the oil components can be desorbed while the soil is in suspension or after formation of sediments.

Two laboratory investigations have been made of runoff from oiled roads.[2,6] One was designed to simulate the application of 0.05 gallon of oil per square foot to two road surfaces, one sand and one clay. Typical New Jersey rainfalls for June and July were simulated with spray nozzles. Oil was then reapplied and

August and September rainfalls were simulated. Runoff was collected and analyzed for oil content (Table 3-5). Oil penetration on the clay road was about one millimeter, and puddles formed as a result of runoff of the oil to the lowest level of the oiled road surface. The "rain" washed the oil from the puddled areas and leached oil from the clay surface, but it did not penetrate the entire clay column. Oil penetrated the sand road to a depth of only a few grain diameters. It was evenly distributed and there was no puddling. The "rain" caused the flotation of oily sand particles, and approximately 24 percent of these sand particles were removed by the application of two simulated monthly rains.

TABLE 3-5. LABORATORY RUNOFF FROM SIMULATED OILED ROADS[a]

Time, days	Oil applied, ml	"Rain" simulated, inches	"Rain" applied[b]	Sand			Clay		
				Water[b]	Oil, ml	Total oil loss, %	Water[b]	Oil	Total oil loss (%)
0	600	-	-	-	-	-	-	-	-
3	-	3.80	28.3	20.5	80.2	13.4	26.0	37.5	6.3
4	-	4.52	33.7	20.9	101.2	30.2	32.5	15.8	8.9
5	600	-	-	-	-	-	-	-	-
6	-	5.02	37.4	31.5	77.1	21.5	37.0	89.7	11.9
7	-	3.59	26.7	19.5	29.5	24.0	23.4	5.3	12.4

[a] Source: Reference 2.

[b] Total water penetration through the sand column was 10.0 liters of water containing 12.1 ml of hydrocarbons. No penetration was observed through the clay column. Units for "rain" and water were not given.

The total rainfall for 4 months was simulated over a 7-day period, with the equivalent of 1 month of rainfall occurring on a single day. It is our opinion that Days 0 through 4 more closely simulate the effect of the occurrence of two consecutive heavy rains of 3.8 and 4.5 inches of rain on the third and fourth days after road oiling. The results of this study actually may approximate an extreme worst-case situation in which more than 8 inches of rain falls within a 2-day period, only 3 days after road oil application. Measurements indicate that 30 percent of the oil was removed from the sand road and 9 percent from the clay road over the 2-day period. The researchers noted high levels of soil particles in the sand road runoff; thus, it may be inferred that erosion processes are primarily responsible for the differences in the oil content of the runoff from sand and clay roads.

In a more recent rainfall runoff study, two simulated road surfaces were oiled with waste oil and then allowed to undergo natural weathering for a period of one month.[6] Rainfall amounted to approximately 2-1/2 inches during the study period. As shown in Table 3-6, tests of runoff from the road surfaces contained only 4 to 6 mg of oil per liter, which was less than 5 percent of the total oil applied to the road surface. It is likely that the lower oil concentrations found in this study (compared with the Freestone study[2]) are due to the lower rainfall amounts and longer period of study. It is believed that a concentration of 4 to 6 mg of oil per liter of rainfall runoff from oiled roads is more typical.

TABLE 3-6. DISPOSITION OR FATE OF OIL ONE MONTH AFTER APPLICATION TO SIMULATED ROADBED SURFACES[a]

Fate of used oil	Percent of total oil applied	
	Roadbed soil	Roadbed soil with 5% bentonite
Evaporation	>12	>12
Rainfall runoff		
Insoluble	2.7	3.5
Soluble	0.3	0.4
Rainfall penetration		
Insoluble	Neg.	Neg.
Soluble	0.06	0.01
Remaining in soil	~85	~84

[a] Source: Reference 6.

3.2 WORST-CASE SCENARIOS FOR WASTE OIL MOVEMENT

The choice of a worst-case scenario depends on the environmental sector for which the impact is being considered. In other words, a worst-case scenario for air quality would differ from the worst-case scenario for surface water quality. High levels of evaporation of organic waste oil components and transport of dust contaminated by waste oil will result in worst-case conditions for air quality. Surface water quality would be affected most severely by rainfall runoff carrying large quantities of waste oil from the road surface to the surface water system. The processes of evaporation, dust transport, and rainfall runoff are competing mechanisms for removal of waste oil from road surfaces. In general, those conditions that would result in worst-case scenarios for evaporation will differ significantly from those

conditions that would result in worst-case scenarios for dust transport or rainfall runoff.

3.2.1 Evaporation

Evaporation rates increase when road surface temperatures are elevated because high road surface temperatures increase the vapor pressure of oil components. Evaporation proceeds most rapidly immediately following oil application because concentrations of oil components are then at their highest and because the oil has not yet begun to penetrate into the surface of the road. Evaporation also increases with windspeed. It should be noted, however, that even though evaporation is greater at higher windspeeds, the wind carries vaporized contaminants away from the road area; thus, ambient air concentrations drop with high windspeed. Road surface type affects evaporation rates because more permeable surfaces allow fairly rapid penetration of the oil, whereas on less permeable surfaces the oil tends to remain on top of the road and thus be more subject to evaporation. In summary, high rates of evaporation result from high road surface temperatures, high vapor pressures of oil components, high windspeeds, and low permeability of road surfaces.

The worst-case scenario for analysis of ambient air concentrations assumes that a one-mile-per-hour (1609 m/h) wind is blowing perpendicular to a freshly oiled road with a surface temperature of 100°F. For simplification of the analysis, the scenario further assumes that the initial evaporation rate remains constant until the entire component in the oil has evaporated. This represents a worst case for evaporation because

actual evaporation rates decrease as the oil penetrates into the road surface. Also, as evaporation proceeds, oil component concentrations drop and, consequently, so do evaporation rates.

3.2.2 Contaminated Dust Emissions

Little is known about the effectiveness of waste oil as a dust suppressant or how rapidly its effectiveness decreases with time. Dust emissions, with or without oiling, are affected by the dryness of the road surface, the silt content, and the amount of traffic. Usually, emissions increase proportionally with the increase of all of these factors.

In general, high levels of contaminants are adsorbed onto dust particles under opposite conditions of those necessary for either high levels of evaporation or high levels of oil concentration in rainfall runoff. For contaminated dust to leave the road surface, oil must remain attached to the dust particles. This means that in a worst-case scenario, rainfall levels must be low or nonexistent so that the oil is not washed from the road surface. Thus, dry conditions result in high levels of waste oil on emitted dust particles.

The worst-case scenario for the modeling of contaminated dust emissions assumes conditions characteristic of the U.S. Southwest. This area was selected because the climatological conditions (low rainfall and dry days) are conducive to high emissions of reentrained dust. June was chosen for the 30-day average used in the modeling because maximum road oiling is expected to occur in this dry month (e.g., average precipitation is less than 0.5 inch in El Paso, Texas).

3.2.3 Rainfall Runoff

High concentrations of waste oil in runoff from oiled road surfaces occur when rainfall closely follows oil application. As more time elapses between oil application and rainfall, greater amounts of the oil penetrate into the road. Oil evaporation also occurs during the time between oil application and rainfall. Both evaporation and seepage decrease the amount of oil available to be washed from the road surface with the rainwater. Although the amount of oil that leaves the road with rainfall has not been investigated, it is obvious that greater intensities of rainfall tend to loosen more oil from the road surface and thereby increase the amount of oil in the surface water runoff. As rainfall intensities increase, however, the oil on the road surface becomes more diluted. The tradeoff point between increased washoff of oil and dilution of oil due to rainwater is not precisely known. In summary, short periods of time between waste oil application and rainfall events that are sufficient to remove oil from the road surface produce the highest levels of surface water runoff contamination.

3.3 DISPERSION MODELING OF ENVIRONMENTAL CONTAMINATION

Dispersion models have been applied to the movement of waste oil from road surfaces in an effort to quantify the extent of possible environmental contamination of air and surface waters. Organic vapors and contaminated dust particles can cause deterioration of air quality. Ambient air concentrations of organic vapors are modeled in two phases. The first phase determines the

rate of evaporation of organic waste oil components from the road surface. The second phase determines the distribution of these organic components above the road surface and their resultant ambient air concentration.

The determination of the level of contaminated dust particles in the ambient air is also a two-phase process. The first phase involves determination of the concentration of waste oil components on dust particles emitted from the road surface. The second phase involves determination of the distribution of these contaminated dust emissions in the ambient air by the use of air transport models. Before the effects of rainfall runoff can be modeled, the concentration of oil and oil components in runoff waters must be determined and the potential for formation of an oil slick must be assessed.

The following subsections present the models used to estimate the extent of air and water contamination due to road oiling with waste oil. In the model presentations, particular attention is given to the model variables, the sources of these variables, and typical and worst-case ranges of values of the variables. Also presented are the model assumptions and the problems that were encountered in use of the model.

3.3.1 Evaporation

Evaporation of organic components can be a major mechanism of waste oil movement. Oil applied to the road begins to evaporate from the surface immediately. Low-molecular-weight, high-vapor-pressure components evaporate most rapidly. As the oil

seeps into the road surface, evaporation continues in subsurface pore spaces, but evaporation rates decrease substantially as a result of a slow rate of diffusion through pore spaces to the soil surface. Because surface evaporation proceeds most rapidly, it has been chosen as a worst-case situation for modeling organics evaporation from roads.

Actual evaporation from an oiled road includes both surface evaporation, which is the major component of the total, plus a minor additional amount of subsurface evaporation. How closely surface evaporation models can approximate actual evaporation rates depends on the rate of seepage of waste oil into the road surface. Seepage calculations are based on variations in the hydraulic conductivity of the oil for different soil types and typical application rates of oil to those road surface types (Tables 3-7 and 3-8). Seepage times for penetration of all applied oil vary from 0.1 second for gravel roads (at a low end of the range) to 4167.6 years for clay road surfaces (at a high end of the range). Because gravel is normally applied to the road surface in thin layers only and is commonly underlain by silt or clay, seepage rates of oil into gravel may not be entirely relevant. Thus, typical seepage rates are expected to vary from the order of magnitude of centimeters per hour to centimeters per year.

Surface evaporation rates were calculated by using the model developed by Mackay[8] (Equations 1 through 3). The ideal vapor

TABLE 3-7. SEEPAGE FACTORS FOR OIL AND WATER IN VARIOUS SOILS

Soil type	Hydraulic conductivity (K)[a]		Intrinsic permeability (k), cm^2
	Oil, cm/s	Water,[b] cm/s	
Clay	1.4×10^{-12} to 1.4×10^{-9}	10^{-10} to 10^{-7}	10^{-15} to 10^{-12}
Silt	1.4×10^{-9} to 1.4×10^{-5}	10^{-7} to 10^{-3}	10^{-12} to 10^{-8}
Sand	1.4×10^{-5} to 1.4×10^{-2}	10^{-3} to 1	10^{-8} to 10^{-5}
Gravel	1.4×10^{-3} to 1.4	10^{-1} to 10^{+2}	10^{-6} to 10^{-3}

[a] $K = 100\ kg/\mu$, where K = hydraulic conductivity (cm/s), k = intrinsic permeability (sq cm), g = acceleration due to gravity (9.8 m/s^2), and μ = kinematic viscosity (0.71 cm^2/s for oil and 0.01 cm^2/s for water).

[b] Reference 7.

TABLE 3-8. TIME SEEPAGE OF OIL INTO ROADS

	Application rate, liters/m^3	Time[a]	
		High	Low
Clay	0.74 - 1.84	4167.6 yr	1.68 yr
Silt[b]	(0.74) - (1.84)	(4.2 yr)	(1.47 h)
Sand	2.76 - 3.68	7.3 h	19.6 s
Gravel	0.92 - 1.84	2.2 min	0.1 s

[a] Time for seepage = application rate ÷ hydraulic conductivity for oil.

[b] Estimated values based on application rate for clay.

pressure of each oil component and their Schmidt numbers are given in Appendix A. Road width is a constant equal to 18 feet (5.5 meters). Soil surface temperature in the calculations was set at worst-case conditions, i.e., 100°F.[9] Wind velocities ranging from 1 through 40 m/h were considered in the sensitivity analysis (Appendix A). The mole fraction of each oil component was determined, based on both the 75th percentile and 90th percentile concentrations.[1] These concentration levels were chosen because they represent reasonably high levels of oil components that may be expected to occur in waste oil applied to roads.

The calculated evaporation rates are only valid for a short time. As evaporation proceeds, oil component concentrations drop, and consequently, so do evaporation rates.

$$q = KP_i/RT_s \quad (1)$$

where K = mass transfer coefficient, m/h

P_i = partial vapor pressure, atm

R = ideal gas constant, m^3 atm/mol K

T_s = soil surface temperature, K

q = evaporation rate, mol/m^2 - h

$$K = 0.0292\ V^{0.78}\ W^{-0.11} Sc^{-0.67} \quad (2)$$

where 0.0292 = units of conversion factor

V = wind velocity measured at height of 10 m, m/h

W = road width, m

Sc = Schmidt number (unitless)

$$P_i = X_i P_i^{\circ} \quad (3)$$

where X_i = mole fraction of oil component i (unitless)

P_i° = ideal vapor pressure of oil component i, atm

Description of Dilution Model Used to Calculate Concentrations of Waste Oil Contaminants Evaporated From an Oiled Road--

A simple dilution model was used to estimate the concentration of waste oil contaminants that would be found in a volume (or "box") of air over an oiled road (Figure 3-1). The road is assumed to be 5.5 meters wide and the box is 1 meter deep. In applying this dilution model, two parameters are of primary importance: generation rate (rate of release of waste oil contaminants from the road surface), and air volume (volume of ambient air likely to contain the waste oil contaminants).

The generation rate is primarily a function of the evaporation rate of a specific contaminant. As shown in Table 3-9, evaporation rates (expressed as m^3/m^2 per hour) were determined for each of the waste oil contaminants. In the construction of the model, it was assumed that the ambient air would blow across the oiled surface in a direction prependicular to the roadway. Based on this assumption, one can estimate a generation rate per unit length of roadway (m^3/min) by multiplying the evaporation rate of a given contaminant by a unit surface area of a roadway 5.5 meters wide and 1 meter in length. The generation rate from this unit area is assumed to be representative of the entire length of roadway. Although the total amount of contaminant released into the atmosphere will increase with larger and larger

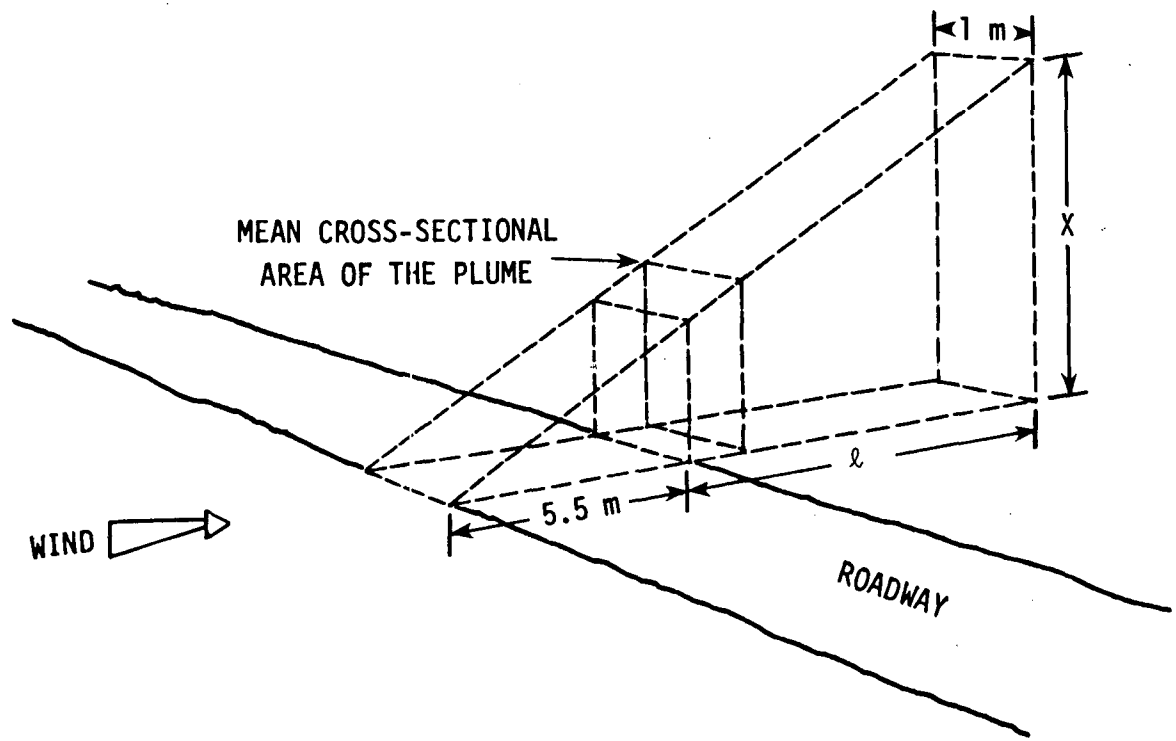

Figure 3-1. Hypothetical plume from an unpaved oiled road.

TABLE 3-9. EVAPORATION AND GENERATION RATES FOR SELECTED WASTE OIL CONTAMINANTS

Waste oil contaminant	Evaporation rate,[a] m^3/m^2 per hour	Generation rate, m^3/min	Estimated time for complete evaporation,[b] min
Aroclar 1248 (PCB)	--	--	5×10^8
Benzene	0.0015	1.4×10^{-4}	255
Dichlorodifluoromethane	0.0096	8.8×10^{-4}	23
Tetrachloroethylene	0.0011	1.0×10^{-4}	161
Toluene	0.0033	3.0×10^{-4}	96
Trichloroethane	0.0092	8.4×10^{-4}	24
Trichloroethylene	0.0047	4.3×10^{-4}	47
Trichlorotrifluoroethane	0.0266	2.44×10^{-3}	5
Xylene	0.0008	7×10^{-5}	343

[a] See Appendix A.

[b] Assumes evaporation rate remains constant during the evaporation period.

surface areas (i.e., longer lengths of roadway), the generation rate remains unchanged as long as the wind continues to blow roughly perpendicular to the roadway. The calculated generation rates based on this scenario are presented in Table 3-9.

Air volume is defined as that quantity of air overhead and downwind of the roadway that will be available to mix with the waste oil emissions emanating from the road surface. This volume was interpreted to be a wedge-shaped plume originating at the upwind side of the roadbed and extending across the surface of the roadway to a distance downwind of the road (Figure 3-1). Determining the volume of the plume is critical to estimating the ambient concentration of various evaporative emissions. In an attempt to provide a worst-case yet realistic estimate of the plume volume, consideration was given to the fact that emissions leaving the surface of the roadbed would be transported downwind of the roadway as a result of mixing conditions of the atmosphere. The distance this plume travels and its maximum length depend on the windspeed of the air and the time involved in complete evaporation of the volatile substances from the roadbed. For purposes of a worst-case situation, a windspeed of 1 mi/h was chosen. This windspeed allows a given parcel of air to remain over the roadbed for a reasonably long period of time to acquire what can be considered a worst-case concentration of volatile substances. Waste oil contaminants with slow evaporation rates will be carried great distances downwind before evaporation of the road oil contaminants is complete; thus, the available amount of each

contaminant will be diluted into a large air volume. These emissions will be diluted into a volume of air larger than those contaminants with faster evaporation rates; i.e., fast evaporation results in short downwind distances and smaller plume volumes. The downwind length (ℓ) of the plume (calculated as that length required for complete evaporation of a contaminant) is determined by using Equation 4.

Given a windspeed of 1 mi/h (1609 m/h), the length of plume can be estimated as the product of the windspeed multiplied by the time required for complete evaporation of a given substance. Table 3-12 also provides estimates for the time to compile evaporation of specific waste oil constituents.

$$\ell = [T\ (W/60)] \qquad (4)$$

where ℓ = downwind length of plume, meters
T = time for complete evaporation, minutes
W = wind speed, 1609 meters per hour (1 mph)

In addition to the downwind length (ℓ) of the plume, a value of 5.5 m (the width of the roadway) is added to provide an estimate of the entire plume, as portrayed in Figure 3-1. The total plume length (L) is the value used to calculate plume volume.

Mixing height depends greatly on atmospheric stability; i.e., the greater the stability, the lower the mixing height. Typically, the more sophisticated dispersion models use categories of atmospheric stability ranging from the most unstable (Class A) to the most stable (Class F). A Class D stability was chosen for this analysis because this stability class represents more than 50 percent of all meteorological conditions.

The potential height of the mixing air volume or plume height (X) is dependent on the downwind distance. Table 3-10 presents the estimated plume height for various downwind plume distances resulting from calculations based on meteorological mixing heights for a D stability class.

TABLE 3-10. DOWNWIND DISTANCES AND RELATED PLUME HEIGHT (meters)

Downwind distance (ℓ)	Plume height (X)
0-10	5
10-100	20
100-1,000	90
1,000-10,000	140
10,000-100,000	330

The road oiling scenario used in this study was set up with the wind blowing perpendicular to the roadway. The rationale behind this orientation is based on the premise that the greatest impact on human health will occur from exposures alongside the oiled roadway. Workers on the trucks applying the waste oil will travel at speeds many times the worst-case windspeed of 1 mi/h; thus, they will stay ahead of the most concentrated plume running parallel to the roadway. Because freshly oiled roads are seldom used immediately, the evaporation rate is nearly complete for most volatile contaminants before automobile traffic reaches a significant level. Individuals working or living adjacent (roughly perpendicular) to the road oiling operations are at greatest risk to prolonged elevated exposures.

The mathematical model used to estimate airborne concentrations resulting from this road oiling scenario is a single-compartment dilution model. The average concentration of each contaminant in the plume is calculated by the following equation:

$$C = \frac{G}{Q}\ (1 - e^{-nt}) \qquad (5)$$

where: C = average concentration in plume

G = generation rate, m^3/min
$= \frac{(5.5m)\,(E,\ m^3/m - h)}{60\ min/h}$

where E = evaporation rate

Q = flow rate, m^3/min
= (W, m/min) (0.5 X, m) (1 m)

n = number of air changes per minute
$= \frac{Q,\ m^3/min}{V,\ m^3}$

t = duration of exposure, min
= 480 min (8 h)

V = volume of plume, m^3
= 0.5 (L) (X m) (1 m)

The flow rate (Q) is determined by multiplying the mean cross-sectional area of the plume (0.5 X · 1 m) by the windspeed (W). The number of air changes per minute (n) is determined by dividing the flow rate (Q) by the volume of the plume [(0.5) (X·L·1m)].

3.3.2 Contaminated Dust Emissions

Contaminated dust emissions from roads that have been oiled with waste oil depend on the amount of dust suppression that resulted from the application and the concentration of contaminants on the dust particles. The effectiveness of waste oil as a dust suppressant (Section 2.5) has not been well documented.

Initial dust suppression has been observed to be 75 percent effective.[5,10] For the purposes of this study, dust suppression is assumed to be 75 percent effective on Day 1 and to decrease in a straight line to zero percent control 30 days later (Table 2-3). Contaminant concentration is highest immediately after the waste oil is applied. This concentration decreases over time as a result of evaporation and removal by rainfall. Worst-case conditions for contaminant concentrations on dust particles are zero rainfall and low temperatures (during which evaporation is minimal).

Metals Concentration on Soil Particles--

Any metals in the waste oil applied to the road are assumed to remain adsorbed to dust particles. The potential metal concentration on dust emissions is determined primarily by the original concentration of metal in the waste oil applied to the road and the type of road surface. Most metals will adsorb (either reversibly or irreversibly) to the surface of soil particles. Worst-case conditions assume irreversible adsorption; however, in the worst-case situation modeled in this report, zero rainfall is assumed, which eliminates the possibility of desorption of metals into rainfall. The concentration of metal on soil particles is determined by multiplying the original metal concentration in the waste oil times the waste oil application rate and then dividing by the depth of penetration of oil into the road surface and the average soil density (Equation 6). Depth of penetration of oil

into the road surface (Equation 7) depends on the road surface type and varies from 0.65 to 7.36 centimeters (Table 3-11).

$$Cs = \frac{C_i A}{10{,}000\ d\ \rho} \tag{6}$$

where 10,000 = conversion factor

C_s = contaminant concentration in soil, g/g

C_i = initial contaminant concentration in oil, g/liter

A = application rate, liters/m²

d = depth of oil penetration, cm

ρ = average soil density, 2.65 g/cm³

$$d = \frac{0.1A}{nS_r} \tag{7}$$

where 0.1 = conversion factor

d = depth of oil penetration, cm

A = application rate, liters/m²

n = porosity

S_r = soil retention factor (0.2 for lube oil)

TABLE 3-11. DEPTH OF OIL PENETRATION INTO VARIOUS ROAD SURFACES

	Application rate, liters/m²	Porosity[a]	Depth,[b] cm
Sand	2.76-3.68	0.25-0.50	3.45-7.36
Clay	0.74-1.84	0.40-0.70	0.74-3.68
Gravel	0.92-1.84	0.25-0.40	0.65-2.30

[a] Reference 7.

[b] Calculated by use of Equation 7 with soil retention factor (S_r = 0.2) from Reference 12.

Organic Chemical Concentration on Soil Particles--

Concentration of organic chemicals on soil particles at any given moment in time depends on the amount of evaporation of that chemical that has occurred during the unit of time under consideration. Evaporation is affected by numerous variables, but it depends most strongly on the temperature of the road surface, the vapor pressure of the organic chemical component, and whether or not the oil is still on the surface of the road or has penetrated into the road subsurface. Evaporation from the road surface, as discussed previously, will proceed as described in Equations 1 through 3 until the waste oil penetrates the road surface. The time required for seepage of oil into the road surface (Table 3-8) varies from a tenth of a second for gravel to 4000 years for some clays. Even though seepage rates are known to vary from minutes to hours or even years, a very rapid seepage rate must be assumed for worst-case conditions to minimize the decrease in concentration that would result from surface evaporation.

The concentration of organic chemical contaminants on soils was calculated by using subsurface evaporation rates and assuming that all of the waste oil has penetrated the road within 5 minutes after its application to the road surface. Calculations assume that evaporation occurs on the surface during the first 5 minutes. Subsequent evaporation rates are based on subsurface evaporation models. The subsurface evaporation model was developed by Thiobodeaux (Equations 8 through 10).[13,14]

$$q = \left(0.5 \times \frac{D_s C_a C_5 A}{10{,}000\ td}\right)^{1/2} \quad (8)$$

where 10,000 = units conversion factor

q = evaporation rate, g/cm²-s

D_s = soil diffusion rate, m²/s

C_a = vapor concentration in soil pore spaces, g/cm³

C_5 = concentration in oil after 5 min. of surface evaporation, g/liter

A = application rate, liters/m²

t = time since oil application, s

d = depth of oil penetration, cm

$$D_s = D_a n^{3/4} \quad (9)$$

where D_a = air diffusion constant, cm²/s

n = soil porosity

$$C_a = M_w P_i / RT \quad (10)$$

where C_a = vapor concentration in soil pore spaces, g/cm³

P_i = partial vapor pressure of oil component i, atm

R = ideal gas constant, cm³ - atm/mol - K

T = soil subsurface temperature, K

M_w = molecular weight of oil component

The constants used in these equations are presented in Appendices A and C.

In the calculation of subsurface evaporation rates, a subsurface soil temperature of 25°C is assumed, primarily because of the availability of air diffusion constants at this temperature.

Actually, typical soil subsurface temperatures are known to range between 20° and 35°C during the months of April through October.[14] In the calculations of evaporation rates, the initial concentration entering the subsurface environment is used, and the time since application varies from zero to 30 days. This results in an evaporation rate that gradually decreases throughout the evaporation period.

Once the subsurface evaporation rate for a particular oil component has been calculated, the concentration of components remaining on the soil can be calculated by simply subtracting the amount that has evaporated from the initial concentration (Equation 11). Concentrations of organic chemicals for various road surface types were calculated for a 30-day period following road oil application (Appendix C, Tables C-8 to C-20).

$$C_s = C - \left(\frac{qt}{d\rho}\right) \qquad (11)$$

where C_s = concentration of soil particle, g/g

C = initial concentration on soil particle, g/g

q = evaporation rate, g/cm²-s

t = time since oil application, s

d = depth of oil penetration, cm

ρ = average soil density, 2.65 g/cm³

Emission Calculations--

The emissions of contaminated dust particles can be calculated by multiplying the contaminant concentration on the soil times the emission rate (Equation 12). Results are expressed as

grams of contaminant emitted per square meter per hour. Particulate emissions rates based on the assumption of a linear decrease in control derived from the application of waste oil are presented in Appendix C. The accuracy of this contaminant emission rate is limited by the accuracy of both the soil contaminant concentration and the emission rate. Emission rate calculations are described in Appendix C.

$$C_D = C_s E \qquad (12)$$

where C_D = concentration of contaminant emitted from the road surface, g/m^2-h

C_s = concentration on soil particle, g/g

E = dust emissions, g/m^2-h

Ambient Dust Concentrations--

The objective of this analysis was to quantify the ambient air impacts of hazardous emissions (both metal and organic contaminants) from unpaved roadways that have been treated with waste oil to suppress dust. Standard dispersion modeling techniques for roadways were applied, and emission factors derived in previous sections of this report were used. Two dispersion models were selected for use in this analysis to ensure that representative consideration was given to roadway oiling emissions. The first model was the HIWAY-2 Model.[15] This model gives 1-hour concentrations of contaminant emissions due to a finite length of roadway. These 1-hour HIWAY-2 concentrations were converted (via statistical techniques[16]) to a maximum 30-day

average. Because the HIWAY-2 Model neither provides a technique for modeling on a monthly basis nor includes a factor for deposition of larger particles downwind of the road, a second model, the Industrial Source Complex (ISC) Model,[17] was used in its long-term (30-day) mode. The ISC Model, however, does not allow receptors closer than 100 m to the roadway.

The two models were used in a complementary fashion to ensure consistency in the ambient concentration estimates. The concentrations estimated by the two models at a receptor located 100 m downwind of a roadway were compared. The results showed that the HIWAY-2 Model generated somewhat higher 30-day estimates. These higher estimates were expected because the ISC model allowed for deposition at this distance. Thus, the models were deemed to give a good assessment of relative ambient concentrations.

For estimation of the maximum 30-day concentrations near the roadways, the HIWAY-2 Model was used with a receptor located 10 m downwind of a 1.0-km length of roadway. Because concentrations at this distance are believed to be roadside concentrations and not necessarily concentrations to which the general public is exposed, estimates were also made with the ISC model at 100 m downwind.

All modeling reflected climatological and meteorological conditions characteristic of the Southwest. This area was selected for analysis because of its numerous unpaved roads, the probable use of waste oil for road oiling, and climatological

conditions conducive to high emissions of reentrained dust (low rainfall and hot and dry days). Meteorological data selected for this analysis were obtained from National Weather Service Station No. 23044 at the airport in El Paso, Texas. The data covered the years 1976-1979. For a worst-case 30-day average, the meteorology for the month of June was chosen because maximum road oiling is expected in this hot, dry month (average precipitation less than 0.5 inch). All observations were processed into a format compatible with the long-term ISC model. Mixing heights and monthly temperature were estimated from standard climatology.[18,19]

Because the HIWAY-2 Model only allows one hour of meteorological data to be processed per model application, worst-case conditions (windspeed, wind direction, atmospheric stability, and mixing height) were selected by a screening analysis. The multiple screening applications of HIWAY-2 indicated that Stability Class F (very stable atmosphere) with a road/wind angle of 01 degrees gave the highest 1-hour concentrations at a receptor 10 m from the downwind edge of the roadway. A windspeed of 1.7 m/s was assumed, which equals the average windspeed under F-stability conditions in El Paso for all months of June in the 1976-1979 period. A mixing height of 1000 m was assumed (the mixing height has negligible influence on receptors near the source). Although the HIWAY-2 Model does not consider the deposition of particulates, little effect on a receptor 10 m downwind is expected because most reentrained dust particles (those with diameters less than 100 μm) will not settle out at this distance.[20]

Figure 3-2 shows the source/receptor configuration used in the HIWAY-2 analysis. A north-south 1000-m roadway was modeled, with receptors located to the east of the road midpoint. The coordinate system, source coordinates, receptor coordinates, and wind directions that were modeled are shown in the figure.

Adjustments were made to the 1-hour HIWAY-2 concentration estimates, based on the assumption of a lognormal distribution of concentrations and the transformation equation suggested by Larsen.[16] The equation, which allows the transformation of one averaging time to another, takes the form:

$$C_{max,\ 30\text{-}day} = C_{max,\ h}\ t^{g} \qquad (13)$$

where $C_{max,\ 30\text{-}day}$ = the expected maximum monthly concentration, $\mu g/m^3$

$C_{max,\ h}$ = the expected 1-hour maximum concentration in a year, $\mu g/m^3$

t = the averaging time, h (30 days = 720 hours)

g = the slope of the maximum line on logarithmic scales and a function of the standard geometric deviation (SGD) ($g = -0.235$ in this application)

where SGD = 1.75 (based on TSP monitor data)

These values result in:

$$C_{max,\ 30\text{-}day} = C_{max/h}\ (0.213)$$

which was used in all subsequent concentration estimates to produce 30-day averages.

The ISC model was used to estimate the ambient air quality impacts from dust emissions from the 1000-m unpaved road at a

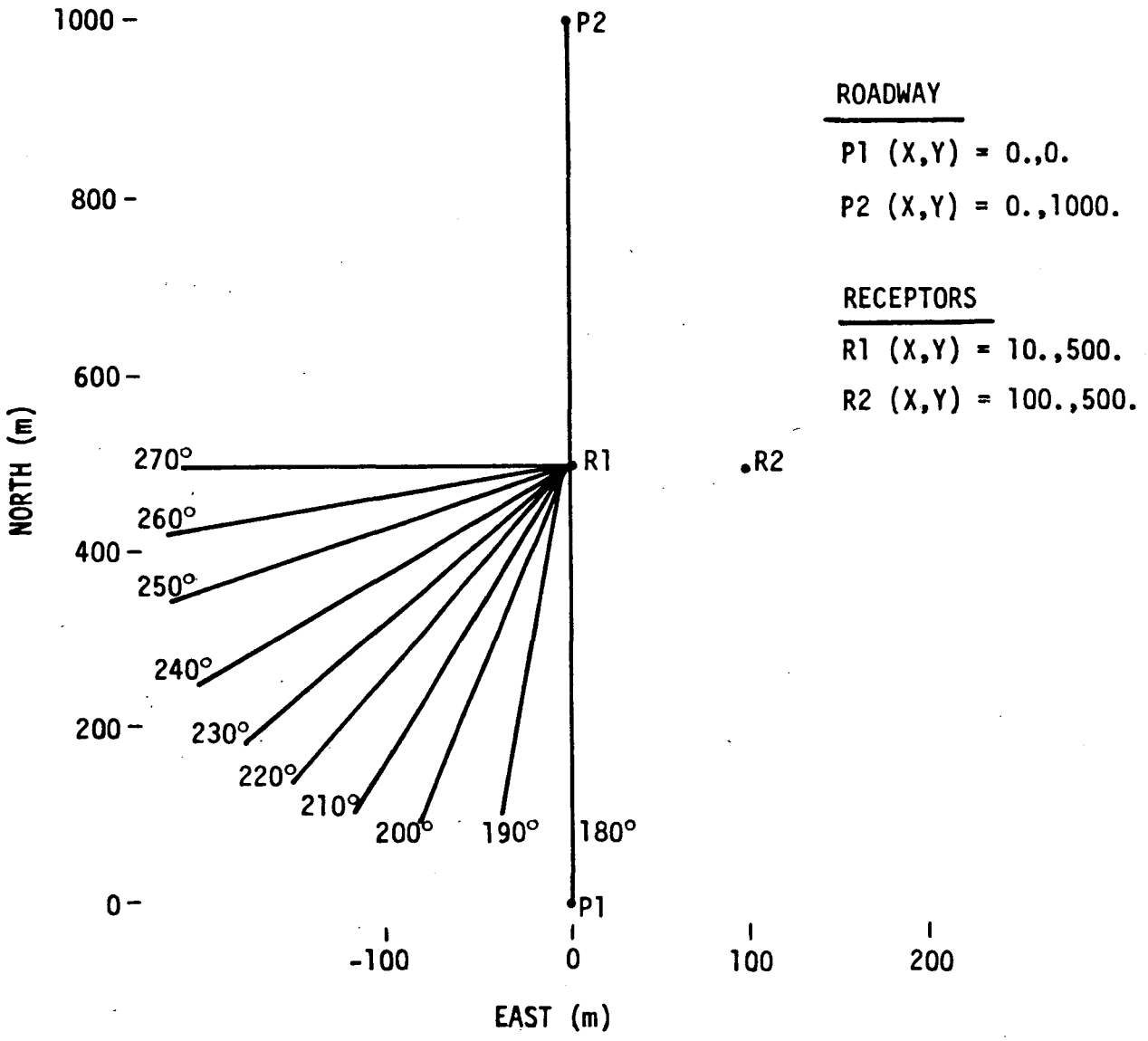

Figure 3-2. Roadway source/receptor grid used in HIWAY-2.

distance of 100 m or greater from the roadway. These estimates were made in conjunction with the worst-case concentrations at 10 m (with HIWAY-2) to show the decrease in concentrations that occurs as a result of particle deposition and dilution at 100 m. The meteorological data from El Paso, Texas, were discussed earlier. Figure 3-3 presents a wind rose for June (1976-1979 average) for all atmospheric stabilities combined and shows the predominance of winds from the southwest to southeast (along the hypothetical roadway). Table 3-12 presents the average June temperatures and mixing heights assumed in the analysis.

TABLE 3-12. AVERAGE JUNE TEMPERATURES AND MIXING HEIGHTS FOR EL PASO, TEXAS

Parameter	Atmospheric stability class					
	A	B	C	D	E	F
Average June temperature, K	306	306	306	300	291	291
Average June mixing heights, m	5,700	3,800	3,800	3,800	10,000	10,000

Because most unpaved roads are in rural or outlying areas, the rural atmospheric effects option, which allows consideration of all stability classes, was assumed in the ISC modeling, i.e., no urban effects on the atmosphere were considered.

Receptors were located at 10, 30, 50, 70, 90, 100, and 120 m east of the roadway midpoint, and an additional grid of receptors was spaced every 100 m, as shown in Figure 3-4. The roadway was comprised of 34 volume sources with dimensions of 5.5 m x 5.5 m x 1 m high, spaced 30 m apart. If receptors are closer than 100 m

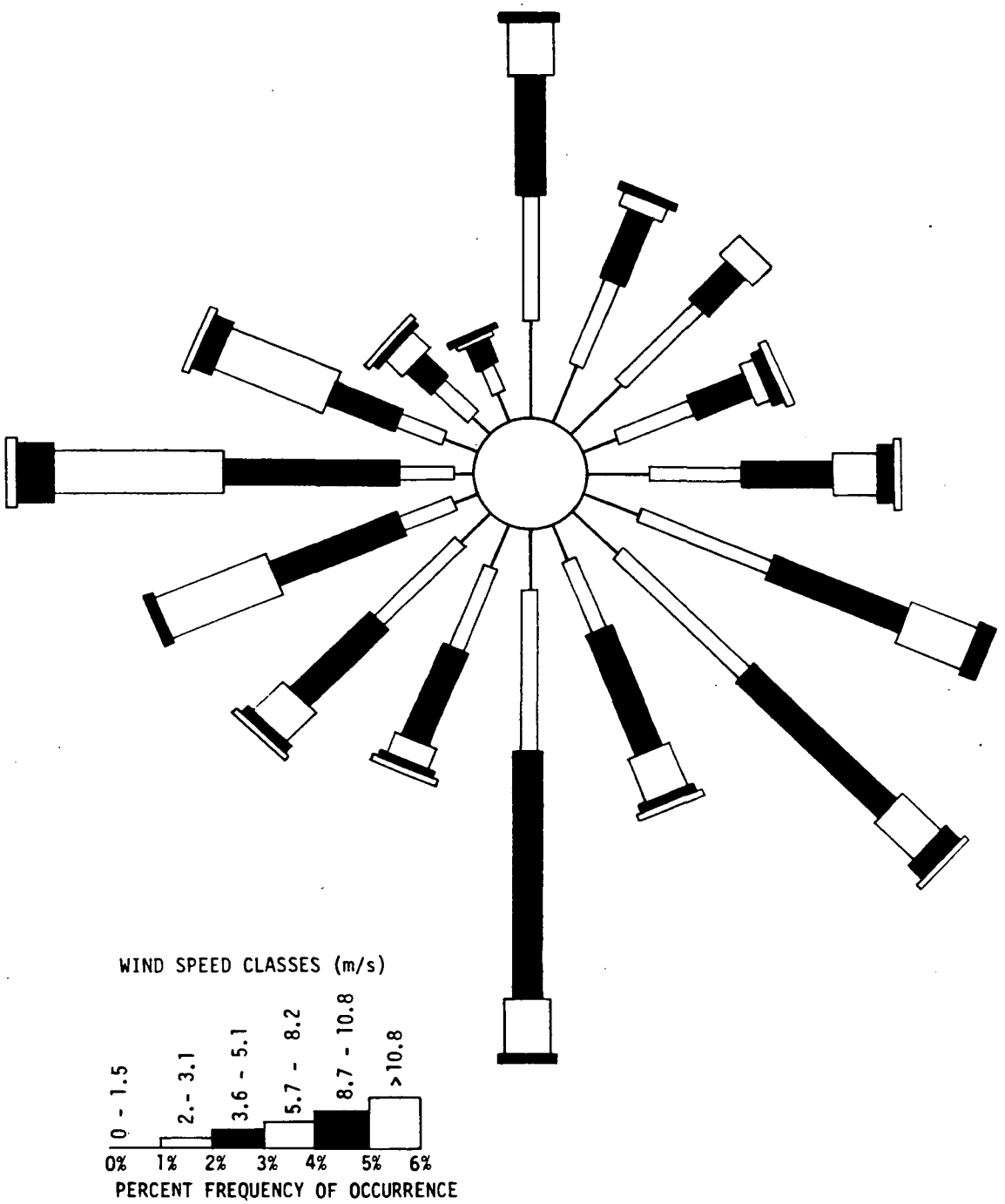

Figure 3-3. Wind rose for June, El Paso, Texas (1976-1979).

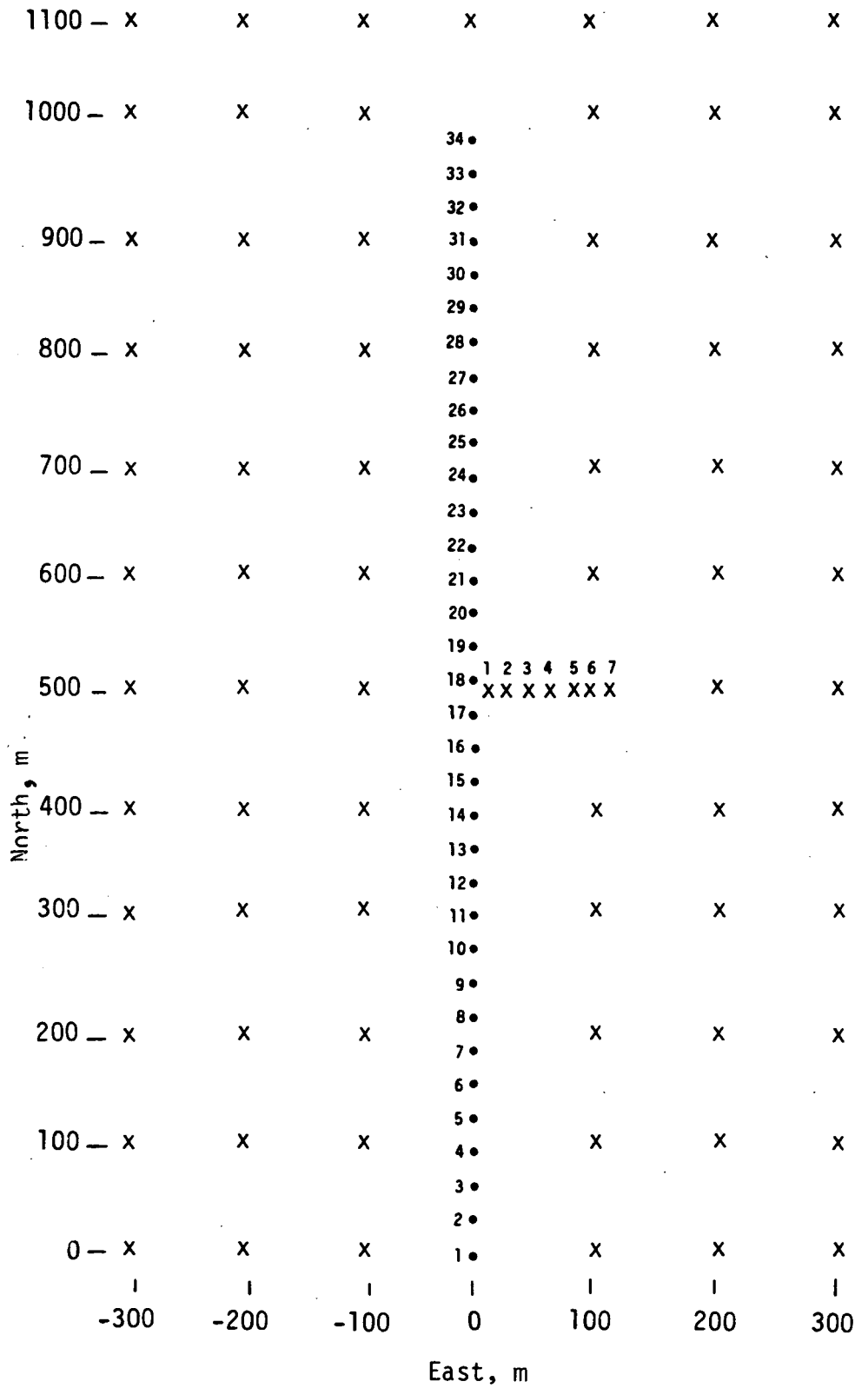

Figure 3-4. Roadway source/receptor grid used in ISC model.

to a given source, the model does not calculate a concentration estimate for that source/receptor combination. Hence, only receptors at or beyond 100 m from any individual roadway element were considered.

Deposition of particulates was included in the ISC model analysis by use of the appropriate model options. The average particle size characteristics for gravel roads described in AP-42[20] were assumed in the modeling analysis:

Particle size, μm	Weight percent
<5	23
5-30	39
>30-100	38

3.3.3 Rainfall Runoff

The modeling approach for contamination of rainfall runoff and surface waters should describe the removal of oil from the road surface and the amount of dilution that will occur as a result of rainfall and surface water runoff. The worst-case scenario described previously indicates that a maximum amount of oil will be available to be washed from the road surface immediately following waste oil application. Once oil has been applied to the road surface, oil components will begin to evaporate, seep into the road, and adsorb onto soil particles.

The amount of oil removed from the road surface would be something less than the total quantity applied as a result of other environmental factors acting upon the oil. For all of the

oil to be removed during a rainfall incident, a thin layer of the road surface would have to be eroded so that oil adsorbed onto soil particles would be carried away in the rainfall runoff. Preliminary calculations (Appendix B) indicate that the rainfall intensities required for removal of a thin road surface layer are greater than those of the heavy rainfalls that occur in this area on an average of once every two years.

When rainfall intensities are less than that required to remove part of the road surface, how much of the oil applied to the road is actually removed during a rainfall incident cannot be determined. For this reason, a sensitivity analysis was conducted to predict the oil concentration in runoff for various rain intensities. Percent oil removal in a single intense rainfall varied from as much as 100 percent (or total oil removal) down to 5 percent.

The rainfall intensities used in the model represent the maximum rainfall intensities that have been recorded over an average 2-year period. Rainfall durations of 5, 10, 30, and 120 minutes are used in the model. In the United States, the greatest rainfall intensities over a 2-year period occurred in Pensacola, Florida, and Port Arthur, Texas, and the lowest maximum rainfall intensities occurred in Reno, Nevada, and Fairbanks, Alaska (Table 3-13).[20] These locations were used as boundaries for the range of worst-case rainfall runoff conditions.

TABLE 3-13. MAXIMUM RAINFALL INTENSITIES FOR A TWO-YEAR PERIOD[a]

Rainfall duration, minutes	Rainfall intensity, in./h	Location	Rainfall intensity, in./h	Location
5	1.5	Reno, Nevada	6.5	Pensacola, Florida
10	1.2	Reno, Nevada	5.1	Pensacola, Florida
30	0.6	Fairbanks, Alaska	3.4	Port Arthur, Texas
120	0.22	Reno, Nevada	1.6	Pensacola, Florida

[a] Source: Reference 21.

The model for determination of the concentration of waste oil components in road surface runoff is a simple one in which the initial oil component concentration is multiplied by the application rate and then divided by the volume of rain that falls on the road surface (Equation 14).

$$C_r = 2.36\ C_i\ A/It \qquad (14)$$

where 2.36 = units conversion factor

C_r = concentration in runoff, mg/liter

C_i = initial concentration in oil, mg/liter

A = application rate, liters/m²

I = rainfall intensity, in./h

t = rainfall duration, min

Calculations of worst-case stream concentrations are based on the assumption that roads are placed at one-mile intervals and that all of the roads in a watershed are oiled. This means that each one mile of road has an individual watershed of 0.5 square mile or 320 acres. Runoff from the road surface is diluted by

runoff from 0.5 square mile of watershed (Figure 3-5). Field runoff, however, is less than the volume of rain that falls on the field surface because of infiltration. Runoff coefficients for fields are reported to vary from 0.05 to 0.35,[22] which means that only 5 to 35 percent of the rain that falls on a field leaves as runoff. Because the concern was high rainfall intensities that result in high runoff, 35 percent rainfall runoff was used in the modeling. Once runoff volume from the field was known, worst-case stream concentrations were calculated.

A sensitivity analysis was conducted to determine stream concentrations when less than 100 percent of the oil is washed from the road surface. A typical-case situation was also evaluated in which 5 percent and 0.5 percent of the oil is washed from the road. The conditions closely approximate those observed by GCA in runoff experiments (Table 3-6).[6] Soluble and adsorbed contaminants are included in the 5 percent runoff, whereas the 0.5 percent value represents only those contaminants that are soluble when they reach the stream.

The potential for an oil slick may be determined once the concentration of oil in the stream has been calculated (Equation 15).[11]

$$H = 10\ C_S D \qquad (15)$$

where 10 = units conversion factor

H = thickness of oil slick, nm

C_S = concentration of oil in the stream, mg/liter

D = depth of the stream or ditch, cm

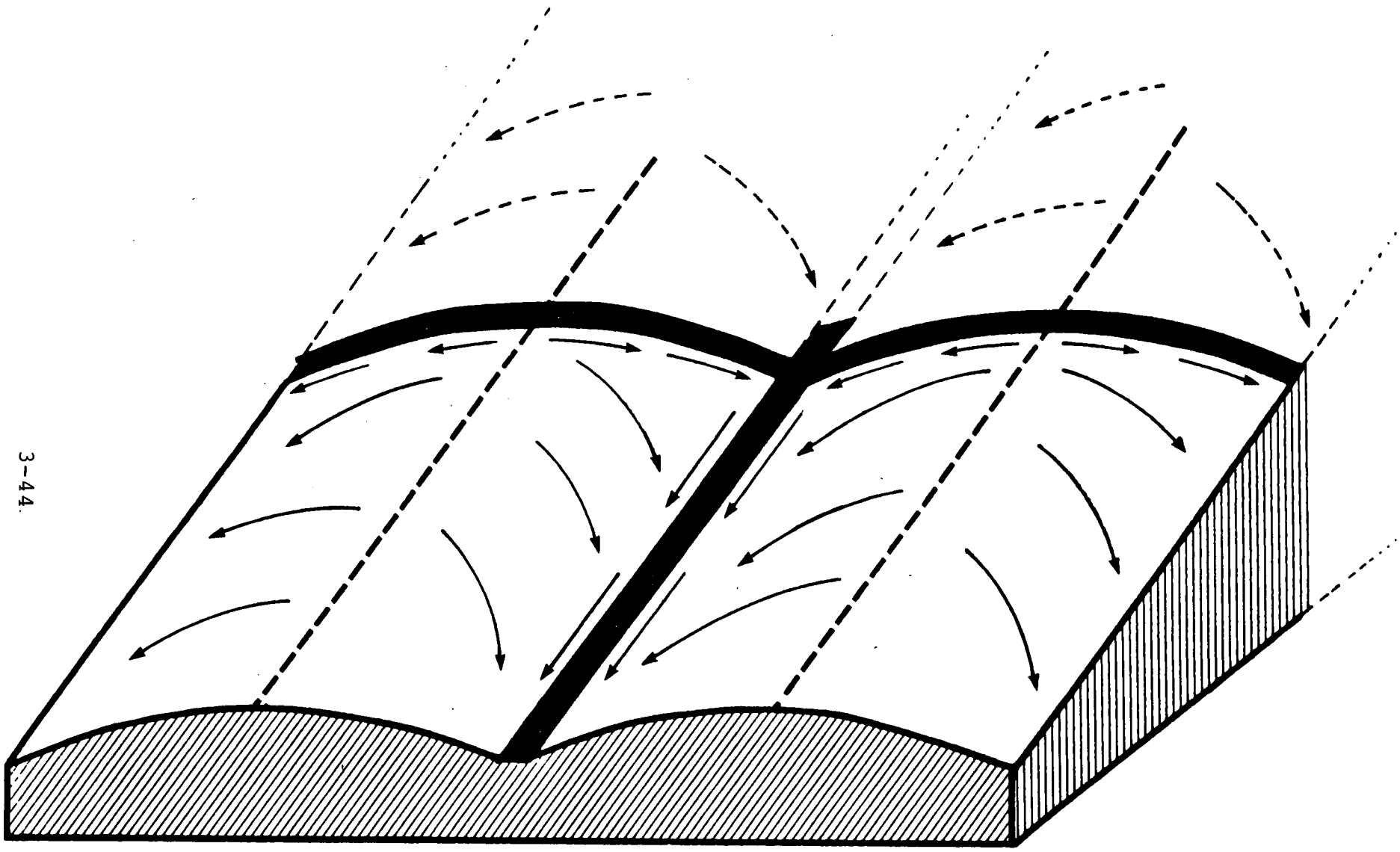

Figure 3-5. Rainfall runoff patterns for a watershed in which roads are placed at one-mile intervals and all roads have been oiled.

Oil slick potential was calculated for a typical-case situation, in which only 5 percent of the oil is washed from the road. It was further assumed that 4.5 percent of the oil was adsorbed onto oil particles and only 0.5 percent was soluble and available for oil slick formation. These conditions closely approximate those observed in runoff experiments conducted by GCA (Table 3-6).[6]

3.4 CONCENTRATIONS OF CONTAMINANTS IN THE ENVIRONMENT--DISPERSION MODELING RESULTS

Where possible, environmental contamination levels were calculated for the following waste oil components: arsenic, barium, cadmium, chromium, lead, zinc, dichlorodifluoromethane, trichlorotrifluoroethane, trichloroethane, trichloroethylene, tetrachloroethylene, benzene, toluene, xylene, benz(a)anthracene, benzo(a)pyrene, naphthalene, and PCB's. Calculations were made for two areas of the environment: the atmosphere (ambient air) and surface waters. Both evaporation and dust transport have an impact on ambient air, whereas contaminated rainfall runoff from road surfaces has an impact on surface waters.

3.4.1 Evaporation

The one-compartment dilution model described in Section 3.3.1 estimates the airborne concentration of each contaminant. The model was used to estimate airborne concentrations 8 hours following application of the waste oil. These concentrations are presented in Table 3-14. This represents a worst case in that the model assumes that the amount of contaminants available for evaporation is unlimited and that the evaporation rate remains constant. If the evaporation rate were to remain constant, the

concentrations of all of the modeled contaminants applied to the road would be completely evaporated in less than 8 hours.

TABLE 3-14. DILUTION MODEL RESULTS FOR EVAPORATIVE EMISSIONS

Substance[a]	Eight-hour airborne concentration, $\mu g/m^3$
Dichlorodifluoromethane	3,598
Toluene	602
1,1,1-Trichloroethane	3,804
Trichloroethylene	1,231
Trichlorotrifluoroethane	15,450
Xylene	127
Benzene	198
Tetrachloroethylene	345
1,1,2-Trichloroethane	3,804

[a] Concentrations of PCB's and Naphthalene are not included because their extremely long evaporation times resulted in very low concentrations.

3.4.2 Rainfall Runoff

The effect of road oiling on surface waters was evaluated from the standpoint of both oil and individual oil component concentrations that could result from rainfall runoff from the roads. Information on the potential for oil slicks was also determined.

Because the quantity of oil that may be removed from the road surface during a given rainfall event is not clearly understood, a sensitivity analysis of various percent oil removals was

conducted. A maximum oil removal of 100 percent and a low or probable minimum oil removal of 5 percent were assumed. Worst-case stream concentrations were then calculated, based on the assumption that roads are located at one-mile intervals and that every road in a watershed has been oiled (Tables 3-15 and 3-16). Stream concentrations are affected by road surface type, oil application rates, rainfall intensity, percent oil removal, and percent of field runoff. Worst-case oil concentrations range from 8 mg/liter to 20,300 mg/liter. These concentrations are most important in determining the potential for an oil slick.

The high values listed for each oil type in Tables 3-15 and 3-16 are based on the highest oil application rate in the range of rates in Table 3-11, and the lowest of the maximum rainfall intensities in Table 3-13. The low values, on the other hand, are based on the lowest application rate in Table 3-11, and the highest of the maximum rainfall intensities in Table 3-13. Both high and low values assume that the streambed was dry before the rain started. Also, in both cases it was assumed that the only water for dilution came from the rain period being modeled and that 35 percent of the rain that fell on adjacent fields entered the stream. For example, in the 5-minute case, 100 percent (Table 3-15) or 5 percent (Table 3-16) of the oil on the road is diluted with rainfall that falls on the road during the 5-minute period and 35 percent of the rainfall that falls on 320 acres during the same 5-minute period.

Oil slick calculations were based on reasonable stream concentrations with the assumption that only 5 percent of the oil

TABLE 3-15. WORST-CASE STREAM CONCENTRATIONS AT VARIOUS RAINFALL DURATIONS WITH 100 PERCENT OIL RUNOFF[a,b]
(mg of oil per liter of water)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	20,300	3,520	10,200	943	10,200	943	10,200	1,170
10	12,700	2,240	6,350	601	6,350	601	6,350	747
30	8,470	1,120	4,230	300	4,230	300	4,230	374
120	5,770	595	2,890	160	2,890	160	2,890	198

[a] Assumes roads placed at one-mile intervals and watershed for each mile of oiled road is therefore 0.5 square mile or 320 acres.

[b] Based on an oil density of 0.9.

TABLE 3-16. WORST-CASE STREAM CONCENTRATIONS AT VARIOUS RAINFALL DURATIONS WITH 5 PERCENT OIL RUNOFF[a,b]
(mg of oil per liter of water)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	1,020	176	508	47.2	508	47.2	508	58.6
10	635	112	318	30.1	318	30.1	318	37.3
30	423	56.0	212	15.0	212	15.0	212	18.7
120	289	29.8	144	7.98	144	7.98	144	9.92

[a] Assumes roads placed at one-mile intervals and watershed for each mile of oiled road is therefore 0.5 square mile or 320 acres.

[b] Based on an oil density of 0.9.

was washed from the road surface and that 35 percent of the field rain entered the stream. It was also assumed that 0.5 percent of the oil was soluble and that the other 4.5 percent that was washed off was absorbed onto soil particles. These assumptions approximate the results obtained by GCA in their road oiling weathering experiments.[6]

The purpose of this analysis is to determine how thick an oil film could be formed by the soluble fraction of the oil. It was assumed that the stream (or roadside ditch) holds a high-intensity rainfall of one-minute duration, after which time the flow out of the ditch equals the flow in. The stream depth used in the calculation of the film thickness (Equation 15) is calculated by assuming there are two one-meter-wide rectangular ditches parallel with the roadway.

Results indicate that film thickness on the stream surface ranges from 77.6 to 9,200 nm (Table 3-17). An oil slick becomes visible at 150 nm,[11] and only two of the potential film thicknesses calculated for the minimum runoff scenario are thinner than the visible range.

Worst-case concentrations of selected waste oil contaminants on the road surfaces and in nearby streams were determined for various road surfaces (Appendix B). Ranges of concentrations based on an assumed 100 percent oil runoff are summarized (Tables 3-18 through 3-21). The 100 percent assumption represents a worst-case situation, which may be modified for a particular location by simply multiplying by the fraction of oil component runoff expected. It is likely that different fractions would

TABLE 3-17. DEPTHS OF OIL ON STREAM SURFACE[a,b]
(nm, except as noted)

Rainfall duration, minutes	Total rainfall, inches		Road surface type					
			Sand		Clay		Gravel	
	Low	High[c]	High	Low	High	Low	High	Low
5	0.13	0.54	9,250	6,940	4,620	1,860	4,623	2,310
10	0.20	0.85	4,630	3,470	2,310	931	2,310	1,160
30	0.30	1.70	1,530	1,160	766	311	766	386
120	0.44	3.20	388	289	194	77.6	194	96.2

[a] Assumes 5 percent of the oil runs off the road, 10 percent of the oil is soluble, and the remaining 90 percent is adsorbed on soil particles.

[b] Based on stream concentrations reported in Table 3-16 and Equation 15.

[c] High rainfall intensity results in low film thickness.

TABLE 3-18. RANGE OF CONTAMINANT CONCENTRATIONS IN ROAD SURFACE RUNOFF BASED ON 90TH PERCENTILE OIL CONTAMINANT LEVELS[a]
(mg of contaminant per liter of water)

	Sand		Silt		Clay		Gravel	
	High[b]	Low[c]	High[b]	Low[c]	High[b]	Low[c]	High[b]	Low[c]
Metals								
Arsenic	18.5	0.54	9.27	0.15	9.27	0.15	9.27	0.18
Barium	562	16.5	281	4.42	281	4.42	281	5.49
Cadmium	4.64	0.14	2.32	0.04	2.32	0.04	2.32	0.05
Chromium	32.5	0.95	16.2	0.25	16.2	0.25	16.2	0.32
Lead	1,160	34.0	579	9.10	579	9.10	579	11.3
Zinc	1,330	39.1	666	10.5	666	10.5	66.6	13.0
Chlorinated organics								
Dichlorodifluoromethane	997	29.2	498	7.83	498	7.83	498	9.73
Trichlorotrifluoroethane	151	4.41	75.3	1.18	75.3	1.18	75.3	1.47
Trichloroethane	1,510	44.1	753	11.8	753	11.8	753	14.7
Trichloroethylene	1,220	35.6	608	9.55	608	9.55	608	11.9
Tetrachloroethylene	1,390	40.8	695	10.9	695	10.9	695	13.6
Other organics								
Benzene	185	5.43	92.7	1.46	92.7	1.46	92.7	1.81
Toluene	1,390	40.7	695	10.9	695	10.9	695	13.6
Xylene	661	19.4	330	5.19	330	5.19	330	6.45
Benz(a)anthracene	40.6	1.19	20.3	0.32	20.3	0.32	20.3	0.40
Benzo(a)pyrene	38.2	1.12	19.1	0.30	19.1	0.30	19.1	0.37
Naphthalene	672	19.7	336	5.28	336	5.28	336	6.56
PCB's	57.9	1.70	29.0	0.46	29.0	0.46	29.0	0.57

[a] Summary of Tables B-5 through B-22. Assumes 100 percent oil removal from road surface. Water for dilution is from the rain that strikes the road and does not include rainfall adjacent to the road.

[b] Based on a heavily oiled road and a heavy Nevada rainfall.

[c] Based on a lightly oiled road and a heavy Florida rainfall.

TABLE 3-19. RANGE OF CONTAMINANT CONCENTRATIONS IN ROAD SURFACE RUNOFF BASED ON 75TH PERCENTILE OIL CONTAMINANT LEVELS[a]
(mg of contaminant per liter of water)

	Sand		Silt		Clay		Gravel	
	High[b]	Low[c]	High[b]	Low[c]	High[b]	Low[c]	High[b]	Low[c]
Metals								
Arsenic	16.2	0.48	8.11	0.13	8.11	0.13	8.11	0.16
Barium	232	6.79	116	1.82	116	1.82	116	2.26
Cadmium	1.51	0.04	0.75	1.18×10^{-2}	0.75	1.18×10^{-2}	0.75	1.47×10^{-2}
Chromium	13.9	0.41	6.95	0.11	6.95	0.11	6.95	0.14
Lead	487	14.3	243	3.82	243	3.82	243	4.75
Zinc	1,030	30.2	516	8.10	516	8.10	516	10.1
Chlorinated organics								
Dichlorodifluoromethane	243	7.13	122	1.91	122	1.91	122	2.38
Trichlorotrifluoroethane	38.2	1.12	19.1	0.30	19.1	0.30	19.1	0.37
Trichloroethane	684	20.0	342	5.37	342	5.37	342	6.68
Trichloroethylene	568	16.6	284	4.46	284	4.46	284	5.55
Tetrachloroethylene	429	12.6	214	3.37	214	3.37	214	4.19
Other organics								
Benzene	89.2	2.61	44.6	0.70	44.6	0.70	44.6	0.87
Toluene	568	16.6	284	4.46	284	4.46	284	5.55
Xylene	313	9.17	156	2.46	156	2.46	156	3.06
Benz(a)anthracene	30.1	0.88	15.1	0.24	15.1	0.24	15.1	0.29
Benzo(a)pyrene	13.9	0.41	6.95	0.11	6.95	0.11	6.95	0.14
Naphthalene	568	16.6	284	4.46	284	4.46	284	5.55
PCB's	47.5	1.39	23.8	0.37	23.8	0.37	23.8	0.46

[a] Summary of Tables B-23 through B-40. Assumes 100 percent oil removal from road surface. Water for dilution is from the rain that strikes the road and does not include rainfall adjacent to the road.

[b] Based on a heavily oiled road and a heavy Nevada rainfall.

[c] Based on a lightly oiled road and a heavy Florida rainfall.

TABLE 3-20. RANGE OF WORST-CASE STREAM CONCENTRATIONS BASED ON 90TH PERCENTILE OIL CONTAMINANT LEVELS[a]
(mg of contaminant per liter of water)

	Sand		Silt		Clay		Gravel	
	High[b]	Low[c]	High[b]	Low[c]	High[b]	Low[c]	High[b]	Low[c]
Metals								
Arsenic	0.36	0.01	0.18	2.84×10^{-3}	0.18	2.84×10^{-3}	0.18	3.53×10^{-3}
Barium	10.95	0.32	5.48	0.09	5.48	0.09	5.48	0.11
Cadmium	0.09	2.65×10^{-3}	0.05	7.09×10^{-4}	0.05	7.09×10^{-4}	0.05	8.82×10^{-4}
Chromium	0.63	1.85×10^{-2}	0.32	4.97×10^{-3}	0.32	4.97×10^{-3}	0.32	6.19×10^{-3}
Lead	22.6	0.66	11.3	0.18	11.3	0.18	11.3	0.22
Zinc	26.0	0.76	13.0	0.20	13.0	0.20	13.0	0.25
Chlorinated organics								
Dichlorodifluoromethane	19.4	0.57	9.71	0.15	9.71	0.15	9.71	0.19
Trichlorotrifluoroethane	2.93	0.09	1.47	2.31×10^{-2}	1.47	2.31×10^{-2}	1.47	2.87×10^{-2}
Trichloroethane	29.4	0.86	14.7	0.23	14.7	0.23	14.7	0.29
Trichloroethylene	23.7	0.69	11.8	0.19	11.8	0.19	11.8	0.23
Tetrachloroethylene	27.1	0.79	13.6	0.21	13.6	0.21	13.6	0.26
Other organics								
Benzene	3.61	0.11	1.81	2.84×10^{-2}	1.81	2.84×10^{-2}	1.81	3.53×10^{-2}
Toluene	27.1	0.79	13.6	0.21	13.6	0.21	13.6	0.26
Xylene	12.9	0.38	6.44	0.10	6.44	0.10	6.44	0.13
Benz(a)anthracene	0.79	2.31×10^{-2}	0.39	6.20×10^{-3}	0.39	6.20×10^{-3}	0.39	7.70×10^{-3}
Benzo(a)pyrene	0.75	0.02	0.37	5.90×10^{-3}	0.37	5.90×10^{-3}	0.37	7.30×10^{-3}
Naphthalene	13.1	0.38	6.55	0.10	6.55	0.10	6.55	0.13
PCB's	1.13	0.03	0.56	8.90×10^{-3}	0.56	8.90×10^{-3}	0.56	1.10×10^{-2}

[a] Summary of Tables B-41 through B-58. Assumes 100 percent oil removal from road surface. Assumes roads placed at one-mile intervals and watershed for each mile of oiled roads is therefore 0.5 square miles or 320 acres.

[b] Based on a heavily oiled road and a heavy Nevada rainfall.

[c] Based on a lightly oiled road and a heavy Florida rainfall.

TABLE 3-21. RANGE OF WORST-CASE STREAM CONCENTRATIONS BASED ON 75TH PERCENTILE OIL CONTAMINANT LEVELS[a]
(mg of contaminant per liter of water)

	Sand		Silt		Clay		Gravel	
	High[b]	Low[c]	High[b]	Low[c]	High[b]	Low[c]	High[b]	Low[c]
Metals								
Arsenic	0.32	9.26×10^{-3}	0.16	2.48×10^{-3}	0.16	2.48×10^{-3}	0.16	3.09×10^{-3}
Barium	4.52	0.13	2.26	0.04	2.26	0.04	2.26	0.04
Cadmium	2.93×10^{-2}	8.60×10^{-4}	1.47×10^{-2}	2.31×10^{-4}	1.47×10^{-2}	2.31×10^{-4}	1.47×10^{-2}	2.87×10^{-4}
Chromium	0.27	7.94×10^{-3}	0.14	2.13×10^{-3}	0.14	2.13×10^{-3}	0.14	2.65×10^{-3}
Lead	9.48	0.28	4.74	0.07	4.74	0.07	4.74	0.09
Zinc	20.1	0.59	10.1	0.16	10.1	0.16	10.1	0.20
Chlorinated organics								
Dichlorodifluoromethane	4.74	0.14	2.37	0.04	2.37	0.04	2.37	0.05
Trichlorotrifluoroethane	0.75	0.02	0.37	5.85×10^{-3}	0.37	5.85×10^{-3}	0.37	7.28×10^{-3}
Trichloroethane	13.3	0.39	6.66	0.10	6.66	0.10	6.66	0.13
Trichloroethylene	11.1	0.32	5.53	0.09	5.53	0.09	5.53	0.11
Tetrachloroethylene	8.35	0.24	4.18	0.07	4.18	0.07	4.18	0.08
Other organics								
Benzene	1.74	0.05	0.87	0.01	0.87	0.01	0.87	0.02
Toluene	11.1	0.32	5.53	0.09	5.53	0.09	5.53	0.11
Xylene	6.10	0.18	3.05	0.05	3.05	0.05	3.05	0.06
Benz(a)anthracene	0.59	0.02	0.29	4.61×10^{-2}	0.29	4.61×10^{-2}	0.29	5.73×10^{-3}
Benzo(a)pyrene	0.27	7.94×10^{-3}	0.14	2.13×10^{-3}	0.14	2.13×10^{-3}	0.14	2.65×10^{-3}
Naphthalene	11.1	0.32	5.53	0.09	5.53	0.09	5.53	0.11
PCB's	0.93	0.03	0.46	7.27×10^{-3}	0.46	7.27×10^{-3}	0.46	9.04×10^{-3}

[a] Summary of Tables B-59 through B-76. Assumes 100 percent oil removal from road surface. Assumes roads placed at one-mile intervals and watershed for each mile of oiled roads is therefore 0.5 square miles or 320 acres.

[b] Based on a heavily oiled road and a heavy Nevada rainfall.

[c] Based on a lightly oiled road and a heavy Florida rainfall.

have to be used for each oil component at a given location and time because of the varying influence of evaporation. The high concentrations in Tables 3-20 and 3-21 represent the worst-case stream for a 5-minute rainfall period in Florida, and the low concentrations represent the worst-case stream for a 120-minute rainfall period in Nevada based on a 2-year maximum rainfall intensity. Both cases are based on an assumed 100 percent road runoff followed by 35 percent field runoff (65 percent infiltration into field).

In real-world conditions, less than 100 percent of the oil on a road would be removed by rainfall. The actual amount removed would vary with soil type and rainfall intensity; however, the data are too limited for accurate quantification of the percentage of oil removed. The GCA data available suggest that about 5 percent of the oil may be removed.[6] Table 3-22 presents a sensitivity analysis in which the percentage of oil removed from the road varies from 100 percent to 0.5 percent. Based only on the GCA data,[6] the 5 percent oil runoff is evaluated in the risk assessment (Section 4) as being most representative of real-world conditions.

3.4.3 Contaminated Dust Emissions

The effect of road oiling on ambient concentrations of threshold (noncarcinogenic) and nonthreshold (carcinogenic) contaminants was evaluated. (See Section 3.3.2 for description of modeling approach.)

TABLE 3-22. SENSITIVITY ANALYSIS OF A STREAM ADJACENT TO AN OILED SAND ROAD BASED ON 90TH PERCENTILE CONTAMINANT LEVELS[a]
(mg contaminant/liter water)

	100% oil runoff		90% oil runoff		75% oil runoff		50% oil runoff		25% oil runoff		5% oil runoff		0.5% oil runoff	
	High[b]	Low[c]	High[b]	Low[c]	High[b]	Low[c]	High[b]	Low[c]	High[b]	Low[c]	High[b]	Low[c]	High[b]	Low[c]
Metals														
Arsenic	0.36	0.01	0.32	9.00×10^{-3}	0.27	7.50×10^{-3}	0.18	5.00×10^{-3}	9.00×10^{-2}	2.50×10^{-3}	1.80^{-2}	5.00×10^{-4}	1.8×10^{-3}	5.00×10^{-5}
Barium	10.95	0.32	9.86	0.29	8.21	0.24	5.48	0.16	2.75	8.0×10^{-2}	0.55	1.60×10^{-2}	5.48×10^{-2}	1.60×10^{-3}
Cadmium	0.09	2.65×10^{-3}	8.1×10^{-2}	2.39×10^{-3}	6.8×10^{-2}	1.99×10^{-3}	4.5×10^{-2}	1.33×10^{-3}	2.3×10^{-2}	6.63×10^{-3}	4.5×10^{-3}	1.33×10^{-4}	4.50×10^{-4}	1.33×10^{-5}
Chromium	0.63	1.85×10^{-2}	5.70×10^{-2}	1.67×10^{-2}	4.7×10^{-2}	1.39×10^{-2}	3.1×10^{-2}	9.25×10^{-3}	1.6×10^{-2}	4.63×10^{-3}	3.20×10^{-3}	9.25×10^{-4}	3.20×10^{-4}	9.25×10^{-5}
Lead	22.6	0.66	20.3	0.59	17.0	0.50	11.3	0.33	5.75	0.17	1.13	3.30×10^{-2}	0.11	3.30×10^{-3}
Zinc	26.0	0.76	23.4	0.68	19.5	0.57	13.0	0.38	6.50	0.19	1.30	3.80×10^{-2}	0.13	3.80×10^{-3}
Chlorinated organics														
Dichlorodifluoromethane	19.4	0.57	17.5	0.51	14.6	0.43	9.70	0.28	4.85	0.14	0.97	2.85×10^{-2}	9.70×10^{-2}	2.85×10^{-3}
Trichlorotrifluoroethane	2.93	0.09	2.64	8.10×10^{-2}	2.20	6.75×10^{-2}	1.47	4.5×10^{-2}	0.73	2.25×10^{-2}	0.15	4.50×10^{-3}	1.47×10^{-2}	4.50×10^{-4}
Trichloroethane	29.4	0.86	26.5	0.77	22.1	0.65	14.7	0.43	7.35	0.22	1.47	4.30×10^{-2}	0.15	4.30×10^{-3}
Trichloroethylene	23.7	0.69	21.3	0.62	17.8	0.52	11.8	0.35	5.93	0.17	1.18	3.45×10^{-2}	0.12	3.45×10^{-3}
Tetrachloroethylene	27.1	0.79	24.4	0.71	20.3	0.59	13.6	0.40	6.78	0.20	1.36	3.95×10^{-2}	0.14	3.95×10^{-3}
Other organics														
Benzene	3.61	0.11	3.25	9.90×10^{-2}	2.71	8.25×10^{-2}	1.81	5.5×10^{-2}	0.90	2.75×10^{-2}	0.18	5.50×10^{-3}	1.81×10^{-2}	5.50×10^{-4}
Toluene	27.1	0.79	24.4	0.71	20.3	0.59	13.6	0.40	6.78	0.20	1.36	3.95×10^{-2}	0.14	3.95×10^{-3}
Xylene	12.9	0.38	11.6	0.34	9.68	0.29	6.45	0.19	3.23	9.50×10^{-2}	0.65	1.90×10^{-2}	6.45×10^{-2}	1.90×10^{-3}
Benzo(a)anthracene	0.79	2.31×10^{-2}	0.71	2.08×10^{-2}	0.59	1.73×10^{-2}	0.40	1.16×10^{-2}	0.20	5.78×10^{-3}	4.00×10^{-2}	1.16×10^{-3}	4.00×10^{-3}	1.16×10^{-4}
Benzo(a)pyrene	0.75	0.02	0.68	1.80×10^{-2}	0.56	1.50×10^{-2}	0.38	1.00×10^{-2}	0.19	5.00×10^{-3}	3.80×10^{-2}	1.00×10^{-3}	3.80×10^{-3}	1.00×10^{-4}
Naphthalene	13.1	0.38	11.8	0.34	9.83	0.29	6.55	0.19	3.28	9.50×10^{-2}	0.66	1.90×10^{-2}	6.55×10^{-2}	1.90×10^{-3}
PCB's	1.13	0.03	1.02	2.70×10^{-2}	0.85	2.25×10^{-2}	0.57	1.50×10^{-2}	0.28	7.50×10^{-3}	5.70×10^{-2}	1.50×10^{-3}	5.70×10^{-3}	1.50×10^{-4}

[a] Assumes roads placed at one-mile intervals and watershed for each mile of oiled road is therefore 0.5 square mile or 320 acres.

[b] Based on a heavily oiled road and a heavy Nevada rainfall.

[c] Based on a lightly oiled road and a heavy Florida rainfall.

Ambient Concentrations of Threshold Contaminants--

The maximum 30-day average ambient air concentrations of toxic waste oil contaminants (i.e., those eliciting a threshold response) associated with the use of waste oil for road oiling are presented in Tables 3-23 through 3-26 for moderate and heavy road-use patterns. Concentrations are much higher at the receptors 10 m downwind than at those 100 m downwind. Contaminant concentrations in the ambient air were generally well below the applicable Environmental Exposure Limits (EEL's) in both moderate and heavy use patterns and for each roadway type (i.e., sand, clay/sand, and gravel). Under these worst-case conditions, barium and lead levels at 10 m from the roadway were 28 and 17 percent of their respective EEL's, but these values fell to 2 percent or less at 100 m downwind. All other metals and organic contaminants were less than 1 percent of their respective EEL's.

Ambient Concentrations of Carcinogens--

Tables 3-27 through 3-30 present the maximum 30-day average ambient air concentrations of carcinogenic contaminants on dust particles associated with road oiling for moderate and heavy road-use patterns. Concentrations of all the contaminants were generally less than 0.2 $\mu g/m^3$ at a receptor 10 m from the roadway. At 100 m from the roadway, downwind concentrations fell to 7 percent of their value at 10 m; therefore, concentrations were generally less than 0.01 $\mu g/m^3$ at 100 m.

TABLE 3-23 AMBIENT AIR IMPACTS OF THRESHOLD CONTAMINANTS DUE TO REENTRAINED DUST FROM ROADS TREATED WITH WASTE OIL UNDER MODERATE USE CONDITIONS (at 10 meters from roadway)

Pollutant	Maximum 30-Day Concentrations (x = 10 m), $\mu g/m^3$						EEL,[a] $\mu g/m^3$	Maximum percentage of EEL
	Sand		Clay/sand		Gravel			
	High	Low	High	Low	High	Low		
Barium	0.0118	0.0042	0.0274	0.0022	0.0312	0.0044	0.43	7
Chromium (II and III)	0.0007	0.0002	0.0016	0.0001	0.0018	0.0002	4.32	<1
Lead	0.0242	0.0085	0.0567	0.0046	0.0646	0.0091	1.50	4
Zinc	0.0271	0.0111	0.0652	0.0049	0.0738	0.0111	43.2	<1
Toluene	0.1518	<0.0001	0.0062	<0.0001	0.0025	<0.0001	3,240.0	<1
Xylene	0.0044	<0.0001	0.0020	<0.0001	0.0019	<0.0001	3,758.0	<1
Naphthalene	0.0129	0.0036	0.0274	<0.0001	0.0312	0.0003	432.0	<1
1,1,1-Trichloroethane	0.0180	<0.0001	0.1514	0.0001	0.0958	0.0024	16,416	<1

[a]Environmental Exposure Limit. See Appendix D.

TABLE 3-24 AMBIENT AIR IMPACTS OF THRESHOLD CONTAMINANTS DUE TO REENTRAINED DUST FROM ROADS TREATED WITH WASTE OIL UNDER MODERATE USE CONDITIONS (at 100 meters from roadway)

Pollutant	Maximum 30-Day Concentrations (x = 100 m), $\mu g/m^3$						EEL,[a] $\mu g/m^3$	Maximum percentage of EEL
	Sand		Clay/sand		Gravel			
	High	Low	High	Low	High	Low		
Barium	0.0009	0.0003	0.0020	0.0002	0.0023	0.0003	0.43	<1
Chromium (II and III)	<0.0001	<0.0001	0.0001	<0.0001	0.0001	0.0001	1.50	<1
Lead	0.0018	0.0006	0.0041	0.0003	0.0047	0.0007	1.50	<1
Zinc	0.0020	0.0008	0.0047	0.0004	0.0053	0.0008	43.2	<1
Toluene	0.0110	<0.0001	0.0005	<0.0001	0.0002	<0.0001	3,240.0	<1
Xylene	0.0003	<0.0001	0.0001	<0.0001	0.0001	<0.0001	3,758.0	<1
Naphthalene	0.0010	0.0003	0.0020	<0.0001	0.0023	<0.0001	432.0	<1
1,1,1-Trichloroethane	0.0003	<0.0001	0.0027	<0.0001	0.0018	<0.0001	16,416	<1

[a]Environmental Exposure Limit. See Appendix D.

TABLE 3-25. AMBIENT AIR IMPACTS OF THRESHOLD CONTAMINANTS DUE TO REENTRAINED DUST FROM ROADS TREATED WITH WASTE OIL UNDER HEAVY USE CONDITIONS (at 10 meters from roadway)

Pollutant	Maximum 30-Day Concentrations (x = 10 m), $\mu g/m^3$						EEL,[a] $\mu g/m^3$	Maximum percentage of EEL
	Sand		Clay/sand		Gravel			
	High	Low	High	Low	High	Low		
Barium	0.0455	0.0160	0.1061	0.0086	0.1209	0.0171	0.43	28
Chromium (II and III)	0.0026	0.0009	0.0061	0.0005	0.0070	0.0010	4.32	<1
Lead	0.0947	0.0332	0.2214	0.0185	0.2534	0.0357	1.5	17
Zinc	0.1070	0.0381	0.2522	0.0209	0.2866	0.0406	43.2	<1
Toluene	0.0066	0.0003	0.0247	<0.0001	0.0099	0.0002	3,240.0	<1
Xylene	0.0175	0.0003	0.0081	0.0010	0.0160	0.0002	3,758.0	<1
Naphthalene	0.0507	0.0140	0.1057	0.0003	0.1224	0.0012	432.0	<1
1,1,1-Trichloroethane	0.0180	<0.0001	0.1514	0.0001	0.0958	0.0024	16,416	<1

[a]See Appendix D, Environmental Exposure Limit.

TABLE 3-26. AMBIENT AIR IMPACTS OF THRESHOLD CONTAMINANTS DUE TO REENTRAINED DUST FROM ROADS TREATED WITH WASTE OIL UNDER HEAVY USE CONDITIONS (at 100 meters from roadway)

Pollutant	Maximum 30-Day Concentrations (x = 100 m), $\mu g/m^3$						EEL,[a] $\mu g/m^3$	Maximum percentage of EEL
	Sand		Clay/sand		Gravel			
	High	Low	High	Low	High	Low		
Barium	0.0033	0.0012	0.0077	0.0006	0.0087	0.0012	0.43	2
Chromium (II and III)	0.0002	<0.0001	0.0004	<0.0001	0.0005	<0.0001	4.32	<1
Lead	0.0069	0.0024	0.0160	0.0013	0.0183	0.0026	1.5	1
Zinc	0.0077	0.0028	0.0182	0.0015	0.0207	0.0029	43.2	<1
Toluene	0.0005	<0.0001	0.0017	<0.0001	0.0007	<0.0001	3,240.0	<1
Xylene	0.0013	<0.0001	0.0006	<0.0001	0.0011	<0.0001	3,758.0	<1
Naphthalene	0.0037	0.0010	0.0077	<0.0001	0.0088	<0.0001	432.0	<1
1,1,1-Trichloroethane	0.0013	<0.0001	0.0110	<0.0001	0.0069	0.0001	16,416	<1

[a]See Appendix D, Environmental Exposure Limit.

TABLE 3-27. AMBIENT AIR IMPACTS OF CARCINOGENIC CONTAMINANTS DUE TO REENTRAINED DUST FROM ROADS TREATED WITH WASTE OIL UNDER MODERATE USE CONDITIONS (at 10 meters from roadway)

Waste oil contaminants	Maximum 30-day concentrations (x = 10 m), $\mu g/m^3$						Cancer risk	Individual risk
	Sand		Clay/sand		Gravel			
	High	Low	High	Low	High	Low		
Arsenic	0.0004	0.0001	0.0009	<0.0001	0.0010	0.0001	4.4×10^{-6}	1:230,000
Cadmium	0.0001	<0.0001	0.0002	<0.0001	0.0003	<0.0001	5.7×10^{-7}	1:1,800,000
Chromium	0.0007	0.0002	0.0016	0.0001	0.0018	0.0002	2.3×10^{-6}	1:430,000
Benzene	<0.0001	<0.0001	0.0001	<0.0001	0.0001	<0.0001	1.5×10^{-9}	1:670,000,000
PCB's	0.0012	0.0004	0.0028	0.0002	0.0032	0.0005	4.0×10^{-6}	1:250,000
1,1,2-Trichloroethane	0.0046	<0.0001	0.0383	0	0.0242	0	1.4×10^{-7}	1:7,100,000
Tetrachloroethylene	0.0035	<0.0001	0.0031	<0.0001	0.0028	0.0001	3.4×10^{-8}	1:2,900,000
Trichloroethylene	0.0008	<0.0001	0.0348	0	0.0305	0	5.6×10^{-7}	1:180,000

TABLE 3-28. AMBIENT AIR IMPACTS OF CARCINOGENIC CONTAMINANTS DUE TO REENTRAINED DUST FROM ROADS TREATED WITH WASTE OIL UNDER MODERATE USE CONDITIONS (at 100 meters from roadway)

Waste oil contaminants	Maximum 30-day concentrations (x = 10 m), $\mu g/m^3$						Cancer risk	Individual risk (Risk per population)
	Sand		Clay/sand		Gravel			
	High	Low	High	Low	High	Low		
Arsenic	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	$<4.0 \times 10^{-7}$	<1:2,500,000
Cadmium	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	$<1.9 \times 10^{-7}$	<1:5,300,000
Chromium	<0.0001	<0.0001	0.0001	<0.0001	0.0001	0.0001	1.3×10^{-6}	1:800,000
Benzene	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	1.5×10^{-9}	1:670,000,000
PCB's	0.0001	<0.0001	0.0002	<0.0001	0.0002	<0.0001	2.5×10^{-7}	1:4,000,000
1,1,2 Trichloroethane	0.0003	<0.0001	0.0027	<0.0001	0.0018	<0.0001	1.0×10^{-8}	1:100,000,000
Tetrachloroethylene	0.0002	<0.0001	0.0002	<0.0001	0.0002	<0.0001	2.3×10^{-9}	1:430,000,000
Trichloroethylene	<0.0001	<0.0001	0.0025	<0.0001	0.0022	<0.0001	8.3×10^{-8}	1:12,000,000

TABLE 3-29. AMBIENT AIR IMPACTS OF CARCINOGENIC CONTAMINANTS DUE TO REENTRAINED DUST FROM ROADS TREATED WITH WASTE OIL UNDER HEAVY USE CONDITIONS (at 10 meters from roadway)

Waste oil contaminants	Maximum 30-day concentrations (x = 10 m), μg/m^3						Cancer risk	Individual risk (Risk per population)
	Sand		Clay/sand		Gravel			
	High	Low	High	Low	High	Low		
Arsenic	0.0015	0.0005	0.0035	0.0003	0.0040	0.0006	1.6×10^{-5}	1:63,000
Cadmium	0.0004	0.0001	0.0009	<0.0001	0.0010	0.0001	1.9×10^{-6}	1:530,000
Chromium	0.0026	0.0009	0.0061	0.0005	0.0070	0.0010	8.8×10^{-5}	1:11,000
Benzene	0.0005	<0.0001	0.0005	<0.0001	0.0005	<0.0001	7.4×10^{-9}	1:2,400,000
PCB's	0.0047	0.0017	0.0110	0.0009	0.0125	0.0018	1.5×10^{-5}	1:67,000
1,1,2 Trichloroethane	0.0180	<0.0001	0.1514	0.0001	0.0958	0.0024	2.5×10^{-6}	1:400,000
Tetrachloroethylene	0.0219	0.0008	0.0198	0.0023	0.0177	0.0005	3.0×10^{-7}	1:3,300,000
Trichloroethylene	0.0031	0.0002	0.1313	<0.0001	0.1203	0.0001	4.7×10^{-7}	1:2,100,000

TABLE 3-30. AMBIENT AIR IMPACTS OF CARCINOGENIC CONTAMINANTS DUE TO REENTRAINED DUST FROM ROADS TREATED WITH WASTE OIL UNDER HEAVY USE CONDITIONS (at 100 meters from roadway)

Waste oil contaminants	Maximum 30-day concentrations (x = 10 m), $\mu g/m^3$						Cancer risk	Individual risk (Risk per population)
	Sand		Clay/sand		Gravel			
	High	Low	High	Low	High	Low		
Arsenic	0.0001	<0.0001	0.0003	<0.0001	0.0003	<0.0001	1.2×10^{-6}	1:830,000
Cadmium	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	$<1.9 \times 10^{-7}$	<1:5,300,000
Chromium	0.0002	<0.0001	0.0004	<0.0001	0.0005	<0.0001	6.3×10^{-6}	1:160,000
Benzene	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	1.5×10^{-10}	1:6,700,000,000
PCB's	0.0003	0.0001	0.0008	<0.0001	0.0009	0.0001	1.1×10^{-6}	1:910,000
1,1,2 Trichloroethane	0.0013	<0.0001	0.0110	<0.0001	0.0069	0.0001	4.0×10^{-8}	1:25,000,000
Tetrachloroethylene	0.0016	<0.0001	0.0014	0.0002	0.0013	<0.0001	1.8×10^{-8}	1:56,000,000
Trichloroethylene	0.0002	<0.0001	0.0095	0	0.0087	0	1.6×10^{-7}	1:6,300,000

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SECTION 4

RISK ASSESSMENT

Road oiling with waste oil can result in contamination of both the air and water. Levels of contamination that may occur under worst-case conditions are estimated in Section 3. In this section, these contaminant concentrations have been used to assess the worst possible health effects that may be associated with the use of waste oil in road oiling operations. Separate assessments are made for airborne evaporative emissions and waterborne and airborne dust emissions. Normally, exposure resulting from airborne emissions occurs via inhalation of re-entrained dust or evaporative emissions; whereas exposure from runoff results from ingestion of contaminated surface water. Appendix D describes the methodology for the assessment of health effects, which involves the analysis of both threshold (noncarcinogenic) and nonthreshold (carcinogenic) effects.

4.1 ENVIRONMENTAL IMPACT AND HEALTH RISK ASSOCIATED WITH EVAPORATIVE EMISSIONS

4.1.1 Threshold Contaminants

The impact on air quality and the risk to human health posed by evaporative emissions of threshold (noncarcinogenic) contaminants from waste oil are assessed by comparing modeled concentrations with environmental exposure limits (EEL's). The exposure

scenario used to assess the health risk is based on the highest generation rate for emissions (a heavily oiled road bed composed of gravel) in the smallest likely air volume (a volume resulting from windspeeds not exceeding 1 mi/h) for a prolonged exposure time (8 hours). The results reflect a worst-case output from the dilution model described in Section 3. A review of the results presented in Table 4-1 indicates that several waste oil threshold contaminants that are likely to evaporate into the atmosphere present a potentially significant health hazard, particularly dichlorodifluoromethane, 1,1,1-trichloroethane, and trichloroethylene. Toluene presents a lesser hazard; trichlorotrifluoroethane and xylene pose relatively small risks.

TABLE 4-1. A COMPARISON OF ESTIMATED AIRBORNE EVAPORATIVE EMISSIONS FROM WASTE OILED ROADBEDS WITH ENVIRONMENTAL EXPOSURE LIMITS

Contaminant	Concentration, $\mu g/m^3$	Percent of EEL[a]
Dichlorodifluoromethane	3,598	85
Toluene	602	19
1,1,1-Trichloroethane	3,804	232
Trichlorotrifluoroethane	15,450	4
Xylene	127	3

[a] The value of individual EEL's and the method used to derive the values are presented in Appendix D.

4.1.2 Nonthreshold Contaminants

The impact on air quality and the risk to human health posed by evaporative emissions of nonthreshold contaminants (carcinogens) from waste oil are assessed by comparing modeled airborne concentrations with reference concentrations determined from

cancer potency factors. The results of this assessment are presented in Table 4-2.

TABLE 4-2. LIFETIME CANCER RISK ASSOCIATED WITH EVAPORATIVE EMISSIONS FROM WASTE-OILED ROADBEDS

Contaminant	Airborne concentration, $\mu g/m^3$	Cancer risk	Approximate risk to an individual
Benzene	198	3×10^{-3}	1:330
Tetrachloroethylene	345	4×10^{-3}	1:250
1,1,2-Trichloroethane	3,804	6×10^{-2}	1:17
Trichloroethylene	1,231	4×10^{-3}	1:250

Based on the estimated airborne concentrations and the reference concentrations, the cancer risk was estimated for each waste oil constituent likely to evaporate from waste-oiled roadbeds. Cancer risk is calculated as a ratio of the modeled airborne concentration over the reference concentration. The resulting value is expressed in scientific notation and represents the frequency of cancers per a given population; e.g., the cancer risk from exposure to benzene is 3.0×10^{-6} or 3 incidences of cancer per 1,000,000 population.

Another means of expressing cancer risk is to present the value in terms of risk to a single individual; e.g., the cancer risk from benzene (3.0×10^{-6}) can be expressed as the risk to a single individual in terms of 1 chance in 330,000 (1:330,000).

As shown in Table 4-2, all of the waste oil constituents modeled present a significant risk well in excess of 10^{-4}, which is usually considered the highest acceptable risk level. The

obvious conclusion is that evaporative emissions from road oiling pose a significant risk. The concentrations modeled, however, represent a worst-case exposure, that which occurs immediately after a road has been newly oiled. Such exposures are most likely to occur for individuals working or living adjacent to the road oiling operation. Laborers involved in oiling the road will suffer high levels of exposure only if the wind is blowing from the oiled area in the same direction as they are driving.

4.2 ENVIRONMENTAL IMPACT AND HEALTH RISKS ASSOCIATED WITH RAINFALL RUNOFF INTO STREAMS

The impact of road oiling on water quality was estimated for worst-case scenarios involving different roadbed materials and heavy rainfalls in Nevada and Florida. (These two states experience the extremes in high-intensity rainfalls.) Estimates were made of waterborne concentrations in the immediate runoff from oiled roads and also in nearby surface water following dilution. The results of the modeling of different roadbed materials indicate that the highest runoff concentrations are likely to occur following the heavy oiling of predominantly sandy roadbeds (see Table 3-18). This worst-case scenario is also likely to produce the highest concentrations in nearby surface stream water (see Table 3-20). As expected, light oiling has a lesser impact on both runoff and surface stream waters. A risk analysis was performed for road oil contaminants in a stream adjacent to an oiled sand road, assuming 5 percent removal of oil from the roads. (See Table 3-22.)

4.2.1 Threshold Contaminants

The impact on water quality and the risk to human health posed by waterborne concentrations of threshold contaminants from waste oil were assessed by comparing the calculated stream concentrations with estimated environmental exposure limits, as shown in Table 4-3. A comparison of the modeling results with the EEL's indicates that several oil constituents in the runoff from oiled roads may have a substantial impact on water quality. Based on a heavily oiled road and a heavy Nevada rainfall, the modeling and risk assessment indicate that barium, lead, and benzo(a)anthracene exceed their respective EEL's and therefore present the greatest risks. Cadmium concentrations are nearly equal to the EEL; therefore, they also pose a potentially significant risk. Zinc, naphthalene, and xylene concentrations in the modeled scenario are between 19 and 26 percent of their EEL's; dichlorodifluoromethane, 1,1,1-trichloroethane, and toluene are between 3 and 10 percent of their EEL's. Only chromium is estimated by the modeling to be less than 1 percent of its EEL.

Risks resulting from a lightly oiled road are substantially less; however, some contaminants are still potentially significant. Benzene concentrations in the hypothetical stream exceed the EEL, lead is present at 66 percent of its EEL, and barium is present at 6 percent. All the other threshold contaminants modeled are at concentrations less than 1 percent of their EEL's.

4.2.2 Nonthreshold Contaminants

Potential cancer risks associated with road oiling were calculated by comparing the estimated waterborne concentrations

TABLE 4-3. COMPARISON OF EEL'S AND ROAD OIL CONTAMINANTS IN A HYPOTHETICAL STREAM, ASSUMING 5 PERCENT OIL RUNOFF FROM THE ROAD

Substance	EEL,[a] µg/liter	Concentration in stream, µg/liter		Percent of EEL	
		High[b]	Low[c]	High[b]	Low[c]
Barium	260	550	16	211	6
Cadmium	10	4.5	0.133	95	1
Chromium (II and III)	5,900	3.2	0.925	<1	<1
Lead	50	1,130	33	2,260	66
Zinc	5,000	1,300	38	26	<1
Benzo(a)anthracene	0.776	40	1.16	5,155	149
Dichlorodifluoromethane	28,000	970	28.5	3	<1
Naphthalene	3,400	660	19	19	<1
Toluene	14,300	1,360	39.5	10	<1
1,1,1-Trichloroethane	18,400	1,470	43	8	<1
Xylene	3,487	650	19	19	<1

[a] Environmental Exposure Limit for substances in water. See Appendix D, Table D-5.

[b] Based on a heavily oiled road and a heavy Nevada rainfall. Values from Table 3-22.

[c] Based on a lightly oiled road and a heavy Florida rainfall. Values from Table 3-22.

of waste oil contaminants in a hypothetical stream with reference concentrations for each carcinogen. This comparison is presented in Table 4-4. The cancer risk is calculated as a ratio of the modeled waterborne concentration to the reference concentration.

In Table 4-5 the results of the comparison are presented according to risk level. For the first road oiling scenario (heavy road oiling followed by a heavy Nevada rainfall), PCB's in road oil present a potentially significant risk at a level of 10^{-4} (1 cancer in 10,000). When the acceptable risk level is reduced to 10^{-5} (1 cancer in 100,000), PCB's and benzo(a)pyrene pose potentially significant risks to human health. At a risk level of 10^{-6} (1 cancer in a million), arsenic, benzene, tetrachloroethylene and 1,1,2-trichloroethane (in addition to PCB's and benzo(a)pyrene) present significant risks.

For the second road oiling scenario (light oil application followed by a heavy Florida rainfall), only PCB's present a significant risk at a level of 10^{-4}. All other contaminants modeled pose cancer risks of less than one in a million.

4.2.3 Other Adverse Environmental Effects of Waterborne Oil

In addition to the dispersion modeling and assessment of risk to human health performed for waste oil contaminants, an evaluation was made of other adverse environmental impacts from oil runoff (rather than oil contaminants) into surface waters. In addition to the more immediate interest in the protection of human health, protection of other species is also vital. A brief review of the literature addressing effects of waste or fuel oil

TABLE 4-4. ESTIMATES OF CANCER RISKS FROM ROAD OIL CONTAMINANTS IN A HYPOTHETICAL STREAM, ASSUMING 5 PERCENT OIL RUNOFF FROM THE ROAD

Substance	Reference concentration µg/liter	Concentration in stream, µg/liter		Cancer risk to a population		Cancer risk to an individual	
		High[a]	Low[b]	High[a]	Low[b]	High[a]	Low[b]
Arsenic	0.22	18	0.5	8.18×10^{-3}	2.27×10^{-4}	1:122	1:4,400
Benzene	6.6	180	5.5	2.72×10^{-4}	8.33×10^{-6}	1:3700	1:120,000
Benzo(a)pyrene	0.028	38	1.0	1.36×10^{-2}	3.57×10^{-4}	1:73	1:2,800
PCB's	0.00079	57	1.5	7.22×10^{-1}	1.90×10^{-2}	1:1.4	1:53
Tetrachloroethylene	8.0	1,360	39.5	1.70×10^{-3}	4.94×10^{-5}	1:588	1:20,300
1,1,2-Trichloroethane	6.0	1,470	43	2.45×10^{-3}	7.17×10^{-5}	1:408	1:14,000
Trichloroethylene	27	1,180	34.5	4.37×10^{-4}	1.28×10^{-5}	1:2290	1:78,300

[a] Based on a heavily oiled road and a heavy Nevada rainfall. Values taken from Table 3-22.

[b] Based on a lightly oiled road and a heavy Florida rainfall. Values taken from Table 3-22.

TABLE 4-5. WASTE OIL CONTAMINANTS POSING GIVEN CANCER RISK LEVELS FROM RUNOFF INTO A STREAM, ASSUMING 5 PERCENT OIL RUNOFF FROM THE ROAD

Road oiling scenario	Contaminants posing given risk levels		
	10^{-4} (1 cancer per 10,000)	10^{-5} (1 cancer per 100,000)	10^{-6} (1 cancer per 1,000,000)
Heavily oiled road and a heavy Nevada rainfall	All contaminants modeled	All contaminants modeled	All contaminants modeled
Lightly oiled road and a heavy Florida rainfall	Arsenic Benzo(a) pyrene PCB's	All contaminants modeled except benzene	All contaminants modeled

on fresh water (potential drinking water sources) revealed the following:

- One study estimated the maximum acceptable toxicant concentration for the water-soluble fraction of used crankcase oil to be between 325 and 930 µl/liter, based on short-term lethality tests on the American Flagfish, Jordanella floridae.[1] The authors speculate that zinc, lead, and cadmium contribute significantly to the toxicity of the waste oil tested.

- Semicontinuous additions of an oil-water dispersion of No. 2 fuel oil to marine ecosystems for 25 weeks resulted in a highly significant decline in the number of species.[2] The water column hydrocarbon levels were maintained at 190 ppb to simulate chronic oil pollution.

- A 7000-gallon diesel fuel oil spill into a freshwater creek near Salem, South Carolina, caused a 90 percent fish kill. Six months later, downstream locations contained reduced numbers and types of organisms. Thirteen months later, sediment samples still revealed the presence of hydrocarbons in the creek and the downstream lake.[3]

- Short-term laboratory mortality tests with the freshwater soluble fraction of waste oil indicated that 0.2 to 1.1 percent by volume (1,000 to 11,000 µl/liter) was lethal to freshwater fish.[4] The chronic, "no-effect" level was between 80 and 330 µl/liter total oil. Tissue residue analysis indicated that significant accumulation of normal hydrocarbons, zinc, lead, and cadmium occurs. The report stated that the potential for damage from lead exists when the soluble oil concentration exceeds 8 µl/liter total oil. The 96-hour LC 50 for fathead minnows exposed to floating oil was 11,000 µl/liter of oil. This is higher than 96-hour LC 50's of 370 µl/liter reported for flagfish exposed to emulsified oil.

- An Illinois oil company was practicing land-spreading of oily sludges on clay soil experienced a fish kill in the refinery lake after a rainstorm washed the sludge into the lake.[4] The sludge had been applied, but not yet cultivated into the soil.

- Large oil applications used in land farming may be toxic to plants in the short term because of mechanical

obstruction to plant surfaces and the resulting inability of the plants to obtain moisture. In the longer term, however, plant life may increase because of increased soil productivity.[4]

- Floating oil can cause damage to waterfowl and aquatic mammals (e.g., muskrats) because of loss of buoyancy and swimming capacity resulting from oil emersion and the potential toxic effects of oil ingestion.

The runoff modeling indicates that waste oil concentrations in streams from oil-contaminated runoff range from 8 mg/liter to 20,300 mg/liter. Results also indicate that oil film thicknesses on a stream could vary from 77.6 to 9200 nm (see Table 3-18); results of all but two of the modeling scenarios indicate film thicknesses are within the visible range.

Experimental data on aquatic toxicity due to oil contamination of water indicate increased mortality above 370 µl/liter and a no-effect level at 80 to 330 µl/liter.[4] Oil concentrations in the stream calculated from the models (8 to 20,300 mg/liter) obviously can be great enough to have adverse effects on aquatic organisms in addition to causing aesthetic deterioration of the stream from visible oil films and possible harm to plant life.

4.3 ENVIRONMENTAL IMPACT AND HEALTH RISKS OF REENTRAINED DUST EMISSIONS

The impact of reentrained dust emissions was estimated for several scenarios involving the use of waste oil on different roadbeds.

Reentrained dust emissions containing inorganic contaminants occur in the greatest quantities following heavy traffic on oiled

gravel roadbeds (see Table 3-24). In contrast, organic contaminants occur in greatest quantities following heavy traffic on several different kinds of roadbeds. Depending on the contaminant of concern, the worst-case scenario may involve sand, clay/sand, or gravel roadbeds (see Table 3-24). An assessment was made of the health implications of waste-oil-contaminated reentrained dust based on the specific worst-case scenario for each contaminant.

4.3.1 Threshold Contaminants

The impact on air quality and the risk to human health posed by reentrained dust containing threshold waste oil contaminants was assessed by comparing the modeling results with estimated environmental exposure limits. The results of this comparison, presented in Table 4-6, indicate that only barium and lead are present in sufficient quantities to be of significant concern. The remaining substances are present at concentrations equal to or less than 1 percent of their EEL's. It should be kept in mind that the concentrations shown are based on one application only; repeated applications could result in increased concentrations over time.

Barium--

The results of modeling for barium compounds in reentrained dust showed levels equal to 0.12 $\mu g/m^3$ or 28 percent of the applicable EEL. Because these modeling results represent a worst-case scenario, concentrations under actual conditions would probably be less.

TABLE 4-6. COMPARISON OF AIRBORNE WASTE OIL CONTAMINANTS RESULTING FROM REENTRAINED DUST EMISSIONS WITH ENVIRONMENTAL EXPOSURE LIMITS[a]

Contaminant	Concentration, $\mu g/m^3$	Percent of EEL
Barium	0.1209[b]	28
Chromium (II and III)[c]	0.0070[b]	<1
Lead	0.2534[b]	17
Zinc	0.2866[b]	1
Naphthalene	0.1224[b]	<1
Toluene	0.0247[d]	<1
1,1,1-Trichloroethane	0.0958[b]	<1
Xylene	0.0175[e]	<1

[a] See Table 3-24.

[b] Based on high concentration on gravel roadbed.

[c] EEL for chromium is based on chromium II and III; modeled concentration is total chromium because the relative quantities of II and III are not known.

[d] Based on high concentration on clay/sand roadbed.

[e] Based on high concentration on sand roadbed.

Lead--

The results of modeling for lead compounds showed levels of 0.25 $\mu g/m^3$ or 17 percent of the applicable EEL. Although this concentration is not of significant concern in itself, the lead content of reentrained dust from waste oil applications could contribute to the already elevated ambient lead levels in certain areas of the country.

4.3.2 Nonthreshold Contaminants

The impact on air quality and the risk to human health posed by nonthreshold substances in reentrained dust emissions was assessed against reference concentrations developed from the EPA's cancer potency factors. (See Appendix D for derivation and discussion of reference concentrations.) The results of this assessment are presented in Table 4-7. The quantification of cancer risk is achieved by comparing the highest modeled airborne concentration of each contaminant (worst-case traffic and road oiling scenario) against its respective reference concentration.

The significance of the results in Table 4-7 depend on the level of risk selected as acceptable. If a risk level of 1 cancer in 10,000 (10^{-4}) is considered acceptable, only chromium presents a significant health problem. On the other hand, if a lower risk level of 1 cancer in 1,000,000 (10^{-6}) is chosen as the highest acceptable level, arsenic, cadmium, chromium, PCB's, and 1,1,2-trichloroethane are all present in unacceptable concentrations. Table 4-8 identifies the waste oil constituents found in

TABLE 4-7. COMPARISON OF AIRBORNE WASTE OIL CONTAMINANTS RESULTING FROM REENTRAINED DUST EMISSIONS WITH REFERENCE CONCENTRATIONS[a]

Contaminant	Concentration, $\mu g/m^3$	Cancer risk	Lifetime cancer risk to an individual
Arsenic	0.0040[b]	1.6×10^{-5}	1:60,000
Cadmium	0.0010[b]	1.9×10^{-6}	1:526,000
Chromium	0.0070[b]	8.8×10^{-5}	1:10,000
Benzene	0.0005[b]	7.4×10^{-9}	1:135,000,000
Polychlorinated biphenols	0.0125[b]	1.5×10^{-5}	1:67,000
1,1,2-trichloroethane	0.1514[c]	2.5×10^{-6}	1:400,000
Tetrachloroethylene	0.0198[c]	3.0×10^{-7}	1:3,300,000
Trichloroethylene	0.1203[c]	4.3×10^{-7}	1:2,310,000

[a] See Table 3-28.

[b] Based on high concentration on gravel roadbed.

[c] Based on high concentration on clay/sand roadbed.

reentrained dust that are of concern for three levels of risk 10^{-4}, 10^{-5}, and 10^{-6}.

TABLE 4-8. WASTE OIL CONSTITUENTS IN CONCENTRATIONS THAT PRESENT A POTENTIALLY UNACCEPTABLE CANCER RISK[a]

Acceptable risk level	Waste oil constituent presenting a significant health problem
10^{-4}	Chromium
10^{-5}	Arsenic, chromium, and PCB's
10^{-6}	Arsenic, cadmium, chromium, PCB's, and 1,1,2-trichloroethane

[a] Assessment is based on results given in Table 4-7.

4.4 SUMMARY

Road oiling can present significant risks to human health and the environment from evaporative emissions, rainfall runoff, and reentrained dust emissions.

4.4.1 Evaporative Emissions

Several threshold contaminants that are likely to evaporate into the atmosphere from an oiled road present a significant risk to human health, particularly dichlorodifluoromethane, 1,1,1-trichloroethane, and trichloroethylene. Toluene presents a lesser hazard. All of the nonthreshold contaminants modeled present a significant risk well in excess of 1 cancer in 10,000. The obvious conclusion from the modeling results is that evaporative emissions from road oiling present significant risks to persons exposed to freshly oiled roads. The models, however,

allow for very little dilution and transport, which would rapidly decrease the concentrations of contaminants in the air.

4.4.2 Rainfall Runoff

The analyses have indicated that road oiling of sand roadbeds followed by high-intensity rainfall is likely to result in waterborne concentration of lead and benzanthracene that could be hazardous to human health if the runoff were to enter nearby drinking water sources. Conversely, the models indicate that concentrations of waste oil contaminants in a stream adjacent to silt and clay roadbeds (assuming a light oil application followed by a high-intensity rainfall) do not pose significant risks to human health.

Runoff from waste-oiled roads can also have an adverse impact on plant life, fish, and other aquatic life. In addition, it can cause oil slicks that decrease the aesthetics of a stream and can be harmful to birds and aquatic animals.

4.4.3 Reentrained Dust Emissions

The threshold contaminants (barium and lead) present low levels of risk to human health. Nonthreshold contaminants also present some risks. At a risk level of 1 cancer in 100,000 people, chromium, arsenic, and PCB's present significant risks. At a risk level of 1 in 10,000, only chromium is significant. At a risk level of 1 in 1,000,000, arsenic, cadmium, chromium, PCB's, and 1,1,2-trichloroethane present significant risks.

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APPENDIX A

SENSITIVITY ANALYSIS OF FACTORS AFFECTING WASTE OIL EVAPORATION

Evaporation of waste oil has been estimated with a model developed by Mackay,[1] Equations A-1 through A-3.

$$q = KP_i/RT_s \qquad \text{(A-1)}$$

where K = mass transfer coefficient, m/h

P_i = partial vapor pressure, atm

R = ideal gas constant, m^3 atm/mol K

T_s = soil surface temperature, K

q = evaporation rate, mol/m^2-h

$$K = 0.0292\ V^{0.78}\ W^{-0.11}\ Sc^{-0.67} \qquad \text{(A-2)}$$

0.0292 = units conversion factor

V = wind velocity measured at height of 10 m, m/h

W = road width, m

Sc = Schmidt number (unitless)

$$P_i = X_i P_i^\circ \qquad \text{(A-3)}$$

X_i = mole fraction of oil component 1 (unitless)

P_i° = ideal vapor pressure of oil component i, atm

Variables

Ideal vapor pressures (Table A-1) and mole fractions are used to calculate the partial vapor pressures for a particular waste oil component at a specific concentration and temperature. Data were not available for ideal vapor pressures of all the oil components of concern. No data were found for benzo(a)anthracene and benzo(a)pyrene. Data for PCB's, dichlorodifluoromethane, and trichlorotrifluoroethane were limited to only one temperature. Calculations of mole fractions were based on an average density of waste oil of 0.91 g/ml and an average molecular weight for waste oil of 449 g/mole.[2]

Schmidt number data were also limited to waste oil components. Values for other components were calculated (Table A-2).

Results

A sensitivity analysis of the effects of variations in windspeed and surface temperature on evaporation rates was conducted for seven organic waste oil components: 1,1,1-trichloroethane, trichloroethylene, tetrachloroethylene, benzene, toluene, xylene, and naphthalene. For those contaminants on which vapor pressure data were available at only one surface temperature (dichlorodifluoromethane, trichlorotrifluoroethane, and PCB's), the sensitivity analysis was restricted to only windspeed. The sensitivity analysis did not include benzo(a)anthracene and benzo(a)pyrene because no data on vapor pressures at any surface temperature were found. Concentration effects were also evaluated. All

compounds for which physical data were available were analyzed at both the 75th and 90th percentile concentrations (Tables A-3 through A-15).

Assumptions and Limitations

Several assumptions were necessary in the calculation of evaporation rates of waste oil components. As a result, application of these results has some limitations, which are listed below.

1. The calculated evaporation rates are based on initial concentration levels. As evaporation proceeds, both concentrations and evaporation rates will decrease.

2. The Schmidt number and vapor pressures were calculated for most components. Because actual values will probably vary somewhat from these calculated values, slight changes may occur in the evaporation rates determined.

3. Worst-case temperature was assumed to be 100F[6]. Actual road surface temperatures will vary; they will be higher in the afternoon and cooler in the morning.

4. Windspeed will vary throughout the day and from day to day, which will cause evaporation rates to vary.

5. All of the applied oil will not be subject to surface evaporation. Some will seep into the road surface, some will be carried away with windblown dust, and some may be washed away by rainfall.

TABLE A-1

VAPOR PRESSURES (ATM) OF SELECTED WASTE OIL COMPONENTS AT VARIOUS TEMPERATURES*

	0°C	25°C	50°C	214°C
Chlorinated Solvents				
Dichlorodifluoromethane	0.57	NA†	NA	NA
Trichlorotrifluoroethane	NA	NA	NA	33.7
Trichloroethane	-‡	0.16	0.45	-
Trichloroethylene	-	9.5×10^{-2}	0.28	-
Tetrachloroethylene	-	2.3×10^{-2}	7.8×10^{-2}	-
Other Organics				
Benzene	-	9.54×10^{-2}	0.27	-
Toluene	-	3.3×10^{-2}	0.11	-
Xylene	-	-	-	-
Benzo(a)anthracene	NA	NA	NA	NA
Benzo(a)pyrene	NA	NA	NA	NA
Naphthalene	-	1.32×10^{-4}	1.32×10^{-3}	-
PCB's				
Aroclor 1242	NA	5.3×10^{-7}§	NA	NA
Aroclor 1248	NA	6.5×10^{-7}§	NA	NA
Aroclor 1254	NA	1.0×10^{-7}§	NA	NA
Aroclor 1260	NA	5.3×10^{-8}§	NA	NA

* All values calculated based on constants in Reference 3.
† NA = not available.
‡ "-" = not calculated.
§ From Reference 4.

TABLE A-2

SCHMIDT NUMBERS FOR SELECTED WASTE OIL COMPONENTS*

Chlorinated solvents	
Dichlorodifluoromethane	(2.34)
Trichlorotrifluoroethane	(2.90)
Trichloroethane	(2.44)
Trichloroethylene	(2.42)
Tetrachloroethylene	(2.72)
Other organics	
Benzene	1.76
Toluene	(2.03)
Xylene	2.18
Benzo(a)anthracene	-†
Benzo(a)pyrene	-
Naphthalene	(2.39)
PCB's	
Aroclor 1242	(3.39)
Aroclor 1248	(3.61)
Aroclor 1254	(3.82)
Aroclor 1260	(4.02)‡

* All values in parentheses are calculated. Other values, Reference 5.

† "-" means values not calculated.

‡ Value used for PCB evaporation calculation (Table A-14).

TABLE A-3

ROAD SURFACE EVAPORATION - DICHLORODIFLUOROMETHANE*

Wind speed (mi/hr)	Wind speed (m/hr)	Mass transfer coefficient (K) (m/hr)	75th Percentile† Evaporation rate @ 0 C (mol/sq. m-hr.)	90th Percentile‡ Evaporation rate @ 0 C (mol/sq. m-hr.)
1	1,609	4.34	0.10	0.39
2	3,218	7.46	0.16	0.67
3	4,827	10.23	0.23	0.92
4	6,436	12.81	0.28	1.15
5	8,045	15.24	0.34	1.37
6	9,654	17.57	0.39	1.58
7	11,263	19.81	0.44	1.79
8	12,872	21.99	0.48	1.98
9	14,481	24.11	0.53	2.17
10	16,090	26.17	0.58	2.36
11	17,699	28.19	0.62	2.54
12	19,308	30.17	0.66	2.72
13	20,917	32.11	0.71	2.90
14	22,526	34.02	0.75	3.07
15	24,135	35.90	0.79	3.24
16	25,744	37.76	0.83	3.40
17	27,353	39.59	0.87	3.57
18	28,962	41.39	0.91	3.73
19	30,571	43.17	0.95	3.89
20	32,180	44.94	0.99	4.05
21	33,789	46.68	1.03	4.21
22	35,398	48.40	1.07	4.36
23	37,007	50.11	1.10	4.52
24	38,616	51.80	1.14	4.67
25	40,225	53.48	1.18	4.82
26	41,834	55.14	1.21	4.97
27	43,443	56.79	1.25	5.12
28	45,052	58.42	1.29	5.27
29	46,661	60.04	1.32	5.41
30	48,270	61.65	1.36	5.56
31	49,879	63.25	1.39	5.70
32	51,488	64.84	1.43	5.85
33	53,097	66.41	1.46	5.99
34	54,706	67.98	1.50	6.13
35	56,315	69.53	1.53	6.27
36	57,924	71.07	1.56	6.41
37	59,533	72.61	1.60	6.55
38	61,142	74.14	1.63	6.68
39	62,751	75.65	1.67	6.82
40	64,360	77.16	1.70	6.96

* Molecular weight = 120.914 g/mol. Schmidt number = 2.34.
† Concentration = 210 mg/l. Partial pressure = 4.935×10^{-4} atm. at 0 C.
‡ Concentration = 860 mg/l. Partial pressure = 2.021×10^{-3} atm. at 0 C.

TABLE A-4

ROAD SURFACE EVAPORATION - TRICHLOROTRIFLUOROETHANE*

Wind speed (mi/hr)	Wind speed (m/hr)	Mass transfer coefficient (K) (m/hr)	75th Percentile† Evaporation rate @ 214 C (mol/sq. m-hr.)	90th Percentile‡ Evaporation rate @ 214 C (mol/sq. m-hr.)
1	1,609	3.76	0.28	1.08
2	3,218	6.46	0.47	1.86
3	4,827	8.86	0.65	2.56
4	6,436	11.09	0.81	3.20
5	8,045	13.20	0.97	3.81
6	9,654	15.22	1.11	4.39
7	11,263	17.16	1.26	4.95
8	12,872	19.04	1.40	5.49
9	14,481	20.88	1.53	6.02
10	16,090	22.67	1.66	6.54
11	17,699	24.41	1.79	7.04
12	19,308	26.13	1.91	7.54
13	20,917	27.81	2.04	8.02
14	22,526	29.47	2.16	8.50
15	24,135	31.10	2.28	8.97
16	25,744	32.70	2.40	9.43
17	27,353	34.29	2.51	9.89
18	28,962	35.85	2.63	10.34
19	30,571	37.39	2.74	10.78
20	32,180	38.92	2.85	11.22
21	33,789	40.43	2.96	11.66
22	35,398	41.92	3.07	12.09
23	37,007	43.40	3.18	12.52
24	38,616	44.87	3.29	12.94
25	40,225	46.32	3.39	13.36
26	41,834	47.76	3.50	13.77
27	43,443	49.18	3.60	14.18
28	45,052	50.60	3.71	14.59
29	46,661	52.00	3.81	15.00
30	48,270	53.40	3.91	15.40
31	49,879	54.78	4.01	15.80
32	51,488	56.15	4.11	16.19
33	53,097	57.52	4.21	16.59
34	54,706	58.87	4.31	16.98
35	56,315	60.22	4.41	17.37
36	57,924	61.56	4.51	17.75
37	59,533	62.89	4.61	18.14
38	61,142	64.21	4.70	18.52
39	62,751	65.52	4.80	18.90
40	64,360	66.83	4.90	19.27

* Molecular weight = 187.38 g/mol. Schmidt number = 2.90.
† Concentration = 33 mg/l. Partial pressure = 2.929×10^{-3} atm. at 214 C.
‡ Concentration = 130 mg/l. Partial pressure = 1.153×10^{-2} atm. at 214 C.

TABLE A-5

ROAD SURFACE EVAPORATION - TRICHLOROETHANE*

Wind speed (mi/hr)	Wind speed (m/hr)	Mass transfer coefficient (K) (m/hr)	75th Percentile† Evaporation rate @ 50 C (mol/sq. m-hr)	75th Percentile† Evaporation rate @ 25 C (mol/sq. m-hr)	90th Percentile‡ Evaporation rate @ 50 C (mol/sq. m-hr)	90th Percentile‡ Evaporation rate @ 25 C (mol/sq. m-hr)
1	1,609	4.22	0.16	0.06	0.35	0.13
2	3,218	7.25	0.27	0.10	0.59	0.23
3	4,827	9.95	0.37	0.14	0.81	0.31
4	6,436	12.45	0.46	0.18	1.02	0.39
5	8,045	14.82	0.55	0.21	1.21	0.46
6	9,654	17.08	0.63	0.24	1.40	0.53
7	11,263	19.27	0.72	0.27	1.58	0.60
8	12,872	21.38	0.79	0.30	1.75	0.67
9	14,481	23.44	0.87	0.33	1.92	0.73
10	16,090	25.45	0.95	0.36	2.08	0.79
11	17,699	27.41	1.02	0.39	2.24	0.85
12	19,308	29.33	1.09	0.41	2.40	0.91
13	20,917	31.22	1.16	0.44	2.56	0.97
14	22,526	33.08	1.23	0.47	2.71	1.03
15	24,135	34.91	1.30	0.49	2.86	1.09
16	25,744	36.71	1.36	0.52	3.01	1.14
17	27,353	38.49	1.43	0.54	3.15	1.20
18	28,962	40.25	1.50	0.57	3.29	1.25
19	30,571	41.98	1.56	0.59	3.44	1.31
20	32,180	43.69	1.62	0.62	3.58	1.36
21	33,789	45.39	1.69	0.64	3.72	1.41
22	35,398	47.07	1.75	0.66	3.85	1.46
23	37,007	48.73	1.81	0.69	3.99	1.52
24	38,616	50.37	1.87	0.71	4.12	1.57
25	40,225	52.00	1.93	0.73	4.26	1.62
26	41,834	53.62	1.99	0.76	4.39	1.67
27	43,443	55.22	2.05	0.78	4.52	1.72
28	45,052	56.81	2.11	0.80	4.65	1.7
29	46,661	58.38	2.17	0.82	4.78	1.8
30	48,270	59.95	2.23	0.85	4.91	1.8
31	49,879	61.50	2.29	0.87	5.04	1.
32	51,488	63.04	2.34	0.89	5.16	1.
33	53,097	64.58	2.40	0.91	5.29	2
34	54,706	66.10	2.46	0.93	5.41	2
35	56,315	67.61	2.51	0.96	5.53	
36	57,924	69.11	2.57	0.98	5.66	
37	59,533	70.60	2.62	1.00	5.78	
38	61,142	72.09	2.68	1.02	5.90	
39	62,751	73.56	2.73	1.04	6.02	
40	64,360	75.03	2.79	1.06	6.14	

* Molecular weight = 133.405 g/mol. Schmidt number = 2.44.
† Concentration = 590 mg/l. Partial pressure = 9.853×10^{-4} atm. at 50 C and 3.456×10^{-4} atm at 25 C.
‡ Concentration = 1300 mg/l. Partial pressure = 2.171×10^{-3} atm. at 50 C and 7.615×10^{-4} atm at 25 C.

TABLE A-6

ROAD SURFACE EVAPORATION - TRICHLOROETHYLENE*

Wind speed (mi/hr)	Wind speed (m/hr)	Mass transfer coefficient (K) (m/hr)	75th Percentile† Evaporation rate @ 50 C (mol/sq. m-hr)	75th Percentile† Evaporation rate @ 25 C (mol/sq. m-hr)	90th Percentile‡ Evaporation rate @ 50 C (mol/sq. m-hr)	90th Percentile‡ Evaporation rate @ 25 C (mol/sq. m-hr)
1	1,609	4.25	0.08	0.03	0.18	0.07
2	3,218	7.29	0.14	0.05	0.31	0.11
3	4,827	10.00	0.20	0.07	0.42	0.15
4	6,436	12.52	0.25	0.09	0.53	0.19
5	8,045	14.90	0.29	0.11	0.63	0.23
6	9,654	17.18	0.34	0.12	0.72	0.26
7	11,263	19.37	0.38	0.14	0.81	0.30
8	12,872	21.50	0.42	0.15	0.90	0.33
9	14,481	23.57	0.46	0.17	0.99	0.36
10	16,090	25.59	0.50	0.18	1.07	0.39
11	17,699	27.56	0.54	0.20	1.16	0.42
12	19,308	29.50	0.58	0.21	1.24	0.45
13	20,917	31.40	0.62	0.22	1.32	0.48
14	22,526	33.27	0.65	0.24	1.40	0.51
15	24,135	35.11	0.69	0.25	1.47	0.54
16	25,744	36.92	0.72	0.26	1.55	0.57
17	27,353	38.71	0.76	0.28	1.62	0.59
18	28,962	40.47	0.79	0.29	1.70	0.62
19	30,571	42.21	0.83	0.30	1.77	0.65
20	32,180	43.94	0.86	0.31	1.84	0.67
21	33,789	45.64	0.90	0.33	1.92	0.70
22	35,398	47.33	0.93	0.34	1.99	0.72
23	37,007	49.00	0.96	0.35	2.06	0.75
24	38,616	50.65	0.99	0.36	2.13	0.78
25	40,225	52.29	1.03	0.37	2.19	0.80
26	41,834	53.91	1.06	0.39	2.26	0.83
27	43,443	55.52	1.09	0.40	2.33	0.85
28	45,052	57.12	1.12	0.41	2.40	0.88
29	46,661	58.71	1.15	0.42	2.46	0.90
30	48,270	60.28	1.18	0.43	2.53	0.92
31	49,879	61.84	1.21	0.44	2.60	0.95
32	51,488	63.39	1.24	0.45	2.66	0.97
33	53,097	64.93	1.27	0.47	2.73	1.00
34	54,706	66.46	1.30	0.48	2.79	1.02
35	56,315	67.98	1.33	0.49	2.85	1.04
36	57,924	69.49	1.36	0.50	2.92	1.07
37	59,533	70.99	1.39	0.51	2.98	1.09
38	61,142	72.49	1.42	0.52	3.04	1.11
39	62,751	73.97	1.45	0.53	3.10	1.13
40	64,360	75.44	1.48	0.54	3.17	1.16

* Molecular weight = 131.389 g /mol. Schmidt number = 2.42.
† Concentration = 490 mg/l. Partial pressure = 5.201×10^{-4} atm. at 50 C and 1.753×10^{-4} at 25 C.
‡ Concentration = 1,049 mg/l. Partial pressure = 1.113×10^{-3} atm. at 50 C and 3.752×10^{-4} at 25 C.

TABLE A-7

ROAD SURFACE EVAPORATION - TETRACHLOROETHYLENE*

Wind speed (mi/hr)	Wind speed (m/hr)	Mass transfer coefficient (K) (m/hr)	75th Percentile† Evaporation rate @ 50 C (mol/sq. m-hr)	75th Percentile† Evaporation rate @ 25 C (mol/sq. m-hr)	90th Percentile‡ Evaporation rate @ 50 C (mol/sq. m-hr)	90th Percentile‡ Evaporation rate @ 25 C (mol/sq. m-hr)
1	1,609	3.93	0.01	4.14 E-3	0.04	0.01
2	3,218	6.74	0.02	7.10 E-3	0.07	0.02
3	4,827	9.25	0.03	9.75 E-3	0.10	0.03
4	6,436	11.58	0.04	1.22 E-2	0.12	0.04
5	8,045	13.78	0.04	1.45 E-2	0.15	0.05
6	9,654	15.88	0.05	1.67 E-2	0.17	0.05
7	11,263	17.91	0.06	1.89 E-2	0.19	0.06
8	12,872	19.88	0.06	2.09 E-2	0.21	0.07
9	14,481	21.80	0.07	2.30 E-2	0.23	0.07
10	16,090	23.66	0.08	2.49 E-2	0.25	0.08
11	17,699	25.49	0.08	2.69 E-2	0.27	0.09
12	19,308	27.28	0.09	2.87 E-2	0.29	0.09
13	20,917	29.03	0.09	3.06 E-2	0.31	0.10
14	22,526	30.76	0.10	3.24 E-2	0.32	0.11
15	24,135	32.46	0.11	3.42 E-2	0.34	0.11
16	25,744	34.14	0.11	3.60 E-2	0.36	0.12
17	27,353	35.79	0.12	3.77 E-2	0.38	0.12
18	28,962	37.42	0.12	3.94 E-2	0.40	0.13
19	30,571	39.03	0.13	4.11 E-2	0.41	0.13
20	32,180	40.63	0.13	4.28 E-2	0.43	0.14
21	33,789	42.20	0.14	4.45 E-2	0.45	0.14
22	35,398	43.76	0.14	4.61 E-2	0.46	0.15
23	37,007	45.31	0.15	4.77 E-2	0.48	0.15
24	38,616	46.84	0.15	4.94 E-2	0.49	0.16
25	40,225	48.35	0.16	5.09 E-2	0.51	0.17
26	41,834	49.85	0.16	5.25 E-2	0.53	0.17
27	43,443	51.34	0.17	5.41 E-2	0.54	0.18
28	45,052	52.82	0.17	5.57 E-2	0.56	0.18
29	46,661	54.29	0.18	5.72 E-2	0.57	0.19
30	48,270	55.74	0.18	5.87 E-2	0.59	0.19
31	49,879	57.18	0.19	6.03 E-2	0.60	0.20
32	51,488	58.62	0.19	6.18 E-2	0.62	0.20
33	53,097	60.04	0.20	6.33 E-2	0.63	0.21
34	54,706	61.46	0.20	6.48 E-2	0.65	0.21
35	56,315	62.86	0.20	6.62 E-2	0.66	0.21
36	57,924	64.26	0.21	6.77 E-2	0.68	0.22
37	59,533	65.65	0.21	6.92 E-2	0.69	0.22
38	61,142	67.03	0.22	7.06 E-2	0.71	0.23
39	62,751	68.40	0.22	7.21 E-2	0.72	0.23
40	64,360	69.76	0.23	7.35 E-2	0.74	0.24

* Molecular weight = 165.834 g/mol. Schmidt number = 2.72.
† Concentration = 370 mg/l. Partial pressure = 8.632×10^{-5} atm. at 50 C and 2.578×10^{-5} atm. at 25 C.
‡ Concentration = 1,200 mg/l. Partial pressure = 2.8×10^{-4} atm. at 50 C and 8.361×10^{-5} atm. at 25 C.

TABLE A-8

ROAD SURFACE EVAPORATION - BENZENE*

Wind speed (mi/hr)	Wind speed (m/hr)	Mass transfer coefficient (K) (m/hr)	75th Percentile† Evaporation rate @ 50 C (mol/sq. m-hr)	75th Percentile† Evaporation rate @ 25 C (mol/sq. m-hr)	90th Percentile‡ Evaporation rate @ 50 C (mol/sq. m-hr)	90th Percentile‡ Evaporation rate @ 25 C (mol/sq. m-hr)
1	1,609	5.26	0.03	0.01	0.06	0.02
2	3,218	9.03	0.05	0.02	0.10	0.04
3	4,827	12.38	0.06	0.02	0.13	0.05
4	6,436	15.50	0.08	0.23	0.16	0.06
5	8,045	18.44	0.09	0.03	0.19	0.07
6	9,654	21.26	0.11	0.04	0.22	0.08
7	11,263	23.98	0.12	0.05	0.25	0.09
8	12,872	26.61	0.14	0.05	0.28	0.10
9	14,481	29.17	0.15	0.06	0.31	0.11
10	16,090	31.67	0.16	0.06	0.33	0.12
11	17,699	34.12	0.17	0.06	0.36	0.13
12	19,308	36.51	0.19	0.07	0.39	0.14
13	20,917	38.86	0.20	0.07	0.41	0.15
14	22,526	41.18	0.21	0.08	0.43	0.16
15	24,135	43.45	0.22	0.08	0.46	0.17
16	25,744	45.70	0.23	0.09	0.48	0.18
17	27,353	47.91	0.24	0.09	0.51	0.19
18	28,962	50.09	0.25	0.09	0.53	0.20
19	30,571	52.25	0.27	0.10	0.55	0.21
20	32,180	54.39	0.28	0.10	0.57	0.21
21	33,789	56.50	0.29	0.11	0.60	0.22
22	35,398	58.58	0.30	0.11	0.62	0.23
23	37,007	60.65	0.31	0.11	0.64	0.24
24	38,616	62.70	0.32	0.12	0.66	0.25
25	40,225	64.73	0.33	0.12	0.68	0.26
26	41,834	66.74	0.34	0.13	0.70	0.26
27	43,443	68.73	0.35	0.13	0.72	0.27
28	45,052	70.71	0.36	0.13	0.75	0.28
29	46,661	72.67	0.37	0.14	0.77	0.29
30	48,270	74.62	0.38	0.14	0.79	0.29
31	49,879	76.55	0.39	0.15	0.81	0.30
32	51,488	78.47	0.40	0.15	0.83	0.31
33	53,097	80.38	0.41	0.15	0.85	0.32
34	54,706	82.27	0.42	0.16	0.87	0.32
35	56,315	84.15	0.43	0.16	0.89	0.33
36	57,924	86.02	0.44	0.16	0.91	0.34
37	59,533	87.88	0.45	0.17	0.93	0.35
38	61,142	89.72	0.46	0.17	0.95	0.35
39	62,751	91.56	0.46	0.17	0.97	0.36
40	64,360	93.39	0.47	0.18	0.98	0.37

* Molecular weight = 78.114 g/mol. Schmidt number = 1.76.
† Concentration = 77 mg/l. Partial pressure = 1.346×10^{-4} atm. at 50 C and 4.639×10^{-5} atm. at 25 C.
‡ Concentration = 160 mg/l. Partial pressure = 2.797×10^{-4} atm. at 50 C and 9.64×10^{-5} atm at 25 C.

TABLE A-9

ROAD SURFACE EVAPORATION - TOLUENE*

Wind speed (mi/hr)	Wind speed (m/hr)	Mass transfer coefficient (K) (m/hr)	75th Percentile† Evaporation rate @ 50 C (mol/sq. m-hr)	75th Percentile† Evaporation rate @ 25 C (mol/sq. m-hr)	90th Percentile‡ Evaporation rate @ 50 C (mol/sq. m-hr)	90th Percentile‡ Evaporation rate @ 25 C (mol/sq. m-hr)
1	1,609	4.78	0.05	0.02	0.13	0.04
2	3,218	8.20	0.09	0.03	0.22	0.07
3	4,827	11.25	0.12	0.04	0.30	0.10
4	6,436	14.09	0.15	0.05	0.37	0.12
5	8,045	16.76	0.18	0.06	0.44	0.14
6	9,654	19.32	0.21	0.07	0.51	0.17
7	11,263	21.79	0.23	0.08	0.57	0.19
8	12,872	24.19	0.26	0.08	0.63	0.21
9	14,481	26.51	0.28	0.09	0.70	0.23
10	16,090	28.78	0.31	0.10	0.75	0.25
11	17,699	31.01	0.33	0.11	0.81	0.27
12	19,308	33.18	0.36	0.12	0.87	0.28
13	20,917	35.32	0.38	0.12	0.93	0.30
14	22,526	37.42	0.40	0.13	0.98	0.32
15	24,135	39.49	0.42	0.14	1.04	0.34
16	25,744	41.53	0.44	0.15	1.09	0.36
17	27,353	43.54	0.47	0.15	1.14	0.37
18	28,962	45.53	0.49	0.16	1.19	0.39
19	30,571	47.49	0.51	0.17	1.24	0.41
20	32,180	49.43	0.53	0.17	1.30	0.42
21	33,789	51.34	0.55	0.18	1.35	0.44
22	35,398	53.24	0.57	0.19	1.40	0.46
23	37,007	55.12	0.59	0.19	1.44	0.47
24	38,616	56.98	0.61	0.20	1.49	0.49
25	40,225	58.82	0.63	0.21	1.54	0.50
26	41,834	60.65	0.65	0.21	1.59	0.52
27	43,443	62.46	0.67	0.22	1.64	0.53
28	45,052	64.26	0.69	0.22	1.68	0.55
29	46,661	66.04	0.71	0.23	1.73	0.57
30	48,270	67.81	0.73	0.24	1.78	0.58
31	49,879	69.57	0.74	0.24	1.82	0.60
32	51,488	71.31	0.76	0.25	1.87	0.61
33	53,097	73.05	0.78	0.26	1.91	0.63
34	54,706	74.77	0.80	0.26	1.96	0.64
35	56,315	76.48	0.82	0.27	2.00	0.65
36	57,924	78.18	0.84	0.27	2.05	0.67
37	59,533	79.86	0.86	0.28	2.09	0.68
38	61,142	81.54	0.87	0.28	2.14	0.70
39	62,751	83.21	0.89	0.29	2.18	0.71
40	64,360	84.87	0.91	0.30	2.22	0.73

* Molecular weight = 490 g/mol. Schmidt number = 2.03.

† Concentration = 490 mg/l. Partial pressure = 2.839×10^{-4} atm. at 50 C and 8.55×10^{-5} atm. at 25 C.

‡ Concentration = 1,200 mg/l. Partial pressure = 6.952×10^{-4} atm. at 50 C and 2.095×10^{-4} atm. at 25 C.

TABLE A-10

ROAD SURFACE EVAPORATION - XYLENE*

Wind speed (mi/hr)	Wind speed (m/hr)	Mass transfer coefficient (K) (m/hr)	75th Percentile† Evaporation rate @ 50 C (mol/sq. m-hr)	75th Percentile† Evaporation rate @ 25 C (mol/sq. m-hr)	90th Percentile‡ Evaporation rate @ 50 C (mol/sq. m-hr)	90th Percentile‡ Evaporation rate @ 25 C (mol/sq. m-hr)
1	1,609	4.55	0.01	4.36 E-3	0.03	0.01
2	3,218	7.82	0.02	7.48 E-3	0.05	0.02
3	4,827	10.73	0.03	1.03 E-2	0.07	0.02
4	6,436	13.43	0.04	1.29 E-2	0.09	0.03
5	8,045	15.98	0.05	1.53 E-2	0.11	0.03
6	9,654	18.42	0.06	1.76 E-2	0.12	0.04
7	11,263	20.78	0.07	1.99 E-2	0.14	0.04
8	12,872	23.06	0.07	2.21 E-2	0.15	0.05
9	14,481	25.28	0.08	2.42 E-2	0.17	0.05
10	16,090	27.44	0.09	2.62 E-2	0.18	0.06
11	17,699	29.56	0.09	2.83 E-2	0.20	0.06
12	19,308	31.64	0.10	3.03 E-2	0.21	0.06
13	20,917	33.67	0.11	3.22 E-2	0.22	0.07
14	22,526	35.68	0.11	3.41 E-2	0.24	0.07
15	24,135	37.65	0.12	3.60 E-2	0.25	0.08
16	25,744	39.59	0.12	3.79 E-2	0.26	0.08
17	27,353	41.51	0.13	3.97 E-2	0.28	0.08
18	28,962	43.40	0.14	4.15 E-2	0.29	0.09
19	30,571	45.27	0.14	4.33 E-2	0.30	0.09
20	32,180	47.12	0.15	4.51 E-2	0.31	0.10
21	33,789	48.95	0.15	4.68 E-2	0.33	0.10
22	35,398	50.76	0.16	4.85 E-2	0.34	0.10
23	37,007	52.55	0.17	5.03 E-2	0.35	0.11
24	38,616	54.32	0.17	5.20 E-2	0.36	0.11
25	40,225	56.08	0.18	5.36 E-2	0.37	0.11
26	41,834	57.82	0.18	5.53 E-2	0.39	0.12
27	43,443	59.55	0.19	5.70 E-2	0.40	0.12
28	45,052	61.26	0.19	5.86 E-2	0.41	0.12
29	46,661	62.96	0.20	6.02 E-2	0.42	0.13
30	48,270	64.65	0.20	6.18 E-2	0.43	0.13
31	49,879	66.32	0.21	6.34 E-2	0.44	0.13
32	51,488	67.99	0.21	6.50 E-2	0.45	0.14
33	53,097	69.64	0.22	6.66 E-2	0.46	0.14
34	54,706	71.28	0.22	6.82 E-2	0.47	0.14
35	56,315	72.91	0.23	6.97 E-2	0.49	0.15
36	57,924	74.53	0.23	7.13 E-2	0.50	0.15
37	59,533	76.14	0.24	7.28 E-2	0.51	0.15
38	61,142	77.74	0.25	7.44 E-2	0.52	0.16
39	62,751	79.33	0.25	7.59 E-2	0.53	0.16
40	64,360	80.91	0.26	7.74 E-2	0.54	0.16

* Molecular weight = 106.168 g/mol. Schmidt number = 2.18.
† Concentration = 270 mg/l. Partial pressure = 8.36×10^{-5} atm. at 50 C and 2.34×10^{-5} atm. at 25 C.
‡ Concentration = 570 mg/l. Partial pressure = 1.76×10^{-4} atm. at 50 C and 4.94×10^{-5} atm. at 25 C.

TABLE A-11

ROAD SURFACE EVAPORATION - PCB'S (AROCLOR 1242)*

Wind speed (mi/hr)	Wind speed (m/hr)	Mass transfer coefficient (K) (m/hr)	75th Percentile† Evaporation rate @ 25 C (mol/sq. m-hr.)	90th Percentile‡ Evaporation rate @ 25 C (mol/sq. m-hr.)
1	1,609	3.39	5.72 E-9	6.98 E-9
2	3,218	5.82	9.83 E-9	1.20 E-8
3	4,827	7.98	1.35 E-8	1.64 E-8
4	6,436	9.99	1.69 E-8	2.06 E-8
5	8,045	11.89	2.01 E-8	2.45 E-8
6	9,654	13.71	2.32 E-8	2.82 E-8
7	11,263	15.46	2.61 E-8	3.18 E-8
8	12,872	17.15	2.90 E-8	3.53 E-8
9	14,481	18.80	3.18 E-8	3.87 E-8
10	16,090	20.41	3.45 E-8	4.21 E-8
11	17,699	21.99	3.71 E-8	4.53 E-8
12	19,308	23.53	3.98 E-8	4.85 E-8
13	20,917	25.05	4.23 E-8	5.16 E-8
14	22,526	26.54	4.48 E-8	5.47 E-8
15	24,135	28.01	4.73 E-8	5.77 E-8
16	25,744	29.45	4.98 E-8	6.07 E-8
17	27,353	30.88	5.22 E-8	6.36 E-8
18	28,962	32.29	5.45 E-8	6.65 E-8
19	30,571	33.68	5.69 E-8	6.94 E-8
20	32,180	35.05	5.92 E-8	7.22 E-8
21	33,789	36.41	6.15 E-8	7.50 E-8
22	35,398	37.76	6.38 E-8	7.78 E-8
23	37,007	39.09	6.60 E-8	8.05 E-8
24	38,616	40.41	6.83 E-8	8.32 E-8
25	40,225	41.72	7.05 E-8	8.59 E-8
26	41,834	43.02	7.27 E-8	8.86 E-8
27	43,443	44.30	7.48 E-8	9.12 E-8
28	45,052	45.57	7.70 E-8	9.39 E-8
29	46,661	46.84	7.91 E-8	9.65 E-8
30	48,270	48.09	8.12 E-8	9.91 E-8
31	49,879	49.34	8.33 E-8	1.02 E-7
32	51,488	50.58	8.54 E-8	1.04 E-7
33	53,097	51.81	8.75 E-8	1.07 E-7
34	54,706	53.03	8.96 E-8	1.09 E-7
35	56,315	54.24	9.16 E-8	1.12 E-7
36	57,924	55.44	9.36 E-8	1.14 E-7
37	59,533	56.64	9.57 E-8	1.17 E-7
38	61,142	57.83	9.77 E-8	1.19 E-7
39	62,751	59.02	9.97 E-8	1.22 E-7
40	64,360	60.19	1.02 E-7	1.24 E-7

* Molecular weight = 257.479 g/mol. Schmidt number = 3.39.
† Concentration = 41 mg/l. Partial pressure = 4.13×10^{-11} atm. at 25 C.
‡ Concentration = 50 mg/l. Partial pressure = 5.04×10^{-11} atm. at 25 C.

TABLE A-12

ROAD SURFACE EVAPORATION - PCB'S (AROCLOR 1248)*

Wind speed (mi/hr)	Wind speed (m/hr)	Mass transfer coefficient (K) (m/hr)	75th Percentile† Evaporation rate @ 25 C (mol/sq. m-hr.)	90th Percentile‡ Evaporation rate @ 25 C (mol/sq. m-hr.)
1	1,609	3.25	5.98 E-9	7.29 E-9
2	3,218	5.58	1.03 E-8	1.25 E-8
3	4,827	7.65	1.41 E-8	1.72 E-8
4	6,436	9.58	1.76 E-8	2.15 E-8
5	8,045	11.40	2.10 E-8	2.56 E-8
6	9,654	13.14	2.42 E-8	2.95 E-8
7	11,263	14.82	2.73 E-8	3.33 E-8
8	12,872	16.45	3.03 E-8	3.69 E-8
9	14,481	18.03	3.32 E-8	4.05 E-8
10	16,090	19.57	3.60 E-8	4.39 E-8
11	17,699	21.08	3.88 E-8	4.73 E-8
12	19,308	22.56	4.15 E-8	5.07 E-8
13	20,917	24.02	4.42 E-8	5.39 E-8
14	22,526	25.45	4.69 E-8	5.71 E-8
15	24,135	26.85	4.94 E-8	6.03 E-8
16	25,744	28.24	5.20 E-8	6.34 E-8
17	27,353	29.61	5.45 E-8	6.65 E-8
18	28,962	30.96	5.70 E-8	6.95 E-8
19	30,571	32.29	5.94 E-8	7.25 E-8
20	32,180	33.61	6.19 E-8	7.55 E-8
21	33,789	34.91	6.43 E-8	7.84 E-8
22	35,398	36.20	6.67 E-8	8.13 E-8
23	37,007	37.48	6.90 E-8	8.42 E-8
24	38,616	38.74	7.13 E-8	8.70 E-8
25	40,225	40.00	7.36 E-8	8.98 E-8
26	41,834	41.24	7.59 E-8	9.26 E-8
27	43,443	42.47	7.82 E-8	9.54 E-8
28	45,052	43.69	8.04 E-8	9.81 E-8
29	46,661	44.91	8.27 E-8	1.01 E-7
30	48,270	46.11	8.49 E-8	1.04 E-7
31	49,879	47.31	8.71 E-8	1.06 E-7
32	51,488	48.49	8.93 E-8	1.09 E-7
33	53,097	49.67	9.14 E-8	1.12 E-7
34	54,706	50.84	9.36 E-8	1.14 E-7
35	56,315	52.00	9.57 E-8	1.17 E-7
36	57,924	53.16	9.79 E-8	1.19 E-7
37	59,533	54.31	1.00 E-7	1.22 E-7
38	61,142	55.45	1.02 E-7	1.25 E-7
39	62,751	56.58	1.04 E-7	1.27 E-7
40	64,360	57.71	1.06 E-7	1.30 E-7

* Molecular weight = 291.932 g/mol. Schmidt number = 3.61.
† Concentration = 41 mg/l. Partial pressure = 4.50×10^{-11} atm. at 25 C.
‡ Concentration = 50 mg/l. Partial pressure = 5.49×10^{-11} atm. at 25 C.

TABLE A-13

ROAD SURFACE EVAPORATION - PCB'S (AROCLOR 1254)*

Wind speed (mi/hr)	Wind speed (m/hr)	Mass transfer coefficient (K) (m/hr)	75th Percentile† Evaporation rate @ 25 C† (mol/sq. m-hr.)	90th Percentile‡ Evaporation rate @ 25 C‡ (mol/sq. m-hr.)
1	1,609	3.13	8.00 E-10	9.76 E-10
2	3,218	5.37	1.37 E-9	1.68 E-9
3	4,827	7.37	1.89 E-9	2.30 E-9
4	6,436	9.22	2.36 E-9	2.88 E-9
5	8,045	10.97	2.81 E-9	3.42 E-9
6	9,654	12.65	3.24 E-9	3.95 E-9
7	11,263	14.27	3.65 E-9	4.45 E-9
8	12,872	15.83	4.05 E-9	4.94 E-9
9	14,481	17.36	4.44 E-9	5.42 E-9
10	16,090	18.84	4.82 E-9	5.88 E-9
11	17,699	20.30	5.19 E-9	6.33 E-9
12	19,308	21.72	5.56 E-9	6.78 E-9
13	20,917	23.12	5.92 E-9	7.21 E-9
14	22,526	24.50	6.27 E-9	7.64 E-9
15	24,135	25.85	6.61 E-9	8.07 E-9
16	25,744	27.19	6.96 E-9	8.48 E-9
17	27,353	28.51	7.29 E-9	8.89 E-9
18	28,962	29.81	7.63 E-9	9.30 E-9
19	30,571	31.09	7.95 E-9	9.70 E-9
20	32,180	32.36	8.28 E-9	1.01 E-8
21	33,789	33.61	8.60 E-9	1.05 E-8
22	35,398	34.86	8.92 E-9	1.09 E-8
23	37,007	36.09	9.23 E-9	1.13 E-8
24	38,616	37.30	9.54 E-9	1.16 E-8
25	40,225	38.51	9.85 E-9	1.20 E-8
26	41,834	39.71	1.02 E-8	1.24 E-8
27	43,443	40.89	1.05 E-8	1.28 E-8
28	45,052	42.07	1.08 E-8	1.31 E-8
29	46,661	43.24	1.11 E-8	1.35 E-8
30	48,270	44.40	1.14 E-8	1.39 E-8
31	49,879	45.55	1.17 E-8	1.42 E-8
32	51,488	46.69	1.19 E-8	1.46 E-8
33	53,097	47.82	1.22 E-8	1.49 E-8
34	54,706	48.95	1.25 E-8	1.53 E-8
35	56,315	50.07	1.28 E-8	1.56 E-8
36	57,924	51.18	1.31 E-8	1.60 E-8
37	59,533	52.29	1.34 E-8	1.63 E-8
38	61,142	53.39	1.37 E-8	1.67 E-8
39	62,751	54.48	1.39 E-8	1.70 E-8
40	64,360	55.56	1.42 E-8	1.73 E-8

* Molecular weight = 326.385 g/mol. Schmidt number = 3.82.
† Concentration = 41 mg/l. Partial pressure = 6.26×10^{-12} atm. at 25 C.
‡ Concentration = 50 mg/l. Partial pressure = 7.63×10^{-12} atm. at 25 C.

TABLE A-14

ROAD SURFACE EVAPORATION - PCB'S (AROCLOR 1260)*

Wind speed (mi/hr)	Wind speed (m/hr)	Mass transfer coefficient (K) (m/hr)	75th Percentile† Evaporation rate @ 25 C (mol/sq. m-hr.)	90th Percentile‡ Evaporation rate @ 25 C (mol/sq. m-hr.)
1	1,609	3.02	3.69 E-10	4.50 E-10
2	3,218	5.19	6.34 E-10	7.73 E-10
3	4,827	7.12	8.70 E-10	1.06 E-9
4	6,436	8.91	1.09 E-9	1.33 E-9
5	8,045	10.61	1.30 E-9	1.58 E-9
6	9,654	12.23	1.49 E-9	1.82 E-9
7	11,263	13.79	1.68 E-9	2.05 E-9
8	12,872	15.30	1.87 E-9	2.28 E-9
9	14,481	16.77	2.05 E-9	2.50 E-9
10	16,090	18.21	2.22 E-9	2.71 E-9
11	17,699	19.62	2.40 E-9	2.92 E-9
12	19,308	20.99	2.56 E-9	3.13 E-9
13	20,917	22.35	2.73 E-9	3.33 E-9
14	22,526	23.68	2.89 E-9	3.53 E-9
15	24,135	24.99	3.05 E-9	3.72 E-9
16	25,744	26.28	3.21 E-9	3.91 E-9
17	27,353	27.55	3.36 E-9	4.10 E-9
18	28,962	28.80	3.52 E-9	4.29 E-9
19	30,571	30.04	3.67 E-9	4.48 E-9
20	32,180	31.27	3.82 E-9	4.66 E-9
21	33,789	32.48	3.97 E-9	4.84 E-9
22	35,398	33.68	4.11 E-9	5.02 E-9
23	37,007	34.87	4.26 E-9	5.19 E-9
24	38,616	36.05	4.40 E-9	5.37 E-9
25	40,225	37.22	4.55 E-9	5.54 E-9
26	41,834	38.37	4.69 E-9	5.72 E-9
27	43,443	39.52	4.83 E-9	5.89 E-9
28	45,052	40.66	4.97 E-9	6.06 E-9
29	46,661	41.78	5.10 E-9	6.22 E-9
30	48,270	42.90	5.24 E-9	6.39 E-9
31	49,879	44.02	5.38 E-9	6.56 E-9
32	51,488	45.12	5.51 E-9	6.72 E-9
33	53,097	46.22	5.64 E-9	6.88 E-9
34	54,706	47.30	5.78 E-9	7.05 E-9
35	56,315	48.39	5.91 E-9	7.21 E-9
36	57,924	49.46	6.04 E-9	7.37 E-9
37	59,533	50.53	6.17 E-9	7.53 E-9
38	61,142	51.59	6.30 E-9	7.68 E-9
39	62,751	52.65	6.43 E-9	7.84 E-9
40	64,360	53.70	6.56 E-9	8.00 E-9

* Molecular weight = 360.838 g/mol. Schmidt number = 4.02.
† Concentration = 41 mg/l. Partial pressure = 2.99×10^{-12} atm. at 25 C.
‡ Concentration = 50 mg/l. Partial pressure = 3.64×10^{-12} atm. at 25 C.

TABLE A-15

ROAD SURFACE EVAPORATION - NAPHTHALENE*

Wind speed (mi/hr)	Wind speed (m/hr)	Mass transfer coefficient (K) (m/hr)	75th Percentile† Evaporation rate @ 50 C (mol/sq. m-hr)	75th Percentile† Evaporation rate @ 25 C (mol/sq. m-hr)	90th Percentile‡ Evaporation rate @ 50 C (mol/sq. m-hr)	90th Percentile‡ Evaporation rate @ 25 C (mol/sq. m-hr)
1	1,609	4.28	4.01 E-4	4.34 E-5	4.74 E-4	5.14 E-5
2	3,218	7.35	6.88 E-4	7.46 E-5	8.15 E-4	8.83 E-5
3	4,827	10.09	9.44 E-4	1.02 E-4	1.12 E-3	1.21 E-4
4	6,436	12.63	1.18 E-3	1.28 E-4	1.40 E-3	1.52 E-4
5	8,045	15.03	1.41 E-3	1.52 E-4	1.66 E-3	1.80 E-4
6	9,654	17.32	1.62 E-3	1.76 E-4	1.92 E-3	2.08 E-4
7	11,263	19.54	1.83 E-3	1.98 E-4	2.16 E-3	2.35 E-4
8	12,872	21.68	2.03 E-3	2.20 E-4	2.40 E-3	2.60 E-4
9	14,481	23.77	2.22 E-3	2.41 E-4	2.63 E-3	2.85 E-4
10	16,090	25.80	2.41 E-3	2.62 E-4	2.86 E-3	3.10 E-4
11	17,699	27.79	2.60 E-3	2.82 E-4	3.08 E-3	3.34 E-4
12	19,308	29.74	2.78 E-3	3.02 E-4	3.30 E-3	3.57 E-4
13	20,917	31.66	2.96 E-3	3.21 E-4	3.51 E-3	3.80 E-4
14	22,526	33.55	3.14 E-3	3.40 E-4	3.72 E-3	4.03 E-4
15	24,135	35.40	3.31 E-3	3.59 E-4	3.92 E-3	4.25 E-4
16	25,744	37.23	3.48 E-3	3.78 E-4	4.12 E-3	4.47 E-4
17	27,353	39.03	3.65 E-3	3.96 E-4	4.32 E-3	4.69 E-4
18	28,962	40.81	3.82 E-3	4.14 E-4	4.52 E-3	4.90 E-4
19	30,571	42.57	3.98 E-3	4.32 E-4	4.72 E-3	5.11 E-4
20	32,180	44.30	4.15 E-3	4.50 E-4	4.91 E-3	5.32 E-4
21	33,789	46.02	4.31 E-3	4.67 E-4	5.10 E-3	5.53 E-4
22	35,398	47.72	4.47 E-3	4.84 E-4	5.29 E-3	5.73 E-4
23	37,007	49.41	4.62 E-3	5.01 E-4	5.47 E-3	5.93 E-4
24	38,616	51.08	4.78 E-3	5.18 E-4	5.66 E-3	6.13 E-4
25	40,225	52.73	4.94 E-3	5.35 E-4	5.84 E-3	6.33 E-4
26	41,834	54.37	5.09 E-3	5.52 E-4	6.02 E-3	6.53 E-4
27	43,443	55.99	5.24 E-3	5.68 E-4	6.20 E-3	6.72 E-4
28	45,052	57.60	5.39 E-3	5.84 E-4	6.38 E-3	6.92 E-4
29	46,661	59.20	5.54 E-3	6.01 E-4	6.56 E-3	7.11 E-4
30	48,270	60.79	5.69 E-3	6.17 E-4	6.73 E-3	7.30 E-4
31	49,879	62.36	5.84 E-3	6.33 E-4	6.19 E-3	7.49 E-4
32	51,488	63.92	5.98 E-3	6.49 E-4	7.08 E-3	7.68 E-4
33	53,097	65.48	6.13 E-3	6.64 E-4	7.25 E-3	7.86 E-4
34	54,706	67.02	6.27 E-3	6.80 E-4	7.43 E-3	8.05 E-4
35	56,315	68.55	6.42 E-3	6.95 E-4	7.60 E-3	8.23 E-4
36	57,924	70.08	6.56 E-3	7.11 E-4	7.76 E-3	8.42 E-4
37	59,533	71.59	6.70 E-3	7.26 E-4	7.93 E-3	8.60 E-4
38	61,142	73.09	6.84 E-3	7.42 E-4	8.10 E-3	8.78 E-4
39	62,751	74.59	6.98 E-3	7.57 E-4	8.26 E-3	8.96 E-4
40	64,360	76.08	7.12 E-3	7.72 E-4	8.43 E-3	9.14 E-4

* Molecular weight = 128.174 g/mol. Schmidt number = 2.39.
† Concentration = 490 mg/l. Partial pressure = 2.482×10^{-6} atm. at 50 C and 2.482×10^{-7} atm. at 25 C.
‡ Concentration = 580 mg/l. Partial pressure = 2.938×10^{-6} atm. at 50 C and 2.938×10^{-7} atm. at 25 C.

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APPENDIX B

SENSITIVITY ANALYSIS OF FACTORS AFFECTING WASTE OIL CONCENTRATION IN RAINFALL RUNOFF

The concentration of road oil components is primarily dependent on four factors: (1) the oil component concentration in the waste oil, (2) the amount of oil applied to the road, (3) the volume of rainfall, and (4) the amount of oil that is removed from the road surface during a rainfall event. It is possible to quantify the first three factors, but no information is available for determination of how much oil can be carried away from a road during rainfall.

ROAD SURFACE EROSION

The first analysis estimates the intensity of rainfall that would be necessary for all of the oil to be removed from an oiled road during a single rainfall event. This analysis assumes that road surface erosion would remove all of the oil by carrying away the surface layer of soil to which oil had adsorbed. The results showed that typical heavy rainfall intensities (Table 3-11) never reach the calculated levels necessary to produce sheet erosion of the road surface. Some erosion will occur, of course, but it will not be rapid enough to remove all of the adsorbed oil during a single rainfall event.

Road surface erosion is dependent on critical shear velocity (Table B-1), and the velocity is dependent on rainfall intensity, the slope of the road surface, and the resultant runoff depth (Equations B-1 and B-2).[1,2] The rainfall intensities necessary to produce road surface erosion were calculated by the use of Equations 1 and 2 and are shown in Table B-2.

$$Y = \frac{Li}{\alpha}^{1/M} \qquad \text{(B-1)}$$

where Y = depth of surface runoff

L = one half the distance between the road crown and the road side

i = rainfall intensity

M = 2 for natural surfaces

$$\alpha = \frac{(1.49)}{c} (S)^{1/2} \qquad \text{(B-2)}$$

where

c = roughness coefficient

S = slope

$$V = \alpha Y^{2/3}$$

where

V = critical shear velocity

TABLE B-1. CRITICAL VELOCITY FOR ROAD SURFACE EROSION[a] (ft/s)

	Velocity	
	Low	High
Sand	1.50	1.75
Silt	0.20	3.75
Clay	3.75	3.75
Gravel	2.50	4.00

[a] Reference 3.

TABLE B-2. RAINFALL INTENSITY FOR ROAD SURFACE EROSION
(inches per hour)

Slope of road	Sand		Silt		Clay		Gravel	
	Low	High	Low	High	Low	High	Low	High
0.50	5.84	41.71	13.84	410.45	91.21	410.45	27.03	498.14
0.33	8.76	62.57	20.76	615.68	136.82	615.68	40.54	747.21
0.25	11.68	83.43	27.67	820.91	182.42	820.91	54.05	998.28
0.20	14.59	104.29	34.59	1,026.14	228.03	1,026.14	67.56	1,245.35
0.10	29.19	208.57	69.19	2,052.27	456.06	2,052.27	135.13	2,490.70
0.01	291.88	2,085.72	691.86	20,522.72	4,560.61	20,522.72	1,351.29	24,909.99

RUNOFF CONCENTRATIONS

Concentrations of waste oil and waste oil components in rainfall runoff were calculated as described in Section 3. The effect of rainfall intensity was evaluated by calculating concentrations resulting from a maximum two-year rainfall of various durations. Because the quantity of oil that may be removed from the road surface during a given rainfall event is not clearly understood, concentrations were calculated at two levels of removal: 1) maximum oil removal of 100 percent, and 2) low or probable minimum oil removal of 5 percent. The results are presented in Tables B-3 and B-4. The high values for each soil type listed in these tables are based on the highest application rate in the range of rates (Table 3-9) and the lowest of the heavy rainfall intensities (Table 3-11). The low values are based on the lowest application rate and the highest of the heavy rainfall intensities. The concentration on the road surface was obtained by dividing the quantity of oil (100 percent or 5 percent of the oil applied) by the quantity of rain that strikes the oiled surface.

TABLE B-3. OIL CONCENTRATION IN ROAD SURFACE RUNOFF AT VARIOUS RAINFALL DURATIONS WITH 100 PERCENT OIL RUNOFF[a]
(mg of oil per liter of water)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	1,040,000	181,000	522,000	48,000	522,000	48,400	522,000	60,200
10	652,000	115,000	326,000	30,800	326,000	30,800	326,000	38,400
30	435,000	57,500	217,000	15,400	217,000	15,400	217,000	19,200
120	296,000	30,600	143,000	8,190	148,000	8,190	148,000	10,200

[a] Based on an oil density of 0.9.

TABLE B-4. OIL CONCENTRATION IN ROAD SURFACE RUNOFF AT VARIOUS RAINFALL DURATIONS WITH 5 PERCENT OIL RUNOFF[a]
(mg of oil per liter of water)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	52,200	9,030	26,100	2,420	26,100	2,420	26,100	3,010
10	32,600	5,750	16,300	1,540	16,300	1,540	61,300	1,920
30	21,700	2,880	10,900	771	10,900	771	10,900	959
120	14,800	1,530	7,410	410	7,410	410	7,410	509

[a] Based on an oil density of 0.9.

It should be pointed out that the surface runoff concentration applies only to the roadway. As the oil leaves the oiled surface, it is immediately diluted with the rain that falls near the road. The results of the concentrations in Tables B-3 and B-4 and in the calculations for specific components that follow are used later to calculate worst-case concentrations in streams.

Road surface runoff concentrations for potentially hazardous waste oil components are shown in Tables B-5 through B-40. Tables B-5 through B-22 use the 90th percentile value for waste oil component concentration, and Tables B-23 through B-40 are based on the 75th percentile value (Table I). All calculations for Tables B-5 through B-40 assume that 100 percent of the oil is washed from the road. The values may be adjusted by multiplying by the fraction of oil removal expected at a particular site. The high and low values are based on the same assumptions as those described for Tables B-3 and B-4.

STREAM CONCENTRATIONS

Potential worst-case concentrations of waste oil components in streams were calculated as described in Section 3. The worst-case scenario assumes that every road in the watershed has been oiled, that roads occur at one-mile intervals, and that 35 percent of the rain that falls on adjacent fields enters the stream and dilutes runoff from the oiled roads. It is further assumed that 100 percent of the oil applied to the road is removed during the rainfall event. Concentrations resulting from lesser removal

TABLE B-5. ARSENIC CONCENTRATION IN ROAD SURFACE RUNOFF DUE TO VARIOUS RAINFALL DURATIONS[a]
(mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	18.54	3.21	9.27	0.86	9.27	0.86	9.27	1.07
10	11.59	2.04	5.80	0.55	5.80	0.55	5.80	0.68
30	7.73	1.02	3.86	0.27	3.86	0.27	3.86	0.34
120	5.27	0.54	2.63	0.15	2.63	0.15	2.63	0.18

[a] Based on the 90th percentile value concentration for arsenic of 16 mg/liter.

TABLE B-6. BARIUM CONCENTRATION IN ROAD SURFACE RUNOFF DUE TO VARIOUS RAINFALL DURATIONS[a] (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	562.14	97.29	281.07	26.09	281.07	26.09	281.07	32.43
10	351.34	62.00	175.67	16.62	175.67	16.62	175.67	20.67
30	234.22	31.00	117.11	8.31	117.11	8.31	117.11	10.33
120	159.70	16.47	79.85	4.42	79.85	4.42	79.85	5.49

[a] Based on the 90th percentile value concentration for barium of 485 mg/liter.

TABLE B-7. CADMIUM CONCENTRATION IN ROAD SURFACE RUNOFF DUE TO VARIOUS RAINFALL DURATIONS[a] (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	4.64	0.80	2.32	0.22	2.32	0.22	2.32	0.27
10	2.90	0.51	1.45	0.14	1.45	0.14	1.45	0.17
30	1.93	0.26	0.97	0.07	0.97	0.07	0.97	0.09
120	1.32	0.14	0.66	0.04	0.66	0.04	0.66	0.05

[a] Based on the 90th percentile value concentration for cadmium of 4 mg/liter.

TABLE B-8. CHROMIUM CONCENTRATION IN ROAD SURFACE RUNOFF DUE TO VARIOUS RAINFALL DURATIONS[a]

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	32.45	5.62	16.23	1.51	16.23	1.51	16.23	1.87
10	20.28	3.58	10.14	0.96	10.14	0.96	10.14	1.19
30	13.52	1.79	6.76	0.48	6.76	0.48	6.76	0.60
120	9.22	0.95	4.61	0.25	4.61	0.25	4.61	0.32

[a] Based on the 90th percentile value concentration for chromium of 28 mg/liter.

TABLE B-9. LEAD CONCENTRATION IN ROAD SURFACE RUNOFF DUE TO VARIOUS RAINFALL DURATIONS[a]
(mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	1,159.06	200.61	579.53	53.79	579.53	53.79	579.53	66.87
10	724.41	127.84	362.20	34.28	362.20	34.28	362.20	42.61
30	482.94	63.92	241.47	17.14	241.47	17.14	241.47	21.31
120	329.28	33.96	164.64	9.10	164.64	9.10	164.64	11.32

[a] Based on the 90th percentile value concentration for lead of 1,000 mg/liter.

TABLE B-10. ZINC CONCENTRATION IN ROAD SURFACE RUNOFF DUE TO VARIOUS RAINFALL DURATIONS[a] (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	1,332.91	230.97	666.46	61.85	666.46	61.85	666.46	79.60
10	833.07	147.01	416.54	39.42	416.54	39.42	416.54	49.00
30	555.38	73.51	277.69	19.71	277.69	19.71	277.69	24.50
120	378.67	39.05	189.33	10.47	189.33	10.47	189.33	13.02

[a] Based on the 90th percentile value concentration for zinc of 1,150 mg/liter.

TABLE B-11. DICHLORODIFLUOROMETHANE CONCENTRATION IN ROAD SURFACE RUNOFF DUE TO VARIOUS RAINFALL DURATIONS[a] (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	996.79	172.52	498.39	46.26	498.39	46.26	498.39	57.51
10	622.99	109.94	311.50	29.48	311.50	29.48	311.50	36.65
30	415.33	54.97	207.66	14.74	207.66	14.74	207.66	18.32
120	283.18	29.20	141.59	7.83	141.59	7.83	141.59	9.73

[a] Based on the 90th percentile value concentration for dichlorodifluoromethane of 860 mg/liter.

TABLE B-12. TRICHLOROTRIFLUOROETHANE CONCENTRATION IN ROAD SURFACE RUNOFF DUE TO VARIOUS RAINFALL DURATIONS[a]
(mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	150.68	26.08	75.34	6.99	75.34	6.99	75.34	8.69
10	94.17	16.62	47.09	4.46	47.09	4.46	47.09	5.54
30	62.78	8.31	31.39	2.23	31.39	2.23	31.39	2.77
120	42.81	4.41	21.40	1.18	21.40	1.18	21.40	1.47

[a] Based on the 90th percentile value concentration for trichlorotrifluoroethane of 130 mg/liter.

TABLE B-13. TRICHLOROETHANE CONCENTRATION IN ROAD SURFACE RUNOFF DUE TO VARIOUS RAINFALL DURATIONS[a]
(mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	1,506.77	260.79	753.39	69.92	753.39	69.92	753.39	86.93
10	941.73	166.19	470.87	44.56	470.87	44.56	470.87	55.40
30	627.82	83.09	313.91	22.28	313.91	22.28	313.91	27.70
120	428.06	44.14	214.03	11.84	214.03	11.84	214.03	14.71

[a] Based on the 90th percentile value concentration for trichloroethane of 1,300 mg/liter.

TABLE B-14. TRICHLOROETHYLENE CONCENTRATION IN ROAD SURFACE RUNOFF DUE TO VARIOUS RAINFALL DURATIONS[a]
(mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	1,215.85	210.44	607.92	56.42	607.92	56.42	607.92	70.15
10	759.91	134.10	379.95	35.95	379.95	35.95	379.95	44.70
30	506.60	67.05	253.30	17.98	253.30	17.98	253.30	22.35
120	345.41	35.62	172.71	9.55	172.71	9.55	172.71	11.87

[a] Based on the 90th percentile value concentration for trichloroethylene of 1,049 mg/liter.

TABLE B-15. TETRACHLOROETHYLENE CONCENTRATION IN ROAD SURFACE RUNOFF DUE TO VARIOUS RAINFALL DURATIONS[a]
(mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	1,390.86	240.73	695.43	64.54	695.43	64.54	695.43	80.24
10	869.29	153.40	434.65	41.13	435.65	41.13	434.65	51.13
30	579.53	76.70	289.76	20.57	289.76	20.57	289.76	25.57
120	395.13	40.75	197.57	10.93	197.57	10.93	197.57	13.58

[a] Based on the 90th percentile value concentration for tetrachloroethylene of 1,200 mg/liter.

TABLE B-16. BENZENE CONCENTRATION IN ROAD SURFACE RUNOFF DUE TO VARIOUS RAINFALL DURATIONS[a] (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	185.45	32.10	97.72	8.61	92.72	8.61	92.72	10.70
10	115.91	20.45	57.95	5.48	57.95	5.48	57.95	6.82
30	77.27	10.23	38.64	2.74	38.64	2.74	38.64	3.41
120	52.68	5.43	26.34	1.46	26.34	1.46	26.34	1.81

[a] Based on the 90th percentile value concentration for Benzene of 160 mg/liter.

TABLE B-17. TOLUENE CONCENTRATION IN ROAD SURFACE RUNOFF DUE TO VARIOUS RAINFALL DURATIONS[a] (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	1,390.87	240.73	695.43	65.54	695.43	64.54	695.43	80.24
10	869.29	153.40	434.65	41.13	434.65	41.13	434.65	51.13
30	579.53	76.70	289.76	20.57	289.76	20.57	289.76	25.57
120	395.13	40.75	197.57	10.93	197.57	10.93	197.57	13.58

[a] Based on the 90th percentile value concentration for Toluene of 1,200 mg/liter.

TABLE B-18. XYLENE CONCENTRATION IN ROAD SURFACE RUNOFF DUE TO VARIOUS RAINFALL DURATIONS[a] (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	660.66	114.35	330.33	30.66	330.33	30.66	330.33	38.12
10	412.91	72.87	206.46	19.54	206.46	19.54	206.46	24.29
30	275.28	36.43	137.64	9.77	137.64	9.77	137.64	12.14
120	187.69	19.36	93.84	5.19	93.84	5.19	93.84	6.45

[a] Based on the 90th percentile value concentration for xylene of 570 mg/liter.

TABLE B-19. BENZ(A)ANTHRACENE CONCENTRATION IN ROAD SURFACE RUNOFF DUE TO VARIOUS RAINFALL DURATIONS[a] (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	40.57	7.02	20.28	1.88	20.28	1.88	20.28	2.34
10	25.35	4.47	12.68	1.20	12.68	1.20	12.68	1.49
30	16.90	2.24	8.45	0.60	8.45	0.60	8.45	0.75
120	11.52	1.19	5.76	0.32	5.76	0.32	5.76	0.40

[a] Based on the 90th percentile value concentration for benzo(a) anthracene of 35 mg/liter.

TABLE B-20. BENZO(A)PYRENE CONCENTRATION IN ROAD SURFACE RUNOFF DUE TO VARIOUS RAINFALL DURATIONS[a] (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	38.25	6.62	19.12	1.77	19.12	1.77	19.12	1.77
10	23.91	4.22	11.95	1.13	11.95	1.13	11.95	1.41
30	15.94	2.11	7.97	0.57	7.97	0.57	7.97	0.70
120	10.87	1.12	5.43	0.30	5.43	0.30	5.43	0.37

[a] Based on the 90th percentile value concentration for benzo(a)pyrene of 35 mg/liter.

TABLE B-21. NAPHTHALENE CONCENTRATION IN ROAD SURFACE RUNOFF DUE TO VARIOUS RAINFALL DURATIONS[a] (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	672.25	116.35	336.13	31.20	336.13	31.20	336.13	38.78
10	520.16	74.15	210.08	19.88	210.08	19.88	210.08	24.72
30	280.11	37.07	140.05	9.94	140.05	9.94	140.05	12.36
120	190.98	19.69	95.49	52.8	95.49	5.28	95.49	6.56

[a] Based on the 90th percentile value concentration for naphthalene of 580 mg/liter.

TABLE B-22. PCB'S CONCENTRATION IN ROAD SURFACE RUNOFF DUE TO VARIOUS RAINFALL DURATIONS[a]
(mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	57.95	10.03	29.98	2.69	29.98	2.69	29.98	3.34
10	36.22	6.39	18.11	1.71	18.11	1.71	18.11	2.13
30	24.15	3.20	12.07	0.86	12.07	0.86	12.07	1.07
120	16.46	1.70	8.23	0.46	8.23	0.46	8.23	0.57

[a] Based on the 90th percentile value concentration for PCB's of 50 mg/liter.

TABLE B-23. ARSENIC CONCENTRATION IN ROAD SURFACE RUNOFF DUE TO VARIOUS RAINFALL DURATIONS--75TH PERCENTILE LEVELS[a] (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	16.23	2.81	8.11	0.75	8.11	0.75	8.11	0.94
10	10.14	1.79	5.07	0.48	5.07	0.48	5.07	0.60
30	6.76	0.89	3.38	0.24	3.38	0.24	3.38	0.30
120	4.61	0.48	2.30	0.13	2.30	0.13	2.30	0.16

[a] The 75th percentile level for arsenic in waste oil is 14 mg/liter.

TABLE B-24. BARIUM CONCENTRATION IN ROAD SURFACE RUNOFF DUE TO VARIOUS RAINFALL DURATIONS--75TH PERCENTILE LEVELS[a] (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	231.81	40.12	115.91	10.76	115.91	10.76	115.91	13.37
10	144.88	25.57	72.44	6.86	72.44	6.86	72.44	8.52
30	96.59	12.78	48.29	3.43	48.29	3.43	48.29	4.26
120	65.86	6.79	32.93	1.82	32.93	1.82	32.93	2.26

[a] The 75th percentile level for barium in waste oil is 200 mg/liter.

TABLE B-25. CADMIUM CONCENTRATION IN ROAD SURFACE RUNOFF DUE TO VARIOUS RAINFALL DURATIONS--75TH PERCENTILE LEVELS[a] (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	1.51	0.26	0.75	6.99 E-2	0.75	6.99 E-2	0.75	8.69 E-2
10	0.94	0.17	0.47	4.46 E-2	0.47	4.46 E-2	0.47	5.54 E-2
30	0.63	0.08	0.31	2.22 E-2	0.31	2.22 E-2	0.31	2.77 E-2
120	0.43	0.04	0.21	1.18 E-2	0.21	1.18 E-2	0.21	1.47 E-2

[a] The 75th percentile level for cadmium in wast eoil is 1.3 mg/liter.

TABLE B-26. CHROMIUM CONCENTRATION IN ROAD SURFACE RUNOFF DUE TO VARIOUS RAINFALL DURATIONS--75TH PERCENTILE LEVELS[a] (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	13.91	2.41	6.95	0.65	6.95	0.65	6.95	0.80
10	8.69	1.53	4.35	0.41	4.35	0.41	4.35	0.51
30	5.80	0.77	2.90	0.21	2.90	0.21	2.90	0.26
120	3.95	0.41	1.98	0.11	1.98	0.11	1.98	0.14

[a] The 75th percentile level for chromium in waste oil is 12 mg/liter.

TABLE B-27. LEAD CONCENTRATION IN ROAD SURFACE RUNOFF DUE TO VARIOUS RAINFALL DURATIONS--75TH PERCENTILE LEVELS[a] (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	486.80	84.25	243.40	22.59	243.40	22.59	243.40	28.08
10	304.25	53.69	152.13	14.40	152.13	14.40	152.13	17.90
30	202.83	26.85	101.42	7.20	101.42	7.20	101.42	8.95
120	138.30	14.26	69.15	3.82	69.15	3.82	69.15	4.75

[a] The 75th percentile level for lead in waste oil is 420 mg/liter.

TABLE B-28. ZINC CONCENTRATION IN ROAD SURFACE RUNOFF DUE TO VARIOUS RAINFALL DURATIONS--75TH PERCENTILE LEVELS[a] (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	1,031.56	178.54	515.78	47.87	515.78	47.87	515.78	59.51
10	644.72	113.77	322.36	30.50	322.36	30.50	322.36	37.92
30	429.82	56.89	214.91	15.25	214.91	15.25	214.91	18.96
120	293.06	30.22	146.53	8.10	146.53	8.10	146.53	10.07

[a] The 75th percentile level for zinc in waste oil is 890 mg/liter.

TABLE B-29. DICHLORODIFLUOROMETHANE CONCENTRATION IN ROAD SURFACE RUNOFF DUE TO VARIOUS RAINFALL DURATIONS--75TH PERCENTILE LEVELS[a] (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	243.40	42.13	121.70	11.29	121.70	11.29	121.70	14.04
10	152.13	26.85	76.06	7.20	76.06	7.20	76.06	8.95
30	101.42	13.42	50.71	3.60	50.71	3.60	50.71	4.47
120	69.15	7.13	34.57	1.91	34.57	1.91	34.57	2.38

[a] The 75th percentile level for dichlorodifluoromethane in waste oil is 210 mg/liter.

TABLE B-30. TRICHLOROTRIFLUOROETHANE CONCENTRATION IN ROAD SURFACE RUNOFF DUE TO VARIOUS RAINFALL DURATIONS--75TH PERCENTILE LEVELS[a] (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	38.25	6.62	19.12	1.77	19.12	1.77	19.12	2.21
10	23.91	4.22	11.95	1.13	11.95	1.13	11.95	1.41
30	15.94	2.11	7.97	0.57	7.97	0.57	7.97	0.70
120	10.87	1.12	5.43	0.30	5.43	0.30	5.43	0.37

[a] The 75th percentile level for trichlorotrifluoroethane in waste is 33 mg/liter.

TABLE B-31. TRICHLOROETHANE CONCENTRATION IN ROAD SURFACE RUNOFF DUE TO VARIOUS RAINFALL DURATIONS--75TH PERCENTILE LEVELS[a] (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	683.84	118.36	341.92	31.73	341.92	31.73	341.92	39.45
10	427.40	75.42	213.70	20.22	213.70	20.22	213.70	25.14
30	284.93	37.71	142.47	10.11	142.47	10.11	142.47	12.57
120	194.27	20.03	97.14	5.37	97.14	5.37	91.14	6.68

[a] The 75th percentile level for trichloroethane in waste oil is 590 mg/liter.

TABLE B-32. TRICHLOROETHYLENE CONCENTRATION IN ROAD SURFACE RUNOFF DUE TO VARIOUS RAINFALL DURATIONS--75TH PERCENTILE LEVELS[a] (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	567.94	98.30	283.97	26.35	283.97	26.35	283.97	32.77
10	354.96	62.64	177.48	16.79	177.48	16.79	177.48	20.88
30	236.64	31.32	118.32	8.40	118.32	8.40	118.32	10.44
120	161.35	16.64	80.67	4.46	80.67	4.46	80.67	5.55

[a] The 75th percentile level for trichloroethylene in waste oil is 490 mg/liter.

TABLE B-33. TETRACHLOROETHYLENE CONCENTRATION IN ROAD SURFACE RUNOFF DUE TO VARIOUS RAINFALL DURATIONS--75TH PERCENTILE LEVELS[a] (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	428.85	74.22	214.43	19.90	214.43	19.90	214.43	24.74
10	268.03	47.30	134.02	12.68	134.02	12.68	124.02	15.77
30	178.69	23.65	89.34	6.34	89.34	6.34	89.34	7.88
120	121.83	12.56	60.92	3.37	60.92	3.37	60.92	4.19

[a] The 75th percentile level for tetrachloroethylene in waste oil is 370 mg/liter.

TABLE B-34. BENZENE CONCENTRATION IN ROAD SURFACE RUNOFF DUE TO VARIOUS RAINFALL DURATIONS--75TH PERCENTILE LEVELS[a] (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	89.25	15.45	44.62	4.14	44.62	4.14	44.62	5.15
10	55.78	9.84	27.89	2.64	27.89	2.64	27.89	3.28
30	37.19	4.92	18.59	1.32	18.49	1.32	18.59	1.64
120	25.35	2.61	12.68	0.70	12.68	0.70	12.68	0.87

[a] The 75th percentile level for benzene in waste oil is 77 mg/liter.

TABLE B-35. TOLUENE CONCENTRATION IN ROAD SURFACE RUNOFF DUE TO VARIOUS RAINFALL DURATIONS--75TH PERCENTILE LEVELS[a] (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	567.94	98.30	283.97	26.35	283.97	26.35	283.97	32.77
10	354.96	62.64	177.48	16.79	117.48	16.79	177.48	20.88
30	236.64	31.32	118.32	8.40	118.32	8.40	118.32	10.44
120	161.35	16.64	80.67	4.46	80.67	4.46	80.67	5.55

[a] The 75th percentile level for toluene in waste oil is 490 mg/liter.

TABLE B-36. XYLENE CONCENTRATION IN ROAD SURFACE RUNOFF DUE TO VARIOUS RAINFALL DURATIONS--75TH PERCENTILE LEVELS[a] (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	312.94	54.16	156.47	14.52	156.47	14.52	156.47	18.08
10	195.59	34.52	97.80	9.25	97.80	9.25	97.80	11.51
30	130.39	17.26	66.20	4.63	65.20	4.63	65.20	5.75
120	88.90	9.17	44.45	2.46	44.45	2.46	44.45	3.06

[a] The 75th percentile level for xylene in waste oil is 270 mg/liter.

TABLE B-37. BENZ(A)ANTHRACENE CONCENTRATION IN ROAD SURFACE RUNOFF DUE TO VARIOUS RAINFALL DURATIONS--75TH PERCENTILE LEVELS[a] (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	30.14	5.22	15.07	1.40	15.07	1.40	15.07	1.74
10	18.83	3.32	9.42	0.89	9.42	0.89	9.42	1.11
30	12.56	1.66	6.28	0.45	6.28	0.45	6.28	0.55
120	8.56	0.88	4.28	0.24	4.28	0.24	4.28	0.29

[a] The 75th percentile level for benzo(a)anthracene in waste oil is 26 mg/liter.

TABLE B-38. BENZO(A)PYRENE CONCENTRATION IN ROAD SURFACE RUNOFF DUE TO VARIOUS RAINFALL DURATIONS--75TH PERCENTILE LEVELS[a] (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	13.91	2.41	6.95	0.65	6.95	0.65	6.95	0.80
10	8.69	1.53	4.35	0.41	4.35	0.41	4.35	0.51
30	5.80	0.77	2.90	0.21	2.90	0.21	2.90	0.26
120	3.95	0.41	1.98	0.11	1.98	0.11	1.98	0.14

[a] The 75th percentile level for benzo(a)pyrene in waste oil is 12 mg/liter.

TABLE B-39. NAPHTHALENE CONCENTRATION IN ROAD SURFACE RUNOFF DUE TO VARIOUS RAINFALL DURATIONS--75TH PERCENTILE LEVELS[a] (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	567.94	98.30	283.97	26.35	283.97	26.35	283.97	32.77
10	354.96	62.64	177.48	16.79	177.48	16.79	177.48	20.88
30	236.64	31.32	118.32	8.40	118.32	8.40	118.32	10.44
120	161.35	16.64	80.67	4.46	80.67	4.46	80.67	5.55

[a] The 75th percentile level for naphthalene in waste oil is 490 mg/liter.

TABLE B-40. PCB'S CONCENTRATION IN ROAD SURFACE RUNOFF DUE TO VARIOUS RAINFALL DURATIONS--75TH PERCENTILE LEVELS[a] (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	47.52	8.22	23.76	2.21	23.76	2.21	23.76	2.21
10	29.70	5.24	14.85	1.41	14.85	1.41	14.85	1.75
30	19.80	2.62	9.90	0.70	9.90	0.70	9.90	0.87
120	13.50	1.39	6.75	0.37	6.75	0.37	6.75	0.46

[a] The 75th percentile level for PCB's in waste oil is 41 mg/liter.

may be calculated by multiplying by the fraction of oil removal expected at a particular site. Concentrations that occur as a result of 90th and 75th percentile level contaminations are presented in Tables B-41 through B-76. The 90th percentile data are shown in Tables B-41 through B-58 and the 75th percentile data are shown in Tables B-59 through B-76.

Calculations of the high and low values in Tables B-41 through B-76 were based on the high and low road surface concentrations in Tables B-5 through B-40. Thus the high stream concentrations assume the highest application rate in the range of rates (Table 3-9), and the lowest of the heavy rainfall intensities (Table 3-11). The low stream concentrations assume the lowest application rate in the range of rates (Table 3-9) and the highest of the heavy rainfall intensities (Table 3-11). Both cases assume the stream was dry at the time the rain washed off the road. In both cases it was also assumed that the rain lasted for only the period shown. For example, in the 5-minute case, 100 percent of the oil applied to the road is diluted by the rainfall that strikes the roadway during the 5-minute period and 35 percent of the rain that falls on 320 acres during the same 5-minute period.

TABLE B-41. WORST-CASE STREAM CONCENTRATIONS OF ARSENIC AT VARIOUS RAINFALL INTENSITIES[a,b]--90TH PERCENTILE LEVELS (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	0.36	0.06	0.18	1.68 E-2	0.18	1.68 E-2	0.18	2.08 E-2
10	0.23	0.04	0.11	1.07 E-2	0.11	1.07 E-2	0.11	1.33 E-2
30	0.15	0.02	0.08	5.34 E-3	0.08	5.43 E-3	0.08	6.64 E-3
120	0.10	0.10	0.05	2.84 E-3	0.05	2.84 E-3	0.05	3.53 E-3

[a] Assumes roads are placed at one-mile intervals; waterhsed for each mile of oiled road is therefore 0.5 square mile or 320 acres.

[b] Based on road surface concentrations (Table B-5).

TABLE B-42. WORST-CASE STREAM CONCENTRATIONS OF BARIUM AT VARIOUS RAINFALL INTENSITIES[a,b]--90TH PERCENTILE LEVELS (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	10.95	1.90	5.48	0.51	5.48	0.51	5.48	0.63
10	6.84	1.21	3.42	0.32	3.42	0.32	3.42	0.40
30	4.56	0.60	2.28	0.16	2.28	0.16	2.28	0.20
120	3.11	0.32	1.56	0.89	1.56	0.89	1.56	0.11

[a] Assumes roads are placed at one-mile intervals; watershed for each mile of oiled road is therefore 0.5 square mile or 320 acres.

[b] Based on road surface concentrations (Table B-6).

TABLE B-43. WORST-CASE STREAM CONCENTRATIONS OF CADMIUM AT VARIOUS RAINFALL INTENSITIES[a,b]--90TH PERCENTILE LEVELS (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	0.09	1.56 E-2	0.05	4.19 E-3	0.05	4.19 E-3	0.05	5.12 E-3
10	0.06	9.96 E-3	0.03	2.67 E-3	0.03	2.67 E-3	0.03	3.32 E-3
30	0.04	4.98 E-3	0.02	1.34 E-3	0.02	1.34 E-3	0.02	1.66 E-3
120	0.03	2.65 E-3	0.01	7.09 E-4	0.01	7.09 E-4	0.03	8.82 E-4

[a] Assumes roads are placed at one-mile intervals; waterhsed for each mile of oiled road is therefore 0.5 square mile or 320 acres.

[b] Based on road surface concentrations (Table B-7).

TABLE B-44. WORST-CASE STREAM CONCENTRATIONS OF CHROMIUM AT VARIOUS RAINFALL INTENSITIES[a,b]--90TH PERCENTILE LEVELS (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	0.63	1.09 E-1	0.32	2.93 E-2	0.32	2.93 E-2	0.32	3.65 E-2
10	0.39	6.97 E-2	0.20	1.87 E-2	0.20	1.87 E-2	0.20	2.32 E-2
30	0.26	3.49 E-2	0.13	9.35 E-3	0.13	9.35 E-3	0.13	1.16 E-2
120	0.18	1.85 E-2	0.09	4.97 E-3	0.09	4.97 E-3	0.09	6.17 E-3

[a] Assumes roads are placed at one-mile intervals; waterhsed for each mile of oiled road is therefore 0.5 square mile or 320 acres.

[b] Based on road surface concentrations (Table B-8).

TABLE B-45. WORST-CASE STREAM CONCENTRATIONS OF LEAD AT VARIOUS RAINFALL INTENSITIES[a,b]--90TH PERCENTILE LEVELS (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	22.58	3.91	11.29	1.05	11.29	1.05	11.29	1.30
10	14.11	2.49	7.06	0.67	7.06	0.67	7.06	0.83
30	9.41	1.25	4.70	0.33	4.70	0.33	4.70	0.42
120	6.41	0.66	3.21	0.18	3.21	0.18	3.21	0.22

[a] Assumes roads are placed at one-mile intervals; watershed for each mile of oiled road is therefore 0.5 square mile or 320 acres.

[b] Based on road surface concentrations (Table B-9).

TABLE B-46. WORST-CASE STREAM CONCENTRATIONS OF ZINC AT VARIOUS RAINFALL INTENSITIES[a,b]--90TH PERCENTILE LEVELS (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	25.97	4.49	12.98	1.20	12.98	1.20	12.98	1.20
10	16.23	2.86	8.11	0.77	8.11	0.77	8.11	0.95
30	10.82	1.43	5.41	0.38	5.41	0.38	5.41	0.48
120	7.38	0.76	3.69	0.20	3.69	0.20	3.69	0.25

[a] Assumes roads are placed at one-mile intervals; watershed for each mile of oiled road is therefore 0.5 square mile or 320 acres.

[b] Based on road surface concentrations (Table B-10).

TABLE B-47. WORST-CASE STREAM CONCENTRATIONS OF DICHLORODIFLUOROMETHANE AT VARIOUS RAINFALL INTENSITIES[a,b]--90TH PERCENTILE LEVELS (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	19.42	3.36	9.71	0.90	9.71	0.90	9.71	1.12
10	12.14	2.14	6.07	0.57	6.07	0.57	6.07	0.71
30	8.09	1.07	4.05	0.29	4.05	0.29	4.05	0.36
120	5.52	0.57	2.76	0.15	2.76	0.15	2.76	0.19

[a] Assumes roads are placed at one-mile intervals; watershed for each mile of oiled road is therefore 0.5 square mile or 320 acres.

[b] Based on road surface concentrations (Table B-11).

TABLE B-48. WORST-CASE STREAM CONCENTRATIONS OF TRICHLOROTRIFLUOROETHANE AT VARIOUS RAINFALL INTENSITIES[a,b]--90TH PERCENTILE LEVELS (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	2.93	0.51	1.47	1.36 E-1	1.47	1.36 E-1	1.47	1.69 E-1
10	1.83	0.32	0.92	8.68 E-2	0.92	8.68 E-2	0.92	1.08 E-1
30	1.22	0.16	0.61	4.34 E-2	0.61	4.34 E-2	0.61	5.40 E-2
120	0.83	0.09	0.42	2.31 E-2	0.42	2.31 E-2	0.42	2.87 E-2

[a] Assumes roads are placed at one-mile intervals; waterhsed for each mile of oiled road is therefore 0.5 square mile or 320 acres.

[b] Based on road surface concentrations (Table B-12).

TABLE B-49. WORST-CASE STREAM CONCENTRATIONS OF TRICHLOROETHANE AT VARIOUS RAINFALL INTENSITIES[a,b]--90TH PERCENTILE LEVELS (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	29.35	5.08	14.68	1.36	14.68	1.36	14.68	1.69
10	18.35	3.24	9.17	0.87	9.17	0.87	9.17	1.08
30	12.23	1.62	6.12	0.43	6.12	0.43	6.12	0.54
120	8.34	0.86	4.17	0.23	4.17	0.23	4.17	0.29

[a] Assumes roads are placed at one-mile intervals; watershed for each mile of oiled road is therefore 0.5 square mile or 320 acres.

[b] Based on road surface concentrations (Table B-13).

TABLE B-50. WORST-CASE STREAM CONCENTRATIONS OF TRICHLOROETHYLENE AT VARIOUS RAINFALL INTENSITIES[a,b]--90TH PERCENTILE LEVELS (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	23.69	4.10	11.84	1.10	11.84	1.10	11.84	1.37
10	14.80	2.61	7.40	0.70	7.40	0.70	7.40	0.87
30	9.87	1.31	4.93	0.35	4.93	0.35	4.93	0.44
120	6.73	0.69	3.36	0.19	3.36	0.19	3.36	0.23

[a] Assumes roads are placed at one-mile intervals; watershed for each mile of oiled road is therefore 0.5 square mile or 320 acres.

[b] Based on road surface concentrations (Table B-14).

TABLE B-51. WORST-CASE STREAM CONCENTRATIONS OF TETRACHLOROETHYLENE AT VARIOUS RAINFALL INTENSITIES[a,b]--90TH PERCENTILE LEVELS (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	27.09	4.69	13.55	1.26	13.55	1.26	13.55	1.56
10	16.93	2.99	8.47	0.80	8.47	0.80	8.47	1.00
30	11.29	1.49	5.64	0.40	5.64	0.40	5.64	0.50
120	7.70	0.79	3.85	0.21	3.85	0.21	3.85	0.26

[a] Assumes roads are placed at one-mile intervals; watershed for each mile of oiled road is therefore 0.5 square mile or 320 acres.

[b] Based on road surface concentrations (Table B-15).

TABLE B-52. WORST-CASE STREAM CONCENTRATIONS OF BENZENE AT VARIOUS RAINFALL INTENSITIES[a,b]--90TH PERCENTILE LEVELS (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	3.61	0.63	1.81	1.67 E-1	1.81	1.67 E-1	1.81	2.08 E-1
10	2.26	0.40	1.13	1.07 E-1	1.13	1.07 E-1	1.13	1.33 E-1
30	1.51	0.20	0.75	5.34 E-2	0.75	5.34 E-2	0.75	6.64 E-2
120	1.03	0.11	0.51	2.84 E-2	0.51	2.84 E-2	0.51	3.53 E-2

[a] Assumes roads are placed at one-mile intervals; watershed for each mile of oiled road is therefore 0.5 square mile or 320 acres.

[b] Based on road surface concentrations (Table B-16).

TABLE B-53. WORST-CASE STREAM CONCENTRATIONS OF TOLUENE AT VARIOUS RAINFALL INTENSITIES[a,b]--90TH PERCENTILE LEVELS (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	27.09	4.69	13.55	1.26	13.55	1.26	13.55	1.56
10	16.93	2.99	8.47	0.80	8.47	0.80	8.47	1.00
30	11.29	1.49	5.64	0.40	5.64	0.40	5.64	0.50
120	7.70	0.79	3.85	0.21	3.85	0.21	3.85	0.26

[a] Assumes roads are placed at one-mile intervals; watershed for each mile of oiled road is therefore 0.5 square mile or 320 acres.

[b] Based on road surface concentrations (Table B-17).

TABLE B-54. WORST-CASE STREAM CONCENTRATIONS OF XYLENE AT VARIOUS RAINFALL INTENSITIES[a,b]--90TH PERCENTILE LEVELS (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	12.87	2.23	6.44	0.60	6.44	0.60	6.44	0.74
10	8.04	1.42	4.02	0.38	4.02	0.38	4.02	0.47
30	5.36	0.71	2.68	0.19	2.68	0.19	2.68	0.24
120	3.66	0.38	1.83	0.10	1.83	0.10	1.83	0.13

[a] Assumes roads are placed at one-mile intervals; watershed for each mile of oiled road is therefore 0.5 square mile or 320 acres.

[b] Based on road surface concentrations (Table B-18).

TABLE B-55. WORST-CASE STREAM CONCENTRATIONS OF BENZ(A)ANTHRACENE AT VARIOUS RAINFALL INTENSITIES[a,b]--90TH PERCENTILE LEVELS (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	0.79	1.37 E-1	0.39	3.67 E-2	0.39	3.67 E-7	0.39	4.56 E-2
10	0.49	8.71 E-2	0.25	2.33 E-2	0.25	2.33 E-2	0.25	2.90 E-2
30	0.33	4.36 E-2	0.16	1.12 E-2	0.16	1.12 E-2	0.16	1.45 E-2
120	0.22	2.31 E-2	0.11	0.62 E-2	0.11	0.62 E-2	0.11	0.77 E-2

[a] Assumes roads are placed at one-mile intervals; watershed for each mile of oiled road is therefore 0.5 square mile or 320 acres.

[b] Based on road surface concentrations (Table B-19).

TABLE B-56. WORST-CASE STREAM CONCENTRATIONS OF BENZO(A)PYRENE AT VARIOUS RAINFALL INTENSITIES[a,b]--90TH PERCENTILE LEVELS (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	0.75	0.13	0.37	3.46 E-2	0.37	3.46 E-2	0.37	4.30 E-2
10	0.47	0.08	0.23	2.20 E-2	0.23	2.20 E-2	0.23	2.74 E-2
30	0.31	0.04	0.16	1.10 E-2	0.16	1.10 E-2	0.16	1.37 E-2
120	0.21	0.02	0.11	5.85 E-3	0.11	5.85 E-3	0.11	0.73 E-2

[a] Assumes roads are placed at one-mile intervals; watershed for each mile of oiled road is therefore 0.5 square mile or 320 acres.

[b] Based on road surface concentrations (Table B-20).

TABLE B-57. WORST-CASE STREAM CONCENTRATIONS OF NAPHTHALENE AT VARIOUS RAINFALL INTENSITIES[a,b]--90TH PERCENTILE LEVELS (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	13.10	2.27	6.55	0.61	6.55	0.61	6.55	0.76
10	8.18	1.44	4.09	0.39	4.09	0.39	4.09	0.48
30	5.46	0.72	2.73	0.19	2.73	0.19	2.73	0.24
120	3.72	0.38	1.86	0.10	1.86	0.10	1.86	0.13

[a] Assumes roads are placed at one-mile intervals; watershed for each mile of oiled road is therefore 0.5 square mile or 320 acres.

[b] Based on road surface concentrations (Table B-21).

TABLE B-58. WORST-CASE CONCENTRATIONS OF PCB'S AT VARIOUS RAINFALL INTENSITIES[a,b]--90TH PERCENTILE LEVELS (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	1.13	0.20	0.56	5.24 E-2	0.56	5.24 E-2	0.56	6.51 E-2
10	0.71	0.12	0.35	3.34 E-2	0.35	3.34 E-2	0.35	4.15 E-2
30	0.47	0.06	0.24	1.67 E-2	0.24	1.67 E-2	0.24	2.08 E-2
120	0.32	0.03	0.16	0.89 E-2	0.16	0.89 E-2	0.16	1.10 E-2

[a] Assumes roads are placed at one-mile intervals; watershed for each mile of oiled road is therefore 0.5 square mile or 320 acres.

[b] Based on road surface concentrations (Table B-22).

TABLE B-59. WORST-CASE STREAM CONCENTRATIONS OF ARSENIC AT VARIOUS RAINFALL INTENSITIES[a,b]--75TH PERCENTILE LEVELS (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	0.32	5.47 E-2	0.16	1.47 E-2	0.16	1.47 E-2	0.16	1.82 E-2
10	0.20	3.49 E-2	0.10	9.35 E-3	0.10	9.35 E-3	0.10	1.16 E-2
30	0.13	1.74 E-2	0.07	4.67 E-3	0.07	4.67 E-3	0.07	5.81 E-3
120	0.09	9.26 E-2	0.04	2.48 E-3	0.04	2.48 E-3	0.04	3.09 E-3

[a] Assumes roads are placed at one-mile intervals; watershed for each mile of oiled road is therefore 0.5 square mile or 320 acres.

[b] Based on road surface concentrations (Table B-23).

TABLE B-60. WORST-CASE STREAM CONCENTRATIONS OF BARIUM AT VARIOUS RAINFALL INTENSITIES[a,b]--75TH PERCENTILE LEVELS (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	4.52	0.78	2.26	0.21	2.26	0.21	2.26	0.26
10	2.82	0.50	1.41	0.13	1.41	0.13	1.41	0.17
30	1.88	0.25	0.94	0.07	0.94	0.07	0.94	0.08
120	1.28	0.13	0.64	0.04	0.64	0.04	0.64	0.04

[a] Assumes roads are placed at one-mile intervals; watershed for each mile of oiled road is therefore 0.5 square mile or 320 acres.

[b] Based on road surface concentrations (Table B-24).

TABLE B-61. WORST-CASE STREAM CONCENTRATIONS OF CADMIUM AT VARIOUS RAINFALL INTENSITIES[a,b]--75TH PERCENTILE LEVELS (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	2.93 E-2	5.08 E-2	1.47 E-2	1.36 E-2	1.47 E-2	1.36 E-2	1.47 E-2	1.69 E-3
10	1.83 E-2	3.24 E-3	9.17 E-3	8.68 E-4	9.17 E-3	8.68 E-4	9.17 E-3	1.08 E-3
30	1.22 E-2	1.62 E-3	6.11 E-3	4.34 E-4	6.11 E-3	4.34 E-4	6.11 E-3	5.40 E-4
120	8.34 E-3	8.60 E-4	4.17 E-3	2.31 E-4	4.17 E-3	2.31 E-4	4.17 E-3	2.87 E-4

[a] Assumes roads are placed at one-mile intervals; watershed for each mile of oiled road is therefore 0.5 square mile or 320 acres.

[b] Based on road surface concentrations (Table B-25).

TABLE B-62. WORST-CASE STREAM CONCENTRATIONS OF CHROMIUM AT VARIOUS RAINFALL INTENSITIES[a,b]--75TH PERCENTILE LEVELS (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	0.27	4.69 E-2	0.14	1.26 E-2	0.14	1.26 E-2	0.14	1.56 E-2
10	0.17	2.99 E-2	0.08	8.01 E-3	0.08	8.01 E-3	0.08	9.96 E-3
30	0.11	1.49 E-2	0.06	4.01 E-3	0.06	4.01 E-3	0.06	4.98 E-3
120	0.08	7.94 E-3	0.04	2.13 E-3	0.04	2.13 E-3	0.04	2.64 E-3

[a] Assumes roads are placed at one-mile intervals; watershed for each mile of oiled road is therefore 0.5 square mile or 320 acres.

[b] Based on road surface concentrations (Table B-26).

TABLE B-63. WORST-CASE STREAM CONCENTRATIONS OF LEAD AT VARIOUS RAINFALL INTENSITIES[a,b]--75TH PERCENTILE LEVELS (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	9.48	1.64	4.74	0.44	4.74	0.44	4.74	0.55
10	5.93	1.05	2.96	0.28	2.96	0.28	2.96	0.35
30	3.95	0.52	1.98	0.14	1.98	0.14	1.98	0.17
120	2.69	0.28	1.35	0.07	1.35	0.07	1.35	0.09

[a] Assumes roads are placed at one-mile intervals; watershed for each mile of oiled road is therefore 0.5 square mile or 320 acres.

[b] Based on road surface concentrations (Table B-27).

TABLE B-64. WORST-CASE STREAM CONCENTRATIONS OF ZINC AT VARIOUS RAINFALL INTENSITIES[a,b]--75TH PERCENTILE LEVELS (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	20.10	3.48	10.05	0.93	10.05	0.93	10.05	1.16
10	12.56	2.22	6.28	0.59	6.28	0.59	6.28	0.74
30	8.37	1.11	4.19	0.30	4.19	0.30	4.19	0.37
120	5.71	0.59	2.85	0.16	2.85	0.16	2.85	0.20

[a] Assumes roads are placed at one-mile intervals; watershed for each mile of oiled road is therefore 0.5 square mile or 320 acres.

[b] Based on road surface concentrations (Table B-28).

TABLE B-65. WORST-CASE STREAM CONCENTRATIONS OF DICHLORODIFLUOROMETHANE AT VARIOUS RAINFALL INTENSITIES[a,b]--75TH PERCENTILE LEVELS (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	4.74	0.82	2.37	0.22	2.37	0.22	2.37	0.27
10	2.96	0.52	1.48	0.14	1.48	0.14	1.48	0.17
30	1.98	0.26	0.99	0.07	0.99	0.07	0.99	0.09
120	1.35	0.14	0.67	0.04	0.67	0.04	0.67	0.05

[a] Assumes roads are placed at one-mile intervals; watershed for each mile of oiled road is therefore 0.5 square mile or 320 acres.

[b] Based on road surface concentrations (Table B-29).

TABLE B-66. WORST-CASE STREAM CONCENTRATIONS OF TRICHLOROTRIFLUOROETHANE AT VARIOUS RAINFALL INTENSITIES[a,b]--75TH PERCENTILE LEVELS (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	0.75	0.13	0.37	3.46 E-2	0.37	3.46 E-2	0.37	4.20 E-2
10	0.47	0.08	0.23	2.20 E-2	0.23	2.20 E-2	0.23	2.74 E-2
30	0.31	0.04	0.16	1.10 E-2	0.16	1.10 E-2	0.16	1.37 E-2
120	0.21	0.02	0.11	5.85 E-3	0.11	5.85 E-3	0.11	7.28 E-3

[a] Assumes roads are placed at one-mile intervals; watershed for each mile of oiled road is therefore 0.5 square mile or 320 acres.

[b] Based on road surface concentrations (Table B-30).

TABLE B-67. WORST-CASE STREAM CONCENTRATIONS OF TRICHLOROETHANE AT VARIOUS RAINFALL INTENSITIES[a,b]--75TH PERCENTILE LEVELS (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	13.32	2.31	6.66	0.62	6.66	0.62	6.66	0.77
10	8.33	1.47	4.16	0.39	4.16	0.39	4.16	0.49
30	5.55	0.73	2.78	0.20	2.78	0.20	2.78	0.24
120	3.78	0.39	1.89	0.10	1.89	0.10	1.89	0.13

[a] Assumes roads are placed at one-mile intervals; watershed for each mile of oiled road is therefore 0.5 square mile or 320 acres.

[b] Based on road surface concentrations (Table B-31).

TABLE B-68. WORST-CASE STREAM CONCENTRATIONS OF TRICHLOROETHYLENE AT VARIOUS RAINFALL INTENSITIES[a,b]--75TH PERCENTILE LEVELS (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	11.06	1.91	5.53	0.51	5.53	0.51	5.53	0.64
10	6.91	1.22	3.46	0.33	3.46	0.33	3.46	0.41
30	4.61	0.61	2.30	0.16	2.30	0.16	2.30	0.20
120	3.14	0.32	1.57	0.09	1.57	0.89	1.57	0.11

[a] Assumes roads are placed at one-mile intervals; watershed for each mile of oiled road is therefore 0.5 square mile or 320 acres.

[b] Based on road surface concentrations (Table B-32).

TABLE B-69. WORST-CASE STREAM CONCENTRATIONS OF TETRACHLOROETHLYENE AT VARIOUS RAINFALL INTENSITIES[a,b]--75TH PERCENTILE LEVELS (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	8.35	1.45	4.18	0.39	4.18	0.39	4.18	0.48
10	5.22	0.92	2.61	0.25	2.61	0.25	2.61	0.31
30	3.48	0.46	1.74	0.12	1.74	0.12	1.74	0.15
120	2.37	0.24	1.19	0.07	1.19	0.07	1.19	0.08

[a] Assumes roads are placed at one-mile intervals; watershed for each mile of oiled road is therefore 0.5 square mile or 320 acres.

[b] Based on raod surface concentrations (Table B-33).

TABLE B-70. WORST-CASE STREAM CONCENTRATIONS OF BENZENE AT VARIOUS RAINFALL INTENSITIES[a,b]--75TH PERCENTILE LEVELS (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	1.74	0.39	0.87	0.08	0.87	0.08	0.87	0.10
10	1.09	0.19	0.54	0.05	0.54	0.05	0.54	0.06
30	0.72	0.10	0.36	0.03	0.36	0.03	0.36	0.03
120	0.49	0.05	0.25	0.01	0.25	0.01	0.25	0.02

[a] Assumes roads are placed at one-mile intervals; watershed for each mile of oiled road is therefore 0.5 square mile or 320 acres.

[b] Based on road surface concentrations (Table B-34).

TABLE B-71. WORST-CASE STREAM CONCENTRATIONS OF TOLUENE AT VARIOUS RAINFALL INTENSITIES[a,b]--75TH PERCENTILE LEVELS (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	11.06	1.91	5.53	0.51	5.53	0.51	5.53	0.64
10	6.91	1.22	3.46	0.33	3.46	0.33	3.46	0.41
30	4.61	0.61	2.30	0.16	2.30	0.16	2.30	0.20
120	3.14	0.32	1.57	0.09	1.57	0.09	1.57	0.11

[a] Assumes roads are placed at one-mile intervals; watershed for each mile of oiled road is therefore 0.5 square mile or 320 acres.

[b] Based on road surface concentrations (Table B-35).

TABLE B-72. WORST-CASE STREAM CONCENTRATIONS OF XYLENE AT VARIOUS RAINFALL INTENSITIES[a,b]--75TH PERCENTILE LEVELS (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	6.10	1.06	3.05	0.28	3.05	0.28	3.05	0.35
10	3.81	0.67	1.91	0.18	1.91	0.18	1.91	0.22
30	2.54	0.34	1.27	0.09	1.27	0.09	1.27	0.11
120	1.73	0.18	0.87	0.05	0.87	0.05	0.87	0.06

[a] Assumes roads are placed at one-mile intervals; watershed for each mile of oiled road is therefore 0.5 square mile or 320 acres.

[b] Based on road surface concentrations (Table B-36).

TABLE B-73. WORST-CASE STREAM CONCENTRATIONS OF BENZ(A)ANTHRACENE AT VARIOUS RAINFALL INTENSITIES[a,b]--75TH PERCENTILE LEVELS (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	0.59	0.10	0.29	2.72 E-2	0.29	2.72 E-2	0.29	3.39 E-2
10	0.37	0.06	0.18	1.74 E-2	0.18	1.74 E-2	0.18	2.16 E-2
30	0.24	0.03	0.12	8.68 E-3	0.12	8.68 E-3	0.12	1.08 E-2
120	0.17	0.02	0.08	4.61 E-3	0.08	4.61 E-3	0.08	5.73 E-3

[a] Assumes roads are placed at one-mile intervals; watershed for each mile of oiled road is therefore 0.5 square mile or 320 acres.

[b] Based on road surface concentrations (Table B-37).

TABLE B-74. WORST-CASE STREAM CONCENTRATIONS OF BENZO(A)PYRENE AT VARIOUS RAINFALL INTENSITIES[a,b]--75TH PERCNETILE LEVELS (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	0.27	4.69 E-2	0.14	1.26 E-2	0.14	1.26 E-2	0.14	1.56 E-2
10	0.17	2.99 E-2	0.08	8.01 E-3	0.08	8.01 E-3	0.08	9.96 E-3
30	0.11	1.49 E-2	0.06	4.01 E-3	0.06	4.01 E-3	0.06	4.98 E-3
120	0.08	7.94 E-3	0.04	2.13 E-3	0.04	2.13 E-3	0.04	2.65 E-3

[a] Assumes roads are placed at one-mile intervals; watershed for ech mile of oiled road is therefore 0.5 square mile or 320 acres.

[b] Based on road surface concentrations (Table B-38).

TABLE B-75. WORST-CASE STREAM CONCENTRATIONS OF PCB'S AT VARIOUS RAINFALL INTENSITIES[a,b]--75TH PERCENTILE LEVELS (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	0.93	0.16	0.46	4.30 E-2	0.46	4.30 E-2	0.46	5.34 E-2
10	0.58	0.10	0.29	2.74 E-2	0.29	2.74 E-2	0.29	3.40 E-2
30	0.39	0.05	0.19	1.37 E-2	0.19	1.37 E-2	0.19	1.70 E-2
120	0.26	0.03	0.13	7.27 E-3	0.13	7.27 E-2	0.13	9.04 E-3

[a] Assumes roads are placed at one-mile intervals; watershed for each mile of oiled road is therefore 0.5 square mile or 320 acres.

[b] Based on road surface concentrations (Table B-40).

TABLE B-76. WORST-CASE STREAM CONCENTRATIONS OF NAPHTHALENE AT VARIOUS RAINFALL INTENSITIES[a,b]--75TH PERCENTILE LEVELS (mg/liter)

Rainfall duration, minutes	Sand		Silt		Clay		Gravel	
	High	Low	High	Low	High	Low	High	Low
5	11.06	1.91	5.53	0.51	5.53	0.51	5.53	0.64
10	6.91	1.22	3.46	0.33	3.46	0.33	3.46	0.41
30	4.61	0.61	2.30	0.16	2.30	0.16	2.30	0.20
120	3.14	0.32	1.57	0.09	1.57	0.09	1.57	0.11

[a] Assumes roads are placed at one-mile intervals; watershed for each mile of oiled road is therefore 0.5 square mile or 320 acres.

[b] Based on road surface concentrations (Table B-39).

REFERENCES FOR APPENDIX B

1. Eagleson, P. S. Dynamic Hydrology. 1970. pp. 331-345.

2. Lensley, R. K., M. A. Kohler, and J. L. H. Paulhus. Hydrology for Engineers. Third edition. McGraw Hill Book Co. 1982.

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APPENDIX C

SENSITIVITY ANALYSIS OF FACTORS AFFECTING CONTAMINATED DUST EMISSIONS

This appendix presents some of the basic equations used to develop predictions of contaminated dust emissions from roads treated with waste oil. The basic data for uncontrolled dust emissions, concentrations of contaminants in road surfaces, and contaminated dust emissions are also presented.

Subsurface Evaporation

The rate of subsurface evaporation of organics controls the concentration of contaminant remaining in the road surface. The equations used to predict subsurface evaporation rates are presented in Section 3 (Equations 8 through 10) as developed by Thibodeaux.[1] Much of the physical data necessary to solve these equations are available in the literature; in the case of air diffusion constants, however, actual values are available for only benzene, toluene, and xylene. Air diffusion constants for other organics are predicted (Equation C-1). These values are shown in Table C-1.

$$D_A = D_B \quad M_B/M_A \qquad \text{(C-1)}$$

where D_A = air diffusion constant for component A, cm^2/s

D_B = air diffusion constant for component B, cm^2/s

M_A = molecular weight of component A

M_B = molecular weight of component B

TABLE C-1

AIR DIFFUSION CONSTANTS*[1]
(cm^2/s)

Chlorinated solvents	
Dichlorodifluoromethane	(0.067)
Trichlorotrifluoroethane	(0.053)
Trichloroethane	(0.063)
Trichloroethylene	(0.064)
Tetrachloroethylene	(0.057)
Other organics	
Benzene	0.088
Toluene	0.076
Xylene	0.071
Naphthalene	(0.065)
PCB's	
Aroclor 1242	(0.046)
Aroclor 1248	(0.043)
Aroclor 1254	(0.040)
Aroclor 1260	(0.039)

*All values in parentheses were calculated based on Equation C-1.

Dust Emissions

The rate at which an unpaved road surface that has not been treated with a dust suppressant emits dust depends on environmental factors and road traffic (Equation C-2).[2] The environmental factors that affect dust emissions are the number of dry days per year and road silt content. To approximate the worst likely environmental conditions, 325 dry days per year[3] and a 12 percent road silt content[4] are used in the model.

$$E = 5.9 \frac{s}{12} \frac{S}{30} \left(\frac{W}{3}\right)^{0.7} \left(\frac{w}{4}\right)^{0.5} \frac{\Delta}{365} \frac{V}{R} 0.0118 \qquad \text{(C-2)}$$

E = dust emissions, g/m²-h

s = percent silt in road surface

S = average vehicle speed, mi/h

W = average vehicle weight, tons

w = average number of wheels per vehicle

Δ = dry days per year (<0.01 in.)

V = average number of vehicles per day

R = road width, m

Two traffic levels are considered: heavy and moderate. The values chosen to represent heavy traffic conditions are those that might be found on a rural public road leading to a sanitary landfill. Moderate traffic levels are also considered because they will occur more frequently than heavy traffic conditions.

TABLE C-2

FACTORS AFFECTING DUST EMISSIONS[4]

Factor	Traffic conditions	
	Heavy	Moderate
Percent silt (s)	12%	12%
Average vehicle speed (S)	40 mph	30 mph
Average vehicle weight (W)	22 tons	12 tons
Average number of wheels (w)	10	6
Average number of dry days per year (Δ)	325	325
Average number of vehicles per day (V)	300	200
Road width (R)	5.5 m	5.5 m

Emission rates have been calculated for roads treated with waste oil, based on the uncontrolled emission rates just

described. Emissions are assumed to be reduced 75 percent following waste oil application[2] and to increase linearly for 30 days (Tables C-3 and C-4), after which dust suppression is no longer effective (see Section 2).

TABLE C-3

PARTICULATE EMISSIONS FROM AN UNPAVED ROAD
TREATED WITH WASTE OIL
HEAVY TRAFFIC - WORST ENVIRONMENT*

Emission rate, g/m^2-h	Percent control	Day number
7.2	75.0	0
7.9	72.5	1
8.6	70.0	2
9.4	67.5	3
10.1	65.0	4
10.8	62.5	5
14.4	50.0	10
18.0	37.5	15
21.6	25.0	20
25.2	12.5	25
28.8	0	30

*Based on Equation C-2.

As a means of ensuring that the emission rates chosen do not exceed the quantity of soil contaminated by application of waste oil to road surfaces, a simple material balance has been prepared for the quantity of soil contaminated versus cumulative soil emissions for a 30-day period (Tables C-5 and C-6). Emissions do not exceed the quantity of contaminated soil during the 30-day modeling period. The most rapid loss of contaminated soil occurs on gravel roads and takes 37 days (Table C-7). Variations in days required for total emissions of contaminated soil are due to

TABLE C-4

PARTICULATE EMISSIONS FROM AN UNPAVED ROAD
TREATED WITH WASTE OIL
MODERATE TRAFFIC - WORST ENVIRONMENT*

Emission rate, g/m^2-h	Percent Control	Day number
1.8	75.0	0
2.0	72.5	1
2.2	70.0	2
2.4	67.5	3
2.6	65.0	4
2.7	62.5	5
3.6	50.0	10
4.6	37.5	15
5.5	25.0	20
6.4	12.5	25
7.3	0	30

* Based on equation C-2.

TABLE C-5

QUANTITY OF SOIL ON ROAD SURFACES
CONTAMINATED BY WASTE OIL APPLIED AS
A DUST SUPPRESSANT*
(g/m^2)

Soil type	Low	High
Sand	91,400	195,000
Clay/Sand	19,600	97,500
Gravel	17,200	61,000

* Calculated based upon depth of oil penetration (see Table 3-11) and soil density.

TABLE C-6

TOTAL SOIL EMITTED AS DUST PARTICLES
FROM UNPAVED ROADS TREATED WITH WASTE OIL

Day	Heavy traffic/worst environment			Moderate traffic/worst environment		
	Emission rate, g/m^2-h	Daily emissions, g/m^2	Cumulative emissions, g/m^2	Emission rate, g/m^2-h	Daily emissions, g/m^2	Cumulative emissions, g/m^2
1	7.2	172.8	172.8	1.8	43.2	43.2
2	7.9	190.1	362.9	2.0	47.6	90.8
3	8.6	207.4	570.3	2.2	52.0	142.8
4	9.4	224.6	794.9	2.3	56.4	199.2
5	10.1	241.9	1,036.8	2.5	60.7	259.9
6	10.8	259.2	1,296.0	2.7	65.2	325.1
7	11.5	276.5	1,572.5	2.9	69.6	394.7
8	12.2	293.8	1,866.3	3.1	73.9	468.6
9	13.0	311.0	2,177.3	3.3	78.3	546.9
10	13.7	328.3	2,505.6	3.4	82.7	629.6
11	14.4	345.6	2,851.2	3.6	87.1	716.7
12	15.1	362.9	3,214.1	3.8	91.5	808.2
13	15.8	380.2	3,594.3	4.0	95.9	904.1
14	16.6	397.4	3,991.7	4.2	100.3	1,004.4
15	17.3	414.7	4,406.4	4.4	104.7	1,109.1
16	18.0	432.0	4,838.4	4.5	109.1	1,218.2
17	18.7	449.3	5,287.7	4.7	113.5	1,331.7
18	19.4	466.6	5,754.3	4.9	117.9	1,449.6
19	20.2	483.8	6,238.1	5.1	122.3	1,571.9
20	20.9	501.1	6,739.2	5.3	126.6	1,698.5
21	21.6	518.4	7,257.6	5.5	131.0	1,829.5
22	22.3	535.7	7,793.3	5.6	135.4	1,964.9
23	23.0	553.0	8,346.3	5.8	139.8	2,104.7
24	23.8	570.2	8,916.5	6.0	144.2	2,248.9
25	24.5	587.5	9,504.0	6.2	148.6	2,397.5
26	25.2	604.8	10,108.8	6.4	153.0	2,550.5
27	25.9	622.1	10,730.9	6.6	157.4	2,707.9
28	26.6	639.4	11,370.3	6.7	161.8	2,869.7
29	27.4	656.6	12,026.9	6.9	166.2	3,035.9
30	28.1	673.9	12,700.9	7.1	170.6	3,206.5

the different rates of waste oil application to the different road surface types, not different emission rates.

TABLE C-7

DAYS REQUIRED FOR TOTAL EMISSIONS OF SOIL CONTAMINATED BY WASTE OIL AS DUST PARTICLES*

	Heavy traffic/ worst environment		Moderate traffic/ worst environment	
Soil type	Low	High	Low	High
Sand	147	301	547	1,154
Clay/sand	40	156	126	583
Gravel	37	102	112	369

*Calculated assuming no particulate control following day 30 and that only contaminated soil is being emitted to the given day of depletion.

Contaminant Concentration in Road Surfaces

Levels of contamination are calculated based on concentration in oil, application rate, and depth of oil penetration into the road surface. Metals concentrations remain constant over time (Table C-8) but organics concentrations drop due to evaporation (Tables C-9 through C-20).

Contaminated Dust Emissions

Emission levels of contaminated dust have been calculated based on contaminant concentration in road surfaces and dust emission rates (Tables C-21 through C-58). The predicted emissions may be adjusted for a particular location by adjusting the dust emission rates (Equation C-2 and Tables C-2 through C-4) and multiplying by the contamination levels (Tables C-8 through C-20).

TABLE C-8

CONCENTRATION OF METALS IN ROAD SOIL AS A RESULT OF CONTAMINATION BY WASTE OIL USED TO SUPPRESS DUST*†
(10^{-6} g metal/g soil)

Metal	Sand		Clay/Sand		Gravel	
	Low	High	Low	High	Low	High
Arsenic	0.23	0.65	0.12	1.48	0.25	1.69
Barium	6.87	19.53	3.68	45.51	7.31	51.86
Cadmium	0.06	0.16	0.03	0.38	0.06	0.43
Chromium	0.39	1.13	0.22	2.65	0.43	3.02
Lead	14.15	40.25	7.59	93.88	15.08	106.98
Zinc	16.28	46.30	8.73	107.96	17.34	123.02

* Calculated based upon metals concentration in oil, application rate, and depth of oil penetration into soil.

† Based on 90th percentile contamination values (Table I).

TABLE C-9

TRICHLOROETHANE CONCENTRATION
ON VARIOUS ROAD SURFACES*
(g contaminant/g soil)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	5.03 E-5	1.09 E-6	1.12 E-4	3.03 E-6	1.28 E-4	1.65 E-5
1	1.97 E-5	0	6.36 E-5	0	6.48 E-5	0
2	1.27 E-5	0	6.36 E-5	0	6.17 E-5	0
3	1.21 E-5	0	6.36 E-5	0	5.93 E-5	0
4	1.16 E-5	0	6.36 E-5	0	5.72 E-5	0
5	1.11 E-5	0	6.36 E-5	0	5.55 E-5	0
10	9.36 E-6	0	6.36 E-5	0	4.84 E-5	0
15	8.00 E-6	0	6.36 E-5	0	4.30 E-5	0
20	6.86 E-6	0	6.36 E-5	0	3.85 E-5	0
25	5.85 E-6	0	6.36 E-5	0	3.45 E-5	0
30	4.98 E-6	0	6.36 E-5	0	3.09 E-5	0

* Calculations based on an original trichloroethane concentration in waste oil of 1,300 mg/l. This represents the 90th percentile level (Table I).

TABLE C-10

TRICHLOROETHYLENE CONCENTRATION
ON VARIOUS ROAD SURFACES*
(g contaminant/g soil)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	4.14 E-5	9.40 E-6	9.46 E-5	2.43 E-8	1.08 E-4	8.44 E-6
1	2.16 E-5	0	5.87 E-5	0	5.04 E-5	0
2	1.34 E-5	0	5.86 E-5	0	5.04 E-5	0
3	8.64 E-6	0	5.85 E-5	0	5.04 E-5	0
4	5.69 E-6	0	5.84 E-5	0	5.04 E-5	0
5	3.10 E-6	0	5.83 E-5	0	5.04 E-5	0
10	0	0	5.81 E-5	0	5.04 E-5	0
15	0	0	5.78 E-5	0	5.04 E-5	0
20	0	0	5.77 E-5	0	5.04 E-5	0
25	0	0	5.75 E-5	0	5.04 E-5	0
30	0	0	5.74 E-5	0	5.04 E-5	0

* Calculations based on an original trichlorothylene concentration in waste oil of 1,049 mg/l. This represents the 90th percentile level (Table I).

TABLE C-11

TETRACHLOROETHYLENE CONCENTRATION
ON VARIOUS ROAD SURFACES*
(g contaminant/g soil)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	4.81 E-5	1.50 E-5	1.11 E-4	5.05 E-6	1.27 E-4	1.16 E-5
1	3.73 E-5	2.52 E-6	6.42 E-5	0	6.85 E-5	0
2	3.28 E-5	0	5.26 E-5	0	5.11 E-5	0
3	2.93 E-5	0	4.36 E-5	0	3.89 E-5	0
4	2.64 E-5	0	3.61 E-5	0	2.87 E-5	0
5	2.39 E-5	0	2.94 E-5	0	1.96 E-5	0
10	1.39 E-5	0	0	0	0	0
15	6.87 E-6	0	0	0	0	0
20	1.12 E-6	0	0	0	0	0
25	0	0	0	0	0	0
30	0	0	0	0	0	0

* Calculations based on an original tetrachloroethylene concentration in waste oil of 1,200 mg/l. This represents the 90th percentile level (Table I).

TABLE C-12

BENZENE CONCENTRATION
ON VARIOUS ROAD SURFACES*
(g contaminant/g soil)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	6.42 E-6	2.07 E-6	1.49 E-5	8.21 E-7	1.70 E-5	1.79 E-6
1	2.80 E-6	0	1.57 E-6	0	1.15 E-7	0
2	1.32 E-6	0	0	0	0	0
3	2.66 E-7	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
10	0	0	0	0	0	0
15	0	0	0	0	0	0
20	0	0	0	0	0	0
25	0	0	0	0	0	0
30	0	0	0	0	0	0

* Calculations based on an original benzene concentration in waste oil of 160 mg/l. This represents the 90th percentile level (Table I).

TABLE C-13

TOLUENE CONCENTRATION
ON VARIOUS ROAD SURFACES*
(g contaminant/g soil)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	4.79 E-5	1.36 E-5	1.11 E-4	2.24 E-6	1.26 E-4	7.13 E-6
1	3.32 E-5	0	6.14 E-5	0	5.73 E-5	0
2	2.72 E-5	0	5.44 E-5	0	4.41 E-5	0
3	2.25 E-5	0	4.90 E-5	0	3.39 E-5	0
4	1.86 E-5	0	4.44 E-5	0	2.54 E-5	0
5	1.51 E-5	0	4.04 E-5	0	1.78 E-5	0
10	3.58 E-6	0	2.46 E-5	0	0	0
15	0	0	1.25 E-5	0	0	0
20	0	0	2.31 E-6	0	0	0
25	0	0	0	0	0	0
30	0	0	0	0	0	0

* Calculations based on an original toluene concentration in waste oil of 1,200 mg/l. This represents the 90th percentile level (Table I).

TABLE C-14

XYLENE CONCENTRATION
ON VARIOUS ROAD SURFACES*
(g contaminant/g soil)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	2.29 E-5	7.64 E-6	5.32 E-5	3.48 E-6	6.06 E-5	7.25 E-6
1	1.93 E-5	3.28 E-6	3.65 E-5	0	4.10 E-5	0
2	1.78 E-5	1.48 E-6	3.01 E-5	0	3.28 E-5	0
3	1.67 E-5	8.93 E-8	2.57 E-5	0	2.71 E-5	0
4	1.57 E-5	0	2.21 E-5	0	2.27 E-5	0
5	1.48 E-5	0	1.89 E-5	0	1.87 E-5	0
10	1.15 E-5	0	6.29 E-6	0	3.25 E-6	0
15	8.92 E-6	0	0	0	0	0
20	6.76 E-6	0	0	0	0	0
25	4.86 E-6	0	0	0	0	0
30	3.14 E-6	0	0	0	0	0

* Calculations based on an original xylene concentration in waste oil of 570 mg/l. This represents the 90th percentile level (Table I).

TABLE C-15

NAPHTHALENE CONCENTRATION
ON VARIOUS ROAD SURFACES*
(g contaminant/g soil)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	2.33 E-5	8.21 E-6	5.44 E-5	4.40 E-6	6.20 E-5	8.75 E-6
1	2.29 E-5	7.68 E-6	5.25 E-5	2.38 E-6	5.97 E-5	6.37 E-6
2	2.28 E-5	7.46 E-6	5.16 E-5	1.54 E-6	5.87 E-5	5.39 E-6
3	2.26 E-5	7.29 E-6	5.10 E-5	9.00 E-7	5.80 E-5	4.64 E-6
4	2.25 E-5	7.15 E-6	5.05 E-5	3.59 E-7	5.73 E-5	4.00 E-6
5	2.24 E-5	7.02 E-6	5.00 E-5	0	5.70 E-5	3.44 E-6
10	2.20 E-5	6.53 E-6	4.82 E-5	0	5.47 E-5	1.24 E-6
15	2.17 E-5	6.16 E-6	4.68 E-5	0	5.30 E-5	0
20	2.15 E-5	5.84 E-6	4.56 E-5	0	5.16 E-5	0
25	2.12 E-5	5.56 E-6	4.46 E-5	0	5.04 E-5	0
30	2.10 E-5	5.31 E-6	4.36 E-5	0	4.93 E-5	0

* Calculations based on an original naphthalene concentration in waste oil of 580 mg/l. This represents the 90th percentile level (Table I).

TABLE C-16

AROCLOR 1242 CONCENTRATION
ON VARIOUS ROAD SURFACES*
(g contaminant/g soil)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	2.01 E-6	7.08 E-7	4.69 E-6	3.79 E-7	5.34 E-6	7.55 E-7
1	2.01 E-6	7.05 E-7	4.68 E-6	3.70 E-7	5.33 E-6	7.44 E-7
2	2.01 E-6	7.04 E-7	4.68 E-6	3.66 E-7	5.33 E-6	7.39 E-7
3	2.01 E-6	7.03 E-7	4.68 E-6	3.63 E-7	5.32 E-6	7.36 E-7
4	2.01 E-6	7.03 E-7	4.67 E-6	3.61 E-7	5.32 E-6	7.33 E-7
5	2.01 E-6	7.02 E-7	4.67 E-6	3.59 E-7	5.32 E-6	7.30 E-7
10	2.01 E-6	7.00 E-7	4.66 E-6	3.50 E-7	5.31 E-6	7.20 E-7
15	2.01 E-6	6.98 E-7	4.66 E-6	3.44 E-7	5.30 E-6	7.12 E-7
20	2.00 E-6	6.97 E-7	4.65 E-6	3.38 E-7	5.29 E-6	7.06 E-7
25	2.00 E-6	6.95 E-7	4.65 E-6	3.33 E-7	5.29 E-6	7.00 E-7
30	2.00 E-6	6.94 E-7	4.64 E-6	3.29 E-7	5.28 E-6	6.95 E-7

* Calculations based on an original Aroclor 1242 concentration in waste oil of 50 mg/l. This represents the 90th percentile level (Table I).

TABLE C-17

AROCLOR 1248 CONCENTRATION
ON VARIOUS ROAD SURFACES*
(g contaminant/g soil)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	2.01 E-6	7.08 E-7	4.69 E-6	3.79 E-7	5.34 E-6	7.55 E-7
1	2.01 E-6	7.05 E-7	4.68 E-6	3.69 E-7	5.33 E-6	7.43 E-7
2	2.01 E-6	7.04 E-7	4.68 E-6	3.65 E-7	5.33 E-6	7.38 E-7
3	2.01 E-6	7.03 E-7	4.68 E-6	3.62 E-7	5.32 E-6	7.35 E-7
4	2.01 E-6	7.02 E-7	4.67 E-6	3.60 E-7	5.32 E-6	7.31 E-7
5	2.01 E-6	7.02 E-7	4.67 E-6	3.57 E-7	5.32 E-6	7.29 E-7
10	2.01 E-6	7.00 E-7	4.66 E-6	3.48 E-7	5.31 E-6	7.18 E-7
15	2.01 E-6	6.98 E-7	4.65 E-6	3.41 E-7	5.30 E-6	7.09 E-7
20	2.00 E-6	6.96 E-7	4.65 E-6	3.35 E-7	5.29 E-6	7.02 E-7
25	2.00 E-6	6.95 E-7	4.64 E-6	3.30 E-7	5.29 E-6	6.96 E-7
30	2.00 E-6	6.93 E-7	4.64 E-6	3.25 E-7	5.28 E-6	6.91 E-7

* Calculations based on an original Aroclor 1248 concentration in waste oil of 50 mg/l. This represents the 90th percentile level (Table I).

TABLE C-18

AROCLOR 1254 CONCENTRATION
ON VARIOUS ROAD SURFACES*
(g contaminant/g soil)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	2.01 E-6	7.07 E-7	4.69 E-6	3.79 E-7	5.34 E-6	7.55 E-7
1	2.01 E-6	7.07 E-7	4.69 E-6	3.76 E-7	5.34 E-6	7.50 E-7
2	2.01 E-6	7.06 E-7	4.69 E-6	3.74 E-7	5.33 E-6	7.48 E-7
3	2.01 E-6	7.06 E-7	4.69 E-6	3.73 E-7	5.33 E-6	7.47 E-7
4	2.01 E-6	7.06 E-7	4.68 E-6	3.72 E-7	5.33 E-6	7.46 E-7
5	2.01 E-6	7.05 E-7	4.68 E-6	3.71 E-7	5.33 E-6	7.45 E-7
10	2.01 E-6	7.04 E-7	4.68 E-6	3.67 E-7	5.33 E-6	7.41 E-7
15	2.01 E-6	7.04 E-7	4.68 E-6	3.65 E-7	5.32 E-6	7.38 E-7
20	2.01 E-6	7.03 E-7	4.68 E-6	3.63 E-7	5.32 E-6	7.35 E-7
25	2.01 E-6	7.03 E-7	4.67 E-6	3.61 E-7	5.32 E-6	7.33 E-7
30	2.01 E-6	7.02 E-7	4.67 E-6	3.59 E-7	5.32 E-6	7.30 E-7

* Calculations based on an original Aroclor 1254 concentration in waste oil of 50 mg/l. This represents the 90th percentile level (Table I).

TABLE C-19

AROCLOR 1260 CONCENTRATION
ON VARIOUS ROAD SURFACES*
(g contaminant/g soil)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	2.01 E-6	7.08 E-7	4.69 E-6	3.79 E-7	5.34 E-6	7.56 E-7
1	2.01 E-6	7.07 E-7	4.69 E-6	3.77 E-7	5.34 E-6	7.52 E-7
2	2.01 E-6	7.07 E-7	4.69 E-6	3.76 E-7	5.34 E-6	7.50 E-7
3	2.01 E-6	7.06 E-7	4.69 E-6	3.75 E-7	5.34 E-6	7.49 E-7
4	2.01 E-6	7.06 E-7	4.69 E-6	3.74 E-7	5.34 E-6	7.48 E-7
5	2.01 E-6	7.06 E-7	4.69 E-6	3.73 E-7	5.33 E-6	7.48 E-7
10	2.01 E-6	7.05 E-7	4.68 E-6	3.71 E-7	5.33 E-6	7.45 E-7
15	2.01 E-6	7.05 E-7	4.68 E-6	3.69 E-7	5.33 E-6	7.42 E-7
20	2.01 E-6	7.04 E-7	4.68 E-6	3.67 E-7	5.33 E-6	7.41 E-7
25	2.01 E-6	7.04 E-7	4.68 E-6	3.66 E-7	5.33 E-6	7.39 E-7
30	2.01 E-6	7.04 E-7	4.68 E-6	3.65 E-7	5.33 E-6	7.37 E-7

* Calculations based on an original Aroclor 1260 concentration in waste oil of 50 mg/l. This represents the 90th percentile level (Table I).

TABLE C-20

RANGE OF CONTAMINANT CONCENTRATIONS ON ROAD SURFACES*
(g contaminant/g soil)

Day Number	0	1	2	3	4	5	10	15	20	25	30
Chlorinated Organics											
Trichloroethane											
High	1.28 E-4	6.48 E-5	6.36 E-5	6.36 E-5	6.36 E-5	6.36 E-5	6.36 E-5	6.36 E-5	6.36 E-5	6.36 E-5	6.36 E-5
Low	1.09 E-6	0	0	0	0	0	0	0	0	0	0
Trichloroethylene											
High	1.08 E-4	5.87 E-5	5.86 E-5	5.85 E-5	5.84 E-5	5.83 E-5	5.81 E-5	5.78 E-5	5.77 E-5	5.75 E-5	5.74 E-5
Low	2.43 E-8	0	0	0	0	0	0	0	0	0	0
Tetrachloroethylene											
High	1.27 E-4	6.85 E-5	5.26 E-5	4.36 E-5	3.61 E-5	2.94 E-5	1.39 E-5	6.87 E-5	1.12 E-6	0	0
Low	5.05 E-6	0	0	0	0	0	0	0	0	0	0
Other Organics											
Benzene											
High	1.70 E-5	2.80 E-6	1.32 E-6	2.66 E-7	0	0	0	0	0	0	0
Low	8.21 E-7	0	0	0	0	0	0	0	0	0	0
Toluene											
High	1.26 E-4	6.14 E-5	5.44 E-5	4.90 E-5	4.44 E-5	4.04 E-5	2.46 E-5	1.25 E-5	2.31 E-6	0	0
Low	2.24 E-6	0	0	0	0	0	0	0	0	0	0
Xylene											
High	6.06 E-5	4.10 E-5	3.28 E-5	2.71 E-5	2.27 E-5	1.89 E-5	1.15 E-5	8.92 E-6	6.76 E-6	4.86 E-6	3.14 E-6
Low	3.48 E-6	0	0	0	0	0	0	0	0	0	0
Naphthalene											
High	6.20 E-5	5.97 E-5	5.87 E-5	5.80 E-5	5.73 E-5	5.70 E-5	5.47 E-5	5.30 E-5	5.16 E-5	5.04 E-5	4.93 E-5
Low	4.40 E-6	2.38 E-6	1.54 E-6	9.00 E-7	3.59 E-7	0	0	0	0	0	0
PCB's											
Aroclor 1242											
High	5.34 E-6	5.33 E-6	5.33 E-6	5.32 E-6	5.32 E-6	5.32 E-6	5.31 E-6	5.30 E-6	5.29 E-6	5.29 E-6	5.28 E-6
Low	3.79 E-7	3.70 E-7	3.66 E-7	3.63 E-7	3.61 E-7	3.59 E-7	3.50 E-7	3.44 E-7	3.38 E-7	3.33 E-7	3.29 E-7
Aroclor 1248											
High	5.34 E-6	5.33 E-6	5.33 E-6	5.32 E-6	5.32 E-6	5.32 E-6	5.31 E-6	5.30 E-6	5.29 E-6	5.29 E-6	5.28 E-6
Low	3.79 E-7	3.69 E-7	3.65 E-7	3.62 E-7	3.60 E-7	3.57 E-7	3.48 E-7	3.41 E-7	3.35 E-7	3.30 E-7	3.25 E-7
Aroclor 1254											
High	5.34 E-6	5.34 E-6	5.33 E-6	5.33 E-6	5.33 E-6	5.33 E-6	5.33 E-6	5.32 E-6	5.32 E-6	5.32 E-6	5.32 E-6
Low	3.79 E-7	3.76 E-7	3.74 E-7	3.73 E-7	3.72 E-7	3.71 E-7	3.67 E-7	3.65 E-7	3.63 E-7	3.61 E-7	3.59 E-7
Aroclor 1260											
High	5.34 E-6	5.34 E-6	5.34 E-6	5.34 E-6	5.34 E-6	5.33 E-6	5.33 E-6	5.33 E-6	5.33 E-6	5.33 E-6	5.33 E-6
Low	3.79 E-7	3.77 E-7	3.76 E-7	3.75 E-7	3.74 E-7	3.73 E-7	3.71 E-7	3.69 E-7	3.67 E-7	3.66 E-7	3.65 E-7

* Summary of Tables C-9 through C-19.

TABLE C-21

ARSENIC EMISSIONS ON DUST PARTICLES
FROM VARIOUS ROAD SURFACES
DUE TO MODERATE TRAFFIC CONDITIONS*†
(10^{-6} g/m^2-h)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	1.2	0.4	2.8	0.2	3.2	0.4
1	1.3	0.5	3.0	0.3	3.5	0.5
2	1.4	0.5	3.3	0.3	3.8	0.5
3	1.5	0.5	3.6	0.3	4.1	0.6
4	1.7	0.6	3.9	0.3	4.4	0.6
5	1.8	0.6	4.2	0.3	4.7	0.7
10	2.4	0.8	5.5	0.5	6.3	0.9
15	3.0	1.0	6.9	0.6	7.9	1.1
20	3.6	1.3	8.3	0.7	9.5	1.3
25	4.2	1.5	9.7	0.8	11.0	1.6
30	4.7	1.7	11.1	0.9	12.6	1.8
Avg.	3.2	1.1	7.4	0.6	8.4	1.2

* Calculations based on an original arsenic concentration in waste oil of 16 mg/l. This represents the 90th percentile level (Table I).
† Based on dust emission factors from Table C-4.

TABLE C-22

BARIUM EMISSIONS ON DUST PARTICLES
FROM VARIOUS ROAD SURFACES
DUE TO MODERATE TRAFFIC CONDITIONS*†
(10^{-5} g/m^2-h)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	3.6	1.3	8.4	0.7	9.6	1.4
1	4.0	1.4	9.2	0.7	10.5	1.5
2	4.3	1.5	10.1	0.8	11.4	1.6
3	4.7	1.6	10.9	0.9	12.4	1.8
4	5.0	1.8	11.7	1.0	13.4	1.9
5	5.4	1.9	12.6	1.0	14.3	2.0
10	7.2	2.5	16.8	1.4	19.1	2.7
15	9.0	3.2	20.9	1.7	23.8	3.4
20	10.8	3.8	25.2	2.0	28.6	4.1
25	12.6	4.4	29.3	2.4	33.4	4.7
30	14.4	5.1	33.5	2.7	38.2	5.4
Avg.	9.6	3.4	22.3	1.8	25.4	3.6

* Calculations based on an original barium concentration in waste oil of 485 mg/l. This represents the 90th percentile level (Table I).

† Based on dust emission factors from Table C-4.

TABLE C-23

CADMIUM EMISSIONS ON DUST PARTICLES
FROM VARIOUS ROAD SURFACES
DUE TO MODERATE TRAFFIC CONDITIONS*†
(10^{-6} g/m^2-h)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	0.3	0.1	0.7	0.1	0.8	0.1
1	0.3	0.1	0.8	0.1	0.9	0.1
2	0.4	0.1	0.8	0.1	0.9	0.1
3	0.4	0.1	0.9	0.1	1.0	0.2
4	0.4	0.2	1.0	0.1	1.1	0.2
5	0.4	0.2	1.0	0.1	1.2	0.2
10	0.6	0.2	1.4	0.1	1.6	0.2
15	0.7	0.3	1.7	0.1	2.0	0.3
20	0.9	0.3	2.1	0.2	2.4	0.3
25	1.0	0.4	2.4	0.2	2.8	0.4
30	1.2	0.4	2.8	0.2	3.2	0.4
Avg.	0.1	0.3	1.8	0.1	2.1	0.3

* Calculations based on an original cadmium concentration in waste oil of 4 mg/l. This represents the 90th percentile level (Table I).

† Based on dust emission factors from Table C-4.

Source : Franklin Associates, Ltd.

TABLE C-24

CHROMIUM EMISSIONS ON DUST PARTICLES
FROM VARIOUS ROAD SURFACES
DUE TO MODERATE TRAFFIC CONDITIONS*†
(10^{-6} g/m^2-h)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	2.1	0.7	4.8	0.4	5.5	0.8
1	2.3	0.8	5.3	0.4	6.1	0.9
2	2.5	0.9	5.8	0.5	6.6	0.9
3	2.7	1.0	6.3	0.5	7.2	1.0
4	2.9	1.0	6.8	0.6	7.7	1.1
5	3.1	1.1	7.3	0.6	8.3	1.2
10	4.2	1.5	9.7	0.8	11.0	1.6
15	5.2	1.8	12.1	1.0	13.8	1.9
20	6.2	2.2	14.5	1.2	16.5	2.3
25	7.3	2.6	16.9	1.4	19.3	2.7
30	8.3	2.9	19.4	1.6	22.0	3.1
Avg.	5.5	1.9	12.9	1.1	14.7	2.0

* Calculations based on an original chromium concentration in waste oil of 28 mg/l. This represents the 90th percentile level (Table I).

† Based on dust emission factors from Table C-4.

TABLE C-25

LEAD EMISSIONS ON DUST PARTICLES
FROM VARIOUS ROAD SURFACES
DUE TO MODERATE TRAFFIC CONDITIONS*†
(10^{-5} g/m^2-h)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	7.2	2.5	16.9	1.4	19.3	2.7
1	8.1	2.8	18.8	1.5	21.4	3.0
2	8.9	3.1	20.7	1.7	23.5	3.3
3	9.7	3.4	22.5	1.8	25.7	3.6
4	10.5	3.7	24.4	2.0	27.8	3.9
5	10.9	3.8	25.3	2.1	28.9	4.1
10	14.5	5.1	33.8	2.7	38.5	5.4
15	18.5	6.5	43.2	3.5	49.2	6.9
20	22.1	7.8	51.6	4.2	58.8	8.3
25	25.8	9.1	60.1	4.9	68.5	9.7
30	29.4	10.3	68.5	5.5	78.1	11.0
Avg.	19.7	6.9	46.1	3.7	52.5	7.4

* Calculations based on an original lead concentration in waste oil of 1,000 mg/l. This represents the 90th percentile level (Table I).

† Based on dust emission factors from Table C-4.

TABLE C-26

ZINC EMISSIONS ON DUST PARTICLES
FROM VARIOUS ROAD SURFACES
DUE TO MODERATE TRAFFIC CONDITIONS*†
(10^{-4} g/m^2-h)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	0.9	0.3	2.0	0.2	2.3	0.3
1	0.9	0.3	2.2	0.2	2.5	0.4
2	1.0	0.4	2.4	0.2	2.7	0.4
3	1.1	0.4	2.6	0.2	2.9	0.4
4	1.2	0.4	2.8	0.2	3.2	0.5
5	1.3	0.5	3.0	0.2	3.4	0.5
10	1.7	0.6	4.0	0.3	4.5	0.6
15	2.1	0.8	5.0	0.4	5.6	0.8
20	2.6	0.9	6.0	0.5	6.8	1.0
25	3.0	1.1	7.0	0.6	7.9	1.1
30	3.4	1.2	8.0	0.6	9.1	1.3
Avg.	2.2	0.9	5.3	0.4	6.0	0.9

* Calculations based on an original zinc concentration in waste oil of 1,150 mg/l. This represents the 90th percentile level (Table I).

† Based on dust emission factors from Table C-4.

TABLE C-27

SUMMARY OF METAL EMISSIONS FROM ROADS DUE TO MODERATE TRAFFIC CONDITIONS*†
(g/m^2-h)

	Day										
	0	1	2	3	4	5	10	15	20	25	30
Arsenic											
Low	2.2 E-7	2.5 E-7	2.7 E-7	2.9 E-7	3.1 E-7	3.3 E-7	4.5 E-7	5.6 E-7	6.7 E-7	7.8 E-7	8.9 E-7
High	31.5 E-7	34.6 E-7	34.6 E-7	40.9 E-7	44.1 E-7	47.2 E-7	63.0 E-7	78.8 E-6	94.5 E-7	110.2 E-7	125.9 E-7
Barium											
Low	6.8 E-6	7.4 E-6	8.1 E-6	8.8 E-6	9.5 E-6	10.2 E-6	13.6 E-6	16.9 E-6	20.3 E-6	23.7 E-6	27.1 E-6
High	95.5 E-6	105.0 E-6	114.4 E-6	124.0 E-6	133.6 E-6	143.2 E-6	190.8 E-6	238.4 E-6	286.3 E-6	334.0 E-6	381.6 E-6
Cadmium											
Low	6.0 E-8	6.0 E-8	7.0 E-8	7.0 E-8	8.0 E-8	8.0 E-8	11.0 E-8	14.0 E-8	17.0 E-8	19.0 E-8	22.0 E-8
High	79.0 E-8	87.0 E-8	94.0 E-8	102.0 E-8	110.0 E-8	118.0 E-8	158.0 E-8	197.0 E-8	236.0 E-8	275.0 E-8	315.0 E-8
Chromium											
Low	3.9 E-7	4.3 E-7	4.7 E-7	5.1 E-7	5.5 E-7	5.9 E-7	7.8 E-7	9.8 E-7	11.7 E-7	13.7 E-7	15.7 E-7
High	55.1 E-7	60.6 E-7	66.1 E-7	71.6 E-7	77.1 E-7	82.7 E-7	110.1 E-7	137.6 E-7	165.3 E-7	192.8 E-7	220.3 E-7
Lead											
Low	1.4 E-5	1.5 E-5	1.7 E-5	1.8 E-5	2.0 E-5	2.1 E-5	2.7 E-5	3.5 E-5	4.2 E-5	4.9 E-5	5.5 E-5
High	19.3 E-5	21.4 E-5	23.5 E-5	25.7 E-5	27.8 E-5	28.9 E-5	38.5 E-5	49.2 E-5	58.8 E-5	68.5 E-5	78.1 E-5
Zinc											
Low	1.6 E-5	1.8 E-5	1.9 E-5	2.1 E-5	2.2 E-5	2.4 E-5	3.2 E-5	4.0 E-5	4.8 E-5	5.6 E-5	6.4 E-5
High	22.7 E-5	24.9 E-5	27.1 E-5	29.4 E-5	31.7 E-5	34.0 E-5	45.2 E-5	56.5 E-5	67.9 E-5	79.2 E-5	90.5 E-5

* Calculations based on 90th percentile contaminant levels in waste oil (Table I).
† Summary of tables C-21 through C-26.

TABLE C-28

ARSENIC EMISSIONS ON DUST PARTICLES
FROM VARIOUS ROAD SURFACES
DUE TO HEAVY TRAFFIC CONDITIONS* †
(10^{-6} g/m^2-h)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	4.6	1.6	10.7	0.9	12.2	1.7
1	5.0	1.8	11.8	1.0	13.4	1.9
2	5.5	1.9	12.8	1.0	14.6	2.1
3	6.0	2.1	13.9	1.1	15.8	2.2
4	6.4	2.3	15.0	1.2	17.0	2.4
5	6.9	2.4	16.0	1.3	18.2	2.6
10	9.2	3.2	21.4	1.7	24.3	3.4
15	11.5	4.0	26.7	2.2	30.4	4.3
20	13.8	4.8	32.1	2.6	36.5	5.2
25	16.0	5.6	37.4	3.0	42.6	6.0
30	18.3	6.4	42.7	3.5	48.6	6.9
Avg.	12.3	4.3	28.5	2.3	32.4	4.6

* Calculations based on an original arsenic concentration in waste oil of 16 mg/l. This represents the 90th percentile level (Table I).

† Based on dust emission factors from Table C-3.

TABLE C-29

BARIUM EMISSIONS ON DUST PARTICLES
FROM VARIOUS ROAD SURFACES
DUE TO HEAVY TRAFFIC CONDITIONS*†
(10^{-5} g/m^2-h)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	13.9	4.9	32.4	2.6	36.9	5.2
1	15.3	5.4	35.6	2.9	40.6	5.7
2	16.7	5.9	38.8	3.2	44.2	6.3
3	18.1	6.3	42.1	3.4	47.9	6.8
4	19.5	6.8	45.3	3.7	51.6	7.3
5	20.8	7.3	48.6	3.9	55.3	7.8
10	27.8	9.8	64.7	5.2	73.7	10.4
15	34.7	12.2	80.9	6.6	92.1	13.0
20	41.7	14.6	97.2	7.9	110.6	15.6
25	48.6	17.1	113.3	9.2	129.0	18.2
30	55.6	19.5	129.5	10.5	147.4	20.8
Avg.	37.0	13.0	86.3	7.0	98.3	13.9

* Calculations based on an original barium concentration in waste oil of 485 mg/l. This represents the 90th percentile level (Table I).

† Based on dust emission factors from Table C-3.

TABLE C-30

CADMIUM EMISSIONS ON DUST PARTICLES
FROM VARIOUS ROAD SURFACES
DUE TO HEAVY TRAFFIC CONDITIONS*†
(10^{-6} g/m^2-h)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	1.1	0.4	2.7	0.2	3.0	0.4
1	1.3	0.4	2.9	0.2	3.4	0.5
2	1.4	0.5	3.2	0.3	3.6	0.5
3	1.5	0.5	3.5	0.3	3.9	0.5
4	1.6	0.6	3.7	0.3	4.3	0.6
5	1.7	0.6	4.0	0.3	4.6	0.7
10	2.3	0.8	5.3	0.4	6.1	0.9
15	2.9	1.0	6.7	0.5	7.6	1.1
20	3.4	1.2	8.0	0.7	9.1	1.3
25	4.0	1.4	9.4	0.8	10.6	1.5
30	4.6	1.6	10.7	0.9	12.2	1.7
Avg.	3.1	1.1	7.1	0.5	8.1	1.2

* Calculations based on an original cadmium concentration in waste oil of 4 mg/l. This represents the 90th percentile level (Table I).

† Based on dust emission factors from Table C-3.

TABLE C-31

CHROMIUM EMISSIONS ON DUST PARTICLES
FROM VARIOUS ROAD SURFACES
DUE TO HEAVY TRAFFIC CONDITIONS*†
(10^{-6} g/m^2-h)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	8.0	2.8	18.7	1.5	21.3	3.0
1	8.8	3.1	20.5	1.7	23.4	3.3
2	9.6	3.4	22.4	1.8	25.5	3.6
3	10.4	3.7	24.3	2.0	27.7	3.9
4	11.2	3.9	26.2	2.1	29.8	4.2
5	12.0	4.2	28.0	2.3	31.9	4.5
10	16.0	5.6	37.4	3.0	42.6	6.0
15	20.0	7.0	46.7	3.8	53.2	7.5
20	24.1	8.5	56.1	4.5	63.9	9.0
25	28.1	9.9	65.4	5.3	74.5	10.5
30	32.1	11.3	74.8	6.1	85.1	12.0
Avg.	21.3	7.5	49.8	4.1	56.8	8.0

* Calculations based on an original chromium concentration in waste oil of 28 mg/l. This represents the 90th percentile level (Table I).

† Based on dust emission factors from Table C-3.

TABLE C-32

LEAD EMISSIONS ON DUST PARTICLES
FROM VARIOUS ROAD SURFACES
DUE TO HEAVY TRAFFIC CONDITIONS*†
(10^{-4} g/m^2-h)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	2.9	1.0	6.8	0.5	7.7	1.1
1	3.2	1.1	7.4	0.6	8.5	1.2
2	3.5	1.2	8.1	0.7	9.2	1.3
3	3.8	1.3	8.8	0.7	10.1	1.4
4	4.1	1.4	9.5	0.8	10.8	1.5
5	4.3	1.5	10.1	0.8	11.6	1.6
10	5.8	2.0	13.5	1.1	15.4	2.2
15	7.2	2.5	16.9	1.4	19.3	2.7
20	8.7	3.1	20.3	1.6	23.1	3.3
25	10.1	3.6	24.7	1.9	27.0	3.8
30	11.6	4.1	27.0	2.2	30.8	4.3
Avg.	7.7	2.7	18.0	1.5	20.6	2.9

* Calculations based on an original lead concentration in waste oil of 1,000 mg/l. This represents the 90th percentile level (Table I).

† Based on dust emission factors from Table C-3.

TABLE C-33

ZINC EMISSIONS ON DUST PARTICLES
FROM VARIOUS ROAD SURFACES
DUE TO HEAVY TRAFFIC CONDITIONS*†
(10^{-4} g/m^2-h)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	3.3	1.2	7.7	0.6	8.8	1.2
1	3.6	1.3	8.5	0.7	9.6	1.4
2	3.9	1.4	9.2	0.8	10.5	1.5
3	4.3	1.5	10.0	0.8	11.4	1.6
4	4.6	1.6	10.7	0.9	12.2	1.7
5	5.0	1.7	11.5	0.9	13.1	1.9
10	6.6	2.3	15.4	1.2	17.5	2.5
15	8.2	2.9	19.2	1.6	21.8	3.1
20	9.9	3.5	23.0	1.9	26.2	3.7
25	11.5	4.1	26.9	2.2	30.6	4.3
30	13.2	4.6	30.7	2.5	34.9	5.0
Avg.	8.7	3.1	20.5	1.7	23.3	3.3

* Calculations based on an original zinc concentration in waste oil of 1,150 mg/l. This represents the 90th percentile level (Table I).

† Based on dust emission factors from Table C-3.

TABLE C-34

SUMMARY OF METAL EMISSIONS FROM ROADS DUE TO HEAVY TRAFFIC CONDITIONS*†
(g/m^2-h)

	Day										
	0	1	2	3	4	5	10	15	20	25	30
Arsenic											
Low	8.7 E-7	9.5 E-7	1.0 E-6	1.1 E-6	1.2 E-6	1.3 E-6	1.7 E-6	2.2 E-6	2.6 E-6	3.0 E-6	3.5 E-6
High	121.7 E-7	133.8 E-7	13.4 E-6	15.8 E-6	17.0 E-6	18.2 E-6	24.3 E-6	30.4 E-6	36.5 E-6	42.6 E-6	48.6 E-6
Barium											
Low	2.6 E-5	2.9 E-5	3.2 E-5	3.4 E-5	3.7 E-5	3.9 E-5	5.2 E-5	6.6 E-5	7.7 E-5	9.2 E-5	1.0 E-4
High	36.9 E-5	40.6 E-5	44.2 E-5	47.9 E-5	51.6 E-5	55.3 E-5	73.7 E-5	92.1 E-5	110.6 E-5	129.0 E-5	14.7 E-4
Cadmium											
Low	2.2 E-7	2.4 E-7	2.6 E-7	2.9 E-7	3.1 E-7	3.2 E-7	4.3 E-7	5.4 E-7	6.5 E-7	7.5 E-7	8.7 E-7
High	30.4 E-7	33.5 E-7	36.4 E-7	39.4 E-7	42.5 E-7	45.6 E-7	60.9 E-7	76.0 E-7	91.3 E-7	106.4 E-7	121.6 E-7
Chromium											
Low	1.5 E-6	1.7 E-6	1.8 E-6	2.0 E-6	2.1 E-6	2.3 E-6	3.0 E-6	3.8 E-6	4.5 E-6	5.3 E-6	6.0 E-6
High	21.3 E-6	23.4 E-6	25.5 E-6	27.7 E-6	29.8 E-6	31.9 E-6	42.6 E-6	53.2 E-6	63.9 E-6	74.5 E-6	85.1 E-6
Lead											
Low	0.5 E-4	0.6 E-4	0.7 E-4	0.7 E-4	0.8 E-4	0.8 E-4	1.1 E-4	1.4 E-4	1.6 E-4	1.9 E-4	2.2 E-4
High	7.7 E-4	8.5 E-4	9.2 E-4	10.1 E-4	10.8 E-4	11.6 E-4	15.4 E-4	19.3 E-4	23.1 E-4	27.0 E-4	30.8 E-4
Zinc											
Low	6.3 E-5	7.0 E-5	7.5 E-5	8.2 E-5	8.7 E-5	9.4 E-5	1.2 E-4	1.6 E-4	1.9 E-4	2.2 E-4	2.5 E-4
High	87.6 E-5	96.2 E-5	104.5 E-5	113.6 E-5	122.2 E-5	131.2 E-5	17.5 E-4	21.9 E-4	26.2 E-4	30.6 E-4	35.0 E-4

* Calculations based on 90th percentile contaminant levels in waste oil (Table I).
† Summary of tables C-28 through C-33.

TABLE C-35

TRICHLOROETHANE EMISSIONS ON DUST PARTICLES
FROM VARIOUS ROAD SURFACES
DUE TO HEAVY TRAFFIC CONDITIONS*†
(g/m^2-h)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	3.62 E-4	7.86 E-6	8.09 E-4	2.18 E-5	9.20 E-4	6.07 E-4
1	1.52 E-4	0	4.90 E-4	0	4.99 E-4	0
2	1.09 E-4	0	5.47 E-4	0	5.31 E-4	0
3	1.14 E-4	0	5.98 E-4	0	5.57 E-4	0
4	1.17 E-4	0	6.42 E-4	0	5.78 E-4	0
5	1.20 E-4	0	6.87 E-4	0	5.99 E-4	0
10	1.35 E-4	0	9.16 E-4	0	6.97 E-4	0
15	1.44 E-4	0	1.15 E-3	0	7.75 E-4	0
20	1.48 E-4	0	1.37 E-3	0	8.31 E-4	0
25	1.47 E-4	0	1.60 E-3	0	8.69 E-4	0
30	1.42 E-4	0	1.83 E-3	0	8.89 E-4	0
Avg.	1.47 E-4	2.54 E-7	1.23 E-3	7.03 E-7	7.75 E-4	1.96 E-5

* Calculations based on an original trichloroethane concentration in waste oil of 1,300 mg/l. This represents the 90th percentile level (Table I).

† Based on dust emission factors from Table C-3.

TABLE C-36

TRICHLOROETHYLENE EMISSIONS ON DUST PARTICLES
FROM VARIOUS ROAD SURFACES
DUE TO HEAVY TRAFFIC CONDITIONS*†
(g/m^2-h)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	2.98 E-4	5.78 E-5	6.81 E-4	0	7.76 E-4	0
1	1.66 E-4	0	4.52 E-4	0	3.88 E-4	0
2	1.15 E-4	0	5.04 E-4	0	4.34 E-4	0
3	8.12 E-5	0	5.50 E-4	0	4.74 E-4	0
4	5.75 E-5	0	5.90 E-4	0	5.09 E-4	0
5	3.35 E-5	0	6.30 E-4	0	5.45 E-4	0
10	0	0	8.36 E-4	0	7.26 E-4	0
15	0	0	1.04 E-3	0	9.08 E-4	0
20	0	0	1.25 E-3	0	1.09 E-3	0
25	0	0	1.45 E-3	0	1.27 E-3	0
30	0	0	1.65 E-3	0	1.45 E-3	0
Avg.	2.43 E-5	1.86 E-6	1.07 E-3	0	9.80 E-4	0

* Calculations based on an original trichloroethylene concentration in waste oil of 1,049 mg/l. This represents the 90th percentile level (Table I).

† Based on dust emission factors from Table C-3.

TABLE C-37

TETRACHLOROETHYLENE EMISSIONS ON DUST PARTICLES
FROM VARIOUS ROAD SURFACES
DUE TO HEAVY TRAFFIC CONDITIONS*†
(g/m^2-h)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	3.46 E-4	1.08 E-4	8.03 E-4	3.64 E-4	9.14 E-4	8.37 E-5
1	2.87 E-4	1.94 E-5	4.95 E-4	0	5.27 E-4	0
2	2.82 E-4	0	4.52 E-4	0	4.39 E-4	0
3	2.76 E-4	0	4.10 E-4	0	3.66 E-4	0
4	2.67 E-4	0	3.64 E-4	0	2.89 E-4	0
5	2.58 E-4	0	3.17 E-4	0	2.12 E-4	0
10	2.00 E-4	0	4.72 E-5	0	0	0
15	1.12 E-4	0	0	0	0	0
20	2.43 E-5	0	0	0	0	0
25	0	0	0	0	0	0
30	0	0	0	0	0	0
Avg.	1.10 E-4	4.11 E-6	9.93 E-5	1.17 E-5	8.86 E-5	2.7 E-6

* Calculations based on an original tetrachloroethylene concentration in waste oil of 1,200 mg/l. This represents the 90th percentile level (Table I).

† Based on dust emission factors from Table C-3.

TABLE C-38

BENZENE EMISSIONS ON DUST PARTICLES
FROM VARIOUS ROAD SURFACES
DUE TO HEAVY TRAFFIC CONDITIONS*†
(g/m^2-h)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	4.62 E-5	1.49 E-5	1.07 E-4	5.91 E-6	1.22 E-4	1.71 E-5
1	2.15 E-5	0	1.21 E-5	0	8.87 E-7	0
2	1.14 E-5	0	0	0	0	0
3	2.50 E-5	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
10	0	0	0	0	0	0
15	0	0	0	0	0	0
20	0	0	0	0	0	0
25	0	0	0	0	0	0
30	0	0	0	0	0	0
Avg.	3.36 E-6	4.81 E-7	3.84 E-6	1.91 E-7	3.96 E-6	5.52 E-7

* Calculations based on an original benzene concentration in waste oil of 160 mg/l. This represents the 90th percentile level (Table I).

† Based on dust emission factors from Table C-3.

TABLE C-39

TOLUENE EMISSIONS ON DUST PARTICLES
FROM VARIOUS ROAD SURFACES
DUE TO HEAVY TRAFFIC CONDITIONS*†
(g/m^2-h)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	3.45 E-4	9.75 E-5	7.97 E-4	1.61 E-5	9.07 E-4	5.13 E-5
1	2.56 E-4	0	4.73 E-4	0	4.42 E-4	0
2	2.34 E-4	0	4.68 E-4	0	3.79 E-4	0
3	2.12 E-4	0	4.60 E-4	0	3.19 E-4	0
4	1.88 E-4	0	4.48 E-4	0	2.56 E-4	0
5	1.63 E-4	0	4.36 E-4	0	1.92 E-4	0
10	5.15 E-5	0	3.54 E-4	0	0	0
15	0	0	2.25 E-4	0	0	0
20	0	0	4.99 E-5	0	0	0
25	0	0	0	0	0	0
30	0	0	0	0	0	0
Avg.	5.34 E-5	3.15 E-6	2.01 E-4	5.19 E-7	8.05 E-5	1.65 E-6

* Calculations based on an original toluene concentration in waste oil of 1,200 mg/l. This represents the 90th percentile level (Table I).

† Based on dust emission factors from Table C-3.

TABLE C-40

XYLENE EMISSIONS ON DUST PARTICLES
FROM VARIOUS ROAD SURFACES
DUE TO HEAVY TRAFFIC CONDITIONS*†
(g/m^2-h)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	1.65 E-4	5.50 E-5	3.83 E-4	2.51 E-4	4.37 E-4	5.22 E-5
1	1.49 E-4	2.53 E-5	2.81 E-4	0	3.15 E-4	0
2	1.53 E-4	1.27 E-5	2.59 E-4	0	2.82 E-4	0
3	1.57 E-4	8.40 E-7	2.42 E-4	0	2.55 E-4	0
4	1.58 E-4	0	2.23 E-4	0	2.29 E-4	0
5	1.60 E-4	0	2.04 E-4	0	2.02 E-4	0
10	1.65 E-4	0	9.06 E-5	0	4.68 E-4	0
15	1.61 E-4	0	0	0	0	0
20	1.46 E-4	0	0	0	0	0
25	1.23 E-4	0	0	0	0	0
30	9.41 E-5	0	0	0	0	0
Avg.	1.42 E-4	3.03 E-6	6.60 E-5	8.10 E-6	1.31 E-4	1.68 E-6

* Calculations based on an original xylene concentration in waste oil of 570 mg/l. This represents the 90th percentile level (Table I).

† Based on dust emission factors from Table C-3.

TABLE C-41

NAPHTHALENE EMISSIONS ON DUST PARTICLES
FROM VARIOUS ROAD SURFACES
DUE TO HEAVY TRAFFIC CONDITIONS*†
(g/m^2-h)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	1.68 E-4	5.91 E-5	3.92 E-4	3.17 E-5	4.46 E-4	6.30 E-5
1	1.76 E-4	5.91 E-5	4.04 E-4	1.83 E-5	4.59 E-4	4.91 E-5
2	1.96 E-4	6.41 E-5	4.44 E-4	1.33 E-5	5.05 E-4	4.64 E-5
3	2.13 E-4	6.85 E-5	4.80 E-4	8.46 E-6	5.49 E-4	4.36 E-5
4	2.27 E-4	7.22 E-5	5.10 E-4	3.63 E-6	5.79 E-4	4.04 E-5
5	2.42 E-4	7.59 E-5	5.40 E-4	0	6.13 E-4	3.72 E-5
10	3.17 E-4	9.41 E-5	6.94 E-4	0	7.87 E-4	1.79 E-5
15	3.91 E-4	1.11 E-4	8.43 E-4	0	9.54 E-4	0
20	4.64 E-4	1.26 E-4	9.86 E-4	0	1.11 E-3	0
25	5.35 E-4	1.40 E-4	1.12 E-3	0	1.27 E-3	0
30	6.06 E-4	1.53 E-4	1.13 E-3	0	1.42 E-3	0
Avg.	4.12 E-4	1.14 E-4	8.59 E-4	2.43 E-6	9.95 E-4	9.60 E-6

* Calculations based on an original naphthalene concentration in waste oil of 580 mg/l. This represents the 90th percentile level (Table I).

† Based on dust emission factors from Table C-3.

TABLE C-42

AROCLOR 1242 EMISSIONS ON DUST PARTICLES
FROM VARIOUS ROAD SURFACES
DUE TO HEAVY TRAFFIC CONDITIONS*†
(g/m^2-h)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	1.45 E-5	5.09 E-6	3.34 E-5	2.73 E-6	3.85 E-5	5.43 E-6
1	1.59 E-5	5.43 E-6	3.61 E-5	2.85 E-6	4.10 E-5	5.73 E-6
2	1.73 E-5	6.06 E-6	4.02 E-5	3.15 E-6	4.58 E-5	6.36 E-6
3	1.89 E-5	6.61 E-6	4.40 E-5	3.42 E-6	5.00 E-5	6.92 E-6
4	2.03 E-5	7.10 E-6	4.72 E-5	3.65 E-6	5.37 E-5	7.40 E-6
5	2.17 E-5	7.59 E-6	5.05 E-5	3.87 E-6	5.74 E-5	7.89 E-6
10	2.89 E-5	1.01 E-5	6.72 E-5	5.04 E-6	7.64 E-5	1.04 E-5
15	3.61 E-5	1.26 E-5	8.38 E-5	6.18 E-6	9.54 E-5	1.28 E-5
20	4.33 E-5	1.51 E-5	1.01 E-4	7.30 E-6	1.14 E-4	1.53 E-5
25	5.05 E-5	1.75 E-5	1.17 E-4	8.40 E-6	1.33 E-4	1.77 E-5
30	5.77 E-5	2.00 E-5	1.34 E-4	9.47 E-6	1.52 E-4	2.00 E-5
Avg.	3.84 E-5	1.34 E-5	8.92 E-5	6.50 E-6	1.01 E-4	1.36 E-5

* Calculations based on an original Aroclor 1242 concentration in waste oil of 50 mg/l. This represents the 90th percentile level (Table I).

† Based on dust emission factors from Table C-3.

TABLE C-43

AROCLOR 1248 EMISSIONS ON DUST PARTICLES
FROM VARIOUS ROAD SURFACES
DUE TO HEAVY TRAFFIC CONDITIONS*†
(g/m^2-h)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	1.45 E-5	5.09 E-6	3.38 E-5	2.73 E-6	3.85 E-5	5.43 E-6
1	1.59 E-5	5.43 E-6	3.61 E-5	2.85 E-6	4.10 E-5	5.72 E-6
2	1.73 E-5	6.05 E-6	4.02 E-5	3.14 E-6	4.58 E-5	6.35 E-6
3	1.89 E-5	6.61 E-6	4.39 E-5	3.40 E-6	5.00 E-5	6.90 E-6
4	2.03 E-5	7.09 E-6	4.72 E-5	3.63 E-6	5.37 E-5	7.39 E-6
5	2.17 E-5	7.58 E-6	5.04 E-5	3.86 E-6	5.74 E-5	7.87 E-6
10	2.89 E-5	1.01 E-5	6.71 E-5	5.01 E-6	7.64 E-5	1.03 E-5
15	3.61 E-5	1.26 E-5	8.38 E-5	6.14 E-6	9.54 E-5	1.28 E-5
20	4.33 E-5	1.50 E-5	1.00 E-4	7.23 E-6	1.14 E-4	1.52 E-5
25	5.05 E-5	1.75 E-5	1.17 E-4	8.31 E-6	1.33 E-4	1.76 E-5
30	5.76 E-5	2.00 E-5	1.34 E-4	9.36 E-6	1.52 E-4	1.99 E-5
Avg.	3.84 E-5	1.34 E-5	8.91 E-5	6.45 E-6	1.01 E-4	1.35 E-5

* Calculations based on an original Aroclor 1248 concentration in waste oil of 50 mg/l. This represents the 90th percentile level (Table I).

TABLE C-44

AROCLOR 1254 EMISSIONS ON DUST PARTICLES
FROM VARIOUS ROAD SURFACES
DUE TO HEAVY TRAFFIC CONDITIONS*†
(g/m^2-h)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	1.45 E-5	5.09 E-6	3.38 E-5	2.73 E-6	3.85 E-5	5.43 E-6
1	1.55 E-5	5.44 E-6	3.61 E-5	2.89 E-6	4.12 E-5	5.78 E-6
2	1.73 E-5	6.07 E-6	4.03 E-5	3.22 E-6	4.59 E-5	6.44 E-6
3	1.89 E-5	6.64 E-6	4.40 E-5	3.51 E-6	5.01 E-5	7.02 E-6
4	2.03 E-5	7.13 E-6	4.73 E-5	3.76 E-6	5.39 E-5	7.53 E-6
5	2.17 E-5	7.62 E-6	5.06 E-5	4.01 E-6	5.76 E-5	8.04 E-6
10	2.90 E-5	1.01 E-5	6.74 E-5	5.29 E-6	7.67 E-5	1.07 E-5
15	3.62 E-5	1.27 E-5	8.42 E-5	6.57 E-6	9.58 E-5	1.33 E-5
20	4.34 E-5	1.52 E-5	1.01 E-4	7.83 E-6	1.15 E-4	1.59 E-5
25	5.06 E-5	1.77 E-5	1.18 E-4	9.08 E-6	1.34 E-4	1.85 E-5
30	5.78 E-5	2.02 E-5	1.35 E-4	1.03 E-5	1.53 E-4	2.10 E-5
Avg.	3.85 E-5	1.35 E-5	8.97 E-5	6.95 E-6	1.48 E-4	1.41 E-5

* Calculations based on an original Aroclor 1254 concentration in waste oil of 50 mg/l. This represents the 90th percentile level (Table I).

† Based on dust emission factors from Table C-3.

TABLE C-45

AROCLOR 1260 EMISSIONS ON DUST PARTICLES
FROM VARIOUS ROAD SURFACES
DUE TO HEAVY TRAFFIC CONDITIONS*†
(g/m^2-h)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	1.45 E-5	5.09 E-6	3.39 E-5	2.73 E-6	3.85 E-5	5.43 E-6
1	1.55 E-5	5.44 E-6	3.61 E-5	2.90 E-6	4.11 E-5	5.79 E-6
2	1.73 E-5	6.08 E-6	4.03 E-5	3.23 E-6	4.59 E-5	6.45 E-6
3	1.89 E-5	6.64 E-6	4.41 E-5	3.52 E-6	5.02 E-5	7.04 E-6
4	2.03 E-5	7.13 E-6	4.73 E-5	3.78 E-6	5.39 E-5	7.56 E-6
5	2.17 E-5	7.62 E-6	5.06 E-5	4.03 E-6	5.76 E-5	8.07 E-6
10	2.90 E-5	1.02 E-5	6.74 E-5	5.34 E-6	7.68 E-5	1.07 E-5
15	3.62 E-5	1.27 E-5	8.43 E-5	6.64 E-6	9.59 E-5	1.35 E-5
20	4.34 E-5	1.52 E-5	1.01 E-4	7.93 E-6	1.15 E-4	1.60 E-5
25	5.07 E-5	1.77 E-5	1.18 E-4	9.22 E-6	1.34 E-4	1.86 E-5
30	5.79 E-5	2.03 E-5	1.35 E-4	1.05 E-5	1.53 E-4	2.12 E-5
Avg.	3.85 E-5	1.35 E-5	8.96 E-5	7.06 E-6	1.02 E-4	1.44 E-5

* Calculations based on an original Aroclor 1260 concentration in waste oil of 50 mg/l. This represents the 90th percentile level (Table I).

† Based on dust emission factors from Table C-3.

TABLE C-46

RANGE OF ORGANIC CONTAMINANT EMISSIONS ON DUST PARTICLES UNDER HEAVY TRAFFIC CONDITIONS*
(g/m^2-h)

	0	1	2	3	4	5	10	15	20	25	30
Chlorinated Organics											
Trichloroethane											
High	9.20 E-4	4.99 E-4	5.47 E-4	5.98 E-4	6.42 E-4	6.87 E-4	9.16 E-4	1.15 E-3	1.37 E-3	1.60 E-3	1.83 E-3
Low	0	0	0	0	0	0	0	0	0	0	0
Trichloroethylene											
High	7.76 E-4	4.52 E-4	5.04 E-4	5.50 E-4	5.90 E-4	6.30 E-4	8.36 E-4	1.04 E-3	1.25 E-3	1.45 E-3	1.65 E-3
Low	0	0	0	0	0	0	0	0	0	0	0
Tetrachloroethylene											
High	9.14 E-4	5.27 E-4	4.52 E-4	4.10 E-4	3.64 E-4	3.17 E-4	2.00 E-4	1.12 E-4	2.43 E-5	0	0
Low	8.37 E-5	0	0	0	0	0	0	0	0	0	0
Other Organics											
Benzene											
High	1.22 E-4	2.15 E-5	1.14 E-5	2.50 E-5	0	0	0	0	0	0	0
Low	0	0	0	0	0	0	0	0	0	0	0
Toluene											
High	9.07 E-4	4.73 E-4	4.68 E-4	4.60 E-4	4.48 E-4	4.36 E-4	3.54 E-4	2.25 E-4	4.99 E-5	0	0
Low	1.61 E-5	0	0	0	0	0	0	0	0	0	0
Xylene											
High	4.37 E-4	3.15 E-4	2.82 E-4	2.55 E-4	2.29 E-4	2.04 E-4	4.68 E-4	1.61 E-4	1.46 E-4	1.23 E-4	9.41 E-5
Low	5.22 E-5	0	0	0	0	0	0	0	0	0	0
Naphthalene											
High	4.46 E-4	4.59 E-4	5.05 E-4	5.49 E-4	5.79 E-4	6.13 E-4	7.87 E-4	9.54 E-4	1.11 E-3	1.27 E-3	1.42 E-3
Low	3.17 E-5	1.83 E-5	1.33 E-5	8.46 E-6	3.63 E-6	0	0	0	0	0	0
PCB's											
Aroclor 1242											
High	3.85 E-5	4.10 E-5	4.58 E-5	5.00 E-5	5.37 E-5	5.74 E-5	7.64 E-5	9.54 E-5	1.14 E-4	1.33 E-4	1.52 E-4
Low	2.73 E-6	2.85 E-6	3.15 E-6	3.42 E-6	3.65 E-6	3.87 E-6	5.04 E-6	6.18 E-6	7.30 E-6	8.40 E-6	9.47 E-6
Aroclor 1248											
High	3.85 E-5	4.10 E-5	4.58 E-5	5.00 E-5	5.37 E-5	5.74 E-5	7.64 E-5	9.54 E-5	1.14 E-4	1.33 E-4	1.52 E-4
Low	2.73 E-6	2.85 E-6	3.14 E-6	3.40 E-6	3.63 E-6	3.86 E-6	5.01 E-6	6.14 E-6	7.23 E-6	8.31 E-6	9.36 E-4
Aroclor 1254											
High	3.85 E-5	4.12 E-5	4.59 E-5	5.01 E-5	5.39 E-5	5.76 E-5	7.67 E-5	9.58 E-5	1.15 E-4	1.34 E-4	1.53 E-4
Low	2.73 E-6	2.89 E-6	3.22 E-6	3.51 E-6	3.76 E-6	4.01 E-6	5.29 E-6	6.57 E-6	7.83 E-6	9.08 E-6	1.03 E-5
Aroclor 1260											
High	3.85 E-5	4.11 E-5	4.59 E-5	5.02 E-5	5.39 E-5	5.76 E-5	7.68 E-5	9.59 E-5	1.15 E-4	1.34 E-4	1.53 E-4
Low	2.73 E-6	2.90 E-6	3.23 E-6	3.52 E-6	3.78 E-6	4.03 E-6	5.34 E-6	6.64 E-6	7.93 E-6	9.22 E-6	1.05 E-5

* Emission ranges based on Tables C-35 through C-45.

TABLE C-47

TRICHLOROETHANE EMISSIONS
ON DUST PARTICLES FROM VARIOUS ROAD SURFACES
DUE TO MODERATE TRAFFIC CONDITIONS*†
(g/m^2-h)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	9.05 E-5	1.97 E-6	2.02 E-4	0	2.30 E-4	0
1	3.95 E-5	0	1.27 E-4	0	1.30 E-4	0
2	2.80 E-5	0	1.40 E-4	0	1.36 E-4	0
3	2.90 E-5	0	1.53 E-4	0	1.42 E-4	0
4	3.01 E-5	0	1.65 E-4	0	1.49 E-4	0
5	3.01 E-5	0	1.72 E-4	0	1.50 E-4	0
10	3.37 E-5	0	2.29 E-4	0	1.74 E-4	0
15	3.68 E-5	0	2.93 E-4	0	1.98 E-4	0
20	3.77 E-5	0	3.50 E-4	0	2.12 E-4	0
25	3.74 E-5	0	4.07 E-4	0	2.21 E-4	0
30	3.60 E-5	0	4.64 E-4	0	2.25 E-4	0
Avg.	3.75 E-5	6.38 E-8	3.12 E-4	0	1.96 E-4	0

* Calculations based on an original trichloroethane concentration in waste oil of 1,300 mg/l. This represents the 90th percentile level (Table I).

† Based on dust emission factors from Table C-4.

TABLE C-48

TRICHLOROETHYLENE CONCENTRATION
ON DUST PARTICLES FROM VARIOUS ROAD SURFACES
DUE TO MODERATE TRAFFIC CONDITIONS*†
(g/m^2-h)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	7.45 E-5	1.45 E-5	1.70 E-4	0	1.94 E-4	0
1	4.32 E-5	0	1.17 E-4	0	1.01 E-4	0
2	2.95 E-5	0	1.29 E-4	0	1.11 E-4	0
3	2.07 E-5	0	1.40 E-4	0	1.21 E-4	0
4	1.48 E-5	0	1.52 E-4	0	1.31 E-4	0
5	8.36 E-6	0	1.58 E-4	0	1.36 E-4	0
10	0	0	2.09 E-4	0	1.82 E-4	0
15	0	0	2.66 E-4	0	2.32 E-4	0
20	0	0	3.17 E-4	0	2.77 E-4	0
25	0	0	3.68 E-4	0	3.23 E-4	0
30	0	0	4.19 E-4	0	3.68 E-4	0
Avg.	6.16 E-6	4.68 E-8	2.83 E-4	0	2.49 E-4	0

* Calculations based on an original trichloroethylene concentration in waste oil of 1,049 mg/l. This represents the 90th percentile level (Table I).

† Based on dust emission factors from Table C-4.

TABLE C-49

TETRACHLOROETHYLENE CONCENTRATION
ON DUST PARTICLES FROM VARIOUS ROAD SURFACES
DUE TO MODERATE TRAFFIC CONDITIONS*†
(g/m^2-h)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	8.65 E-5	2.69 E-5	2.01 E-4	9.09 E-6	2.28 E-4	2.09 E-5
1	7.45 E-5	5.04 E-6	1.29 E-4	0	1.37 E-4	0
2	7.21 E-5	0	1.16 E-4	0	1.12 E-4	0
3	7.04 E-5	0	1.05 E-4	0	9.34 E-5	0
4	6.88 E-5	0	9.37 E-5	0	7.45 E-5	0
5	6.45 E-5	0	7.94 E-5	0	5.30 E-5	0
10	5.00 E-5	0	1.18 E-5	0	0	0
15	3.16 E-5	0	0	0	0	0
20	6.18 E-6	0	0	0	0	0
25	0	0	0	0	0	0
30	0	0	0	0	0	0
Avg.	2.82 E-5	1.03 E-6	2.53 E-5	2.93 E-7	2.25 E-5	6.74 E-7

* Calculations based on an original tetrachloroethylene concentration in waste oil of 1,200 mg/l. This represents the 90th percentile level (Table I).

† Based on dust emission factors from Table C-4.

TABLE C-50

BENZENE CONCENTRATION
ON DUST PARTICLES FROM VARIOUS ROAD SURFACES
DUE TO MODERATE TRAFFIC CONDITIONS*†
(g/m^2-h)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	1.16 E-5	3.72 E-6	2.68 E-5	1.48 E-6	3.05 E-5	3.22 E-6
1	5.59 E-6	0	3.13 E-6	0	2.30 E-7	0
2	2.91 E-6	0	0	0	0	0
3	6.39 E-7	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
10	0	0	0	0	0	0
15	0	0	0	0	0	0
20	0	0	0	0	0	0
25	0	0	0	0	0	0
30	0	0	0	0	0	0
Avg.	6.69 E07	1.20 E-7	9.65 E-7	4.77 E-8	9.91 E-7	1.04 E-7

* Calculations based on an original benzene concentration in waste oil of 160 mg/l. This represents the 90th percentile level (Table I).

† Based on dust emission factors from Table C-4.

TABLE C-51

TOLUENE CONCENTRATION
ON DUST PARTICLES FROM VARIOUS ROAD SURFACES
DUE TO MODERATE TRAFFIC CONDITIONS*†
(g/m^2-h)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	8.62 E-5	2.44 E-5	1.99 E-4	4.03 E-6	2.27 E-4	1.28 E-5
1	6.45 E-5	0	1.23 E-4	0	1.15 E-4	0
2	5.98 E-5	0	1.20 E-4	0	9.70 E-5	0
3	5.40 E-5	0	1.18 E-4	0	8.14 E-5	0
4	4.83 E-5	0	1.15 E-4	0	6.60 E-5	0
5	4.08 E-5	0	1.09 E-4	0	4.81 E-5	0
10	5.56 E-6	0	8.86 E-5	0	0	0
15	0	0	5.76 E-5	0	0	0
20	0	0	1.27 E-5	0	0	0
25	0	0	0	0	0	0
30	0	0	0	0	0	0
Avg.	1.23 E-5	7.87 E-7	5.09 E-5	1.3 E-7	2.05 E-5	4.13 E-7

* Calculations based on an original toluene concentration in waste oil of 1,200 mg/l. This represents the 90th percentile level (Table I).

† Based on dust emission factors from Table C-4.

TABLE C-52

XYLENE CONCENTRATION
ON DUST PARTICLES FROM VARIOUS ROAD SURFACES
DUE TO MODERATE TRAFFIC CONDITIONS*†
(g/m^2-h)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	4.12 E-5	1.38 E-5	9.58 E-5	6.27 E-6	1.09 E-4	1.31 E-5
1	3.56 E-5	6.56 E-6	7.31 E-5	0	8.19 E-5	0
2	3.91 E-5	3.25 E-6	6.52 E-5	0	7.22 E-5	0
3	4.00 E-5	2.14 E-7	6.18 E-5	0	6.52 E-5	0
4	4.08 E-5	0	5.74 E-5	0	5.90 E-5	0
5	4.01 E-5	0	5.10 E-5	0	5.06 E-5	0
10	4.14 E-5	0	2.27 E-5	0	1.17 E-5	0
15	4.11 E-5	0	0	0	0	0
20	3.72 E-5	0	0	0	0	0
25	3.14 E-5	0	0	0	0	0
30	2.29 E-5	0	0	0	0	0
Avg.	3.57 E-5	7.68 E-7	1.67 E-5	2.02 E-7	1.60 E-5	4.23 E-7

* Calculations based on an original xylene concentration in waste oil of 570 mg/l. This represents the 90th percentile level (Table I.).

† Based on dust emission factors from Table C-4.

TABLE C-53

NAPHTHALENE CONCENTRATION
ON DUST PARTICLES FROM VARIOUS ROAD SURFACES
DUE TO MODERATE TRAFFIC CONDITIONS*†
(g/m^2-h)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	4.20 E-5	1.48 E-5	9.80 E-5	7.91 E-6	1.11 E-4	1.57 E-5
1	4.59 E-5	1.54 E-5	1.05 E-4	4.76 E-6	1.19 E-4	1.28 E-5
2	5.01 E-5	1.64 E-5	1.14 E-4	3.40 E-6	1.29 E-4	1.19 E-5
3	5.43 E-5	1.75 E-5	1.22 E-4	2.16 E-6	1.39 E-4	1.11 E-5
4	5.85 E-5	1.86 E-5	1.31 E-4	9.34 E-7	1.49 E-4	1.04 E-5
5	6.05 E-5	1.90 E-5	1.35 E-4	0	1.53 E-4	9.29 E-6
10	7.93 E-5	2.35 E-5	1.74 E-4	0	1.97 E-4	4.48 E-6
15	9.99 E-5	2.83 E-5	2.15 E-4	0	2.44 E-4	0
20	1.18 E-4	3.21 E-5	2.51 E-4	0	2.84 E-4	0
25	1.36 E-4	3.56 E-5	2.85 E-4	0	3.23 E-4	0
30	1.54 E-4	3.88 E-5	3.19 E-4	0	3.60 E-4	0
Avg.	1.05 E-4	2.88 E-5	2.23 E-4	6.18 E-7	2.53 E-4	3.02 E-6

* Calculations based on an original naphthalene concentration in waste oil of 580 mg/l. This represents the 90th percentile level (Table I).

† Based on dust emission factors from Table C-4.

TABLE C-54

AROCLOR 1242 CONCENTRATION
ON DUST PARTICLES FROM VARIOUS ROAD SURFACES
DUE TO MODERATE TRAFFIC CONDITIONS*†
(g/m^2-h)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	3.62 E-6	1.27 E-6	8.45 E-6	6.83 E-7	9.61 E-6	1.36 E-6
1	4.02 E-6	1.41 E-6	9.37 E-6	7.40 E-7	1.07 E-5	1.49 E-6
2	4.42 E-6	1.55 E-6	1.03 E-5	8.06 E-7	1.17 E-5	1.63 E-6
3	4.82 E-6	1.69 E-6	1.12 E-5	8.72 E-7	1.28 E-5	1.77 E-6
4	5.22 E-6	1.83 E-6	1.22 E-5	9.38 E-7	1.38 E-5	1.91 E-6
5	5.42 E-6	1.90 E-6	1.26 E-5	9.69 E-7	1.44 E-5	1.97 E-6
10	7.22 E-6	2.52 E-6	1.68 E-5	1.26 E-6	1.91 E-5	2.59 E-6
15	9.22 E-6	3.21 E-6	2.14 E-5	1.58 E-6	2.44 E-5	3.28 E-6
20	1.10 E-5	3.83 E-6	2.59 E-5	1.86 E-6	2.91 E-5	3.88 E-6
25	1.28 E-5	4.45 E-6	2.97 E-5	2.13 E-6	3.38 E-5	4.48 E-6
30	1.46 E-5	5.07 E-6	3.39 E-5	2.40 E-6	3.56 E-5	5.07 E-6
Avg.	9.73 E-6	3.38 E-6	2.78 E-5	1.63 E-7	2.53 E-5	3.44 E-6

* Calculations based on an original Aroclor 1242 concentration in waste oil of 50 mg/l. This represents the 90th percentile level (Table I).

† Based on dust emission factors from Table C-4.

TABLE C-55

AROCLOR 1248 CONCENTRATION
ON DUST PARTICLES FROM VARIOUS ROAD SURFACES
DUE TO MODERATE TRAFFIC CONDITIONS*†
(g/m^2-h)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	3.62 E-6	1.27 E-6	8.45 E-6	6.83 E-7	9.61 E-6	1.36 E-6
1	4.02 E-6	1.41 E-6	9.36 E-6	7.39 E-7	1.07 E-5	1.49 E-6
2	4.42 E-6	1.55 E-6	1.03 E-5	8.04 E-7	1.17 E-5	1.62 E-6
3	4.82 E-6	1.69 E-6	1.12 E-5	8.69 E-7	1.28 E-5	1.76 E-6
4	5.22 E-6	1.83 E-6	1.22 E-5	9.35 E-7	1.38 E-5	1.90 E-6
5	5.42 E-6	1.90 E-6	1.26 E-5	9.64 E-7	1.44 E-5	1.97 E-6
10	7.22 E-6	2.52 E-6	1.68 E-5	1.25 E-6	1.91 E-5	2.58 E-6
15	9.22 E-6	3.21 E-6	2.14 E-5	1.57 E-6	2.44 E-5	3.26 E-6
20	1.10 E-5	3.83 E-6	2.56 E-5	1.84 E-6	2.91 E-5	3.86 E-6
25	1.28 E-5	4.45 E-6	2.97 E-5	2.11 E-6	3.38 E-5	4.46 E-6
30	1.46 E-5	5.06 E-6	3.39 E-5	2.37 E-6	3.85 E-5	5.04 E-6
Avg.	9.73 E-6	3.39 E-6	2.26 E-5	1.64 E-6	3.75 E-5	3.42 E-6

* Calculations based on an original Aroclor 1248 concentration in waste oil of 50 mg/l. This represents the 90th percentile level (Table I).

† Based on dust emission factors from Table C-4.

TABLE C-56

AROCLOR 1254 CONCENTRATION
ON DUST PARTICLES FROM VARIOUS ROAD SURFACES
DUE TO MODERATE TRAFFIC CONDITIONS*†
(g/m^2-h)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	3.62 E-6	1.27 E-6	8.45 E-6	6.83 E-7	9.61 E-6	1.36 E-6
1	4.02 E-6	1.41 E-6	9.38 E-6	7.51 E-7	1.07 E-5	1.50 E-6
2	4.42 E-6	1.55 E-6	1.03 E-5	8.23 E-7	1.17 E-5	1.65 E-6
3	4.83 E-6	1.69 E-6	1.12 E-5	8.95 E-7	1.28 E-5	1.79 E-6
4	5.23 E-6	1.83 E-6	1.23 E-5	9.67 E-7	1.39 E-5	1.94 E-6
5	5.43 E-6	1.90 E-6	1.26 E-5	1.00 E-6	1.44 E-5	2.01 E-6
10	7.24 E-6	2.54 E-6	1.69 E-5	1.32 E-6	1.92 E-5	2.67 E-6
15	9.24 E-6	3.24 E-6	2.15 E-5	1.68 E-6	2.45 E-5	3.39 E-6
20	1.11 E-5	3.87 E-6	2.57 E-5	1.99 E-6	2.93 E-5	4.04 E-6
25	1.29 E-5	4.50 E-6	2.99 E-5	2.31 E-6	3.40 E-5	4.69 E-6
30	1.47 E-5	5.13 E-6	3.41 E-5	2.62 E-6	3.88 E-5	5.33 E-6
Avg.	9.79 E-6	3.42 E-6	2.27 E-5	1.77 E-6	2.59 E-5	3.58 E-6

* Calculations based on an original Aroclor 1254 concentration in waste oil of 50 mg/l. This represents the 90th percentile level (Table I).

† Based on dust emission factors from Table C-4.

TABLE C-57

AROCLOR 1260 CONCENTRATION
ON DUST PARTICLES FROM VARIOUS ROAD SURFACES
DUE TO MODERATE TRAFFIC CONDITIONS*†
(g/m^2-h)

Day Number	Sand		Clay/Sand		Gravel	
	High	Low	High	Low	High	Low
0	3.62 E-6	1.27 E-6	8.45 E-6	6.83 E-7	9.61 E-6	1.36 E-6
1	4.02 E-6	1.41 E-6	9.38 E-6	7.53 E-7	1.07 E-5	1.50 E-6
2	4.23 E-6	1.55 E-6	1.03 E-5	8.26 E-7	1.17 E-5	1.65 E-6
3	4.83 E-6	1.70 E-6	1.13 E-5	8.99 E-7	1.28 E-5	1.80 E-6
4	5.23 E-6	1.84 E-6	1.23 E-5	9.72 E-7	1.39 E-5	1.95 E-6
5	5.43 E-6	1.91 E-6	1.27 E-5	1.01 E-6	1.44 E-5	2.02 E-6
10	7.24 E-6	2.54 E-6	1.69 E-5	1.33 E-6	1.92 E-5	2.68 E-6
15	9.29 E-6	3.24 E-6	2.15 E-5	1.70 E-6	2.45 E-5	3.42 E-6
20	1.11 E-5	3.87 E-6	2.57 E-5	2.02 E-6	2.93 E-5	4.07 E-6
25	1.29 E-5	4.51 E-6	2.99 E-5	2.34 E-6	3.41 E-5	4.73 E-6
30	1.47 E-5	5.14 E-6	3.41 E-5	2.66 E-6	3.89 E-5	5.38 E-6
Avg.	9.67 E-6	3.43 E-6	2.27 E-5	1.78 E-6	2.59 E-5	3.60 E-6

* Calculations based on an original Aroclor 1260 concentration in waste oil of 50 mg/l. This represents the 90th percentile level (Table I).

† Based on dust emission factors from Table C-4.

TABLE C-58

RANGE OF ORGANIC CONTAMINANTS EMISSIONS ON DUST PARTICLES UNDER MODERATE TRAFFIC CONDITIONS*
(g/m^2-h)

Day Number	0	1	2	3	4	5	10	15	20	25	30
Chlorinated Organics											
Trichloroethane											
High	2.30 E-4	1.30 E-4	1.40 E-4	1.53 E-4	1.65 E-4	1.72 E-4	2.29 E-4	2.93 E-4	3.50 E-4	4.07 E-4	4.64 E-4
Low	0	0	0	0	0	0	0	0	0	0	0
Trichloroethylene											
High	1.94 E-4	1.17 E-4	1.29 E-4	1.40 E-4	1.52 E-4	1.58 E-4	2.09 E-4	2.66 E-4	3.17 E-4	3.68 E-4	4.19 E-4
Low	0	0	0	0	0	0	0	0	0	0	0
Tetrachloroethylene											
High	2.28 E-4	1.37 E-4	1.16 E-4	1.05 E-4	9.37 E-4	7.94 E-5	5.00 E-5	3.16 E-5	6.18 E-6	0	0
Low	9.09 E-6	0	0	0	0	0	0	0	0	0	0
Other Organics											
Benzene											
High	3.05 E-5	5.59 E-6	2.91 E-6	6.39 E-7	0	0	0	0	0	0	0
Low	1.48 E-6	0	0	0	0	0	0	0	0	0	0
Toluene											
High	2.27 E-4	1.23 E-4	1.20 E-4	1.18 E-4	1.15 E-4	1.09 E-4	8.86 E-5	5.76 E-5	1.27 E-5	0	0
Low	4.03 E-6	0	0	0	0	0	0	0	0	0	0
Xylene											
High	1.09 E-4	8.19 E-5	7.22 E-5	6.52 E-5	5.90 E-5	5.10 E-5	4.14 E-5	4.11 E-5	3.72 E-5	3.14 E-5	2.29 E-5
Low	6.27 E-6	0	0	0	0	0	0	0	0	0	0
Naphthalene											
High	1.11 E-4	1.19 E-4	1.29 E-4	1.39 E-4	1.49 E-4	1.53 E-4	1.97 E-4	2.44 E-4	2.84 E-4	3.23 E-4	3.60 E-4
Low	7.91 E-6	4.76 E-6	3.40 E-6	2.16 E-6	9.34 E-7	0	0	0	0	0	0
PCB's											
Aroclor 1242											
High	8.45 E-5	9.37 E-5	1.17 E-5	1.28 E-5	1.38 E-5	1.44 E-5	1.91 E-5	2.44 E-5	2.91 E-5	3.38 E-5	3.56 E-5
Low	6.83 E-7	7.40 E-7	8.06 E-7	8.72 E-7	9.38 E-7	9.69 E-7	1.26 E-6	1.58 E-6	1.86 E-6	2.13 E-6	2.40 E-6
Aroclor 1248											
High	9.61 E-6	1.07 E-5	1.17 E-5	1.28 E-5	1.38 E-5	1.44 E-5	1.91 E-5	2.44 E-5	2.91 E-5	3.38 E-5	3.85 E-5
Low	6.83 E-7	7.39 E-7	8.04 E-7	8.69 E-7	9.35 E-7	9.64 E-7	1.25 E-6	1.57 E-6	1.84 E-6	2.11 E-6	2.37 E-6
Aroclor 1254											
High	9.61 E-6	1.07 E-5	1.17 E-5	1.28 E-5	1.39 E-5	1.44 E-5	1.92 E-5	2.45 E-5	2.93 E-5	3.40 E-5	3.88 E-5
Low	6.83 E-7	7.51 E-7	8.23 E-7	8.95 E-7	9.67 E-7	1.00 E-6	1.32 E-6	1.68 E-6	1.99 E-6	2.31 E-6	2.62 E-6
Aroclor 1260											
High	9.61 E-6	1.07 E-5	1.17 E-5	1.28 E-5	1.39 E-5	1.44 E-5	1.92 E-5	2.45 E-5	2.93 E-5	3.41 E-5	3.89 E-5
Low	6.83 E-7	7.53 E-7	8.26 E-7	8.99 E-7	9.72 E-7	1.01 E-7	1.33 E-6	1.70 E-6	2.02 E-6	2.34 E-6	2.66 E-6

* Summary of Tables C-47 through C-57.

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APPENDIX D

HEALTH EFFECTS ASSESSMENT METHOD

INTRODUCTION

Assessing the human health effects of using waste oil to suppress dust requires an individual analysis of the impact of each waste oil contaminant. Analysis of waste oil emissions as a single airborne or waterborne waste stream is not practical because of the wide range of health effects produced by the various individual emission components. When the impact on human health is examined, two general classes of effects can be distinguished: threshold and nonthreshold.

The traditional approach to the establishment of safe exposure levels to chemical substances is to identify concentrations that will have no adverse effects in target populations.[1-3] This approach assumes the existence of a threshold dose below which no deleterious effects will occur. Indeed, many chemical substances have been characterized as eliciting a threshold-type response, e.g., irritants and simple poisons.[4] In this report, concentration limits likely to protect public health from acute adverse reactions resulting from chronic exposure to toxic emissions eliciting a threshold effect are referred to as Environmental Exposure Limits (EEL's).

Safe exposure levels are not easily identified for some chemical substances. These chemicals elicit a response for any exposure, no matter how small the concentration. Such substances are said to produce nonthreshold responses in their target populations. Several substances that appear to elicit a nonthreshold response have been identified. A pathological end-point of great public concern that results from a nonthreshold response is cancer. In the case of carcinogens, evidence indicates that these substances have the potential to produce deleterious effects regardless of the quantity of the chemical present in the body; i.e., one molecule can initiate the process of carcinogenesis (one-hit theory). Although a debate still goes on within the regulatory community on how best to regulate cancer-producing chemicals, it is generally accepted that the weight of scientific data clearly supports the existence of the nonthreshold phenomenon.[5]

Because threshold doses have not been established for carcinogens, the practice of "risk estimation" has gained wide acceptance.[5,6] Estimates of cancer risk involve the use of animal toxicological data, human epidemiological data, and mathematical models to estimate the cancer incidence rates associated with exposures to suspected carcinogens. This risk estimation method entails the use of a carcinogen's exposure-response relationship to estimate the health impact of the substances. These estimates are generally expressed as the number of excess cancers

per unit of population or the lifetime risk to the highest exposed individual. For the purposes of this report it was convenient to express the exposure-response relationship as specific risk reference concentrations (i.e., at what concentration could a risk of cancer of 10^{-4}, 10^{-5}, 10^{-6}, etc., be expected). This appendix describes the data and assumptions used to determine both the EEL's and the reference concentrations.

MODEL FOR ESTIMATING ENVIRONMENTAL EXPOSURE LEVELS

Environmental exposure levels were needed for both airborne and waterborne emissions of waste oil because normal exposure is likely to occur via inhalation of reentrained dust or evaporative emissions, or through the consumption of contaminated water. The approach to determining both air and water exposure levels is presented in the following subsections.

Air Exposure Levels

The structure of the model chosen to estimate airborne EEL's for use in the waste oil risk assessment study is similar to that of several models currently used in the health risk assessment community.[7-11] The major premise behind all of these models (a premise that is not universally accepted) is that workplace threshold limit values (TLV's) published by the American Conference of Governmental Industrial Hygienists (ACGIH) can be adjusted mathematically for use in assessing nontraditional workplace or environmental exposures.[4] These mathematical adjustments have ranged from simple time adjustments[9] to a few sophisticated models that incorporate uptake and excretion coefficients.[7,8]

The success of each attempt depends on how well the authors have accounted for the limitations inherently associated with the use of TLV's. The preface to the ACGIH publication clearly states the limitations associated with the TLV's as identified by the committee:[3]

> "Threshold limit values refer to airborne concentrations of substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse effect. Because of wide variation in individual susceptibility, however, a small percentage of workers may experience discomfort from some substances at concentrations at or below the threshold limit; a smaller percentage may be affected more seriously by aggravation of a pre-existing condition or by development of an occupational illness.
>
> "Threshold limits are based on the best available information from industrial experience, from experimental human and animal studies, and when possible, from a combination of the three. The basis on which the values are established may differ from substance to substance; protection against impairment of health may be a guiding factor for some, whereas reasonable freedom from irritation, narcosis, nuisance, or other forms of stress may form the basis for others.
>
> "The amount and nature of the information available for establishing a TLV varies from substance to substance; consequently, the precision of the estimated TLV is also subject to variation, and the latest documentation should be consulted in order to assess the extent of the data available for a given substance."

This preface identifies five important caveats that should be addressed when TLV's are adjusted to account for environmental exposures: 1) the exposure duration, 2) the population at greatest risk (susceptibility), 3) pre-existing conditions or illnesses in the exposed population, 4) the basis for determining the original TLV, and 5) the type of protection intended.

All models developed to date (including the model presented herein) are only partially successful in addressing each of these

caveats or limitations. Mathematical models are usually developed for specific purposes (e.g., to establish exposure limits for 10- or 12-hour workdays, overtime, the additive effects of a second job, avocational exposures to toxic agents, or chronic environmental exposures). These needs have limited the past application to the most applicable or important caveats (e.g., accounting for the duration of exposure when the 8-hour TLV is used to derive a 12-hour workplace exposure limit). Also, models usually were designed to address only those limitations for which corrective information was readily available. Despite these deficiencies, outputs from these modified models are of greater utility than the original TLV's simply because the adjusted value accounts for one or more of the limitations. The greater the number of limitations addressed, the more confidence one can place in the model.

The model used to calculate TLV-derived EEL's for use during this waste oil risk assessment is presented in Equation D-1.

$$EEL = \frac{TLV\ (D_{af})\quad (M_{af})}{S_f} \times 10^3 \qquad (D\text{-}1)$$

where EEL = environmental exposure limit, $\mu g/m^3$

TLV = 8-hour time-weighted average threshold limit value, mg/m^3

D_{af} = duration of exposure adjustment factor (0.12), nondimensional

M_{af} = magnitude of exposure adjustment factor (0.72), nondimensional

S_f = safety factor (10-1000), nondimensional

This model adjusts for differences in duration and magnitude of exposure. Also, through the selection of a safety factor, it accounts for differences in the documentation used to develop each TLV and the type of protection the TLV is intended to provide.

Duration of Exposure Adjustment Factor (D_{af})

The ACGIH TLV's were developed to provide protection "...for a normal 8-hour workday and a 40-hour workweek, to which nearly all workers may be repeatedly exposed, day after day, without adverse effect." This excerpt defines the length of a "normal" weekly work schedule and also implies a normal working lifetime.

Because environmental exposures are not limited to an 8-hour day, a 40-hour workweek, or a working lifetime, an adjustment in exposure was made by estimating the ratio of a "normal" work exposure duration to a public lifetime exposure. The normal working lifetime of an adult male worker* was calculated to be 8.0×10^4 hours.** This value represents the likely duration of an occupational exposure.

Environmental exposures have the potential of occurring over an entire lifetime. The value used to define the duration of a

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* The term "adult male workers" is sometimes used when referring to TLV's. This distinction is made because the vast majority of industrial experience and human exposure data cited in the ACGIH documentation is based on adult male subjects.

** Value is based on 8 hours/day, 5 days/week, 50 weeks/year, and a working lifetime of 40 years. The selection of 40 years assumes a starting age of 25 years and a retirement age of 65. This work period provides some allowance for job changes, college, and early retirement, which are not considered in a 47-year working lifetime (18 to 65 years old).

biological lifetime must account for variations in longevity within the general population. Consideration of this variation is important because a person with a long life span will experience a greater total exposure and ultimately more stress than a person with a shorter life span. In the United States a significant gender difference exists regarding average life expectancy. An American female born in 1979 has a longer average life expectancy than an American male born at the same time (77.8 years for females versus 69.9 years for males).[12] This difference will result in a longer lifetime exposure duration for females (6.8×10^5 hours versus 6.1×10^5 hours).* Taking the gender difference into account, the resulting adjustment factor for the change in the duration of exposure is 8.0×10^4 hours/6.8×10^5 hours, or approximately 0.12. This adjustment factor addresses, in part, the first caveat and accounts for the cohort in the general population with the longest life expectancy.

Magnitude of Exposure Adjustment Factor (M_{af})

Identifying population groups at greatest risk is difficult. The ACGIH noted this difficulty in describing the limitation of the TLV's: "...Because of wide variation in individual susceptibility... a small percentage of workers may experience discomfort from some substances at concentrations at or below the threshold limit..." The reasons for this discomfort may be differences in

* Female value is based on 24 hours/day, 7 days/week, and 50 weeks/year over a lifetime of 77.8 years. Male value is based on the same hours/day, days/week, and weeks per year but over a lifetime of 69.9 years.

morphology, physiology, behavior, or genetics among certain members of an exposed population. It is not possible to lower threshold limits to levels that presumably would protect all workers at all times; nor is it possible to reduce EEL's to levels that presumably would protect every portion of the population, regardless of size. The data needed to make such decisions are not available.

Nevertheless, because environmental exposures, unlike workplace exposures, affect a larger and more heterogenous population, EEL's derived from workplace TLV's must strive to account for and protect those portions of the population that are at risk.

Based on a comparison of daily volumes of air breathed with the body weights of the four cohorts of the general population (i.e., adult males, adult females, children, and infants), airborne contaminants present the greatest risk to a 10-year-old child (Table D-1). A magnitude-of-exposure adjustment factor was developed to account for this increased risk to a 10-year-old child. Workplace TLV's are determined from data on adult males (70-kg reference/man) with a daily air volume of 2.3×10^4 liters, which results in a ratio of 3.28×10^2 liters of air/kg of body weight. The daily volume of air breathed by a child (33-kg reference/10-year-old) is 1.5×10^4 liters, which results in a ratio of 4.54×10^2 liters of air/kg body weight.

TABLE D-1. DAILY AIR VOLUMES, REFERENCE BODY WEIGHTS, AND ESTIMATED ADJUSTMENT FACTORS FOR VARIATIONS IN THE LEVEL OF EXPOSURE EXPERIENCED BY VARIOUS POPULATION COHORTS

Reference individual (cohort)	Daily air volume breathed,[a] liters	Reference body weight,[b] kg	Exposure per unit body weight, liters/kg	Ratio of adult male value to value for reference individual (nondimensional)
Adult male	2.3×10^4	70	328	1.00
Adult female	2.1×10^4	58	362	0.91
Child (10 years)	1.5×10^4	~33[c]	454	0.72
Infant (1 year)	0.38×10^4	~10[c]	380	0.86

[a] Reference 13, p. 346. Daily air volumes breathed by adult men and women and the 10-year-old child are based on 8 hours of working ("light activity"), 8 hours of nonoccupational activity, and 8 hours of resting. The value for an infant is based on 8 hours of "light activity" and 16 hours of resting.

[b] Reference 13, p. 13.

[c] Reference 13, p. 11. Reference body weights for a 10-year-old child and a one-year-old infant were taken as an average of both sexes for each age group. In both age groups the actual sex-specific mean body weights vary less than 0.5 kg from the values given above.

An adjustment factor of 0.72 ($3.28 \times 10^2/4.54 \times 10^2$) accounts for the greater ventilation rate per unit body weight of a 10-year-old child compared with that of an adult male.

Safety Factor (S_f)

Despite attempts to adjust for differences in exposure duration and to account for large population cohorts known to be at the greatest risk, much uncertainty is still associated with the estimated EEL's. The uncertainty associated with each EEL is directly related to the paucity and quality of information used in the definition of the original TLV's. In an attempt to account for this source of uncertainty, safety factors have been included in the estimation procedure. Table D-2 presents the safety factors used to define the uncertainty associated with specific conditions of information or experimental data. These factors, which were developed for the determination of water quality criteria,[14] are also applicable to the estimating of environmental exposure limits.

These safety factors are used because the amount and nature of the information available for establishing a TLV vary from substance to substance. Within these limitations, the information that forms the basis of the ACGIH documentation and the nature of the illness or disease the TLV is designed to provide protection against are presented in Table D-3. The safety factors that best describe the uncertainty associated with each TLV are also presented in this table.

TABLE D-2. UNCERTAINTY FACTORS ASSOCIATED WITH SPECIFIC CONDITIONS OF THE EXPERIMENTAL DATA

Nature and conditions of experimental data[a]	Uncertainty (safety) factor[b]
Valid experimental results of chronic exposure studies on man	10
Valid results of chronic exposure studies on experimental animals; human exposure data limited to acute studies	100
Acute exposure studies on experimental animals; no human data available	1000

[a] Data that present no indication of carcinogenicity.

[b] Reference 14. Uncertainty factors developed by the National Academy of Sciences during a study of Drinking Water and Health.

TABLE D-3. SUMMARY OF ACGIH DOCUMENTATION FOR SPECIFIC TLV's AND SELECTED UNCERTAINTY (SAFETY) FACTORS[14,15]

Substance	ACGIH TLV 8-h TWA, mg/m^3	Type of information forming basis of ACGIH documentation	Targeted prevention	Selected uncertainty (safety) factor
Barium	0.5	Industrial experience related to barium nitrate exposures	Excitability	100
Cadmium compounds	0.05	Epidemiological and occupational exposure studies	Proteinuria, pulmonary edema, and emphysema	10
Chromium (II and III)	0.5	Clinical studies of exposed workers	Pulmonary edema and irritation	10
Hydrogen chloride	~7.0 (5 ppm)	Occupational exposure studies and animal studies	Irritation	10
Lead	0.15	Occupational exposure studies, clinical studies of exposed workers, and animal studies	Encephalopathy and renal damage	10
Naphthalene	50.0	Industrial experience, occupational exposure studies, and animal studies	Irritation	10[a]
Xylene	~435 (100 ppm)	Industrial experience, occupational exposure studies, clinical studies of exposed workers, and animal studies	Narcosis, chronic	10
Zinc (as zinc oxide)	5.0	Occupational exposure studies and animal studies	Reduced incidence of metal fume fever	10

(continued)

TABLE D-3 (continued)

Substance	ACGIH TLV 8-h TWA, mg/m³	Type of information forming basis of ACGIH documentation	Targeted prevention	Selected uncertainty (safety) factor
Toluene	~375 (10 ppm)	Occupational exposure studies, clincial studies of exposed workers, and animal studies	Loss of muscle coordination and cardiomuscular changes	10
Trichloroethane (1,1,1-)	~1900 (350 ppm)	Occupational exposure studies, clincial studies of exposed workers, and animal studies	Anesthetic effects and objectionable odor	10
Dichlorodifluoromethane	~4950 (1000 ppm)	Clinical studies of exposed humans and animal studies	Cardiac sensitization and systemic injury	10
Trichlorotrifluoroethane	~7600 (1000 ppm)	Clinical studies of exposed humans and animal studies	Cardiac sensitization and systemic injury	10

[a] There is some support within the scientific health effects community for applying a safety factor of 1 to those substances identified as irritants. This practice appears to be reasonable for those substances for which no other health effects have been observed. The ACGIH TLV for naphthalene was established to protect against ocular irritation.[4] Although this end-point is still a major concern, acute exposures to airborne naphthalene are recognized to produce direct hemolytic effects in vivo, and oral exposure may result in the development of cataracts.[6] Because naphthalene exposures may result in toxic end-points other than irritation, an uncertainty factor of 10 has been selected for use in determining a TLV-derived EEL.

Results

Table D-4 presents the estimated airborne EEL's (based on Equation D-1) for 11 substances found in waste oil. Specific adjustments were made for expected duration differences between workplace and environmental exposures and exposures of a population cohort at great risk. A safety factor was used to account for the condition and quality of information used to develop the workplace TLV's and for the type of protection they are intended to provide.

Water Exposure Levels

Obtaining waterborne exposure levels for use in the waste oil study does not require extensive estimating. Most of the chemical contaminants have established water quality criteria levels that have direct application in the waste oil study. Table D-5 presents the water quality criteria levels for substances of concern.

Environmental exposure limits were estimated for three substances for which no water quality criteria have been established: barium, benzanthracene, and naphthalene. These estimates were made by using the U.S. EPA's equation for determining acceptable levels in water, shown as Equation D-2.

$$C_{(EEL)} = \frac{ADI - (DT + IN)}{2 \text{ liters} + (0.0065 \text{ kg})(R)} \times 10^{-3} \qquad \text{(D-2)}$$

where $C_{(EEL)}$ = estimated environmental exposure limit in water, µg/liter
ADI = acceptable daily intake, mg
DT = nonfish dietary intake, mg
IN = inhalation intake, mg
2 liters = assumed daily water consumption
0.0065 kg = assumed daily fish consumption
R = bioconcentration factor, liters/kg

TABLE D-4 . ESTIMATED AIRBORNE ENVIRONMENTAL EXPOSURE LIMITS IN AIR

Substance	Environmental exposure level, $\mu g/m^3$
Barium	0.43
Cadmium	0.34
Chromium (II and III)	4.32
Lead	1.30[a]
Zinc	43.2
Dichlorodifluoromethane	42,768
Naphthalene	432
Toluene	3,240
1,1,1-Trichloroethane	16,416
Trichlorotrifluoroethane	65,664
Xylene	3,758

[a] The ambient air quality standard of 1.5 $\mu g/m^3$ was used instead of the estimated environmental exposure limit of 1.3 $\mu g/m^3$.

TABLE D-5. WATER QUALITY CRITERIA AND ESTIMATED ENVIRONMENTAL EXPOSURE LIMITS

Substance	Environmental exposure limits in water[a], µg/liter
Barium	260[b]
Cadmium	10
Chromium (II and III)	5,900
Lead	50
Zinc	5,000
Benzanthracene (1,2-Benzanthracene)	0.776[b]
Dichlorodifluoromethane	28,000[c]
Naphthalene	3,400[b]
Toluene	14,300
1,1,1 Trichloroethane	18,400
Xylene (Dimethylbenzene)	3,487

[a] Values taken from the U.S. EPA's Water Quality Criteria (Ref. 14) unless specified otherwise. A value for trichlorotrifluoroethane is not available.

[b] Estimated values using U.S. EPA's equation for determining acceptable levels in water (see Equation 2).

[c] Proposed revised (draft) value, obtained from Josephine Brecher, U.S. EPA Office of Water Regulations and Standards, August 29, 1983.

The waterborne EEL for barium was estimated by using an average daily intake (ADI) of 0.684 mg. This ADI was based on the airborne EEL for barium (see Table D-4) and an inhalation rate of 20 m^3/day. The nonfish dietary intake for barium was assumed to be zero. A bioconcentration factor of 3100 was used in the calculation.[14]

The waterborne EEL for benzanthracene was estimated by using an airborne EEL-derived ADI of 0.1728 mg. The nonfish dietary intake for benzanthracene was assumed to be zero. A bioconcentration factor of 150 was used in the calculation.[14]

The waterborne EEL for naphthalene was also estimated by using an airborne EEL-derived ADI of 86.4 mg. The nonfish dietary intake for naphthalene was assumed to be zero. A bioconcentration factor of 77 was used in the calculation.[14]

APPROACH USED TO DETERMINE REFERENCE CONCENTRATIONS FROM CARCINOGENIC POTENCY FACTORS

The reference concentrations provide reference points against which to assess the relative impact of air or water quality on health and to calculate the cancer risks attributable to that exposure; they are not estimates of safety, nor are they statements of acceptable levels of risk. The EPA procedures used to evaluate the toxicological data were consistent with the Agency's objective of estimating a maximum likely risk.[2] The carcinogenic risk factors were developed from data sets that gave the highest estimate of a lifetime cancer risk. This maximum likely risk probably errs on the side of safety. The reference concentrations

were determined from the carcinogenic potency factors developed for the EPA Water Quality Criteria Documents and updated in the Health Effects Assessment Summary for 300 Hazardous Organic Constituents.[10]

Chemicals eliciting a carcinogenic response are assessed by use of a linear *nonthreshold* dose-response model. Use of this model is based on the following assumptions: 1) a nonthreshold dose-response relationship exists for carcinogens, 2) the dose-response relationship developed from animal and human studies at relatively high exposure levels can be extrapolated to low exposure levels likely to be experienced by the general public over an entire lifetime, and 3) the dose-response relationship is linear. These linear nonthreshold models are used by the Interagency Regulating Liaison Group (IRLG)[5] and the EPA Carcinogen Assessment Group (CAG)[16-18] to evaluate risks posed by potentially carcinogenic substances.

In this study, reference concentrations have been developed by the use of the carcinogenic potency factor q_1^* and equivalent dosage estimates.

The EPA developed the q_1^* factors from lifetime animal experiments or human epidemiological studies.[16,18] Because of the variety of studies accessed for data, EPA had to correct for differences in metabolism between species and for variable absorption rates via different routes of administration. The resulting q_1^* factors are therefore based on exposures likely to produce a given cancer incidence rate. Table D-6 presents potency factors for carcinogenic substances found in waste oil.

TABLE D-6. CARCINOGENIC POTENCY FACTORS

Substance	Risk, $(mg/kg/day)^{-1}$
Arsenic	14.0[a]
Benzene	0.52[b]
Benzo(a)pyrene	11.53[a]
Cadmium	6.65[b]
Chromium (VI)	41.0[b]
Carbon tetrachloride	0.13[b]
Polychlorinated biphenols (PCB's)	4.34[a]
Tetrachloroethylene	0.0531[b]
1,1,2-Trichloroethane	0.0573[a]
Trichloroethylene	0.0126[a]

[a] Reference 10, p. 3.
[b] Reference 18.

Airborne Reference Concentrations

Equation D-3 presents the method used to derive airborne reference concentrations from the established carcinogenic potency factors.

$$C_a = \frac{K\ (70\ kg)}{q_1^*\ \ (20\ m^3)} \times 10^3 \qquad \text{(D-3)}$$

where C_a = reference concentration in air for a lifetime risk to cancer of 10^{-5}, $\mu g/m^3$

K = risk level (10^{-5})

q_1^* = carcinogenic potency factor, risk per mg/kg per day (Table B-6)

Again, the value of 70 kg represents the weight of a reference adult male.[13] The value of 20 m^3 is an estimate of the total daily volume of air ventilated by an adult male. The derived values for the airborne reference concentrations are presented in Table D-7.

Waterborne Reference Concentration

It was not necessary to estimate reference concentrations for any of the waste oil contaminants in water because these concentrations are available from the Water Quality Criteria documentation. The waterborne reference concentrations are presented in Table D-8.

TABLE D-7. REFERENCE CONCENTRATIONS FOR A 10^{-5} RISK LEVEL

Substance	Air,[a] µg/m³
Arsenic	0.0025[a]
Benzene	0.6731
Benzo(a)pyrene	0.0030
Cadmium	0.0053
Chromium	0.0008
Carbon tetrachloride	0.2692
Polychlorinated biphenols (PCB's)	0.0081
Tetrachloroethylene	0.6591
1,1,2-Trichloroethane	0.6100
Trichloroethylene	2.7800

[a] Airborne reference concentration was determined by using published carcinogenic potency factors (Table D-6) and a conversion methodology (Equation 3).

TABLE D-8. WATERBORNE REFERENCE CONCENTRATIONS

Substance	Reference concentration in water for 10^{-5} risk level,[a] µg/liter
Arsenic	0.022
Benzene	6.6
Benzo(a)pyrene	0.028
Tetrachloroethylene	8.0
1,1,2-Trichloroethane	6.0
Polychlorinated biphenols	0.00079
Trichloroethylene	27.0

[a] Ref. 14.

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