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**MWH**
MONTGOMERY WATSON HARZA

May 24, 2002

Eva Chu
Alameda County Environmental Health
1131 Harbor Bay Parkway
Alameda, California 94502

***Subject:*** ***Risk-Based Corrective Action Evaluation for the BP Facility (No. 11133), Oakland, California***

2220 · 98th Ave
Oakland 94603

Dear Eva:

Enclosed is the revised *Risk-Based Corrective Action (RBCA) Evaluation* report for the above referenced site. This version of the RBCA evaluation addresses comments received from the City of Oakland, Alameda County Environmental Health Services, and the San Francisco Bay Regional Water Quality Control Board (RWQCB) on two previous versions of the RBCA evaluation. The primary issue addressed in this revised report (from the December 2000 version) is the incorporation of data collected by Cambria, including soil vapor data, to adequately evaluate exposures to the residential properties adjacent to the site.

It is important to note that risks to off-site residents were addressed by the soil vapor data collected adjacent to the off-site residential structures. An important aspect to any risk-based evaluation is the development of representative exposure concentrations. In the absence of directly measured data (e.g., indoor air sampling), it is preferable to collect data as near to potentially exposed individuals as possible. For this reason, soil vapor data are considered more representative of potential off-site residential exposures than soil or groundwater data. The indoor air model used, the Johnson & Ettinger model, allows for the incorporation of directly measured soil vapor data, thus avoiding the compounding of conservative assumptions made by the model related to estimating soil vapor concentrations. The use of soil vapor data for evaluating exposure and risks is consistent with the RWQCB's recent *Application of Risk-Based Screening Levels and Decision Making to Sites with Impacted Soil and Groundwater*, which states that because of the over-predictions made by the Johnson & Ettinger model for petroleum-based volatile organic compounds "...use of the model for this group of chemicals [is] questionable, particularly in the absence of field-based soil gas data."

Results of the RBCA evaluation indicate that theoretical upper-bound incremental lifetime cancer risks and non-cancer hazard indices associated with levels of BTEX, MTBE, and TPH in both soil and groundwater are below acceptable levels. Therefore, existing soil and groundwater conditions at the site should not pose a risk to current and future on-site workers or off-site residents. Therefore, no further action should be necessary for the protection of human health at the site.

If you have any questions or comments concerning this report please call me at (916) 565-4205.

Sincerely,

Mark K. Jones
Senior Scientist
Health and Risk Services Program

cc: Scott Hooton – BP Oil
Mark Gomez – City of Oakland
David Camille – Tosco Marketing Company
Khaled Rahman – Cambria Environmental Technology, Inc.

**MWH**
MONTGOMERY WATSON HARZA

# RISK-BASED CORRECTIVE ACTION (RBCA) EVALUATION
# BP OIL SITE NO. 11133

## OAKLAND, CALIFORNIA

*Prepared for*

**BP OIL COMPANY**

**May 2002**

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*Delivering Innovative Projects and Solutions Worldwide*

# RISK-BASED CORRECTIVE ACTION (RBCA) EVALUATION FOR BP OIL FACILITY NO. 11133

## OAKLAND, CALIFORNIA

Prepared for

BP Oil Company

May 24, 2002

Prepared by

MWH
MONTGOMERY WATSON HARZA

**MWH Americas, Inc.**
777 Campus Commons, Suite 175
Sacramento, California 95825

# RISK-BASED CORRECTIVE ACTION (RBCA) EVALUATION FOR BP OIL FACILITY NO. 11133

## OAKLAND, CALIFORNIA

The material and data in this report were prepared under the supervision and direction of the undersigned.

*MWH Americas, Inc.*

Mark K. Jones
Supervising Scientist

Mark A. Bowland
Senior Scientist

**Table 21.** RBCA Tier 3 Hazard/Risk Summary

| | **On-Site Construction Worker** | **On-Site Commercial Worker** | **Off-Site Resident**[a] Eastern Property Line | **Off-Site Resident**[a] Southeastern Property Line |
|---|---|---|---|---|
| **Hazard Index** | | | | |
| Soil | 0.47 | 0.00067 | 0.0025 | 0.0045 |
| Groundwater | 0.00013 | 0.012 | | |
| **Incremental Lifetime Cancer Risk** | | | | |
| Soil | --- | --- | 2 E-11 | 1 E-12 |
| Groundwater | --- | --- | | |

[a] Based on soil vapor data, therefore incorporates both soil and groundwater petroleum-related impacts.

**Table 20.** Product-Specific Fractions, Fraction Composition, and Toxicity Criteria[a]

| Product | Fractions | Composition | Toxicity Criteria |
|---|---|---|---|
| **Benzene** | | | CSF = 0.1 $(mg/kg\text{-}d)^{-1}$[b] |
| **TPH as gasoline (TPH-g)** | | | |
| | C5-C8 aliphatics | 35% | RfD = 0.06 mg/kg-d (n-hexane) |
| | C9-C18 aliphatics | 25% | RfD = 0.6 mg/kg-d (n-nonane) |
| | C9-C22 aromatics | 40% | RfD = 0.03 mg/kg-d (pyrene) |
| **TPH as diesel (TPH-d)** | | | |
| | C9-C18 aliphatics | 65% | RfD = 0.6 mg/kg-d (n-nonane) |
| | C9-C22 aromatics | 35% | RfD = 0.03 mg/kg-d oral (pyrene)<br>RfD = 0.057 mg/kg-d inhalation (pyrene)[c] |

[a] From MaDEP, 1997.

[b] From OEHHA, 2002.

[c] From TPHCWG, 1996.

**Table 19.** RBCA Tier 3 Evaluation for Off-Site Residential (Southeastern Samples-Adjacent to 2-Story Apartment Building)

| Chemical | Exposure Pathway | RfD[a] (mg/kg-d) | CSF[a] $(mg/kg\text{-}d)^{-1}$ | Conc.[b] | LADD[c] (mg/kg-d) | ILCR[d] | ADD[c] (mg/kg-d) | Hazard Index[d] | Odor Threshold[b] | Nuisance Index[g] |
|---|---|---|---|---|---|---|---|---|---|---|
| **Indoor Air** | | | | | | | | | | |
| Benzene | Inhalation | 0.0017 | 0.1 | 1.0 E-10 | 1.3 E-11 | **1 E-12** | 8.5 E-11 | **5.0 E-8** | 5 | 2.0 E-11 |
| Toluene | Inhalation | 0.11 | --- | 6.1 E-11 | 7.7 E-12 | --- | 5.2 E-11 | **4.7 E-10** | 10 | 6.1 E-12 |
| Ethylbenzene | Inhalation | 0.29 | --- | 8.5 E-12 | 1.1 E-12 | --- | 7.2 E-12 | **2.5 E-11** | 31 | 2.7 E-13 |
| Xylenes | Inhalation | 0.2 | --- | 3.0 E-11 | 3.8 E-12 | --- | 2.5 E-11 | **1.3 E-10** | 0.35 | 8.6 E-11 |
| MTBE | Inhalation | --- | --- | NA | --- | --- | --- | --- | 15.8 | --- |
| TPH-G | | | | 2.4 E-4 | | | | | 281 | 8.5 E-7 |
| C5-C8 aliphatics | Inhalation | 0.06 | --- | 4.2 E-5 | 5.3 E-6 | --- | 3.6 E-5 | **0.00060** | | |
| C9-C18 aliphatics | Inhalation | 0.6 | --- | 5.9 E-5 | 7.4 E-6 | --- | 5.0 E-5 | **0.000083** | | |
| C9-C22 aromatics | Inhalation | 0.03 | --- | 1.4 E-4 | 1.7 E-5 | --- | 1.2 E-4 | **0.0039** | | |
| Total Risk/HI Across Pathways | | | | | | **1 E-12** | | **0.0045** | | |
| SSTL Exceeded by Exposure Concentration? | | | | | | **NO** | | **NO** | | |
| Target Risk/HI | | | | | | **1 E-5** | | **1.0** | | |

[a] From OEHHA (2002), EPA (2002).

[b] For air, concentration is in $mg/m^3$. Based on average soil vapor concentrations (See Table 11).

[c] Air: LADD/ADD = $(C_{air} \times IR \times ED \times EF \times AF_i) / (AT \times BW)$.

[d] ILCR = LADD × CSF; HI = ADD × RfD.

[f] The most conservative odor thresholds from ATSDR Toxicological Profiles.

[g] Nuisance index = air concentration/odor threshold.

**Table 18.** RBCA Tier 3 Evaluation for Off-Site Residential (Eastern Samples-Adjacent to Single-Story Residence)

| Chemical | Exposure Pathway | RfD[a] (mg/kg-d) | CSF[a] $(mg/kg-d)^{-1}$ | Conc.[b] | LADD[c] (mg/kg-d) | ILCR[d] | ADD[c] (mg/kg-d) | Hazard Index[d] | Odor Threshold[b] | Nuisance Index[g] |
|---|---|---|---|---|---|---|---|---|---|---|
| **Indoor Air** | | | | | | | | | | |
| Benzene | Inhalation | 0.0017 | 0.1 | 1.9 E-9 | 2.4 E-10 | **2 E-11** | 1.6 E-9 | **9.5 E-7** | 5 | 3.8 E-10 |
| Toluene | Inhalation | 0.11 | --- | 9.8 E-10 | 1.2 E-10 | --- | 8.3 E-10 | **7.6 E-9** | 10 | 9.7 E-11 |
| Ethylbenzene | Inhalation | 0.29 | --- | 2.4 E-10 | 3.0 E-11 | --- | 2.0 E-10 | **6.9 E-10** | 31 | 7.7 E-12 |
| Xylenes | Inhalation | 0.2 | --- | 2.8 E-9 | 3.5 E-10 | --- | 2.4 E-9 | **1.2 E-8** | 0 | 8.0 E-9 |
| MTBE | Inhalation | --- | --- | NA | --- | --- | --- | --- | 15.8 | --- |
| TPH-G | | | | 1.3 E-4 | | | | | 281 | 4.6 E-7 |
| C5-C8 aliphatics | Inhalation | 0.06 | --- | 2.3 E-5 | 2.9 E-6 | --- | 1.9 E-5 | **0.00032** | | |
| C9-C18 aliphatics | Inhalation | 0.6 | --- | 3.2 E-5 | 4.0 E-6 | --- | 2.7 E-5 | **0.000045** | | |
| C9-C22 aromatics | Inhalation | 0.03 | --- | 7.4 E-5 | 9.3 E-6 | --- | 6.3 E-5 | **0.0021** | | |
| Total Risk/HI Across Pathways | | | | | | **2 E-11** | | **0.0025** | | |
| SSTL Exceeded by Exposure Concentration? | | | | | | **NO** | | **NO** | | |
| Target Risk/HI | | | | | | **1 E-5** | | **1.0** | | |

[a] From OEHHA (2002), EPA (2002).

[b] For air, concentration is in $mg/m^3$. Based on average soil vapor concentrations (See Table 11).

[c] Air: LADD/ADD = $(C_{air} \times IR \times ED \times EF \times AF_i) / (AT \times BW)$.

[d] ILCR = LADD × CSF; HI = ADD × RfD.

[f] The most conservative odor thresholds from ATSDR Toxicological Profiles.

[g] Nuisance index = air concentration/odor threshold.

## Table 17. RBCA Tier 3 Evaluation for Groundwater - On-Site Construction Worker

| Chemical | Exposure Pathway | RfD[a] (mg/kg-d) | CSF[a] (mg/kg-d)$^{-1}$ | Conc.[b] | LADD[c] (mg/kg-d) | ILCR[d] | ADD[c] (mg/kg-d) | Hazard Index[d] | Odor Threshold[b] | Nuisance Index[g] |
|---|---|---|---|---|---|---|---|---|---|---|
| **Outdoor Air** | | | | | | | | | | |
| TPH-G | | | | 4.3 E-4 | | | | | 281 | 1.5 E-6 |
| C5-C8 aliphatics | Inhalation | 0.06 | --- | 8.9 E-5 | 6.8 E-8 | --- | 4.8 E-6 | **0.00008** | | |
| C9-C18 aliphatics | Inhalation | 0.6 | --- | 3.3 E-4 | 2.5 E-7 | --- | 1.8 E-5 | **0.00003** | | |
| C9-C22 aromatics | Inhalation | 0.03 | --- | 1.3 E-5 | 1.0 E-8 | --- | 7.2 E-7 | **0.00002** | | |
| Total Risk/HI Across Pathways | | | | | | --- | | **0.00013** | | |
| Site-Specific Target Level (SSTL, in mg/L)[e]-TPG-G | | | | | | --- | | **274,594** | | |
| SSTL Exceeded? | | | | | | --- | | **NO** | | |
| Target Risk/HI | | | | | | **1 E-5** | | **1.0** | | |

[a] From OEHHA (2002), EPA (2002).

[b] For air, concentration is in mg/m$^3$.

[c] Air: LADD/ADD = ($C_{air}$ × IR × ED × EF × $AF_i$) / (AT × BW).

[d] ILCR = LADD × CSF; HI = ADD × RfD.

[e] SSTL = (C × (1 × $10^{-5}$)) / ILCR or (C × 1.0) / HI.

[f] The most conservative odor thresholds from ATSDR Toxicological Profiles.

[g] Nuisance index = air concentration/odor threshold.

**Table 16.** RBCA Tier 3 Evaluation for Groundwater - On-Site Commercial Worker

| Chemical | Exposure Pathway | RfD[a] (mg/kg-d) | CSF[a] $(mg/kg\text{-}d)^{-1}$ | Conc.[b] | LADD[c] (mg/kg-d) | ILCR[d] | ADD[c] (mg/kg-d) | Hazard Index[d] | Odor Threshold[b] | Nuisance Index[h] |
|---|---|---|---|---|---|---|---|---|---|---|
| **Indoor Air** | | | | | | | | | | |
| TPH-G | | | | 2.9 E-2 | | | | | 281 | 1.0 E-4 |
| C5-C8 aliphatics | Inhalation | 0.06 | --- | 5.9 E-3 | 1.6 E-4 | --- | 4.4 E-4 | **0.0073** | | |
| C9-C18 aliphatics | Inhalation | 0.6 | --- | 2.2 E-2 | 5.7 E-4 | --- | 1.6 E-3 | **0.0026** | | |
| C9-C22 aromatics | Inhalation | 0.03 | --- | 9.3 E-4 | 2.5 E-5 | --- | 6.9 E-5 | **0.0023** | | |
| Total Risk/HI Across Pathways[e] | | | | | | --- | | **0.012** | | |
| Site-Specific Target Level (SSTL, in mg/L)[f]-TPG-G | | | | | | --- | | **2,991** | | |
| SSTL Exceeded? | | | | | | --- | | **NO** | | |
| Target Risk | | | | | | **1 E-5** | | **1.0** | | |

[a] From OEHHA (2002), EPA (2002).

[b] For air, concentration is in $mg/m^3$.

[c] Air: LADD/ADD = $(C_{air} \times IR \times ED \times EF \times AF_i) / (AT \times BW)$.

[d] ILCR = LADD × CSF; HI = ADD × RfD.

[e] Assumes either an indoor or outdoor occupational worker.

[f] SSTL = $(C \times (1 \times 10^{-5})) / ILCR$ or $(C \times 1.0) / HI$.

[g] The most conservative odor thresholds from ATSDR Toxicological Profiles.

[h] Nuisance index = air concentration/odor threshold.

**Table 15.** RBCA Tier 3 Evaluation for Soil - On-Site Construction Worker

| Chemical | Exposure Pathway | RfD[a] (mg/kg-d) | CSF[a] $(mg/kg\text{-}d)^{-1}$ | Conc.[b] | LADD[c] (mg/kg-d) | ILCR[d] | ADD[c] (mg/kg-d) | Hazard Index[d] | Odor Threshold[b] | Nuisance Index[g] |
|---|---|---|---|---|---|---|---|---|---|---|
| Total Risk/HI Across Pathways | | | | | | --- | | 0.47 | | |
| Site-Specific Target Level (SSTL, in mg/kg)[e]-TPG-G | | | | | | --- | | 8,351 | | |
| Site-Specific Target Level (SSTL, in mg/kg)[e]-TPG-D | | | | | | --- | | 8,249 | | |
| SSTL Exceeded? | | | | | | --- | | NO | | |
| Target Risk/HI | | | | | | 1 E-5 | | 1.0 | | |

[a] From OEHHA (2002), EPA (2002).

[b] For air, concentration is in $mg/m^3$; for soil, concentration is in mg/kg.

[c] Air: LADD/ADD = $(C_{air} \times IR \times ED \times EF \times AF_i) / (AT \times BW)$.

Soil-Ingestion: LADD/ADD = $(C_{soil} \times CF \times IR_s \times ED \times EF) / (AT \times BW)$.

Soil-Dermal Contact: LADD/ADD = $(C_{soil} \times CF \times SA \times SAF \times ED \times EF \times AFd) / (AT \times BW)$.

[d] ILCR = LADD × CSF; HI = ADD × RfD.

[e] SSTL = $(C_{soil} \times (1 \times 10^{-5})) / ILCR$ or $(C_{soil} \times 1.0) / HI$.

[f] The most conservative odor thresholds from ATSDR Toxicological Profiles.

[g] Nuisance index = air concentration/odor threshold.

**Table 15.** RBCA Tier 3 Evaluation for Soil - On-Site Construction Worker

| Chemical | Exposure Pathway | RfD[a] (mg/kg-d) | CSF[a] $(mg/kg\text{-}d)^{-1}$ | Conc.[b] | LADD[c] (mg/kg-d) | ILCR[d] | ADD[c] (mg/kg-d) | Hazard Index[d] | Odor Threshold[b] | Nuisance Index[g] |
|---|---|---|---|---|---|---|---|---|---|---|
| <u>**Soil**</u> | | | | | | | | | | |
| TPH-G | | | | 13.20 | | | | | | |
| C5-C8 aliphatics | Ingestion | 0.06 | --- | 4.62 | 2.3 E-7 | --- | 1.6 E-5 | **0.0003** | | |
| C9-C18 aliphatics | Ingestion | 0.6 | --- | 3.30 | 1.6 E-7 | --- | 1.1 E-5 | **0.00002** | | |
| C9-C22 aromatics | Ingestion | 0.03 | --- | 5.28 | 2.6 E-7 | --- | 1.8 E-5 | **0.0006** | | |
| TPH-D | | | | 3,900 | | | | | | |
| C9-C18 aliphatics | Ingestion | 0.06 | --- | 2,535 | 1.2 E-4 | --- | 8.7 E-3 | **0.15** | | |
| C9-C22 aromatics | Ingestion | 0.03 | --- | 1,365 | 6.7 E-5 | --- | 4.7 E-3 | **0.16** | | |
| TPH-G | | | | 13.20 | | | | | | |
| C5-C8 aliphatics | Dermal | 0.06 | --- | 4.62 | 1.2 E-7 | --- | 8.3 E-6 | **0.0001** | | |
| C9-C18 aliphatics | Dermal | 0.6 | --- | 3.30 | 8.4 E-8 | --- | 5.9 E-6 | **0.000010** | | |
| C9-C22 aromatics | Dermal | 0.03 | --- | 5.28 | 1.4 E-7 | --- | 9.5 E-6 | **0.0003** | | |
| TPH-D | | | | 3,900 | | | | | | |
| C9-C18 aliphatics | Dermal | 0.06 | --- | 2,535 | 6.5 E-5 | --- | 4.5 E-3 | **0.076** | | |
| C9-C22 aromatics | Dermal | 0.03 | --- | 1,365 | 3.5 E-5 | --- | 2.4 E-3 | **0.081** | | |
| <u>**Outdoor Air**</u> | | | | | | | | | | |
| TPH-G | | | | 2.6 E-4 | | | | | 281 | 9.3 E-7 |
| C5-C8 aliphatics | Inhalation | 0.06 | --- | 2.5 E-4 | 1.9 E-7 | --- | 1.4 E-5 | **0.0002** | | |
| C9-C18 aliphatics | Inhalation | 0.6 | --- | 6.2 E-6 | 4.8 E-9 | --- | 3.3 E-7 | **0.0000006** | | |
| C9-C22 aromatics | Inhalation | 0.03 | --- | 5.6 E-7 | 4.3 E-10 | --- | 3.0 E-8 | **0.0000010** | | |
| TPH-D | | | | 1.6 E-2 | | | | | 888 | 1.8 E-5 |
| C9-C18 aliphatics | Inhalation | 0.06 | --- | 1.5 E-2 | 1.2 E-5 | --- | 8.1 E-4 | **0.014** | | |
| C9-C22 aromatics | Inhalation | 0.057 | --- | 4.6 E-4 | 3.5 E-7 | --- | 2.5 E-5 | **0.0004** | | |

**Table 14.** RBCA Tier 3 Evaluation for Soil - On-Site Commercial Worker

| Chemical | Exposure Pathway | RfD[a] (mg/kg-d) | CSF[a] $(\text{mg/kg-d})^{-1}$ | Conc.[b] | LADD[c] (mg/kg-d) | ILCR[d] | ADD[c] (mg/kg-d) | Hazard Index[d] | Odor Threshold[b] | Nuisance Index[h] |
|---|---|---|---|---|---|---|---|---|---|---|
| **Indoor Air** | | | | | | | | | | |
| TPH-G | | | | 2.8 E-4 | | | | | 281 | 1.0 E-6 |
| C5-C8 aliphatics | Inhalation | 0.06 | --- | 2.8 E-4 | 7.2 E-6 | --- | 2.0 E-5 | **0.00034** | | |
| C9-C18 aliphatics | Inhalation | 0.6 | --- | 6.8 E-6 | 1.8 E-7 | --- | 5.0 E-7 | **0.000008** | | |
| C9-C22 aromatics | Inhalation | 0.03 | --- | 6.2 E-7 | 1.6 E-8 | --- | 4.6 E-8 | **0.0000008** | | |
| TPH-D | | | | 2.7 E-4 | | | | | 888 | 3.0 E-7 |
| C9-C18 aliphatics | Inhalation | 0.06 | --- | 2.6 E-4 | 6.8 E-6 | --- | 1.9 E-5 | **0.0003** | | |
| C9-C22 aromatics | Inhalation | 0.057 | --- | 8.0 E-6 | 2.1 E-7 | --- | 5.9 E-7 | **0.00001** | | |
| Total Risk/HI Across Pathways[e] | | | | | | --- | | **0.0007** | | |
| Site-Specific Target Level (SSTL, in mg/kg)[f]-TPG-G | | | | | | --- | | **25,022** | | |
| Site-Specific Target Level (SSTL, in mg/kg)[f]-TPG-D | | | | | | --- | | **>100,000** | | |
| SSTL Exceeded? | | | | | | --- | | **NO** | | |
| Target Risk/HI | | | | | | **1 E-5** | | **1.0** | | |

[a] From OEHHA (2002), EPA (2002).

[b] For air, concentration is in $\text{mg/m}^3$; for soil, concentration is in mg/kg.

[c] Air: $\text{LADD/ADD} = (C_{air} \times IR \times ED \times EF \times AF_i) / (AT \times BW)$.

Soil-Ingestion: $\text{LADD/ADD} = (C_{soil} \times CF \times IR_s \times ED \times EF) / (AT \times BW)$.

Soil-Dermal Contact: $\text{LADD/ADD} = (C_{soil} \times CF \times SA \times SAF \times ED \times EF \times AFd) / (AT \times BW)$.

[d] $ILCR = LADD \times CSF$; $HI = ADD \times RfD$.

[e] Assumes either an indoor or outdoor occupational worker.

[f] $SSTL = (C_{soil} \times (1 \times 10^{-5})) / ILCR$ or $(C_{soil} \times 1.0) / HI$.

[g] The most conservative odor thresholds from ATSDR Toxicological Profiles.

[h] Nuisance index = air concentration/odor threshold.

**Table 13.** Exposure Parameters

| Parameter | Abbrev. | Units | Value[a] Commercial Worker | Construction Worker | Resident Child | Resident Adult |
|---|---|---|---|---|---|---|
| Dermal absorption factor | ABS | -- | 0.1 | 0.1 | NA | NA |
| Averaging time for carcinogens | $AT_c$ | days | 25,550 | 25,550 | 25,550 | 25,550 |
| Averaging time for non-carcinogens | $AT_{nc}$ | days | 9,125 | 365 | 2,190 | 8,760 |
| Body weight | BW | kg | 70 | 70 | 15 | 70 |
| Exposure frequency | EF | d/yr | 250 | 183 | 350 | 350 |
| Exposure duration | ED | years | 25 | 1 | 6 | 24 |
| Skin surface area exposed to soil | SA | $cm^2$ | 5,000 | 5,000 | NA | NA |
| Soil adherence factor | AF | $mg/cm^2$ | 0.5 | 0.5 | NA | NA |
| Soil ingestion rate | SI | mg/d | 50 | 480 | NA | NA |
| Exposure time to indoor air | $ET_{ia}$ | hr/d | 9 | -- | 24 | 24 |
| Exposure time to outdoor air | $ET_{oa}$ | hr/d | -- | 9 | -- | -- |
| Outdoor air inhalation rate | $IR_{am}$ | $m^3/d$ | -- | 20 | -- | -- |
| Indoor air inhalation rate | $IR_{es}$ | $m^3/d$ | 20 | -- | 10 | 15 |

[a]Oakland RBCA (2000a) unless otherwise noted.

**Table 12.** Leaching Model - Soil to Groundwater[a]

| Parameter | Abbrev. | Units | TPH-G<br>C5-C8 aliphatics | TPH-G<br>C9-C18 aliphatics | TPH-G<br>C9-C22 aromatics | TPH-D<br>C9-C18 aliphatics | TPH-D<br>C9-C22 aromatics |
|---|---|---|---|---|---|---|---|
| Henry's law constant[b] | H | unitless | 42.64 | 250.51 | 0.17 | 250.51 | 0.17 |
| Volumetric air content in vadose zone soils[b] | $\theta_{as}$ | $cm^3/cm^3$ | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 |
| Volumetric water content in vadose zone soils[b] | $\theta_{ws}$ | $cm^3/cm^3$ | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 |
| Groundwater darcy velocity[b] | $U_{air}$ | cm/s | 33.0 | 33.0 | 33.0 | 33.0 | 33.0 |
| Groundwater mixing zone thickness[b] | $\delta_{gw}$ | cm | 1143 | 1143 | 1143 | 1143 | 1143 |
| Partition coefficient for organic carbon[b] | $k_{oc}$ | $cm^3/g$ | 1,778 | 341,455 | 4,217 | 341,455 | 4,217 |
| Organic carbon content of soil[b] | $f_{oc}$ | -- | 1.8% | 1.8% | 1.8% | 1.8% | 1.8% |
| Sorption coefficient[d] | $k_s$ | $cm^3/g$ | 31.12 | 5975.46 | 73.80 | 5975.46 | 73.80 |
| Soil bulk density[b] | $\rho_s$ | $g/cm^3$ | 1.72 | 1.72 | 1.72 | 1.72 | 1.72 |
| Infiltration rate[b] | I | cm/yr | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 |
| Width of source area[e] | W | cm | 2286.0 | 2286.0 | 2286.0 | 305 | 305 |
| Soil to ambient air volatilization factor[f] | LF | (mg/L) / (mg/kg) | 6.2 E-3 | 3.6 E-5 | 2.9 E-3 | 5.9 E-6 | 4.7 E-4 |
| Concentration in soil[e] | $C_s$ | mg/kg | 3.04 | 2.17 | 3.47 | 2,535 | 1,365 |
| Predicted groundwater concentration[g] | $C_{gw}$ | mg/L | 0.019 | 0.00008 | 0.010 | 0.015 | 0.647 |
| Current average groundwater concentration[e] | $C_{gw}$ | mg/L | 12.77 | 9.12 | 14.60 | ND | ND |
| Predicted concentration>current concentration? | | | NO | NO | NO | YES* | YES* |

* This model assumes that the asphalt is removed from the site. If the asphalt remains it will act as an effective barrier to infiltration. If infiltration is impeded, it is considered likely that there will no driving force for this COPC to move through the vadose zone, and if it does reach water it is unlikely to be in detectable amounts.

[a] ASTM, 1999, Oakland RBCA (2000a).

[b] Oakland RBCA (2000a) default value. The soils beneath the site are predominantly silty clay; therefore, soil parameters are the average of the sandy silt and clayey silt parameters.

[c] Based on available scientific literature.

[d] $f_{oc} \times k_{oc}$.

[e] Based on site data.

[f] $\rho_s/[\theta_{as}+ks\times\rho s+\theta as\times H]\times(1+((U_{gwr}\times\delta_{gw}/(I\times W))$ $cm^3$-kg/l-g.

[g] $C_s \times LF$.

## Table 12. Leaching Model - Soil to Groundwater[a]

| Parameter | Abbrev. | Units | Benzene | Toluene | Ethyl-benzene | Xylene | MTBE |
|---|---|---|---|---|---|---|---|
| Henry's law constant[c] | H | unitless | 0.22 | 0.22 | 0.22 | 0.22 | 0.22 |
| Volumetric air content in vadose zone soils[b] | $\theta_{as}$ | $cm^3/cm^3$ | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 |
| Volumetric water content in vadose zone soils[b] | $\theta_{ws}$ | $cm^3/cm^3$ | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 |
| Groundwater darcy velocity[b] | $U_{air}$ | cm/s | 33.0 | 33.0 | 33.0 | 33.0 | 33.0 |
| Groundwater mixing zone thickness[b] | $\delta_{gw}$ | cm | 1143 | 1143 | 1143 | 1143 | 1143 |
| Partition coefficient for organic carbon[b] | $k_{oc}$ | $cm^3/g$ | 83 | 83 | 83 | 83 | 83 |
| Organic carbon content of soil[b] | $f_{oc}$ | -- | 1.8% | 1.8% | 1.8% | 1.8% | 1.8% |
| Sorption coefficient[d] | $k_s$ | $cm^3/g$ | 1.45 | 1.45 | 1.45 | 1.45 | 1.45 |
| Soil bulk density[b] | $\rho_s$ | $g/cm^3$ | 1.72 | 1.72 | 1.72 | 1.72 | 1.72 |
| Infiltration rate[b] | I | cm/yr | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 |
| Width of source area[e] | W | cm | 2286.0 | 2286.0 | 2286.0 | 2286.0 | 2286.0 |
| Soil to ambient air volatilization factor[f] | LF | (mg/L) / (mg/kg) | 1.3 E-1 | 1.3 E-1 | 1.3 E-1 | 1.3 E-1 | 1.3 E-1 |
| Concentration in soil[e] | $C_s$ | mg/kg | 0.41 | 0.42 | 0.18 | 1.23 | 2.97 |
| Predicted groundwater concentration[g] | $C_{gw}$ | mg/L | 0.053 | 0.054 | 0.023 | 0.159 | 0.384 |
| Current average groundwater concentration[e] | $C_{gw}$ | mg/L | 2.81 | 6.27 | 1.33 | 5.91 | 2.78 |
| Predicted concentration>current concentration? | | | NO | NO | NO | NO | NO |

* This model assumes that the asphalt is removed from the site. If the asphalt remains it will act as an effective barrier to infiltration. If infiltration is impeded, it is considered likely that there will no driving force for this COPC to move through the vadose zone, and if it does reach water it is unlikely to be in detectable amounts.

[a] ASTM, 1999, Oakland RBCA (2000a).

[b] Oakland RBCA (2000a) default value. The soils beneath the site are predominantly silty clay; therefore, soil parameters are the average of the sandy silt and clayey silt parameters.

[c] Based on available scientific literature.

[d] $f_{oc} \times k_{oc}$.

[e] Based on site data.

[f] $\rho_s/[\theta_{as}+ks\times\rho s+\theta as\times H]\times (1+((U_{gwr}\times\delta_{gw}/(I\times W))\ cm^3\text{-kg/l-g}$.

[g] $C_s \times LF$.

**Table 11.** Off-Site Vapor Diffusion Model Results - Soil Vapor to Indoor Air[a]

| Chemical | Southeastern | Eastern |
|---|---|---|
| Benzene | 1.0 E-10 | 1.9 E-9 |
| Toluene | 6.1 E-11 | 9.8 E-10 |
| Ethylbenzene | 8.5 E-12 | 2.4 E-10 |
| Xylenes | 3.0 E-11 | 2.8 E-9 |
| MTBE | NA | NA |
| TPH-G | | |
| - C5-C8 aliphatics | 4.2 E-5 | 2.3 E-5 |
| - C9-C18 aliphatics | 5.9 E-5 | 3.2 E-5 |
| - C9-C22 aromatics | 1.4 E-4 | 7.4 E-5 |

Note: all concentrations in mg/m$^3$.

[a] From Johnson and Ettinger model (1997).

NA = Not available; MTBE is not supported in the model.

**Table 10.** On-Site Vapor Diffusion Model - Groundwater to Ambient Air[a]

| | | | TPH-G | | |
|---|---|---|---|---|---|
| **Parameter** | **Abbrev.** | **Units** | C5-C8 aliphatics | C9-C18 aliphatics | C9-C22 aromatics |
| Henry's law constan[b] | H | unitless | 42.64 | 250.51 | 0.17 |
| Volumetric air content in vadose zone soils[b] | $\theta_{as}$ | $cm^3/cm^3$ | 0.13 | 0.13 | 0.13 |
| Volumetric air content in capillary fringe soils[b] | $\theta_{a,cap}$ | $cm^3/cm^3$ | 0.015 | 0.015 | 0.015 |
| Volumetric water content in vadose zone soils[b] | $\theta_{ws}$ | $cm^3/cm^3$ | 0.33 | 0.33 | 0.33 |
| Volumetric water content in capillary fringe soils[b] | $\theta_{w,cap}$ | $cm^3/cm^3$ | 0.44 | 0.44 | 0.44 |
| Effective diffusion coefficient through capillary fringe[c] | $D_{eff,cap}$ | $cm^2/s$ | 4.9 E-7 | 4.3 E-7 | 1.8 E-5 |
| Effective diffusion coefficient in soil[d] | $D_{eff,s}$ | $cm^2/s$ | 4.9 E-4 | 4.9 E-4 | 4.9 E-4 |
| Groundwater/soil effective diffusion coefficient[e] | $D_{eff,ws}$ | $cm^2/s$ | 2.5 E-6 | 2.2 E-6 | 7.9 E-5 |
| Thickness of capillary fringe[b] | $h_{cap}$ | cm | 106 | 106 | 106 |
| Thickness of vadose zone[f] | $h_v$ | cm | 427 | 427 | 427 |
| Total soil porosity[b] | $\theta_T$ | $cm^3/cm^3$ | 0.45 | 0.45 | 0.45 |
| Diffusion coefficient in water[b] | $D_w$ | $cm^2/s$ | 1.0 E-5 | 1.0 E-5 | 1.0 E-5 |
| Vapor phase diffusion coefficient in air[b] | $D_{air}$ | $cm^2/s$ | 0.100 | 0.100 | 0.100 |
| Wind speed above source parallel to groundwater flow[b] | $U_{air}$ | cm/s | 322 | 322 | 322 |
| Ambient air mixing zone height[b] | $\delta_{air}$ | cm | 200 | 200 | 200 |
| Width of source area parallel to groundwater flow[f] | W | cm | 2,286 | 2,286 | 2,286 |
| Soil bulk density[b] | $\rho_s$ | $g/cm^3$ | 1.5 | 1.5 | 1.5 |
| Depth to groundwater[f] | $L_{GW}$ | cm | 533.4 | 533.4 | 533.4 |
| Groundwater to ambient air volatilization factor[g] | $VF_{am}$ | $(mg/m^3)/(mg/kg)$ | 7.0 E-6 | 3.6 E-5 | 9.2 E-7 |
| Concentration in groundwater[f] | $C_{gw}$ | mg/L | 12.8 | 9.1 | 14.6 |
| Ambient air concentration[h] | $C_{am}$ | $mg/m^3$ | 8.9 E-5 | 3.3 E-4 | 1.3 E-5 |

[a] ASTM, 1999, Oakland RBCA (2000a).

[b] Oakland RBCA (2000a) default value. The soils beneath the site are predominantly silty clay; therefore, soil parameters are the average of the sandy silt and clayey silt parameters.

[c] $D_a \times (\theta_{a,cap}^{3.33}/\theta_T^2) + D_w \times (1/H) \times (\theta_{w,cap}^{3.33}/\theta_T^2)$.

[d] $D_a \times (\theta_{as}^{3.33}/\theta_T^2) + D_w \times (1/H) \times (\theta_{ws}^{3.33}/\theta_T^2)$.

[e] $(h_{cap} + h_v)/[(h_{cap}/D_{eff,cap}) + (h_v/D_{s,eff})]$.

[f] Based on site data.

[g] $1000\ L/m^3 \times H/[1 + (U_{air} \times \delta_{air} \times L_{GW})/(W \times D_{eff,ws})]$.

[h] $C_{gw} \times VF_{am}$.

## Table 9. On-Site Vapor Diffusion Model - Groundwater to Indoor Air[a]

[a] ASTM, 1999, Oakland RBCA (2000a).

[b] Oakland RBCA (2000a) default value. The soils beneath the site are predominantly silty clay; therefore, soil parameters are the average of the sandy silt and clayey silt parameters.

[c] $D_a \times (\theta_{a,cap}{}^{3.33}/\theta_T{}^2) + D_w \times (1/H) \times (\theta_{w,cap}{}^{3.33}/\theta_T{}^2)$.

[d] $D_a \times (\theta_{as}{}^{3.33}/\theta_T{}^2) + D_w \times (1/H) \times (\theta_{ws}{}^{3.33}/\theta_T{}^2)$.

[e] $(h_{cap} + h_v)/[(h_{cap}/D_{eff,cap}) + (h_v/D_{eff,s})]$.

[f] $D_a \times (\theta_{a,crack}{}^{3.33}/\theta_T{}^2) + D_w \times (1/H) \times (\theta_{w,crack}{}^{3.33}/\theta_T{}^2)$.

[g] Based on site data. For resident exposures, only the wells with detected concentrations in 1999 are used (AW-2, AW-3, and AW-4).

[h] $1000\ \mathrm{L/m^3} \times H \times [D_{eff,ws}/(L_{GW} \times ER \times L_B)]/[1 + D_{eff,ws})/(L_{GW} \times ER \times L_B) + (D_{eff,s} \times L_{crack})/(L_{GW} \times D_{eff,crack} \times \eta)]$.

[i] $C_{gw} \times VF_{es}$.

**Table 9.** On-Site Vapor Diffusion Model - Groundwater to Indoor Air[a]

| Parameter | Abbrev. | Units | TPH-G C5-C8 aliphatics | TPH-G C9-C18 aliphatics | TPH-G C9-C22 aromatics |
|---|---|---|---|---|---|
| Henry's law constant[b] | H | unitless | 42.64 | 250.51 | 0.17 |
| Volumetric air content in vadose zone soils[b] | $\theta_{as}$ | $cm^3/cm^3$ | 0.13 | 0.13 | 0.13 |
| Volumetric air content in capillary fringe soils[b] | $\theta_{a,cap}$ | $cm^3/cm^3$ | 0.015 | 0.015 | 0.015 |
| Volumetric water content in vadose zone soils[b] | $\theta_{ws}$ | $cm^3/cm^3$ | 0.33 | 0.33 | 0.33 |
| Volumetric water content in capillary fringe soils[b] | $\theta_{w,cap}$ | $cm^3/cm^3$ | 0.44 | 0.44 | 0.44 |
| Volumetric air content in foundation/wall cracks[b] | $\theta_{acrack}$ | $cm^3/cm^3$ | 0.26 | 0.26 | 0.26 |
| Volumetric water content in foundation/wall cracks[b] | $\theta_{wcrack}$ | $cm^3/cm^3$ | 0.12 | 0.12 | 0.12 |
| Effective diffusion coefficient through capillary fringe[c] | $D_{eff,cap}$ | $cm^2/s$ | 5.0 E-7 | 4.3 E-7 | 2.0 E-5 |
| Effective diffusion coefficient in soil[d] | $D_{eff,s}$ | $cm^2/s$ | 4.9 E-4 | 4.9 E-4 | 4.9 E-4 |
| Effective diffusion coefficient between groundwater and soil[e] | $D_{eff,ws}$ | $cm^2/s$ | 2.5 E-6 | 2.2 E-6 | 8.6 E-5 |
| Effective diffusion coefficient through cracks[f] | $D_{eff,crack}$ | $cm^2/s$ | 5.6 E-3 | 5.6 E-3 | 5.6 E-3 |
| Thickness of capillary fringe[b] | $h_{cap}$ | cm | 106 | 106 | 106 |
| Thickness of vadose zone[g] | $h_v$ | cm | 427 | 427 | 427 |
| Total soil porosity[b] | $\theta_T$ | $cm^3/cm^3$ | 0.45 | 0.45 | 0.45 |
| Diffusion coefficient in water[b] | $D_w$ | $cm^2/s$ | 1.1 E-5 | 1.1 E-5 | 1.1 E-5 |
| Vapor phase diffusion coefficient in air[b] | $D_{air}$ | $cm^2/s$ | 0.100 | 0.100 | 0.100 |
| Soil bulk density[b] | $\rho_s$ | $g/cm^3$ | 1.5 | 1.5 | 1.5 |
| Depth to groundwater[g] | $L_{GW}$ | cm | 533.4 | 533.4 | 533.4 |
| Enclosed-space volume/infiltration ratio[b] | $L_B$ | cm | 305 | 305 | 305 |
| Enclosed-space foundation or wall thickness[b] | $L_{crack}$ | cm | 1 | 1 | 1 |
| Areal fraction of cracks in foundations/walls[b] | $\eta$ | $cm^2/cm^2$ | 0.001 | 0.001 | 0.001 |
| Enclosed space air exchange rate[b] | ER | L/s | 1.4 E-3 | 1.4 E-3 | 1.4 E-3 |
| Groundwater to indoor air volatilization factor[h] | $VF_{es}$ | $(mg/m^3)/(mg/L)$ | 4.7 E-4 | 2.4 E-3 | 6.4 E-5 |
| Concentration in groundwater[g] | $C_{gw}$ | mg/L | 12.8 | 9.1 | 14.6 |
| Enclosed-space air concentration[i] | $C_{es}$ | $mg/m^3$ | 5.9 E-3 | 2.2 E-2 | 9.3 E-4 |

## **Table 8.** On-Site Vapor Diffusion Model - Subsurface Soil to Ambient and Indoor Air[a]

-- = parameter not required for this model.

[a] ASTM, 1999, Oakland RBCA (2000a).

[b] Oakland RBCA (2000a) default value. The soils beneath the site are predominantly silty clay; therefore, soil parameters are the average of the sandy silt and clayey silt parameters.

[c] $D^{air} \times (\theta_{as}^{3.33}/\theta_T^2) + D^{wat} \times (1/H) \times (\theta_{ws}^{3.33}/\theta_T^2)$.

[d] Based on site data.

[e] Based on available scientific literature.

[f] $f_{oc} \times k_{oc}$.

[g] For TPH-G estimates, the default is used. For TPH-D, only one sample had detected TPH-D. Because of the limited area suspected to be impacted by TPH-D, it is assumed that an area 10' by 10' is impacted with TPH-D. For commercial buildings, Building volume/ Building Volume/(Building Area Over Plume). Building dimensions (W × L × H) = 36' × 86' × 10', where 100 ft$^2$ is the estimated amount of the building which is assumed to extend over impacted soils. For residential area, the DTSC residential lot size of 1000 ft$^2$ (DTSC, 1992) is assumed, of which, 100 ft$^2$ is assumed to be the amount of the building (10%) over the TPH-D soils.

[h] $(H \times \rho_s) / ((\theta_{wa} + k_s \times \rho_s + H \times \theta_{as}) \times (1 + ((U_{air} \times \delta_{air} \times L_S) / (D^{eff}{}_s \times W)))) \times 1{,}000$ cm$^3$-kg/m$^3$-g (indoor).

$1000$ L/m$^3 \times H \times [D_{eff,ws}/(L_{GW} \times ER \times L_B)]/[1 + D_{eff,ws})/(L_{GW} \times ER \times L_B) + (D_{eff,ws} \times L_{crack})/(L_{GW} \times D_{eff,crack} \times \eta)]$ (outdoor).

[i] $C_s \times VF$.

## Table 8. On-Site Vapor Diffusion Model - Subsurface Soil to Ambient and Indoor Air[a]

| | | | TPH-D | | | |
|---|---|---|---|---|---|---|
| | | | C9-C18 aliphatics | | C9-C22 aromatics | |
| **Parameter** | **Abbrev.** | **Units** | Outdoor | Indoor Commercial | Outdoor | Indoor Commercial |
| Henry's law constant[b] | H | unitless | 250.51 | 250.51 | 0.17 | 0.17 |
| Volumetric air content in vadose zone soils[b] | $\theta_{as}$ | $cm^3/cm^3$ | 0.13 | 0.13 | 0.13 | 0.13 |
| Volumetric water content in vadose zone soils[b] | $\theta_{ws}$ | $cm^3/cm^3$ | 0.35 | 0.35 | 0.35 | 0.35 |
| Volumetric air content in crack[b] | $\theta_{acrack}$ | $cm^3/cm^3$ | 0.26 | 0.26 | 0.26 | 0.26 |
| Volumetric water content in crack[b] | $\theta_{wcrack}$ | $cm^3/cm^3$ | 0.12 | 0.12 | 0.12 | 0.12 |
| Total soil porosity[b] | $\theta_T$ | $cm^3/cm^3$ | 0.45 | 0.45 | 0.45 | 0.45 |
| Diffusion coefficient in water[b] | $D^{wat}$ | $cm^2/s$ | 1.0 E-5 | 1.0 E-5 | 1.0 E-5 | 1.0 E-5 |
| Vapor phase diffusion coefficient in air[b] | $D^{air}$ | $cm^2/s$ | 0.100 | 0.100 | 0.100 | 0.100 |
| Effective diffusion coefficient-soil[c] | $D^{eff}_s$ | $cm^2/s$ | 4.6 E-4 | 4.9 E-4 | 4.6 E-4 | 4.9 E-4 |
| Effective diffusion coefficient-crack[c] | $D^{eff}_{crack}$ | | 5.2 E-3 | 5.2 E-3 | 5.2 E-3 | 5.2 E-3 |
| Wind speed[d] | $U_{air}$ | cm/s | 322.0 | -- | 322.0 | -- |
| Mixing zone height[b] | $\delta_{air}$ | cm | 200 | -- | 200 | -- |
| Partition coefficient for organic carbon[e] | $k_{oc}$ | $cm^3/g$ | 341,455 | 341,455 | 4,217 | 4,217 |
| Organic carbon content of soil[b] | $f_{oc}$ | -- | 1.8% | 1.8% | 1.8% | 1.8% |
| Sorption coefficient[f] | $k_s$ | $cm^3/g$ | 5975.46 | 5975.46 | 73.80 | 73.80 |
| Soil bulk density[b] | $\rho_s$ | $g/cm^3$ | 1.5 | 1.5 | 1.5 | 1.5 |
| Depth to subsurface soil sources[d] | $L_S$ | cm | 15.2 | 15.2 | 15.2 | 15.2 |
| Width of source area parallel to wind[d] | W | cm | 305 | -- | 305 | -- |
| Enclosed space air exchange rate[b] | ER | $sec^{-1}$ | -- | 1.4 E-3 | -- | 1.4 E-3 |
| Enclosed space volume/infiltration area ratio[g] | $L_B$ | cm | -- | 9.4 E+3 | -- | 9.4 E+3 |
| Enclosed space or wall thickness[b] | $L_{crack}$ | cm | -- | 15 | -- | 15 |
| Areal fraction of cracks in foundations/walls[b] | $\eta$ | $cm^2/cm^2$ | -- | 0.001 | -- | 0.001 |
| Soil to ambient air volatilization factor[h] | VF | $(mg/m^3) / (mg/kg)$ | 6.0 E-6 | 1.0 E-7 | 3.4 E-7 | 5.9 E-9 |
| Concentration in soil[d] | $C_s$ | mg/kg | 2,535 | 2,535 | 1,365 | 1,365 |
| Ambient air concentration[i] | $C_{air}$ | $mg/m^3$ | 1.5 E-2 | 2.6 E-4 | 4.6 E-4 | 8.0 E-6 |

**Table 8.** On-Site Vapor Diffusion Model - Subsurface Soil to Ambient and Indoor Air[a]

| | | | TPH-G | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | C5-C8 aliphatics | | C9-C18 aliphatics | | C9-C22 aromatics | |
| **Parameter** | **Abbrev.** | **Units** | Outdoor | Indoor Commercial | Outdoor | Indoor Commercial | Outdoor | Indoor Commercial |
| Henry's law constant[b] | H | unitless | 42.64 | 42.64 | 250.51 | 250.51 | 0.17 | 0.17 |
| Volumetric air content in vadose zone soils[b] | $\theta_{as}$ | $cm^3/cm^3$ | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 |
| Volumetric water content in vadose zone soils[b] | $\theta_{ws}$ | $cm^3/cm^3$ | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 |
| Volumetric air content in crack[b] | $\theta_{acrack}$ | $cm^3/cm^3$ | 0.26 | 0.26 | 0.26 | 0.26 | 0.26 | 0.26 |
| Volumetric water content in crack[b] | $\theta_{wcrack}$ | $cm^3/cm^3$ | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 |
| Total soil porosity[b] | $\theta_T$ | $cm^3/cm^3$ | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 |
| Diffusion coefficient in water[b] | $D^{wat}$ | $cm^2/s$ | 1.0 E-5 | 1.0 E-5 | 1.0 E-5 | 1.0 E-5 | 1.0 E-5 | 1.0 E-5 |
| Vapor phase diffusion coefficient in air[b] | $D^{air}$ | $cm^2/s$ | 0.100 | 0.100 | 0.100 | 0.100 | 0.100 | 0.100 |
| Effective diffusion coefficient-soil[c] | $D^{eff}_s$ | $cm^2/s$ | 4.6 E-4 | 4.9 E-4 | 4.6 E-4 | 4.9 E-4 | 4.6 E-4 | 4.9 E-4 |
| Effective diffusion coefficient-crack[c] | $D^{eff}_{crack}$ | | 5.2 E-3 | 5.2 E-3 | 5.2 E-3 | 5.2 E-3 | 5.2 E-3 | 5.2 E-3 |
| Wind speed[d] | $U_{air}$ | cm/s | 322.0 | -- | 322.0 | -- | 322.0 | -- |
| Mixing zone height[b] | $\delta_{air}$ | cm | 200 | -- | 200 | -- | 200 | -- |
| Partition coefficient for organic carbon[e] | $k_{oc}$ | $cm^3/g$ | 1,778 | 1,778 | 341,455 | 341,455 | 4,217 | 4,217 |
| Organic carbon content of soil[b] | $f_{oc}$ | -- | 1.8% | 1.8% | 1.8% | 1.8% | 1.8% | 1.8% |
| Sorption coefficient[f] | $k_s$ | $cm^3/g$ | 31.12 | 31.12 | 5975.46 | 5975.46 | 73.80 | 73.80 |
| Soil bulk density[b] | $\rho_s$ | $g/cm^3$ | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 |
| Depth to subsurface soil sources[d] | $L_S$ | cm | 237.7 | 237.7 | 237.7 | 237.7 | 237.7 | 237.7 |
| Width of source area parallel to wind[d] | W | cm | 2,286 | -- | 2,286 | -- | 2,286 | -- |
| Enclosed space air exchange rate[b] | ER | $sec^{-1}$ | -- | 1.4 E-3 | -- | 1.4 E-3 | -- | 1.4 E-3 |
| Enclosed space volume/infiltration area ratio[g] | $L_B$ | cm | -- | 3.1 E+2 | -- | 3.1 E+2 | -- | 3.1 E+2 |
| Enclosed space or wall thickness[b] | $L_{crack}$ | cm | -- | 15 | -- | 15 | -- | 15 |
| Areal fraction of cracks in foundations/walls[b] | $\eta$ | $cm^2/cm^2$ | -- | 0.001 | -- | 0.001 | -- | 0.001 |
| Soil to ambient air volatilization factor[h] | VF | $(mg/m^3) / (mg/kg)$ | 8.4 E-5 | 9.1 E-5 | 2.9 E-6 | 3.1 E-6 | 1.6 E-7 | 1.8 E-7 |
| Concentration in soil[d] | $C_s$ | mg/kg | 3.0 | 3.0 | 2.17 | 2.17 | 3.47 | 3.47 |
| Ambient air concentration[i] | $C_{air}$ | $mg/m^3$ | 2.5 E-4 | 2.8 E-4 | 6.2 E-6 | 6.8 E-6 | 5.6 E-7 | 6.2 E-7 |

**Table 7.** Soil Vapor Statistical Analysis

| | Soil Concentration (ppmv)[a] | | | | | |
|---|---|---|---|---|---|---|
| | **Southeastern[b]** | | | | | |
| | **Benzene** | **Toluene** | **Ethyl-benzene** | **Xylenes** | **MTBE** | **TPH-G** |
| **Soil Vapor** | | | | | | |
| Samples | 9 | 9 | 9 | 9 | 9 | 9 |
| Detections | 8 | 9 | 1 | 8 | 4 | 9 |
| Detection Frequency | 89% | 100% | 11% | 89% | 44% | 100% |
| Minimum Detection | 0.0014 | 0.0033 | 0.0010 | 0.0013 | 0.0013 | 1.6 |
| Mean | 0.0082 | 0.0079 | 0.0015 | 0.0048 | 0.0027 | 5.2 |
| Maximum Detection | 0.026 | 0.019 | 0.0027 | 0.0098 | 0.0050 | 11 |
| Standard Deviation | 0.0070 | 0.0045 | 0.00051 | 0.0025 | 0.0016 | 3.6 |
| Distribution | Lognormal | Lognormal | NP | Normal | NP | Normal |
| 95% UCL | 0.018 | 0.012 | 0.0018* | 0.0064 | 0.0037* | 7.4 |
| | **Eastern[c]** | | | | | |
| | **Benzene** | **Toluene** | **Ethyl-benzene** | **Xylenes** | **MTBE** | **TPH-G** |
| **Soil Vapor** | | | | | | |
| Samples | 9 | 9 | 9 | 9 | 9 | 9 |
| Detections | 8 | 9 | 4 | 8 | 6 | 8 |
| Detection Frequency | 89% | 100% | 44% | 89% | 67% | 89% |
| Minimum Detection | 0.0021 | 0.0055 | 0.0012 | 0.0021 | 0.0013 | 1.3 |
| Mean | 0.05 | 0.041 | 0.020 | 0.085 | 0.01 | 2.6 |
| Maximum Detection | 0.34 | 0.23 | 0.15 | 0.59 | 0.062 | 6.2 |
| Standard Deviation | 0.11 | 0.073 | 0.049 | 0.19 | 0.019 | 1.6 |
| Distribution | Lognormal | Lognormal | NP | Lognormal | Lognormal | Lognormal |
| 95% UCL | 0.34 | 0.19 | 0.050* | 0.59 | 0.041 | 4.0 |

* Determined assuming the underlying distribution of the data is normal. See text.

[a] Half the detection limit was used for non-detect values.

[b] Located near southeastern property line, adjacent to a 2-story apartment building; borings B-1, B-2, and B-3.

[c] Located near eastern property line, adjacent to a single-story residence; borings B-4, B-5, and B-6.

NP = Non-parametric

**Table 6.** Groundwater Statistical Analysis

| | Groundwater Concentration (µg/L)[a] | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Benzene** | **Toluene** | **Ethyl-benzene** | **Xylenes** | **MTBE** | **TPH-G** | **TPH-D** |
| **Groundwater** | | | | | | | |
| Minimum Detection | 1.0 | 6.60 | 1.40 | 2.0 | 23.0 | 60 | ND |
| Mean | 2,811 | 6,272 | 1,332 | 5,906 | 2778.8 | 36,492 | ND |
| Maximum Detection | 19,000 | 46,000 | 5,800 | 28,000 | 37,000.0 | 330,000 | ND |
| Standard Deviation | 5,519 | 14,194 | 1,580 | 9,315 | 6,867 | 72,598 | ND |
| Distribution | NP | NP | NP | NP | NP | NP | ND |
| 95% UCL | 4,587* | 11,759* | 1,885* | 9,165* | 4,839* | 57,026* | ND |

* Determined assuming the underlying distribution of the data is normal.

[a] Data used are the last four quarters of sampling where samples were collected. Only those wells which had at least one detection for the constituent were used. Half the detection limit was used for non-detect values.

NP = Non-parametric

ND = not detected

**Table 5.** Soil Statistical Analysis

| | Soil Concentration (mg/kg)[a] | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Benzene** | **Toluene** | **Ethyl-benzene** | **Xylenes** | **MTBE** | **TPH-G** | **TPH-D** |
| **Soil (all depths)** | | | | | | | |
| Samples | 58 | 58 | 58 | 58 | 16 | 58 | 2 |
| Detections | 29 | 19 | 19 | 22 | 5 | 11 | 1 |
| Detection Frequency | 50% | 33% | 33% | 38% | 31% | 19% | 50% |
| Minimum Detection | 0.01 | 0.01 | 0.030 | 0.01 | 0.10 | 1.00 | 3,900 |
| Mean | 0.14 | 0.10 | 0.061 | 0.29 | 0.5 | 9.20 | NA |
| Maximum Detection | 1.0 | 0.71 | 0.520 | 3.0 | 4.0 | 33 | 3,900 |
| Standard Deviation | 0.28 | 0.18 | 0.12 | 0.73 | 1.59 | 8.79 | NA |
| Distribution | Lognormal | Lognormal | Lognormal | Lognormal | Normal | NP | NA |
| 95% UCL | 0.41 | 0.42 | 0.18 | 1.2 | 3.0 | 8.7* | 3,900 |
| **Soil (0-10 feet)** | | | | | | | |
| Samples | | | | | | 23 | 2 |
| Detections | | | | | | 8 | 1 |
| Detection Frequency | | | | | | 35% | 50% |
| Minimum Detection | | | | | | 1.20 | 3,900 |
| Mean-Detects | | | | | | 8.3 | NA |
| Mean | | | | | | 8.3 | NA |
| Maximum Detection | | | | | | 23.0 | 3,900 |
| Standard Deviation | | | | | | 7.46 | NA |
| Distribution | | | | | | Normal | NA |
| 95% UCL | | | | | | 13.2 | 3,900 |

* Determined assuming the underlying distribution of the data is normal. See text

[a] Half the detection limit was used for non-detect values

NP = Non-parametric

NA= not applicable

**Table 4.** Groundwater RBCA Tier 2 Analysis

| | **Concentration (µg/L)[a]** | |
|---|---|---|
| | **Benzene** | **TPH-G** |
| Minimum | 1 | 60 |
| Mean | 2,811 | 36,492 |
| Maximum | 19,000 | 330,000 |
| Location of Maximum | RW-1 | AW-1 |
| GW to Outdoor Air-Construction | | |
| Tier 2 level (Oakland-Sandy Silts)[b,c] | NA | NA |
| Tier 2 level (Cal-EPA adjusted)[d] | NA | -- |
| Proceed to Tier 3 | NA | **Yes** |
| GW to Indoor Air-Commercial | | |
| Tier 2 level (Oakland-Sandy Silts) | 53,000 | NA |
| Proceed to Tier 3 | No | **Yes** |
| GW to Enclosed Space Air-Residential | | |
| Tier 2 level (Oakland-Sandy Silts) | 3,400 | NA |
| Proceed to Tier 3 | **Yes** | **Yes** |

[a] From groundwater sampling for the site; the last four quarters where the constituent was analyzed-see text.

[b] Construction benzene Tier 2 level was adjusted to reflect the difference between the construction worker exposure duration (1 year) versus the commercial worker exposure duration (assumed to be 25 years).

[c] Sandy Silts Tier 2 values are used because they are considered the most appropriate based on the soil types beneath the site.

**Table 3.** Soil RBCA Tier 2 Analysis

| | Concentration (mg/kg)[a] | | |
|---|---|---|---|
| | **Benzene** | **TPH-G** | **TPH-D** |
| Minimum | 0.01 | 1.00 | 3,900 |
| Mean | 0.08 | 3.0 | -- |
| Maximum | 1.00 | 33.0 | 3,900 |
| Location of Maximum | RW-1@25[d] | RW-1@25[d] | TD-5-0.5[e] |
| <u>Soil Direct Contact-Construction</u> | | | |
| Tier 2 level (Oakland-RBCA-Sandy Silts)[b,c] | NA | NA | NA |
| Proceed to Tier 3 | NA | **Yes** | **Yes** |
| <u>Soil to Outdoor Air-Construction</u> | | | |
| Tier 2 level (Oakland-RBCA-Sandy Silts)[b,c] | NA | NA | NA |
| Tier 2 level (Cal-EPA adjusted)[d] | NA | -- | -- |
| Proceed to Tier 3 | NA | **Yes** | **Yes** |
| <u>Soil to Enclosed Space Air-Workers</u> | | | |
| Tier 2 level (Oakland-RBCA-Sandy Silts) | NA | NA | NA |
| Proceed to Tier 3 | NA | **Yes** | **Yes** |
| <u>Soil to Enclosed Space Air-Residents</u> | | | |
| Tier 2 level (Oakland-RBCA-Sandy Silts) | 1.1 | NA | NA |
| Proceed to Tier 3 | No | **Yes** | **Yes** |

[a] From soil sampling for the site.

[b] Construction benzene Tier 1 level was adjusted to reflect the difference between the construction worker exposure duration (1 year) versus the commercial worker exposure duration (assumed to be 25 years).

[c] Sandy Silts Tier 2 values are used because they are considered the most appropriate based on the soil types beneath the site.

[d] Alton Geoscience (1990b).

[e] EMCON (1994).

SAT = soil saturation concentration

**Table 2.** Groundwater RBCA Tier 1 Analysis

| | Groundwater Concentration (µg/L)[a] | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Benzene** | **Toluene** | **Ethyl-benzene** | **Xylenes** | **MTBE** | **TPH-G** | **TPH-D** |
| Minimum | 1 | 6.6 | 1.4 | 2 | 23.0 | 60 | ND |
| Mean | 2,811 | 6,272 | 1,332 | 5,906 | 2,779 | 36,492 | ND |
| Maximum | 19,000 | 46,000 | 5,800 | 28,000 | 37,000 | 330,000 | ND |
| Location of Maximum | RW-1 | RW-1 | RW-1 | RW-1 | AW-1 | AW-1 | NA |
| GW to Outdoor Air-Construction | | | | | | | |
| Tier 1 level (Oakland)[b] | 525,000 | >Sol | >Sol | >Sol | >Sol | NA | NA |
| Proceed to Tier 2 | No | No | No | No | No | **Yes** | No |
| GW to Indoor Air-Commercial | | | | | | | |
| Tier 1 level (Oakland) | 1,800 | >Sol | >Sol | >Sol | >Sol | NA | NA |
| Proceed to Tier 2 | **Yes** | No | No | No | No | **Yes** | No |
| GW to Enclosed Space Air-Residential | | | | | | | |
| Tier 1 level (Oakland) | 110 | 210,000 | >Sol | >Sol | >1,000,000 | NA | NA |
| Proceed to Tier 2 | **Yes** | No | No | No | No | **Yes** | No |

[a] From groundwater sampling for the site; the last four quarters where the constituent was analyzed (Blaine Tech Sevices, 1999).

[b] Construction benzene Tier 1 level was adjusted to reflect the difference between the construction worker exposure duration (1 year) versus the commercial worker exposure duration (assumed to be 25 years).

> Sol = the acceptable concentration is greater than the constituent's solubility in water. The constituent's solubility was not exceeded by the maximum detected concentration.

**Table 1.** Soil RBCA Tier 1 Analysis

| | Soil Concentration (mg/kg)[a] | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Benzene** | **Toluene** | **Ethyl-benzene** | **Xylenes** | **MTBE** | **TPH-G** | **TPH-D** |
| Minimum | 0.01 | 0.01 | 0.003 | 0.01 | 0.10 | 1.00 | 3,900 |
| Mean | 0.08 | 0.04 | 0.025 | 0.14 | 0.5 | 3.0 | -- |
| Maximum | 1.0 | 0.71 | 0.520 | 3.0 | 4.0 | 33.0 | 3,900 |
| Location of Maximum | RW-1@25[c] | RW-1@25[c] | P3@2.5[d] | P3@2.5[d] | P3@3.5[d] | RW-1@25[c] | TD-5-0.5[e] |
| Soil Direct Contact-Construction | | | | | | | |
| Tier 1 level (Oakland-RBCA)[b] | 195.0 | 5,833 | 3,438 | 31,250 | 177 | NA | NA |
| Proceed to Tier 2? | No | No | No | No | No | **Yes** | **Yes** |
| Soil to Outdoor Air-Construction | | | | | | | |
| Tier 1 level (Oakland-RBCA)[b] | 18.3 | SAT | SAT | SAT | SAT | NA | NA |
| Proceed to Tier 2? | No | No | No | No | No | **Yes** | **Yes** |
| Soil to Enclosed Space Air-Workers | | | | | | | |
| Tier 1 level (Oakland-RBCA) | 1.1 | SAT | SAT | SAT | SAT | NA | NA |
| Proceed to Tier 2? | No | No | No | No | No | **Yes** | **Yes** |
| Soil to Enclosed Space Air-Residents | | | | | | | |
| Tier 1 level (Oakland-RBCA) | 0.069 | SAT | SAT | SAT | SAT | NA | NA |
| Proceed to Tier 2? | **Yes** | No | No | No | No | **Yes** | **Yes** |

[a] From soil sampling for the site

[b] Construction benzene Tier 1 level was calculated using construction worker exposure parameters (480 mg/day ingestion, exposure duration of one year).

[c] Alton Geoscience (1990b).

[d] Gettler-Ryan Inc (1999).

[e] EMCON (1994).

SAT = soil saturation concentration

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### *5.2 Nuisance Analysis*

In addition to standard health risk and hazard analyses, an analysis of the "nuisance hazard" was conducted. In conducting the nuisance analysis, the odor threshold for each petroleum compound for which a Tier 3 RBCA evaluation was conducted was identified. These odor thresholds were considered "nuisance thresholds," that is, any air concentration of a compound which exceeded its odor threshold would be considered a "nuisance." The odor thresholds identified for TPH-G (gasoline), TPH-D (diesel fuel oil), and BTEX are listed in Tables 14 through 19. The ratio of the air concentration estimates for each compound to the odor threshold was called the "nuisance index." Although it would not be indicative of a health hazard, any nuisance index that exceeded 1.0 (air concentration estimate equal to or greater than the odor threshold) would be considered a nuisance. As shown in Tables 14 through 19, none of the estimated air concentrations are within four orders of magnitude of their respective odor thresholds. Therefore, in addition to not posing a risk, residual hydrocarbons present in both soil and groundwater at the site are not considered to pose a nuisance to current and future on-site workers or off-site residents.

RBCA Tier 2 evaluation indicate that levels of benzene in soil should not pose a risk to current and future on-site workers.

Results of the RBCA Tier 3 evaluation indicate that levels of benzene in groundwater and soil vapor, and TPH in soil, soil vapor, and groundwater should not pose a risk to current and future on-site workers or off-site residents. The concentrations of chemicals to which individuals could potentially be exposed were based on available measured data and estimation of indoor air and outdoor air concentrations. This evaluation indicates that the theoretical upper-bound incremental lifetime cancer risk levels for benzene are below $10^{-5}$, and well within or below the EPA acceptable cancer risk range of $10^{-4}$ to $10^{-6}$. The evaluation indicates that the HI levels are below the acceptable level of 1.0. Because these values are less than 1.0, adverse non-carcinogenic health effects are not likely to be associated with the site.

Results of the risk assessment also served as a basis for the development of site-specific target level (SSTLs). The SSTLs calculated for each receptor were compared to the concentrations measured at the site and presented in Tables 14 through 17. Construction, commercial, and residential scenarios were evaluated and soil 95 percent UCL concentrations and groundwater average plume concentrations at the site are below their respective SSTLs.

It is important to note, that although some specific sample locations may have detected concentrations greater than the SSTLs, it is inappropriate to compare individual sample results to the SSTLs. Rather, the 95 percent UCL concentrations should be used for determining whether conditions at the site pose a risk to workers. There are two reasons why it is more appropriate to use the 95 percent UCL versus a single sample result: (1) any risk-based cleanup levels developed for the site are derived using toxicity criteria that are based on lifetime average exposures; and (2) the 95 percent UCL concentration is more representative of the concentration that would be contacted at the site over time (EPA, 1992). That is, a person would not expect to be exposed to soil at a single point on the site, rather they would be exposed to soil over an area of the site.

Chapter 2 of DTSC's supplemental guidance states, "Estimates of chemical concentrations in soil are to be derived using these principles for all state-lead sites…" (DTSC, 1992). Chapter 2 recommends calculating a 95 percent UCL for "an appropriate-sized area…" (DTSC, 1992). For a commercial site, this area of exposure may be very large and may in fact consist of the entire site. Risk assessors within both EPA and DTSC support and endorse this position. EPA and DTSC have consistently used this approach at other sites in California. There are numerous examples of sites where the 95 percent UCL was used to determine whether further action was warranted that were approved by DTSC. Scientists at DTSC's Office of Scientific Affairs should be contacted for supporting information regarding this issue.

In addition, there are Occupational Safety and Health Administration (OSHA) training requirements for workers engaged in construction activities at retail gasoline outlets. Proper adherence to OSHA requirements will enable a worker to take appropriate actions to mitigate potential chemical exposures.

Use of fate and transport models, in general, introduces some degree of uncertainty in any analysis In particular, environmental transport models were used in this evaluation to estimate partitioning of chemicals from soil. Uncertainties result both from any model's limited ability to predict complicated, constantly changing environmental conditions, as well as in the input parameters used to solve the models.

### 4.4.4 Toxicological Data and Dose Response Extrapolations

The availability and quality of toxicological data is another source of uncertainty in the risk assessment. Uncertainties associated with animal and human studies may have influenced the toxicity criteria. Carcinogenic criteria are classified according to the amount of evidence available that suggests human carcinogenicity. EPA assigns each carcinogen a designation of A through E, dependent upon the strength of the scientific evidence for carcinogenicity.

Extrapolation of toxicological data from animal tests is one of the largest sources of uncertainty in a risk assessment. There may be important, but unidentified, differences in uptake, metabolism, and distribution of chemicals in the body between the test species and humans. For the most part, these uncertainties are addressed through use of conservative assumptions in establishing values for CSFs, which results in the likelihood that the risk is overstated. Even if studies of chemical effect in humans are available (*e.g.*, for benzene), they generally are for workplace exposures far in excess of those expected in the environment. Uncertainties can be large because the activity patterns, exposure duration and frequency, individual susceptibility, and dose may not be the same in the study populations as in the individuals exposed to environmental concentrations. Because conservative methods are used in developing the toxicity criteria, the possibility of underestimating risks is low.

# 5. SUMMARY

## *5.1 Risk Assessment Results*

MWH, has evaluated the potential risks to human health posed by BTEX, MTBE, and TPH in soil and groundwater at 2220 98th Avenue, Oakland, California. To ensure that human health is adequately protected, conservative concentrations, exposure parameters, and toxicity assumptions were used in estimating exposure potential and risks. Results of the RBCA Tier 1 and Tier 2 evaluations indicate that concentrations of benzene, toluene, ethylbenzene, xylenes, and MTBE in soil and groundwater should not pose a risk to construction workers, and that concentrations of toluene, ethylbenzene, xylenes, and MTBE should not pose a risk to commercial workers or off-site residents. Results of the estimates, which are often upper-bound values, for each parameter, as was done at the facility, a probability distribution function representing a range of data is used. A computer model performs the risk calculations up to 10,000 times, and each iteration incorporates a different combination of data from the various probability distribution functions. The result is a distribution of risks instead of a single value.

In general, theoretical upper-bound risks calculated in probabilistic risk assessments are lower and more realistic than those calculated in deterministic evaluations, and because the result is a distribution and not a point estimate, there is a greater level of certainty associated with the calculated risks. Regulatory agencies recognize the usefulness of a quantitative uncertainty analysis. However, the use of probabilistic methods is beyond the scope of this Oakland RBCA Tier 3 evaluation.

### 4.4.1 Uncertainty in Site Characterization

Uncertainty can exist in characterizing the nature and extent of the petroleum impacts on soils at the site. In an effort to reduce this uncertainty, multiple samples were collected from the site. The number of sampling locations and events is large and spans several years; therefore, the sampling and analysis data should be sufficient to characterize the distribution of petroleum hydrocarbons and the associated potential risks.

### 4.4.2 Soil Sampling Bias

The RBCA evaluation was based on data obtained during site characterization activities. Most data collected was focused on finding and delineating petroleum hydrocarbons in soil at the gasoline and diesel fueling systems. Sampling plans are designed to be efficient in defining the vertical and horizontal extent of petroleum hydrocarbons in soil. Thus, more samples are collected from impacted areas than non-impacted areas. This adds additional conservative bias to the evaluation, given that the assumed exposure concentration actually only make up a portion of the site, while actual exposure patterns would cover the whole site.

### 4.4.3 Uncertainty in the Exposure Assessment

Exposure assessment inputs used in this evaluation, and typically in risk assessments in general, attempt to incorporate reasonable maximum exposure assumptions to protect individuals likely to have the highest exposure. Therefore, while there is a great deal of variability and uncertainties in these exposure inputs because they are high-end assumptions, they would likely tend to overestimate rather than underestimate exposure to most individuals. In addition, no attempt was made to predict biodegradation or environmental decay of petroleum compounds. However, over the exposure durations used in the evaluation, some decrease in concentrations would be expected. A decrease in concentrations over time would lead to decreased risk. Therefore, the steady state assumption used in this evaluation would tend to overestimate risk.

For carcinogens, risk is estimated as the incremental probability of an individual developing cancer over a lifetime as a result of a chemical exposure. Theoretical upper-bound incremental lifetime cancer risks are evaluated by multiplying the estimated average exposure rate (*i.e.*, LADD) by the chemical's CSF. The CSF converts estimated daily intakes averaged over a lifetime to the incremental risk of an individual developing cancer. Theoretical upper-bound incremental lifetime cancer risk estimates are compared to EPA's acceptable risk range of one in one million ($10^{-6}$) to one in ten thousand ($10^{-4}$). A risk level of $10^{-5}$ is consistent with Oakland RBCA process for risk management decisions. A risk level of $1 \times 10^{-5}$ represents a probability of one in one hundred thousand that an individual could develop cancer from exposure to the potential carcinogen under a defined set of exposure assumptions.

For non-carcinogenic health effects, a Hazard Index (HI) is used to evaluate exposure relative to a toxicity reference value. The HI is calculated by dividing the average exposure rate (ADD) by the chemical-specific RfD. An HI of 1.0 is typically used as an acceptable hazard level.

The pathway, location, and chemical or TPH fraction-specific HIs and theoretical upper-bound incremental lifetime cancer risks are presented in Tables 14 through 19. A summary of the HIs and risk estimates is presented in Table 21.

## *4.4 Uncertainty Analysis*

Risk estimates are values that have uncertainties associated with them. These uncertainties, which arise at every step of a risk assessment, are evaluated to provide an indication of the relative degree of uncertainty associated with a risk estimate. In this section, a qualitative discussion of the uncertainties associated with the estimation of risks for the site is presented.

Risk assessments are not intended to estimate actual risks to a receptor associated with exposure to chemicals in the environment. Risk assessment is a means of estimating the probability that an adverse health effect (*e.g.*, cancer, and impaired reproduction) will occur in a receptor. The multitude of conservative assumptions used in risk assessments guard against underestimation of risks.

Risk estimates are calculated by combining site data, assumptions about individual receptor's exposures to impacted media, and toxicity data. The uncertainties in this risk assessment can be grouped into three main categories that correspond to these steps:

- Uncertainties in environmental sampling and analysis
- Uncertainties in assumptions concerning exposure scenarios
- Uncertainties in toxicity data and dose-response extrapolations

It is possible to quantify the uncertainty in a risk assessment through the use of Monte Carlo simulations in the risk calculations. Risk assessments with quantitative uncertainty analyses are called "probabilistic evaluations." Instead of calculating risks using point

Assume the composition of residual TPH in soil is equivalent to fresh product. This approach has become feasible with the development by EPA of provisional toxicity criteria for several petroleum products, including gasoline, diesel, and jet fuels. This approach also assumes the presence of BTEX in the toxicity criteria, thus double counting the effects of BTEX, which are usually evaluated separately from TPH. In addition, petroleum products can change appreciably after release into soil due to the influence of differential rates of degradation and dispersion on individual compounds in the mixture (*i.e.*, weathering). For example, the aromatic versus the aliphatic constituents in hydrocarbon mixtures are prone to faster rates of degradation and dispersion. Therefore, the assumption that a TPH fraction in soil is equivalent to fresh product is likely to greatly overestimate risk.

The fractionation approach. This approach accounts for the differential weathering of petroleum hydrocarbons and estimation of risks of mixtures for which toxicity data are not available. The approach consists of a) fractionation of fuel products into chemical families or fractions, b) selection of surrogate chemicals that are considered representative of each fraction, c) normalization of surrogate chemicals to represent all chemicals within a fraction, d) fate and transport modeling of the surrogate chemicals, and e) risk characterization of the surrogate chemicals.

In order to develop risk-based screening benchmark values for petroleum hydrocarbons in soil for the Oakland site, the fractionation approach developed by the Massachusetts Department of Environmental Protection (MaDEP) in which the total mass of petroleum hydrocarbons is separated into aromatic and aliphatic fractions, is used. For each quantifiable analytical fraction, a "reference" toxicity value is assigned to conservatively represent the toxicity of that fraction. The utility of the MaDEP fractionation approach is its applicability to all forms of petroleum products, whether fresh or weathered. The environmental fractions identified using this approach are aliphatics (alkanes) and aromatics.

MaDEP recommended product-specific fractions and toxicity criteria for each fraction were used to develop the human health screening benchmark values. In the absence of site-specific TPH fractionation analytical data, composition recommendations for TPH-G and TPH-D from the MaDEP are used to determine the percent of each fraction present in the environment. The product-specific fractions, fraction composition for each petroleum product, and toxicity criteria for each fraction used in the Tier 3 evaluation are presented in Table 20.

### *4.3 Risk Characterization*

In the last step of a risk assessment, the estimated rate at which a person intakes a chemical is compared with information about the toxicity of that chemical to estimate the potential risks to human health posed by exposure to the chemical. This step is known as the risk characterization.

### 4.2.1 Total Petroleum Hydrocarbons

Gasoline, diesel, motor oil and other petroleum products are complex mixtures of hydrocarbons. Once these products have been released into the environment, the composition of the mixture changes because the components have different physical and chemical properties (*e.g.*, solubility in water, volatility, and soil adsorption coefficients). These properties dictate the behavior of each component in the environment. Consequently, a receptor will not be exposed to fresh product but to a mixture of the various chemical components of petroleum hydrocarbons as they have 'weathered,' or changed in composition, during migration in the environment.

The chemical composition has not been quantitatively identified in most petroleum-based complex mixtures, such as gasoline and diesel. Routine qualitative and quantitative analyses of either commercial products or samples of impacted soil or groundwater for the purpose of establishing the chemical breakdown of hydrocarbon mixtures are currently impractical, primarily because the low potential usefulness of such data does not justify the high cost of routine chemical analysis. In addition, specific toxicity criteria that are essential to risk assessment have been developed for only a handful of the constituent hydrocarbons. The reason is that most of these hydrocarbons have not been subjected to the battery of toxicity tests required for developing the criteria.

Because a consensus method for setting cleanup levels for complex hydrocarbon mixtures has not been established, a number of different approaches that are not health-based or site-specific have been recommended by regulatory agencies. Two such approaches are:

Remediate TPH to a concentration equivalent to the practical limit of quantification (PLQ). This approach is generally considered by most environmental professionals to lack scientific basis and be an inefficient use of resources.

Remediate TPH to pre-established cleanup levels. These levels vary among regulatory agencies, and typically range between 10 and 10,000 mg/kg for soil. This approach is frequently criticized for being arbitrary and lacking scientific basis.

In an effort to move away from methods that are inefficient and lacking in scientific foundation, several approaches have been developed for the determination of more appropriate site-specific and health-based cleanup levels. Some of these approaches include:

Assess certain discrete compounds with established toxicity criteria. Typical examples of compounds included are benzene and the alkyl benzenes such as ethylbenzene, toluene, and total xylenes in gasoline, or polynuclear aromatic hydrocarbons (PAHs). The main rationale cited for this approach are: (a) these selected compounds are the predominate contributors to total risk; thus, the relative significance of other TPH constituents is low, (b) analytical procedures are well-established and affordable for individual the more toxic compounds, and (c) essential toxicity criteria have been established.

$$ADD\ or\ LADD_{dermal}(mg/kg-d)=\frac{C_{soil}\times CF\times SA\times SAF\times EF\times ED\times AF_{d}}{BW\times AT}$$

$$ADD\ or\ LADD_{ingestion}(mg/kg-d)=\frac{C_{soil}\times CF\times IR_{s}\times EF\times ED}{BW\times AT}$$

where:

$C_{air}$ = chemical concentration in air (mg/m$^3$)
$C_{soil}$ = 95 percent UCL chemical concentration in soil (mg/kg)
CF = conversion factor ($1 \times 10^{-6}$ kg/mg)
IR = inhalation rate; the amount of the transport medium contacted per unit time (m$^3$/day)
$IR_s$ = soil ingestion rate (mg/day)
EF = exposure frequency (days/year)
ED = exposure duration (years)
$AF_i$ = inhalation absorption fraction (fraction)
AT = averaging time; the time over which the exposure is averaged (days)
BW = body weight (kilograms)
$AF_d$ = dermal absorption fraction (fraction)
SA = skin surface area exposed (cm$^2$/day)
SAF = soil-skin adherence factor (mg/cm$^2$)

For residential exposures, the exposure equation is calculated twice, once for adults, and once for children (using their respective exposure parameters) and the results are added together. The exposure parameter that differs between the calculation of an ADD and a LADD is averaging time (AT). A lifetime, 70 year, AT is used for the LADD while an AT equal to exposure duration is used for the ADD. The resulting LADDs and ADDs are presented in Section 4.3 (Risk Characterization) and Tables 14 through 19.

### *4.2 Toxicity Assessment*

Toxicity values, when available, are published by EPA in the on-line Integrated Risk Information System ([IRIS]; EPA, 2002) and by the California Office of Environmental Health Hazard Assessment (OEHHA, 2002). Cancer slope factors (CSFs) are chemical-specific, experimentally derived potency values that are used to calculate the risk of cancer resulting from exposure to potentially carcinogenic chemicals. A higher value implies a more potent carcinogen. The CSF for benzene obtained from OEHHA is more than three times greater (more conservative) than that developed by the EPA. The benzene CSF derived by OEHHA was used in this assessment. Reference Doses (RfDs) are used to evaluate exposures against non-cancer endpoints. The non-TPH RfDs were obtained from IRIS (EPA, 2002). For adverse non-cancer health effects, EPA assumes that a dose threshold exists, below which adverse effects are not expected to occur. A chronic RfD of a chemical is an estimate of an average daily dose to humans that is likely to be without appreciable deleterious non-carcinogenic effects.

The mobility of a liquid in the unsaturated zone depends upon a variety of factors, including (1) the kinematic viscosity, a physical parameter that represents the resistance of a fluid (*e.g.*, diesel) to move through soil, affecting the rate of percolation; (2) the quantity of free product released, which will affect the depth of penetration into the soil; (3) the permeability of the soil, which affects both the rate of percolation and the plume geometry; and (4) the residual saturation level of free product in the soil, which is dependent on both the soil type and the product viscosity (Dragun, 1988). Heavier petroleum hydrocarbons with higher viscosity do not penetrate as readily into soil as do lighter hydrocarbons with lower viscosity.

Because of retention by soil, the extent of migration of a particular quantity of petroleum hydrocarbons in soil is limited. As a mass of hydrocarbons migrates in the unsaturated zone, a small amount of the total hydrocarbon mass will remain adsorbed to the soil. The hydrocarbons that are retained by soil particles are considered immobile. In addition, petroleum hydrocarbons are biodegradable. In the unsaturated zone, vapor-phase molecular diffusion can maintain an oxygen supply even at depths of tens of feet bgs. This oxygen supply facilitates biodegradation. Thus, it is likely that hydrocarbon levels in the subsurface will decrease over time, further reducing vertical migration.

### 4.1.6 Quantification of Exposure

The risks associated with exposure to chemicals depend not only on the concentrations of chemicals, but also on the extent to which receptors are exposed. For example, the risks associated with exposure to chemicals for one hour per day are less than those associated with exposure at the same concentrations for two hours per day. Because risks depend upon both the concentration and the extent of the exposure, the assumptions regarding the extent of exposure are discussed in this section for each of the complete exposure pathways identified above. Table 13 presents each of the exposure parameters used in this Tier 3 evaluation. All values are EPA and ASTM referenced values as selected by the Oakland RBCA and RWQCB (2001) processes. These values are scientifically defensible and are regularly used in risk assessment. Using more site-specific data would be part of a more sophisticated Tier 3 evaluation, and would require additional site characterization.

Chemicals are grouped into carcinogens and non-carcinogens and risks are assessed differently depending on which classification a chemical has. Benzene has both carcinogenic and non-carcinogenic effects. TPH-D and TPH-G are assessed as non-carcinogens only. The lifetime average daily dose (LADD) for carcinogens and average daily dose (ADD) for non-carcinogens are estimated based on the parameters identified in Table 13, the air and soil concentrations presented in Tables 5, and 8 through 11, and the following equations:

$$ADD\ or\ LADD_{inhalation}(mg/kg-d)=\frac{C_{air}\times IR\times EF\times ED\times AF_i}{BW\times AT}$$

**Johnson and Ettinger Model.** Soil vapor data were collected at two areas of interest (southeast and east) to determine potential exposures to off-site residential receptors. Soil vapor data is a direct measurement of the sub-surface to surface migration potential for petroleum compounds in both soil and groundwater. Without measured soil vapor data, indoor air modeling must include a calculated estimate of the potential migration of volatile chemicals into soil pore vapor from soil and groundwater, and subsequent calculation of the migration of this vapor into indoor air. There are inherent uncertainties in these types of calculations, which propagate through to the associated risk and hazard estimates. Use of measured soil vapor data is more appropriate and is a preferred method for understanding and predicting the potential source of subsurface vapors that may enter a structure. Therefore, the soil vapor data are used to evaluate the adjacent off-site residential exposures to chemicals from both soil and groundwater. This is consistent with RWQCB (2001) guidance.

The RBCA equations cannot utilize soil vapor concentration data as input, therefore, consistent with RWQCB (2001) guidance, soil vapor data were incorporated into the Johnson and Ettinger (1991) model for estimating potential impacts to off-site indoor air following EPA guidelines (EPA, 1997). Soil vapor concentrations can be directly input into the model as replacements for the values the model generally estimates from groundwater and soil matrix data. The Johnson and Ettinger model provides an output of predicted indoor air concentrations.

The soil types found beneath the site are silty clays, clayey silts, and sandy clays. Silt loam was used as the default soil type in the Johnson and Ettinger model to represent these soil types. A slab on grade construction was assumed and the 15 cm default value was used for the depth below grade (bgs) to the bottom of the enclosed space floor. The 95 percent UCLs for soil vapor samples collected from zero to 15 feet bgs (approximate average depth to groundwater) were used as concentration inputs. The soil vapor concentrations used in the model are listed in Table 7. It was conservatively assumed that the 95 percent UCL vapor concentration was present at five feet bgs. Johnson and Ettinger modeling was based on default model data for most parameters. The predicted indoor air concentrations are presented in Table 11.

**RBCA Soil to Groundwater Equations.** In addition to modeling the infiltration of vapors from soil and groundwater through the vadose zone and into ambient and indoor air, RBCA equations were also used to evaluate whether the concentrations of BTEX, MTBE, and TPH might be expected to increase in groundwater beneath the site in the future as a result of vadose zone leaching. Results of the RBCA modeling predict that residual petroleum hydrocarbon concentrations in soils may reach groundwater beneath the site, but not in sufficient concentrations to increase the concentrations currently measured groundwater (see Table 12). The only exception to this is TPH-D. However, due to its limited extent in soils, and the current presence of asphalt and anticipated presence of asphalt over the site in the future, it is unlikely that sufficient infiltration by groundwater will occur to provide a means for TPH-D to reach groundwater. The following discussion provides further support for this conclusion.

### 4.1.4 Potential Exposure Pathways

An exposure pathway is a description of the ways in which a person could be exposed to chemicals and is defined by four elements: (1) a source and mechanism of chemical release to the environment; (2) an environmental transport medium (*e.g.*, air) for the released chemical; (3) a point of potential contact with the contaminated medium (the exposure point); and (4) an exposure route (*e.g.*, inhalation) at the contact point. In order for an exposure pathway to be considered complete, all four elements must be present. As presented in Figure 6, one potential exposure pathway exists for on-site commercial workers and off-site residents; inhalation of vapors volatilized from soil and groundwater. Exposures to off-site residents are evaluated using recently collected soil vapor sample data. Direct contact with soil will not occur for residents or commercial workers because the site is currently paved and there are no plans for removal of the pavement. For on-site construction workers, inhalation of vapors volatilized from soil into ambient air, and direct contact with soils via incidental ingestion and dermal contact during construction activities are evaluated.

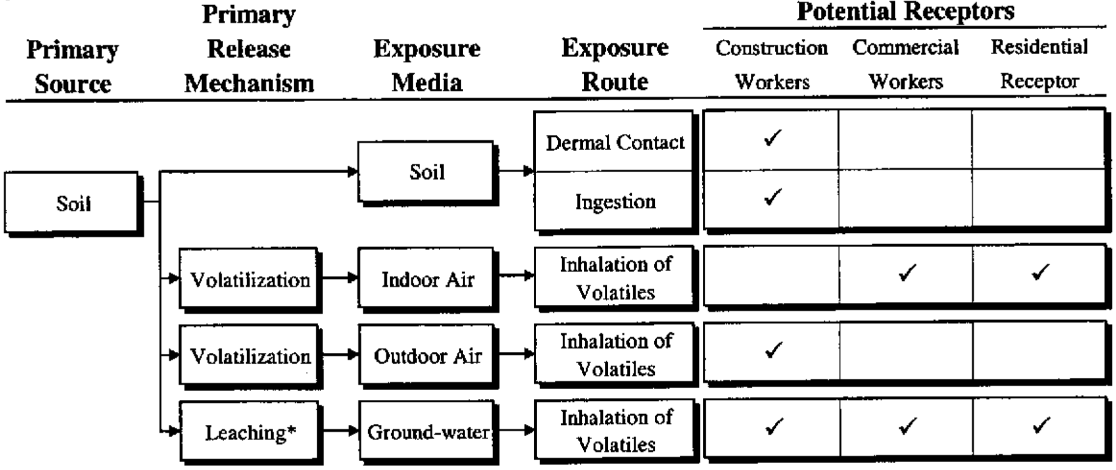
### 4.1.5 Fate and Transport Modeling

Indirect exposure to chemicals in soil can occur when chemicals migrate from the original media (soil) to a new media (*e.g.*, air) with which receptors could come into contact. Chemicals at a site can volatilize from impacted soil into indoor and outdoor ambient air. Predicting migration of chemicals at the site to indoor and ambient air from subsurface soil involved three models. Flux of chemicals from soil into air (as well as downward migration) is determined based on results of the use of the standard RBCA fate and transport equations presented in the Oakland and ASTM RBCA guidance documents. No changes have been made to the previous RBCA modeling for the site; however, use of soil vapor data necessitates the use of an additional model. The Johnson and Ettinger model (EPA, 1997) was used to estimate the flux of chemicals detected in southeastern and eastern soil vapor into indoor residential air.

In assessing the fate and transport of TPH-G and TPH-D, a "fractionation approach" was used, whereby the measurement of TPH is broken down into several indication fractions for the purposes of modeling exposure and toxicity assessment. Section 4.2.1 details this approach further.

**<u>RBCA Soil to Air Equations</u>.** As the soil parameters used in each of the RBCA equations are dependent upon the type of soils being assessed, it is important to identify the soil types present beneath the site. As described in Section 1.4, the primary soil types found beneath the site are silty clays, clayey silts, and sandy clays. Therefore, the soil parameters for the sandy silts and clayey silts, as identified in the Oakland RBCA guidance (2000a) were used in the RBCA models. The point value used for each parameter is the average of the parameter values for sandy silts and clayey silts. The RBCA predicted indoor and outdoor air concentrations are given in Tables 8 through 10.

**Figure 6.** Tier 3 RBCA Conceptual Site Model



| Primary Source | Primary Release Mechanism | Exposure Media | Exposure Route | Potential Receptors | | |
|---|---|---|---|---|---|---|
| | | | | Construction Workers | Commercial Workers | Residential Receptor |
| Soil | | Soil | Dermal Contact | ✓ | | |
| | | | Ingestion | ✓ | | |
| | Volatilization | Indoor Air | Inhalation of Volatiles | | ✓ | ✓ |
| | Volatilization | Outdoor Air | Inhalation of Volatiles | ✓ | | |
| | Leaching* | Ground-water | Inhalation of Volatiles | ✓ | ✓ | ✓ |

✓ Potentially complete exposure pathway.

* Evaluated using the RBCA equations.

### 4.1.2 Land Use

To determine which receptor populations might be at risk for chemical exposure at the property, it is necessary to determine the present and potential future land use at and around the property. The site is in Oakland, and is currently planned for redevelopment to a commercial carwash. Under these conditions, the exposure patterns associated with the site would include not only those associated with a commercial site, but might also include construction worker exposures. The site has thus been evaluated using construction and commercial land use assumptions for human exposure. Because some of the adjacent areas have residential development, these properties have been evaluated using potential residential land use assumptions for human exposure associated with vapor transport pathways. The residential scenario is evaluated to ensure protection of current and potential future land uses for adjacent properties.

### 4.1.3 Potential Receptors

The identification of people who could potentially be exposed to chemicals at a site involves consideration of current and future land uses of a particular site. Because the site is in a commercial area, and is currently planned for commercial use and future use of the site will also be commercial, the most likely receptor to be exposed to chemicals in soils are on-site commercial workers (*e.g.*, convenience store workers, car wash workers) and construction workers. Because the chemicals in soil are not at the surface as well as lower exposure frequencies, this scenario would also be protective of the less intensely exposed individuals using the site (*e.g.*, visitors to the site [patrons], landscape workers). In addition, adjacent residential receptors and a construction worker receptor were also evaluated for the site.

are combined with chemical toxicity criteria to estimate the risks associated with the exposures. The differences between the RBCA Tier 3 evaluation and the RBCA Tier 2 evaluation are the use of the 95 percent UCLs as exposure point concentrations, quantification of TPH exposures and risks, use of site-specific soil parameters (see Section 4.1.5), and use of soil vapor data for off-site residential exposures.

## *4.1 Exposure Assessment*

The exposure assessment step combines information about the chemical concentrations in site media with assumptions about how a potential receptor could contact the impacted media. The result is an estimation of the level of intake, or dose, of a chemical.

In this section, the ways in which human receptors could be exposed to chemicals in soil and groundwater, and the populations of receptors that could be exposed, are identified and discussed. The concentrations of chemicals detected in soil, groundwater and soil vapor at locations where receptors might be exposed are identified and this information, presented in tables, is summarized. Fate and transport modeling were used to estimate potential exposure of receptors at potential receptor locations away from the currently impacted areas. Potential receptors are identified and assumptions regarding the activities of potential receptors, such as the frequency with which a person could come into contact with chemicals in soil and air, are also discussed. Finally, the methods used to estimate daily doses at the points of potential human contact, using the exposure assumptions and the chemical concentrations, are reviewed.

### 4.1.1 Tier 3 Conceptual Site Model

The conceptual site model is a tool used in risk assessment to describe relationships between chemicals and potentially exposed populations, thereby delineating the relationships between the suspected sources of chemicals identified at the property, the mechanisms by which the chemicals could be released and transported in the environment, and the means by which the receptors could come in contact with the chemicals. The potentially complete exposure pathways identified in the conceptual site model were carried through the risk evaluation. The conceptual site model for the Oakland site is presented on Figure 6.

where:

UCL = 95 percent upper confidence limit on the arithmetic mean
$\mu$ = mean of the data
s = standard deviation of the data
t = t-statistic (from Gilbert, 1987)
n = number of samples

For the lognormally distributed data, the following equation was used:

$$UCL = e^{(\mu + 0.5s^2 + sH/\sqrt{n-1})}$$

where:

e = constant (base of the natural log, equal to 2.718)
$\mu$ = mean of the transformed data
s = standard deviation of the transformed data
H = H-statistic (from Gilbert, 1987)

For the RBCA Tier 3 evaluation, estimates of exposure point concentrations for direct soil contacts (construction workers only) are based on soil data from zero to ten feet bgs (DTSC, 1992). For certain datasets the estimated 95 percent UCL may result in a concentration higher then the maximum detected concentration. Therefore, the 95 percent UCL or the maximum detected value (whichever is lower) was the concentration used as the exposure point concentration used to assess risk from direct exposures to soil (*i.e.*, direct contact with surface soil, incidental soil ingestion).

Additionally, the soil data collected during the October 2001 supplemental investigation (Cambria, 2002) was not included in the statistical analysis or the estimation of exposure point concentration for direct contact. These samples were obtained from perimeter areas of the site where minimal direct contact potential exists. The concentrations in the soil are also low, and incorporation of these data into the statistical evaluation would result in lower direct contact exposure point concentrations at the site. It is determined that use of the existing soil concentrations collected during the 1990-1998 investigations produces more conservative but still representative exposure point concentrations. Similarly, groundwater samples collected at these perimeter locations were not included in the groundwater data evaluation. There are no direct contact pathways associated with groundwater, and soil vapor measurements collected in these perimeter areas provide better estimates of groundwater chemical contribution to potential indoor air exposures. The results of the statistical analyses for soil, groundwater, and soil vapor are presented in Tables 5 through 7.

## 4. RBCA TIER 3 EVALUATION

This evaluation follows a series of steps common to risk assessments. First, the ways in which people could be exposed to the chemicals are identified, and assumptions are made about the extent to which people could be exposed. Lastly, the estimated exposure rates evaluations could not be performed for TPH because Tier 1 and 2 look-up values were not available for TPH. Therefore, the RBCA Tier 3 evaluation also includes TPH. In addition, soil vapor data collected from the eastern and southeastern portions of the site (Appendix A, Table A-3; Figure 3) are used in the RBCA Tier 3 evaluation to assess off-site residential exposures. The two residential structures addressed using the soil vapor data in the RBCA Tier 3 evaluation are an adjacent two-story apartment building (southeastern property line), and a single-story residence (eastern property line).

## 3. STATISTICAL EVALUATION OF CHEMICAL DATA

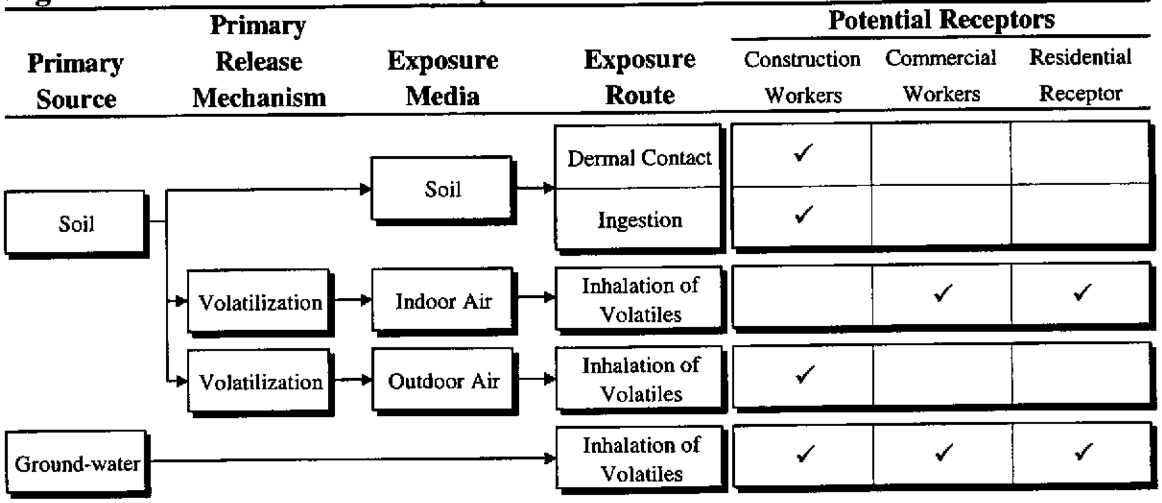
For the purposes of conducting statistical analyses for each chemical, non-detects were included at one-half the detection limit (EPA, 1989). For example, if benzene was not found at a detection limit of 0.005 mg/kg, a concentration of 0.0025 mg/kg was used as an assumed concentration of benzene at this location. For groundwater, four quarters of monitoring data for each chemical were compiled (between the years 1998 and 2000). For each constituent, only wells in which at least one sample had a positive detection in these four quarters of analytical data were combined. For soil vapor, the sampling results for each area (southeastern, including sample locations B-1, B-2, and B-3, and eastern, including locations B-4, B-5, and B-6) were compiled.

For each chemical and sampling location, the distribution of the data was determined using either the Shapiro-Wilk W Test for sample sizes less than 50, or the D'Agostino's Test for sample sizes greater than 50 (D-Test; Gilbert, 1987). Three different types of distribution profiles are possible: normal distribution, lognormal distribution, and non-parametric (*i.e.*, neither normal nor lognormal). Based on the distribution profile for each chemical, the 95 percent upper confidence limit (UCL) of the arithmetic mean was calculated. For data sets that did not fit normal or lognormal distributions, the 95 percent UCL was calculated as a normal distribution, resulting in a higher and more conservative UCL than using the non-parametric approach for these data sets. The non-parametric calculation of the 95 percent UCL tended to be lower than the estimation based on a normal distribution because of the large number of non-detect values. Therefore, using the normal distribution estimate is more conservative. That is, use of the normal distribution results in a higher estimate of exposure concentrations and consequently higher estimates of potential risks.

The purpose for using the 95 percent UCL instead of the average concentration is to account for "...the uncertainty associated with estimating the true average concentration at a site... The 95 percent UCL provides reasonable confidence that the true site average will not be underestimated" (EPA, 1992). The 95 percent UCL on the arithmetic mean was calculated following methods in EPA (1992) and Gilbert (1987). All of the chemical concentration distributions were non-parametric. For these non-parametrically distributed data, the following equation for a normal distribution was used:

$$UCL = \mu + \left( t \times \frac{s}{\sqrt{n}} \right)$$

**Figure 5.** Tier 1 and 2 RBCA Conceptual Site Model



✓ Potentially complete exposure pathway.

No Tier 1 groundwater criteria are available for TPH-G. Because the maximum detected benzene concentration exceeded the Tier 1 value, and because no Tier 1 groundwater values are available for TPH, a RBCA Tier 2 groundwater evaluation was performed for benzene, TPH-D, and TPH-G. The results of the RBCA Tier 1 evaluation for groundwater are presented in Table 2.

## Soil RBCA Tier 2 Evaluation

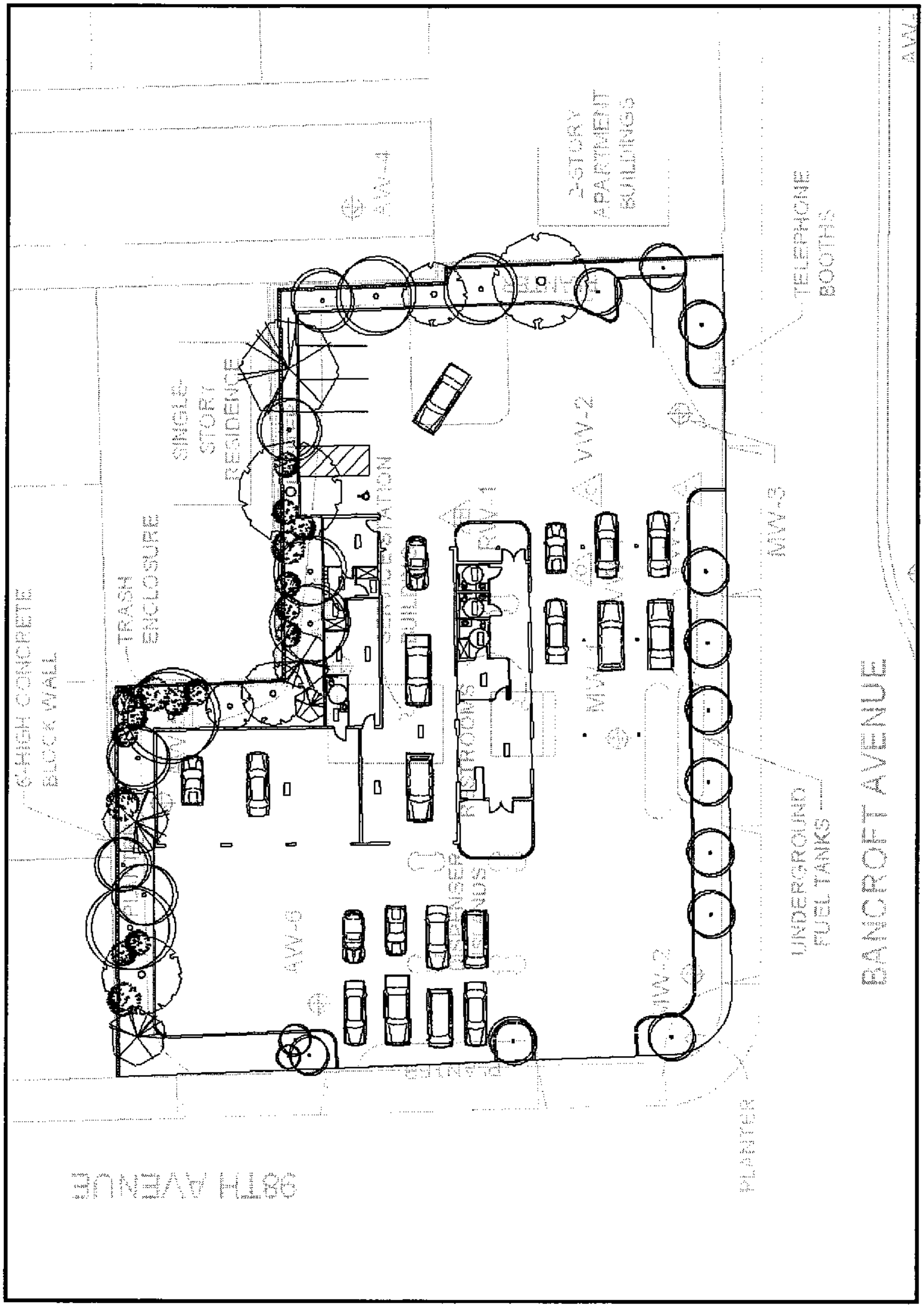
The soils beneath the site are predominantly silty clays, clayey silts and clayey sands. Based on these soil types, the Tier 2 values for sandy silts were used. Based on the results of the Tier 2 soil evaluation, benzene in soil was not evaluated further. Tier 2 look-up values for TPH-G and TPH-D were not available. Therefore, a RBCA Tier 3 evaluation of each in soil was performed for TPH-G and TPH-D. The results of the RBCA Tier 2 evaluation for soil are presented in Table 3.

## Groundwater RBCA Tier 2 Evaluation

Based on the soil types beneath the site, the Tier 2 values for sandy silts were used. Based on the results of the Tier 2 groundwater evaluation, benzene in groundwater for commercial indoor air exposures was not evaluated further. However, maximum benzene concentrations for residential indoor air exposures exceeded Tier 2 lookup values. In addition, Tier 2 values were not available for TPH in groundwater. Because the maximum detected benzene concentrations exceeded the Tier 2 residential concentrations, and because Tier 2 values do not exist for TPH, a Tier 3 RBCA evaluation of each in groundwater was performed. The results of the Tier 2 evaluation for groundwater are presented in Table 4.

The remainder of this report presents the RBCA Tier 3 evaluation for the site. The results of the Tier 1 and 2 comparisons are presented in Tables 1 through 4. RBCA Tier 1 and 2

**Figure 4.** Car Wash Site Plan



below a building will enter a basement and become well-mixed once in the building. This model is widely used for screening purposes only due to its conservative assumptions.

The site is currently a commercial property. Plans to build a commercial car wash on the property are underway. Because a commercial car wash is being constructed on the property, it is considered unlikely that the site will become residential any time in the near future. The car wash site plan is presented on Figure 4. Surrounding the site are residential areas. The RBCA Tier 1 evaluation considered exposures to on-site commercial workers, construction workers, and off-site residents. For the RBCA Tier 1 and 2 evaluations, indirect exposures to off-site residents were evaluated without adjusting on-site soil and groundwater data to account for migration off-site. In other words, for off-site residents, it is assumed that the concentrations to which they may be exposed are the same as the concentrations to which they would be exposed if residential units were constructed directly on the site. This is a conservative assumption because the concentrations to which off-site residents might be exposed would be lower than these estimates. For construction workers, exposures from direct contact with soils and inhalation of vapors were assessed. For commercial workers and off-site residents, inhalation of vapors was assessed. Because the site is planned for development into a car wash and will be paved, direct soil exposures were not assessed for commercial workers or off-site residents. The conceptual site model is presented on Figure 5.

Unlike the ASTM approach, the Oakland RBCA Tier 2 evaluation is much like a Tier 1 evaluation, except that the lookup values are specific to one of three soil types specific to the Oakland area: Merritt sands, sandy silts, and clayey silts. For each of these soil types, RBCA Tier 2 lookup values were calculated (by the City of Oakland Environmental Services Division) by modifying the Tier 1 soil property input parameters to reflect the properties of each of the soil types used in Tier 2 (*i.e.*, the soil properties for each of the three soil types are used to calculate new lookup values unique to each soil type).

## Soil RBCA Tier 1 Evaluation

Based on the results of the Tier 1 soil evaluation, only benzene exceeded the Oakland default Tier 1 value for off-site residents exposed to indoor air. Toluene, ethylbenzene, xylene, and MTBE concentrations in soil at the site did not exceed the Oakland default Tier 1 look-up values. No Tier 1 criteria are available for TPH-G and TPH-D. Because the maximum detected benzene concentration exceeded the Tier 1 value, and because no Tier 1 values are available for TPH, a RBCA Tier 2 soil evaluation was performed for benzene, TPH-D, and TPH-G. The results of the RBCA Tier 1 evaluation for soil are presented in Table 1.

## Groundwater RBCA Tier 1 Evaluation

Based on the results of the Tier 1 groundwater evaluation, only benzene exceeded the Oakland default Tier 1 value for for commercial workers and residents exposed to indoor air. Toluene, ethylbenzene, xylene, and MTBE concentrations in groundwater at the site did not exceed the Oakland default Tier 1 look-up values.

Avenue) has detected low μg/L levels of BTEX from 1992 to 1994, with concentrations dropping below detection limits from 1995 to 1997. In late 1997, BTEX concentrations increased to low mg/L levels (0.87 to 13 mg/L) for a single event, and then dropped below detection limits again, including during the most recent event. TPH-G concentrations have fluctuated between 0.5 and 1.5 mg/L increasing to 40 mg/L in late 1997, subsequently dropping back to former levels. MTBE concentrations consistently range between 0.5 and 4.3 mg/L.

Well MW-1, near the former UST area on the western portion of the site, has demonstrated a consistent downward trend of concentrations of all constituents from 1993 to the present, with brief periods of flux (increase) in the concentrations of TPH. The maximum concentrations occurred in March 1994. All constituents have dropped one to two orders of magnitude over the past six years. Well MW-2, in the northwest corner of the site, has detected petroleum compounds inconsistently between 1991 and 1994, and when found, the levels were generally below 1 μg/L. From late 1994 to 1998, all compounds were below detection limits. In 1998, benzene was detected at 1 μg/L, and TPH-G was detected at 160 μg/L. TPH-G and benzene have not been detected since 1998.

### 1.5.3 Soil Vapor

Soil vapor sample locations for the site (Appendix A, Table A-3) are shown on Figure 3. The following summarizes the results of these samples. TPH-G was reported in the soil vapor samples at concentrations ranging from 1.3 to 11 parts per million by volume (ppmv). BTEX were reported in the analyzed samples at concentrations ranging from 0.0033 to 0.34 ppmv, 0.0033 to 0.23 ppmv, 0.0027 to 0.15 ppmv, and 0.0031 to 0.59 ppmv, respectively. MTBE was reported in the analyzed vapor samples from five borings at concentrations ranging from 0.0033 to 0.062 ppmv (Cambria, 2002).

This RBCA evaluation was performed for chemicals detected at the site. Statistical summaries of the soil, soil vapor, and groundwater analytical results were done for BTEX, MTBE, and TPH-G and TPH-D. The statistical analyses performed on the data are described in Section 3.

## 2. RBCA TIER 1 AND TIER 2 EVALUATIONS

The Oakland and ASTM RBCA processes consist of three tiers. Using the Oakland RBCA process, the first two tiers are comparisons of site data to acceptable concentrations presented in Tier 1 and Tier 2 look-up tables. For the purposes of this analysis, Oakland RBCA Tier 1 and Tier 2 look-up values are based on conservative, generic exposure and modeling parameters, resulting in conservative risk-based screening levels considered appropriate for the site. For example, the vapor migration from soil into indoor air screening values used in the Oakland RBCA Tier 1 look-up table are based on a model by Johnson and Ettinger (1991). This model assumes that all chemical vapors

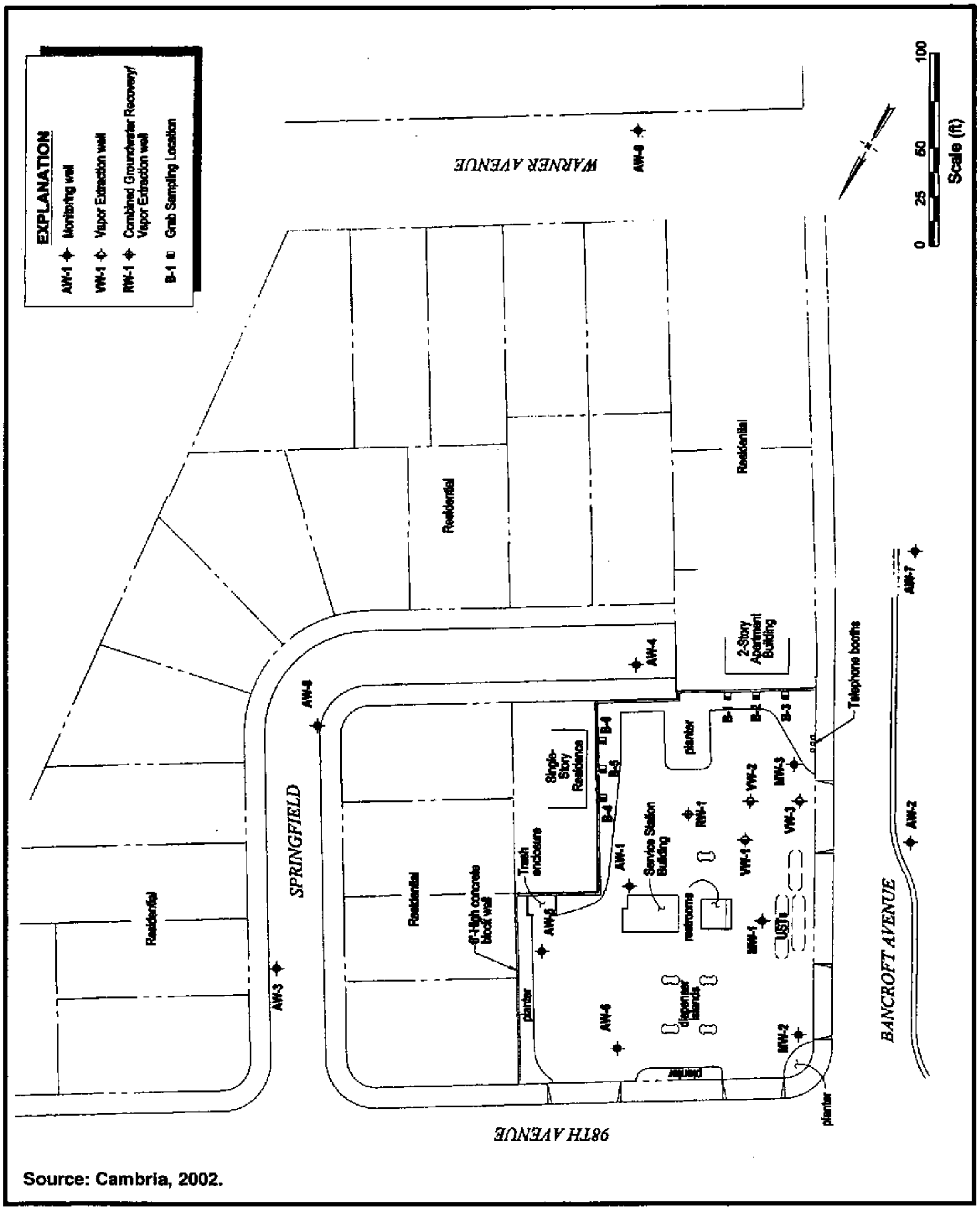
**Perimeter Wells.** Well AW-3 (northeast of the site near the corner of Springfield Street and 98th Avenue) has had low microgram per liter ($\mu$g/L) levels of most BTEX constituents from 1991 to 1995, with generally low mg/L to high $\mu$g/L levels of TPH in the same period. Since 1995, most constituents have not been detected, and since mid-1998 all constituents have not been detected. Well AW-8, east of the site (on Springfield Street), has historically been "non-detect" for all constituents, with the occasional low $\mu$g/L detection (six out of 27 sampling events) of BTEX compounds. Since 1995, only one detection of a petroleum-related compounds (MTBE; less than 1 mg/L; in 1997) has been found. Well AW-4 (southeast of the site at the end of Springfield Street) has experienced a steady decline of all constituents since 1991 to low mg/L levels of TPH and low $\mu$g/L levels of BTEX and MTBE in 1995 to non-detect levels in 1996 and 1997. Low mg/L levels of all constituents were detected in 1999, with most dropping below detection limits again in 2000.

Well AW-9, southeast of the site beyond the residential area (Warner Avenue), has never detected petroleum compounds in the off-site groundwater. Well AW-7, south of the site along Bancroft Avenue, has historically had only a few detections of low $\mu$g/L and sub-$\mu$g/L levels of BTEX before 1993. Since 1993, no BTEX or TPH have been detected, and only one sample in 1997 had a MTBE detection of 1 mg/L. Well AW-2, west of the site (also along Bancroft Avenue), has also been an historically clean well, with only a few events detecting low $\mu$g/L and sub-$\mu$g/L levels of BTEX compounds and TPH in 1992, 1993, and 1998. In the last two years, no petroleum compounds have been detected.

**Site Wells.** Well AW-6, in the northern portion of the site (near 98th Avenue), has historically had only a few detections of low $\mu$g/L and sub-$\mu$g/L levels of all constituents. All constituents have been below detection levels from 1996 to 1998, with a recent detection of low mg/L levels of TPH and MTBE in 1999. Well AW-5, in the northeast portion of the site, has historically had low $\mu$g/L levels of petroleum compounds, with a decreasing trend from 1991 to 1998, dropping below detection levels in 1996. In 1998 and 2000, concentrations of all compounds have increased above detection levels to low $\mu$g/L levels (BTEX) to low mg/L levels (TPH and MTBE). Well AW-1, on the sites' western boundary (near the former service station building), has had consistent detections of petroleum compounds throughout its monitoring history, with BTEX hovering consistently in the one to 10 mg/L range, and TPH in the 10 to 40 mg/L range. During recent sampling events (2000), an increase occurred in the concentrations of both TPH-G and MTBE occurred (three-fold and 15-fold, respectively). In the most recent sampling event, TPH-G has returned to its former levels.

Well RW-1, in the southern portion of the site near the centrally located dispenser island, has also consistently detected petroleum compounds throughout its monitoring history, with BTEX consistently in the 10 to 40 mg/L range, and TPH in the 200 mg/L range. Benzene appears to have a generally decreasing trend over time, with the most significant drops in concentration occurring over the most recent monitoring events (2000). During the April 1997 sampling event, the concentrations of TPH-G, ethylbenzene and toluene more than tripled, only to return back to former levels the following sampling event. Well MW-3, in the southeastern corner of the site (near the telephone booths along Bancroft

Figure 3. Monitoring Wells and Soil Vapor Sample Locations



Source: Cambria, 2002.

Hydraulic gradient is approximately 0.08 feet/feet across the site. Groundwater flow fluctuates across the site but is generally westward.

### *1.5 Site Characterization Results*

The data used in this evaluation were obtained from Alton Geoscience (1990a,b, 1991) Blaine Tech Services (1999), Alisto Engineering Group (1996, 1997), KEI Consulting Engineers (1990), Gettler-Ryan Inc (1999), EMCON (1994), and Cambria (2002). The soil and soil vapor sampling results, and the results of the four recent quarters of on-site groundwater monitoring are presented in Appendix A.

#### 1.5.1 Soils

Soil sample locations for the site (Appendix A, Table A-1) are shown on Figures 2 and 3. The following discusses the areal distribution of constituents found in site soils.

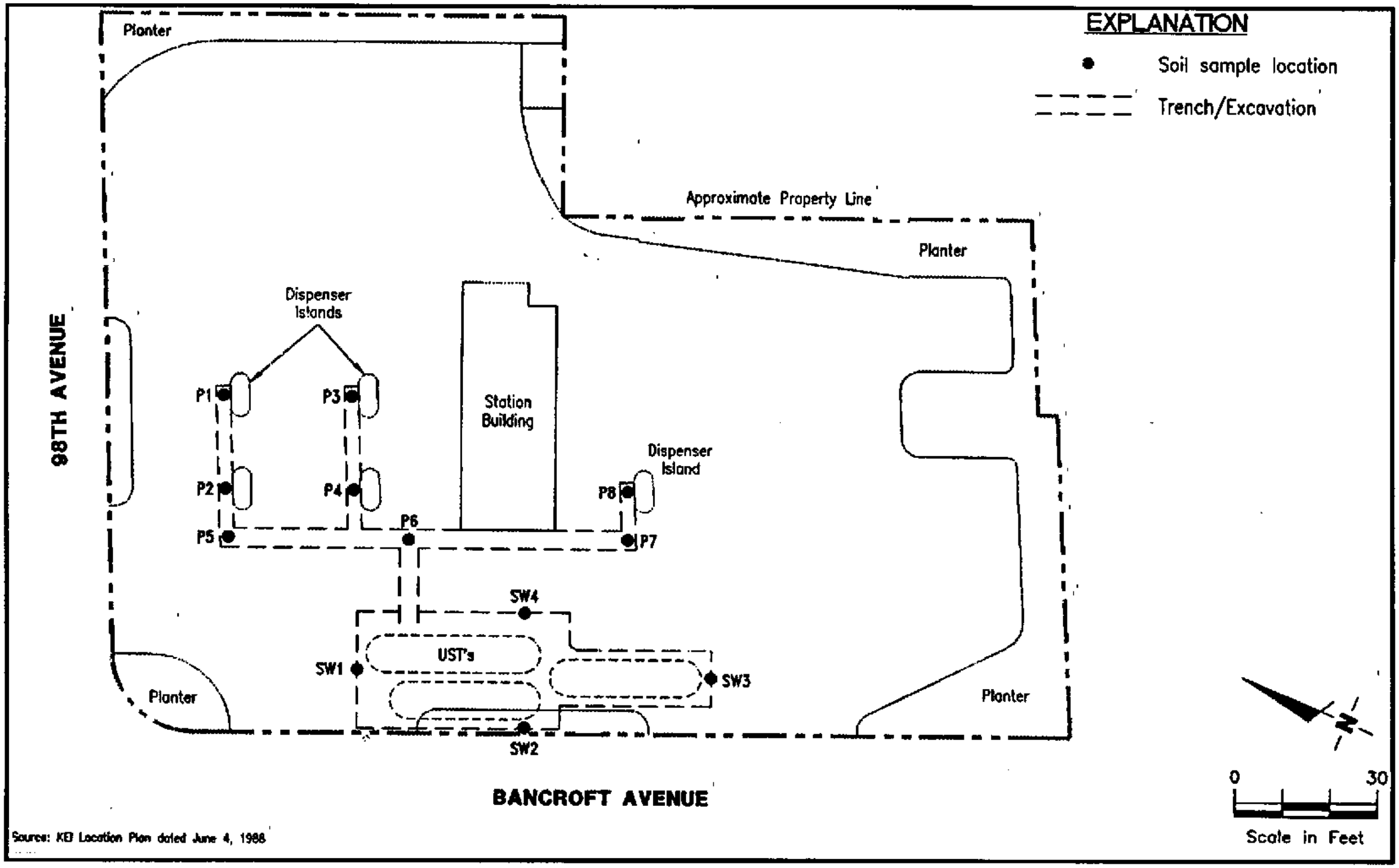
**TPH.** TPH-G has been detected at low concentrations near the former dispenser islands and product lines in the western portion of the site. The maximum detected TPH-G concentration was 33 mg/kg at RW-1 (at 25 feet bgs), which is southeast of the dispenser island, south of the former service station building. The maximum detected concentration of diesel-range organics (TPH-D) of 3,900 mg/kg was at location TD-5 at 0.5 feet bgs. TD-5 is at the southern most dispenser island. TPH-G was also detected in several near-surface samples (within five feet bgs; B-1, B-2, and B-5) and one deep off-site soil location (AW-4, south of the site, 21 feet bgs) at low concentrations (0.084 to 1.6 mg/kg). Low concentrations of TPH-G have also been detected in on-site soil vapor samples (1.3 to 6.2 ppm-volume). No TPH-G or TPH-D were detected at the northern-most site sample (AW-6), eastern most site sample (AW-5), or along the western extent of the former dispenser islands on the northwest portion of the site.

**Benzene, Toluene, Ethylbenzene, Xylenes and MTBE.** Benzene was detected in approximately 50 percent of the samples collected at the site, whereas toluene, ethylbenzene and xylenes were detected in approximately 30 to 38 percent of the samples. Most of the higher benzene concentrations were detected in the "center axis" of the site, samples running the length of the site northwest to southeast (P1 through RW-1), with lower concentrations detected throughout the remainder of the site. Most of the benzene detections at the site have occurred below 7 to 10 feet bgs, with the highest detection at 25 feet bgs. Toluene, ethylbenzene, and xylene concentrations show a similar trend. MTBE was only detected in a few locations along the former UST areas and product line samples (P2, P5, P7, SW-2, SW-3, SW-4) on the northwestern portion of the site.

#### 1.5.2 Groundwater

Groundwater monitoring locations (Appendix A, Table A-2) are shown on Figure 3. The following discusses the areal distribution of constituents found in groundwater in and around the site. Concentration trend charts for each well are presented in Appendix B.

Figure 2. Soil Sample Locations – Product Lines and Dispensers



Source: KEI Location Plan dated June 4, 1988 were conducted in late 1998. The samples collected during this second UST removal and closure are considered representative of the current soil conditions at these former tank locations (formerly represented by samples A1, A2, B1, B2, and C1 described above). Quarterly groundwater monitoring activities have occurred for many of the groundwater monitoring wells at the site since 1991.

Currently, seven on-site monitoring wells, three on-site vapor extraction wells, and six off-site monitoring wells are located at the site (see Figure 2). The results of the investigations identified petroleum releases that account for the current petroleum products found in the soil and groundwater. The site investigations have shown that most petroleum products on site to be limited to soils in the vicinity of the product lines, dispensers, and USTs.

In response to agency comments received on the previous version (December 2000) of the RBCA evaluation, Cambria Environmental Technology, Inc. (Cambria) collected soil, soil vapor, and groundwater grab samples near the eastern and southeastern property boundaries (Figure 3). Three borings were sampled near both the eastern and southeastern property boundaries, adjacent to residential buildings. These locations are hereinafter referred to as 'eastern' and 'southeastern,' respectively. The primary reason for collection of these samples was to address potential indoor air exposures associated with petroleum compounds in soil and groundwater, on adjacent off-site residents.

Soil vapor data is a direct measurement of the sub-surface to surface migration potential for petroleum compounds in both soil and groundwater. Without measured soil vapor data, indoor air modeling must include a calculated estimate of the potential migration of volatile chemicals into soil pore vapor from soil and groundwater, and subsequent calculation of the migration of this vapor into indoor air. There are inherent uncertainties in these types of calculations, which propagate through to the associated risk and hazard estimates. Use of measured soil vapor data is a more correct and preferred method for understanding and predicting the potential source of subsurface vapors that may enter a structure. Therefore, only the soil vapor data are used to evaluate exposures to the adjacent off-site residents. This is consistent with RWQCB (2001) guidance.

### 1.4.1 Geology

The site is approximately 40 feet above mean sea level in Oakland California, in the Alameda Bay Plain Groundwater Basin. The underlying unit in the area is Undivided Quaternary deposits. Site investigations have revealed silty clays, clayey silts, and clayey sands beneath the site.

### 1.4.2 Groundwater

Depth to groundwater beneath the site ranges from approximately 10 to greater than 20 feet bgs, varying among the wells installed at the site, with notable seasonal fluctuations.

(prepared by NewFields, Inc. dated May 12, 2000 and December 15, 2000). The primary issue addressed in this revised report (from the December 2000 version) is the incorporation of soil vapor data collected to adequately evaluate exposures to the residential properties adjacent to the site.

### *1.3 Organization*

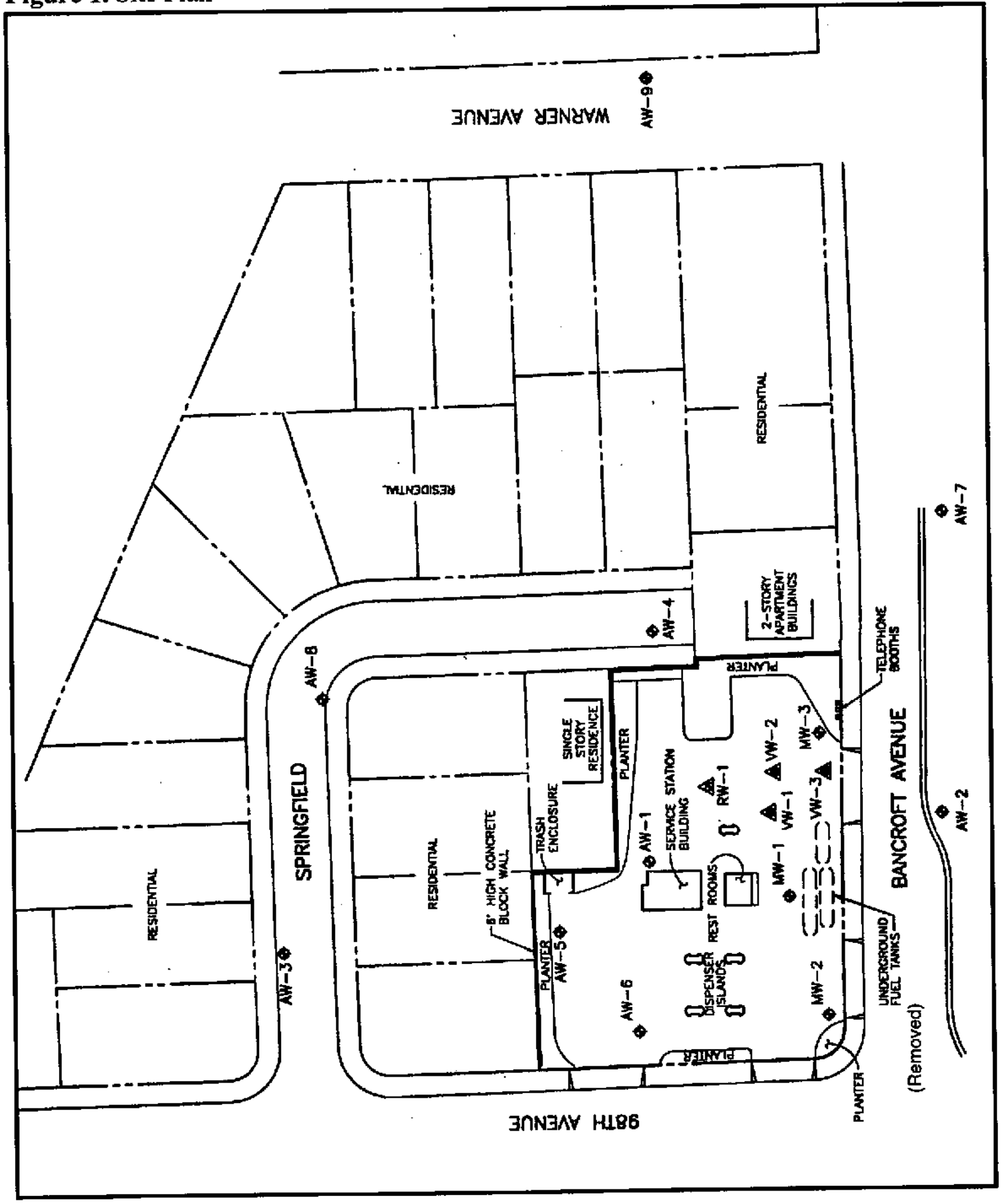
The report is composed of several sections that are outlined below. This section presents the methods used in this evaluation and background on the site. Section 2 presents the results of the Oakland RBCA Tier 1 and Tier 2 evaluations. Section 3 contains a summary of the statistical evaluation conducted for the site. Section 4 presents the focused Oakland RBCA Tier 3 evaluation conducted for the site. Specifically, this section includes a discussion of the ways that people could be exposed to chemicals detected in soil, soil vapor, and groundwater, the assumptions that are made about the extent to which people could be exposed, and the rates at which people could potentially intake the chemicals via the various exposure pathways. This section also presents a summary of the toxicity assessment component of the risk assessment, the risk characterization, and reviews the sources of uncertainty factored into the risk estimates. Section 5 summarizes the results, and Section 6 presents the references used to complete this evaluation.

### *1.4 Site Background*

Mobil operated the site prior to 1989. BP Oil operated the site from 1990 to 1994. BP Oil transferred the property to TOSCO Marketing Company (TOSCO) in 1994 and has not operated the facility since that time. The site consists of a fenced lot with a service station building and canopy. The following site background summarizes information provided in the Gettler-Ryan *Underground Storage Tank and Product Piping Removal Report* (1999), EMCON *Baseline Assessment Report* (1994), Alton Geoscience Phase III-*Supplemental Site Investigation Study* (1991), and Alton Geoscience *Supplemental Site Investigation Report* (1990a).

In 1987, three underground storage tanks (USTs) were removed from the site. Soil samples were collected from the soils beneath the tanks (samples A1, A2, B1, B2, and C1), and TPH was detected in these samples. Subsequent to the tank removal, new tanks were installed at the former tank locations. In 1988, three monitoring wells were installed at the site (MW-1, MW-2, MW-3). Initial sampling from these wells indicated soil and groundwater at the site had been impacted with TPH. In 1990, additional soil borings were advanced at the site and additional monitoring wells and an extraction well were installed. Soil types encountered at the site were silty clays, clayey silts, and clayey sands. Results of chemical analyses indicated that on-site soils and groundwater were impacted with BTEX and TPH as gasoline (TPH-G). Additional soil borings and conversion of these borings to wells was conducted in 1991 by Alton. TPH and BTEX compounds were detected in these soil and groundwater samples. Supplemental soil borings were collected by EMCON in 1994. One location had a detected diesel concentration of 3,900 milligrams per kilogram (mg/kg) from below a dispenser. Further soil removal activities

**Figure 1.** Site Plan



# RISK-BASED CORRECTIVE ACTION (RBCA) EVALUATION

## 1. INTRODUCTION

This report presents the results of a risk-based corrective action (RBCA) evaluation for the former BP Oil Facility No. 11133, a dormant 76-branded gasoline retail outlet at 2220 98th Avenue, Oakland, California (Figure 1). RBCA uses risk assessment to identify technically defensible and site-specific solutions, in place of generic, universally-applied cleanup standards. The RBCA process is guided by standards issued by the American Society for Testing and Materials (ASTM) in the *Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites (E1739-95e1),* and in Oakland, the *Oakland Risk-Based Corrective Action: Technical Background Document* (2000a), and the California Regional Water Quality Control Board - San Francisco Bay Region (RWQCB) *Application of Risk Based Screening Levels and Decision Making to Sites with Impacted Soil and Groundwater* (2001).

### *1.1 Purpose of Report*

The purpose of this report is to evaluate whether constituents of gasoline and diesel, namely benzene, toluene, ethylbenzene and xylenes (BTEX), methyl-tert-butyl ether (MTBE), and total petroleum hydrocarbons (TPH) detected in soil, soil vapor, and groundwater at the site present a potential health risk to current and future on-site workers, and off-site residents. Depth to groundwater is believed to range from 10 to 22 feet below ground surface (bgs) based on measurements from multiple wells on-site. Potential downward migration to groundwater from soil is also assessed in this report.

### *1.2 Methodology*

The evaluation follows the basic procedures outlined in the *Oakland Risk-Based Corrective Action: Technical Background Document* (2000a), the *Oakland Urban Land Redevelopment Program: Guidance Document* (2000b), the ASTM *Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites* (*E1739-95e1*; ASTM, 1999), the RWQCB *Application of Risk Based Screening Levels and Decision Making to Sites with Impacted Soil and Groundwater* (2001) and the U.S. Environmental Protection Agency's *Risk Assessment Guidance for Superfund: Volume I—Human Health Evaluation Manual* (EPA, 1989). Other guidance documents consulted include the California Department of Toxic Substances Control's *Supplemental Guidance for Human Health Multimedia Risk Assessments of Hazardous Waste Sites and Permitted Facilities* (DTSC, 1992).

This version of the RBCA evaluation for the former BP Oil Facility No. 11133 addresses comments received from the City of Oakland, Alameda County Environmental Health Services (ACEHS), and the RWQCB on two previous versions of the RBCA evaluation

## Table E-1

## Oakland RBCA Eligibility Checklist

The Oakland Tier 1 RBSLs and Tier 2 SSTLs are intended to address human health concerns at the majority of sites in Oakland where commonly-found contaminants are present. Complicated sites—especially those with continuing releases, ecological concerns or unusual subsurface conditions—will likely require a Tier 3 analysis. The following checklist is designed to assist you in determining your site's eligibility for the Oakland RBCA levels.

| CRITERIA | YES | NO |
|---|---|---|
| 1. Is there a continuing, *primary* source of a chemical of concern, such as a leaking container, tank or pipe? (This does *not* include residual sources.) | ☐ | ☒ |
| 2. Is there any mobile or potentially-mobile free product?[1] | ☐ | ☒ |
| 3. Are there more than five chemicals of concern at the site at a concentration greater than the lowest applicable Oakland RBCA level? | ☐ | ☒ |
| 4. Are there any preferential vapor migration pathways—such as gravel channels or utility corridors—that are potential conduits for the migration, on-site or off-site, of a volatilized chemical of concern? | ☐ | ☒ |
| 5. Do both of the following conditions exist?<br>(a) Groundwater is at depths less than 300 cm (10 feet)[2]<br>(b) Inhalation of volatilized chemicals of concern from groundwater in indoor or outdoor air is a pathway of concern but groundwater ingestion is *not** | ☐ | ☒ |
| 6. Are there any existing on-site or off-site structures intended for future use where exposure to indoor air vapors from either soil or groundwater is of concern *and* one of the following three conditions is present?[3]<br>(a) A slab-on-grade foundation that is less than 15 cm (6 inches) thick<br>(b) An enclosed, below-grade space (e.g., a basement) that has floors or walls less than 15 cm (6 inches) thick<br>(c) A crawl space that is not ventilated | ☐ | ☒ |
| 7. Are there any immediate, acute health risks to humans associated with contamination at the site, including explosive levels of a chemical? | ☐ | ☒ |
| 8. Are there any complete exposure pathways to nearby ecological receptors, such as endangered species, wildlife refuge areas, wetlands, surface water bodies or other protected areas? | ☐ | ☒ |

*If groundwater ingestion *is* a pathway of concern, the associated Oakland RBCA levels will be more stringent than those for any groundwater-related inhalation scenario, rendering depth to groundwater irrelevant in the risk analysis.

[1] Liquid hydrocarbon product accumulations have been documented in wells MW-1 and RW-1. Remedial activities have abated product in well MW-1. Liquid product recently observed in RW-1 was removed by bailing. Product in RW-1 appears to be an isolated occurrence associated with the former location of the UST system and not subject to rapid or easy subsurface movement.

[2] Although depth to groundwater in some areas of the site is sometimes below 10 feet, the average depth to groundwater is greater than 10 feet.

[3] Because building conditions for off-site structures is unknown, a conservative foundation thickness of one inch was used in the Tier 3 analysis.

If you answer "no" to all questions, your site is eligible for the Oakland RBCA levels. If you answer "yes" to any of the questions, your site is *not* eligible for the Oakland Tier 1 or Tier 2 RBCA levels at this time.

# EXECUTIVE SUMMARY

This report presents the results of a risk-based corrective action (RBCA) evaluation for the former BP Oil Facility No. 11133, a dormant 76-branded gasoline retail outlet, at 2220 98th Avenue, Oakland, California (Figure 1). The site is currently a commercial property. Plans to build a commercial car wash on the property are underway. Because a commercial car wash is proposed to be constructed on the property and the site is not zoned for residential, it is considered unlikely that the site will become residential any time in the near future. Surrounding the site are residential areas.

The purpose of this report is to evaluate whether constituents of gasoline and diesel, namely benzene, toluene, ethylbenzene, and xylenes (BTEX), methyl-tert-butyl ether (MTBE), and total petroleum hydrocarbons (TPH) detected in soil, soil vapor, and groundwater at the site present a potential health risk to current and future on-site workers, and off-site residents. RBCA uses risk assessment to tailor site-specific solutions. The evaluation follows the basic procedures outlined in the *Oakland Risk-Based Corrective Action: Technical Background Document*, the *Oakland Urban Land Redevelopment Program: Guidance Document*, and the ASTM *Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites* (*E1739-95e1*) and the California Regional Water Quality Control Board - San Francisco Bay Region (RWQCB) *Application of Risk Based Screening Levels and Decision Making to Sites with Impacted Soil and Groundwater* (2001). The completed Oakland RBCA Eligibility Checklist for the site is presented in Table E-1.

The Oakland and ASTM RBCA processes consist of three steps or tiers. Using the Oakland RBCA process, the first two tiers are comparisons of site data to concentrations presented in Tier 1 and Tier 2 look-up tables. The Oakland RBCA Tier 1 and Tier 2 look-up values are based on conservative, generic exposure and modeling parameters, resulting in conservative risk-based screening levels. Where site conditions exceeded Oakland RBCA Tier 1 and Tier 2 levels, these conditions were further assessed under the Oakland RBCA Tier 3 analysis. The Tier 3 analysis replaces some of the conservative, generic assumptions of Tiers 1 and 2 with data that represent actual site conditions, thus more accurately reflecting existing and future risks.

This version of the RBCA evaluation for the former BP Oil Facility No. 11133 addresses comments received from the City of Oakland, Alameda County Environmental Health Services, and the RWQCB on two previous versions of the RBCA evaluation. The primary issue addressed in this revised report (from the December 2000 version) is the incorporation of soil vapor data collected to adequately evaluate exposures to the residential properties adjacent to the site. Results of the Oakland RBCA Tier 3 evaluation indicate that remnant levels of petroleum hydrocarbons are below City of Oakland, U.S. Environmental Protection Agency (EPA) and RWQCB acceptable cancer risks and non-cancer levels. Therefore, soil and groundwater conditions at the site should not pose a risk to current and future on-site workers or off-site residents.

# ACRONYMS

| | |
|---|---|
| ADD | Average Daily Dose |
| ASTM | American Society for Testing and Materials |
| bgs | below ground surface |
| BTEX | Benzene, Toluene, Ethylbenzene, and Xylenes |
| CSF | Cancer Slope Factor |
| DTSC | California Department of Toxic Substances Control |
| EPA | U.S. Environmental Protection Agency |
| HI | Hazard Index |
| ILCR | Incremental Lifetime Cancer Risk |
| IRIS | Integrated Risk Information System |
| LADD | Lifetime Average Daily Dose |
| MADEP | Massachusetts Department of Environmental Protection |
| NA | Not Applicable |
| OEHHA | California Office of Environmental Health Hazard Assessment |
| OSHA | Occupational Safety and Health Administration |
| PAHs | Polynuclear Aromatic Hydrocarbons |
| RBCA | Risk-Based Corrective Action |
| RfD | Reference Dose |
| SSTL | Site-Specific Target Level |
| TPH | Total Petroleum Hydrocarbons |
| TPHCWG | Total Petroleum Hydrocarbon Working Group |
| UCL | Upper Confidence Limit |
| UST | Underground Storage Tank |

# FIGURES AND TABLES

## FIGURES

## TABLES

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# APPENDIX A

# DATA SUMMARY

## **Table A-1.** Soil Data Summary

| Sample | Media | Sample Depth | Date | Units | TPH-G | TPH-D | TPH-O | Benzene | Toluene | Ethyl-benzene | Xylenes | MTBE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TD-5-0.5 | Soil | 0.5 | Dec-94 | ppm | ND | 3900 | ND | ND | ND | ND | ND | NA |
| P3 | Soil | 2.5 | Jul-90 | ppm | 9.4 | NA | NA | 0.029 | 0.096 | 0.52 | 3 | NA |
| P1 | Soil | 3 | Jul-90 | ppm | <1 | NA | NA | 0.9 | 0.079 | 0.0066 | 0.034 | NA |
| P1 | Soil | 3.5 | Oct-98 | ppm | <1 | NA | NA | <0.005 | <0.005 | <0.005 | 0.029 | <0.05 |
| P2 | Soil | 3.5 | Oct-98 | ppm | <1 | NA | NA | <0.005 | <0.005 | <0.005 | <0.005 | 4 |
| P3 | Soil | 3.5 | Oct-98 | ppm | <1 | NA | NA | <0.005 | <0.005 | <0.005 | <0.005 | <0.05 |
| P4 | Soil | 3.5 | Oct-98 | ppm | <1 | NA | NA | <0.005 | <0.005 | <0.005 | <0.005 | <0.05 |
| P5 | Soil | 3.5 | Oct-98 | ppm | <1 | NA | NA | 0.0085 | 0.047 | 0.0071 | 0.057 | 0.74 |
| P6 | Soil | 3.5 | Oct-98 | ppm | <1 | NA | NA | <0.005 | <0.005 | <0.005 | <0.005 | <0.05 |
| P7 | Soil | 3.5 | Oct-98 | ppm | 1.2 | NA | NA | 0.067 | 0.09 | <0.005 | 0.042 | 2 |
| P8 | Soil | 3.5 | Oct-98 | ppm | <1 | NA | NA | <0.005 | <0.005 | <0.005 | <0.005 | <0.05 |
| P2 | Soil | 4.5 | Jul-90 | ppm | <1 | NA | NA | <0.005 | 0.047 | 0.011 | 0.037 | NA |
| AW-1 | Soil | 5 | Jun-90 | ppm | <1 | NA | NA | <0.005 | <0.005 | <0.005 | <0.005 | NA |
| RW-1 | Soil | 5 | Jun-90 | ppm | <1.0 | NA | NA | <0.005 | <0.005 | <0.005 | <0.005 | NA |
| D1 | Soil | 7 | Jul-90 | ppm | 12 | NA | NA | 0.053 | 0.39 | 0.16 | 0.96 | NA |
| D2 | Soil | 7 | Jul-90 | ppm | 3.3 | NA | NA | 0.029 | 0.48 | 0.044 | 0.22 | NA |
| THP1-S-9.5-10.5 | Soil | 9.5 | Oct-94 | ppm | ND | ND | ND | 0.92 | ND | 0.008 | ND | NA |
| AW-1 | Soil | 10 | Jun-90 | ppm | <1 | NA | NA | 0.011 | <0.005 | <0.005 | <0.005 | NA |
| RW-1 | Soil | 10 | Jun-90 | ppm | <1.0 | NA | NA | 0.006 | <0.005 | <0.005 | <0.005 | NA |
| SW1 | Soil | 10 | Jul-90 | ppm | 1.3 | NA | NA | 0.011 | 0.056 | 0.025 | 0.035 | NA |
| SW2 | Soil | 10 | Jul-90 | ppm | 23 | NA | NA | 0.015 | 0.1 | 0.23 | 0.18 | NA |
| SW3 | Soil | 10 | Jul-90 | ppm | 12 | NA | NA | 0.016 | 0.018 | 0.12 | 0.25 | NA |
| SW4 | Soil | 10 | Jul-90 | ppm | 3.8 | NA | NA | 0.016 | 0.02 | 0.05 | 0.064 | NA |
| AW-4 | Soil | 11 | Jun-90 | ppm | <1.0 | NA | NA | <0.005 | <0.005 | <0.005 | <0.005 | NA |
| SW1 | Soil | 12 | Oct-98 | ppm | <1 | NA | NA | <0.005 | <0.005 | <0.005 | <0.005 | <0.05 |
| SW2 | Soil | 12 | Oct-98 | ppm | <1 | NA | NA | <0.005 | <0.005 | <0.005 | <0.005 | 0.43 |
| SW3 | Soil | 12 | Oct-98 | ppm | <1 | NA | NA | <0.005 | <0.005 | <0.005 | <0.005 | 0.099 |
| SW4 | Soil | 12 | Oct-98 | ppm | <1 | NA | NA | <0.005 | <0.005 | <0.005 | <0.005 | <0.05 |
| THP-1-S-13-13.5 | Soil | 13 | Oct-94 | ppm | ND | ND | ND | 0.024 | ND | ND | ND | NA |
| AW-1 | Soil | 15 | Jun-90 | ppm | <1 | NA | NA | 0.007 | <0.005 | <0.005 | <0.005 | NA |
| RW-1 | Soil | 15 | Jun-90 | ppm | <1.0 | NA | NA | 0.031 | <0.005 | <0.005 | <0.005 | NA |
| AW-4 | Soil | 16 | Jun-90 | ppm | <1.0 | NA | NA | 0.17 | 0.01 | 0.024 | 0.045 | NA |
| VEW-9 | Soil | 16.5 | May-96 | ppm | <0.1 | NA | NA | <0.001 | <0.002 | <0.002 | <0.002 | <0.1 |

**Table A-1.** Soil Data Summary

| Sample | Media | Sample Depth | Date | Units | TPH-G | TPH-D | TPH-O | Benzene | Toluene | Ethyl-benzene | Xylenes | MTBE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AW-1 | Soil | 20 | Jun-90 | ppm | 1.2 | NA | NA | 0.47 | <0.005 | <0.005 | <0.005 | NA |
| RW-1 | Soil | 20 | Jun-90 | ppm | <1.0 | NA | NA | 0.23 | 0.088 | 0.01 | 0.04 | NA |
| AW-2 | Soil | 21 | Jun-90 | ppm | <1.0 | NA | NA | <0.005 | <0.005 | <0.005 | <0.005 | NA |
| AW-3 | Soil | 21 | Jun-90 | ppm | <1.0 | NA | NA | 0.074 | 0.027 | 0.01 | 0.049 | NA |
| AW-4 | Soil | 21 | Jun-90 | ppm | 1 | NA | NA | 0.15 | 0.013 | 0.04 | 0.09 | NA |
| AW-1 | Soil | 25 | Jun-90 | ppm | <1.0 | NA | NA | 0.013 | <0.005 | <0.005 | <0.005 | NA |
| RW-1 | Soil | 25 | Jun-90 | ppm | 33 | NA | NA | 1 | 0.71 | <0.005 | 2.3 | NA |
| AW-2 | Soil | 26 | Jun-90 | ppm | <1.0 | NA | NA | <0.005 | <0.005 | <0.005 | <0.005 | NA |
| AW-3 | Soil | 26 | Jun-90 | ppm | <1.0 | NA | NA | 0.083 | 0.01 | 0.04 | 0.018 | NA |
| AW-1 | Soil | 30 | Jun-90 | ppm | <1.0 | NA | NA | <0.005 | <0.005 | <0.005 | <0.005 | NA |
| SBA-5 (AW-5) | Soil | 10.5-11 | Apr-91 | ppm | <1 | NA | NA | 0.016 | <0.003 | <0.003 | <0.003 | NA |
| SBA-6 (AW-6) | Soil | 10.5-11 | Apr-91 | ppm | <1 | NA | NA | 0.091 | 0.022 | 0.008 | 0.04 | NA |
| SBA-7 (AW-7) | Soil | 10.5-11 | Apr-91 | ppm | <1 | NA | NA | <0.003 | <0.003 | <0.003 | <0.003 | NA |
| SBA-8 (AW-8) | Soil | 10.5-11 | Apr-91 | ppm | <1 | NA | NA | <0.003 | <0.003 | <0.003 | <0.003 | NA |
| AW-9 | Soil | 16.5-17 | Dec-96 | ppm | <0.1 | NA | NA | <0.001 | <0.002 | <0.002 | <0.002 | <0.1 |
| AW-9 | Soil | 19-19.5 | Dec-96 | ppm | <0.1 | NA | NA | <0.001 | <0.002 | <0.002 | <0.002 | <0.1 |
| SBA-5 (AW-5) | Soil | 20.5-21 | Apr-91 | ppm | <1 | NA | NA | 0.02 | <0.003 | 0.007 | 0.008 | NA |
| SBA-6 (AW-6) | Soil | 20.5-21 | Apr-91 | ppm | <1 | NA | NA | <0.003 | <0.003 | <0.003 | <0.003 | NA |
| SBA-7 (AW-7) | Soil | 20.5-21 | Apr-91 | ppm | <1 | NA | NA | <0.003 | <0.003 | <0.003 | <0.003 | NA |
| SBA-8 (AW-8) | Soil | 20.5-21 | Apr-91 | ppm | <1 | NA | NA | <0.003 | <0.003 | <0.003 | <0.003 | NA |
| SBA-5 (AW-5) | Soil | 25.5-26 | Apr-91 | ppm | <1 | NA | NA | 0.077 | <0.003 | 0.003 | 0.011 | NA |
| SBA-6 (AW-6) | Soil | 25.5-26 | Apr-91 | ppm | <1 | NA | NA | 0.005 | 0.01 | <0.003 | 0.0066 | NA |
| SBA-7 (AW-7) | Soil | 25.5-26 | Apr-91 | ppm | <1 | NA | NA | <0.003 | <0.003 | <0.003 | <0.003 | NA |
| SBA-8 (AW-8) | Soil | 25.5-26 | Apr-91 | ppm | <1 | NA | NA | <0.003 | <0.003 | <0.003 | <0.003 | NA |
| VEW-9 | Soil | comp | May-96 | ppm | <0.1 | NA | NA | <0.001 | <0.002 | <0.002 | <0.002 | <0.1 |

NA = not analyzed

ND = not detected, no detection limit located

**Table A-2.** Groundwater Data Summary

| Sample | Media | Date | Units | TPH-G | Benzene | Toluene | Ethyl-benzene | Xylenes | MTBE |
|---|---|---|---|---|---|---|---|---|---|
| MW-1 | GW | 7/9/99 | ppb | 58,000 | 140 | 100 | 1,800 | 6,900 | 1,200 |
| MW-1 | GW | 11/3/99 | ppb | 20,000 | 62 | 42 | 620 | 2,100 | 630 |
| MW-1 | GW | 1/12/00 | ppb | 72,000 | 110 | 120 | 2,400 | 8,200 | 630 |
| MW-1 | GW | 4/13/00 | ppb | 37,000 | 300 | 32 | 1,000 | 1,700 | 810 |
| MW-2 | GW | 4/30/99 | ppb | NA | NA | NA | NA | NA | NA |
| MW-2 | GW | 7/9/99 | ppb | NA | NA | NA | NA | NA | NA |
| MW-2 | GW | 11/3/99 | ppb | NA | NA | NA | NA | NA | NA |
| MW-2 | GW | 6/19/98 | ppb | <50 | <0.5 | <1 | <1 | <1 | <10 |
| MW-2 | GW | 4/10/98 | ppb | <50 | 1 | <1 | <1 | <1 | 23 |
| MW-2 | GW | 1/21/98 | ppb | 160 | <0.5 | <1 | <1 | <1 | 100 |
| MW-2 | GW | 1/12/00 | ppb | <50 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| MW-3 | GW | 1/21/99 | ppb | 1,100 | <0.5 | <1 | <1 | <1 | 1,200 |
| MW-3 | GW | 4/30/99 | ppb | NA | NA | NA | NA | NA | NA |
| MW-3 | GW | 7/9/99 | ppb | 470 | <0.5 | <1 | <1 | <1 | 470 |
| MW-3 | GW | 11/3/99 | ppb | NA | NA | NA | NA | NA | NA |
| MW-3 | GW | 1/12/00 | ppb | <50 | <0.5 | <0.5 | <0.5 | <0.5 | 34 |
| MW-3 | GW | 7/26/00 | ppb | <50 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| AW-1 | GW | 4/30/99 | ppb | 21,000 | 5,300 | 67 | 2,800 | 750 | 1,500 |
| AW-1 | GW | 7/9/99 | ppb | 11,000 | 3,000 | <10 | 760 | 180 | 1,300 |
| AW-1 | GW | 11/3/99 | ppb | NA | NA | NA | NA | NA | NA |
| AW-1 | GW | 1/12/00 | ppb | 330,000 | 5,300 | 10 | 2,900 | 560 | 2,200 |
| AW-1 | GW | 7/26/00 | ppb | 15,000 | 290 | 98 | 77 | 220 | 37,000 |
| AW-2 | GW | 4/9/98 | ppb | NA | NA | NA | NA | NA | NA |
| AW-2 | GW | 4/10/98 | ppb | <50 | <0.5 | <1 | <1 | <1 | <10 |
| AW-2 | GW | 6/19/98 | ppb | 60 | <0.5 | <1 | <1 | <1 | <10 |
| AW-2 | GW | 11/30/98 | ppb | NA | NA | NA | NA | NA | NA |
| AW-2 | GW | 1/21/99 | ppb | <50 | <0.5 | <1 | <1 | <1 | <1 |
| AW-2 | GW | 4/30/99 | ppb | NA | NA | NA | NA | NA | NA |
| AW-2 | GW | 7/9/99 | ppb | NA | NA | NA | NA | NA | NA |
| AW-2 | GW | 11/3/99 | ppb | NA | NA | NA | NA | NA | NA |
| AW-2 | GW | 1/12/00 | ppb | <50 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| AW-3 | GW | 4/9/98 | ppb | NA | NA | NA | NA | NA | NA |
| AW-3 | GW | 4/10/98 | ppb | <50 | <0.5 | <1 | 1 | 2 | <10 |
| AW-3 | GW | 6/19/98 | ppb | <50 | <0.5 | <1 | <1 | <1 | <10 |
| AW-3 | GW | 11/30/98 | ppb | NA | NA | NA | NA | NA | NA |
| AW-3 | GW | 1/21/99 | ppb | <50 | <1 | <1 | <1 | <1 | <1 |
| AW-3 | GW | 4/30/99 | ppb | NA | NA | NA | NA | NA | NA |
| AW-3 | GW | 7/9/99 | ppb | NA | NA | NA | NA | NA | NA |
| AW-3 | GW | 11/3/99 | ppb | NA | NA | NA | NA | NA | NA |
| AW-3 | GW | 1/12/00 | ppb | <50 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| AW-4 | GW | 11/30/98 | ppb | NA | NA | NA | NA | NA | NA |
| AW-4 | GW | 1/21/99 | ppb | 3,700 | 830 | 93 | 200 | 360 | 30 |
| AW-4 | GW | 4/30/99 | ppb | NA | NA | NA | NA | NA | NA |
| AW-4 | GW | 7/9/99 | ppb | 76,000 | 12,000 | 7 | 2,000 | 8,700 | 320 |
| AW-4 | GW | 11/3/99 | ppb | NA | NA | NA | NA | NA | NA |
| AW-4 | GW | 1/12/00 | ppb | 67,000 | 12,000 | 3,500 | 2,900 | 15,000 | 280 |
| AW-4 | GW | 7/26/00 | ppb | 910 | <0.5 | <0.5 | <0.5 | <0.5 | 3,500 |

**Table A-2.** Groundwater Data Summary

| Sample | Media | Date | Units | TPH-G | Benzene | Toluene | Ethyl-benzene | Xylenes | MTBE |
|---|---|---|---|---|---|---|---|---|---|
| AW-5 | GW | 11/30/98 | ppb | NA | NA | NA | NA | NA | NA |
| AW-5 | GW | 1/21/99 | ppb | 2,800 | <1 | <1 | <1 | <1 | 1,800 |
| AW-5 | GW | 4/30/99 | ppb | NA | NA | NA | NA | NA | NA |
| AW-5 | GW | 7/9/99 | ppb | 4,000 | <1 | <1 | <1 | <1 | 3,500 |
| AW-5 | GW | 11/3/99 | ppb | NA | NA | NA | NA | NA | NA |
| AW-5 | GW | 1/12/00 | ppb | 1,000 | 7 | 30 | 7 | 40 | 4,600 |
| AW-5 | GW | 7/26/00 | ppb | 1,800 | 94 | 35 | 6 | 27 | 16,000 |
| AW-6 | GW | 4/9/98 | ppb | NA | NA | NA | NA | NA | NA |
| AW-6 | GW | 4/10/98 | ppb | 370 | <0.5 | <1 | <1 | <1 | 300 |
| AW-6 | GW | 6/19/98 | ppb | 830 | 2 | <1 | <1 | <1 | 690 |
| AW-6 | GW | 11/30/98 | ppb | NA | NA | NA | NA | NA | NA |
| AW-6 | GW | 1/21/99 | ppb | 2,300 | <1 | <1 | <1 | <1 | 1,900 |
| AW-6 | GW | 4/30/99 | ppb | NA | NA | NA | NA | NA | NA |
| AW-6 | GW | 7/9/99 | ppb | NA | NA | NA | NA | NA | NA |
| AW-6 | GW | 11/3/99 | ppb | NA | NA | NA | NA | NA | NA |
| AW-6 | GW | 1/12/00 | ppb | <50 | <0.5 | <0.5 | <0.5 | <0.5 | 2,700 |
| AW-7 | GW | 1/21/98 | ppb | <50 | <0.5 | <1 | <1 | <1 | <10 |
| AW-7 | GW | 6/19/98 | ppb | <50 | <0.5 | <1 | <1 | <1 | <10 |
| AW-7 | GW | 11/30/98 | ppb | NA | NA | NA | NA | NA | NA |
| AW-8 | GW | 4/9/98 | ppb | <50 | <0.5 | <1 | <1 | <1 | <10 |
| AW-8 | GW | 6/19/98 | ppb | <50 | <0.5 | <1 | <1 | <1 | <10 |
| AW-8 | GW | 1/21/99 | ppb | NA | NA | NA | NA | NA | NA |
| AW-9 | GW | 4/9/98 | ppb | <50 | <0.5 | <1 | <1 | <1 | <10 |
| AW-9 | GW | 6/19/98 | ppb | <50 | <0.5 | <1 | <1 | <1 | <10 |
| AW-9 | GW | 1999 | ppb | NA | NA | NA | NA | NA | NA |
| RW-1 | GW | 7/9/99 | ppb | NA | NA | NA | NA | NA | NA |
| RW-1 | GW | 11/3/99 | ppb | 160,000 | 19,000 | 37,000 | 3,800 | 25,000 | 1,500 |
| RW-1 | GW | 1/12/00 | ppb | 240,000 | 18,000 | 46,000 | 5,800 | 26,000 | 2,100 |
| RW-1 | GW | 4/13/00 | ppb | 120,000 | 2,100 | 33,000 | 2,800 | 28,000 | 1,500 |
| RW-1 | GW | 7/26/00 | ppb | 67,000 | 160 | 5,300 | 2,100 | 18,000 | 1,100 |

NA = not analyzed
TPH-G = Total petroleum hydrocarbons as gasoline
TPH-D = Total petroleum hydrocarbons as diesel
MTBE = Methyl tertiary butyl ether

## **Table A-3.** Soil Vapor Data Summary[a]

| Sample ID (Depth in feet) | Date Sampled | TPH-G (ppmv) | Benzene (ppmv) | Toluene (ppmv) | Ethyl-benzene (ppmv) | Xylenes (ppmv) | MTBE (ppmv) | Oxygen (%) | Total Methane (%) | Carbon Dioxide (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| B-1-V1 (5') | 10/22/01 | 6.6 | 0.0073 | 0.0062 | <0.0020 | 0.0049 | 0.0038 | - | - | - |
| B-1-V2 (10') | 10/22/01 | 9.9 | <0.0027 | 0.0033 | <0.0027 | 0.0031 | <0.0027 | - | - | - |
| B-1-V3 (15') | 10/22/01 | 1.8 | 0.0033 | 0.0096 | <0.0025 | 0.0067 | 0.0050 | - | - | - |
| B-2-V1 (5') | 10/22/01 | 2.4 | 0.0080 | 0.0070 | <0.0026 | 0.0038 | <0.0026 | 22 | <0.0026 | 0.28 |
| B-2-V2 (10') | 10/22/01 | 11 | 0.0062 a | 0.0063 | <0.0026 | <0.0026 | <0.0026 | 21 | <0.0026 | 0.33 |
| B-2-V3 (15') | 10/22/01 | 4.5 | 0.0072 | 0.0072 | <0.0025 | 0.0035 | <0.0025 | 20 | <0.0025 | 0.33 |
| B-3-V1 (5') | 10/22/01 | 7.0 | 0.026 | 0.019 | <0.0025 | 0.0098 | 0.0047 | - | - | - |
| B-3-V2 (10') | 10/22/01 | 2.2 | 0.0079 | 0.0055 | <0.0036 | 0.0039 | <0.0036 | - | - | - |
| B-3-V3 (15') | 10/22/01 | 1.6 | 0.0064 | 0.0074 | 0.0027 | 0.0063 | 0.0040 | - | - | - |
| B-4-V1 (5') | 10/22/01 | 1.3 | 0.010 a | 0.0082 | <0.0029 | 0.0043 | <0.0029 | 20 | <0.0029 | 0.066 |
| B-4-V2 (10') | 10/22/01 | 1.3 | 0.0042 a | 0.0060 | <0.0026 | 0.0051 | <0.0026 | 20 | <0.0026 | 0.070 |
| B-4-V3 (15') | 10/22/01 | 2.1 | 0.013 | 0.011 | 0.0040 a | 0.0090 | 0.0042 | 20 | <0.0025 | 0.092 |
| B-5-V1 (5') | 10/23/01 | 6.2 | 0.023 a | 0.020 | <0.0040 | 0.012 | 0.0070 | - | - | - |
| B-5-V2 (10') | 10/23/01 | 2.0 | 0.0058 | 0.0094 | <0.0024 | 0.0084 | 0.0033 | - | - | - |
| B-5-V3 (15') | 10/23/01 | 1.7 | <0.0042 b | 0.0055 | <0.0042 b | <0.0042 b | <0.0042 b | - | - | - |
| B-6-V1 (5') | 10/23/01 | 4.2 | 0.030 a | 0.017 | 0.0078 | 0.11 | 0.0062 | - | - | - |
| B-6-V2 (10') | 10/23/01 | 2.3 | 0.029 | 0.060 | 0.0070 | 0.025 | 0.0061 | - | - | - |
| B-6-V3 (15') | 10/23/01 | 2.4 | 0.34 | 0.23 | 0.15 | 0.59 | 0.062 | - | - | - |

[a] From Cambria (2002).

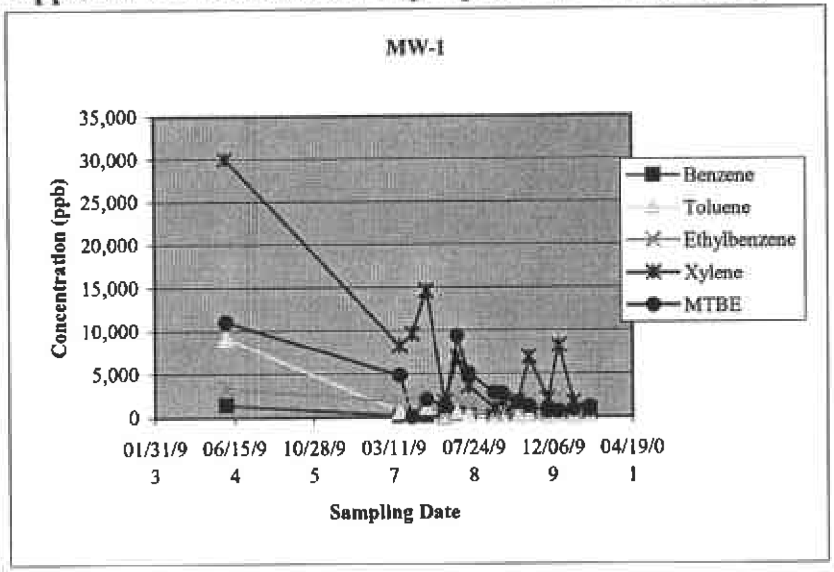
ppmv = Parts per million by volume
MTBE = Methyl tert-butyl ether
DIPE = Diisopropyl ether
TPHg = Total petroleum hydrocarbons as gasoline
<n = Below detection limit of n mg/kg
--- = Not analyzed
a = Reported value may be biased due to apparent matrix interferences.
b = Elevated reporting limits due to high residual canister vacuum.

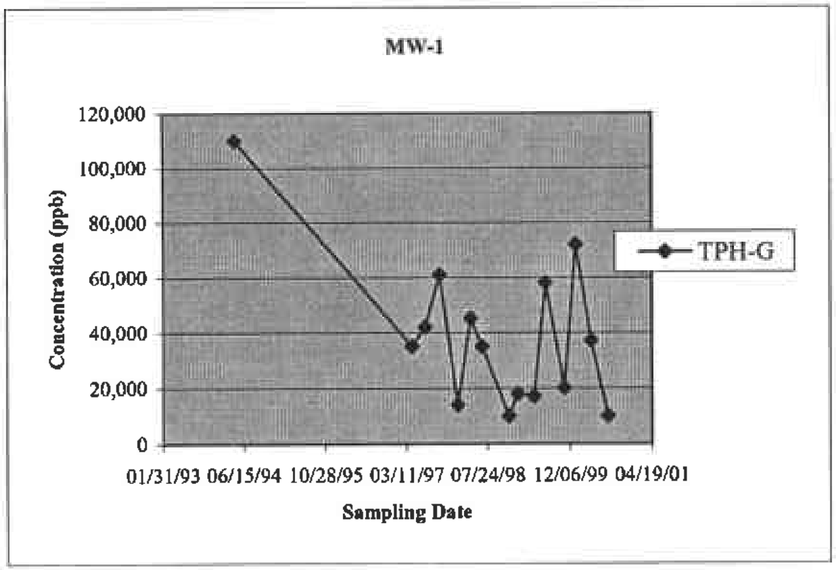
ETBE = Ethyl tert-butyl ether
TAME = Tert-amyl methyl ether
TBA = Tert-butyl alcohol
1,2-DCA = 1,2-dichloroethane
EDB = 1,2-dibromoethane

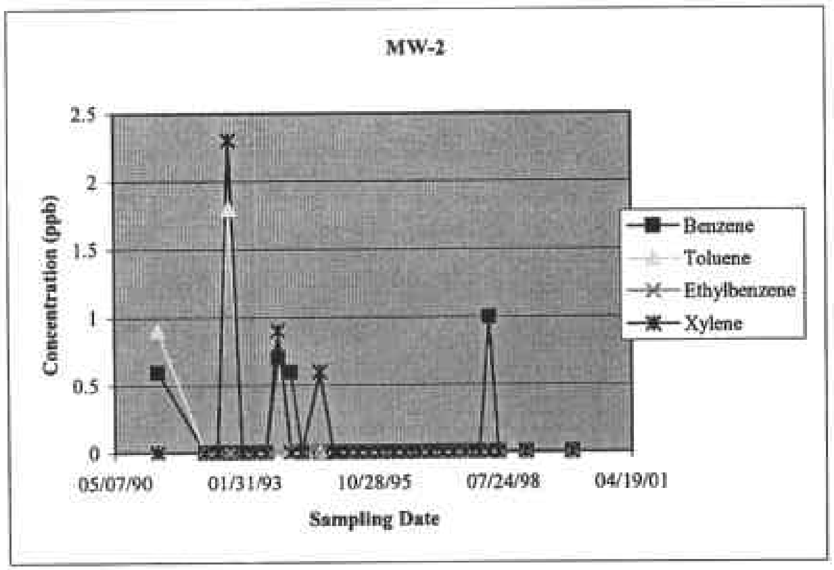
# APPENDIX B

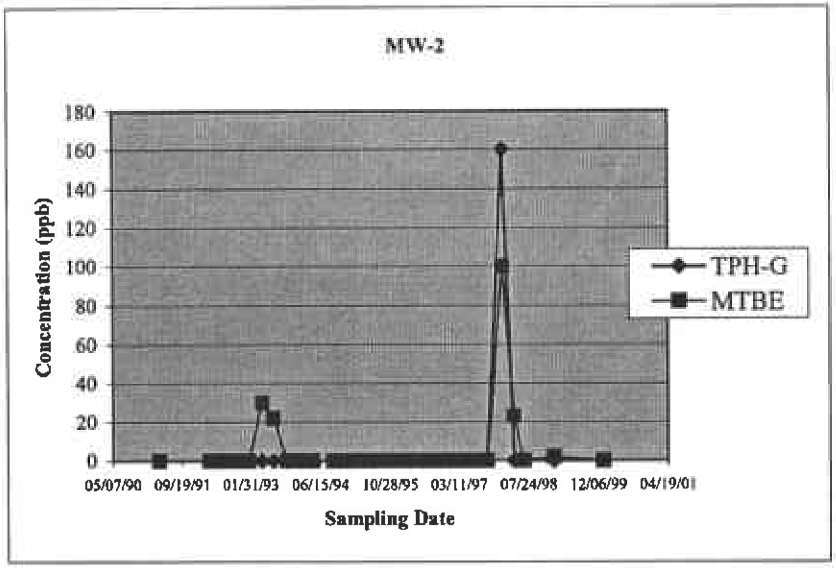
# GROUNDWATER SAMPLING RESULTS – TREND CHARTS

## Appendix B. Groundwater Sampling Results – Trend Charts

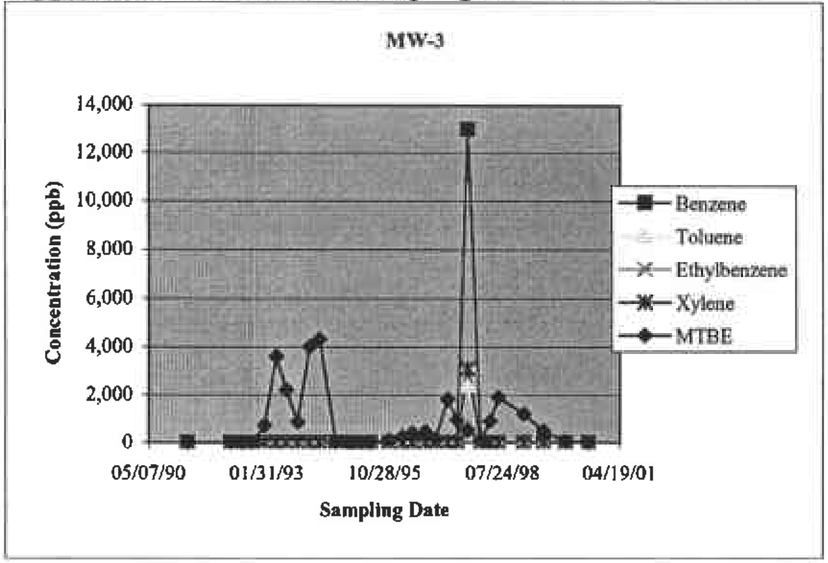


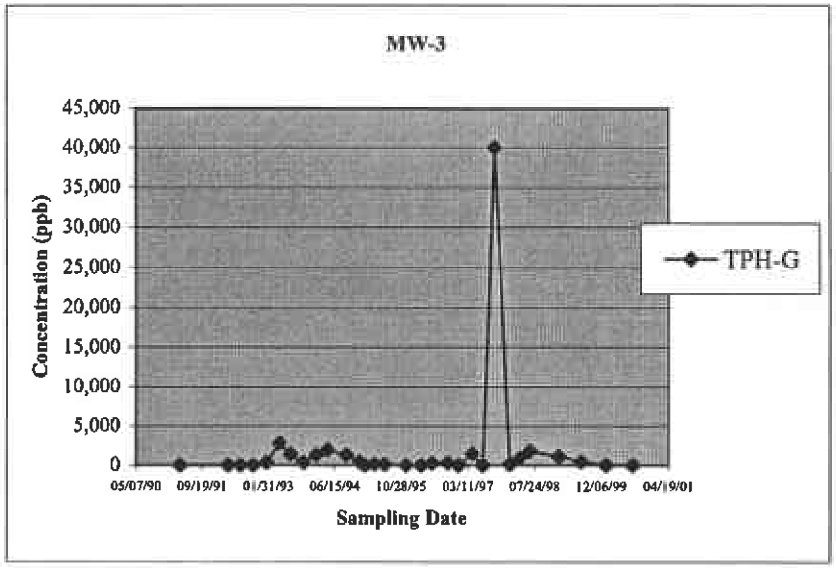


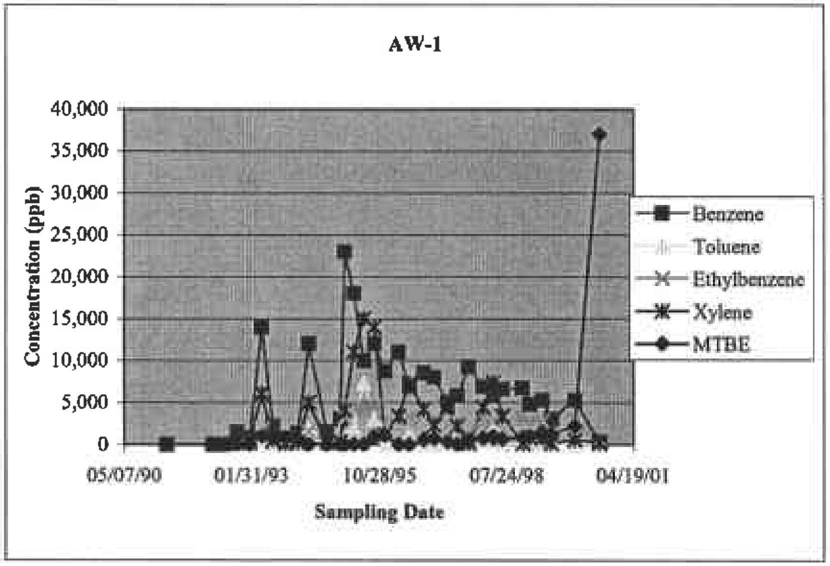


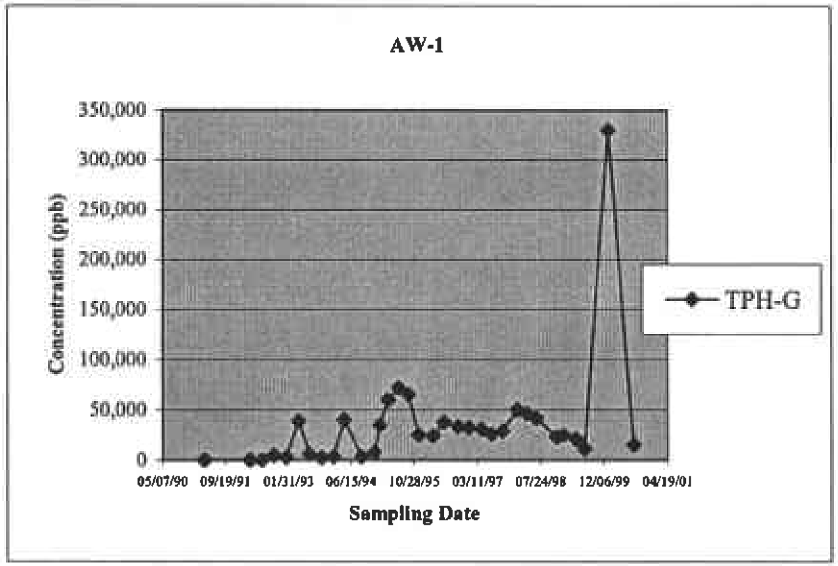


# **Appendix B.** Groundwater Sampling Results – Trend Charts









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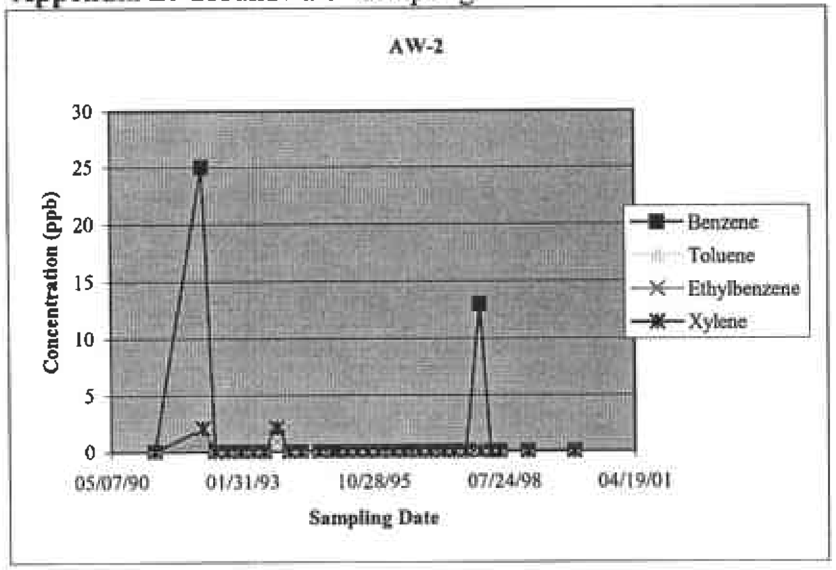

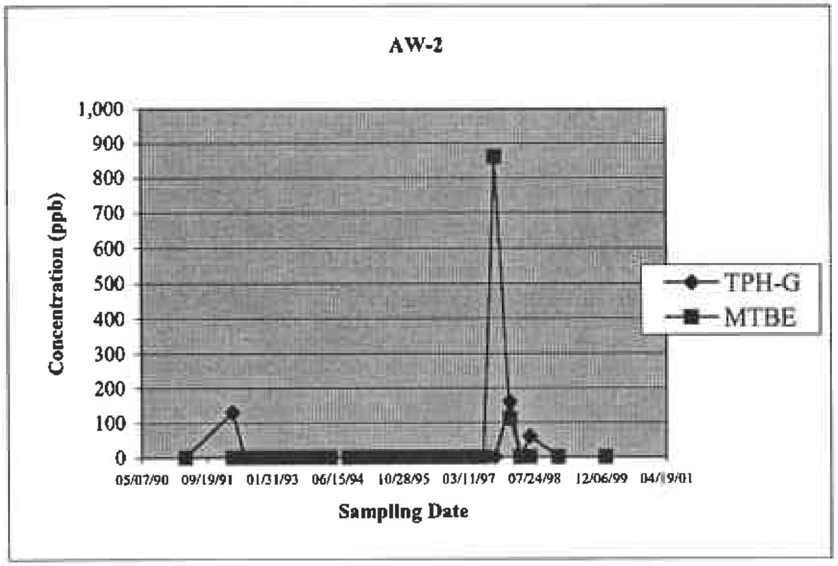

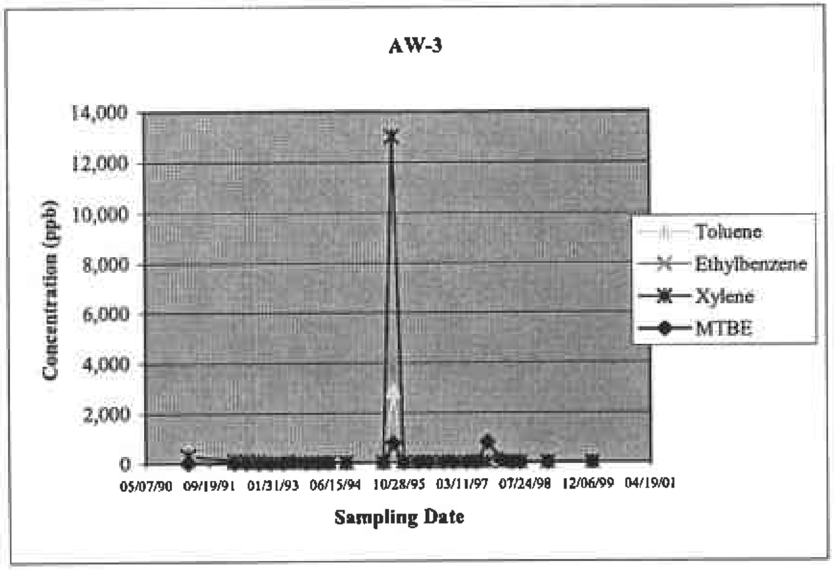

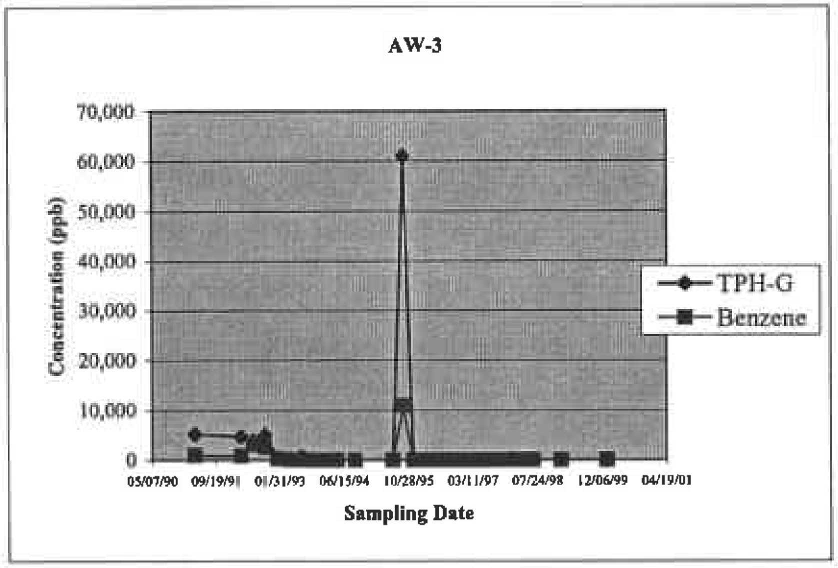

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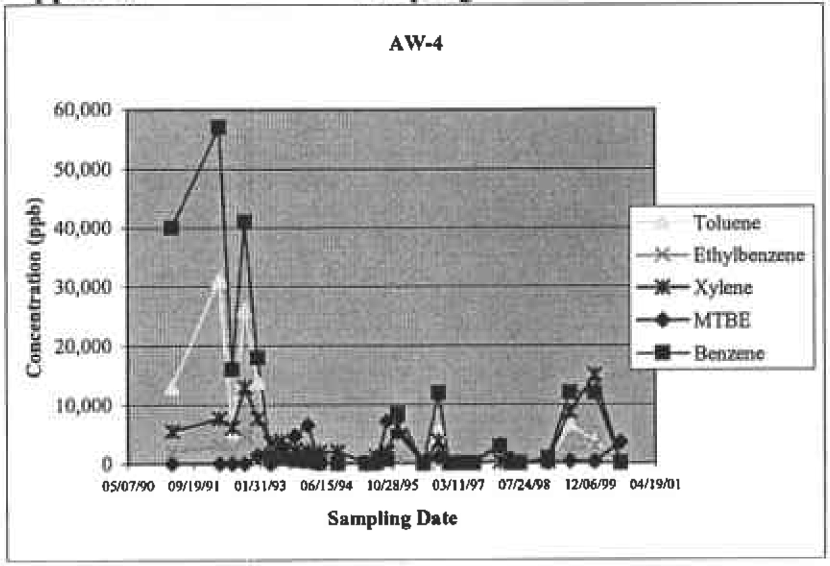

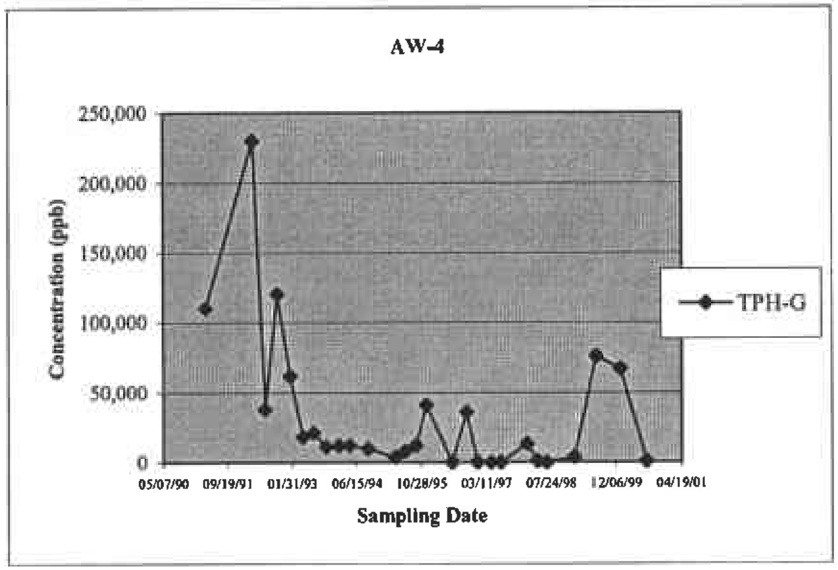

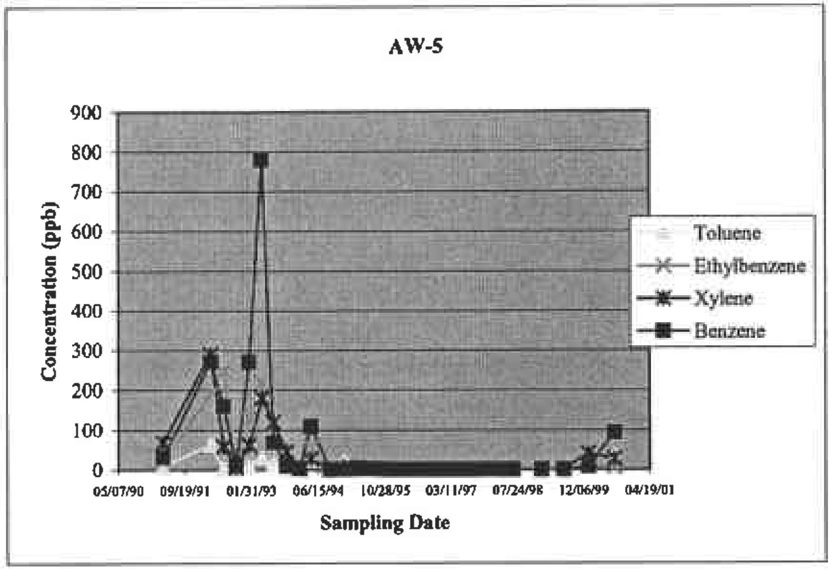

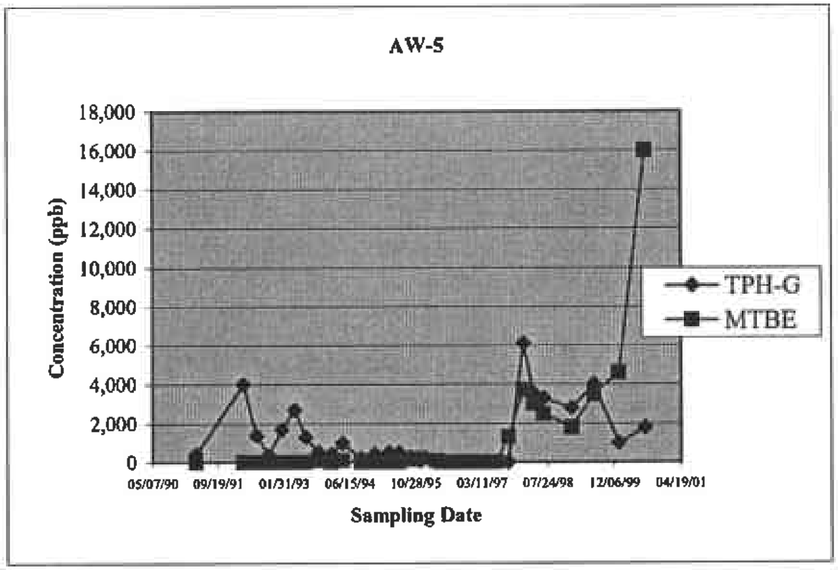

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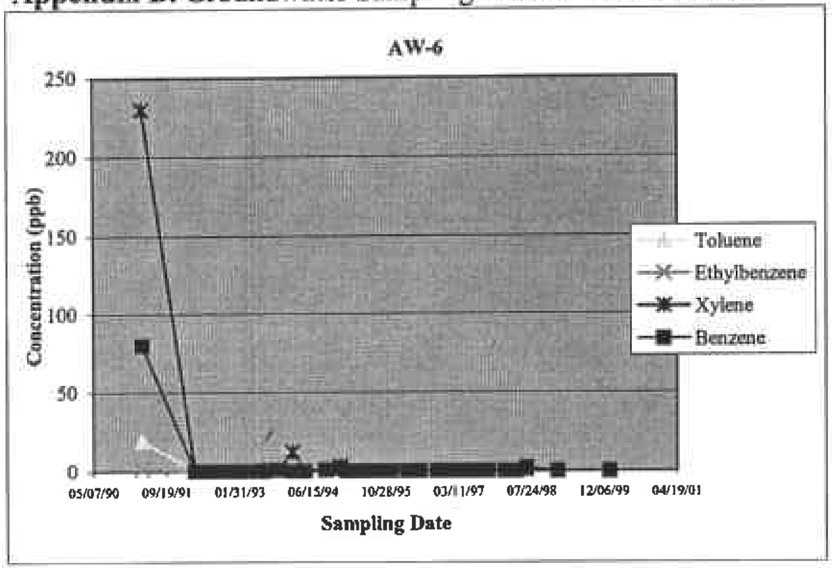

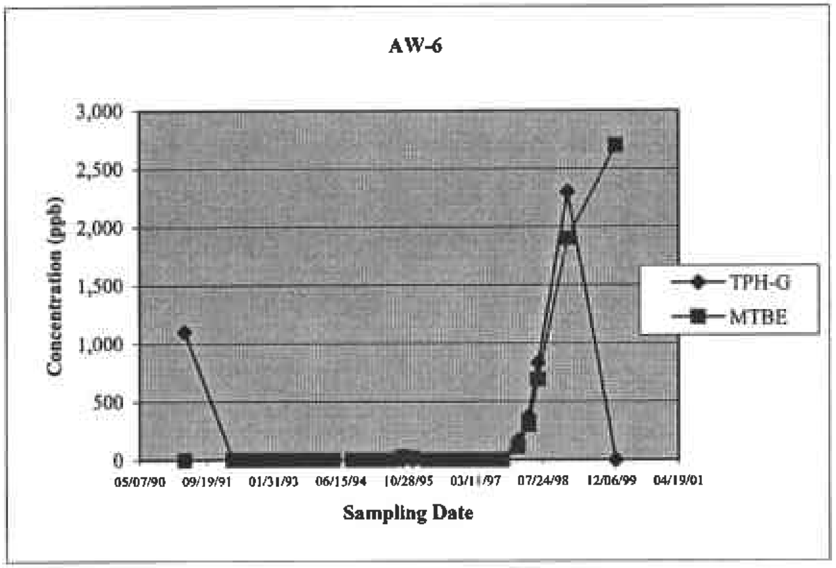

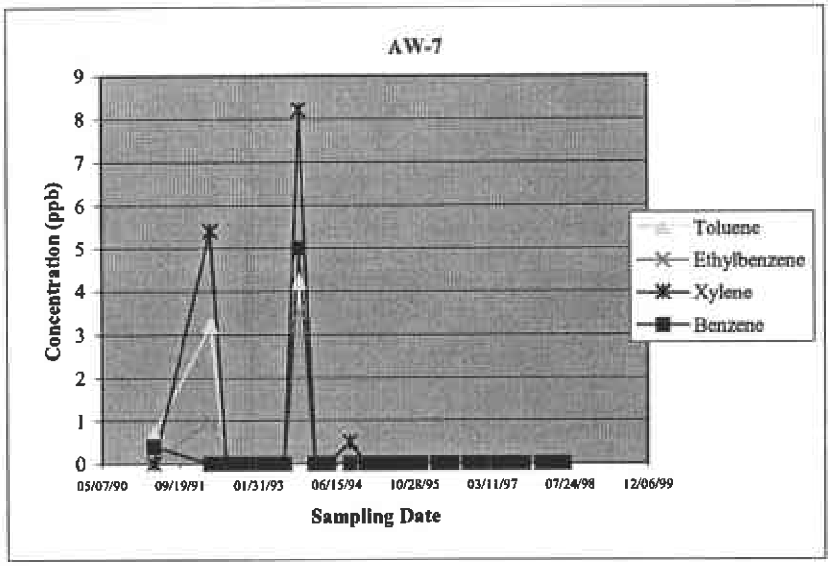

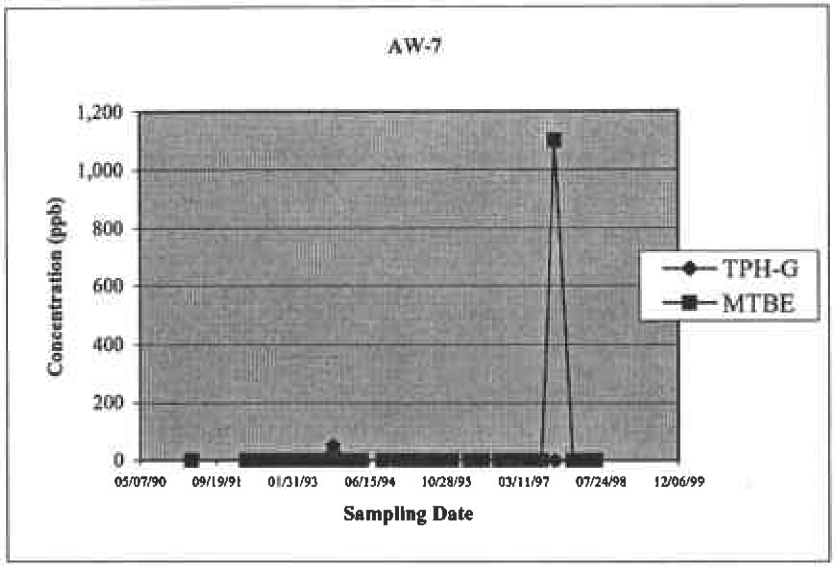

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