EMCON
W. 7106 Will D. Alton Lane • Suite 101 • Spokane, Washington 99204-5760 • (509) 838-1144 • Fax (509) 838-1382

Lust - 100
80 S. Hudson St,
King Co / Seattle

RECEIVED 6-4-97
DEPARTMENT OF ECOLOGY
TANKS UNIT
INTERIM CLEANUP REPORT ☑
SITE CHARACTERIZATON ☐
FINAL CLEANUP REPORT ☐
OTHER ☐
AFFECTED MEDIA: SOIL ☑
OTHER ______ GW ☑
INSPECTOR (INIT.) DATE 6-4-97

December 10, 1996
Project 40565-001.003

Mr. Joe Hickey
Washington State Department of Ecology
3190 160th Avenue SE
Bellevue, Washington 98008

RECEIVED
DEC 12 1996
DEPT. OF ECOLOGY

Re: S.E.S. Seattle, Inc
80 South Hudson Street, Seattle Washington

Dear Mr. Hickey:

At your request, EMCON has prepared this letter in response to our phone conversations (particularly with Priscilla Zieber on October 14, 1996) regarding your review and comment of the remediation effort at the above referenced facility and our letter to you dated April 17, 1996.

BACKGROUND

On December 21, 1995, EMCON submitted to you a report titled *"Final Site Investigation Summary and Independent Remedial Action Report,"* for review. The report summarized the remedial actions performed at the site, including the removal of petroleum hydrocarbons from soil and groundwater beneath and hydraulically downgradient of the site in accordance with the requirements of WAC 173-340, Model Toxics Control Act.

The report identified two locations where residual soil impacted with petroleum hydrocarbons was not removed from the site due to the proximity to major structural elements of the building. The locations, revised estimated quantities, and total petroleum hydrocarbon (TPH) concentrations are summarized below. The locations are shown on Figure 1.

- Approximately 30 to 50 cubic yards of soil impacted by TPH as oil (TPH-O) remain in the vicinity of the southeast corner of the West Shop. As reported, TPH-O concentrations in the soil were 3,550 mg/kg and 13,000 mg/kg beneath interior walls adjacent to the eastern and southern portions, respectively, of the previous excavation.

Independent Action Report Update

Site Name: 80 S. Hudson St. (GES-Wheelabrator)

Inc. #: 1884 Date of Report: 12-10-96

County: King Date Report Rec'd: 12-12-96

Reviewed by: Joe Hickey

Comments (please include: free prod., tank info., contaminant migration, GW depth & flow, conc. trends, PCS treated?):

This report attempts to justify leaving somewhat high levels of PCS in place by using human health risk & fate & transport calculations. I have asked for clarifications, but the approach looks good especially in light of the new TPH policy, and the fact that the remaining PCS at this site is very heavy ended petroleum.

- Approximately 60 to 80 cy of soil impacted by TPH as diesel (TPH-D) and TPH-O remain in the vicinity of the northwest corner of the West Shop. As reported, TPH-D was detected at 14,000 mg/kg and TPH-O was detected at 9,200 mg/kg in the soil beneath the western exterior wall of the building. TPH-O was detected at 1,700 mg/kg in the soil beneath the northern exterior wall of the building. The highest concentrations of TPH-D (14,000 mg/kg) were limited to the area near the north end of the west wall of the building.

Additional soil sampling and analysis were conducted in the uncapped area outside of the northwest corner of the building. No additional assessment was performed in the vicinity of the southeast portion of the building as the threat to human health and the environment is evaluated as minor in that area. The residual impacted soil in that area is beneath the roof of the building and a concrete floor, thus eliminating the potential for direct contact and for leaching of petroleum hydrocarbons to groundwater. Analytical data from former monitoring well MW-3, located approximately in the center of the previous remedial excavation (Figure 1), indicated that groundwater was not impacted by TPH-D or TPH-O at concentrations exceeding the MTCA Method A cleanup level of 1 mg/L.

As discussed in our letter dated April 17, 1996, the analytical data indicate that TPH-D concentrations range from not detected at or above the method reporting limits (MRL) to 14,000 mg/kg and that TPH-O concentrations range from not detected at or above the MRL to 800 mg/kg. The highest concentrations of TPH-D and TPH-O were limited to the area near the north end of the west wall of the building.

Based on the distribution of TPH in the recently collected soil samples, approximately 60 to 80 cy of residual soil in the northwest corner of the building exceed the MTCA Method A cleanup level. The samples collected near the groundwater surface (7 feet bgs) contained TPH-D at concentrations ranging from 67 mg/kg to 7,760 mg/kg.

PRACTICABILITY OF REMEDIATING SOIL BENEATH STRUCTURES

As was previously reported, all petroleum hydrocarbon impacted soil that could practicably be excavated without compromising the structural integrity of the building was removed from the interior southeast corner of the West Shop and from the interior of the northwest corner of the West Shop. Soil samples collected from the side walls of the remedial excavations indicate that petroleum hydrocarbons remain mainly in areas near building footings and walls.

Based on cost estimates obtained by EMCON for previous site work, the estimated construction cost to shore excavations, support the structure, and back-fill and compact with suitable materials could range between $50,000 to $150,000. Based on a maximum estimated total quantity of 130 cy of soil, the per yard cost to remove the soil would range between $385 and $1,150. For comparison purposes, the typical per yard cost to remove and dispose of impacted soil is $30 to $50.

Given the relatively minor quantity of soil remaining beneath the interior and exterior walls of the building, the option of excavation is evaluated as a cost-prohibitive remedial solution. Additionally, based on EMCON's experience, the feasibility of in situ biodegradation of semivolatile petroleum hydrocarbons to concentrations below MTCA Method A cleanup levels is unlikely for this site. Therefore, development of alternate soil action levels for the site which are protective of human health and the environment is the appropriate action.

ALTERNATIVE SOIL ACTION LEVELS

Land use in the vicinity of the site is primarily industrial. The zoning code for the site and adjacent properties is IG1-U85, (industrial general). Alternative soil action levels (SALs) for TPH that are protective of human health and the environment were developed, based on industrial land use, using the following methods:

- An alternative reference dose (ARfD) was back-calculated from the Method A Cleanup Level for diesel in soil and then used in the Method C equation for industrial soil to calculate an SAL that should be protective of human health.

- USEPA's RfD for diesel was used in the Method C equation for industrial soil to calculate an SAL that is protective of human health.

Alternative RfD Based on Method A

The ARfD for diesel was back-calculated from the Method A Cleanup Level of 200 mg/kg for soil, using the Method B equation for soil. The ARfD, which was 0.0025 mg/kg/day, was used in the Method C equation for industrial soil to calculate an SAL for diesel in industrial soil. The calculated SAL for direct contact with soil was 8,750 mg/kg.

USEPA's RfD

In 1992, USEPA published a memorandum that presented an RfD of 0.008 mg/kg/day for diesel[1]. The 1992 RfD was used with the Method C equation for industrial soil to calculate an SAL for direct contact of 28,000 mg/kg.

Protection of Groundwater

As was demonstrated in our December 21, 1995 report, groundwater cleanup levels are based on the protection of surface water due to the nonpotability of the groundwater beneath the site. The Duwamish River, located approximately 1,400 feet hydraulically downgradient (west) of the site, is the groundwater receptor. The surrogate approach for protection of groundwater included an evaluation of TPH infiltration, migration rates to the river, and natural attenuation.

Site remediation included the re-infiltration and flushing of over 6 million gallons of treated groundwater through the saturated soil beneath the northwest corner of the West Shop building. This flushing action should have removed the TPH in the saturated soil beneath the area; therefore, the leaching of residual TPH in unsaturated soil above the water table is the only potential source of TPH to groundwater.

The leaching of TPH at the site can be caused only by infiltration of surface water through the unsaturated soil. Surface water infiltration occurs only in those areas where the site is not capped by concrete (outside of the building). Silt layers in the unsaturated soil limit the infiltration rate, and surface water ponding has been observed along the outside edge of the building during rainfall events. EMCON conservatively estimates the infiltration rate to be in the range of 2.5 to 25 percent of the annual precipitation rate (100 cm/yr). The infiltration rate beneath the building is zero. Approximately 60 to 80 percent of the impacted soil near the northwest corner of the building (36 to 64 cy) is located outside of the building and is a potential source for leaching by surface water infiltration.

Once the TPH has been released from the soil, it will be transported as a dissolved phase in groundwater. Dissolved diesel compounds are slightly soluble in water and will bind to organic carbon adsorbed to soil particles. During groundwater flow, a significant portion

[1] USEPA. 1992. Oral reference doses and oral slope factors for JP-4 (CAS No. not identified), JP-5 (CAS No. not identified; similar to kerosene, CAS No. 8008-20-6), diesel fuel (CAS No. 68334-30-5), and gasoline (CAS No. 8006-61-9) (AVGAS) [McChord AFB (Wash Rack/Treatment)/Tacoma, WA]. Memo from J.S. Dollarhide, USEPA Office of Research and Development, Environmental Criteria and Assessment Office, Cincinnati, Ohio, to C. Sweeney, USEPA Region X, Seattle, Washington.

of the dissolved TPH will attach to soil and will be removed from the groundwater. Microbial biodegradation will also decrease the TPH concentration during groundwater transport.

EMCON calculated a 19-year advective groundwater travel time from the site to the Duwamish River (approximately 1,400 feet); however, due to chemical retardation (TPH adsorption to soil organic carbon), a 430-year travel time was calculated for dissolved TPH to reach the Duwamish River. These travel times are based on the site hydraulic conductivity (0.02 cm/sec) and gradient (0.0014 ft/ft), flowpath length (1,400 ft), soil porosity (0.38), fractional organic carbon content (0.005), and the minimum soil-water partitioning coefficient (K_{oc}=1,000). The calculations are presented in Appendix A.

TPH-D concentrations in groundwater immediately downgradient of the impacted soil were monitored at wells MW-1 and MW-2. TPH-D concentrations in samples collected from these wells generally decreased or remained constant from the time of soil excavation in 1992 through 1995. TPH-O concentrations were typically below method reporting limits. The TPH-D concentrations in the groundwater samples were below surface water quality criteria for TPH (10 milligrams per liter). Because the majority of the TPH source to groundwater has been removed, the concentrations of TPH in groundwater will likely not increase.

Natural attenuation of TPH-D in groundwater has been exhibited at wells MW-10, MW-11, and MW-12. Prior to September 1995, the wells were approximately 10 feet downgradient of the former free product plume. Over the 10-foot distance of groundwater flow, natural attenuation decreased the concentration of TPH-D in groundwater from nonaqueous phase liquid to less than 5 mg/L. The natural attenuation over an additional 1,300 feet to the Duwamish River will be even greater.

For the surrogate approach, groundwater action levels (GALs) were derived for each diesel compound group using the following site cleanup levels based on protection of surface water:

- Naphthalene cleanup level (0.62 mg/L) used for aromatics C10-C12.

- Fluorene cleanup level (0.37 mg/L) apportioned equally among three aromatic groups C12-C16, C16-C21, and C21-C35.

- TPH cleanup level (10 mg/L), apportioned equally among all thirteen compound groups, used for the six aliphatic groups C5-C6, C6-C8, C8-C10, C10-C12, C12 C16, and C16-C21 (i.e., 10 mg/L was divided by 13 to yield 0.77 mg/L, which was assigned as the GAL for the six aliphatic groups).

The range of infiltration rates and other site-related fate and transport values were used in the ASTM Standard E 1739-95 Risk-Based Corrective Action (RBCA) screening level model. The model calculates a soil cleanup level to meet surface water cleanup criteria, assuming that the TPH is leached from soil by infiltration. Attenuation related to irreversible adsorption and biodegradation were factored into the model. Assuming a conservative infiltration rate of 25 cm/yr and a natural attenuation factor that decreases the TPH-D concentration in groundwater by 99 percent during the 430 year travel time to the Duwamish River, the calculated SAL for TPH is 46,866 mg/kg. The calculations are presented in Appendix B.

SUMMARY

- Approximately 60 to 80 cy of TPH impacted soil remain near the northwest corner of the West Shop, and an estimated 60 to 80 percent of the impacted soil (36 to 64 cy) is located outside of the building. As previously reported, the TPH D concentrations range up to 14,000 mg/kg and the TPH-O concentrations range up to 800 mg/kg.

- Approximately 30 to 50 cy of soil impacted by TPH-O remain in the covered area near the southeast corner of the West Shop. As previously reported, TPH-O concentrations in the soil were 3,550 mg/kg and 13,000 mg/kg beneath interior walls adjacent to the eastern and southern portions, respectively, of the previous excavation.

- Based on cost estimates obtained by EMCON for previous site work, the estimated construction cost to shore excavations, support the structure, and back-fill and compact with suitable materials could range between $385 and $1,150 per cubic yard. For comparison purposes, the typical cost to remove and dispose of impacted soil is $30 to $50 per cubic yard. Given the relatively minor quantity of soil remaining at the site, the option of excavation is evaluated as a cost-prohibitive; the development of alternate soil action levels for the site which are protective of human health and the environment is the appropriate action.

- Soil action levels for diesel that are protective of direct human contact were developed for the site using two different RfDs. The SAL based on the alternative RfD back-calculated from Method A is 8,750 mg/kg. The SAL based on USEPA's RfD is 28,000 mg/kg. These SALs are in the range of, or higher than, the maximum concentrations of TPH-D remaining on site.

- A soil action level for diesel that is protective of surface water quality, using a screening fate and transport model, is estimated at 46,866 mg/kg. This SAL assumes that natural attenuation will degrade 99 percent of all TPH leached from soil and transported in groundwater before it reaches the Duwamish River. This SAL is greater than 3 times the maximum TPH concentration detected in soil near the West Shop building.

Based on this, EMCON recommends that the site status on the Ecology LUST list be changed from "ongoing " to "completed." Please contact the undersigned or Mike Staton at (206) 485-5000 if you have any questions.

Sincerely,

EMCON

Rob Lindsay, R.G.
Dir. of Environmental Services

Priscilla Zieber by Janene Lucht
Priscilla Zieber
Senior Toxicologist

h. 206 822 - 5068

Attachments: Figure 1
Appendix A (Table 1)- Contaminant Attenuation Calculations
Appendix B (Table 1-3) Supporting Calulations

cc: Bob Closs, Wheelabrator Technologies

FIGURES

APPENDIX A

CONTAMINANT ATTENUATION CALCULATIONS
TABLE 1

Table 1
Calculation of Groundwater (Advective) and Contaminant Travel Time

Distance	Hydraulic onductivit	Porosity	Hydraulic Gradient	Soil Density	Fraction Carbon	Partition Coefficient	etardatio Factor	Advect Veloc.	Contam Velocity
d	K	n	i	Ro	foc	Koc	R	vw	vc
(ft)	(cm/sec)	-	ft/ft	gm/cm^3	-	gm/cm^3	-	ft/day	ft/day
1400	0.02	0.38	0.0014	2.67	0.005	1000	22.78158	0.209	0.009

Advective Travel Time		Contaminant Travel Time	
day	yr	day	yr
6701.9	18.4	152681	418.3

APPENDIX B

SUPPORTING CALCULATIONS
TABLES 1-3

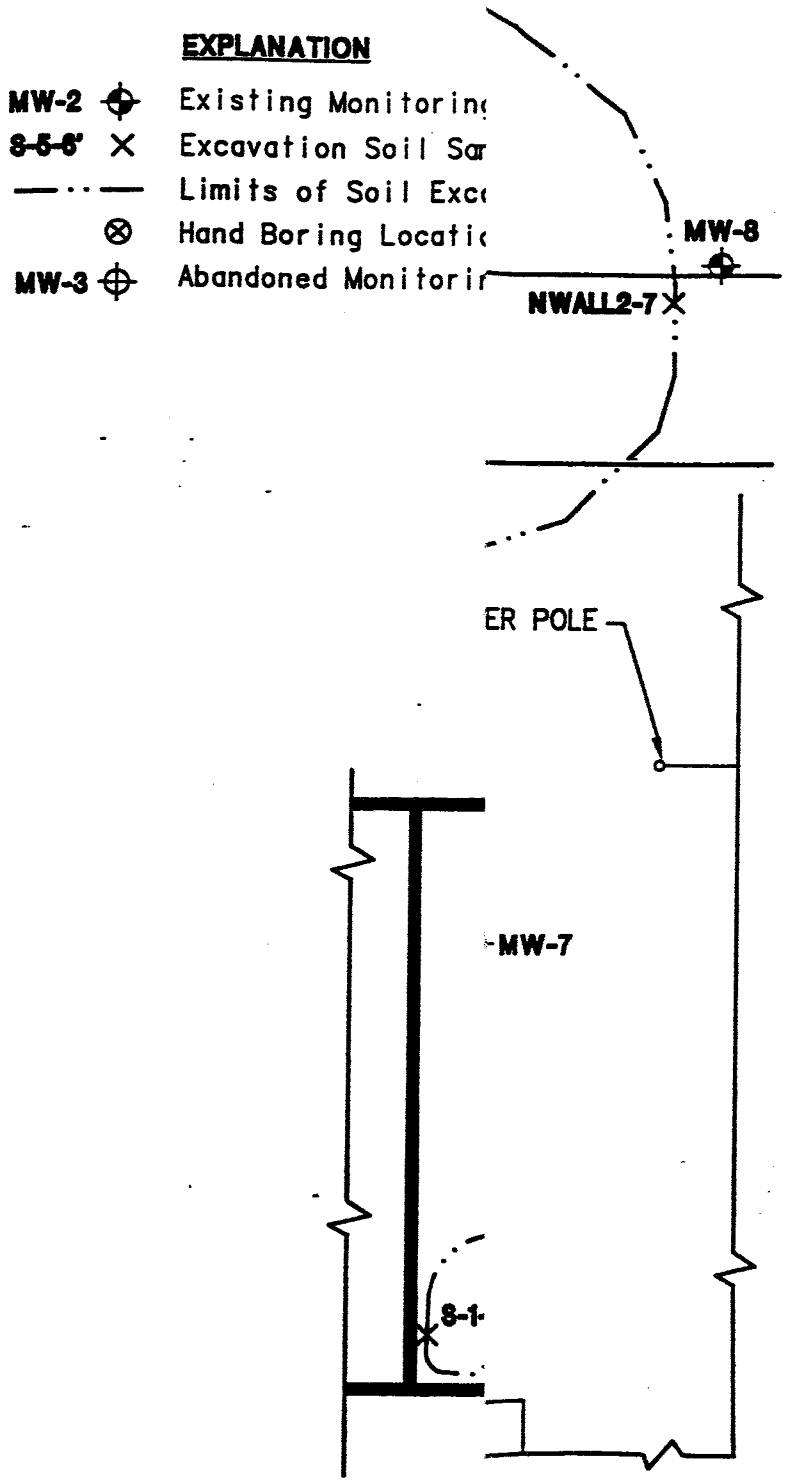
Table 2
Fate and Transport Parameters

Parameter	Symbol	Value	Units	Source
Lower depth of surficial soil zone	d	100	cm	ASTM E 1739-95
Diffusion coefficient in air	D_{air}	0.1	cm^2/s	TPHCWG
Diffusion coefficient in water	D_{wat}	1.00E-05	cm^2/s	TPHCWG
Enclosed-space air exchange rate for residential	RER	1.40E-04	L/s	ASTM E 1739-95
Enclosed-space air exchange rate for occupational	OER	2.30E-04	L/s	ASTM E 1739-95
Fraction of organic carbon in soil	f_{oc}	0.005	g/g	ASTM E 1739-95
Thickness of capillary fringe	h_{cap}	5	cm	ASTM E 1739-95
Thickness of vadose zone	h_v	245	cm	ASTM E 1739-95
Infiltration rate of water through soil	I	25	cm/yr	ASTM E 1739-95
Enclosed-space volume/infiltration area ratio for residential	RL_B	200	cm	ASTM E 1739-95
Enclosed-space volume/infiltration area ratio for occupational	OL_B	300	cm	ASTM E 1739-95
Enclosed-space foundation or wall thickness	L_{crack}	15	cm	ASTM E 1739-95
Depth to groundwater	L_{GW}	250	cm	ASTM E 1739-95
Depth to subsurface soil source	L_S	750	cm	ASTM E 1739-95
Particulate emission rate	P_e	6.90E-14	$g/cm^2/s$	ASTM E 1739-95
Wind speed above ground surface in ambient mixing zone	U_{air}	225	cm/s	ASTM E 1739-95
Groundwater Darcy velocity	U_{gw}	3465	cm/yr	ASTM E 1739-95
Width of source area parallel to wind or groundwater direction	W	1200	cm	ASTM E 1739-95
Ambient air mixing zone height	δ_{air}	200	cm	ASTM E 1739-95
Groundwater mixing zone thickness	δ_{gw}	200	cm	ASTM E 1739-95
Areal fraction of cracks in foundations or walls	η	0.01	cm^2/cm^2	ASTM E 1739-95
Volumetric air content in capillary fringe soils for residential	$R\theta_{acap}$	0.038	cm^3/cm^3	ASTM E 1739-95
Volumetric air content in capillary fringe soils for occupational	$O\theta_{acap}$	0.38	cm^3/cm^3	ASTM E 1739-95
Volumetric air content in foundation or wall cracks	θ_{acrack}	0.26	cm^3/cm^3	ASTM E 1739-95
Volumetric air content in vadose zone soils	θ_{as}	0.26	cm^3/cm^3	ASTM E 1739-95
Total soil porosity	θ_T	0.38	cm^3/cm^3	ASTM E 1739-95
Volumetric water content in capillary fringe soils	θ_{wcap}	0.342	cm^3/cm^3	ASTM E 1739-95
Volumetric water content in foundation or wall cracks	θ_{wcrack}	0.12	cm^3/cm^3	ASTM E 1739-95
Volumetric water content in vadose zone soils	θ_{ws}	0.12	cm^3/cm^3	ASTM E 1739-95
Soil bulk density	ρ_s	1.7	g/cm^3	ASTM E 1739-95
Averaging time for vapor flux	τ	7.88E+08	s	ASTM E 1739-95

Sources

ASTM E 1739-95:
Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites.
American Society for Testing and Materials, West Conshohocken, Pennsylvania.

TPHCWG:
Total Petroleum Hydrocarbon Criteria Working Group. Presentation to Washington Department of Ecology, Olympia, Washington. January 17, 1996.



EMCON Northwest, Inc.

Figure 1
S.E.S. SEATTLE, INC.
80 S. HUDSON ST., SEATTLE, WASHINGTON
SOIL EXCAVATION LIMITS AND SOIL SAMPLING LOCATIONS

PLOT 1=20 G:\DWG\0565\001\03C11-K1.DWG SJR 4-1

Table 1

Chemical-Specific Parameters

Compound Group	Surrogate Chemical	f (unitless)	S (mg/L)	H (cm^3/cm^3)	log k_{oc}	k_{oc} (g/g)	k_s (g/g)	C_{sat} (mg/kg)	Csat/ks	D_s (cm^2/s)	D_{crack} (cm^2/s)	RD_{cap} (cm^2/s)	RD_{ws} (cm^2/s)	RfDo (mg/kg/day)	RfDi (mg/kg/day)	CPFo $(mg/kg/day)^{-1}$	CPFi $(mg/kg/day)^{-1}$	INH (unitless)	AB1 (unitless)	ABS (unitless)
Source		BPJ	TPHCWG	TPHCWG	TPHCWG	10^(log k_{oc})	Eq 1	Eq 2		Eq 3	Eq 4	Eq 5	Eq 6	TPHCWG	TPHCWG	IRIS	IRIS	BPJ	WAC 173-340-745	WAC 173-340-750
Aliphatic C5-C6	n-Hexane	0	3.00E+01	4.00E+01	3.00E+00	1.00E+03	5.00E+00	3.36E+02	6.71E+01	7.80E-03	7.80E-03	1.30E-05	5.99E-04	0.06	0.06	NA	NA	2	1	1
Aliphatic C7-C8	n-Hexane	0	5.00E+00	4.00E+01	4.00E+00	1.00E+04	5.00E+01	2.81E+02	5.62E+00	7.80E-03	7.80E-03	1.30E-05	5.99E-04	0.06	0.06	NA	NA	2	1	1
Aliphatic C9-C10	n-Nonane	0	4.00E-01	5.00E+01	4.00E+00	1.00E+04	5.00E+01	2.31E+01	4.62E-01	7.80E-03	7.80E-03	1.30E-05	5.99E-04	0.6	0.6	NA	NA	2	1	1
Aliphatic C11-C12	n-Nonane	0.024	3.00E-02	6.00E+01	5.00E+00	1.00E+05	5.00E+02	1.53E+01	3.06E-02	7.80E-03	7.80E-03	1.29E-05	5.99E-04	0.6	0.6	NA	NA	2	1	1
Aliphatic C13-C16	n-Nonane	0.249	7.00E-04	7.00E+01	7.00E+00	1.00E+07	5.00E+04	3.50E+01	7.00E-04	7.80E-03	7.80E-03	1.29E-05	5.99E-04	0.6	0.6	NA	NA	1	1	1
Aliphatic C17-C21	Mineral oil	0.377	2.00E-06	9.00E+01	9.00E+00	1.00E+09	5.00E+06	1.00E+01	2.00E-06	7.80E-03	7.80E-03	1.29E-05	5.98E-04	0.6	0.6	NA	NA	1	1	1
Aromatic C5-C6	Toluene	0	2.00E+03	2.00E-01	2.00E+00	1.00E+02	5.00E-01	1.20E+03	2.40E+03	7.80E-03	7.80E-03	2.26E-05	9.91E-04	0.29	0.1	NA	NA	2	1	1
Aromatic C7-C8	Toluene	0	5.00E+02	3.00E-01	2.00E+00	1.00E+02	5.00E-01	3.08E+02	6.16E+02	7.80E-03	7.80E-03	1.94E-05	8.65E-04	0.29	0.1	NA	NA	2	1	1
Aromatic C9-C10	Naphthalene	0	6.00E+01	3.00E-01	3.00E+00	1.00E+03	5.00E+00	3.07E+02	6.14E+01	7.80E-03	7.80E-03	1.94E-05	8.65E-04	0.04	0.004	NA	NA	2	1	1
Aromatic C11-C12	Naphthalene	0.013	2.00E+01	1.00E-01	3.00E+00	1.00E+03	5.00E+00	1.02E+02	2.03E+01	7.80E-03	7.80E-03	3.24E-05	1.34E-03	0.04	0.004	NA	NA	1	1	1
Aromatic C13-C16	Naphthalene	0.134	6.00E+00	3.00E-02	4.00E+00	1.00E+04	5.00E+01	3.00E+02	6.01E+00	7.81E-03	7.81E-03	7.77E-05	2.61E-03	0.04	0.004	NA	NA	1	1	1
Aromatic C17-C21	Pyrene	0.153	7.00E-01	4.00E-03	4.00E+00	1.00E+04	5.00E+01	3.50E+01	7.01E-01	7.82E-03	7.82E-03	4.99E-04	6.04E-03	0.03	0.03	NA	NA	1	1	1
Aromatic C22-C35	Pyrene	0.050	7.00E-03	4.00E-05	5.00E+00	1.00E+05	5.00E+02	3.50E+00	7.00E-03	9.29E-03	9.29E-03	4.86E-02	9.44E-03	0.03	0.03	NA	NA	1	1	1
Benzene	NA	NA	1.75E+03	2.29E-01	NA	8.30E+01	4.15E-01	9.11E+02	2.20E+03	7.80E-03	7.80E-03	2.14E-05	9.43E-04	NA	NA	0.029	0.029	2	1	1
Benzo(a)pyrene	NA	NA	1.20E-03	6.36E-05	NA	5.50E+06	2.75E+04	3.30E+01	1.20E-03	8.74E-03	8.74E-03	3.06E-02	8.86E-03	NA	NA	7.3	7.3	1	1	1
		1																		

Abbreviations

AB1	Gastrointestinal absorption factor	INH	Inhalation correction factor
ABS	Inhalation absorption factor	K_{oc}	Carbon-water sorption coefficient
BPJ	Best professional judgement	K_s	Soil-water sorption coefficient
C_{sat}	Soil concentration at which dissolved pore-water and vapor phases become saturated	NA	Not applicable
CPFi	Inhalation carcinogenic potency factor	RD_{cap}	Diffusion coefficient through capillary fringe for residential
CPFo	Oral carcinogenic potency factor	RD_{ws}	Diffusion coefficient between groundwater and soil surface for residential
D_{crack}	Diffusion coefficient through foundation cracks	RfDi	Inhalation reference dose
D_s	Diffusion coefficient in soil based on vapor-phase concentration	RfDo	Oral reference dose
Eq	Equation	S	Water solubility
f	Fraction of compound group in petroleum mixture	TPHCWG	Total Petroleum Hydrocarbon Criteria Working Group
H	Henry's law constant		

Equations

Number	Equation	Source
1	$k_s = f_{oc} \times k_{oc}$	ASTM E 1739-95
2	$C_{sat} = S \times (H \times \theta_{as} + \theta_{ws} + k_s \times \rho_s) / \rho_s$	ASTM E 1739-95
3	$D_s = D_{air} \times \theta_{as}$^3.33 / θ_T^2 + $D_{wat} \times \theta_{ws}$^3.33 / (H x θ_T^2)	ASTM E 1739-95
4	$D_{crack} = D_{air} \times \theta_{acrack}$^3.33 / θ_T^2 + $D_{wat} \times \theta_{wcrack}$^3.33 / (H x θ_T^2)	ASTM E 1739-95
5	$D_{cap} = D_{air} \times \theta_{acap}$^3.33 / θ_T^2 + $D_{wat} \times \theta_{wcap}$^3.33 / (H x θ_T^2)	ASTM E 1739-95
6	$D_{ws} = (h_{cap} + h_v) / (h_{cap} / D_{cap} + h_v / D_s)$	ASTM E 1739-95

Sources

ASTM E 1739-95: Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites.
American Society for Testing and Materials, West Conshohocken, Pennsylvania.

TPHCWG: Total Petroleum Hydrocarbon Criteria Working Group. Presentation to Washington Department of Ecology, Olympia, WA, January 17,1996
[S, H, and Koc for benzene and benzo(a)pyrene were obtained from USEPA's Superfund Public Health Evaluation Manual (1986).]

Table 3
Groundwater and Soil Cleanup Levels for Diesel, Noncancer Effects
Protection of Groundwater for Residential Scenario

Compound Group	H (cm^3/cm^3)	k_s (g/g)	LFi_1 (cm^3/cm^3)	LF_{sw} (kg/L)	GW CUL (mg/L)	Soil CUL (mg/kg)	f (unitless	C_{sat} (mg/kg)	Min	Min/ Soil CUL	f/ GW CUL
Source	Tbl 1	Tbl 1	Eq 1	Eq 2	Water quality criteria	Eq 4	Tbl 1	Tbl 1	Minimum of f or C_{sat}		
Aliphatic C5-C6	4.00E+01	5.00E+00	1.90E+01	3.71E-03	7.70E-01	2.08E+02	0	3.36E+02	0.00E+00	0.00E+00	0.00E+00
Aliphatic C7-C8	4.00E+01	5.00E+01	9.55E+01	7.38E-04	7.70E-01	1.04E+03	0	2.81E+02	0.00E+00	0.00E+00	0.00E+00
Aliphatic C9-C10	5.00E+01	5.00E+01	9.81E+01	7.19E-04	7.70E-01	1.07E+03	0	2.31E+01	0.00E+00	0.00E+00	0.00E+00
Aliphatic C11-C12	6.00E+01	5.00E+02	8.66E+02	8.15E-05	7.70E+01	9.45E+05	0.024	1.53E+01	2.38E-02	2.52E-08	3.10E-04
Aliphatic C13-C16	7.00E+01	5.00E+04	8.50E+04	8.30E-07	7.70E+01	9.28E+07	0.249	3.50E+01	2.49E-01	2.68E-09	3.24E-03
Aliphatic C17-C21	9.00E+01	5.00E+06	8.50E+06	8.30E-09	7.70E+01	9.28E+09	0.377	1.00E+01	3.77E-01	4.06E-11	4.90E-03
Aromatic C5-C6	2.00E-01	5.00E-01	1.02E+00	6.90E-02	7.10E-02	1.03E+00	0	1.20E+03	0.00E+00	0.00E+00	0.00E+00
Aromatic C7-C8	3.00E-01	5.00E-01	1.05E+00	6.73E-02	2.90E+01	4.31E+02	0	3.08E+02	0.00E+00	0.00E+00	0.00E+00
Aromatic C9-C10	3.00E-01	5.00E+00	8.70E+00	8.11E-03	6.20E-01	7.65E+01	0	3.07E+02	0.00E+00	0.00E+00	0.00E+00
Aromatic C11-C12	1.00E-01	5.00E+00	8.65E+00	8.16E-03	6.20E+01	7.60E+03	0.013	1.02E+02	1.28E-02	1.69E-06	2.07E-04
Aromatic C13-C16	3.00E-02	5.00E+01	8.51E+01	8.29E-04	1.23E+01	1.49E+04	0.134	3.00E+02	1.34E-01	9.01E-06	1.09E-02
Aromatic C17-C21	4.00E-03	5.00E+01	8.51E+01	8.29E-04	1.23E+01	1.49E+04	0.153	3.50E+01	1.53E-01	1.03E-05	1.24E-02
Aromatic C22-C35	4.00E-05	5.00E+02	8.50E+02	8.30E-05	1.23E+01	1.49E+05	0.050	3.50E+00	5.02E-02	3.38E-07	4.07E-03
						Total:	1	TPH CUL (Eqs 5 & 6):		46,866	27.79

Fate and Transport Parameters

Parameter	Symbol	Value	Units	Source
Fraction organic carbon in soil	f_{oc}	0.005	unitless	Table 3
Groundwater Darcy velocity	U_{gw}	3465	cm/yr	Table 3
Infiltration rate	I	25	cm/yr	Table 3
Intermediate leaching factor 2	LFi2	23.10	unitless	Equation 7
Mixing zone thickness	δ_{gw}	200	cm	Table 3
Soil bulk density	ρ_s	1.7	g/cm^3	Table 3
Volumetric air in vadose zone	θ_{as}	0.26	cm^3/cm^3	Table 3
Volumetric water in vadose zone	θ_{ws}	0.12	cm^3/cm^3	Table 3

Table 3
Groundwater and Soil Cleanup Levels for Diesel, Noncancer Effects
Protection of Groundwater for Residential Scenario

Width of source parallel to groundwater flow	W	1200	cm	Table 3

Additional Abbreviations

Abbreviation	Definition
C_{sat}	Soil concentration at which dissolved pore-water and vapor phases become saturated
CUL	Cleanup level NOTE: Cleanup level is 100 times the CUL based on 10 mg/L for TPH. This accounts for 99% attenuation
Eq	Equation
f	Fraction of compound group in petroleum mixture
GW	Groundwater
H	Henry's law constant
INH	Inhalation correction factor
k_{oc}	Organic carbon partition coefficient
k_s	Soil-water sorption coefficient
LFi_1	Intermediate leaching factor 1
LF_{sw}	Leaching factor from subsurface soil to groundwater
Min	Minimum of f or C_{sat}
RfDo	Oral reference dose
Tbl	Table
TPH	Total petroleum hydrocarbons
TPHCWG	TPH Criteria Working Group
WAC	Washington Administrative Code

Equations

Number	Equation	Source
1	$LFi_1 = \theta_{ws} + k_s \times \rho_s + H \times \theta_{as}$	ASTM E 1739-95 (partial equation designed for computational ease)
2	$LF_{sw} = \rho_s / [LFi_1 \times (1 + LFi_2)]$	ASTM E 1739-95 Table X2.5
3	Not used.	
4	Soil CUL = GW CUL / LF_{sw}	
5	Soil TPH CUL = 1 / sum (Min / Soil CUL)	TPHCWG
6	GW TPH CUL = 1 / sum (f / GW CUL)	
7	$LFi_2 = U_{gw} \times \delta_{gw} / (I \times W)$	ASTM E 1739-95 (partial equation designed for computational ease)