**REPORT**

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# DEVELOPMENT OF SITE-SPECIFIC TARGET LEVELS FOR SOIL AND GROUNDWATER

# FIRE STATION NO. 2, EMERYVILLE, CALIFORNIA



*Prepared for*

City of Emeryville Redevelopment Agency
2200 Powell Street, 12th Floor
Emeryville, CA 94608-4356

May 1997

**Woodward-Clyde**

Woodward-Clyde Consultants
500 12th Street, Suite 100
Oakland, CA 94607-4014
(510) 874-3000
Project 951276NA

**Woodward-Clyde**

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June 2, 1997
961276NA

Ms. Susan Hugo
Division of Environmental Protection
Department of Environmental Health
Alameda County Health Agency
1131 Harbor Bay Parkway, 2nd Floor
Alameda, California 94502

Subject: Transmittal of RBCA Evaluation Report for the Fire Station No. 2 UST Site Emeryville, California

Dear Ms. Hugo:

On behalf of the City of Emeryville Redevelopment Agency, transmitted herewith is the subject site RBCA evaluation results for your review and approval. The RBCA evaluation followed the steps detailed in the workplan, which was submitted to you on March 10, 1997.

Please do not hesitate to call the undersigned or Mr. Ignacio Dayrit at (510) 596-4356 for questions or comments.

Sincerely,

Xinggang Tong, P.E., Ph.D.
Project Manager
(510) 874-3060

Marco C. Lobascio, P.E., R.E.A.
RBCA Specialist
(510) 874-3254

Enclosure.

REPORT

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## 1.1 PURPOSE OF REPORT

The purpose of this report is to present the results of a risk-based evaluation to develop site-specific target levels (SSTLs) for chemicals detected in soil and shallow groundwater for the Fire Station No. 2 located at 6303 Hollis Street in Emeryville, California (the site). This report was prepared by Woodward-Clyde Consultants (WCC) on behalf of the City of Emeryville Redevelopment Agency (the City).

A Risk-Based Corrective Action (RBCA) evaluation based on the American Society for Testing and Materials (ASTM) Standard E 1739-95 (ASTM 1995) was used to develop the SSTLs, following the recommendations in the Regional Water Quality Control Board (RWQCB) - San Francisco Bay Region's Directive of January 5, 1996. The RBCA evaluation approach for the site was outlined in the Workplan for Additional Site Investigation (WCC 1996), which was approved by the Alameda County Department of Environmental Health (ACDEH) in a letter to the City dated October 8, 1996. Details about site-specific approach and parameters for the risk-based evaluation were presented in the RBCA approach workplan (WCC 1997) to the ACDEH dated March 5, 1997. The soil and groundwater SSTLs developed here were utilized to evaluate the need and extent of remediation activities at the site, with the goal of ultimately obtaining a no further action (NFA) decision from the ACDEH.

Section 2.0 of this report presents the RBCA Tier 1 screening evaluation. Section 3.0 provides the development of SSTLs for the site according to RBCA Tier 2. Conclusions and recommendations are provided in Section 4.0. Uncertainties and limitations of this study are discussed in Section 5.0. References are in Section 6.0.

## 1.2 THE ASTM RISK-BASED CORRECTIVE ACTION TIER 1 AND 2 PROCESSES

This risk-based evaluation was performed according to the ASTM RBCA methodology. The RBCA methodology is a consistent and comprehensive approach to risk-based remediation of site contamination based on the protection of human health and environmental resources (e.g., groundwater quality). RBCA is also a risk management tool that may be used to support the selection of appropriate remedial measures. The RBCA methodology evaluates sites according to a tiered approach of increased site-specificity and released conservatism. Tier 1 is applied to initially classify the site, and screen for chemicals and areas of concern using non-site-specific risk-based screening levels (RBSLs). Site-specific risk-based target levels (SSTLs) are then developed using Tier 2. The SSTLs represent a conservative starting point for development of cleanup goals, which are the result of risk management decisions based on protection of human health and environment, and other remedial action criteria such as feasibility, cost effectiveness, public acceptability, etc. A brief description of the ASTM RBCA Tier 1 and Tier 2 processes is provided below.

### *RBCA Tier 1*

The scope of the RBCA Tier 1 process is to classify the site in terms of urgency of need for initial corrective action, based on (1) historical information, (2) visual inspection, and (3) available site assessment data.

Specifically, Tier 1 consists of the following:

- Identification of site-related contaminant sources, obvious environmental impacts, potential transport pathways, and potentially impacted receptors.
- Comparison of site-related contaminant concentrations with conservative corrective action goals based on a list of non-site-specific risk-based screening levels (RBSLs) and other appropriate standards.

The sequence of tasks and decisions associated with the RBCA Tier 1 process are outlined below:

Step 1: Initial Site Assessment, involving source characterization, potential for exposure and degradation of beneficial uses, extent of migration, and summary of results.

Step 2: Site Classification and Initial Response Action, based on the scenarios and actions recommended in Table 1 of the RBCA guidance (ASTM 1995).

Step 3: Comparison of Site Conditions with Tier 1 RBSLs and Tier 1 Corrective Action Selection, involving exposure pathway characterization, exposure scenario characterization, selection of acceptable risk range, comparison of chemical concentrations with RBSLs, corrective action assessment, and evaluation of Tier 1 results.

Tier 1 RBSLs are based on default exposure factors and generic site characteristics. Since the exposure and site parameters are not site-specific, the RBSLs incorporate a great amount of conservatism, and therefore they are quite stringent. According to the RBCA guidance, if chemical concentrations detected in soil and groundwater at the site exceed the Tier 1 RBSLs, after the initial RBCA Tier 1 assessment, the site should be evaluated and classified according to Tier 2.

### *RBCA Tier 2*

In Tier 2, site-specific risk-based target levels (SSTLs) for the chemicals and exposure scenarios of concern are developed based on site-specific input parameters. Comparison of site chemical concentrations in soil and groundwater with the SSTLs allows risk managers to evaluate whether the site may be closed without need of further action or, if appropriate, identify specific areas where additional consideration in terms of investigation/remediation is required.

## 1.3 ASSUMPTIONS OF THIS STUDY

This risk-based evaluation of soil and shallow groundwater was performed according to the methods described in the ASTM guidance E 1739-95 "Emergency Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites" (ASTM 1995). The RBCA methodology evaluates sites according to a tiered approach of increased site-specificity and released conservatism. Tier 1 is applied to initially classify the site, and screen for compounds and areas of concern using non-site-specific risk-based screening levels (RBSLs). Site-specific risk-based target levels (SSTLs) are then developed using Tier 2. The SSTLs represent a conservative starting point for development of cleanup goals, which are the result of risk management decisions based on protection of human health and environment, and other remedial action criteria such as feasibility, cost effectiveness, public acceptability, etc., as explained in detail in Section 3.3.

The RBCA Tier 1 and Tier 2 evaluation was applied using the following overall approach and assumptions (approved by ACDEH) for the site:

### *Overall Approach*

For each of the areas of concern, the maximum detected media concentration was compared with the appropriate Tier 1 RBSL concentration. If the maximum detections do not exceed RBSL in a given area, the area is considered not of concern. If RBSLs are exceeded, a new set of SSTLs is generated according to Tier 2, as appropriate. Soil and groundwater that exceed Tier 2 SSTLs are recommended for further consideration in terms of additional investigation and/or remedial action.

### *Source Characterization*

Chemicals of concern for the risk-based assessment include the following:

- Gasoline and diesel indicator compounds: benzene, toluene, ethylbenzene, xylenes (BTEX), benzo(a)pyrene, and naphthalene.
- MTBE and lead.

In case benzo(a)pyrene and naphthalene data were not available for soil and groundwater in a specific area, concentration for these compounds was based on available total petroleum hydrocarbon (TPH) as diesel data assuming the following: naphthalene concentration is 0.13 percent of TPH diesel concentration (Calabrese et al., 1993), and benzo(a)pyrene concentration is 0.07 milligrams (mg) for every kilogram (kg) of TPH diesel detected (Guerin et al., 1984).

Due to the historical nature of the hydrocarbon source(s), MTBE is not expected to be a significant concern at the site. However, we developed SSTLs for MTBE to provide reference criteria for future monitoring activities.

For lead in soil we used the USEPA Region 9 Industrial PRG of 1,000 mg/kg as screening level. If necessary, a lead SSTL can be developed using the Cal-EPA DTSC Leadspread model. Due to the very low detected concentration with respect to screening level, lead was not considered further in this assessment.

### *Exposure Scenarios and Assumptions*

1) The site conceptual model illustrated in Figures 3 and 4 provides a schematic illustration of plausible chemical migration pathways and potential exposure scenarios relevant for the site.
2) Soil and shallow groundwater SSTLs were developed for an indoor commercial exposure scenario, since the present and future land use for the site is to continue to be a fire station. It was conservatively assumed that the station's employees may be spending up to forty hours per week at the site, 50 weeks per year, for 25 years.

3) The exposure pathway of concern for commercial receptors is inhalation of vapor emissions from soil and from shallow groundwater. It is assumed that the site will remain covered with the existing asphalt or concrete pavement or buildings.
4) We also evaluated a construction worker scenario, to verify that the above described SSTLs are also protective of construction workers.
5) The exposure pathway of concern for construction receptors is the "surficial soil" pathway, as defined by ASTM RBCA, including inhalation of vapor and particulate emissions from soil and direct contact with soil.
6) Exposure point concentrations for the exposure estimations were based on detected concentrations averaged over the respective area of emission and depth of emission. Where appropriate, particular "hot spots" were addressed individually.
7) Shallow groundwater at the site is not considered a viable source of drinking water, since the water supply wells in the area are screened in hydraulically separated units, and are located at considerable distance from the site.
8) Soil and groundwater SSTLs were calculated for a cancer risk level of $1 \times 10^{-5}$ and a chronic hazard quotient of 1.

## 2.1 SCOPE OF RBCA TIER 1

The scope of the RBCA Tier 1 process is to classify the site in terms of urgency of need of initial corrective action, based on (1) historical information, (2) visual inspection, and (3) minimal site assessment data.

Specifically, Tier 1 consists of the following:

- Identification of site-related contaminant sources, environmental impacts, potential transport pathways, and potentially impacted receptors.
- Comparison of site-related contaminant concentrations with conservative corrective action goals based on a list of non-site-specific risk-based screening levels (RBSLs) and other appropriate standards.

Information about the environmental setting at the site and a description of the implementation of the above tasks associated with the RBCA Tier 1 process is described below.

## 2.2 DESCRIPTION OF SITE ENVIRONMENTAL CONDITIONS

The City of Emeryville Fire Station No. 2 is located at 6303 Hollis Street, in Emeryville, at the northwest corner of Hollis and 63rd Streets, as shown in Figure 1. The facility is located in a generally mixed commercial and residential land use area. However, structures immediately near the facility are all commercial buildings. The site is located about one-half mile east of San Francisco Bay, and its approximate elevation is 15 feet above mean sea level. The site is underlain by Holocene alluvial deposits, primarily unconsolidated, fine sand, silt, and clayey silt with occasional thin beds of coarse sand. A brief overview of past investigation and remediation activities is provided below.

### *Initial Investigations - March and July 1995*

WCC performed a preliminary investigation of the tank site area in March 1995 and presented the results in a report dated June 20, 1995 (WCC 1995a). The detections of TPH gasoline and BTEX in soil appear to occur mostly in the soil samples from approximately 5 feet in depth. Borings SB-1 through SB-5 were drilled at the site during the March 1995 investigation (see Figure 2).

The highest reported detection of gasoline in soil was 540 mg/kg in a soil sample from a depth of 5 feet in SB-1. The highest reported detection of benzene in soil was 0.63 mg/Kg in a soil sample from a depth of 6 feet in SB-2. TPH diesel was not detected in soil from these borings. The March 1995 investigation included grab groundwater samples collected from SB-1 and SB-3. Only 0.99 mg/L TPH gasoline was reported in groundwater from SB-1. Benzene was detected at 0.22 mg/L in water from SB-3, and 0.0061 mg/L in water from SB-1.

A further round of site investigation was conducted by WCC in July 1995 (WCC 1995b) to better characterize the site and to prepare for tank removal. Borings SB-6 through SB-12 were selected to explore for evidence of petroleum in soil or groundwater at distances farther from the USTs. The July 1995 samples were not analyzed for diesel, because diesel was not detected in the March 1995 investigation. Like in March, the detections of TPH gasoline and BTEX in soil appear to occur mostly in the soil samples from approximately 5 feet in depth. The highest reported concentration of TPH gasoline in soil was 480 mg/Kg at 5.5 feet in SB-7. The highest reported concentration of benzene in soil was 1.2 mg/Kg at 5.5 feet in SB-6.

The July 1995 investigation included grab groundwater samples collected from SB-6 through SB-12. The highest reported detection of TPH gasoline was 5.5 mg/L in groundwater from SB-7. The highest reported detection of benzene was 0.04 mg/L in groundwater from SB-12. Tables of results and figures from these prior reports are included in Appendix A.

### *Underground Tank Removal - October 1995*

The two USTs and associated piping were removed in October 1995 (WCC 1996). The depth of both tank excavations was approximately 7.5 feet. Groundwater was encountered at an approximate depth of 7 feet. Soil samples from the floor of each end of both UST excavations were collected after the tanks were removed. Although groundwater was encountered in the excavations, groundwater samples were not collected from the excavations because, in accordance with the workplan for this phase of work, groundwater samples had been collected in the previous site investigations.

TPH gasoline was detected at 380 mg/Kg, and benzene was detected at 0.34 mg/Kg from the east end of the gasoline UST excavation. TPH gasoline was detected up to 560 mg/Kg in stockpile sample Stock-Gas-2, and benzene was detected in sample Stock-Gas-2 at 0.58 mg/Kg. These samples were also analyzed for MTBE, with one detection of MTBE at 0.28 mg/Kg in the west end of the gasoline UST excavation. TPH diesel was not detected in the diesel UST excavation samples or the stockpile sample. The diesel UST samples were not analyzed for parameters other than TPH diesel. The soils from the two excavations were placed in two separate stockpiles. After sampling the stockpiles, the gasoline UST excavation was backfilled with soils from both tank excavations. The diesel UST excavation was backfilled with imported soil. Both excavation areas were paved with asphalt and concrete to match the surrounding grade.

### *Additional Site Investigation - 1996-97*

At the request of ACDEH, one groundwater monitoring well and four additional borings were installed in March 1997. The groundwater monitoring well was installed approximately 15 feet from the former gasoline UST location in the downgradient direction, located near SB-8. Borings SB-13 through SB-15 were drilled further downgradient of the former USTs. SB-16 was located upgradient approximately 30 feet south of SB-12. Total lead in soil varied from 3.5 to 8.2 mg/kg. TPH gasoline and benzene concentrations were below laboratory detection limits in both soil and groundwater samples collected from SB-13 through SB-15. These results indicate that the gasoline contamination is limited to the immediate area surrounding the former gasoline UST. However, the grab groundwater sample from the upgradient boring SB-16 had TPH gasoline of 29 mg/l and benzene of 430 ug/l, both were the highest concentrations detected in groundwater samples from all borings. This indicates that potential upgradient source(s) may exist and affect this site.

## 2.3 CONCEPTUAL SITE MODEL

Figures 3 and 4 are provided as a visual aid to understand the site conceptual model. Figure 3 graphically illustrates relevant potential chemical exposure scenarios for the site. The site conceptual model is presented in flowchart format in Figure 4, which provides a schematic description of chemical migration pathways and potential exposure pathways and scenarios for the site.

The site conceptual model shows that the potential sources of chemicals at the site are represented by past spills or leaks from USTs into soil. Subsequently, chemicals may be released from soil into air as a result of emissions of soil vapors and/or particulates (in case the soil is uncovered, for instance, during excavation of trenches for utility work). Chemicals may be released from soil into shallow groundwater due to leaching and vertical infiltration. Further downward and lateral migration may potentially affect deeper groundwater.

Exposure to chemicals in air may occur through the inhalation route. Exposure to chemicals in soil may occur through the incidental ingestion and dermal contact routes. Exposure to chemicals in water may occur through the ingestion and dermal contact routes. Impact of chemicals on water quality may occur through leaching and migration to a water-bearing zone and groundwater withdrawal (e.g., if the water is pumped for domestic or municipal water supply).

Exposure receptors of potential concern at the site are (see Figure 3 and 4):

- Off-site residents living in the area.
- On-site commercial workers (e.g., employees at the station, fire fighters).
- Construction workers(e.g., during utility trenches excavation).

The importance of each of the exposure routes associated with the above receptors is represented in Figure 4 by a black dot for potentially significant (complete) pathways, and by a white dot for minor or insignificant pathways (which are evaluated in a qualitative way only). Quantitative target levels for the site (the SSTLs) were developed only for exposure scenarios involving pathways evaluated to be potentially significant (black dots).

Potential for exposure to volatile emissions is higher for onsite workers than for offsite residents. Therefore the target levels developed for onsite exposure to vapors are also protective of offsite receptors, which are assigned a white dot in Figure 4.

As long as the existing asphalt/concrete pavement is left undisturbed, the potential for impact on human health through direct contact is evaluated to be insignificant. Therefore direct contact exposure to chemicals in soil is evaluated to be potentially significant only for construction workers.

Shallow groundwater beneath the site may be affected by chemicals leaching from the soil. However, drinking water is supplied by municipal water system, and no water supply wells are located nearby or screened in the shallow zones. Therefore the water ingestion pathway is considered incomplete.

Exposure to ecological receptors is evaluated to be insignificant due to the residential and commercial land use of the site area. In addition, the pavement prevents potential exposure to biota.

In conclusion, based on the above evaluations, we developed soil target levels for the protection of receptors potentially exposed under the following exposure scenarios:

- Commercial workers potentially exposed to chemicals in air via inhalation of volatile emissions from shallow groundwater and soil.
- Construction workers potentially exposed to chemicals in air and soil via inhalation of volatile and particulate emissions and direct contact with soil.

Target excess cancer risk for this assessment was selected as $1 \times 10^{-5}$ (1 in 100,000) for both exposure scenarios. This means that soil and groundwater screening and target levels are calculated for a cancer risk level of $1 \times 10^{-5}$ and a chronic hazard quotient of 1 for both current and potential future on-site commercial receptors. This cancer risk level is within the target range of $1 \times 10^{-6}$ to $1 \times 10^{-4}$, described as acceptable by the U.S. EPA in the National Contingency Plan (NCP, 40 CFR Part 300).

## 2.4 TIER 1 SCREENING

Tables 1 and 2 provide the maximum reported residual soil and shallow groundwater chemical concentrations for each of the investigation phases described in the previous section. Appendix B provides a compilation of site investigation results. Tables 3 and 4 present the comparison of maximum detected on-site soil and shallow groundwater concentration with ASTM RBCA non-site-specific RBSLs and other relevant screening level criteria. Lead was not included in the tables as a chemical of concern, since it was detected at concentrations well below the screening criterion.

Tier 1 RBSLs reported in Table 3 are the screening level soil concentrations for volatilization to indoor air for commercial scenario and for the surficial soil pathway (which is indicative of exposure due to intrusive activities such as construction). Tier 1 RBSLs reported in Table 4 are the screening level water concentrations for indoor vapor emissions from groundwater for commercial receptors.

The RBSLs for the BTEX and PNA compounds are taken from page 22 of the ASTM RBCA guidance. The selected target risk level for the Tier 1 comparisons is $1 \times 10^{-6}$ for both receptors.

The results of the ASTM RBCA Tier 1 on-site screening assessment are summarized as follows:

- The Tier 1 comparisons indicate exceedance of RBSLs for benzene.
- MTBE does not have a Tier 1 RBSL.
- According to ASTM RBCA guidance, because of the exceedances of screening criteria (or absence of criteria, for MTBE), the site will be evaluated in Tier 2 (see Section 3.0).

## 2.5 INITIAL SITE CLASSIFICATION ACCORDING TO RBCA TIER 1

Based on the results of the Tier 1 evaluation and on the site classification scenarios presented in Table 1 of the RBCA guidance (ASTM 1995), we conclude that the site should be initially classified under either Level 3: Long-Term Threat to Human Health, Safety, or Sensitive Environmental Receptors or Level 4: No Demonstrable Long-Term Threat to Human Health, Safety, or Sensitive Environmental Receptors. The final site classification depends on the results of the Tier 2 evaluation, which will indicate if chemicals present in soil and groundwater present a significant risk by developing site-specific target levels (SSTLs). The Tier 2 evaluation is presented in Section 3.0 of this report.

## 3.1 DEVELOPMENT OF TIER 2 SITE-SPECIFIC TARGET LEVELS (SSTLS)

According to the RBCA process, in the cases where chemical concentrations detected in soil and groundwater at the site exceed the Tier 1 look-up table RBSL concentrations, after the initial RBCA Tier 1 screening, the site should be evaluated according to RBCA Tier 2. In Tier 2, a new set of risk-based SSTLs for the chemicals and exposure pathways of concern is developed based on site-specific input parameters. Comparison of site chemical concentrations in soil and groundwater with the SSTLs is used to evaluate whether the site may be closed without need of further remediation or, if appropriate, to identify specific areas where remediation is recommended. This section describes the development of SSTLs and presents the site-specific inputs used to calculate the SSTLs. Note that if ASTM default exposure parameters are used in the ASTM RBCA equations, the SSTLs are numerically equivalent to the RBSLs. Recommendations on how to use the SSTLs for remedial decisions and the final site classification according to ASTM RBCA conclude this section.

### *Inputs for Development of Commercial SSTLs for Soil*

SSTLs for soil for the commercial indoor exposure scenario were developed based on the ASTM RBCA default input parameters and equations for exposure to soil emissions. The following parameters affecting exposure to site chemicals were modified from the ASTM Tier 1 defaults to reflect relevant site-specific conditions based on field measurements and/or on professional judgment as follows:

- Exposure duration = 25 years as adults
- Exposure time and frequency = 40 hours per week, 50 weeks per year
- Emission reduction factor = 0.02 (50-fold) based on an areal fraction of cracks in concrete pavement = 5 $cm^2/m^2$

The areal fraction of cracks in the concrete pavement was set at 5 $cm^2/m^2$ to represent a good condition pavement slab. The model estimating indoor exposure to vapors relies on an estimate of "emission reduction factor", representative of the vapor barrier effect provided by (as an example) a standard ventilated crawl-space or a concrete slab-on-grade. In ASTM RBCA, the reduction factor relates to the thickness of pavement and the areal fraction of cracks. A 10-fold to 100-fold emission reduction factor is usually adopted when a concrete pavement is present (Landman 1982). In our case (6 inches thickness, 0.05% cracks) the reduction factor we adopted amounts to about a 50-fold decrease. The remainder of the inputs used to calculate the SSTLs were ASTM RBCA default values. In particular, the ASTM RBCA Tier 1 indoor air exchange rate was assumed to conservatively represent natural ventilation (0.83 exchanges per hour). A summary of the inputs used in calculating the SSTLs is tabulated in Appendix C. SSTLs were calculated using the equations provided in Tables X2.2 through X2.7 of the ASTM RBCA guidance. The calculations spreadsheets are shown in Appendix C. Appendix D provides example calculations of SSTLs. Appendix E presents the ASTM RBCA equations.

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## 3.1 DEVELOPMENT OF TIER 2 SITE-SPECIFIC TARGET LEVELS (SSTLS)

According to the RBCA process, in the cases where chemical concentrations detected in soil and groundwater at the site exceed the Tier 1 look-up table RBSL concentrations, after the initial RBCA Tier 1 screening, the site should be evaluated according to RBCA Tier 2. In Tier 2, a new set of risk-based SSTLs for the chemicals and exposure pathways of concern is developed based on site-specific input parameters. Comparison of site chemical concentrations in soil and groundwater with the SSTLs is used to evaluate whether the site may be closed without need of further remediation or, if appropriate, to identify specific areas where remediation is recommended. This section describes the development of SSTLs and presents the site-specific inputs used to calculate the SSTLs. Note that if ASTM default exposure parameters are used in the ASTM RBCA equations, the SSTLs are numerically equivalent to the RBSLs. Recommendations on how to use the SSTLs for remedial decisions and the final site classification according to ASTM RBCA conclude this section.

### *Inputs for Development of Commercial SSTLs for Soil*

SSTLs for soil for the commercial indoor exposure scenario were developed based on the ASTM RBCA default input parameters and equations for exposure to soil emissions. The following parameters affecting exposure to site chemicals were modified from the ASTM Tier 1 defaults to reflect relevant site-specific conditions based on field measurements and/or on professional judgment as follows:

- Exposure duration = 25 years as adults
- Exposure time and frequency = 40 hours per week, 50 weeks per year
- Emission reduction factor = 0.02 (50-fold) based on an areal fraction of cracks in concrete pavement = 5 $cm^2/m^2$

The areal fraction of cracks in the concrete pavement was set at 5 $cm^2/m^2$ to represent a good condition pavement slab. The model estimating indoor exposure to vapors relies on an estimate of "emission reduction factor", representative of the vapor barrier effect provided by (as an example) a standard ventilated crawl-space or a concrete slab-on-grade. In ASTM RBCA, the reduction factor relates to the thickness of pavement and the areal fraction of cracks. A 10-fold to 100-fold emission reduction factor is usually adopted when a concrete pavement is present (Landman 1982). In our case (6 inches thickness, 0.5% cracks) the reduction factor we adopted amounts to about a 50-fold decrease. The remainder of the inputs used to calculate the SSTLs were ASTM RBCA default values. In particular, the ASTM RBCA Tier 1 indoor air exchange rate was assumed to conservatively represent natural ventilation (0.83 exchanges per hour). A summary of the inputs used in calculating the SSTLs is tabulated in Appendix C. SSTLs were calculated using the equations provided in Tables X2.2 through X2.7 of the ASTM RBCA guidance. The calculations spreadsheets are shown in Appendix C. Appendix D provides example calculations of SSTLs. Appendix E presents the ASTM RBCA equations.

### Inputs for Development of Construction SSTLs

SSTLs for soil for the construction worker exposure scenario were developed based on the ASTM RBCA default input parameters and equations for the surficial soil pathway. The following parameters affecting exposure to site chemicals were modified from the ASTM Tier 1 defaults to reflect relevant site-specific conditions based on field measurements and/or on professional judgment as follows:

- Exposure duration = 0.5 years
- Exposure time and frequency = 8 hours per day, 5 days per week
- Particulate emission rate = 1.5E-9 g/cm$^2$-sec

The particulate emission rate of 1.5E-9 g/cm$^2$-sec was chosen to correspond to a PM10 concentration of 50 µg/m$^3$, the maximum allowed by the Clean Air Act, representing a worst case scenario of bare soil erosion. The remainder of the inputs used to calculate SSTLs are default values from the ASTM RBCA guidance. A summary of the inputs used in calculating the SSTLs is tabulated in Appendix C. SSTLs were calculated using the equations provided in Tables X2.2 through X2.7 of the ASTM RBCA guidance. The calculations spreadsheets are shown in Appendix C.

### Inputs for Development of Commercial SSTLs for Shallow Groundwater

SSTLs for shallow groundwater for the commercial worker exposure scenario were developed based on the ASTM RBCA default input parameters and equations for exposure to groundwater emissions. The following parameters affecting exposure to site chemicals were modified from the ASTM Tier 1 defaults to reflect relevant site-specific conditions based on field measurements and/or on professional judgment as follows:

- Emission reduction factor = 0.02 (50-fold) based on an areal fraction of cracks in concrete pavement = 5 cm$^2$/m$^2$

The areal fraction of cracks in the concrete pavement was set at 5 cm$^2$/m$^2$ to represent a good condition pavement slab. The rationale for the selection of this parameter is the same as described above for the SSTLs for soil indoor commercial scenario. The remainder of the inputs used to calculate the SSTLs were ASTM RBCA default values. A summary of the inputs used in calculating the SSTLs is tabulated in Appendix C. SSTLs were calculated using the equations provided in Tables X2.2 through X2.7 of the ASTM RBCA guidance. The calculations spreadsheets are shown in Appendix C.

### Summary of ASTM RBCA Tier 2 SSTLs

Based on the above assumptions, SSTLs protective of human health for BTEX, PNAs, and MTBE were calculated for commercial exposure to indoor vapors emitted from soil, exposure to vapors emitted from shallow groundwater, and construction workers exposed to surficial soil, according to ASTM RBCA Tier 2. The SSTLs are presented below (see also Table 5):

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Phone Numbers: (510) 874-3060 (510)

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| Chemical | Receptor: / Medium: | Comm. Indoor Soil SSTLs | Comm. Indoor Shallow GW SSTLs |
|---|---|---|---|
| Benzene | | 1.7 mg/kg | 2.3 mg/L |
| Ethylbenzene | | 350* mg/kg | 150* mg/L |
| Toluene | | 781* mg/kg | 540* mg/L |
| Xylene | | 498* mg/kg | 200* mg/L |
| Benzo(a)pyrene | | 4.7* mg/kg | 0.0012* mg/L |
| Naphthalene | | 400* mg/kg | 31* mg/L |
| MTBE | | 9,900* mg/kg | 51,000* mg/L |

** Target risk level is not exceeded above the soil saturation or water solubility concentration shown, hence the SSTL is set at saturation or solubility.*

The benzene SSTL for construction workers scenario is 1,300 mg/kg (see Appendix C). The construction worker SSTL are not shown above since the commercial SSTLs are protective of the construction scenario (see detailed results in the last page of Appendix C). For instance, the construction worker SSTL for benzene is 1,300 mg/kg, compared to 1.7 mg/kg for commercial indoor exposure.

### RBCA Tier 2 Comparison

The table below provides a RBCA Tier 2 comparison of maximum detected soil and shallow groundwater concentration of benzene and MTBE (soil only) with the SSTLs. The Tier 2 comparison involves only benzene and MTBE because they are the only chemicals that failed the Tier 1 screening.

Chemical: Benzene

| *Exp. Medium* | *Receptor* | *SSTL* | *Max. Detected* |
|---|---|---|---|
| *Onsite Soil* | *Comm. Indoor* | 1.7 mg/kg | 1.2 mg/kg |
| *Onsite Shallow GW* | *Comm. Indoor* | 2.3 mg/L | 0.43 mg/L |

Chemical: MTBE

| *Exp. Medium* | *Receptor* | *SSTL* | *Max. Detected* |
|---|---|---|---|
| *Onsite Soil* | *Comm. Indoor* | 9,900* mg/kg | 0.28 mg/kg |

| Chemical | Receptor: / Medium: | *Comm. Indoor Soil SSTLs* | *Comm. Indoor Shallow GW SSTLs* |
|---|---|---|---|
| Benzene | | 1.7 mg/kg | 2.3 mg/L |
| Ethylbenzene | | 350* mg/kg | 150* mg/L |
| Toluene | | 781* mg/kg | 540* mg/L |
| Xylene | | 498* mg/kg | 200* mg/L |
| Benzo(a)pyrene | | 4.7* mg/kg | 0.0012* mg/L |
| Naphthalene | | 400* mg/kg | 31* mg/L |
| MTBE | | 9,900* mg/kg | 51,000* mg/L |

** Target risk level is not exceeded above the soil saturation or water solubility concentration shown, hence the SSTL is set at saturation or solubility.*

The benzene SSTL for construction workers scenario is 1,300 mg/kg (see Appendix C). The construction worker SSTL are not shown above since the commercial SSTLs are protective of the construction scenario (see detailed results in the last page of Appendix C). For instance, the construction worker SSTL for benzene is 1,300 mg/kg, compared to 1.7 mg/kg for commercial indoor exposure.

### *RBCA Tier 2 Comparison*

The table below provides a RBCA Tier 2 comparison of maximum detected soil and shallow groundwater concentration of benzene and MTBE (soil only) with the SSTLs. The Tier 2 comparison involves only benzene and MTBE because they are the only chemicals that failed the Tier 1 screening.

Chemical: Benzene

| *Exp. Medium* | *Receptor* | *SSTL* | *Max. Detected* |
|---|---|---|---|
| *Onsite Soil* | *Comm. Indoor* | 1.7 mg/kg | 0.63 mg/kg |
| *Onsite Shallow GW* | *Comm. Indoor* | 2.3 mg/L | 0.43 mg/L |

Chemical: MTBE

| *Exp. Medium* | *Receptor* | *SSTL* | *Max. Detected* |
|---|---|---|---|
| *Onsite Soil* | *Comm. Indoor* | 9,900* mg/kg | 0.28 mg/kg |

** Target risk level is not exceeded above the soil saturation or water solubility concentration shown, hence the SSTL is set at saturation or solubility.*

The above comparison indicates that maximum detections of benzene and MTBE do not exceed the Tier 2 SSTL. Therefore, on-site soil and shallow groundwater do not warrant further consideration related to protection of human health. We recommend the implementation of a groundwater monitoring program to gather evidence of plume stability and chemical degradation.

## 3.2 FINAL SITE CLASSIFICATION

Based on the results of the ASTM RBCA Tier 1 and 2 evaluation, and on the site classification scenarios presented in Table 1 of the RBCA guidance (ASTM 1995), we conclude that, once the recommended groundwater monitoring program shows evidence of plume stability and chemical degradation, the site should be classified under Level 4: No Demonstrable Long-Term Threat to Human Health, Safety, or Sensitive Environmental Receptors. This final site classification is based on the results of Tier 1 and Tier 2 evaluation, which indicate that petroleum constituents and other chemicals detected in soil at the site do not present a significant potential risk to residents and construction workers. In addition, the Tier 2 indicates the concentration in shallow groundwater which is protective of residents, construction workers, and commercial workers. Uncertainties and limitations of this study are addressed in Section 5.0. Recommendations about the use of SSTLs in remedial decision are provided below.

## 3.3 USE OF SSTLS IN REMEDIAL DECISIONS

The SSTLs developed in RBCA Tier 2 for the site are site-specific concentrations in soil and shallow groundwater that are estimated to be protective of human health and the environment based on the application of exposure and risk assessment models. The SSTLs are based on conservative exposure assumptions and input parameters (e.g., for the commercial scenario: 25 years, 250 days/year, 8 hours/day continuous exposure to an infinite mass, non-degrading chemical source, etc.). The SSTLs are not necessarily the final cleanup goals selected for the site. In general, if the SSTLs are exceeded, the site conditions may warrant further consideration in terms of additional investigation, monitoring, fate and transport modeling, or remedial action. On the other hand, if the SSTLs are not exceeded, then the site does not require further consideration.

Cleanup goals should consider potential effects on human health and the environment as well as criteria described by the National Contingency Plan (NCP). The SSTLs produced by a risk-based evaluation represent only one of the variables in the remedial action equation leading towards cleanup goals. The SSTLs are a conservative reference point for site cleanup, but the final cleanup goals should be the outcome of risk management decisions, which include risk assessment considerations as well as the other remedial action criteria listed in the NCP (i.e., implementability, cost effectiveness, time frame of remediation, public acceptability, etc.). In conclusion, the ASTM RBCA Tier 2 SSTLs that have been developed for the site represent a conservative starting point for remedial decision making, and may be selected by the risk managers as cleanup goals.

The conclusions of this study are the following:

- Since maximum detections of benzene and the other chemicals of concern do not exceed the Tier 2 SSTL, on-site soil and shallow groundwater do not warrant further consideration related to protection of human health.

The recommendations of this study are the following:

- We recommend no further action for soil.
- For groundwater, a monitoring program should be implemented to evaluate current groundwater conditions, and gather evidence of plume stability and chemical degradation.
- If evidence of plume stability and chemical degradation is found, and groundwater concentration of benzene is still below SSTL, no further action for groundwater should be required.

The quantitative methods and procedures described in this document for evaluating potential exposure and risk are based on a number of simplifying assumptions related to the characterization of the contaminant sources and of the subsurface environment. The exposure models are based on descriptions of relevant physical/chemical phenomena. Any mechanisms that are neglected, such as neglecting attenuation due to natural biodegradation, result in predictions of exposure and risk that are conservative relative to those likely to occur. In other words, the models are biased towards predicting exposure concentrations in excess of those likely to occur (page 12, ASTM 1994). Uncertainty and variability affect the input parameters of all of the exposure and fate and transport models. Conservative values of those input parameters are selected to deal with this uncertainty and variability. Since the exposure models are multiplicative, conservatism is compounded in the calculations. For this reason, the modeling results in this study are expected to overestimate exposure and risk, rather than underestimate the actual risk posed by the site.

The degree of conservatism in this assessment is illustrated by the following: the screening levels for commercial workers proposed in this study are estimated by the models to be protective of a receptor assumed to work at the site for 25 years, 250 days per year, 8 hours per day, and to inhale volatile emissions from soil and groundwater generated by a continuous (i.e., non-degrading, infinite mass) source for the entire exposure duration. The models estimate that if the average source concentrations do not exceed the cleanup goals, such a receptor would be subject to an excess cancer risk of less than 1 in 100,000 as a consequence of exposure to chemicals in soil and groundwater.

Conservatism is an important feature of predictive modeling in the RBCA process. Tier 1 is the most conservative level and provides a "worst-case scenario" for potential exposure and risk. Tier 1 utilizes conservative models and input parameters (that is, USEPA reasonable maximum exposure (RME) values, and conservative inputs for the contaminant fate and transport models) to establish non-site specific risk-based screening criteria (the RBSLs). Tier 2 is still conservative, but provides flexibility for a site-specific RME scenario evaluation, or a "reasonable case scenario" (that is, USEPA most likely exposure (MLE) values), depending on whether the inputs reflect more of a site-specific RME or MLE exposure scenario. Tier 2 uses site-specific information about the release site and the exposure scenario to develop conservative, site-specific corrective action objectives (the SSTLs) that are protective of human health (ASTM 1995). Tier 2 models still represent a conservative approach, by neglecting, for instance, natural attenuation due to benign biodegradation and source decay due to volatilization and flushing. In fact, Tier 2 models assume no chemical degradation and source of chemicals of constant concentration and infinite mass. More detailed discussion of the exposure models assumptions and limitations is provided in ASTM (1995). In the application of ASTM RBCA to the site that is presented here, conservative but reasonable site-specific estimates of the input parameters have been selected. Rationales and references for input parameters estimated values used in the models are reported in the text and tables.

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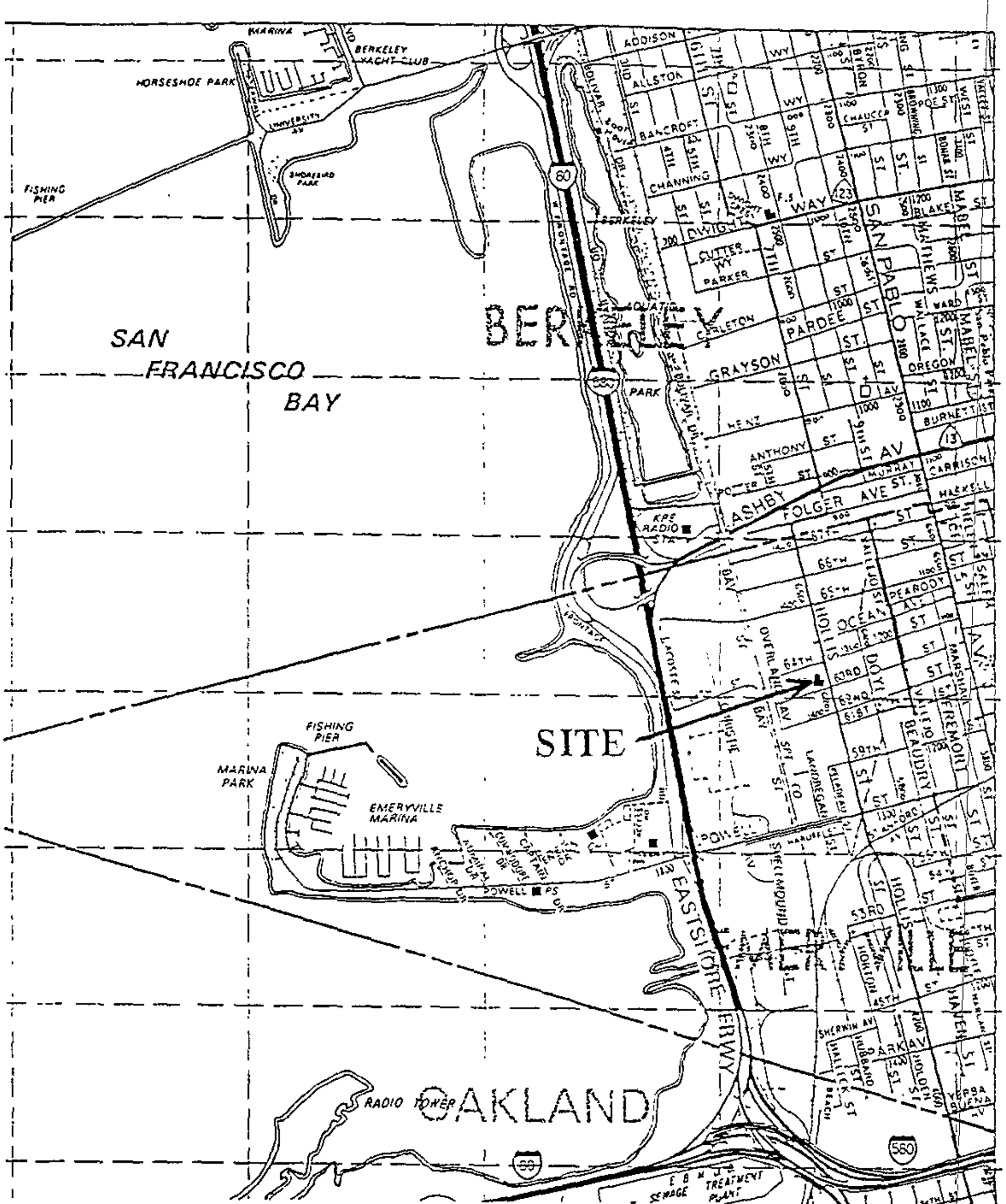
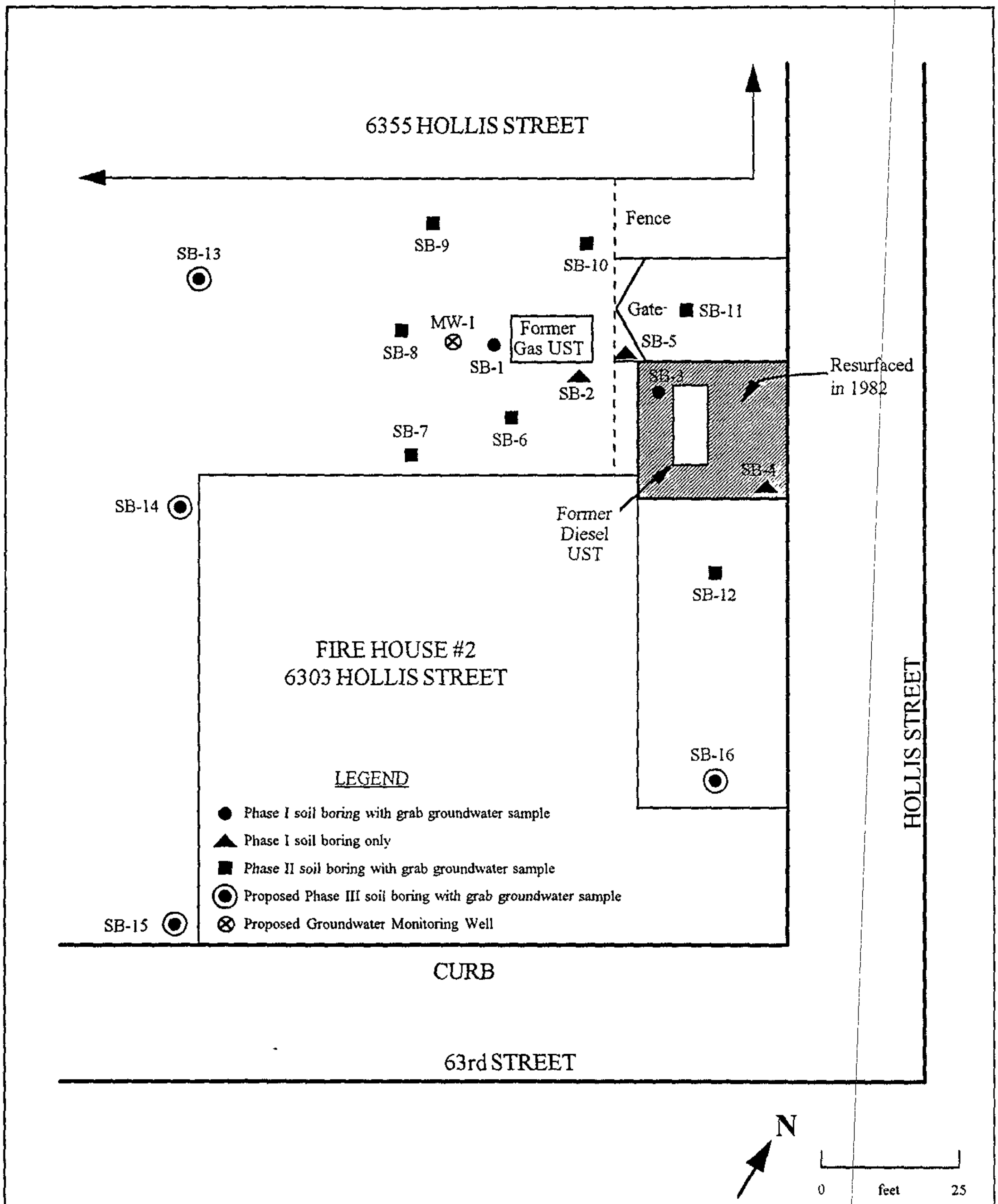



N

1" = 0.5 mile

from Thomas Map 1991

| CITY OF EMERYVILLE<br>Fire Station No. 2 | SITE LOCATION MAP | Figure<br>1 |
|---|---|---|
| Woodward-Clyde Consultants | | |




| Project No. 941366NA | City of Emeryville Fire Station No. 2 | PHASE III PROPOSED SAMPLE AND MONITORING WELL LOCATIONS | Figure 2 |
|---|---|---|---|
| **Woodward-Clyde Consultants** | | | |

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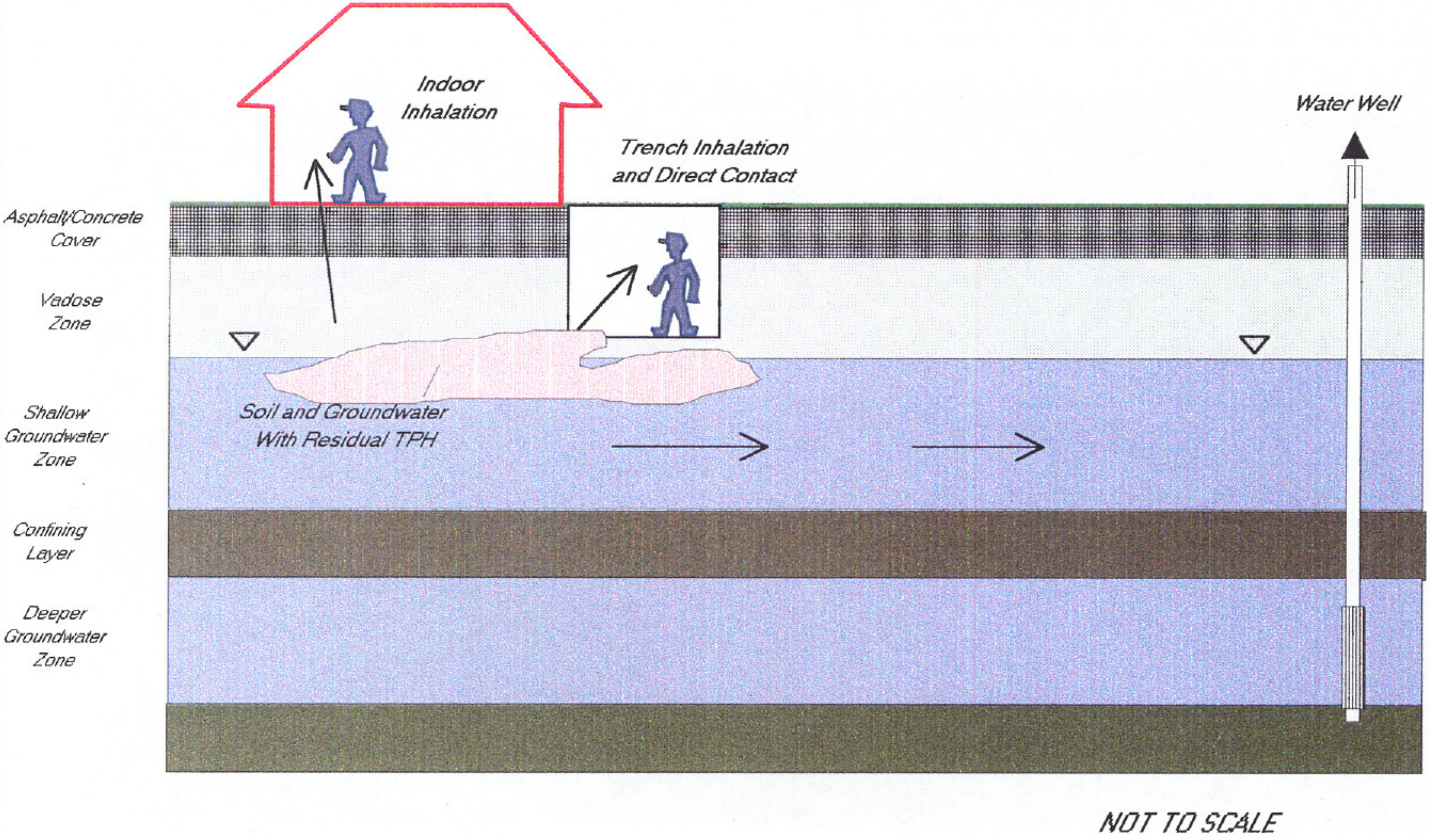
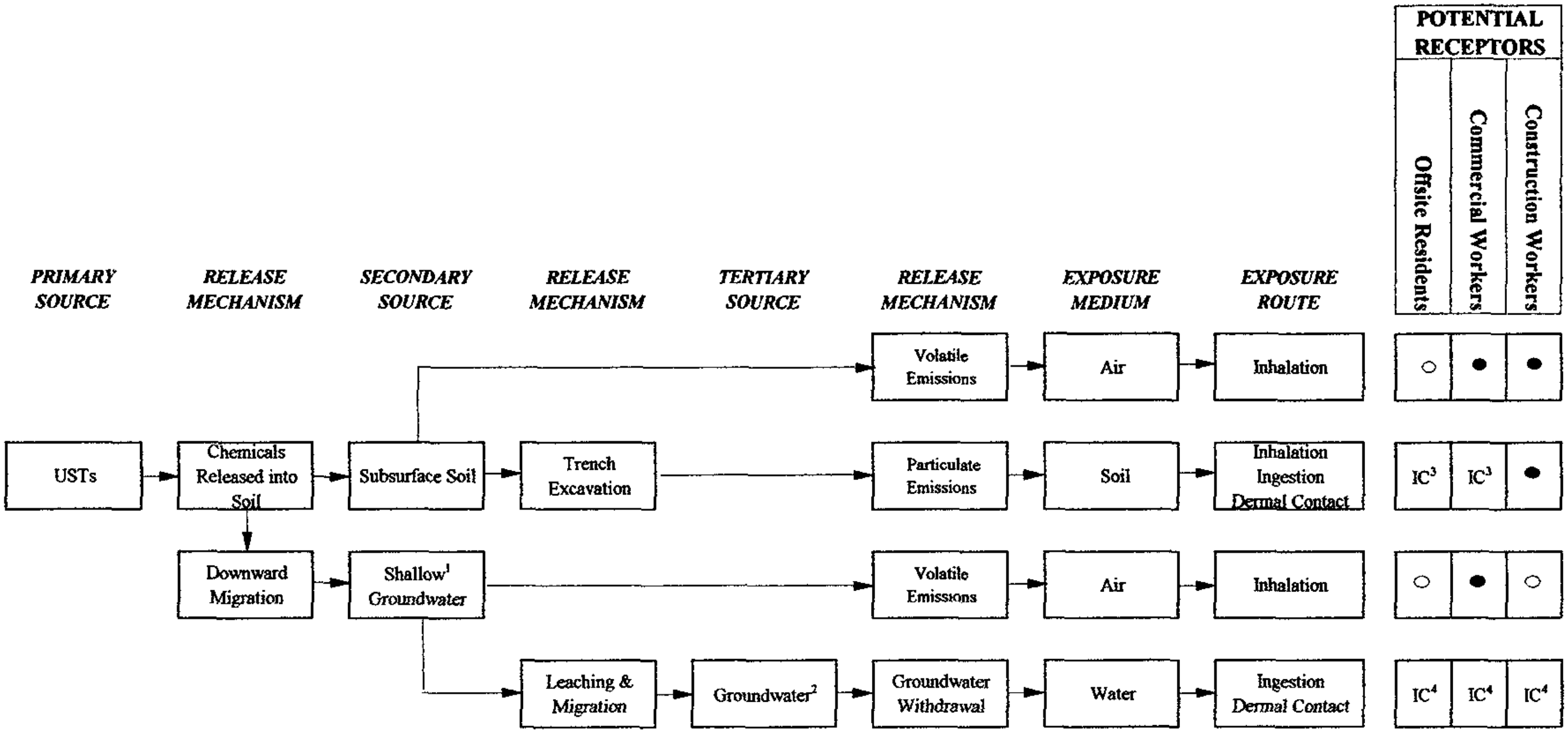



| Project No. 961276NA | Fire Station No. 2 | ILLUSTRATION OF POTENTIAL EXPOSURE SCENARIOS | Figure 3 |
|---|---|---|---|
| Woodward-Clyde Consultants | | | |




Legend:

● Potentially complete pathway (will be evaluated in a quantitative way)

○ Insignificant pathway (will be evaluated in a qualitative way)

IC Incomplete pathway

na Not Applicable

Notes:

[1] Represented by the first encountered groundwater, typically 10 feet below ground surface

[2] Represented by the groundwater beneath the first encountered aquitard.

[3] Asphalt/concrete pavement prevents direct soil contact exposure

[4] Drinking water is supplied by municipal water system, and no water supply wells are located nearby or screened in the shallow zones.

| Project No. 961276NA | Fire Station No. 2 | SITE CONCEPTUAL MODEL | Figure 4 |
|---|---|---|---|
| Woodward-Clyde Consultants | | | |

## TABLE 1
## MAXIMUM DETECTED RESIDUAL SOIL CONCENTRATIONS

| Chemical of Concern in Soil | Initial Invest. March 1995 | | | Initial Invest. July 1995 | | | Tank Removal October 1995 | | | Additional Invest. 1996-97 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Maximum Detected Conc. [mg/kg] | Location | Depth [feet] | Maximum Detected Conc. [mg/kg] | Location | Depth [feet] | Maximum Detected Conc. [mg/kg] | Location | Depth [feet] | Maximum Detected Conc. [mg/kg] | Location | Depth [feet] |
| **Benzene** | 0.63 | SB-2 | 6 | 1.2 | SB-6/11 | 5.5 | 0.58 | Stock-Gas-2 | -- | <0.5 | -- | -- |
| **Ethylbenzene** | 10 | SB-1 | 5 | 8.6 | SB-6 | 5.5 | 12 | Stock-Gas-2 | -- | 4.2 | MW-1 | 6 |
| **Toluene** | 11 | SB-3 | 6 | 5.3 | SB-11 | 5.5 | 4.2 | GE-1 | 7 | 1.3 | MW-1 | 6 |
| **Xylenes** | 51 | SB-1 | 5 | 47 | SB-6 | 5.5 | 56 | Stock-Gas-2 | -- | 21 | MW-1 | 6 |
| **Napthalene*** | 0.70 | est. SB-1 | 5 | 0.62 | est. SB-7 | 5.5 | 0.73 | est. Stock-Gas-2 | -- | 0.35 | MW-1 | 6 |
| **Benzo(a)pyrene**** | 3.8E-5 | est. SB-1 | 5 | 3.4E-5 | est. SB-7 | 5.5 | 3.9E-5 | est. Stock-Gas-2 | -- | 1.9E-5 | est. MW-1 | 6 |
| **TPH (gas)** | 540 | SB-1 | 5 | 480 | SB-7 | 5.5 | 560 | Stock-Gas-2 | -- | 270 | est. MW-1 | 6 |
| **TPH (diesel)** | <1 | -- | -- | na | -- | -- | <1 | -- | -- | na | -- | -- |
| **MTBE** | na | -- | -- | na | -- | -- | 0.28 | GW-1 | 7 | 0.021 | SB-13 | 10 |

**Legend:**
*** Assumed as 0.13% of maximum TPH-diesel or gas concentration (Calabrese et al., 1993).**
**** Assumed as 0.07 mg/kg of maximum TPH-diesel or gas concentration (Guerin et al., 1984).**

## TABLE 2
## MAXIMUM DETECTED SHALLOW GROUNDWATER CONCENTRATIONS

| Chemical of Concern in Groundwater | Initial Invest. March 1995 | | Initial Invest. July 1995 | | Additional Invest. 1996-97 | |
|---|---|---|---|---|---|---|
| | Maximum Detected Conc. [mg/L] | Location | Maximum Detected Conc. [mg/L] | Location | Maximum Detected Conc. [mg/L] | Location |
| **Benzene** | 0.22 | SB-3 | 0.04 | SB-12 | 0.43 | SB-16-W |
| **Ethylbenzene** | 2.5 | SB-3 | 0.18 | SB-7 | 1 | SB-16-W |
| **Toluene** | 3.8 | SB-3 | 0.13 | SB-12 | 1.2 | SB-16-W |
| **Xylenes** | 14 | SB-3 | 0.51 | SB-7 | 4.7 | SB-16-W |
| **Napthalene*** | 0.001287 | est. SB-1 | 0.00715 | est. SB-7 | 0.0377 | est. SB-16-W |
| **Benzo(a)pyrene**** | 6.9E-8 | est. SB-1 | 3.9E-7 | est. SB-7 | 2.0E-6 | est. SB-16-W |
| **TPH (gas)** | 0.99 | SB-1 | 5.5 | SB-7 | 29 | SB-16-W |
| **TPH (diesel)** | na | -- | na | -- | na | -- |
| **MTBE** | na | -- | na | -- | <0.5 | -- |
| | | | | | | |

**Legend:**
*** Assumed as 0.13% of maximum TPH-diesel or gas concentration (Calabrese et al., 1993).**
**** Assumed as 0.07 mg/kg of maximum TPH-diesel or gas concentration (Guerin et al., 1984).**

## TABLE 3
## COMPARISON OF MAXIMUM DETECTED RESIDUAL SOIL CONCENTRATIONS WITH RBCA TIER 1 RBSLs

| Chemical of Concern in Soil | Overall Maximum Detected Conc. [mg/kg] | Location of Maximum Detection | Depth | 1.00E-06 Risk: Commercial Indoor Exposure Tier 1 RBSL*** Concentration [mg/kg] | 1.00E-06 Risk: Commercial Surficial Soil Exp. Tier 1 RBSL*** Concentration [mg/kg] | RBCA Tier 1 RBSL Exceeded ? |
|---|---|---|---|---|---|---|
| **Benzene** | 0.63 | SB-2 | 6 | 0.0169 | 10 | ***Exceeded*** |
| **Ethylbenzene** | 12 | Stock-Gas-2 | -- | 90.8 | >SATUR (1980) | *None Exceeded* |
| **Toluene** | 11 | SB-3 | 6 | 54.5 | >SATUR (781) | *None Exceeded* |
| **Xylenes** | 56 | Stock-Gas-2 | -- | >SATUR (498) | >SATUR (498) | *None Exceeded* |
| **Napthalene*** | 0.728 | est. Stock-Gas-2 | -- | 107 | >SATUR (402) | *None Exceeded* |
| **Benzo(a)pyrene**** | 3.9E-5 | est. Stock-Gas-2 | -- | >SATUR (4.67) | 0.304 | *None Exceeded* |
| **TPH (gas)** | 560 | Stock-Gas-2 | -- | na | na | na |
| **TPH (diesel)** | <1 | -- | -- | na | na | na |
| **MTBE** | 0.28 | GW-1 | 7 | na | na | na |
| | | | | | | |

**Legend:**
*** Assumed as 0.13% of maximum TPH-diesel or gas concentration (Calabrese et al., 1993).**
**** Assumed as 0.07 mg/kg of maximum TPH-diesel or gas concentration (Guerin et al., 1984).**
***** Based on 10e-6 risk for carcinogens or a unit hazard index for non-carcinogens and for commercial exposure scenario.**
**> SATUR = Selected risk level is not exceeded at saturated soil concentration (shown in parenthesis).**

## TABLE 4
## COMPARISON OF MAXIMUM DETECTED SHALLOW GROUNDWATER CONCENTRATIONS WITH RBCA TIER 1 RBSLs

| Chemical of Concern in Groundwater | Overall Maximum Detected Conc. [mg/L] | Location of Maximum Detection | Date | 1.00E-06 Risk Commercial Indoor Exposure Tier 1 RBSL*** Concentration [mg/L] | RBCA Tier I Threshold*** Exceeded ? |
|---|---|---|---|---|---|
| **Benzene** | 0.43 | SB-16-W | March 1997 | 0.0739 | ***Exceeded*** |
| **Ethylbenzene** | 2.5 | SB-3 | March 1995 | >SOLUB(152) | *None Exceeded* |
| **Toluene** | 3.8 | SB-3 | March 1995 | 85 | *None Exceeded* |
| **Xylenes** | 14 | SB-3 | March 1995 | >SOLUB (198) | *None Exceeded* |
| **Napthalene*** | 0.0377 | est. SB-16-W | March 1997 | 12.3 | *None Exceeded* |
| **Benzo(a)pyrene**** | 2.0E-6 | est. SB-16-W | March 1997 | >SOLUB (1.2E-3) | *None Exceeded* |
| **TPH (gas)** | 29 | SB-16-W | March 1997 | na | na |
| **TPH (diesel)** | na | -- | -- | na | na |
| **MTBE** | <0.5 | -- | March 1997 | na | na |
| | | | | | |

**Legend:**

*** Assumed as 0.13% of maximum TPH-diesel or gas concentration (Calabrese et al., 1993).**

**** Assumed as 0.07 mg/kg of maximum TPH-diesel or gas concentration (Guerin et al., 1984).**

***** Based on 10e-6 risk for carcinogens or a unit hazard index for non-carcinogens and for commercial exposure scenario.**

**> SOLUB = Selected risk level is not exceeded in water at solubility (shown in parenthesis).**

# TABLE 5. SUMMARY OF SITE-SPECIFIC TARGET LEVELS

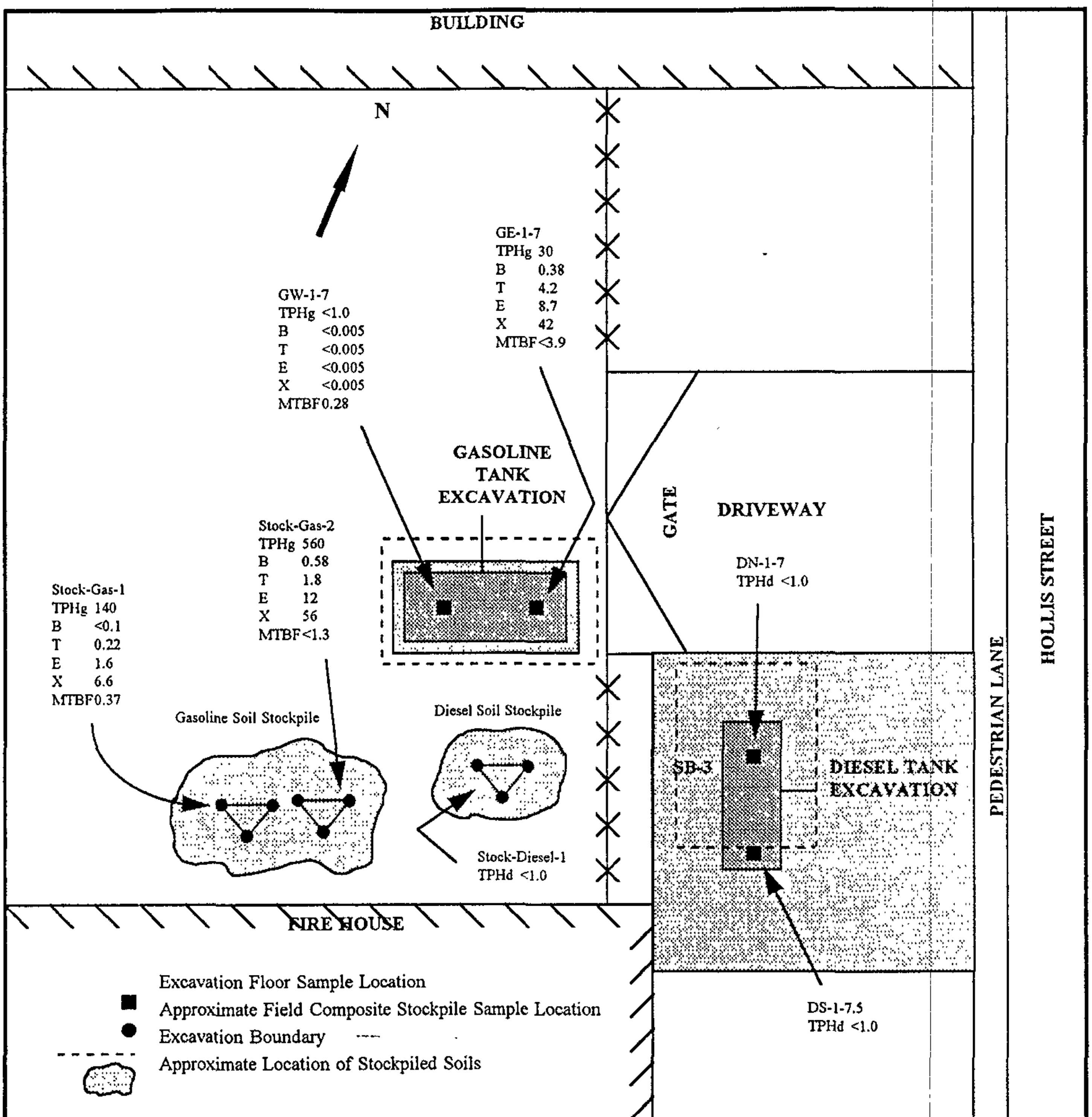
| CHEMICAL | SITE-SPECIFIC TARGET LEVELS (1,2) Commercial Indoor Exposure to Soil Emissions [mg/kg] | Commercial Indoor Exposure to GW Emissions [mg/L] | Construction Outdoor Exposure to Surficial Soil [mg/kg] |
|---|---|---|---|
| **Benzene** | 1.7E+0 | 2.3E+0 | 1.3E+3 |
| **Toluene** | 7.8E+2 * | 5.4E+2 * | 7.8E+2 * |
| **Ethylbenzene** | 3.5E+2 * | 1.5E+2 * | 3.5E+2 * |
| **Xylene (mixed)** | 5.0E+2 * | 2.0E+2 * | 5.0E+2 * |
| **Naphthalene** | 4.0E+2 * | 3.1E+1 * | 4.0E+2 * |
| **Benzo(a)pyrene** | 4.7E+0 * | 1.2E-3 * | 4.7E+0 * |
| **MTBE** | 9.9E+3 * | 5.1E+4 * | 9.9E+3 * |
| | | | |

* Indicates SSTL exceeded soil saturation limit or water solubility and hence saturation or solubility are listed as SSTL

(1) Calculated using the equations in ASTM RBCA guidance. Target risk concentrations are corresponding to a cancer risk of one in 100000 or a non-carcinogenic hazard quotient of unity for the exposure pathway being evaluated.
(2) The SSTL is the lower of the target risk concentrations for carcinogenic and non-carcinogenic effect, unless they exceed soil saturation of water solubility, in which case the SSTL is set at saturation or solubility concentration.

na = Not Applicable/Not Available

# APPENDIX A Summary of Site Investigation and Remediation Results




| Project No. 941366NA | CITY OF EMERYVILLE Fire Station Number 2 | SITE PLAN SHOWING UST EXCAVATIONS, SOIL SAMPLE LOCATIONS AND TPH, BTEX, AND MTBE CONCENTRATIONS | Figure 3 |
|---|---|---|---|
| Woodward-Clyde Consultants | | | December 1995 |

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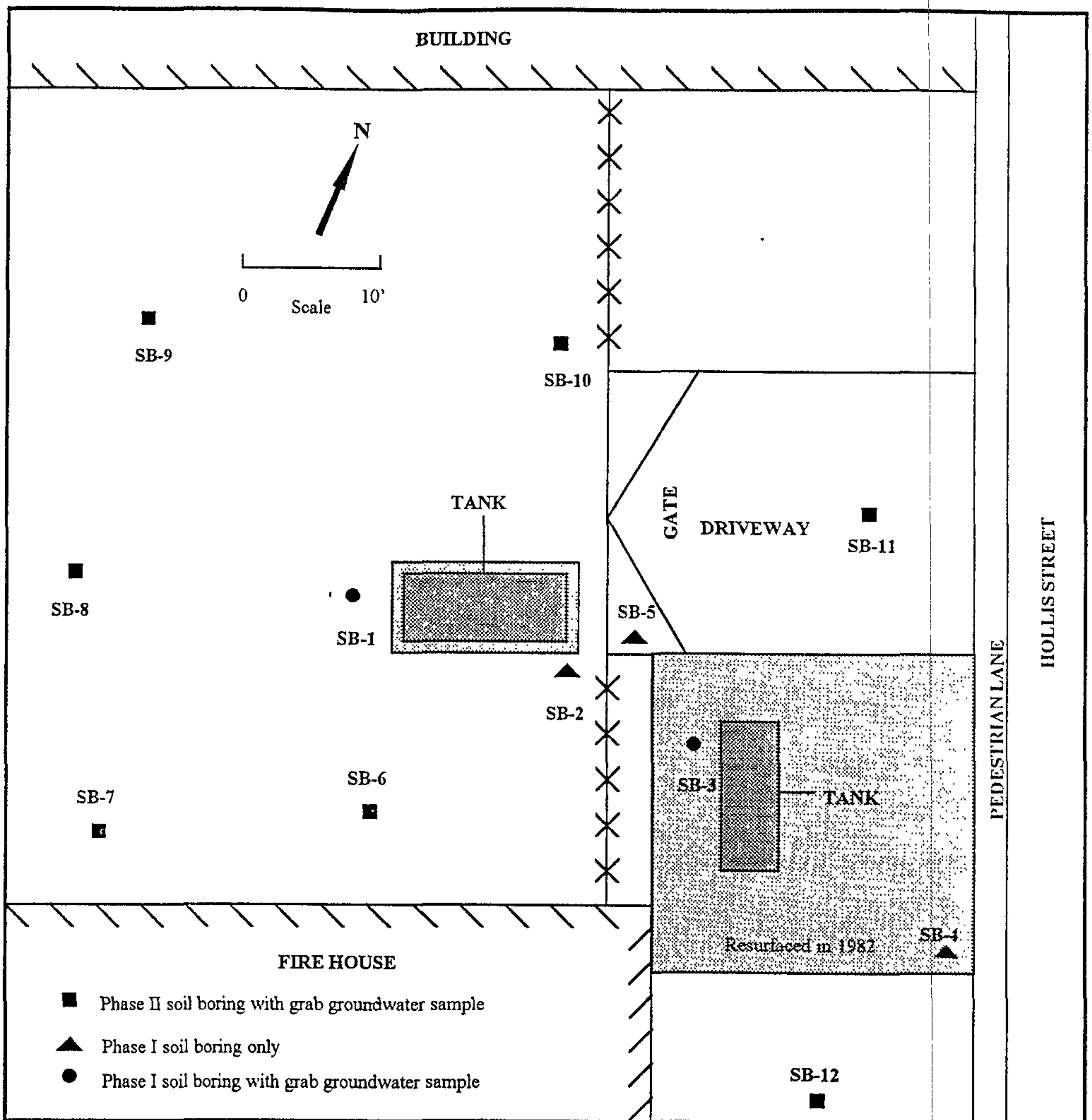
# TABLE 1

## SOIL ANALYTICAL RESULTS
## CITY OF EMERYVILLE
## FIRE STATION NO. 2

| Sample No. | TPH[a] Gasoline (mg/kg) | TPH[b] Diesel (mg/kg) | Benzene[c] (mg/kg) | Toluene[c] (mg/kg) | Ethylbenzene[c] (mg/kg) | Xylenes[c] (mg/kg) | MTBE[c] (mg/kg) |
|---|---|---|---|---|---|---|---|
| GE-1-7' | 380 | --- | 0.34 | 4.2 | 8.7 | 42 | <3.9 |
| GW-1-7' | <1.0 | --- | <0.005 | <0.005 | <0.005 | <0.005 | 0.28 |
| STOCK-GAS-1 | 140 | --- | <0.1 | 0.22 | 1.6 | 6.6 | <0.37 |
| STOCK-GAS-2 | 560 | --- | 0.58 | 1.8 | 12 | 56 | <1.3 |
| STOCK-DIESEL-1 | --- | <1.0 | --- | --- | --- | --- | --- |
| DN-1-7.5' | --- | <1.0 | --- | --- | --- | --- | --- |
| DS-1-7.5' | --- | <1.0 | --- | --- | --- | --- | --- |

Notes:
- a Total petroleum hydrocarbons by EPA Method 8015 (Mod.), quantified as gasoline.
- b Total petroleum hydrocarbons by EPA Method 8015 (Mod.), quantified as diesel.
- c Benzene, toluene, ethylbenzene, xylenes, and MTBE by EPA Method 8020.
- --- Not analyzed




| | | | |
|---|---|---|---|
| Project No.<br>941366NA | CITY OF EMERYVILLE<br>Fire Station Number 2 | PHASE I & II<br>SOIL BORING LOCATIONS | Figure 2 |
| | | | July 15, 1995 |

## TABLE 2.

## SOIL SAMPLES ANALYTICAL RESULTS SUMMARY
## FIRE STATION NO. 2
## EMERYVILLE, CALIFORNIA

| Sample ID | TPH as Gasoline/BTEX (EPA modified 8015/8020) | | | | |
|---|---|---|---|---|---|
| (Depth, ft) | Benzene | Toluene | Ethylbenzene | Total Xylenes | TPH as Gasoline |
| SB-6-5.5 | 1200 | 4900 | 8600 | 47000 | 440 |
| SB-6-11 | ND | ND | ND | ND | ND |
| SB-7-5.5 | 690 | 760 | 7500 | 28000 | 480 |
| SB-7-11 | ND | ND | ND | ND | ND |
| SB-8-5.5 | 190 | 230 | 1500 | 3500 | 120 |
| SB-8-11 | ND | ND | ND | ND | ND |
| SB-9-5.5 | ND | ND | ND | ND | ND |
| SB-9-13 | ND | ND | ND | ND | ND |
| SB-10-11.5 | ND | ND | ND | ND | ND |
| SB-11-5.5 | 1200 | 5300 | 3300 | 17000 | 170 |
| SB-11-11 | ND | ND | 5.7 | 26 | ND |
| SB-12-5.5 | 8.3 | 15 | ND | 24 | ND |
| SB-12-11.5 | ND | ND | ND | ND | ND |

Notes:
(1) Gasoline results are in mg/Kg, all other results are in ug/Kg
(2) Samples analyzed by Chromalab, Inc., July 17-18, 1995
(3) Refer to laboratory reports for analytical reporting limits
ND Not detected

**TABLE 3.**

**GROUNDWATER SAMPLES ANALYTICAL RESULTS SUMMARY**
**FIRE STATION NO. 2**
**EMERYVILLE, CALIFORNIA**

| Sample ID (Depth, ft) | TPH as Gasoline/BTEX (EPA Modified 8015/8020) | | | | |
|---|---|---|---|---|---|
| | Benzene | Toluene | Ethylbenzene | Total Xylenes | TPH as Gasoline |
| SB-6-W | 24 | 27 | 27 | 110 | 0.41 |
| SB-7-W | 36 | 30 | 180 | 510 | 5.5 |
| SB-8-W | 18 | 36 | 27 | 100 | 0.46 |
| SB-9-W | ND | ND | 0.7 | 3.7 | ND |
| SB-10-W | ND | ND | 0.6 | 3.3 | ND |
| SB-11-W | 12 | 8.6 | 12 | 44 | 0.23 |
| SB-12-W | 40 | 130 | 38 | 170 | 0.97 |
| TB | ND | ND | ND | ND | ND |

Notes:
(1) Gasoline results are in mg/L, all other results are in ug/L
(2) Samples analyzed by Chramolab, Inc., July 17-18, 1995
(3) Refer to laboratory reports for analytical reporting limits
ND Not Detected

**TABLE 1**
**PHASE I SOIL ANALYTICAL RESULTS**
**CITY OF EMERYVILLE**
**FIRE STATION No. 2**

| Sample No. | Date Sampled | TPH[a] Gasoline (mg/kg) | TPH[b] Diesel (mg/kg) | Benzene (µg/kg) | Toluene (µg/kg) | Ethylbenzene (µg/kg) | Total Xylenes (µg/kg) |
|---|---|---|---|---|---|---|---|
| SB-1-2' | 3/15/95 | 2.4 | NA | 280 | 12 | 200 | 370 |
| SB-1-5' | 3/15/95 | 540 | NA | ND (1,000) | 7,000 | 10,000 | 51,000 |
| SB-1-10' | 3/15/95 | ND (1.0) | NA | ND (5.0) | ND (5.0) | ND (5.0) | ND (5.0) |
| SB-2-6' | 3/15/95 | 3.0 | NA | 630 | 5.7 | ND (5.0) | 15 |
| SB-2-10' | 3/15/95 | ND (1.0) | NA | 110 | ND (5.0) | 9.7 | 6.1 |
| SB-3-6' | 3/15/95 | NA | ND (1.0) | 420 | 11,000 | 5,500 | 27,000 |
| SB-3-10' | 3/15/95 | NA | ND (1.0) | 47 | 81 | 60 | 80 |
| SB-4-6' | 3/15/95 | NA | ND (1.0) | ND (50) | 54 | 1,100 | 3,300 |
| SB-4-11' | 3/15/95 | NA | ND (1.0) | ND (5.0) | ND (5.0) | ND (5.0) | ND (5.0) |
| SB-5-5.5' | 3/15/95 | NA | ND (1.0) | 240 | 170 | 2,300 | 8,200 |
| SB-5-10' | 3/15/95 | NA | ND (1.0) | ND (5.0) | ND (5.0) | ND (5.0) | ND (5.0) |

Notes:
[a] Total petroleum hydrocarbons by EPA Method 8015 (Mod.), quantified as gasoline.
[b] Total petroleum hydrocarbons by EPA Method 8015 (Mod.), quantified as diesel.
Benzene, toluene, ethylbenzene and xylenes by EPA Method 8020.
NA - Not analyzed; ND - Not detected at or above the detection limit given in parentheses.

TABLE 2
GROUNDWATER ANALYTICAL RESULTS
CITY OF EMERYVILLE
FIRE STATION No. 2

| Sample No. | Date Sampled | TPH[a] Gasoline (mg/L) | TPH[b] Diesel (mg/L) | Benzene (µg/L) | Toluene (µg/L) | Ethylbenzene (µg/L) | Total Xylenes (µg/L) |
|---|---|---|---|---|---|---|---|
| SB-3 | 3/15/95 | NA | NA | 220 | 3,800 | 2,500 | 14,000 |
| SB-1 | 3/15/95 | 0.99 | NA | 6.1 | 40 | 33 | 160 |
| Trip Blank | 3/15/95 | NA | NA | ND (0.5) | ND (0.5) | ND (0.5) | ND (0.5) |

Notes: [a] Total petroleum hydrocarbons by EPA Method 8015 (Mod.), quantified as gasoline.
[b] Total petroleum hydrocarbons by EPA Method 8015 (Mod.), quantified as diesel.
Benzene, toluene, ethylbenzene and xylenes by EPA Method 8020.
NA - Not analyzed; ND - Not detected at or above the detection limit given in parentheses.

# APPENDIX B

# Compilation of Field Invstigation Results

**TABLE 1**
**SOIL ANALYTICAL RESULTS**
**CITY OF EMERYVILLE**
**FIRE STATION No. 2**

| Sample No. | Date Sampled | TPH[a] Gasoline (mg/kg) | TPH[b] Diesel (mg/kg) | Benzene (µg/kg) | Toluene (µg/kg) | Ethylbenzene (µg/kg) | Total Xylenes (µg/kg) | MTBE (ug/kg) | Total Lead (mg/kg) |
|---|---|---|---|---|---|---|---|---|---|
| SB-1-2' | 3/15/95 | 2.4 | NA | 280 | 12 | 200 | 370 | NA | NA |
| SB-1-5' | 3/15/95 | 540 | NA | ND (1,000) | 7,000 | 10,000 | 51,000 | NA | NA |
| SB-1-10' | 3/15/95 | ND (1.0) | NA | ND (5.0) | ND (5.0) | ND (5.0) | ND (5 0) | NA | NA |
| SB-2-6' | 3/15/95 | 3.0 | NA | 630 | 5.7 | ND (5 0) | 15 | NA | NA |
| SB-2-10' | 3/15/95 | ND (1.0) | NA | 110 | ND (5.0) | 9.7 | 6.1 | NA | NA |
| SB-3-6' | 3/15/95 | NA | ND (1.0) | 420 | 11,000 | 5,500 | 27,000 | NA | NA |
| SB-3-10' | 3/15/95 | NA | ND (1.0) | 47 | 81 | 60 | 80 | NA | NA |
| SB-4-6' | 3/15/95 | NA | ND (1.0) | ND (50) | 54 | 1,100 | 3,300 | NA | NA |
| SB-4-11' | 3/15/95 | NA | ND (1.0) | ND (5 0) | ND (5.0) | ND (5.0) | ND (5.0) | NA | NA |
| SB-5-5.5' | 3/15/95 | NA | ND (1.0) | 240 | 170 | 2,300 | 8,200 | NA | NA |
| SB-5-10' | 3/15/95 | NA | ND (1 0) | ND (5 0) | ND (5.0) | ND (5.0) | ND (5.0) | NA | NA |
| SB-6-5.5 | 6/17/95 | 440 | NA | 1,200 | 4,900 | 8,600 | 47,000 | NA | NA |
| SB-6-11 | 6/17/95 | ND (1.0) | NA | ND (5 0) | ND (5.0) | ND (5.0) | ND (5 0) | NA | NA |
| SB-7-5.5 | 6/17/95 | 480 | NA | 690 | 760 | 7,500 | 28,000 | NA | NA |
| SB-7-11 | 6/17/95 | ND (1.0) | NA | ND (5.0) | ND (5 0) | ND (5 0) | ND (5.0) | NA | NA |
| SB-8-5.5 | 6/17/95 | 120 | NA | 190 | 230 | 1,500 | 3,500 | NA | NA |
| SB-8-11 | 6/17/95 | ND (1.0) | NA | ND (5.0) | ND (5 0) | ND (5 0) | ND (5 0) | NA | NA |
| SB-9-5 5 | 6/17/95 | ND (1.0) | NA | ND (5.0) | ND (5 0) | ND (5 0) | ND (5.0) | NA | NA |
| SB-9-13 | 6/17/95 | ND (1.0) | NA | ND (5.0) | ND (5 0) | ND (5.0) | ND (5 0) | NA | NA |
| SB-10-11 5 | 6/17/95 | ND (1 0) | NA | ND (5.0) | ND (5.0) | ND (5 0) | ND (5 0) | NA | NA |
| SB-11-5.5 | 6/17/95 | 170 | NA | 1,200 | 5,300 | 3,300 | 17,000 | NA | NA |
| SB-11-11 | 6/17/95 | ND (1 0) | NA | ND (5.0) | ND (5.0) | 5.7 | 26 | NA | NA |
| SB-12-5.5 | 6/17/95 | ND (1.0) | NA | 8 3 | 15 | ND (5.0) | 24 | NA | NA |
| SB-12-11.5 | 6/17/95 | ND (1 0) | NA | ND (5.0) | ND (5.0) | ND (5.0) | ND (5.0) | NA | NA |
| GE-1-7 | 10/12/95 | 380 | NA | 340 | 4 | 8,700 | 42,000 | ND (3900) | NA |
| GW-1-7 | 10/12/95 | ND (1.0) | NA | ND (5 0) | ND (5.0) | ND (5.0) | ND (5 0) | 280 | NA |
| Stock-Gas-1 | 10/12/95 | 140 | NA | ND (100) | 220 | 1,600 | 6,600 | ND (370) | NA |
| Stock-Gas-2 | 10/12/95 | 560 | NA | 580 | 1,800 | 12,000 | 56,000 | ND (1300) | NA |
| Stock-Diesel-1 | 10/12/95 | NA | ND (1.0) | NA | NA | NA | NA | NA | NA |
| DN-1-7.5 | 10/12/95 | NA | ND (1.0) | NA | NA | NA | NA | NA | NA |
| DS-1-7.5 | 10/12/95 | NA | ND (1.0) | NA | NA | NA | NA | NA | NA |
| SB-13-5 | 3/25/97 | ND (0 5) | NA | ND (5 0) | ND (5 0) | ND (5.0) | ND (5.0) | ND (5 0) | NA |
| SB-13-10 | 3/25/97 | ND (0.5) | NA | ND (5.0) | ND (5.0) | ND (5 0) | ND (5.0) | 21 | 2 |
| SB-14-5 | 3/25/97 | ND (0.5) | NA | ND (5.0) | ND (5 0) | ND (5 0) | ND (5.0) | ND (5.0) | NA |
| SB-14-10 | 3/25/97 | ND (0 5) | NA | ND (5 0) | ND (5 0) | ND (5.0) | ND (5 0) | ND (5 0) | 4 |
| SB-15-5 | 3/25/97 | ND (0.5) | NA | ND (5.0) | ND (5.0) | ND (5 0) | ND (5 0) | ND (5.0) | NA |
| SB-15-10 | 3/25/97 | ND (0 5) | NA | ND (5.0) | ND (5 0) | ND (5.0) | ND (5.0) | ND (5 0) | 7 |
| SB-16-5 | 3/25/97 | 45 | NA | ND (50) | 60 | 260 | 1,200 | ND (50) | NA |
| SB-16-12 | 3/25/97 | ND (0.5) | NA | ND (5.0) | ND (5.0) | ND (5 0) | ND (5 0) | ND (5.0) | 7 |
| MW-1-6 | 3/24/97 | 270 | NA | ND (500) | 1,300 | 4,200 | 21,000 | ND (500) | 8.2 |
| MW-1-11 | 3/24/97 | ND (0 5) | NA | ND (5.0) | 7 | 9 | 38 | ND (5 0) | 3.5 |
| MW-1-16 | 3/24/97 | ND (0.5) | NA | ND (5.0) | ND (5.0) | ND (5.0) | ND (5 0) | ND (5 0) | 5.4 |

Notes. [a] Total petroleum hydrocarbons by EPA Method 8015 (Mod.), quantified as gasoline
[b] Total petroleum hydrocarbons by EPA Method 8015 (Mod ), quantified as diesel.
Benzene, toluene, ethylbenzene and xylenes by EPA Method 8020.
NA - Not analyzed; ND - Not detected at or above the detection limit given in parentheses

**TABLE 2**
**GROUNDWATER ANALYTICAL RESULTS**
**CITY OF EMERYVILLE**
**FIRE STATION No. 2**

| Sample No. | Date Sampled | TPH[a] Gasoline (mg/L) | TPH[b] Diesel (mg/L) | Benzene (µg/L) | Toluene (µg/L) | Ethylbenzene (µg/L) | Total Xylenes (µg/L) | MTBE (ug/L) | Total Lead (ug/L) |
|---|---|---|---|---|---|---|---|---|---|
| SB-3 | 3/15/95 | NA | NA | 220 | 3,800 | 2,500 | 14,000 | NA | NA |
| SB-1 | 3/15/95 | 0.99 | NA | 6.1 | 40 | 33 | 160 | NA | NA |
| Trip Blank | 3/15/95 | NA | NA | ND (0.5) | ND (0 5) | ND (0.5) | ND (0.5) | NA | NA |
| SB-6-W | 6/17/95 | 0.41 | NA | 24 | 27 | 27 | 110 | NA | NA |
| SB-7-W | 6/17/95 | 5 50 | NA | 36 | 30 | 180 | 510 | NA | NA |
| SB-8-W | 6/17/95 | 0.46 | NA | 18 | 36 | 27 | 100 | NA | NA |
| SB-9-W | 6/17/95 | ND (0.05) | NA | ND (0.5) | ND (0.5) | 0.7 | 3.7 | NA | NA |
| SB-10-W | 6/17/95 | ND (0 05) | NA | ND (0.5) | ND (0.5) | 0.6 | 3 3 | NA | NA |
| SB-11-W | 6/17/95 | 0.23 | NA | 12 | 8 6 | 12 | 44 | NA | NA |
| SB-12-W | 6/17/95 | 0.97 | NA | 40 | 130 | 38 | 170 | NA | NA |
| Trip Blank | 6/17/95 | ND (0 05) | NA | ND (0.5) | ND (0.5) | ND (0 5) | ND (0 5) | NA | NA |
| SB-13-W | 3/26/97 | ND (0 05) | NA | ND (0 5) | ND (0.5) | ND (0.5) | ND (0 5) | ND (5) | NA |
| SB-14-W | 3/26/97 | ND (0 05) | NA | ND (0.5) | ND (0.5) | ND (0.5) | ND (0.5) | ND (5) | NA |
| SB-15-W | 3/26/97 | ND (0.05) | NA | ND (0 5) | ND (0 5) | ND (0.5) | ND (0.5) | ND (5) | NA |
| SB-16-W | 3/26/97 | 29 | NA | 430 | 1,200 | 1,000 | 4,700 | ND (500) | NA |
| Trip Blank | 3/26/97 | ND (0.05) | NA | ND (0.5) | ND (0.5) | ND (0.5) | ND (0 5) | ND (5) | NA |

Notes: [a] Total petroleum hydrocarbons by EPA Method 8015 (Mod.), quantified as gasoline.
[b] Total petroleum hydrocarbons by EPA Method 8015 (Mod ), quantified as diesel.
Benzene, toluene, ethylbenzene and xylenes by EPA Method 8020.
NA - Not analyzed. ND - Not detected at or above the detection limit given in parentheses

# APPENDIX C

# Spreadsheet Calculations of Tier 2 SSTLs

## Commercial Exposure Scenario
## EXPOSURE FACTORS AND OTHER RELEVANT PARAMETERS

| PARAMETER | Units | Input Value | Reference |
|---|---|---|---|
| **EXPOSURE PARAMETERS** | | | |
| Averaging Time for Carcinogens | yr | 70 | ASTM 1995 - Guide for RBCA |
| Averaging Time for Noncarcinogens | yr | 25 | ASTM 1995 - Guide for RBCA |
| Body Weight Adult | kg | 70 | ASTM 1995 - Guide for RBCA |
| Exposure Duration Adult | yr | 25 | ASTM 1995 - Guide for RBCA |
| Exposure Frequency | days/yr | 250 | ASTM 1995 - Guide for RBCA |
| Soil ingestion rate Adult | mg/day | 100 | ASTM 1995 - Guide for RBCA |
| Daily Indoor Inhalation Rate Adult | $m^3$/day | 15 | ASTM 1995 - Guide for RBCA |
| Daily Outdoor Inhalation Rate Adult | $m^3$/day | 20 | ASTM 1995 - Guide for RBCA |
| Daily water ingestion rate Adult | L/day | 2 | ASTM 1995 - Guide for RBCA |
| Soil to skin adherence factor | mg/$cm^2$ | 0.5 | ASTM 1995 - Guide for RBCA |
| Dermal relative absorption factor (volatiles) | --- | 0.5 | ASTM 1995 - Guide for RBCA |
| Dermal relative absorption factor (PAHs) | --- | 0.05 | ASTM 1995 - Guide for RBCA |
| Oral relative absorption factor | --- | 1 | ASTM 1995 - Guide for RBCA |
| Skin surface area Adult | $cm^2$ | 3,160 | ASTM 1995 - Guide for RBCA |
| Target Hazard Quotient for individual constituents | --- | 1 | ASTM 1995 - Guide for RBCA |
| Target Excess Individual Lifetime Cancer Risk | --- | 1.0E-5 | ASTM 1995 - Guide for RBCA |
| **CONTAMINANT FATE AND TRANSPORT PARAMETERS** | | | |
| Lower depth of surficial soil zone | cm | 100 | ASTM 1995 - Guide for RBCA |
| Enclosed space air exchange rate | 1/sec | 0.00023 | ASTM 1995 - Guide for RBCA |
| Fraction of organic carbon in soil | g-C/g-soil | 0.01 | ASTM 1995 - Guide for RBCA |
| Thickness of capillary fringe | cm | 5 | ASTM 1995 - Guide for RBCA |
| Thickness of vadose zone | cm | 295 | ASTM 1995 - Guide for RBCA |
| Infiltration rate of water through soil | cm/yr | 30 | ASTM 1995 - Guide for RBCA |
| Enclosed space volume/infiltration area | cm | 300 | ASTM 1995 - Guide for RBCA |
| Enclosed space foundation/wall thickness | cm | 15 | ASTM 1995 - Guide for RBCA |
| Depth to groundwater | cm | 300 | ASTM 1995 - Guide for RBCA |
| Depth to subsurface soil sources | cm | 100 | ASTM 1995 - Guide for RBCA |
| Particulate emission rate | g/$cm^2$-s | 1.5E-09 | selected to correspond to 50 $\mu g/m^3$ |
| Wind speed above ground surface in ambient mixing zone | cm/s | 225 | ASTM 1995 - Guide for RBCA |
| Groundwater Darcy velocity | cm/yr | 2500.0 | ASTM 1995 - Guide for RBCA |
| Width of source area parallel to wind or gw flow | cm | 1500 | ASTM 1995 - Guide for RBCA |
| Ambient air mixing zone height | cm | 200 | ASTM 1995 - Guide for RBCA |
| Groundwater mixing zone height | cm | 200 | ASTM 1995 - Guide for RBCA |
| Areal fraction of cracks in foundation/walls | $cm^2/cm^2$ | 0.0005 | corresponding to a 50-fold reduction factor |
| Volumetric air content in capillary fringe soils | cc/cc | 0.038 | ASTM 1995 - Guide for RBCA |
| Volumetric air content in found./wall cracks | cc/cc | 0.26 | ASTM 1995 - Guide for RBCA |
| Volumetric air content in vadose zone soils | cc/cc | 0.26 | ASTM 1995 - Guide for RBCA |
| Total soil porosity | cc/cc-soil | 0.38 | ASTM 1995 - Guide for RBCA |
| Volumetric water content in capillary fringe soils | cc/cc | 0.342 | ASTM 1995 - Guide for RBCA |
| Volumetric water content in found./wall cracks | cc/cc | 0.12 | ASTM 1995 - Guide for RBCA |
| Volumetric water content in vadose zone soils | cc/cc | 0.12 | ASTM 1995 - Guide for RBCA |
| Soil bulk density | g/cc | 1.7 | ASTM 1995 - Guide for RBCA |
| Averaging time for vapor flux | sec | 7.88E+8 | ASTM 1995 - Guide for RBCA |

Reference : ASTM 1995. Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites. E 1739-95. November.

## Commercial Exposure Scenario
## CHEMICAL-SPECIFIC TOXICITY PARAMETERS

| CHEMICAL | SLOPE FACTOR | | | | REFERENCE DOSE | | | |
|---|---|---|---|---|---|---|---|---|
| | ORAL | | INHALATION | | ORAL | | INHALATION | |
| | [1/(mg/kg-day)] | ref. | [1/(mg/kg-day)] | ref. | [mg/kg-day] | ref. | [mg/kg-day] | ref. |
| **Benzene** | 1.1E-1 | cal/epa | 1.1E-1 | cal/epa | 1.7E-3 | r | 1.7E-3 | n |
| **Toluene** | na | ASTM | na | ASTM | 2.0E-1 | ASTM | 1.1E-1 | ASTM |
| **Ethylbenzene** | na | ASTM | na | ASTM | 1.0E-1 | ASTM | 2.9E-1 | ASTM |
| **Xylene (mixed)** | na | ASTM | na | ASTM | 2.0E+0 | ASTM | 2.0E+0 | ASTM |
| **Naphthalene** | na | ASTM | na | ASTM | 4.0E-2 | n | 4.0E-2 | r |
| **Benzo(a)pyrene** | 7.3E+0 | ASTM | 7.3E+0 | ASTM | na | ASTM | na | ASTM |
| **MTBE** | na | -- | na | -- | 5.0E-3 | n | 8.6E-1 | i |
| | | | | | | | | |

**References**
ASTM = Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites (ASTM E 1739-95, November, 1995).
(i,n,x,r,h) = As referenced in US EPA Region IX Preliminary Remediation Goals (PRGs) 1996
cal/epa = Cal/EPA Memorandum on California Cancer Potency Factors: Update 11/94
na = Not Applicable/Not Available.

## Commercial Exposure Scenario
## CHEMICAL-SPECIFIC FATE AND TRANSPORT PARAMETERS

| CHEMICAL | Koc [$cm^3/g$] | H [$atm\text{-}m^3/mol$] | H' = H/RT [--] | Solubility [mg/L] | Dair [$cm^2/sec$] | Dwater [$cm^2/sec$] | ABS [--] |
|---|---|---|---|---|---|---|---|
| **Benzene** | 6.5E+1 | 5.5E-3 | 2.3E-1 | 1.8E+3 | 9.3E-2 | 1.10E-5 | 0.5 |
| **Toluene** | 1.4E+2 | 6.6E-3 | 2.7E-1 | 5.4E+2 | 8.5E-2 | 9.40E-6 | 0.5 |
| **Ethylbenzene** | 2.2E+2 | 7.9E-3 | 3.2E-1 | 1.5E+2 | 7.6E-2 | 8.50E-6 | 0.5 |
| **Xylene *(mixed)*** | 2.4E+2 | 5.3E-3 | 2.2E-1 | 2.0E+2 | 8.7E-2 | 8.50E-6 | 0.5 |
| **Naphthalene** | 1.3E+3 | 1.3E-3 | 5.3E-2 | 3.1E+1 | 7.2E-2 | 9.40E-6 | 0.05 |
| **Benzo(a)pyrene** | 3.9E+5 | 1.4E-9 | 5.7E-8 | 1.2E-3 | 5.0E-2 | 5.80E-6 | 0.05 |
| **MTBE** | 1.2E+1 | 5.4E-4 | 2.2E-2 | 5.1E+4 | 1.0E-1 | 1.10E-5 | 0.5 |
| | | | | | | | |

**Definitions of Parameters**
Koc = Organic carbon partition coefficient
H = Henry's Law constant
Dair = Diffusion coefficient in air
Dwater = Diffusion coefficient in water
ABS = Dermal Absorption Factor

**References**

Basics of Pump and Treat Groundwater Remediation Technology. EPA Office of Research and Development. EPA/600/8-90/003. March 1990.
US EPA Region IX Preliminary Remediation Goals (PRGs) 1996.
ASTM Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites (November, 1995).

## Commercial Exposure Scenario
## CHEMICAL-SPECIFIC FATE AND TRANSPORT DIFFUSION PARAMETERS

| CHEMICAL | Ds [cm$^2$/s] | Dcrack [cm$^2$/s] | Dcap [cm$^2$/s] | Dws [cm$^2$/s] | Csat [mg/kg] | Kd [cm$^3$/g] |
|---|---|---|---|---|---|---|
| **Benzene** | 7.26E-3 | 7.26E-3 | 2.15E-5 | 1.10E-3 | 1.32E+3 | 6.50E-1 |
| **Toluene** | 6.63E-3 | 6.63E-3 | 1.77E-5 | 9.19E-4 | 7.82E+2 | 1.35E+0 |
| **Ethylbenzene** | 5.93E-3 | 5.93E-3 | 1.49E-5 | 7.79E-4 | 3.53E+2 | 2.20E+0 |
| **Xylene (mixed)** | 6.79E-3 | 6.79E-3 | 1.88E-5 | 9.71E-4 | 4.96E+2 | 2.40E+0 |
| **Naphthalene** | 5.62E-3 | 5.62E-3 | 4.36E-5 | 1.79E-3 | 4.02E+2 | 1.29E+1 |
| **Benzo(a)pyrene** | 6.05E-1 | 6.05E-1 | 1.96E+1 | 6.14E-1 | 4.67E+0 | 3.89E+3 |
| **MTBE** | 7.81E-3 | 7.81E-3 | 1.10E-4 | 3 60E-3 | 9.89E+3 | 1.20E-1 |
| | | | | | | |

**Definitions of Parameters**
Ds = Effective diffusion coefficient in soil based on vapor-phase concentration
Dcrack = Effective diffusion coefficient through foundation cracks
Dcap = Effective diffusion coefficient through capillary fringe
Dws = Effective diffusion coefficient between groundwater and soil surface
Csat = Saturated soil concentration

## Commercial Exposure Scenario
## CHEMICAL-SPECIFIC FATE AND TRANSPORT VOLATILIZATION FACTORS

| CHEMICAL | VOLATILIZATION FACTORS | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | VFwesp [mg/$m^3$-air/ mg/L-H2O] | VFwamb [mg/$m^3$-air/ mg/L-H2O] | VFss1 [mg/$m^3$-air/ mg/kg-soil] | VFss2 [mg/$m^3$-air/ mg/kg-soil] | VFp [mg/$m^3$-air/ mg/kg-soil] | VFsamb [mg/$m^3$-air/ mg/kg-soil] | VFsesp [mg/$m^3$-air/ mg/kg-soil] | LFsw [mg/L/ mg/kg] |
| **Benzene** | 7.42E-4 | 2.75E-5 | 8.14E-5 | 7.19E-6 | 5.00E-8 | 7.22E-4 | 1.04E-3 | 1.09E-1 |
| **Toluene** | 8.09E-4 | 2.76E-5 | 6.12E-5 | 7.19E-6 | 5.00E-8 | 4.09E-4 | 5.91E-4 | 5.65E-2 |
| **Ethylbenzene** | 8.62E-4 | 2.81E-5 | 5.03E-5 | 7.19E-6 | 5.00E-8 | 2.76E-4 | 3.99E-4 | 3.56E-2 |
| **Xylene (mixed)** | 6.66E-4 | 2.35E-5 | 4.24E-5 | 7.19E-6 | 5.00E-8 | 1.96E-4 | 2.84E-4 | 3.30E-2 |
| **Naphthalene** | 1.40E-4 | 1.06E-5 | 8.40E-6 | 7.19E-6 | 5.00E-8 | 7.70E-6 | 1.11E-5 | 6.37E-3 |
| **Benzo(a)pyrene** | 1.66E-8 | 3.92E-9 | 5.22E-9 | 7.19E-6 | 5.00E-8 | 2.97E-12 | 4.29E-12 | 2.12E-5 |
| **MTBE** | 8.17E-5 | 8.84E-6 | 5.22E-5 | 7.19E-6 | 5.00E-8 | 2.97E-4 | 4.29E-4 | 4.26E-1 |
| | | | | | | | | |

**Definitions of Factors**

VFwesp = Volatilization factor from groundwater to enclosed-space vapors
VFwamb = Volatilization factor from groundwater to ambient (outdoor) vapors
VFss = Volatilization factor from surficial soils to ambient air (vapors)
VFp = Volatilization factor from surficial soils to ambient air (particulates)
VFsamb = Volatilization factor from subsurface soils to ambient air
VFsesp = Volatilization factor from subsurface soils to enclosed space vapors
LFsw = Leaching factor from subsurface soils to ground water

## Commercial Exposure Scenario
## SUMMARY OF TARGET LEVELS FOR SOIL EXPOSURE PATHWAYS

| CHEMICAL | SOIL TARGET LEVELS (1,2) | | | |
|---|---|---|---|---|
| | **Surficial** *Soil* [mg/kg] | **Indoor** *Soil Emiss.* [mg/kg] | **Outdoor** *Soil Emiss.* [mg/kg] | **Leaching to** *GW (MCL)* [mg/kg] |
| **Benzene** | 2.5E+1 | 1.7E+0 | 1.8E+0 | 2.6E-2 |
| **Toluene** | 7.8E+2 * | 7.8E+2 * | 7.8E+2 * | 1.0E+1 |
| **Ethylbenzene** | 3.5E+2 * | 3.5E+2 * | 3.5E+2 * | 1.1E+1 |
| **Xylene (mixed)** | 5.0E+2 * | 5.0E+2 * | 5.0E+2 * | 1.7E+2 |
| **Naphthalene** | 4.0E+2 * | 4.0E+2 * | 4.0E+2 * | 1.8E-2 |
| **Benzo(a)pyrene** | 2.2E+0 | 4.7E+0 * | 4.7E+0 * | 4.7E+0 * |
| **MTBE** | 5.7E+2 | 9.9E+3 * | 9.9E+3 * | 4.0E-2 |
| | | | | |

* Indicates SSTL exceeded pure component soil saturation limit and hence saturation is listed as SSTL
na = Not Applicable/Not Available
(1) Calculated using the equations in ASTM RBCA guidance. Target risk concentrations are corresponding to a cancer risk of one in 100000 or a non-carcinogenic hazard quotient of unity for the exposure pathway being evaluated
(2) The SSTL is the lower of the target risk concentrations for carcinogenic and non-carcinogenic effect, unless they exceed soil saturation of water solubility, in which case the SSTL is set at saturation or solubility concentration.

## Commercial Exposure Scenario
## SUMMARY OF TARGET LEVELS FOR WATER EXPOSURE PATHWAYS

| CHEMICAL | MCL | SHALLOW GROUNDWATER TARGET LEVELS (1,2) | | |
|---|---|---|---|---|
| | | Water Ingestion | Outdoor GW Emissions | Indoor GW Emissions |
| | [mg/L] | [mg/L] | [mg/L] | [mg/L] |
| Benzene | 5.0E-3 | 1.3E-2 | 4.7E+1 | 2.3E+0 |
| Toluene | 1.0E+0 | 1.0E+1 | 5.4E+2 * | 5.4E+2 * |
| Ethylbenzene | 7.0E-1 | 5.1E+0 | 1.5E+2 * | 1.5E+2 * |
| Xylene (mixed) | 1.0E+1 | 1.0E+2 | 2.0E+2 * | 2.0E+2 * |
| Naphthalene | 2.0E-4 | 2.0E+0 | 3.1E+1 * | 3.1E+1 * |
| Benzo(a)pyrene | 2.0E-4 | 2.0E-4 | 1.2E-3 * | 1.2E-3 * |
| MTBE | 3.0E-2 | 2.6E-1 | 5.1E+4 * | 5.1E+4 * |

* Indicates SSTL exceeded pure component water solubility and hence water solubility is listed as SSTL
na = Not Applicable/Not Available
(1) Calculated using the equations in ASTM RBCA guidance Target risk concentrations are corresponding
to a cancer risk of one in 100000 or a non-carcinogenic hazard quotient of unity for the exposure pathway being evaluated
(2) The SSTL is the lower of the target risk concentrations for carcinogenic and non-carcinogenic effect, unless
they exceed soil saturation of water solubility, in which case the SSTL is set at saturation or solubility concentration

**Commercial Exposure Scenario**

## SUMMARY OF TARGET LEVELS FOR AIR EXPOSURE PATHWAYS

| CHEMICAL | AIR TARGET LEVELS (1,2) | |
|---|---|---|
| | Indoor Inhalation [mg/m$^3$] | Outdoor Inhalation [mg/m$^3$] |
| **Benzene** | 1.7E+0 | 1.3E+0 |
| **Toluene** | 7.8E+2 | 5.8E+2 |
| **Ethylbenzene** | 1.9E+3 | 1.5E+3 |
| **Xylene (mixed)** | 1.4E+4 | 1.0E+4 |
| **Naphthalene** | 2.7E+2 | 2.0E+2 |
| **Benzo(a)pyrene** | 2.6E-2 | 2.0E-2 |
| **MTBE** | 5.8E+3 | 4.4E+3 |
| | | |

* Indicates SSTL exceeded pure component water solubility and hence water solubility is listed as SSTL
na = Not Applicable/Not Available
(1) Calculated using the equations in ASTM RBCA guidance. Target risk concentrations are corresponding to a cancer risk of one in 100000 or a non-carcinogenic hazard quotient of unity for the exposure pathway being evaluated.
(2) The SSTL is the lower of the target risk concentrations for carcinogenic and non-carcinogenic effect, unless they exceed soil saturation of water solubility, in which case the SSTL is set at saturation or solubility concentration.

## Construction Exposure Scenario
## EXPOSURE FACTORS AND OTHER RELEVANT PARAMETERS

| PARAMETER | Units | Input Value | Reference |
|---|---|---|---|
| **EXPOSURE PARAMETERS** | | | |
| **Averaging Time for Carcinogens** | yr | **70** | ASTM 1995 - Guide for RBCA |
| **Averaging Time for Noncarcinogens** | yr | **25** | ASTM 1995 - Guide for RBCA |
| **Body Weight Adult** | kg | **70** | ASTM 1995 - Guide for RBCA |
| **Exposure Duration Adult** | yr | **0.5** | six month exposure duration |
| **Exposure Frequency** | days/yr | **250** | ASTM 1995 - Guide for RBCA |
| **Soil ingestion rate Adult** | mg/day | **100** | ASTM 1995 - Guide for RBCA |
| **Daily Indoor Inhalation Rate Adult** | $m^3$/day | **15** | ASTM 1995 - Guide for RBCA |
| **Daily Outdoor Inhalation Rate Adult** | $m^3$/day | **20** | ASTM 1995 - Guide for RBCA |
| **Daily water ingestion rate Adult** | L/day | **2** | ASTM 1995 - Guide for RBCA |
| **Soil to skin adherence factor** | $mg/cm^2$ | **0.5** | ASTM 1995 - Guide for RBCA |
| **Dermal relative absorption factor (volatiles)** | --- | **0.5** | ASTM 1995 - Guide for RBCA |
| **Dermal relative absorption factor (PAHs)** | --- | **0.05** | ASTM 1995 - Guide for RBCA |
| **Oral relative absorption factor** | --- | **1** | ASTM 1995 - Guide for RBCA |
| **Skin surface area Adult** | $cm^2$ | **3,160** | ASTM 1995 - Guide for RBCA |
| **Target Hazard Quotient for individual constituents** | --- | **1** | ASTM 1995 - Guide for RBCA |
| **Target Excess Individual Lifetime Cancer Risk** | --- | **1.0E-5** | ASTM 1995 - Guide for RBCA |
| **CONTAMINANT FATE AND TRANSPORT PARAMETERS** | | | |
| **Lower depth of surficial soil zone** | cm | **100** | ASTM 1995 - Guide for RBCA |
| **Enclosed space air exchange rate** | 1/sec | **0.00014** | ASTM 1995 - Guide for RBCA |
| **Fraction of organic carbon in soil** | g-C/g-soil | **0.01** | ASTM 1995 - Guide for RBCA |
| **Thickness of capillary fringe** | cm | **5** | ASTM 1995 - Guide for RBCA |
| **Thickness of vadose zone** | cm | **295** | ASTM 1995 - Guide for RBCA |
| **Infiltration rate of water through soil** | cm/yr | **30** | ASTM 1995 - Guide for RBCA |
| **Enclosed space volume/infiltration area** | cm | **200** | ASTM 1995 - Guide for RBCA |
| **Enclosed space foundation/wall thickness** | cm | **15** | ASTM 1995 - Guide for RBCA |
| **Depth to groundwater** | cm | **300** | ASTM 1995 - Guide for RBCA |
| **Depth to subsurface soil sources** | cm | **100** | ASTM 1995 - Guide for RBCA |
| **Particulate emission rate** | $g/cm^2$-s | **1.5E-09** | selected to correspond to 50 $\mu g/m^3$ |
| **Wind speed above ground surface in ambient mixing zone** | cm/s | **225** | ASTM 1995 - Guide for RBCA |
| **Groundwater Darcy velocity** | cm/yr | **2500.0** | ASTM 1995 - Guide for RBCA |
| **Width of source area parallel to wind or gw flow** | cm | **1500** | ASTM 1995 - Guide for RBCA |
| **Ambient air mixing zone height** | cm | **200** | ASTM 1995 - Guide for RBCA |
| **Groundwater mixing zone height** | cm | **200** | ASTM 1995 - Guide for RBCA |
| **Areal fraction of cracks in foundation/walls** | $cm^2/cm^2$ | **0.01** | ASTM 1995 - Guide for RBCA |
| **Volumetric air content in capillary fringe soils** | cc/cc | **0.038** | ASTM 1995 - Guide for RBCA |
| **Volumetric air content in found./wall cracks** | cc/cc | **0.26** | ASTM 1995 - Guide for RBCA |
| **Volumetric air content in vadose zone soils** | cc/cc | **0.26** | ASTM 1995 - Guide for RBCA |
| **Total soil porosity** | cc/cc-soil | **0.38** | ASTM 1995 - Guide for RBCA |
| **Volumetric water content in capillary fringe soils** | cc/cc | **0.342** | ASTM 1995 - Guide for RBCA |
| **Volumetric water content in found./wall cracks** | cc/cc | **0.12** | ASTM 1995 - Guide for RBCA |
| **Volumetric water content in vadose zone soils** | cc/cc | **0.12** | ASTM 1995 - Guide for RBCA |
| **Soil bulk density** | g/cc | **1.7** | ASTM 1995 - Guide for RBCA |
| **Averaging time for vapor flux** | sec | **7.88E+8** | ASTM 1995 - Guide for RBCA |

Reference : ASTM 1995. Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites. E 1739-95. November.

## Construction Exposure Scenario
## CHEMICAL-SPECIFIC TOXICITY PARAMETERS

| CHEMICAL | SLOPE FACTOR | | | | REFERENCE DOSE | | | |
|---|---|---|---|---|---|---|---|---|
| | ORAL | | INHALATION | | ORAL | | INHALATION | |
| | [1/(mg/kg-day)] | ref. | [1/(mg/kg-day)] | ref. | [mg/kg-day] | ref. | [mg/kg-day] | ref. |
| **Benzene** | 1.1E-1 | cal/epa | 1.1E-1 | cal/epa | 1.7E-3 | r | 1.7E-3 | n |
| **Toluene** | na | ASTM | na | ASTM | 2.0E-1 | ASTM | 1.1E-1 | ASTM |
| **Ethylbenzene** | na | ASTM | na | ASTM | 1.0E-1 | ASTM | 2.9E-1 | ASTM |
| **Xylene (mixed)** | na | ASTM | na | ASTM | 2.0E+0 | ASTM | 2.0E+0 | ASTM |
| **Naphthalene** | na | ASTM | na | ASTM | 4.0E-2 | n | 4.0E-2 | r |
| **Benzo(a)pyrene** | 7.3E+0 | ASTM | 7.3E+0 | ASTM | na | ASTM | na | ASTM |
| **MTBE** | na | -- | na | -- | 5.0E-3 | n | 8.6E-1 | i |
| | | | | | | | | |

**References**
ASTM = Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites (ASTM E 1739-95, November, 1995).
(i,n,x,r,h) = As referenced in US EPA Region IX Preliminary Remediation Goals (PRGs) 1996
cal/epa = Cal/EPA Memorandum on California Cancer Potency Factors: Update 11/94
na = Not Applicable/Not Available.

## Construction Exposure Scenario
## CHEMICAL-SPECIFIC FATE AND TRANSPORT PARAMETERS

| CHEMICAL | Koc [$cm^3/g$] | H [$atm-m^3/mol$] | H' = H/RT [--] | Solubility [mg/L] | Dair [$cm^2/sec$] | Dwater [$cm^2/sec$] | ABS [--] |
|---|---|---|---|---|---|---|---|
| **Benzene** | 6.5E+1 | 5.5E-3 | 2.3E-1 | 1.8E+3 | 9.3E-2 | 1.10E-5 | 0.5 |
| **Toluene** | 1.4E+2 | 6.6E-3 | 2.7E-1 | 5.4E+2 | 8.5E-2 | 9.40E-6 | 0.5 |
| **Ethylbenzene** | 2.2E+2 | 7.9E-3 | 3.2E-1 | 1.5E+2 | 7.6E-2 | 8.50E-6 | 0.5 |
| **Xylene (mixed)** | 2.4E+2 | 5.3E-3 | 2.2E-1 | 2.0E+2 | 8.7E-2 | 8.50E-6 | 0.5 |
| **Naphthalene** | 1.3E+3 | 1.3E-3 | 5.3E-2 | 3.1E+1 | 7.2E-2 | 9.40E-6 | 0.05 |
| **Benzo(a)pyrene** | 3.9E+5 | 1.4E-9 | 5.7E-8 | 1.2E-3 | 5.0E-2 | 5.80E-6 | 0.05 |
| **MTBE** | 1.2E+1 | 5.4E-4 | 2 2E-2 | 5.1E+4 | 1.0E-1 | 1.10E-5 | 0.5 |
| | | | | | | | |

**Definitions of Parameters**
Koc = Organic carbon partition coefficient
H = Henry's Law constant
Dair = Diffusion coefficient in air
Dwater = Diffusion coefficient in water
ABS = Dermal Absorption Factor

**References**

Basics of Pump and Treat Groundwater Remediation Technology. EPA Office of Research and Development EPA/600/8-90/003 March 1990.
US EPA Region IX Preliminary Remediation Goals (PRGs) 1996.
ASTM Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites (November, 1995)

## Construction Exposure Scenario
## CHEMICAL-SPECIFIC FATE AND TRANSPORT DIFFUSION PARAMETERS

| CHEMICAL | Ds [$cm^2/s$] | Dcrack [$cm^2/s$] | Dcap [$cm^2/s$] | Dws [$cm^2/s$] | Csat [mg/kg] | Kd [$cm^3/g$] |
|---|---|---|---|---|---|---|
| **Benzene** | 7.26E-3 | 7.26E-3 | 2.15E-5 | 1.10E-3 | 1.32E+3 | 6.50E-1 |
| **Toluene** | 6.63E-3 | 6.63E-3 | 1.77E-5 | 9.19E-4 | 7.82E+2 | 1.35E+0 |
| **Ethylbenzene** | 5.93E-3 | 5.93E-3 | 1.49E-5 | 7.79E-4 | 3.53E+2 | 2.20E+0 |
| **Xylene (mixed)** | 6.79E-3 | 6.79E-3 | 1.88E-5 | 9.71E-4 | 4.96E+2 | 2.40E+0 |
| **Naphthalene** | 5.62E-3 | 5.62E-3 | 4.36E-5 | 1.79E-3 | 4.02E+2 | 1.29E+1 |
| **Benzo(a)pyrene** | 6.05E-1 | 6.05E-1 | 1.96E+1 | 6.14E-1 | 4.67E+0 | 3.89E+3 |
| **MTBE** | 7.81E-3 | 7.81E-3 | 1.10E-4 | 3.60E-3 | 9.89E+3 | 1.20E-1 |
| | | | | | | |

**Definitions of Parameters**
Ds = Effective diffusion coefficient in soil based on vapor-phase concentration
Dcrack = Effective diffusion coefficient through foundation cracks
Dcap = Effective diffusion coefficient through capillary fringe
Dws = Effective diffusion coefficient between groundwater and soil surface
Csat = Saturated soil concentration

## Construction Exposure Scenario
## CHEMICAL-SPECIFIC FATE AND TRANSPORT VOLATILIZATION FACTORS

| CHEMICAL | VOLATILIZATION FACTORS | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | VFwesp [mg/m$^3$-air/ mg/L-H2O] | VFwamb [mg/m$^3$-air/ mg/L-H2O] | VFss1 [mg/m$^3$-air/ mg/kg-soil] | VFss2 [mg/m$^3$-air/ mg/kg-soil] | VFp [mg/m$^3$-air/ mg/kg-soil] | VFsamb [mg/m$^3$-air/ mg/kg-soil] | VFsesp [mg/m$^3$-air/ mg/kg-soil] | LFsw [mg/L/ mg/kg] |
| **Benzene** | 1.68E-2 | 2.75E-5 | 8.14E-5 | 7.19E-6 | 5.00E-8 | 7.22E-4 | 4.84E-2 | 1.09E-1 |
| **Toluene** | 1.75E-2 | 2.76E-5 | 6.12E-5 | 7.19E-6 | 5.00E-8 | 4.09E-4 | 2.74E-2 | 5.65E-2 |
| **Ethylbenzene** | 1.81E-2 | 2.81E-5 | 5.03E-5 | 7.19E-6 | 5.00E-8 | 2.76E-4 | 1.85E-2 | 3.56E-2 |
| **Xylene (mixed)** | 1.46E-2 | 2.35E-5 | 4.24E-5 | 7.19E-6 | 5.00E-8 | 1.96E-4 | 1.32E-2 | 3.30E-2 |
| **Naphthalene** | 4.38E-3 | 1.06E-5 | 8.40E-6 | 7.19E-6 | 5.00E-8 | 7.70E-6 | 5.16E-4 | 6.37E-3 |
| **Benzo(a)pyrene** | 6.82E-7 | 3.92E-9 | 5.22E-9 | 7.19E-6 | 5.00E-8 | 2.97E-12 | 1.96E-10 | 2.12E-5 |
| **MTBE** | 2.87E-3 | 8.84E-6 | 5.22E-5 | 7.19E-6 | 5.00E-8 | 2.97E-4 | 1.99E-2 | 4.26E-1 |

**Definitions of Factors**

VFwesp = Volatilization factor from groundwater to enclosed-space vapors
VFwamb = Volatilization factor from groundwater to ambient (outdoor) vapors
VFss = Volatilization factor from surficial soils to ambient air (vapors)
VFp = Volatilization factor from surficial soils to ambient air (particulates)
VFsamb = Volatilization factor from subsurface soils to ambient air
VFsesp = Volatilization factor from subsurface soils to enclosed space vapors
LFsw = Leaching factor from subsurface soils to ground water

## Construction Exposure Scenario
## SUMMARY OF TARGET LEVELS FOR SOIL EXPOSURE PATHWAYS

| CHEMICAL | SOIL TARGET LEVELS (1,2) | | | |
|---|---|---|---|---|
| | Surficial Soil [mg/kg] | Indoor Soil Emiss. [mg/kg] | Outdoor Soil Emiss. [mg/kg] | Leaching to GW (MCL) [mg/kg] |
| Benzene | 1.3E+3 | 1.8E+0 | 9.0E+1 | 2.6E-2 |
| Toluene | 7.8E+2 * | 7.8E+2 * | 7.8E+2 * | 1.0E+1 |
| Ethylbenzene | 3.5E+2 * | 3.5E+2 * | 3.5E+2 * | 1.1E+1 |
| Xylene (mixed) | 5.0E+2 * | 5.0E+2 * | 5.0E+2 * | 1.7E+2 |
| Naphthalene | 4.0E+2 * | 4.0E+2 * | 4.0E+2 * | 1.8E-2 |
| Benzo(a)pyrene | 4.7E+0 * | 4.7E+0 * | 4.7E+0 * | 4.7E+0 * |
| MTBE | 9.9E+3 * | 9.9E+3 * | 9.9E+3 * | 4.0E-2 |

* Indicates SSTL exceeded pure component soil saturation limit and hence saturation is listed as SSTL
na = Not Applicable/Not Available
(1) Calculated using the equations in ASTM RBCA guidance Target risk concentrations are corresponding to a cancer risk of one in 100000 or a non-carcinogenic hazard quotient of unity for the exposure pathway being evaluated.
(2) The SSTL is the lower of the target risk concentrations for carcinogenic and non-carcinogenic effect, unless they exceed soil saturation of water solubility, in which case the SSTL is set at saturation or solubility concentration

## Construction Exposure Scenario
## SUMMARY OF TARGET LEVELS FOR WATER EXPOSURE PATHWAYS

| CHEMICAL | MCL | SHALLOW GROUNDWATER TARGET LEVELS (1,2) | | |
|---|---|---|---|---|
| | | Water Ingestion | Outdoor GW Emissions | Indoor GW Emissions |
| | [mg/L] | [mg/L] | [mg/L] | [mg/L] |
| **Benzene** | 5.0E-3 | 6.5E-1 | 1.8E+3 * | 5.2E+0 |
| **Toluene** | 1.0E+0 | 5.1E+2 | 5.4E+2 * | 5.4E+2 * |
| **Ethylbenzene** | 7.0E-1 | 1.5E+2 * | 1.5E+2 * | 1.5E+2 * |
| **Xylene (mixed)** | 1.0E+1 | 2.0E+2 * | 2.0E+2 * | 2.0E+2 * |
| **Naphthalene** | 2.0E-4 | 3.1E+1 * | 3.1E+1 * | 3.1E+1 * |
| **Benzo(a)pyrene** | 2.0E-4 | 1.2E-3 * | 1.2E-3 * | 1.2E-3 * |
| **MTBE** | 3.0E-2 | 1.3E+1 | 5.1E+4 * | 5.1E+4 * |

* Indicates SSTL exceeded pure component water solubility and hence water solubility is listed as SSTL
na = Not Applicable/Not Available
(1) Calculated using the equations in ASTM RBCA guidance. Target risk concentrations are corresponding to a cancer risk of one in 100000 or a non-carcinogenic hazard quotient of unity for the exposure pathway being evaluated
(2) The SSTL is the lower of the target risk concentrations for carcinogenic and non-carcinogenic effect, unless they exceed soil saturation of water solubility, in which case the SSTL is set at saturation or solubility concentration

## Construction Exposure Scenario
## SUMMARY OF TARGET LEVELS FOR AIR EXPOSURE PATHWAYS

| CHEMICAL | AIR TARGET LEVELS (1,2) | |
|---|---|---|
| | Indoor Inhalation [mg/m$^3$] | Outdoor Inhalation [mg/m$^3$] |
| **Benzene** | 8.7E+1 | 6.5E+1 |
| **Toluene** | 3.9E+4 | 2.9E+4 |
| **Ethylbenzene** | 9.7E+4 | 7.3E+4 |
| **Xylene (mixed)** | 6.8E+5 | 5.1E+5 |
| **Naphthalene** | 1.4E+4 | 1.0E+4 |
| **Benzo(a)pyrene** | 1.3E+0 | 9.8E-1 |
| **MTBE** | 2.9E+5 | 2.2E+5 |
| | | |

* Indicates SSTL exceeded pure component water solubility and hence water solubility is listed as SSTL
na = Not Applicable/Not Available
(1) Calculated using the equations in ASTM RBCA guidance Target risk concentrations are corresponding to a cancer risk of one in 100000 or a non-carcinogenic hazard quotient of unity for the exposure pathway being evaluated.
(2) The SSTL is the lower of the target risk concentrations for carcinogenic and non-carcinogenic effect, unless they exceed soil saturation of water solubility, in which case the SSTL is set at saturation or solubility concentration.

# TABLE. EXAMPLE CALCULATION OF BENZENE SSTL

***Chemical: Benzene (Based on Carcinogenic Risk)***
***Exposure Pathway : Indoor inhalation of vapors from subsurface soil***
***Exposure scenario : Commercial***

**SSTLs [mg/kg]** = SSTLair [mg/m3] x 10-3 [mg/mg] / VFsesp

**SSTLair [µg/m3]** = TR x ATc x 365 [days/year] x 1000 [mg/mg] / [ SFi x EF x ( $ED_{adult}$ x $IR_{air,adult}$ / $BW_{adult}$ )]
*(ASTM RBCA Guidance E 1739 - 95, p. 23, formula 1)*
**SSTLair [µg/m3]** = 1e-5 x 70 x 365 x 1000 / [1.10E-1 x 250 x ( 25 x 15 / 70 )]
**SSTLair [µg/m3]** = **1.73E+0**

$\mathbf{VF_{sesp}}$ = H' x $\rho_s$ x $D_{eff,s}$ x 1000 [ $cm^3$-kg/$m^3$-g] / [$L_S$ x ER x $L_B$ x ( $\theta_{ws}$ + $k_s$ x $\rho_s$ + H' x $\theta_{as}$)] / { 1 + $D_{eff,s}$ / ($L_S$ x ER x $L_B$) + $D_{eff,s}$ x $L_{crack}$ /( $D_{eff,crack}$ x $L_s$ x $\eta$) }

$\mathbf{D_{eff,s}}$ **[cm²/s]** = $D_{air}$ x $\theta_{as}^{3.33}$ / $\theta_T^2$ + $D_{wat}$ x $\theta_{ws}^{3.33}$ / (H' x $\theta_T^2$)
$\mathbf{D_{eff,s}}$ **[cm²/s]** = 0.093 x (0.26)^3.33 / (0.38)^2 + 1.10E-5 x (0.12)^3.33 / ( 2.20E-1 x (0.38)^2)
$\mathbf{D_{eff,s}}$ **[cm²/s]** = **7.26E-3**

$\mathbf{D_{eff,crack}}$ **[cm²/s]** = $D_{air}$ x $\theta_{acrack}^{3.33}$ / $\theta_T^2$ + $D_{wat}$ x $\theta_{wcrack}^{3.33}$ / (H' x $\theta_T^2$)
$\mathbf{D_{eff,crack}}$ **[cm²/s]** = 0.093 x (0.26)^3.33 / (0.38)^2 + 1.10E-5 x (0.12)^3.33 / ( 2.20E-1 x (0.38)^2)
$\mathbf{D_{eff,crack}}$ **[cm²/s]** = **7.26E-3**

$\mathbf{VF_{sesp}}$ = 2.20E-1 x 1.7 x 7.26E-3 x 1000 / [100 x 0.00023 x 300 x (0.12 + 0.01 x 65 x 1.7 + 2.20E-1 x 0.26)] /
{ 1 + 7.26E-3 /(100 x 0.00023 x 300 ) + 7.26E-3 x 15 / ( 7.26E-3 x 100 x 0.0005 )}
$\mathbf{VF_{sesp}}$ = **1.02E-3**

**SSTLs [mg/kg]** = 1.73E+0 x 1E-3 / 1.02E-3
**SSTLs [mg/kg]** = **1.70E+0**

# APPENDIX E

# ASTM RBCA Equations

# 1 RISK-BASED SCREENING LEVEL (RBSLs) – CARCINOGENIC EFFECTS

## 1.1 DEFINITION OF PARAMETERS

| | | |
|---|---|---|
| $AT_c$ | = | Averaging time for carcinogens [years] |
| $BW_{child}$ | = | Child body weight [kg] |
| $BW_{adult}$ | = | Adult body weight [kg] |
| $BW$ | = | Adult body weight [kg] |
| $ED_{child}$ | = | Exposure duration of child [years] |
| $ED_{adult}$ | = | Exposure duration of adult [years] |
| $ED$ | = | Exposure duration of adult[years] |
| $EF$ | = | Exposure frequency [days/year] |
| $IR_{soil,child}$ | = | Soil ingestion rate for child [mg/day] |
| $IR_{soil,adult}$ | = | Soil Ingestion rate for adult [mg/day] |
| $IR_{soil}$ | = | Soil ingestion rate for adult[mg/day] |
| $IR_{air,child}$ - *indoor* | = | Daily indoor inhalation rate for child [$m^3$/day] |
| $IR_{air,adult}$ - *indoor* | = | Daily indoor inhalation rate for adult [$m^3$/day] |
| $IR_{air}$ - *indoor* | = | Daily indoor inhalation rate for adult [$m^3$/day] |
| $IR_{air,child}$ - *outdoor* | = | Daily outdoor inhalation rate for child [$m^3$/day] |
| $IR_{air,adult}$ - *outdoor* | = | Daily outdoor inhalation rate for adult [$m^3$/day] |
| $IR_{air}$ - *outdoor* | = | Daily outdoor inhalation rate for adult [$m^3$/day] |
| $IR_{w,child}$ | = | Daily water ingestion rate for child [L/day] |
| $IR_{w,adult}$ | = | Daily water ingestion rate for adult [L/day] |
| $IR_w$ | = | Daily water ingestion rate for adult [L/day] |
| $LF_{sw}$ | = | Leaching factor from subsurface soils to ground water [(mg/L-$H_2O$)/(mg/kg-soil)] |
| $M$ | = | Soil to skin adherence factor [mg/$cm^2$] |
| $RAF_d$ | = | Dermal relative absorption factor [volatiles/PAHs] |
| $RAF_o$ | = | Oral relative absorption factor [---] |

| | | |
|---|---|---|
| $RBSL_{air}$ | = | Risk-based screening level for air [µg/m$^3$-air] |
| $RBSL_s$ | = | Risk-based screening level for soil [µg/kg-soil or mg/kg-soil] |
| $RBSL_w$ | = | Risk-based screening level for water [mg/L-$H_2O$] |
| $SA_{child}$ | = | Child skin surface area [cm$^2$/day] |
| $SA_{adult}$ | = | Adult skin surface area [cm$^2$/day] |
| $SA$ | = | Adult skin surface area [cm$^2$/day] |
| $SF_i$ | = | Inhalation cancer slope factor [(mg/kg-day)$^{-1}$] |
| $SF_o$ | = | Oral cancer slope factor [(mg/kg-day)$^{-1}$] |
| $TR$ | = | Target excess individual lifetime cancer risk [---] |
| $VF_p$ | = | Volatilization factor from surficial soils to ambiant air (particulates) [(mg/ m$^3$-air)/(mg/kg-soil)] |
| $VF_{samb}$ | = | Volatilization factor from subsurface soils to ambient air [(mg/m$^3$-air)/(mg/kg-soil)] |
| $VF_{sesp}$ | = | Volatilization factor from subsurface soils to enclosed-space vapors [(mg/m$^3$-air)/(mg/kg-soil)] |
| $VF_{ss}$ | = | Volatilization factor from surficial soils to ambiant air (vapors) [(mg/m$^3$-air)/(mg/kg-soil)] |
| $VF_{wamb}$ | = | Volatilization factor from ground water to ambient (outdoor) vapors [(mg/m$^3$-air)/(mg/L-$H_2O$)] |
| $VF_{wesp}$ | = | Volatilization factor from ground water to enclosed-space vapors [(mg/m$^3$-air)/(mg/L-$H_2O$)] |

## 1.2 EQUATIONS

**Risk-Based Screening Level for inhalation of air**

The Risk-Based Screening Level for this route is estimated using:

**For adults:**

$$RBSL_{air}\left[\frac{\mu g}{m^3-air}\right]=\frac{TR\ x\ BW\ x\ AT_c\ x\ 365\ \frac{days}{years}\ x\ 10^3\ \frac{\mu g}{mg}}{SF_i\ x\ IR_{air}\ x\ EF\ x\ ED} \qquad (1)$$

**For children and adults:**

$$RBSL_{air}=\frac{TR\ x\ AT_c\ x\ 365\ x\ 10^3}{SF_i\ \ x\ \ EF}\left(\frac{1}{\left(\frac{ED_{child}\ \ x\ IR_{air.child}}{BW_{child}}+\frac{ED_{adult}\ x\ IR_{air.adult}}{BW_{adult}}\right)}\right) \qquad (2)$$

**Risk-Based Screening Level for ingestion of potable ground water**

The Risk-Based Screening Level for this route is estimated using:

**For adults:**

$$RBSL_{w}\left[\frac{mg}{L-H_2O}\right]=\frac{TR\ x\ BW\ x\ AT_c\ x\ 365\ \frac{days}{years}}{SF_o\ x\ IR_w\ x\ EF\ x\ ED} \qquad (3)$$

**For children and adults:**

$$RBSL_w = \frac{TR \; x \; AT_c \;\; x \; 365}{SF_o \; x \;\; EF}\left(\frac{1}{\left(\frac{ED_{child} \;\; x \; IR_{w,child}}{BW_{child}} + \frac{ED_{adult} \;\; x \; IR_{w,adult}}{BW_{adult}}\right)}\right) \qquad (4)$$

**<u>Risk-Based Screening Level for inhalation of enclosed-space (indoor) vapors from ground water</u>**

The Risk-Based Screening Level for this route is estimated using:

$$RBSL_w\left[\frac{mg}{L-H_2O}\right] = \frac{RBSL_{air}\left[\frac{\mu g}{m^3-air}\right]}{VF_{wesp}} \; x \; 10^{-3} \; \frac{mg}{\mu g} \qquad (5)$$

**<u>Risk-Based Screening Level for inhalation of ambient (outdoor) vapors from ground water</u>**

The Risk-Based Screening Level for this route is estimated using:

$$RBSL_w\left[\frac{mg}{L-H_2O}\right] = \frac{RBSL_{air}\left[\frac{\mu g}{m^3-air}\right]}{VF_{wamb}} \; x \; 10^{-3} \; \frac{mg}{\mu g} \qquad (6)$$

**Risk-Based Screening Level for ingestion of soil, inhalation of vapors and particulates, and dermal contact from surficial soil**

The Risk-Based Screening Level for this route is estimated using:

**For adults:**

$$RBSL_s \left[\frac{\mu g}{kg - soil}\right] = \frac{TR \, x \, BW \, x \, AT_c \, x \, 365 \, \frac{days}{years}}{EF \, x \, ED \, x \left[\left(SF_o \;\; x \, 10^{-6} \frac{kg}{mg} \, x \, (IR_{soil} \, x \, RAF_o \; + \; SA \, x \, M \, x \, RAF_d)\right) + (SF_i \, x \, IR_{air} \, x \, (VF_{as} \; + \; VF_p))\right]} \quad (7)$$

**For children and adults:**

$$RBSL_s = \frac{TR \, x \, AT_c \, x \, 365}{EF \, x \begin{Bmatrix} \frac{ED_{child}}{BW_{child}} x \left[\left(SF_o x \, 10^{-6} x \, (IR_{soil,child} x \, RAF_o + SA_{child} x \, M \, x \, RAF_d)\right) + (SF_i \, x \, IR_{air,child} \, x \, (VF_{ss} + VF_p))\right] + \\ + \frac{ED_{adult}}{BW_{adult}} x \left[\left(SF_o x \, 10^{-6} x \, (IR_{soil,adult} x \, RAF_o + SA_{adult} x \, M \, x \, RAF_d)\right) + (SF_i \, x \, IR_{air,adult} \, x \, (VF_{ss} + VF_p))\right] \end{Bmatrix}} \quad (8)$$

**Risk-Based Screening Level for inhalation of ambient (outdoor) vapors from subsurface soil**

The Risk-Based Screening Level for this route is estimated using:

$$RBSL_s\left[\frac{mg}{kg-soil}\right]=\frac{RBSL_{air}\left[\frac{\mu g}{m^3-air}\right]}{VF_{samb}}\ x\ 10^{-3}\ \frac{mg}{\mu g} \qquad (9)$$

**Risk-Based Screening Level for inhalation of enclosed-space (indoor) vapors from subsurface soil**

The Risk-Based Screening Level for this route is estimated using:

$$RBSL_s\left[\frac{mg}{kg-soil}\right]=\frac{RBSL_{air}\left[\frac{\mu g}{m^3-air}\right]}{VF_{sesp}}\ x\ 10^{-3}\ \frac{mg}{\mu g} \qquad (10)$$

**Risk-Based Screening Level for leaching to ground water from subsurface soil**

The Risk-Based Screening Level for this route is estimated using:

$$RBSL_s\left[\frac{mg}{kg-soil}\right]=\frac{RBSL_w\left[\frac{mg}{L-H_2O}\right]}{LF_{sw}} \qquad (11)$$

# 2 RISK-BASED SCREENING LEVEL (RBSLs) – NONCARCINOGENIC EFFECTS

## 2.1 DEFINITION OF PARAMETERS

| | | |
|---|---|---|
| $AT_n$ | = | Averaging time for non-carcinogens [years] |
| $BW_{child}$ | = | Child body weight [kg] |
| $BW_{adult}$ | = | Adult body weight [kg] |
| $BW$ | = | Adult body weight [kg] |
| $ED_{child}$ | = | Exposure duration of child [years] |
| $ED_{adult}$ | = | Exposure duration of adult [years] |
| $ED$ | = | Exposure duration [years] |
| $EF$ | = | Exposure frequency [days/year] |
| $IR_{soil,child}$ | = | Soil ingestion rate for child [mg/day] |
| $IR_{soil,adult}$ | = | Soil Ingestion rate for adult [mg/day] |
| $IR_{soil}$ | = | Soil ingestion rate for adult [mg/day] |
| $IR_{air,child}$ - *indoor* | = | Daily indoor inhalation rate for child [$m^3$/day] |
| $IR_{air,adult}$ - *indoor* | = | Daily indoor inhalation rate for adult [$m^3$/day] |
| $IR_{air}$ - *indoor* | = | Daily indoor inhalation rate for adult [$m^3$/day] |
| $IR_{air,child}$ - *outdoor* | = | Daily outdoor inhalation rate for child [$m^3$/day] |
| $IR_{air,adult}$ - *outdoor* | = | Daily outdoor inhalation rate for adult [$m^3$/day] |
| $IR_{air}$ - *outdoor* | = | Daily outdoor inhalation rate for adult [$m^3$/day] |
| $IR_{w,child}$ | = | Daily water ingestion rate for child [L/day] |
| $IR_{w,adult}$ | = | Daily water ingestion rate for adult [L/day] |
| $IR_w$ | = | Daily water ingestion rate for adult [L/day] |
| $LF_{sw}$ | = | Leaching [(mg/L-$H_2O$)/(mg/kg-soil)] |
| $M$ | = | Soil to skin adherence factor [mg/$cm^2$] |
| $RAF_d$ | = | Dermal relative absorption factor [volatiles/PAHs] |
| $RAF_o$ | = | Oral relative absorption factor [---] |

| | | |
|---|---|---|
| $RBSL_{air}$ | = | Risk-based screening level for air [µg/m$^3$-air] |
| $RBSL_s$ | = | Risk-based screening level for soil [µg/kg-soil or mg/kg-soil ] |
| $RBSL_w$ | = | Risk-based screening level for water [mg/L-$H_2O$] |
| $RfD_i$ | = | Inhalation chronic reference dose [mg/kg-day] |
| $RfD_o$ | = | Oral chronic reference dose[mg/kg-day] |
| $SA_{child}$ | = | Child skin surface area for child [cm$^2$/day] |
| $SA_{adult}$ | = | Adult skin surface area for adult [cm$^2$/day] |
| $SA$ | = | Adult skin surface area [cm$^2$/day] |
| $SF_i$ | = | Inhalation cancer slope factor [(mg/kg-day)$^{-1}$] |
| $SF_o$ | = | Oral cancer slope factor [(mg/kg-day)$^{-1}$] |
| $THQ$ | = | Target hazard quotient for individual constituents [---] |
| $VF_p$ | = | Volatilization factor from surficial soils to ambiant air (particulates) [(mg/ m$^3$-air)/(mg/kg-soil)] |
| $VF_{samb}$ | = | Volatilization factor from subsurface soils to ambient [(mg/m$^3$-air)/(mg/kg-soil)] |
| $VF_{sesp}$ | = | Volatilization factor from subsurface soils to enclosed-space vapors [(mg/m$^3$-air)/(mg/kg-soil)] |
| $VF_{ss}$ | = | Volatilization factor from surficial soils to ambiant air (vapors) [(mg/m$^3$-air)/(mg/kg-soil)] |
| $VF_{wamb}$ | = | Volatilization factor from ground water to ambient (outdoor) vapors [(mg/m$^3$-air)/(mg/L-$H_2O$)] |
| $VF_{wesp}$ | = | Volatilization factor from ground water to enclosed-space vapors [(mg/m$^3$-air)/(mg/L-$H_2O$)] |

## 2.2 EQUATIONS

**Risk-Based Screening Level for inhalation of air**

The Risk-Based Screening Level for this route is estimated using:

**For adults:**

$$RBSL_{air}\left[\frac{\mu g}{m^3 - air}\right] = \frac{THQ \; x \; RfD_i \; x \; BW \; x \; AT_n \; x \; 365 \; \frac{days}{years} \; x \; 10^3 \; \frac{\mu g}{mg}}{IR_{air} \; x \; EF \; x \; ED} \qquad (12)$$

**For children and adults:**

$$RBSL_{air} = \frac{THQ \; x \; RfD_i \; x \; AT_n \; x \; 365 \; x \; 10^3}{EF}\left(\frac{1}{\left(\frac{ED_{child} \; x \; IR_{air.child}}{BW_{child}} + \frac{ED_{adult} \; x \; IR_{air\;adult}}{BW_{adult}}\right)}\right) \qquad (13)$$

**Risk-Based Screening Level for ingestion of potable ground water**

The Risk-Based Screening Level for this route is estimated using:

**For adults:**

$$RBSL_w\left[\frac{mg}{L - H_2O}\right] = \frac{THQ \; x \; RfD_o \; x \; BW \; x \; AT_n \; x \; 365 \frac{days}{years}}{IR_w \; x \; EF \; x \; ED} \qquad (14)$$

**For children and adults:**

$$RBSL_w = \frac{THQ \; x \; RfD_o \; x \; AT_n \; x \; 365}{EF}\left(\frac{1}{\left(\frac{ED_{child} \; x \; IR_{w,child}}{BW_{child}} + \frac{ED_{adult} \; x \; IR_{w,adult}}{BW_{adult}}\right)}\right) \quad (15)$$

**<u>Risk-Based Screening Level for inhalation of enclosed-space (indoor) vapors from ground water</u>**

The Risk-Based Screening Level for this route is estimated using:

$$RBSL_w\left[\frac{mg}{L-H_2O}\right] = \frac{RBSL_{air}\left[\frac{\mu g}{m^3-air}\right]}{VF_{wesp}} \; x \; 10^{-3}\,\frac{mg}{\mu g} \quad (16)$$

**<u>Risk-Based Screening Level for inhalation of ambient (outdoor) vapors from ground water</u>**

The Risk-Based Screening Level for this route is estimated using:

$$RBSL_w\left[\frac{mg}{L-H_2O}\right] = \frac{RBSL_{air}\left[\frac{\mu g}{m^3-air}\right]}{VF_{wamb}} \; x \; 10^{-3}\,\frac{mg}{\mu g} \quad (17)$$

**Risk-Based Screening Level for ingestion of soil, inhalation of vapors and particulates, and dermal contact from surficial soil**

The Risk-Based Screening Level for this route is estimated using:

**For adults:**

$$RBSL_s \left[\frac{\mu g}{kg - soil}\right] = \qquad (18)$$

$$\frac{THQ \; x \; BW \; x \; AT_n \;\; x \; 365 \; \frac{days}{years}}{EF \; x \; ED \; x \left[\frac{\left(10^{-6} \; \frac{kg}{mg} \; x \; (IR_{soil} \; x \; RAF_o \; + \; SA \; x \; M \; x \; RAF_d)\right)}{RfD_o} + \frac{(IR_{air} \; x \; (VF_{ss} \; + \; VF_p))}{RfD_i}\right]}$$

**For children and adults:**

$$RBSL_s = \qquad (19)$$

$$\frac{THQ \; x \; AT_n \;\; x \; 365}{EF \; x \left\{ \frac{ED_{child}}{BW_{child}} \left[\frac{\left(10^{-6} \; x \; (IR_{soil.child} \; x \; RAF_o \; + \; SA_{child} \; x \; M \; x \; RAF_d)\right)}{RfD_o} + \frac{(IR_{air\;child} \; x \; (VF_{ss} \; + \; VF_p))}{RfD_i}\right] + \frac{ED_{adult}}{BW_{adult}} \left[\frac{\left(10^{-6} \; x \; (IR_{soil.adult} \; x \; RAF_o \; + \; SA_{adult} \; x \; M \; x \; RAF_d)\right)}{RfD_o} + \frac{(IR_{air,adult} \; x \; (VF_{ss} \; + \; VF_p))}{RfD_i}\right] \right\}}$$

**Risk-Based Screening Level for inhalation of ambient (outdoor) vapors from subsurface soil**

The Risk-Based Screening Level for this route is estimated using:

$$RBSL_s \left[\frac{mg}{kg-soil}\right] = \frac{RBSL_{air}\left[\frac{\mu g}{m^3-air}\right]}{VF_{samb}} \ x \ 10^{-3} \ \frac{mg}{\mu g} \tag{20}$$

**Risk-Based Screening Level for inhalation of enclosed-space (indoor) vapors from subsurface soil**

The Risk-Based Screening Level for this route is estimated using:

$$RBSL_s \left[\frac{mg}{kg-soil}\right] = \frac{RBSL_{air}\left[\frac{\mu g}{m^3-air}\right]}{VF_{sesp}} \ x \ 10^{-3} \ \frac{mg}{\mu g} \tag{21}$$

**Risk-Based Screening Level for leaching to ground water from subsurface soil**

The Risk-Based Screening Level for this route is estimated using:

$$RBSL_s \left[\frac{mg}{kg-soil}\right] = \frac{RBSL_w\left[\frac{mg}{L-H_2O}\right]}{LF_{sw}} \tag{22}$$

## 3 EQUATIONS OF VOLATILIZATION FACTORS ( $VF_i$ ), LEACHING FACTOR ( $LF_{sw}$ ), AND EFFECTIVE DIFFUSION COEFFICIENTS ( $D_i^{eff}$ )

### 3 1 DEFINITION OF PARAMETERS

| | | |
|---|---|---|
| $d$ | = | Lower depth of surficial soil zone [cm] |
| $D^{air}$ | = | Diffusion coefficient in air [$cm^2/s$] |
| $D^{wat}$ | = | diffusion coefficient in water [$cm^2/s$] |
| $ER$ | = | Enclosed-space air exchange rate [L/s] |
| $f_{oc}$ | = | Fraction of organic carbon in soil [g-C/g-soil] |
| $H$ | = | henry's law constant [$cm^3$-$H_2O$]/[ $cm^3$-air] |
| $h_{cap}$ | = | Thickness of capillary fringe [cm] |
| $h_v$ | = | Thickness of vadose zone [cm] |
| $I$ | = | Infiltration rate of water through soil [cm/yr] |
| $k_{oc}$ | = | Carbon-water sorption coefficient [$cm^3$-$H_2O$/g-C] |
| $k_s$ | = | Soil-Water sorption coefficient [$cm^3$-$H_2O$/g-soil] |
| $L_B$ | = | Enclosed-space volume/infiltration area ratio [cm] |
| $L_{crack}$ | = | Enclosed-space foundation of wall thickness [cm] |
| $L_{GW}$ | = | Depth to groundwater = $h_{cap} + h_v$ [cm] |
| $L_s$ | = | Depth to subsurface soil sources [cm] |
| $P_e$ | = | Particulate emission rate [g/$cm^2$-s] |
| $S$ | = | Pure component solubility in water [mg/L-$H_2O$] |
| $U_{air}$ | = | Wind speed above ground surface in ambient mixing zone [cm/s] |
| $U_{gw}$ | = | Ground water Darcy velocity [cm/yr] |
| $W$ | = | Width of source area parallel to wind, or ground water flow direction [cm] |
| $\delta_{air}$ | = | Ambient air mixing zone height [cm] |

| | | |
|---|---|---|
| $\delta_{gw}$ | = | Ground water mixing zone thickness [cm] |
| $\eta$ | = | Areal fraction of cracks in foundations/walls [$cm^2$-cracks/$cm^2$-total area] |
| $\theta_{acap}$ | = | Volumetric air content in capillary fringe soils [$cm^3$-air/$cm^3$-soil] |
| $\theta_{acrack}$ | = | Volumetric air content in foundation/wall cracks [$cm^3$-air/ $cm^3$-total volume] |
| $\theta_{as}$ | = | Volumetric air content in vadose zone soils [$cm^3$-air/$cm^3$-soil] |
| $\theta_T$ | = | Total soil porosity [$cm^3$/ $cm^3$-soil] |
| $\theta_{wcap}$ | = | Volumetric water content in capillary fringe soils [$cm^3$-$H_2O$/ $cm^3$-soil] |
| $\theta_{wcrack}$ | = | Volumetric water content in foundation/wall cracks [$cm^3$-$H_2O$/ $cm^3$-total volume] |
| $\theta_{ws}$ | = | Volumetric water content in vadose zone soils [$cm^3$-$H_2O$/ $cm^3$-soil] |
| $\rho_s$ | = | Soil bulk density [g-soil/ $cm^3$-soil] |
| $\tau$ | = | Averaging time for vapor flux [s] |

## 3.2 EQUATIONS

**Volatilization factor from ground water to enclosed-space vapors**

(23)

**Volatilization factor from ground water to ambient (outdoor) vapors**

$$VF_{wamb}\left[\frac{(mg/m^3-air)}{(mg/L-H_2O)}\right] = \frac{H}{1+\left[\dfrac{U_{air}\ x\ \delta_{air}\ x\ L_{GW}}{W\ x\ D_{ws}^{eff}}\right]}\ x\ 10^3\ \frac{L}{m^3} \qquad (24)$$

**Volatilization factor from surficial soils to ambient air (vapors)**

$$VF_{ss}\left[\frac{(mg/m^3\text{ - air})}{(mg/kg-soil)}\right] = \frac{2\ x\ W\ x\ \rho_s}{U_{air}\ x\ \delta_{air}}\sqrt{\frac{D_s^{eff}\ x\ H}{\pi\ x\left[\theta_{ws}+k_s\ x\ \rho_s+H\ x\ \theta_{as}\right]x\ \tau}}\ x\ 10^3\ \frac{cm^3-kg}{m^3-g} \qquad (25)$$

or:

$$VF_{ss}\left[\frac{(mg/m^3\text{ - air})}{(mg/kg-soil)}\right] = \frac{W\ x\ \rho_s\ x\ d}{U_{air}\ x\ \delta_{air}}\ x\ 10^3\ \frac{cm^3-kg}{m^3-g}\text{ ; whichever is less} \qquad (26)$$

**Volatilization factor from surficial soils to ambient air (particulates)**

$$VF_{p}\left[\frac{(mg/m^3\text{ - air})}{(mg/kg-soil)}\right] = \frac{P_e\ x\ W}{U_{air}\ x\ \delta_{air}}\ x\ 10^3\ \frac{cm^3-kg}{m^3-g} \qquad (27)$$

**Volatilization factor from surficial soils to ambient air**

$$VF_{samb}\left[\frac{(mg/m^3\text{ - air})}{(mg/kg-soil)}\right] = \frac{H\ x\ \rho_s}{\left[\theta_{ws}+k_s\ x\ \rho_s+H\ x\ \theta_{as}\right]\text{x}\left(1+\dfrac{U_{air}\ x\ \delta_{air}\ x\ L_S}{D_s^{eff}\ x\ W}\right)}\ x\ 10^3\ \frac{cm^3-kg}{m^3-g} \qquad (28)$$

**Volatilization factor from surficial soil to enclosed-space vapors**

$$VF_{sesp}\left[\frac{(mg/m^3\text{ - air})}{(mg/kg - soil)}\right] = \frac{\dfrac{H\,x\,\rho_s}{\left[\theta_{ws} + k_s\ x\ \rho_s + H\,x\,\theta_{as}\right]}\ \text{x}\left[\dfrac{D_s^{eff}/L_S}{ER\,x\,L_B}\right]}{1 + \left[\dfrac{D_s^{eff}/L_S}{ER\,x\,L_B}\right] + \left[\dfrac{D_s^{eff}/L_S}{(D_{crack}^{eff}/L_{crack})\,x\,\eta}\right]}\ x\ 10^3\ \frac{cm^3 - kg}{m^3 - g} \tag{29}$$

**Leaching factor from subsurface soils to ground water**

$$LF_{sw}\left[\frac{(mg/L - H_2O)}{(mg/kg - soil)}\right] = \frac{\rho_s}{\left[\theta_{ws} + k_s\ x\ \rho_s + H\,x\,\theta_{as}\right]x\left(1 + \dfrac{U_{gw}\ x\ \delta_{gw}}{I\,x\,W}\right)}\ x\ 10^0\ \frac{cm^3 - kg}{L - g} \tag{30}$$

**Effective diffusion coefficient in soil based on vapor-phase concentration**

$$D_s^{eff}\left[\frac{cm^2}{s}\right] = D^{air}\ x\ \frac{\theta_{as}^{3\,33}}{\theta_T^2} + D^{wat}\ x\ \frac{1}{H}\ x\ \frac{\theta_{ws}^{3\,33}}{\theta_T^2} \tag{31}$$

**Effective diffusion coefficient through foundation cracks**

$$D_{crack}^{eff}\left[\frac{cm^2}{s}\right] = D^{air}\ x\ \frac{\theta_{acrack}^{3\,33}}{\theta_T^2} + D^{wat}\ x\ \frac{1}{H}\ x\ \frac{\theta_{wcrack}^{3\,33}}{\theta_T^2} \tag{32}$$

**Effective diffusion coefficient through capillary fringe**

$$D_{cap}^{eff}\left[\frac{cm^2}{s}\right] = D^{air}\ x\ \frac{\theta_{acap}^{3.33}}{\theta_T^2} + D^{wat}\ x\ \frac{1}{H}\ x\ \frac{\theta_{wcap}^{3.33}}{\theta_T^2} \tag{33}$$

**Effective diffusion coefficient between ground water and soil surface**

$$D_{ws}^{eff}\left[\frac{cm^2}{s}\right] = (\,h_{cap} + h_v\,)\ x \left[\frac{h_{cap}}{D_{cap}^{eff}} + \frac{h_v}{D_s^{eff}}\right]^{-1} \tag{34}$$

**Soil concentration at which dissolved pore-water and vapor phases become saturated**

$$C_s^{sat}\left[\frac{mg}{kg - soil}\right] = \frac{S}{\rho_s}\ x\left[\theta_{ws} + k_s\ x\ \rho_s + H\ x\ \theta_{as}\right] x\ 10^0\ \frac{L-g}{cm^3 - kg} \tag{35}$$

## TABLE. PARAMETERS FOR EXPOSURE AND CONTAMINANT FATE TRANSPORT MODELING

| EXPOSURE PARAMETERS | | | | |
|---|---|---|---|---|
| **Parameters** | **Definitions** | **Units** | **Residential** | **Commercial/Industrial** |
| $AT_c$ | Averaging time for carcinogens | years | 70 | 70 |
| $AT_n$ | Averaging time for noncarcinogens | years | 30 | 25 |
| $BW$ | Adult body weight | kg | 70 | 70 |
| $ED$ | Exposure duration of adult | years | 30 | 25 |
| $EF$ | Exposure frequency | days/years | 350 | 250 |
| $IR_{soil}$ | Soil ingestion rate for adult | mg/day | 100 | 50 |
| $IR_{air}$-indoor | Daily indoor inhalation rate of adult | $m^3$/day | 15 | 20 |
| $IR_{air}$-outdoor | Daily outdoor inhalation rate of adult | $m^3$/day | 20 | 20 |
| $IR_w$ | Daily water ingestion rate for adult | L/day | 2 | 1 |
| $LF_{sw}$ | Leaching factor | (mg/L-$H_2O$)/(mg/kg-soil) | Chemical-specific | Chemical-specific |
| $M$ | Soil to skin adherence factor | mg/$cm^2$ | 0.5 | 0 5 |
| $RAF_d$ | Dermal relative absorption factor (volatiles/PAHs) | --- | 0.5/ 0.05 | 0 5/ 0 05 |
| $RAF_o$ | Oral relative absorption factor | --- | 1.0 | 1.0 |
| $RBSL_i$ | Risk-Based screening level for media i | mg/kg-soil, mg/L-$H_2O$, or mg/$m^3$-air | Chemical-, media- and exposure route-specific | Chemical- media- and exposure route-specific |
| $RfD_i$ | Inhalation chronic reference dose | mg/kg-day | Chemical-specific | Chemical-specific |
| $RfD_o$ | Oral chronic reference dose | mg/kg-day | Chemical-specific | Chemical-specific |
| $SA$ | Adult skin surface area | $cm^2$/day | 3160 | 3 160 |
| $SF_i$ | Inhalation cancer slope factor | $(mg/kg\text{-}day)^{-1}$ | Chemical-specific | Chemical-specific |
| $SF_o$ | Oral cancer slope factor | $(mg/kg\text{-}day)^{-1}$ | Chemical-specific | Chemical-specific |
| $THQ$ | Target hazard quotient for individual constituents | --- | 1 0 | 1 0 |
| $TR$ | Target excess individual lifetime cancer risk | --- | $10^{-6}$ to $10^{-4}$ | $10^{-6}$ to $10^{-4}$ |
| $VF_i$ | Volatilization factor | (mg/$m^3$-air)/(mg/kg-soil) or (mg/$m^3$-air)/(mg/L-$H_2O$) | Chemical- and media-specific | Chemical- and media-specific |

| CONTAMINANT FATE AND TRANSPORT PARAMETERS | | | | |
|---|---|---|---|---|
| **Parameters** | **Definitions** | **Units** | **Residential** | **Commercial/Industrial** |
| $d$ | Lower depth of surficial soil zone | cm | 100 | 100 |
| $D^{air}$ | Diffusion coefficient in air | $cm^2$/s | Chemical-specific | Chemical-specific |
| $D^{wat}$ | Diffusion coefficient in water | $cm^2$/s | Chemical-specific | Chemical-specific |
| $ER$ | Enclosed-space air exchange rate | L/sec | 0 00014 | 0 00023 |
| $f_{oc}$ | Fraction of organic carbon in soil | g-C/g-soil | 0 01 | 0 01 |
| $H$ | Henry's law constant | ($cm^3$-$H_2O$)/($cm^3$-air) | Chemical-specific | Chemical-specific |
| $h_{cap}$ | Thickness of capillary fringe | cm | 5 | 5 |
| $h_v$ | Thickness of vadose zone | cm | 295 | 295 |
| $I$ | Infiltration rate of water through soil | cm/year | 30 | 30 |
| $k_{oc}$ | Carbon-water sorption coefficient | $cm^3$-$H_2O$/g-C | Chemical-specific | Chemical-specific |
| $k_s$ | Soil-water sorption coefficient | $cm^3$-$H_2O$/g-soil | $f_{oc} \times k_{oc}$ | $f_{oc} \times k_{oc}$ |
| $L_B$ | Enclosed-space volume/infiltration area ratio | cm | 200 | 300 |
| $L_{crack}$ | Enclosed-space foundation or wall thickness | cm | 15 | 15 |
| $L_{GW}$ | Depth to groundwater = $h_{cap} + h_v$ | cm | 300 | 300 |
| $L_s$ | Depth to subsurface soil sources | cm | 100 | 100 |
| $P_e$ | Particulate emission rate | g/$cm^2$-s | $6.9 \times 10^{-14}$ | $6 9 \times 10^{-14}$ |
| $S$ | Pure component solubility in water | mg/L-$H_2O$ | Chemical-specific | Chemical-specific |
| $U_{air}$ | Wind speed above ground surface in ambient mixing zone | cm/s | 225 | 225 |
| $U_{gw}$ | Groundwater Darcy velocity | cm/year | 2500 | 2500 |
| $W$ | Width of source area parallel to wind, or gw flow direction | cm | 1500 | 1500 |
| $\delta_{air}$ | Ambient air mixing zone height | cm | 200 | 200 |
| $\delta_{gw}$ | Ground water mixing zone thickness | cm | 200 | 200 |
| $\eta$ | Areal fraction of cracks in foundation/walls | $cm^2$-cracks/$cm^2$-total area | 0 01 | 0 01 |
| $\theta_{acap}$ | Volumetric air content in capillary fringe soils | $cm^3$-air/$cm^3$-soil | 0.038 | 0 038 |
| $\theta_{acrack}$ | Volumetric air content in foundation/wall cracks | $cm^3$-air/$cm^3$ total volume | 0.26 | 0 26 |
| $\theta_{as}$ | Volumetric air content in vadose zone soils | $cm^3$-air/$cm^3$-soil | 0 26 | 0.26 |
| $\theta_T$ | Total soil porosity | $cm^3$/$cm^3$-soil | 0.38 | 0.38 |
| $\theta_{wcap}$ | Volumetric water content in capillary fringe soils | $cm^3$-$H_2O$/$cm^3$-soil | 0.342 | 0 342 |

| | | | | |
|---|---|---|---|---|
| $\theta_{w,crack}$ | **Volumetric water content in foundation/wall cracks** | $cm^3$-$H_2O$/$cm^3$ total volume | 0.12 | 0.12 |
| $\theta_{ws}$ | **Volumetric water content in vadose zone soils** | $cm^3$-air/$cm^3$-soil | 0.12 | 0.12 |
| $\rho_s$ | **Soil bulk density** | g-soil/$cm^3$-soil | 1.7 | 1.7 |
| $\tau$ | **Averaging time for vapor flux** | sec | $7.88 \times 10^8$ | $7.88 \times 10^8$ |

**Reference : ASTM Emergency Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites (September, 1995)**