Developing Risk-Based Standards for Residential Heating Oil Tank Sites

Heating Oil Tank Generic Remedy Addendum
Generic Risk Assessment Documentation

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1.0 Purpose

The Department of Environmental Quality (DEQ) Underground Storage Tank (UST) Program has developed a guidance document on *Risk-Based Decision Making for the Remediation of Petroleum-Contaminated Sites* (DEQ, 1999 – updated September 22, 2003). Although that document is primarily intended for the remediation of releases from gas stations and other commercial properties with USTs, the procedures are generally applicable to other types of sites, including residential heating oil tank (HOT) sites. However, conditions at residential HOT sites are likely to be much more homogeneous than at UST sites in general. Since there are a large number of HOT sites that could benefit from standards based on HOT-specific conditions, the Department examined the factors used in the risk-based decision making (RBDM) guidance to determine if it is feasible to develop alternative standards for releases of heating oil from residential HOTs.

The purpose of this document is to summarize the results of the Department's findings and make recommendations on their use for the UST program's *Heating Oil Tank Generic Remedy Guidance Document* (DEQ, 2000 – updated August 2007). The review was carried out by following a process similar to what would be used for a site-specific risk assessment. The steps were:

- Compile and review data, both from published sources and from soil samples collected at residential HOT sites, on concentrations of constituents found in heating oil and in soil samples from heating oil contaminated sites;
- Develop a conceptual site model (CSM) describing the typical residential heating oil site and the potential exposure pathways resulting from heating oil releases;
- Screen the data using generic risk-based concentrations (RBCs) from the Department's RBDM guidance; and
- If appropriate, develop residential HOT-specific RBCs or modifications to the RBDM guidance that might be implemented in the form of a generic remedy specifically for residential HOT sites.

An additional task was to determine if constituent data and risk-based concentrations could be used to recommend when TPH measurements might be used for risk-based closures at residential HOT sites without the need for constituent data.

2.0 Data Sources

2.1 Field Data

Members of the Residential Heating Oil Generic Remedy Workgroup submitted analytical data for 258 soil samples collected from residential heating oil tank sites. The breakdown of sample sources is listed below.

DEQ Northwest Region Office 31

DEQ Western Region Office	26
Bergeson-Boese & Associates	93
Goodman Brothers, Inc.	108

Since the samples were collected by different groups, analyzed by different laboratories, and are from work done over a several year period, the Department believes that there is probably more variation than would be obtained from a formal study. However, the data are still useful for establishing ranges and limits for the constituent levels found in soils at typical residential HOT sites in Oregon.

2.2 Literature Data

The literature data for the constituent concentrations in heating oil were obtained from Potter and Simmons (1998). This reference, which was developed for the Total Petroleum Hydrocarbon Criteria Working Group, includes tables of composition data for 11 petroleum products. The two tables from which data were extracted for this review are Table 10: Summary of Composition Data for Diesel (#2) Fuel Oil, and Table 11: Summary of Composition Data for No. 2 Fuel Oil. Both tables are referenced since the characteristics of the two products described in the reference (e.g., alkane range, distillate characteristics, and compound classes) are identical except for the end use. Diesel (#2) is used for "high-speed engines" whereas No. 2 fuel oil is used for “domestic burners, medium capacity commercial, industrial burners." Note that these data are for product samples, whereas the field data are for soil samples contaminated with product.

3.0 Data Summary

3.1 Tests Performed

Samples were analyzed for total petroleum hydrocarbons (TPH); the aromatic hydrocarbons benzene, toluene, ethylbenzene, and total xylenes (BTEX); and polynuclear aromatic hydrocarbons (PAHs). All 258 samples were analyzed for TPH and for benzene. However, not all were tested for toluene, ethylbenzene, xylenes, nor all 16 of EPA's "priority pollutant" PAHs. Table 1 summarizes how many samples were tested for each constituent and how often each constituent was detected.

Of the 20 constituents for which we have field data, 17 are included in the Department's Table of Risk-Based Concentrations (RBCs) (DEQ, 1999 – updated September 22, 2003). The three shown in gray — acenaphthylene, phenanthrene, and benzo[g,h,i]perylene — are not included in the Table of RBCs since there are no toxicological data (*i.e.*, slope factors or reference doses) for these compounds in EPA's Integrated Risk Information System (IRIS) with which to calculate RBCs. Therefore, these three constituents are not included in the data analysis. The remaining 17 are either categorized as carcinogens or noncarcinogens as indicated by "c" or "nc" in the table.

Five of the remaining compounds — benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, indeno[1,2,3-cd]pyrene, and dibenz[a,h]anthracene — were detected so infrequently that there were insufficient data to analyze. Based on the low detection frequency, it was assumed that these constituents are not routinely present at residential heating oil. Therefore, these five compounds were not included in the generic risk analysis.

Table 1: Summary of Constituents Detected in Soil Samples

Constituent		No. of Samples	Detection Frequency	Max. Concentration
TPH		258	258	107,000 ppm
Benzene	c	258	84	3,700 ppb
Toluene	nc	209	120	32,200
Ethylbenzene	nc	209	175	74,000
Xylenes	nc	209	186	136,000
Acenaphthene	nc	214	176	13,260
Acenaphthylene[1]		214	82	4,100
Anthracene	nc	213	151	21,000
Benz[a]anthracene	c	168	17	410
Benzo[a]pyrene[2]	c	168	1	160
Benzo[b]fluoranthene[2]	c	168	2	300
Benzo[g,h,i]perylene[1]		167	1	90
Benzo[k]fluoranthene[2]	c	168	1	93
Chrysene	c	213	68	430
Dibenz[a,h]anthracene[2]	c	168	0	0
Fluoranthene	nc	213	120	3,000
Fluorene	nc	214	186	103,000
Indeno[1,2,3-cd]pyrene[2]	c	168	1	83
Naphthalene	nc	214	166	67,000
Phenanthrene[1]		214	193	179,000
Pyrene	nc	213	166	23,500

[1] Toxicity information is not available in EPA's Integrated Risk Information System. Therefore, RBCs have not been calculated for these compounds.

[2] Due to their very low detection frequency, it is assumed that these compounds do not contribute to risk at residential heating oil tank sites.

Data for the remaining 12 constituents were analyzed in the following manner:

1. The number of samples analyzed, frequency of constituent detection, and range of results were determined.
2. Sample groupings were made to count numbers of samples exceeding certain constituent levels.
3. Constituent and TPH data were used to calculate weight percents for samples having detectable levels of the constituent of interest. Weight percentage ranges and averages were determined.
4. A plot of the constituent versus TPH was prepared to visually examine trends and data scatter and to estimate an upper bound for the weight percentage of constituent.
5. Regression analysis was used out to determine significance of trend and ability to predict constituent levels from TPH levels.

The results of the field data were compared to literature data for the composition of heating oil and diesel oil.

3.2 Constituent Results

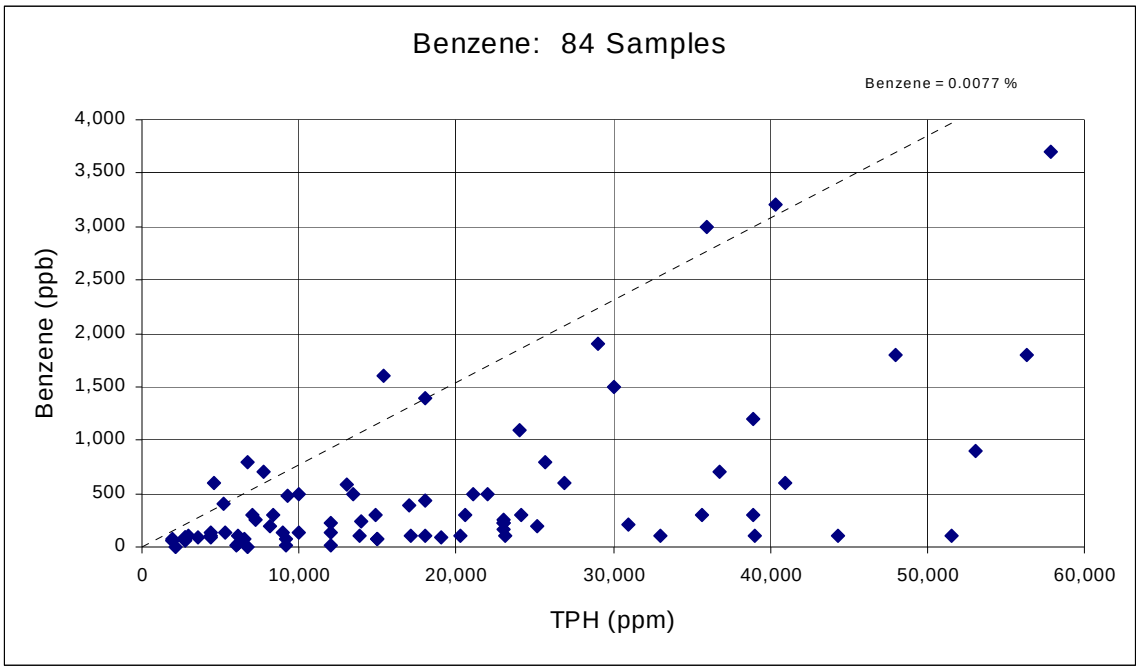
Data summaries for the 12 constituents covered in this report are in Appendix A. Representative results are discussed below.

3.2.1 Benzene

Benzene was detected in 84 of the 258 samples, with concentrations ranging up to 3700 ppb. This is the highest concentration of any of the carcinogenic constituents. 65 out of the 84 detects exceed 100 ppb while 13 exceed 1000 ppb. The benzene concentrations range from 6.7×10^{-5} % up to 0.013% of the TPH. The average weight percent is 0.0028. This is about an order of magnitude lower than the average concentration of 0.029 reported by Potter and Simmons (1998) for diesel (#2) fuel oil. It is not surprising to see lower values in the soil data since benzene is volatile, leachable, and biodegradable.

A regression analysis of benzene versus TPH was performed with Microsoft Excel 97®. The initial analysis showed that the intercept was not significantly different from zero, so a subsequent analysis was run using the no-intercept option. This, of course, is consistent with the idea that the benzene is from the TPH and both concentrations should converge on zero. Results indicate that there is a significant trend between benzene and TPH. However, the wide scatter in the data (see Figure 1) leads to an R-square value of only 0.29. Therefore, using the results of the regression to predict benzene from TPH values would give results with very large uncertainties.

Figure 1: Plot of Benzene versus TPH Showing Data Trend and Scatter



Despite the scatter in the results, this data set can still be used to set generic standards. Since generic standards must be conservative enough to cover all sites to which they might be applied,

data sets with widely varying values are better represented by some "upper limit" rather than an average value. Unless the data set is small, the maximum value ("worst case") is usually not used for this limit, thus avoiding the use of data points that may be outliers or errors. Rather, the 90^{th} or 95^{th} percentiles are commonly used for such purposes. When combined with other equally conservative exposure factors to produce generic RBCs, the results are conservative enough to adequately protect against unacceptable exposures.

Since the Department relies on the 90^{th} percentile for establishing default exposure factors for deterministic risk assessments (DEQ, 1998b – Revised October 1999 – Editorial Updates January 2008), that percentile will be used in this document for defining default contaminant weight percentages associated with heating oil contamination at residential HOT sites in Oregon. For the benzene data set, the 90^{th} percentile for weight percentage versus TPH is 0.0077%. The dashed line in the graph above represents the line where benzene is 0.0077% of the TPH concentration.

3.2.2 Toluene

Toluene was detected more frequently than benzene, being measured in 120 out of 209 samples. This is consistent with the fact that toluene concentrations range up to 32,200 ppb; about 10 times higher than the benzene concentrations. 101 out of the 120 detects exceed 100 ppb, 39 exceed 1000 ppb, and 12 exceed 10,000 ppb. The toluene concentrations range from 2.2×10^{-5}% up to 0.23% of the TPH. The average weight percent is 0.016. This is about an order of magnitude lower than the average concentration of 0.18 reported by Potter and Simmons (1998) for diesel (#2) fuel oil, but about 1/4 of the concentration listed for No. 2 fuel oil. The 90^{th} percentile for the toluene weight percent is 0.047.

The results of the regression analysis of toluene versus TPH were similar to that for benzene: the trend is significant but the widely scattered data yield an R-square of about 0.3.

3.2.3 Ethylbenzene and Xylenes

Ethylbenzene and xylenes continue the trend of being detected at higher frequencies and at higher concentrations than benzene. They were detected in 175 and 186 samples at concentrations ranging up to 74,000 ppb and 136,000 ppb respectively. The average weight percent of ethylbenzene in the field data, 0.037%, falls within the range of the literature values, whereas the average xylene weight percent, 0.11%, is only 1/5 to 1/2 of the literature values. The 90^{th} percentiles are 0.062 and 0.19, respectively.

3.2.4 Naphthalene

Naphthalene was detected in 166 out of 214 samples, with concentrations ranging up to 67,000 ppb. Naphthalene has the second highest concentration of the eight PAHs included in this study. 152 out of the 166 detects exceed 100 ppb, 120 exceed 1000 ppb, and 45 exceed 10,000 ppb. The naphthalene concentrations range from 2.0×10^{-4}% up to 1.6% of the TPH. The average weight percent for naphthalene is 0.085. This is less than half of the average concentration of 0.26% reported by Potter and Simmons (1998) for diesel (#2) fuel oil, and 0.22% for No. 2 fuel oil. The 90^{th} percentile of the field data is 0.16%.

The results of the regression analysis of naphthalene versus TPH were similar to that for benzene and toluene: the trend is significant but the widely scattered data yield an R-square of about 0.3.

3.2.5 Fluorene

Fluorene is the most frequently detected of the noncarcinogenic PAHs and the one with the highest measured concentration. It was detected in 186 out of 214 samples with concentrations ranging up to 103,000 ppb. 131 of the 186 detects exceed 1000 ppb and 16 exceed 10,000 ppb.

The fluorene concentrations range from 6.6 x 10^{-4}% up to 17 % of the TPH, with an average weight percent of 0.14%. This is considerably higher than the average literature values of 0.086% for diesel (#2) fuel oil, and 0.019% for No. 2 fuel oil reported by Potter and Simmons (1998). However, the 17% result is suspected of being an error since the next highest result is 0.55%. The average without the suspected error is 0.048%, a value that falls within the range reported by Potter and Simmons (1998). The 90th percentile is 0.090%.

3.2.6 Chrysene

Chrysene is the most frequently detected of the carcinogenic PAHs and also the one with the highest measured concentration. It was detected in 68 out of 213 samples with concentrations ranging up to 430 ppb. 31 of the 68 detects exceed 100 ppb. Compared to the noncarcinogens, however, its detection frequency and concentrations are significantly lower.

Chrysene concentrations range from 1.1 x 10^{-4}% up to 5.9 x 10^{-3}% of the TPH, with an average weight percent of 7.8 x 10^{-4}%. The average lies within the range of the average concentration of 4.5 x 10^{-5}% reported by Potter and Simmons (1998) for diesel (#2) fuel oil, and 1.4 x 10^{-4}% for No. 2 fuel oil. The 90th percentile of the field data is 0.0012%. The lower volatility of fluorene and chrysene may be the reason that their field data are closer to their respective literature values than are the BTEX data.

The results of the regression analysis of the chrysene data were similar to that for benzene, toluene, and naphthalene. However, decreased scatter in the data resulted in an improved R-square of about 0.4. The improved correlation may also be the related to chrysene being nonvolatile.

3.2.7 Benz[a]anthracene

Benz[a]anthracene is the only other carcinogenic PAH detected in more than 1 or 2 samples. It was, however, only detected in 17 out of 168 samples. Concentrations range up to 410 ppb. The average concentration is 8.4 x 10^{-4}% of TPH, which is higher than the values of 9.6 x 10^{-5}% and 4.5 x 10^{-5}% reported by Potter and Simmons (1998) for diesel (#2) fuel oil and No. 2 fuel oil, respectively. The 90th percentile corresponds to a concentration of 0.0042%.

3.3 Composition of Generic Heating Oil Contaminated Soil

Using the information discussed above along with similar data on acenaphthene, anthracene, fluoranthene and pyrene found in Appendix A, the composition of a generic heating oil contaminated soil was developed by using the 90th percentiles to represent the weight percent of each constituent. The calculated percentages are listed in the Table 2 (shown rounded to one

significant figure). Note that the five constituents shown in gray are eliminated from further consideration due to their zero or near-zero detection frequency. The remaining 12 constituents are considered contaminants of potential concern (COPCs) at residential heating oil sites.

Table 2: Weight Percentages of Constituents to TPH in Heating Oil Soil Samples

Constituent	Weight Percent (90th Percentile)
Benzene	0.008
Toluene	0.05
Ethylbenzene	0.06
Xylenes	0.2
Acenaphthene	0.03
Anthracene	0.02
Benz[a]anthracene	0.004
Benzo[a]pyrene	0
Benzo[b]fluoranthene	0
Benzo[k]fluoranthene	0
Chrysene	0.001
Dibenz[a,h]anthracene	0
Fluoranthene	0.006
Fluorene	0.09
Indeno[1,2,3-cd]pyrene	0
Naphthalene	0.2
Pyrene	0.02

Note again that these are generic percentages of constituents measured in heating oil contaminated soil samples, not in pure product. As discussed in some of the specific comments in sections 3.2.1 through 3.2.7, these percentages range from roughly an order of magnitude lower than pure product for the more volatile constituents like benzene, to about the same as the product for nonvolatile constituents like fluorene and chrysene.

The Department's Table of RBCs was used to screen these COPCs in the context of the CSM developed by the residential HOT generic remedy workgroup. The contaminants of concern that remained after the screening were examined to establish cleanup levels for residential heating oil sites that meet acceptable risk levels.

4.0 Conceptual Site Model

4.1 Description

The information in this document pertains to releases from residential heating oil tanks. These are typically sites that meet all of the following conditions:

- Single family residence approximately 1200 square feet or larger;
- Contamination only from No. 2 fuel oil released from an underground heating oil tank;
- No groundwater contamination;

- No free product;
- No surface soil contamination;
- Soil contamination is located at a depth of 3 feet or greater;
- Contamination is only found on site;
- There are no dirt floors or conditions which would allow contact with contaminated soils;
- Sufficient data are available to estimate the amount of contaminated soil remaining on site; and
- The volume of contaminated soil remaining on the site does not exceed 65 cubic yards.

Although the conditions described in this CSM are not based on an analysis of site data, the generic remedy workgroup, based on their combined experience at hundreds of residential HOT sites, believe that these conditions represent a significant number of the sites.

4.2 Exposure Pathways

For a summary of the pathways covered by the Department's Table of RBCs, please refer to Table 2.4 in DEQ (1999 – updated September 22, 2003). Since one of the underlying assumptions of this study is that it is only for contaminated soils, all of the groundwater exposure pathways are eliminated from consideration. The only pathways reviewed for the residential HOT generic remedy are, therefore:

- Soil ingestion, inhalation of particulates or vapors, and dermal absorption;
- Volatilization to outdoor air from contaminated subsurface soil;
- Vapor intrusion into buildings from contaminated subsurface soil; and
- Leaching to groundwater from contaminated vadose zone soil.

4.2.1 Ingestion, Inhalation of Particulates or Vapors, and Dermal Absorption

This pathway is for situations where people come into direct contact with contaminated soil. For residential and commercial settings the RBDM guidance (DEQ, 1999 – updated September 22, 2003) indicates that this pathway can be eliminated when there is no contamination in the top three feet of soil. However, in cases where an excavation is likely in the area where the contamination is located, the excavation worker scenario should be applied. Since the CSM indicates that there is no soil contamination in the top three feet, the standard residential exposure can be eliminated. However, since the contamination is likely to be in areas where the soil could be encountered if construction is done on the residence, the excavation worker scenario should be retained for additional review.

4.2.2 Volatilization to Outdoor Air

This pathway should be considered at any site where vadose zone soils are contaminated with volatile compounds. Since heating oil does contain volatile constituents, such as benzene,

toluene, ethylbenzene and xylenes, this pathway should be retained for additional review under a residential scenario.

4.2.3 Vapor Intrusion into Buildings

This pathway should be considered whenever vadose zone soils contaminated with volatile contaminants are located beneath or within 50 feet of a residential building. This pathway should be retained for additional review under a residential scenario.

4.2.4 Leaching to Groundwater

This pathway should be considered whenever vadose zone contamination overlies an aquifer that is currently used or likely to be used for drinking water or other beneficial uses. Although it may be possible to eliminate this on a site-specific basis, this pathway should be retained for additional review for the purposes of a generic remedy.

5.0 Screening With Generic RBCs

Using the pathways retained from the initial screening of the CSM, and the list of constituents measured at residential heating oil sites, an initial list of RBCs was assembled from the Table of RBCs in DEQ (1999 – updated September 22, 2003). This reduced list of 48 constituent-pathway pairs is shown in Table 3. All numbers are mg/kg (ppm) of the constituent listed in the first column. See Appendix A in DEQ (1999 – updated September 22, 2003) for an explanation of the notes.

Using the constituent-specific RBCs in Table 3, and the constituent weight percentages in Table 2, it is possible to calculate heating oil TPH concentrations that result in the same level of protection as the constituent concentrations in Table 3 by using Equation [1].

Table 3: RBCs from DEQ (1999) for Pathways and Constituents Covered by HOT Generic Remedy

Exposure Pathway →		Direct Contact RBCss		Volatilization to Outdoor Air RBCso		Vapor Intrusion into Buildings RBCsi		Leaching to Groundwater RBCsw	
Receptor Scenario →		Excavation Worker		Residential		Residential		Residential	
Contaminant of Concern	Note		Note		Note		Note		Note
Benzene	c, v	1,100	>Csat	11		0.091		0.044	
Toluene	nc, v	40,000	>Csat	540	=Csat	190		390	
Ethylbenzene	nc, v	85,000	>Csat	330	=Csat	330	=Csat	330	=Csat
Xylenes	nc, v	72,000	>Csat	360	=Csat	360	=Csat	360	=Csat
Acenaphthene	nc, v	110,000	>Csat	100	=Csat	100	=Csat	100	=Csat
Anthracene	nc, v	750,000	>Csat	6.4	=Csat	6.4	=Csat	6.4	=Csat
Benz[a]anthracene	c, nv	270	>Csat	19	=Csat	19	=Csat	8.6	
Chrysene	c, nv	27,000	>Csat	3.2	=Csat	3.2	=Csat	3.2	=Csat
Fluoranthene	nc, nv	110,000	>Csat	110	=Csat	110	=Csat	110	=Csat
Fluorene	nc, v	94,000	>Csat	140	=Csat	140	=Csat	140	=Csat
Naphthalene	nc, v	1,000	>Csat	230		290		310	=Csat
Pyrene	nc, nv	84,000	>Csat	71	=Csat	71	=Csat	71	=Csat

$$\text{Equivalent TPH RBC (mg/kg)} = \frac{\text{Constituent RBC (mg/kg)}}{\text{Wt. \% of Constituent}} \times 100 \qquad [1]$$

The results are shown in Table 4. All of the numbers in Table 4 are TPH concentrations in mg/kg (ppm). The compounds listed in the first column are the constituents having acceptable risk levels protected by the associated TPH levels.

The results show that many of the risk-based TPH concentrations derived by this approach exceed 1 million parts-per-million. This, of course, is not physically possible. Therefore, we can easily eliminate from consideration those combinations of constituents and pathways with TPH RBCs exceeding 1.0E+06. The 15 constituent-pathway pairs eliminated for this reason are shown shaded in gray.

Of the 33 remaining constituent-pathway combinations, 28 exceed 100,000 ppm. Although the Department has encountered sites where TPH levels have exceeded 40,000 to 50,000 ppm, levels in excess of 100,000 ppm are rare, if they exist at all.[1] Furthermore, TPH concentrations at the 100,000-ppm level (10% product) are probably indicative of the presence of free product. Since sites with free product are NOT included in the CSM, these constituent-pathway combinations can be eliminated from consideration. In fact, since free product mobility may also be a "non-risk" or nuisance concern, it would be worthwhile to consider setting a maximum TPH level for a residential heating oil generic remedy which would serve the dual purpose of protecting against mobility and eliminating these low-risk pathways from consideration. The Department uses a TPH concentration of 10,000 ppm for mobility concerns at low-risk sites (DEQ, 1998b – Revised October 1999 – Editorial Updates January 2008). A similar maximum TPH level would be useful at residential HOT sites being remediated under a generic remedy.

Table 4: Equivalent TPH RBCs for Residential Heat Oil Sites (mg/kg)

Exposure Pathway →		Direct Contact RBCss		Volatilization to Outdoor Air RBCso		Vapor Intrusion into Buildings RBCsi		Leaching to Groundwater RBCsw	
Receptor Scenario →		Excavation Worker		Residential		Residential		Residential	
Constituent Protected by TPH RBC	Note		Note		Note		Note		Note
Benzene	c, v	1.4E+07	>Csat	1.4E+05		**1.1E+03**		**5.5E+02**	
Toluene	nc, v	8.0E+07	>Csat	1.1E+06	=Csat	3.8E+05		7.8E+05	
Ethylbenzene	nc, v	1.4E+08	>Csat	5.5E+05	=Csat	5.5E+05	=Csat	5.5E+05	=Csat
Xylenes	nc, v	3.6E+07	>Csat	1.8E+05	=Csat	1.8E+05	=Csat	1.8E+05	=Csat
Acenaphthene	nc, v	3.7E+08	>Csat	3.3E+05	=Csat	3.3E+05	=Csat	3.3E+05	=Csat
Anthracene	nc, v	3.8E+09	>Csat	3.2E+04	=Csat	3.2E+04	=Csat	3.2E+04	=Csat
Benz[a]anthracene	c, nv	6.8E+06	>Csat	4.8E+05	=Csat	4.8E+05	=Csat	2.2E+05	

[1] The theoretical maximum concentration of 1 million parts per million TPH could only exist for pure product (*i.e.*, no soil, water or air could be present in the sample). In a soil sample with porosity = 0.4, bulk density = 1.7 g/cm^3, and fuel oil density = 0.9 g/cm^3, a fuel oil saturated sample would have a maximum concentration of approximately 175,000 ppm TPH. The presence of water and/or air would reduce this even further.

Chrysene	c, nv	2.7E+09	>Csat	3.2E+05	=Csat	3.2E+05	=Csat	3.2E+05	=Csat
Fluoranthene	nc, nv	1.8E+09	>Csat	1.8E+06	=Csat	1.8E+06	=Csat	1.8E+06	=Csat
Fluorene	nc, v	1.0E+08	>Csat	1.6E+05	=Csat	1.6E+05	=Csat	1.6E+05	=Csat
Naphthalene	nc, v	5.0E+05	>Csat	1.2E+05		1.5E+05		1.6E+05	=Csat
Pyrene	nc, nv	4.2E+08	>Csat	3.6E+05	=Csat	3.6E+05	=Csat	3.6E+05	=Csat

Applying a 10,000 ppm TPH maximum as a requirement of the HOT generic remedy leaves only two pathway-constituent pairs remaining that may result in unacceptable levels of risk (shown in bold in Table 4). These are benzene/vapor-intrusion-into-buildings, and benzene/leaching-to-groundwater. The screening TPH levels for these pathways are on the order of 500 - 1000 ppm; levels commonly encountered at residential HOT sites. Therefore, this process cannot screen out these two pathways. They will be examined to determine if there are any conditions specific to residential HOT sites that may be used to calculate HOT-specific cleanup levels. If not, the contaminant specific cleanup levels in Table 3 or their TPH equivalents in Table 4 would be the levels to apply for these two cases.

6.0 Remedy-Specific Considerations

The purpose of a remedy-specific analysis is similar to that of a site-specific risk assessment. The pathways and constituents that are not screened out with generic RBCs are examined to determine if any remedy-specific conditions can be used to generate alternative RBCs suitable to the remedy.

6.1 Vapor Intrusion Into Buildings

The RBCs for the vapor-into-buildings pathway were derived from a number of generic factors including those listed in Table 5 (DEQ, 1999 – updated September 22, 2003).

Table 5: Factors Associated With the Vapor-Intrusion-Into-Building Pathway

Factor (units)	Symbol	Value
Averaging Time - Carcinogen (yr)	AT_c	70
Averaging Time - Noncarcinogen (yr)	AT_n	30
Averaging Time - Noncarcinogen, Child (yr)	AT_{nc}	6
Body Weight - Adult (kg)	BW_a	70
Body Weight - Child (kg)	BW_c	15
Exposure Duration - Adult (yr)	**ED**	**30**
Exposure Duration - Child (yr)	ED_c	6
Exposure Frequency (day/yr)	EF	350
Inhalation Rate - Adult (m^3/day)	IRA	15.2
Inhalation Rate - Child (m^3/day)	IRA_c	8.30
Building Air Exchange Rate (1/day)	**ER**	**24**
Building Height (indoor air mixing zone) (cm)	**L_B**	**200**
Thickness of Subsurface Contamination (cm)	L_s	200

Thickness of Clean Soils Under Building (cm)	L_{cb}	100
Thickness of Contaminated Soils Under Building (cm)	L_{sb}	200
Fraction of Contaminated Soils Under Building	f_{sb}	0.50
Soil bulk density (g/cm^3)	**ρ_b**	**1.7**

Although many of these factors are not amenable to site-specific determination, those relating to the size and location of the contaminated zone are candidates for modification for the particular conditions of the residential HOT CSM. The concentrations in the Table of RBCs are designed to be protective for exposure to a 2-meter thick layer of contaminated soil (L_s) that extends under 50% of the building (f_{sb}). This means that for the 1200 square foot (56 m^2) or larger residence covered by the residential heating oil generic remedy, the assumed amount of contaminated soil is at least 112 m^3, or approximately 150 yd^3. Since the generic remedy is for cases where the maximum amount of contaminated soil remaining at the site is 65 yd^3 (50 m^3), alternative standards may be worth developing.

A conservative method for estimating soil concentrations that are protective of the vapor-intrusion-to-buildings pathway is to base the outcome on the assumption that all of the contaminant in the soil will make it into the building during the exposure duration. If that is the case, the average air concentration in the building over the exposure duration (C_{air}) is:

$$C_{air} = \frac{V_{soil} \cdot \rho_b \cdot C_{soil}}{V_B \cdot ER \cdot ED} \qquad [2]$$

where:

V_{soil} = the volume of the contaminated soil
ρ_b = the bulk density of the soil
C_{soil} = the concentration of the contaminated soil
V_B = the volume of the building
ER = the building air-exchange rate
ED = the exposure duration

In order to meet the acceptable risk level, the average air concentration must not exceed the RBC_{air} for any constituent. Therefore, the RBC for soil to indoor air (RBC_{si}) calculated by this method can be obtained by rearranging equation [2] and substituting the building area times height ($A_B \cdot L_B$) for volume to derive:

$$RBC_{si} = \frac{A_B \cdot L_B \cdot ER \cdot ED \cdot RBC_{air}}{V_{soil} \cdot \rho_b} \qquad [3]$$

Using the four default parameters shown in bold in Table 5, remedy-specific parameters for A_B (56 m^2) and V_{soil} (50 m^3), the RBC_{air} for benzene from the Department's Table of RBCs (0.295

g/μm^3), and appropriate unit conversion factors, the RBC_{si} for benzene for the conditions specified in the CSM is:

$$RBC_{si}\ (mg/kg) = \frac{56\,m^2 \cdot 2\,m \cdot 24\,day^{-1} \cdot 30\,yr \cdot 0.295\,\mu g/m^3}{50\,m^3 \cdot 1700\ kg/m^3} \cdot \frac{365\,day/yr}{10^3\ \mu g/mg} \quad [4]$$

$$RBC_{si}\ =\ 0.1\ mg/kg \quad [5]$$

A TPH-equivalent RBC_{si} can be calculated from this result using Equation [1] and the 90th percentile weight percent of benzene at heating oil sites (0.008%).

$$Equivalent\ TPH\ RBC_{si}\ =\ \frac{0.1\ mg/kg}{0.008} \times 100 \quad [6]$$

$$Equivalent\ TPH\ RBC_{si}\ =\ 2500\ mg/kg \quad [7]$$

Therefore, for residential heating oil tank sites meeting all of the conditions of the CSM, a cleanup level of 2500 ppm TPH can be considered protective for the vapor intrusion pathway and could be applied without requiring analysis for individual constituents. In order to leave contamination greater than 2500 ppm TPH, soil samples would have to be analyzed for benzene concentrations and shown to contain no greater than 0.1 ppm. If benzene concentrations exceed 0.1 ppm, then either additional cleanup would be required, or a site-specific risk assessment would have to be carried out. A site-specific assessment would only be worthwhile if conditions at the site differed significantly from those used in this discussion. The easiest site-specific changes would be the volume of the contaminated soil and the area of the house.

6.2 Leaching to Groundwater

The RBCs for the leaching-to-groundwater pathway were derived from a number of generic and contaminant-specific factors including those listed in Table 6 (DEQ, 1999 – updated September 22, 2003). A relatively conservative infinite-source model was used for the calculation. As in the case of the vapor intrusion pathway discussed in Section 6.1, most of these factors do not lend themselves to remedy-specific evaluation or modification. However, since infinite source models are better for estimating potential contamination from large source areas, and since the residential HOT CSM incorporates a relatively small source, this pathway is also a candidate for remedy-specific modeling.

The modeling was carried out by following a procedure used by the Department in an earlier study for the development of the soil cleanup levels contained in OAR 340-122-0045 (DEQ, 1992). The 1992 modeling study used SESOIL and AT123D to simulate leaching from a 10 m x 10 m x 1 m vadose zone source with subsequent movement in the groundwater to a well 10 m downgradient. The procedure for this study was essentially the same as that used in the 1992 study. However, the following modifications were made to adapt it to the specifics of the CSM for residential HOT sites, and take advantage of updated information on the use of SESOIL:

- The source size for the SESOIL model was set at 7.1 m x 7.1 m x 1 m to represent a total volume of 50 m^3 of contaminated soils. The three 1-meter layers used in the original study (clean, contaminated, clean) were retained (see Figure 2).
- To be consistent with the factors used in the RBDM guidance, the soil bulk density and fraction of organic carbon values in Table 6 were used.
- Initial values for intrinsic permeability and disconnectedness index were taken from Hetrick *et al*. (1993).
- Using a procedure suggested by Scott *et al*. (1997), a series of test runs were carried out while varying the effective porosity and disconnectedness index to adjust the hydrogeological cycle of the model until the water content was in line with observed or expected average conditions. In this case, the goal was to be consistent with the 12% value for n_w used in the RBDM guidance.

The parameters from the RBDM guidance that were used in the models are shown in bold in Table 6.

Table 6: Factors Associated With the Leaching-to-Groundwater Pathway

Factor (units)	Symbol	Value
Averaging Time - Carcinogen (yr)	AT_c	70
Averaging Time - Noncarcinogen (yr)	AT_n	30
Averaging Time - Noncarcinogen, Child (yr)	AT_{nc}	6
Body Weight - Adult (kg)	BW_a	70
Body Weight - Child (kg)	BW_c	15
Exposure Duration - Adult (yr)	ED	30
Exposure Duration - Child (yr)	ED_c	6
Exposure Frequency (day/yr)	EF	350
Water Ingestion Rate - Adult (L/day)	IRW	2.3
Water Ingestion Rate - Child (L/day)	IRW_c	1.5
Henry's Constant	**H**	**Contaminant-specific**
Organic carbon partition coefficient (cm^3/g)	**K_{oc}**	**Contaminant-specific**
Water-filled porosity in vadose zone	**n_w**	**0.12**
Air-filled porosity in vadose zone	n_a	0.26
Fraction of organic carbon in soil	**f_{oc}**	**0.005**
Soil bulk density (g/cm^3)	**ρ_b**	**1.7**
Dilution-attenuation factor	DAF	60

The SESOIL model was run with varying vadose zone benzene concentrations until the maximum groundwater concentration predicted by AT123D for the 10-m downgradient point equaled the RBC for groundwater ingestion listed in the Table of RBCs (0.0018 mg/L). The input that gave this result was a contaminant loading of 37 $\mu g/cm^2$. Since this is the contaminant loading into a 100-cm thick layer with a bulk density of 1.7 g/cm^3, this corresponds to a concentration of 0.22 mg/kg. The groundwater concentrations predicted by AT123D are shown

in Figure 3. All of the SESOIL and AT123D input parameters, as well as the groundwater concentrations simulated by AT123D are provided in Appendix B.

Figure 2: SESOIL/AT123D Modeling Scenario

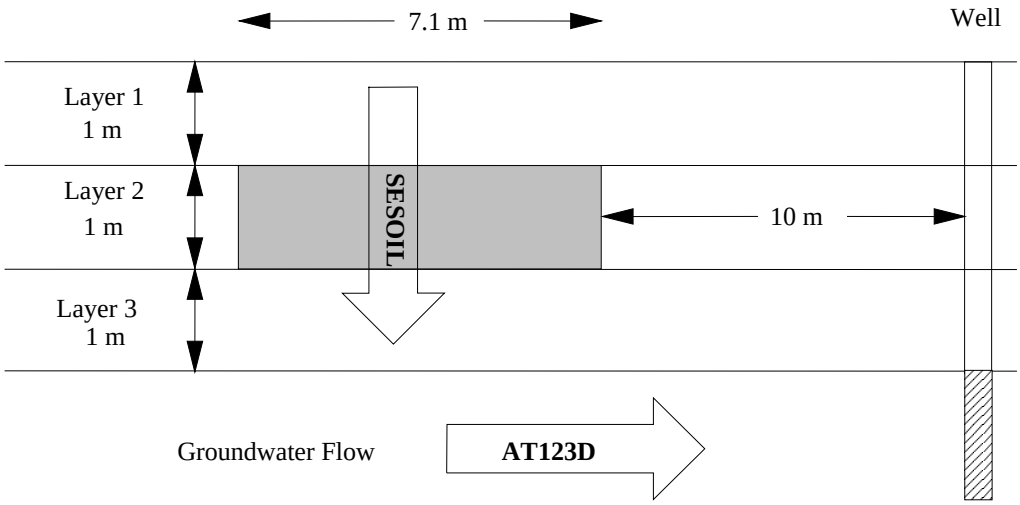
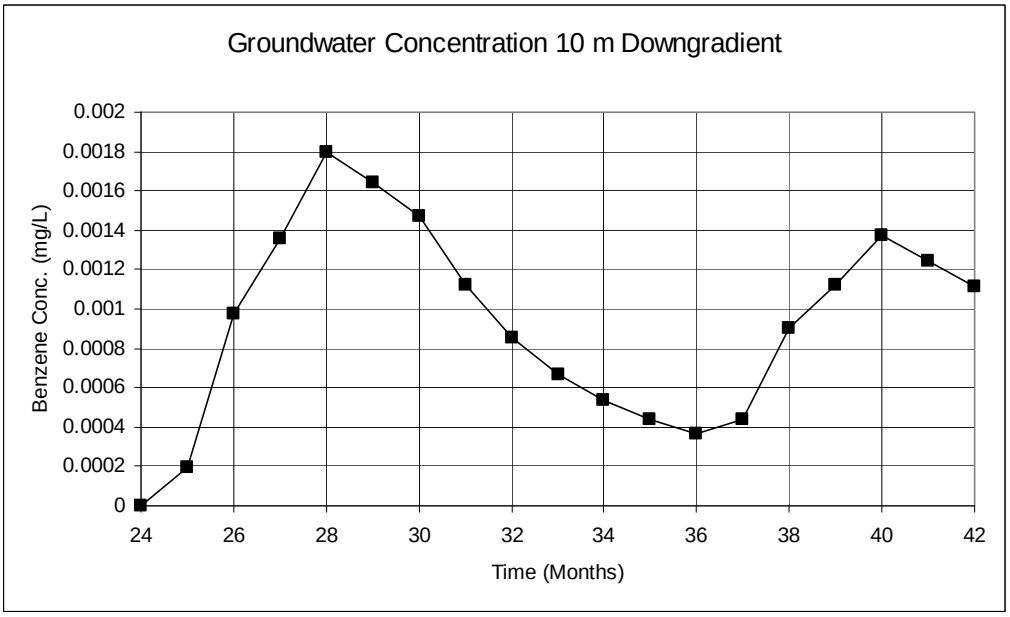


Figure 3: Groundwater Concentrations Predicted by AT123D for 0.22 mg/kg Source



7.0 Conclusions and Recommendations

Analysis of constituent and TPH data from 258 soil samples collected at residential heating oil sites indicates that for the conditions described in the residential oil CSM:

- BTEX and 8 PAHs are found with sufficient frequency to be considered potential contaminants of concern.
- The vapor-intrusion-to-buildings and the leaching-to-groundwater pathways are the only exposure pathways with the potential to generate unacceptable levels of risk;
- Benzene is the only constituent that is likely to be a contaminant of concern via the two candidate pathways;
- A benzene concentration of 0.1 mg/kg should be adequate to protect against unacceptable exposures from vapor-intrusion-to-buildings;
- Based on the amount of benzene in heating oil contaminated soil samples, a TPH level of 2500 ppm should also be adequate to protect against unacceptable exposures from vapor-intrusion-to-buildings;
- A benzene concentration of 0.22 mg/kg should be adequate to protect against unacceptable exposures from leaching-to-groundwater; and
- Based on the amount of benzene in heating oil contaminated soil samples, a TPH level of 2750 ppm should also be adequate to protect against unacceptable exposures from leaching-to-groundwater.

Based on these findings it is recommended that the following be considered when developing a generic remedy for residential heating oil sites:

- Cleanups at residential heating oil sites should be considered adequately protective without the need to require constituent analysis if remaining contamination does not exceed 2500 ppm TPH.
- TPH cleanup levels greater than 2500 ppm TPH should be adequately protective if constituent analyses show that benzene concentrations do not exceed 0.1 mg/kg.
- If site-specific modifications to the 0.1 mg/kg cleanup level are allowed by a process similar to that shown in Equations [4] and [5], site-specific values should not be allowed to exceed 0.22 mg/kg without specific consideration of the leaching-to-groundwater pathway.
- Although risk is a primary consideration, a maximum TPH level might be warranted to protect against continued product mobility and other non-risk conditions. The 10,000-ppm level required for low-impact sites in OAR 340-122-0243 should be considered.
- Analysis for PAHs may not be warranted at residential HOT sites that meet the above requirements.

Note again that comments and recommendations in this document are predicated on the site meeting all of the conditions described in the conceptual site model.

8.0 References

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Potter, T. L., and K. E. Simmons, 1998, *Total Petroleum Hydrocarbon Criteria Working Group Series, Volume 2, Composition of Petroleum Mixtures*, Amherst Scientific Publishers, Amherst, MA.

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Appendix A: Heating Oil Constituent Data Summaries

Benzene Data

258	Total samples
258	Samples tested for benzene
174	Samples were ND
84	Samples had detectable levels of benzene

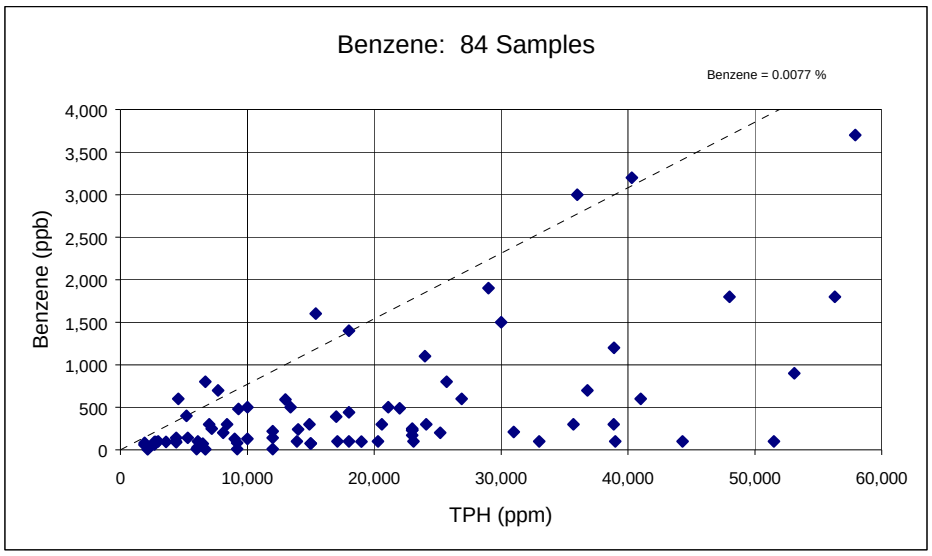
TPH Range: 1900 - 107,000 ppm
Benzene Range: 5 - 3700 ppb

84	are >=	1	ppb, with	1900	= lowest ppm TPH
65		100		2970	
46		200		4560	
25		500		4560	
13		1000		15,400	

Comparison to Literature Data

	Average Wt. Percent	Minimum	Maximum	Std. Dev	CV	No. of Samples	90th %-ile	95th %-ile
Table 10	2.9E-02	2.6E-03	1.0E-01	4.7E-02	1.6E+02	4	-	-
Table 11	NR	-	-	-	-	-	-	-
Field Data	2.8E-03	6.7E-05	1.3E-02	2.7E-03	7.5E-06	84	7.7E-03	9.1E-03

Graph of Benzene vs. TPH Data
Dashed line = 0.0077 wt. percent



SUMMARY OUTPUT: Benzene vs. TPH

Regression Statistics	
Multiple R	0.53993004
R Square	0.291524448
Adjusted R Squar	0.279476255
Standard Error	652.8535806
Observations	84

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	14556594.6	14556594.6	34.15294874	9.95381E-08
Residual	83	35376077.21	426217.7977		
Total	84	49932671.81			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
X Variable 1	0.023511036	0.002476467	9.493780553	6.7197E-15	0.018585441	0.028436631

Toluene Data

258	Total samples
209	Samples tested for toluene
89	Samples were ND
120	Samples had detectable levels of toluene

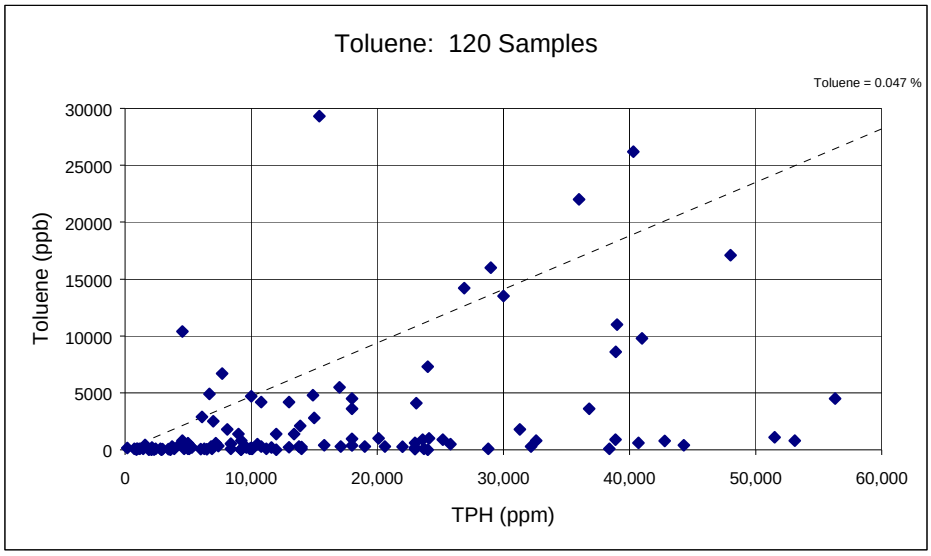
TPH Range: 190 - 82,500 ppm
Toluene Range: 5 - 32,200 ppb

120	are >=	1	ppb, with	190	= lowest ppm TPH
101		100		190	
56		500		4360	
39		1000		4560	
17		5000		4560	
12		10,000		4560	

Comparison to Literature Data

	Average Wt. Percent	Minimum	Maximum	Std. Dev	CV	No. of Samples	90th %-ile	95th %-ile
Table 10	1.8E-01	6.9E-03	7.0E-01	2.7E-01	1.5E+02	6	-	-
Table 11	6.2E-02	2.5E-02	1.1E-01	4.4E-02	7.1E+01	3	-	-
Field Data	1.6E-02	2.2E-05	2.3E-01	3.1E-02	9.9E-04	120	4.7E-02	6.5E-02

Graph of Toluene vs. TPH Data
Dashed line = 0.047 wt. percent



SUMMARY OUTPUT: Toluene vs. TPH

Regression Statistics	
Multiple R	0.545197287
R Square	0.297240082
Adjusted R Squar	0.28883672
Standard Error	5181.010403
Observations	120

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1351065109	1351065109	50.33236644	1.03819E-10
Residual	119	3194301387	26842868.8		
Total	120	4545366496			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
X Variable 1	0.189810305	0.020023056	9.479587241	3.19963E-16	0.150162707	0.229457904

Ethylbenzene Data

258	Total samples
209	Samples tested for ethylbenzene
34	Samples were ND
175	Samples had detectable levels of ethylbenzene

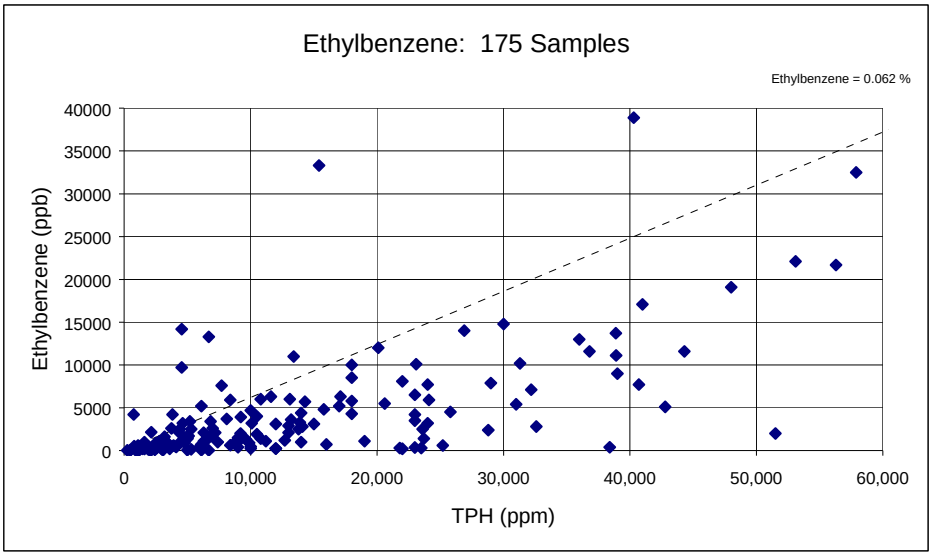
TPH Range: 250 - 82,500 ppm
Ethylbenzene Range: 8 - 74,000 ppb

175	are >=	1	ppb, with	250	= lowest ppm TPH
164		100		754	
129		500		754	
107		1000		754	
47		5000		4550	
24		10,000		4560	

Comparison to Literature Data

	Average Wt. Percent	Minimum	Maximum	Std. Dev	CV	No. of Samples	90th %-ile	95th %-ile
Table 10	6.8E-02	7.0E-03	2.0E-01	7.2E-02	1.1E+02	6	-	-
Table 11	3.4E-02	2.8E-02	4.0E-02	-	-	2	-	-
Field Data	3.7E-02	3.3E-04	5.6E-01	6.5E-02	4.3E-03	175	6.2E-02	9.9E-02

Graph of Ethylbenzene vs. TPH Data
Dashed line = 0.062 wt. percent



SUMMARY OUTPUT: Ethylbenzene vs. TPH

Regression Statistics	
Multiple R	0.511505098
R Square	0.261637465
Adjusted R Squar	0.255890339
Standard Error	6982.45338
Observations	175

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	3006045980	3006045980	61.65659396	4.11493E-13
Residual	174	8483310006	48754655.21		
Total	175	11489355986			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
X Variable 1	0.304644175	0.026115976	11.66505018	1.34017E-23	0.253099336	0.356189014

Xylene Data

258	Total samples
209	Samples tested for xylene
23	Samples were ND
186	Samples had detectable levels of xylene

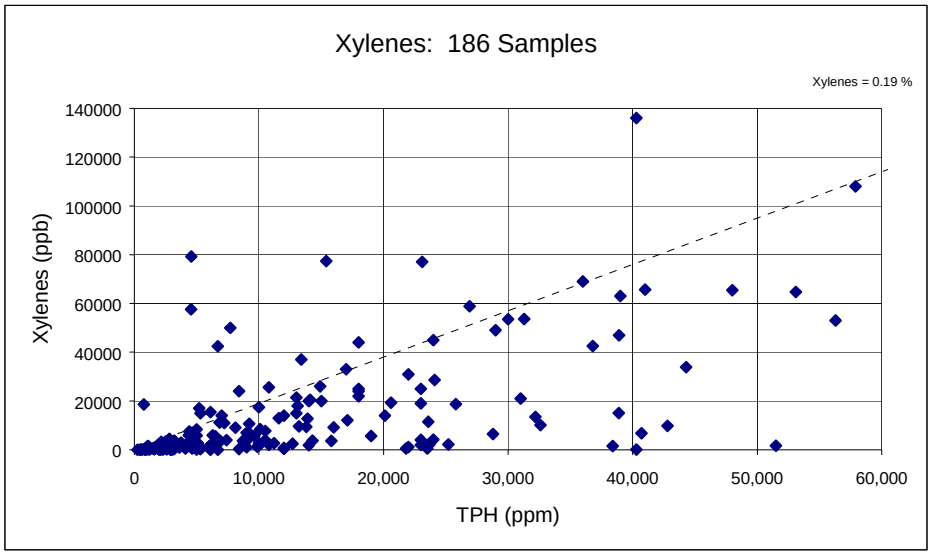
TPH Range: 250 - 82,500 ppm
Xylene Range: 6 - 136,000 ppb

186	are >=	1	ppb, with	250	= lowest ppm TPH
177		100		610	
135		1000		754	
64		10,000		754	
18		50,000		4,550	
3		100,000		40,300	

Comparison to Literature Data

	Average Wt. Percent	Minimum	Maximum	Std. Dev	CV	No. of Samples	90th %-ile	95th %-ile
Table 10	5.0E-01	-	-	-	-	1	-	-
Table 11	2.3E-01	1.5E-01	4.3E-01	1.3E-01	5.8E+01	4	-	-
Field Data	1.1E-01	2.0E-04	2.5E+00	2.5E-01	6.2E-02	186	1.9E-01	3.3E-01

Graph of Xylene vs. TPH Data
Dashed line = 0.19 wt. percent



SUMMARY OUTPUT: Xylene vs. TPH

Regression Statistics	
Multiple R	0.660980711
R Square	0.4368955
Adjusted R Squar	0.431490094
Standard Error	17226.0293
Observations	186

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	42592257995	42592257995	143.5358222	8.02742E-25
Residual	185	54896175786	296736085.3		
Total	186	97488433781			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
X Variable 1	1.048723543	0.063675507	16.46981067	4.12877E-38	0.923099959	1.174347127

Acenaphthene Data

258	Total samples
214	Samples tested for acenaphthene
38	Samples were ND
176	Samples had detectable levels of acenaphthene

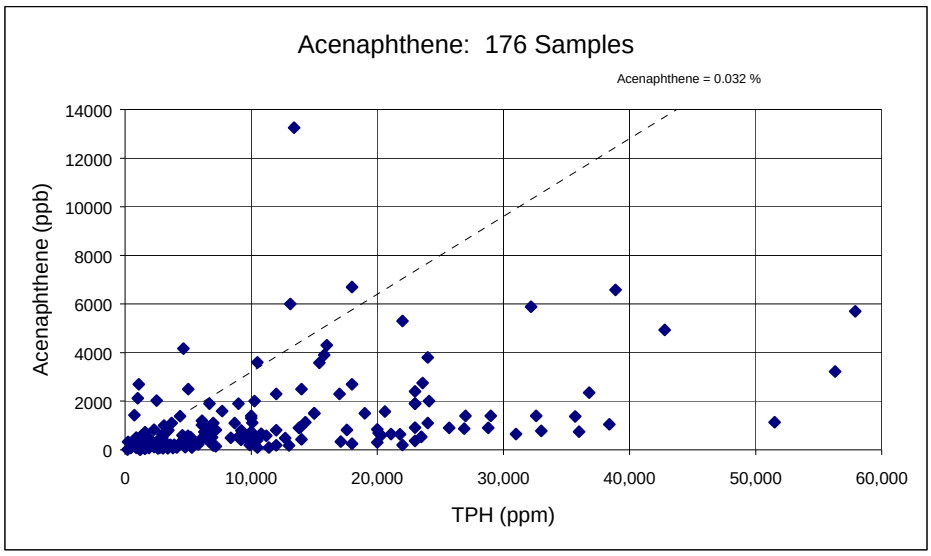
TPH Range: 194 - 107,000 ppm
Acenaphthene Range: 4 - 13,260 ppb

176	are >=	1	ppb, with	194	= lowest ppm TPH
156		100		250	
100		500		754	
60		1000		754	
8		5000		13,100	
1		10,000		13,400	

Comparison to Literature Data

	Average Wt. Percent	Minimum	Maximum	Std. Dev	CV	No. of Samples	90th %ile	95th %ile
Table 10	NR	-	-	-	-	-	-	-
Table 11	1.8E-02	1.3E-02	2.2E-02	-	-	2	-	-
Field Data	1.7E-02	3.4E-04	2.5E-01	3.1E-02	9.9E-04	176	3.2E-02	5.0E-02

Graph of Acenaphthene vs. TPH Data
Dashed line = 0.032 wt. percent.



SUMMARY OUTPUT: Acenaphthene vs. TPH

Regression Statistics	
Multiple R	0.357503865
R Square	0.127809014
Adjusted R Squar	0.122094728
Standard Error	1543.898117
Observations	176

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	61125892.42	61125892.42	25.64412812	1.03933E-06
Residual	175	417133744	2383621.394		
Total	176	478259636.4			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
X Variable 1	0.066623163	0.005875823	11.33852473	1.07709E-22	0.055026565	0.078219761

Anthracene Data

258	Total samples
213	Samples tested for anthracene
62	Samples were ND
151	Samples had detectable levels of anthracene

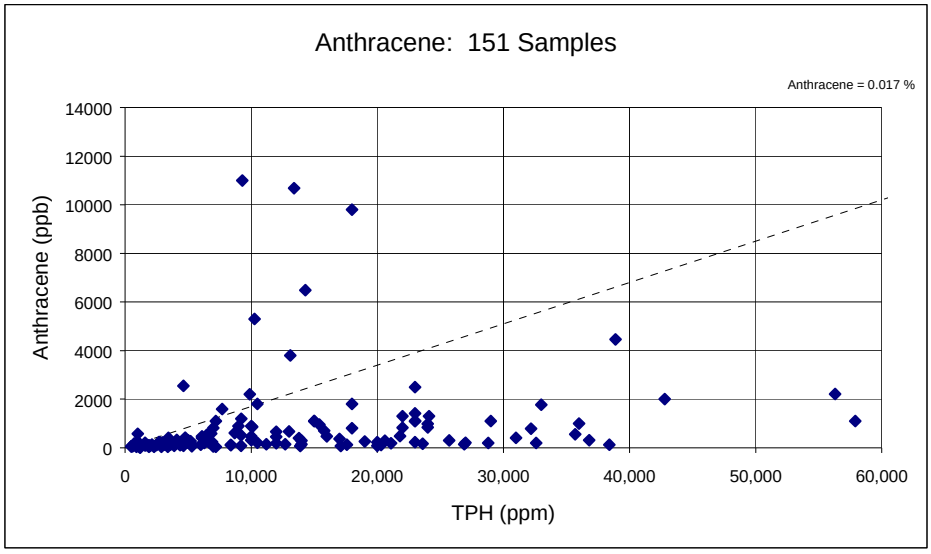
TPH Range: 500 - 107,000 ppm
Anthracene Range: 1 - 21,000 ppb

151	are >=	1	ppb, with	500	= lowest ppm TPH
130		100		754	
52		500		1,020	
31		1000		4,624	
7		5000		9,300	
3		10,000		9,300	

Comparison to Literature Data

	Average Wt. Percent	Minimum	Maximum	Std. Dev	CV	No. of Samples	90th %ile	95th %ile
Table 10	5.8E-03	3.0E-06	2.0E-02	7.5E-03	1.3E+02	14	-	-
Table 11	2.8E-03	1.0E-04	1.1E-02	4.3E-03	1.5E+02	6	-	-
Field Data	9.2E-03	1.3E-04	1.2E-01	1.7E-02	2.7E-04	151	1.7E-02	4.5E-02

Graph of Anthracene vs. TPH Data
Dashed line = 0.017 wt. percent.



SUMMARY OUTPUT: Anthracene vs. TPH

Regression Statistics	
Multiple R	65535
R Square	-0.005859376
Adjusted R Squar	-0.012526043
Standard Error	2365.992202
Observations	151

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	-4891386.437	-4891386.437	-0.873786553	#NUM!
Residual	150	839687865.1	5597919.101		
Total	151	834796478.7			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
X Variable 1	0.045456696	0.009264776	4.906399832	2.39067E-06	0.027150383	0.063763009

Benz[a]anthracene Data

258	Total samples
168	Samples tested for benz[a]anthracene
151	Samples were ND
17	Samples had detectable levels of benz[a]anthracene

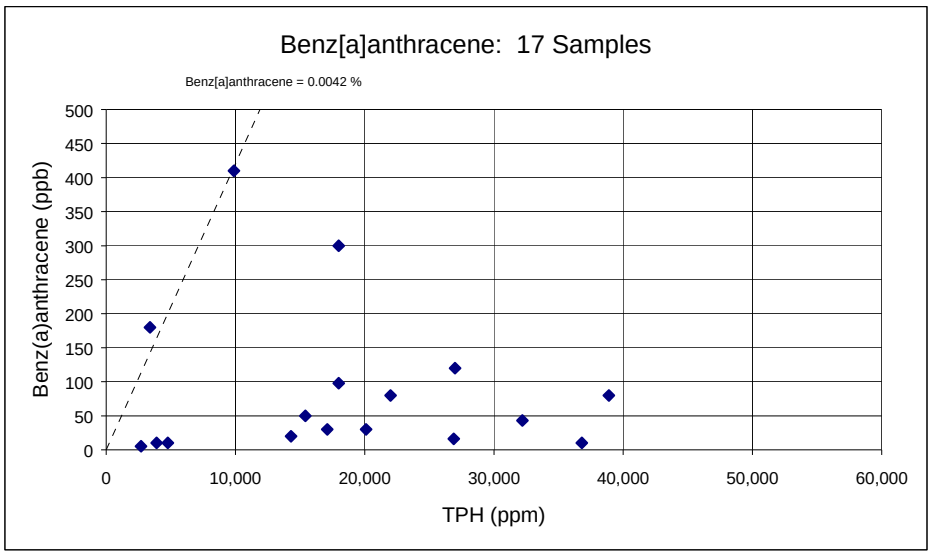
TPH Range: 2700 - 38,882 ppm
Benz[a]anthracene Range: 5.3 - 410 ppb

17	are >=	1	ppb, with	2,700	= lowest ppm TPH
16		10		3,400	
8		50		3,400	
4		100		3,400	

Comparison to Literature Data

	Average Wt. Percent	Minimum	Maximum	Std. Dev	CV	No. of Samples	90th %ile	95th %ile
Table 10	9.6E-05	2.0E-06	6.7E-04	2.2E-04	2.3E+02	9	-	-
Table 11	4.5E-05	2.0E-06	1.2E-04	5.5E-05	1.2E+02	8	-	-
Field Data	8.4E-04	2.7E-05	5.3E-03	1.5E-03	2.3E-06	17	4.2E-03	5.3E-03

Graph of Benz[a]anthracene vs. TPH Data
Dashed line = 0.0042 wt. percent.



SUMMARY OUTPUT: Benz[a]anthracene vs. TPH

Regression Statistics	
Multiple R	65535
R Square	-0.267967597
Adjusted R Squar	-0.330467597
Standard Error	126.9730962
Observations	17

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	-54515.18983	-54515.18983	-3.381381008	#NUM!
Residual	16	257954.6745	16122.16716		
Total	17	203439.4847			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
X Variable 1	0.003135351	0.001439518	2.178056231	0.044706015	8.371E-05	0.006186993

Chrysene Data

258	Total samples
213	Samples tested for chrysene
145	Samples were ND
68	Samples had detectable levels of chrysene

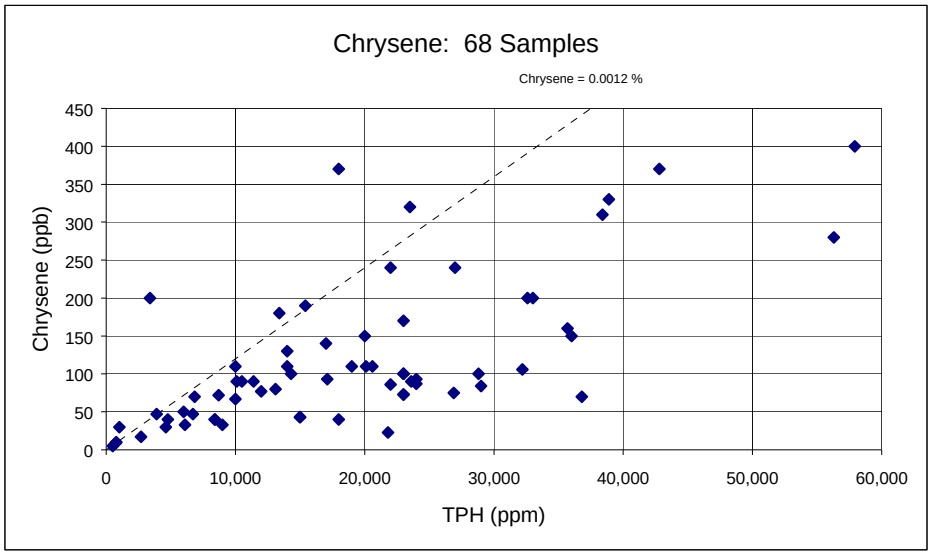
TPH Range: 510 - 107,000 ppm
Chrysene Range: 5 - 430 ppb

68	are >=	1	ppb, with	510	= lowest ppm TPH
66		10		789	
51		50		3,400	
31		100		3,400	
13		200		3,400	
2		400		57,900	

Comparison to Literature Data

	Average Wt. Percent	Minimum	Maximum	Std. Dev	CV	No. of Samples	90th %-ile	95th %-ile
Table 10	4.5E-05	-	-	-	-	1	-	-
Table 11	1.4E-04	3.7E-05	3.9E-04	1.3E-04	9.2E+01	8	-	-
Field Data	7.8E-04	1.1E-04	5.9E-03	7.7E-04	5.9E-07	68	1.2E-03	2.1E-03

Graph of Chrysene vs. TPH Data
Dashed line = 0.0012 wt. percent



SUMMARY OUTPUT: Chrysene vs. TPH

Regression Statistics	
Multiple R	0.628718078
R Square	0.395286422
Adjusted R Squar	0.380361048
Standard Error	78.42839575
Observations	68

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	269391.3469	269391.3469	43.79625527	7.70023E-09
Residual	67	412117.8884	6151.01326		
Total	68	681509.2353			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
X Variable 1	0.005136922	0.000354203	14.5027443	2.39045E-22	0.004429929	0.005843915

Fluoranthene Data

258	Total samples
213	Samples tested for fluoranthene
93	Samples were ND
120	Samples had detectable levels of fluoranthene

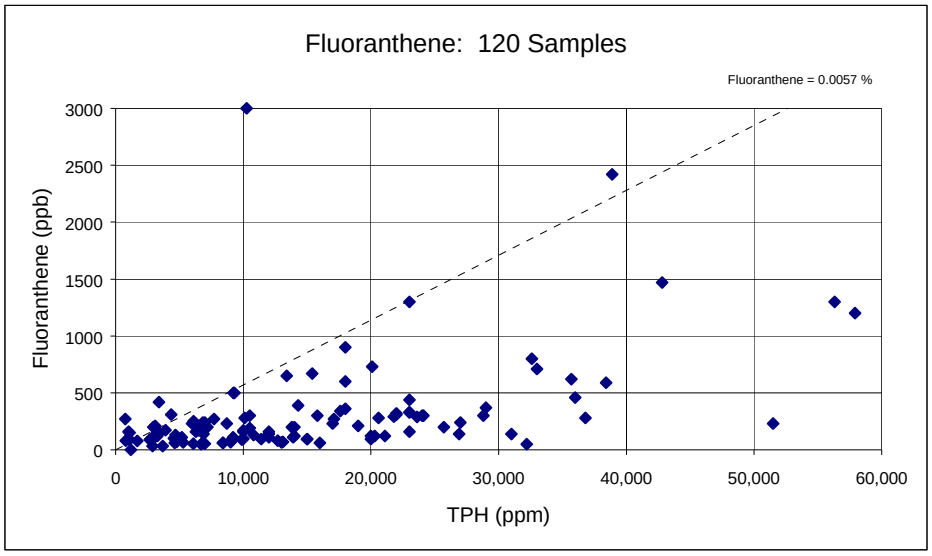
TPH Range: 754 - 107,000 ppm
Fluoranthene Range: 0.1 - 3,000 ppb

119	are >=	1	ppb, with	754 = lowest ppm TPH
89		100		
20		500		
8		1000		

Comparison to Literature Data

	Average Wt. Percent	Minimum	Maximum	Std. Dev	CV	No. of Samples	90th %-ile	95th %-ile
Table 10	5.9E-03	6.8E-07	2.0E-02	8.0E-03	1.4E+02	15	-	-
Table 11	1.4E-03	4.7E-05	3.7E-03	1.5E-03	1.1E+02	9	-	-
Field Data	3.0E-03	9.2E-06	3.6E-02	4.7E-03	2.2E-05	120	5.7E-03	1.0E-02

Graph of Fluoranthene vs. TPH Data
Dashed line = 0.0057 wt. percent



SUMMARY OUTPUT: Fluoranthene vs. TPH

Regression Statistics	
Multiple R	0.517009617
R Square	0.267298944
Adjusted R Squar	0.258895582
Standard Error	374.1342395
Observations	120

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	6076762.97	6076762.97	43.41275889	1.29898E-09
Residual	119	16657195.07	139976.4292		
Total	120	22733958.04			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
X Variable 1	0.016781959	0.001443972	11.62208204	2.49675E-21	0.013922754	0.019641164

Fluorene Data

258	Total samples
214	Samples tested for fluorene
28	Samples were ND
186	Samples had detectable levels of fluorene

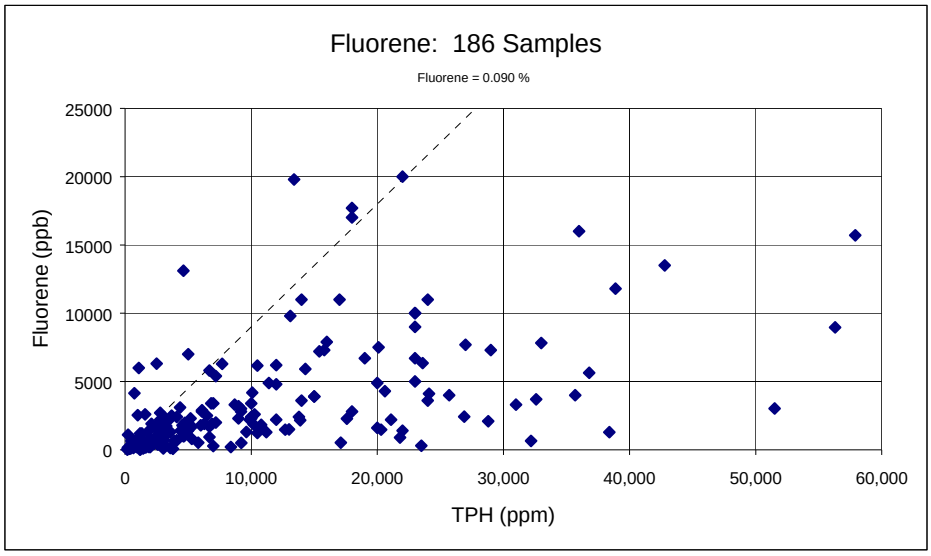
TPH Range: 186 - 107,000 ppm
Fluorene Range: 7.9 - 103,000 ppb

186	are >=	1	ppb, with	186	= lowest ppm TPH
131		1000		250	
42		5000		590	
16		10000		590	
1		50000		590	

Comparison to Literature Data

	Average Wt. Percent	Minimum	Maximum	Std. Dev	CV	No. of Samples	90th %-ile	95th %-ile
Table 10	8.6E-02	3.4E-02	1.5E-01	4.3E-02	5.0E+01	13	-	-
Table 11	1.9E-02	4.3E-03	4.5E-02	1.9E-02	1.0E+02	4	-	-
Field Data	1.4E-01	6.6E-04	1.7E+01	1.3E+00	1.6E+00	186	9.0E-02	1.5E-01

Graph of Fluorene vs. TPH Data
Dashed line = 0.09 wt. percent



SUMMARY OUTPUT: Fluorene vs. TPH

Regression Statistics	
Multiple R	0.081793188
R Square	0.006690126
Adjusted R Squar	0.00128472
Standard Error	8389.820158
Observations	186

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	87705444.51	87705444.51	1.246009206	0.265771662
Residual	185	13021980221	70389082.28		
Total	186	13109685666			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
X Variable 1	0.210552277	0.031951332	6.589780874	4.45081E-10	0.147516409	0.273588144

Naphthalene Data

258	Total samples
214	Samples tested for naphthalene
48	Samples were ND
166	Samples had detectable levels of naphthalene

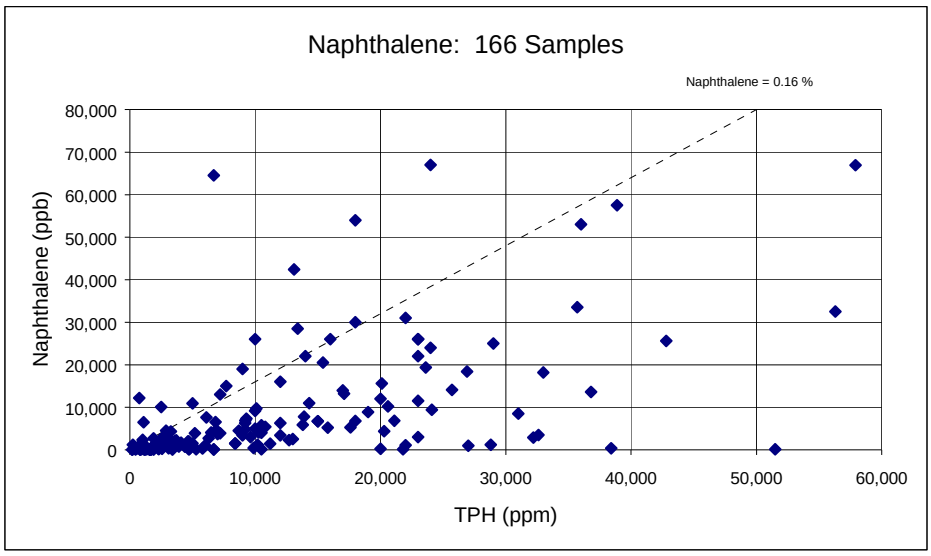
TPH Range: 186 - 107,000 ppm
Naphthalene Range: 3 - 67,000 ppb

166	are >=	1	ppb, with	186	= lowest ppm TPH
152		100		220	
131		500		250	
120		1000		250	
68		5000		754	
45		10,000		754	

Comparison to Literature Data

	Average Wt. Percent	Minimum	Maximum	Std. Dev	CV	No. of Samples	90th %ile	95th %ile
Table 10	2.6E-01	1.0E-02	8.0E-01	1.8E-01	7.0E+01	29	-	-
Table 11	2.2E-01	9.0E-03	4.0E-01	1.3E-01	6.1E+01	10	-	-
Field Data	8.5E-02	1.9E-04	1.6E+00	1.6E-01	2.6E-02	166	1.6E-01	2.8E-01

Graph of Naphthalene vs. TPH Data
Dashed line = 0.16 wt. percent.



SUMMARY OUTPUT: Naphthalene vs. TPH

Regression Statistics	
Multiple R	0.548337732
R Square	0.300674268
Adjusted R Squar	0.294613662
Standard Error	11786.80393
Observations	166

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	9855821207	9855821207	70.941554	1.76409E-14
Residual	165	22923243255	138928747		
Total	166	32779064462			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
X Variable 1	0.575298352	0.043899372	13.10493367	2.38219E-27	0.488621467	0.661975238

Pyrene Data

258	Total samples
213	Samples tested for pyrene
47	Samples were ND
166	Samples had detectable levels of pyrene

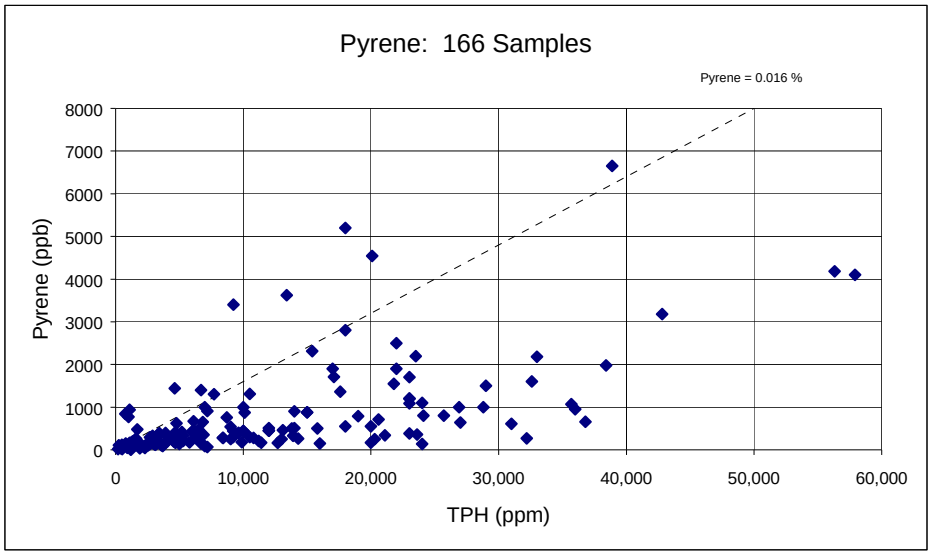
TPH Range: 194 - 107,000 ppm
Pyrene Range: 0.4 - 23,500 ppb

165	are >=	1	ppb, with	194	= lowest ppm TPH
150		100		250	
66		500		754	
38		1000		4,624	
5		5000		10,270	
1		10,000		10,270	

Comparison to Literature Data

	Average Wt. Percent	Minimum	Maximum	Std. Dev	CV	No. of Samples	90th %-ile	95th %-ile
Table 10	4.6E-03	1.8E-05	1.5E-02	6.0E-03	1.3E+02	15	-	-
Table 11	2.9E-03	4.5E-05	1.2E-02	3.8E-03	1.3E+02	9	-	-
Field Data	1.0E-02	3.5E-05	2.3E-01	2.2E-02	4.6E-04	166	1.6E-02	2.9E-02

Graph of Pyrene vs. TPH Data
Dashed line = 0.016 wt. percent



SUMMARY OUTPUT: Pyrene vs. TPH

Regression Statistics	
Multiple R	0.399577063
R Square	0.15966183
Adjusted R Squar	0.153601224
Standard Error	1951.890199
Observations	166

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	119437779.9	119437779.9	31.34952429	8.89144E-08
Residual	165	628629432.8	3809875.35		
Total	166	748067212.7			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
X Variable 1	0.06391998	0.007587812	8.424032629	1.699E-14	0.048938263	0.078901697

Appendix B: SESOIL and AT123D Model Inputs

```
*****************************************************************************************************
*****                                                                                           *****
***** SESOIL-84 :  SEASONAL CYCLES OF WATER, SEDIMENT, AND POLLUTANTS IN SOIL ENVIRONMENTS       *****
*****                                                                                           *****
***** DEVELOPERS:  M. BONAZOUNTAS,ARTHUR D. LITTLE INC.  ,(617)864-5770,X5871                  *****
*****              J. WAGNER     ,DIS/ADLPIPE, INC.      ,(617)492-1991,X5820                  *****
*****                                                                                           *****
***** MODIFIED EXTENSIVELY BY:                                                                 *****
***** D.M. HETRICK                                                                             *****
***** OAK RIDGE NATIONAL LABORATORY                                                            *****
***** (615) 576-7556                                                                           *****
***** VERSION   :  JANUARY 1995                                                                *****
*****                                                                                           *****
*****************************************************************************************************

                      ****** MONTHLY SESOIL MODEL OPERATION ******
                            MONTHLY SITE SPECIFIC SIMULATION

REGION          :      PORTLAND WSFO AP
SOIL TYPE       :      RBDM Defaults
COMPOUND        :      Benzene
WASHLOAD DATA   :
APPLICATION AREA:      Generic Heating Oil Site

     GENERAL INPUT PARAMETERS
     ========================

     -- SOIL INPUT PARAMETERS --

SOIL DENSITY (G/CM**3):                                  1.70
INTRINSIC PERMEABILITY (CM**2):                          .100E-07
DISCONNECTEDNESS INDEX (-):                              6.90
POROSITY (-):                                            .300
ORGANIC CARBON CONTENT (%):                              .500
CATION EXCHANGE CAPACITY (MILLI EQ./100G DRY SOIL):      .000
FREUNDLICH EXPONENT (-):                                 1.00

     -- CHEMICAL INPUT PARAMETERS --

SOLUBILITY (UG/ML):                                      .175E+04
DIFFUSION COEFFICIENT IN AIR (CM**2/SEC):                .880E-01
HENRYS LAW CONSTANT (M**3-ATM/MOLE):                     .555E-02
ADSORPTION COEFFICIENT ON ORGANIC CARBON(KOC):           88.9
```

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ADSORPTION COEFFICIENT ON SOIL (K):                        .000
MOLECULAR  WEIGHT (G/MOL):                                78.1
VALENCE (-):                                               .000
NEUTRAL HYDROLYSIS CONSTANT (/DAY):                        .000
BASE HYDROLYSIS CONSTANT (L/MOL-DAY):                      .000
ACID HYDROLYSIS CONSTANT (L/MOL-DAY):                      .000
DEGRADATION RATE IN MOISTURE (/DAY):                       .000
DEGRADATION RATE ON SOIL (/DAY):                           .000
LIGAND-POLLUTANT STABILITY CONSTANT (-):                   .000
NO. MOLES LIGAND/MOLE POLLUTANT (-):                       .000
LIGAND MOLECULAR WEIGHT (G/MOL):                           .000

     -- APPLICATION INPUT PARAMETERS --

NUMBER OF SOIL LAYERS:                                       3
YEARS TO BE SIMULATED:                                       5
AREA (CM**2):                                          0.500E+06
APPLICATION AREA LATITUDE (DEG.):                         45.6
SPILL (1) OR STEADY APPLICATION (0):                         0
MODIFIED SUMMERS MODEL USED (1) OR NOT (0) FOR GWR. CONC.:   0
INITIAL CHEMICAL CONCENTRATIONS GIVEN (1) OR NOT GIVEN (0)   0
DEPTHS (CM):                                           0.10E+03 0.10E+03 0.10E+03
NUMBER OF SUBLAYERS/LAYER                                     1        1        1
PH (CM):                                                  0.00     0.00     0.00
INTRINSIC PERMEABILITIES (CM**2):                         0.00     0.00     0.00
KDEL RATIOS (-):                                           1.0      1.0
KDES RATIOS (-):                                           1.0      1.0
OC RATIOS (-):                                             1.0      1.0
CEC RATIOS (-):                                            1.0      1.0
FRN RATIOS(-):                                             1.0      1.0
ADS RATIOS(-):                                             1.0      1.0


     YEAR - 1    MONTHLY INPUT PARAMETERS
     ========    ========================

     -- CLIMATIC INPUT PARAMETERS --

                       OCT      NOV      DEC      JAN      FEB      MAR      APR      MAY      JUN      JUL      AUG      SEP

TEMP. (DEG C)        11.670    7.220    4.720    3.500    5.780    7.060    9.670   12.830   15.720   18.560   18.330   16.220
CLOUD CVR (FRAC.)     0.600    0.800    0.850    0.800    0.800    0.800    0.700    0.700    0.700    0.400    0.500    0.550
REL. HUM.(FRAC.)      0.800    0.850    0.900    0.850    0.800    0.900    0.750    0.700    0.700    0.650    0.700    0.750
ALBEDO (-)            0.150    0.150    0.170    0.210    0.160    0.160    0.150    0.150    0.150    0.150    0.150    0.150
EVAPOT. (CM/DAY)      0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000

PRECIP. (CM)          8.070   13.430   16.420   15.250   10.550    9.220    5.790    5.000    3.910    1.310    2.820    4.190
```

M.TIME RAIN(DAYS)	0.560	0.670	0.740	0.730	0.700	0.630	0.560	0.540	0.490	0.310	0.390	0.490
M. STORM NO. (-)	7.090	9.780	10.750	9.890	8.470	8.660	6.540	5.310	4.110	1.430	2.370	3.830
M. SEASON (DAYS)	30.400	30.400	30.400	30.400	30.400	30.400	30.400	30.400	30.400	30.400	30.400	30.400

```
      -- POLLUTANT INPUT PARAMETERS --

                            OCT      NOV      DEC      JAN      FEB      MAR      APR      MAY      JUN      JUL      AUG
SEP

 POL. INP-1 (UG/CM**2)  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0.00E+00
 TRNSFORMD-1 (UG/CM**2) 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0.00E+00
 SINKS-1 (UG/CM**2)     0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0.00E+00
 LIG.INPUT-1 (UG/CM**2) 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0.00E+00
 VOLATILIZATION MULT.-1 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01
2.00E-01
 SURFACE RUNOFF MULT.   0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0.00E+00
 POL. IN RAIN (FRAC-SL) 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0.00E+00

 POL. INP-2 (UG/CM**2)  3.70E+01 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0.00E+00
 TRNSFORMD-2 (UG/CM**2) 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0.00E+00
 SINKS-2 (UG/CM**2)     0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0.00E+00
 LIG.INPUT-2 (UG/CM**2) 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0.00E+00
 VOLATILIZATION MULT.-2 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01
2.00E-01

 POL. INP-L (UG/CM**2)  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0.00E+00
 TRNSFORMD-L (UG/CM**2) 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0.00E+00
 SINKS-L (UG/CM**2)     0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0.00E+00
 LIG.INPUT-L (UG/CM**2) 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0.00E+00
 VOLATILIZATION MULT.-L 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01
2.00E-01


      YEAR -   2    MONTHLY INPUT PARAMETERS
      ========    ========================
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      -- CLIMATIC INPUT PARAMETERS ARE SAME AS LAST YEAR

      -- POLLUTANT INPUT PARAMETERS --

                            OCT      NOV      DEC      JAN      FEB      MAR      APR      MAY      JUN      JUL      AUG
SEP

 POL. INP-1 (UG/CM**2)  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0.00E+00
 TRNSFORMD-1 (UG/CM**2) 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0.00E+00
 SINKS-1 (UG/CM**2)     0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0.00E+00
 LIG.INPUT-1 (UG/CM**2) 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0.00E+00
 VOLATILIZATION MULT.-1 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01
2.00E-01
 SURFACE RUNOFF MULT.   0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0.00E+00
 POL. IN RAIN (FRAC-SL) 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0.00E+00

 POL. INP-2 (UG/CM**2)  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0.00E+00
 TRNSFORMD-2 (UG/CM**2) 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0.00E+00
 SINKS-2 (UG/CM**2)     0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0.00E+00
 LIG.INPUT-2 (UG/CM**2) 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0.00E+00
 VOLATILIZATION MULT.-2 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01
2.00E-01
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 POL. INP-L (UG/CM**2)  0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0.00E+00
 TRNSFORMD-L (UG/CM**2) 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0.00E+00
 SINKS-L (UG/CM**2)     0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0.00E+00
 LIG.INPUT-L (UG/CM**2) 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
0.00E+00
 VOLATILIZATION MULT.-L 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01 2.00E-01
2.00E-01


      YEAR 3-5    MONTHLY INPUT PARAMETERS
      ========    ========================

      -- CLIMATIC INPUT PARAMETERS ARE SAME AS LAST YEAR

      -- POLLUTANT INPUT PARAMETERS ARE SAME AS LAST YEAR


      YEAR - 1    MONTHLY RESULTS (OUTPUT)
      ========    ========================

      -- HYDROLOGIC CYCLE COMPONENTS --

                          OCT      NOV      DEC      JAN      FEB      MAR      APR      MAY      JUN      JUL      AUG      SEP

 MOIS. IN L1 (%)       12.768   14.658   15.318   15.288   14.238   13.428   10.968   10.218    9.768    8.988    9.438    9.918
 MOIS. BELOW L1 (%)    12.768   14.658   15.318   15.288   14.238   13.428   10.968   10.218    9.768    8.988    9.438    9.918
 PRECIPATION (CM)       8.084   13.375   16.412   15.348   10.613    9.241    5.831    4.995    3.920    1.306    2.810    4.203
 NET INFILT. (CM)       8.084   13.375   16.412   15.348   10.613    9.241    5.831    4.995    3.920    1.306    2.810    4.203
 EVAPOTRANS. (CM)       3.125    0.689    0.304    0.140    1.628    3.336    5.529    4.954    4.121    2.017    2.975    4.054
 MOIS. RETEN (CM)       0.307    0.472    0.165   -0.008   -0.262   -0.202   -0.615   -0.187   -0.112   -0.195    0.113    0.120
 SUR. RUNOFF (CM)       0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000
 GRW. RUNOFF (CM)       4.652   12.213   15.943   15.215    9.247    6.108    0.917    0.228   -0.089   -0.516   -0.277    0.029
 YIELD (CM)             4.652   12.213   15.943   15.215    9.247    6.108    0.917    0.228   -0.089   -0.516   -0.277    0.029

 PAU/MPA (GZU)          1.002    0.996    1.000    1.006    1.006    1.002    1.007    0.999    1.003    0.997    0.996    1.003
 PA/MPA (GZ)            1.002    0.996    1.000    1.006    1.006    1.002    1.007    0.999    1.003    0.997    0.996    1.003

                     -- POLLUTANT MASS INPUT TO COLUMN (UG) - INCLUDES INITIAL POLLUTANT CONCENTRATIONS --
                     ------------------------------------------------------------------------------------

                OCT       NOV       DEC       JAN       FEB       MAR       APR       MAY       JUN       JUL       AUG
SEP
```

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 PRECIP.     0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
0.000E+00
 LOAD UPPER  0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
0.000E+00
 LOAD ZONE 2 1.850E+07 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
0.000E+00
 LOAD LOWER  0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
0.000E+00

 TOTAL INPUT 1.850E+07 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
0.000E+00
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          -- POLLUTANT MASS DISTRIBUTION IN COLUMN (UG) -- NOTE: IF COMPONENT IS ZERO EACH MONTH, IT IS NOT PRINTED
          ------------------------------------------------------------------------------------------------------

     UPPER SOIL ZONE:

 VOLATILIZED 4.000E+03 1.271E+04 1.714E+04 2.165E+04 3.318E+04 4.719E+04 9.245E+04 1.283E+05 1.601E+05 2.037E+05 2.061E+05
1.998E+05
 IN SOIL MOI 4.286E+04 1.050E+05 1.441E+05 1.728E+05 1.983E+05 2.230E+05 2.350E+05 2.637E+05 2.893E+05 3.011E+05 3.358E+05
3.624E+05
 ADS ON SOIL 2.537E+05 5.412E+05 7.109E+05 8.541E+05 1.053E+06 1.255E+06 1.619E+06 1.950E+06 2.238E+06 2.531E+06 2.689E+06
2.761E+06
 IN SOIL AIR 1.367E+04 2.638E+04 3.347E+04 4.050E+04 5.319E+04 6.647E+04 9.706E+04 1.201E+05 1.395E+05 1.612E+05 1.677E+05
1.692E+05

     SOIL ZONE 2:

 DIFFUSED UP 3.443E+05 4.375E+05 3.666E+05 3.596E+05 4.006E+05 4.143E+05 5.862E+05 5.920E+05 5.666E+05 5.686E+05 4.730E+05
3.992E+05
 IN SOIL MOI 2.510E+06 2.778E+06 2.849E+06 2.693E+06 2.242E+06 1.931E+06 1.507E+06 1.328E+06 1.203E+06 1.055E+06 1.049E+06
1.048E+06
 ADS ON SOIL 1.485E+07 1.432E+07 1.405E+07 1.331E+07 1.190E+07 1.087E+07 1.038E+07 9.822E+06 9.310E+06 8.872E+06 8.401E+06
7.985E+06
 IN SOIL AIR 8.004E+05 6.982E+05 6.617E+05 6.312E+05 6.013E+05 5.758E+05 6.222E+05 6.049E+05 5.802E+05 5.651E+05 5.240E+05
4.894E+05

     LOWER SOIL ZONE:

 IN SOIL MOI 0.000E+00 0.000E+00 0.000E+00 1.184E+05 3.576E+05 4.953E+05 4.568E+05 4.560E+05 4.561E+05 4.300E+05 4.620E+05
5.003E+05
 ADS ON SOIL 0.000E+00 0.000E+00 0.000E+00 5.852E+05 1.898E+06 2.787E+06 3.147E+06 3.372E+06 3.529E+06 3.615E+06 3.699E+06
3.812E+06
 IN SOIL AIR 0.000E+00 0.000E+00 0.000E+00 2.775E+04 9.591E+04 1.476E+05 1.886E+05 2.077E+05 2.199E+05 2.303E+05 2.307E+05
2.336E+05


     -- POLLUTANT CONCENTRATIONS (UG/ML) OR (UG/G) -- NOTE: IF CONCENTRATIONS ARE ZERO FOR EACH MONTH, THEY ARE NOT PRINTED --
     ---------------------------------------------------------------------------------------------------------------------

     UPPER SOIL ZONE:

 MOISTURE    6.714E-03 1.432E-02 1.881E-02 2.261E-02 2.786E-02 3.321E-02 4.286E-02 5.161E-02 5.923E-02 6.699E-02 7.116E-02
7.307E-02
 %SOLUBILITY 3.837E-04 8.185E-04 1.075E-03 1.292E-03 1.592E-03 1.898E-03 2.449E-03 2.949E-03 3.384E-03 3.828E-03 4.066E-03
4.176E-03
 ADSORBED    2.985E-03 6.367E-03 8.363E-03 1.005E-02 1.238E-02 1.476E-02 1.905E-02 2.294E-02 2.633E-02 2.978E-02 3.163E-02
3.248E-02
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 SOIL AIR    1.587E-03 3.440E-03 4.559E-03 5.506E-03 6.749E-03 8.021E-03 1.020E-02 1.214E-02 1.379E-02 1.534E-02 1.631E-02
1.685E-02

      SOIL ZONE 2:

 MOISTURE    3.931E-01 3.790E-01 3.720E-01 3.523E-01 3.150E-01 2.877E-01 2.747E-01 2.600E-01 2.464E-01 2.348E-01 2.223E-01
2.113E-01
 %SOLUBILITY 2.246E-02 2.166E-02 2.126E-02 2.013E-02 1.800E-02 1.644E-02 1.570E-02 1.485E-02 1.408E-02 1.342E-02 1.271E-02
1.208E-02
 ADSORBED    1.747E-01 1.685E-01 1.653E-01 1.566E-01 1.400E-01 1.279E-01 1.221E-01 1.155E-01 1.095E-01 1.044E-01 9.883E-02
9.394E-02
 SOIL AIR    9.290E-02 9.101E-02 9.014E-02 8.580E-02 7.630E-02 6.949E-02 6.538E-02 6.115E-02 5.736E-02 5.379E-02 5.096E-02
4.874E-02

      LOWER SOIL ZONE:

 MOISTURE    0.000E+00 0.000E+00 0.000E+00 1.549E-02 5.023E-02 7.377E-02 8.329E-02 8.925E-02 9.339E-02 9.569E-02 9.791E-02
1.009E-01
 %SOLUBILITY 0.000E+00 0.000E+00 0.000E+00 8.850E-04 2.871E-03 4.215E-03 4.760E-03 5.100E-03 5.337E-03 5.468E-03 5.595E-03
5.765E-03
 ADSORBED    0.000E+00 0.000E+00 0.000E+00 6.884E-03 2.233E-02 3.279E-02 3.702E-02 3.967E-02 4.151E-02 4.254E-02 4.352E-02
4.484E-02
 SOIL AIR    0.000E+00 0.000E+00 0.000E+00 3.772E-03 1.217E-02 1.782E-02 1.982E-02 2.100E-02 2.174E-02 2.192E-02 2.244E-02
2.327E-02

 POL DEP CM  1.569E+02 1.705E+02 1.876E+02 2.038E+02 2.139E+02 2.211E+02 2.230E+02 2.241E+02 2.248E+02 2.248E+02 2.253E+02
2.261E+02
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                          YEAR -   1 ANNUAL SUMMARY REPORT
                          ================================

       -- TOTAL INPUTS (UG) --


UPPER SOIL ZONE              0.000E+00
SOIL ZONE 2                  1.850E+07
LOWER SOIL ZONE              0.000E+00


          -- HYDROLOGIC CYCLE COMPONENTS --

AVERAGE SOIL MOISTURE ZONE 1 (%)               12.083
AVERAGE SOIL MOISTURE BELOW ZONE 1 (%)         12.083
TOTAL PRECIPITATION (CM)                       96.138
TOTAL INFILTRATION (CM)                        96.138
TOTAL EVAPOTRANSPIRATION (CM)                  32.871
TOTAL SURFACE RUNOFF (CM)                       0.000
TOTAL GRW RUNOFF (CM)                          63.671
TOTAL MOISTURE RETENTION (CM)                  -0.404
TOTAL YIELD (CM)                               63.671
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AT123D:  Generic Heating Oil Site

NO. OF POINTS IN X-DIRECTION ......................    1
NO. OF POINTS IN Y-DIRECTION ......................    1
NO. OF POINTS IN Z-DIRECTION ......................    1
NO. OF ROOTS: NO. OF SERIES TERMS .................  400
NO. OF BEGINNING TIME STEP ........................   25
NO. OF ENDING TIME STEP ...........................   44
NO. OF TIME INTERVALS FOR PRINTED OUT SOLUTION ....    1
INSTANTANEOUS SOURCE CONTROL = 0 FOR INSTANT SOURCE    1
SOURCE CONDITION CONTROL = 0 FOR STEADY SOURCE ....   60
INTERMITTENT OUTPUT CONTROL = 0 NO SUCH OUTPUT ....    1
CASE CONTROL =1 THERMAL, = 2 FOR CHEMICAL, = 3 RAD     2

AQUIFER DEPTH, = 0.0 FOR INFINITE DEEP (METERS) ...  0.0000E+00
AQUIFER WIDTH, = 0.0 FOR INFINITE WIDE (METERS) ...  0.0000E+00
BEGIN POINT OF X-SOURCE LOCATION (METERS) ......... -0.7071E+01
END POINT OF X-SOURCE LOCATION (METERS) ...........  0.0000E+00
BEGIN POINT OF Y-SOURCE LOCATION (METERS) ......... -0.3536E+01
END POINT OF Y-SOURCE LOCATION (METERS) ...........  0.3536E+01
BEGIN POINT OF Z-SOURCE LOCATION (METERS) .........  0.0000E+00
END POINT OF Z-SOURCE LOCATION (METERS) ...........  0.0000E+00

POROSITY ..........................................  0.3000E+00
HYDRAULIC CONDUCTIVITY (METER/HOUR) ...............  0.5000E+00
HYDRAULIC GRADIENT ................................  0.5000E-02
LONGITUDINAL DISPERSIVITY (METER) .................  0.2000E+02
LATERAL DISPERSIVITY (METER) ......................  0.2000E+01
VERTICAL DISPERSIVITY (METER) .....................  0.2000E+01
DISTRIBUTION COEFFICIENT, KD (M**3/KG) ............  0.4445E-03
HEAT EXCHANGE COEFFICIENT (KCAL/HR-M**2-DEGREE C)..  0.0000E+00

MOLECULAR DIFFUSION MULTIPLY BY POROSITY (M**2/HR)   0.0000E+00
DECAY CONSTANT (PER HOUR) .........................  0.0000E+00
BULK DENSITY OF THE SOIL (KG/M**3) ................  0.1700E+04
ACCURACY TOLERANCE FOR REACHING STEADY STATE ......  0.1000E-02
DENSITY OF WATER (KG/M**3) ........................  0.1000E+04
TIME INTERVAL SIZE FOR THE DESIRED SOLUTION (HR) ..  0.7300E+03
DISCHARGE TIME (HR) ...............................  0.4380E+05
WASTE RELEASE RATE (KCAL/HR), (KG/HR), OR (CI/HR) .  0.0000E+00

LIST OF TRANSIENT SOURCE RELEASE RATE
   0.000E+00   0.000E+00   0.000E+00   0.000E+00   0.000E+00   0.000E+00   0.000E+00   0.000E+00   0.000E+00   0.000E+00
   0.000E+00   0.000E+00   0.000E+00   0.000E+00   0.000E+00   0.000E+00   0.000E+00   0.000E+00   0.000E+00   0.000E+00
   0.000E+00   0.000E+00   0.000E+00   0.000E+00   0.535E-06   0.147E-05   0.178E-05   0.157E-05   0.905E-06   0.576E-06
   0.860E-07   0.212E-07   0.000E+00   0.000E+00   0.000E+00   0.248E-08   0.347E-06   0.950E-06   0.115E-05   0.102E-05
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0.584E-06	0.371E-06	0.554E-07	0.136E-07	0.000E+00	0.000E+00	0.000E+00	0.159E-08	0.223E-06	0.610E-06
0.740E-06	0.653E-06	0.375E-06	0.238E-06	0.355E-07	0.875E-08	0.000E+00	0.000E+00	0.000E+00	0.102E-08

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RETARDATION FACTOR ..............................  0.3519E+01
RETARDED DARCY VELOCITY (M/HR) ..................  0.2368E-02
RETARDED LONGITUDINAL DISPERSION COEF. (M**2/HR) ..  0.4736E-01
RETARDED LATERAL DISPERSION COEFFICIENT (M**2/HR) .  0.4736E-02
RETARDED VERTICAL DISPERSION COEFFICIENT (M**2/HR).  0.4736E-02

ADSORBED CHEMICAL CONC. =   0.4445E+00 * DISSOLVED CHEMICAL CONC.


MONTH CONC. (PPM)

24.   0.000E+00
25.   0.196E-03
26.   0.974E-03
27.   0.136E-02
28.   0.180E-02 <-- Cmax
29.   0.164E-02
30.   0.147E-02
31.   0.112E-02
32.   0.853E-03
33.   0.665E-03
34.   0.534E-03
35.   0.439E-03
36.   0.369E-03
37.   0.441E-03
38.   0.901E-03
39.   0.112E-02
40.   0.137E-02 <--
41.   0.124E-02
42.   0.111E-02
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