Final
Operable Unit Carbon Tetrachloride Plume Groundwater Remedial Investigation/ Feasibility Study Former Fort Ord, California

Volume II: Human Health Risk Assessment

Prepared for

United States Army Corps of Engineers
Sacramento District
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MACTEC Project No. 55596.001703

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May 19, 2006

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ACRONYMS AND ABBREVIATIONS

ADD	average daily dose
AE	average exposure
ARAR	applicable or relevant and appropriate requirement
AT	averaging time
BW	body weight
Cal/EPA	California Environmental Protection Agency
CF	conversion factor
COPC	chemical of potential concern
CSEM	conceptual site exposure model
CT	carbon tetrachloride
DAD	dermally absorbed dose
DA_{event}	dermally absorbed dose per event
1,2-DCA	1,2-dichloroethane
DI	daily intake
DTSC	Department of Toxic Substances Control
DTW	Depth to Water
ECLR	excess lifetime cancer risk
ED	exposure duration
EF	exposure frequency
EPA	U.S. Environmental Protection Agency
EPC	exposure point concentration
ET	exposure time
EV	event frequency
feet bgs	feet below ground surface
FOD	frequency of detection
GI	gastrointestinal
HEAST	Health Effects Assessment Summary Tables
HHRA	Human Health Risk Assessment
HI	hazard index
HQ	hazard quotient
IR_{ing}	ingestion rate ingestion
IR_{inh}	inhalation rate inhalation
IRIS	Integrated Risk Information System
IUR	inhalation unit risk
J&E Model	Johnson and Ettinger Model
L/m^3	liter per cubic meter
LADD	lifetime average daily dose
LOAEL	lowest-observed-adverse-effect level
mg/kg-day	milligrams per kilogram per day
mg/m^3	milligrams per cubic meter
MACTEC	MACTEC Engineering and Consulting, Inc.
MCL	maximum contamination level
MCWD	Marina Coast Water District
MDL	method detection limit
MEK	methyl ethyl ketone
MTBE	methyl tert-butyl ether
NCEA	National Center for Environmental Assessment

NOAEL	no-observed-adverse-effect level
OEHHA	Office of Environmental Health Hazard Assessment
OU 2	operable unit 2
OUCTP	operable unit carbon tetrachloride plume
PCE	tetrachloroethene
PPRTV	provisional peer review toxicity values
PRG	preliminary remediation goal
PVC	polyvinyl chloride
QC	quality control
R	rejected
REL	reference exposure level
RfC	reference concentration
RfD	reference dose
RI	remedial investigation
RME	reasonable maximum exposure
SA	skin surface area
SAP	Sampling and Analysis Plan
SF	slope factor
SVE	soil vapor extraction
TCE	trichloroethene
UCL	upper confidence limit
µg/L	micrograms per liter
$\mu g/m^3$	micrograms per cubic meter
USACE	U.S. Army Corps of Engineers
VC	vinyl chloride
VOC	volatile organic compound

1.0 HUMAN HEALTH RISK ASSESSMENT

This human health risk assessment (HHRA) was conducted to evaluate potential human health risks from exposure to contaminants in the operable unit carbon tetrachloride plume (OUCTP) using groundwater and soil gas data collected at the site. This HHRA was conducted in accordance with U.S. Environmental Protection Agency (EPA), California Environmental Protection Agency (Cal/EPA)-Department of Toxic Substances Control (DTSC), and U.S. Army Corps of Engineers (USACE) guidance.

2.0 DATA EVALUATION AND CHEMICALS OF POTENTIAL CONCERN

This section describes the HHRA data sets, the groundwater and soil gas data are evaluated to determine their usability in the HHRA, and the chemicals evaluated in the HHRA are selected. The complete list of groundwater samples used in the HHRA is presented in Tables 1 through 4, and the soil gas samples are listed in Table 5. The groundwater sample locations are presented on Plate 3 in Volume I, the soil gas sample locations are presented in Appendix G of Volume I.

2.1 Selection of HHRA Data Sets

A detailed evaluation of the available groundwater and soil gas data was conducted to identify data applicable to the HHRA. The following criteria were used to select appropriate and representative data for inclusion in the HHRA: (1) sample location, (2) sample date, (3) sample depth, (4) duplicate samples, (5) analyte, and (6) data validation and assigned qualifiers. Results of this evaluation are provided in the following text.

1. Sample location. Groundwater samples collected from all wells that are monitored within the OUCTP network were included in the HHRA data set, except for Westbay monitoring wells MP-BW-41 and MP-BW-42. Samples from these two wells were not included in the HHRA data set because groundwater from these wells is being captured and treated by the OU 2 treatment system.

2. Sample date. The OUCTP groundwater has been monitored since 1992 (Section 2.8.2 of Volume I). The most recent groundwater data are considered most representative of current and future concentrations. Therefore, this HHRA focused on groundwater monitoring data from the most recent sampling events from August 2003 to September 2004. Typically, five monitoring events have been conducted per well from August 2003 to September 2004. This is consistent with EPA's guidance requiring data from at least two quarters but preferring four quarters of data in order to account for the impact of seasonal variations (*EPA, 1993*).

   Soil gas data has been collected from July 2002 to October 2004. A soil vapor extraction (SVE) pilot study was conducted in two phases. Phase I started April 6, 2004 and was shut down on June 14, 2004. Phase II started September 9, 2004 and was shut down on November 8, 2004 (Section 3.10 of Volume I). Data that were collected post-Phase I SVE pilot study are considered most representative of current and future conditions.

3. Sample depth. Groundwater data were collected from four different aquifer zones: the A-Aquifer, upper 180 foot, lower 180 – 400 foot, and 400 foot (Section 2.8.1 of Volume I). The groundwater data were divided into four data sets, A-Aquifer, upper 180 foot, lower 180 – 400 foot, and 400 foot, and evaluated separately in the HHRA.

   Samples that were collected from a single well at different depths within an aquifer during a sampling event were considered one sample. Multiple samples corrected at different depths within the same well were evaluated as a single sampling event in the HHRA using the following criteria:

   - Where all results were reported as non-detect, the most conservative (i.e., highest) reporting limit was used in the HHRA;
   - Where all results were reported as detected, the highest of the results was used in the HHRA; and
   - Where there were both detected and non-detected results, the highest detected result was used in the HHRA.

   Soil gas samples were collected at depths ranging from 6 to 85 feet below ground surface (bgs). In the HHRA, data collected at 6 feet bgs was utilized as it considered most representative of contaminant concentrations in the shallow vadose zone.

4. Duplicate samples. Duplicate samples were also collected for selected soil gas samples. For duplicate samples, the following criteria were used to select the results to be applied in the HHRA:

   - Where all results were reported as non-detect, the most conservative (i.e., highest) reporting limit was used in the HHRA;
   - Where all results were reported as detected, the highest of the results was used in the HHRA; and
   - Where there were both detected and non-detected results, the highest detected result was used in the HHRA.

5. Analyte. The OUCTP is monitored for volatile organic compounds (VOCs) by EPA test methods 524.2, 8260, and/or 8260B for groundwater and by EPA test method TO-15 for soil gas. The chemicals of potential concern (COPCs) selected for quantitative evaluation in this HHRA are discussed in Section 2.2 .

6. Data validation and assigned qualifiers. Groundwater data collected from the OUCTP are routinely validated in accordance with the 2002 Draft Basewide Sampling and Analysis Plan

(*SAP; Harding ESE, 2002*). Data that were used in the HHRA included acceptable validated data without qualifiers or with the following qualifiers:

- J – The reported concentration of the constituent was below the reporting limit but above the method detection limit (MDL) and the result was qualified as an estimated value;
- U – The constituent was analyzed but not detected at or above the reporting limit and was qualified as non-detect;
- UJ – The chemical was analyzed but not detected at or above the reporting limit, and the reporting limit is an estimated quantity; and
- Data qualified with an R (rejected) were not used in the HHRA. The R qualifier indicates that quality control (QC) criteria were not met and the resulting values are unusable for the associated sample and chemical.

Tables 1 through 4 present the data sets for the aquifer zones and Table 5 presents the data sets for soil gas that are evaluated in this HHRA.

2.2 Selection of Chemicals of Potential Concern

COPCs are the chemicals in groundwater and soil gas that, based on concentration and toxicity, are most likely to contribute significantly to risks calculated for the exposure pathways evaluated in this HHRA (*EPA, 1989*). A screening process was used in this HHRA to select the COPCs in groundwater that were further evaluated for each data set. All chemicals that were detected in soil gas were included in the HHRA evaluation.

For each groundwater data set (or aquifer), a chemical was selected as a COPC if the frequency of detection (FOD) was greater than 2.5 percent in the HHRA data set (*EPA, 1989*). This criterion was used for COPC selection so that chemicals that have either been routinely detected in each aquifer and/or recently detected within the last year would be evaluated in the HHRA. The COPC screening process based on the FOD criterion is detailed in Table 6.

Although the FOD was greater than 2.5 percent for acetone, methyl ethyl ketone (MEK), and vinyl chloride (VC) in some data sets, these chemicals were excluded as COPCs in groundwater from the HHRA evaluation due to suspect results (Table 6). Acetone and MEK have been identified as false positives because they appear to be related to passive diffusion bags and associated hardware (Section 4.2.1 of Volume I). All VC detections within the lower 180 – 400 foot and 400 foot aquifers were associated with samples collected from Westbay monitoring wells. The sampling technique from the Westbay wells may lead to biased VC detections due to the polyvinyl chloride (PVC) material comprising the monitoring well casing is the source of VC (Section 4.2.3 of Volume I). VC has never been detected

in the only three non-Westbay monitoring wells screened within the lower 180 – 400 foot aquifer (MCWD Well No. 8a, Mini-Storage, and Airfield). The fact that these non-Westbay monitoring wells are located adjacent to or are surrounded by VC detections derived from Westbay wells strongly suggests that the presence of VC is not due to degradation of trichloroethene (TCE), but rather is an artifact of well construction and sampling technique (Section 4.2.3 of Volume I). For this reason, VC detections within the lower 180-400 foot and 400 foot aquifers are considered to be false positives and not related to OUCTP contamination; therefore, VC is not selected as COPC within these two aquifers.

Even though the FOD was less than 2.5 percent for bromoform, this chemical was included as a COPC in the groundwater data set because the weight-of-evidence classification is a probable human carcinogen. Bromodichloromethane, bromoform, chloroform, and dibromochloromethane are not associated with historical site activities, but are commonly encountered as by-products of disinfection of water by chlorination.

Based on the COPC screening process described above and shown in Table 6, the following chemicals were selected as COPCs for each data set (or aquifer) and further evaluated in this HHRA:

- A-aquifer COPCs are bromodichloromethane, bromoform, carbon tetrachloride (CT), chloroform, dibromochloromethane, tetrachloroethene (PCE), and TCE.
- Upper 180 foot aquifer COPCs are CT, chloroform, and chloromethane.
- Lower 180 – 400 foot aquifer COPCs are 1,2-dichloroethane (1,2-DCA), CT, chloroform, and toluene.
- Soil Gas COPCs are CT, chloroform, PCE, and TCE.

No COPCs were selected for the 400-foot aquifer. Therefore, this aquifer was not quantitatively evaluated in the HHRA.

3.0 EXPOSURE ASSESSMENT

Exposure is defined as the contact of a receptor with a chemical or physical agent (*EPA, 1989*). The goal of the exposure assessment is to identify and quantify complete and potentially complete exposure pathways under current and future land use conditions. This section describes the potential receptors and exposure pathways selected for quantitative risk characterization in the HHRA. Exposure assumptions, equations used to estimate dose for the selected receptors, and methods used to derive exposure point concentrations (EPCs) are also described.

3.1 Conceptual Site Exposure Model

A conceptual site exposure model (CSEM) was developed to facilitate the analysis of potentially complete exposure pathways within the OUCTP and surrounding areas. The CSEM schematically represents the relationship between chemical sources and receptors at a site, and identifies potentially complete and significant pathways through which receptors may be exposed to the COPCs. The CSEM is presented in Plate 1.

A complete exposure pathway consists of four components (*EPA, 1989*):

- A source and mechanism of chemical release (e.g., release to the subsurface);
- A retention or transport medium (e.g., groundwater);
- A receptor at a point of potential exposure to a contaminated medium (e.g., resident); and
- An exposure route at the exposure point (e.g., ingestion of groundwater).

If any of these four components are not present, then a exposure pathway is considered incomplete and is not evaluated further. If all four components are present, a pathway is considered complete. In addition to the distinction between complete and incomplete pathways, complete exposure pathways can be further delineated into those expected to be insignificant and those that may be significant. The two types of potentially complete pathways are discussed below:

- Potentially Complete but Insignificant Exposure Pathways. Exposure pathways in this category meet all four requirements to be considered complete. However, these pathways are not expected to contribute significantly to the overall exposure for a receptor, due to the nature of the particular fate and transport mechanisms that comprise the pathway. For this reason, the potential health

impacts associated with these types of pathways are evaluated qualitatively but not quantified this risk assessment.

- Potentially Complete and Significant Exposure Pathways. A potentially complete and significant exposure pathway is comprised of fate and transport mechanisms and exposure characteristics that tend to result in more substantial exposures than complete but insignificant pathways. These pathways comprise the majority of exposure, and as such potential health effects associated with these pathways are quantified in the risk assessment.

The potential receptors and potentially complete exposure pathways for the site are discussed in the sections below.

3.1.1 Potential Receptors

Groundwater within the OUCTP currently is not used by residents within the Fort Ord area for domestic household purposes. Drinking water in the Fort Ord area is provided by the Marina Coast Water District (MCWD) and is pumped from wells that are located east of the OUCTP area screened in the Lower 180-Foot Aquifer. Groundwater from these drinking water wells is then blended together and treated with chlorine before it reaches housing and facilities on former Fort Ord (*MCWD, 2003*). Based on groundwater monitoring data and data provided by the MCWD, these drinking water wells have not been impacted by contaminants related to the OUCTP (*MCWD, 2003; MACTEC, 2005*). Groundwater within the OUCTP is located in a "prohibition zone" within which the installation of new supply wells is restricted by the County. According to Section 3, Subsection D of Section 15.08.140 of Chapter 15.08 of Title 15, of the Monterey County Code, a prohibition zone is an area overlying or adjacent to a contaminant plume where water well construction is prohibited and applications for water supply wells will not be accepted. Therefore, direct contact groundwater exposure pathways for residents potentially exposed to groundwater within the OUCTP are currently incomplete and are expected to remain so in the future. For the evaluation of potential future conditions, it is assumed in this HHRA that the OUCTP groundwater is used by child and adult residents in the area; therefore, all exposure pathways associated with the groundwater are considered complete for evaluation purposes only.

3.1.2 Exposure Pathways

This HHRA assumes that future residents within the Fort Ord area use groundwater for domestic purposes that is directly pumped from the aquifers within the OUCTP. Direct groundwater exposure pathways (i.e., ingestion, dermal contact, and indoor inhalation of vapors during domestic use) for future resident

receptors are considered complete and potentially significant and are quantitatively evaluated in this HHRA.

Vapor intrusion from the subsurface in to indoor air was previously evaluated by collecting indoor air and soil gas data overlying the OUCTP, as reported in the *Draft Final Report, March 2004 Indoor Air Sampling, Lexington Court, Former Fort Ord, California* (*Shaw, 2004b*). Concentrations of VOCs in indoor air were found to be within the range of concentrations detected in background outdoor air, suggesting that subsurface vapors from the OUCTP are not contributing significantly to VOCs in indoor air in residences in the vicinity of the OUCTP (*Shaw, 2004a, b*). However, this HHRA assumes that current and future residents within the OUCTP will be exposed to vapor intrusion from the subsurface to indoor air. This pathway is considered complete and potentially significant and is quantitatively evaluated in this HHRA.

Concentrations of VOCs in outdoor air were previously evaluated for the operable unit 2 (OU 2) landfills. The OU 2 landfills are located adjacent and crossgradient from the OUCTP. Concentrations of VOCs detected in outdoor air from the OU 2 were found to be within the range of concentrations detected in background outdoor air (*Shaw, 2004b*). Vapor intrusion from the subsurface to indoor air could result in concentrations of COPCs that are greater than concentrations in outdoor air. Therefore, outdoor air exposure pathway for future resident receptors are considered potentially complete but insignificant, relative to exposures to indoor air, and qualitatively evaluated in this HHRA.

In summary, the following potentially exposed populations and potentially complete and significant exposure pathways are identified and evaluated in this HHRA (Plate 1):

- Future onsite resident receptors (adult and child):
    - Ingestion of groundwater – Exposure of residents to groundwater contaminants it is assuming that they may ingest contaminated groundwater as drinking water;
    - Dermal contact with groundwater during domestic use – Exposure of residents to groundwater contaminants may result from dermal contact while to showering and/or bathing;
    - Inhalation of vapors from groundwater in indoor air - Exposure of residents to contaminants may result during showering and domestic water use; and
    - Inhalation of vapors from soil gas in indoor air – Exposure of residents to contaminants may result from intrusion of subsurface vapor contamination into indoor air.

3.2 Exposure Point Concentrations

The EPA defines EPCs as the representative chemical concentrations a receptor may contact at an exposure area over the exposure period (*EPA, 1989*). The typical concept of human exposure at a site or within a defined exposure area is that individuals contact the contaminated medium on a periodic and random basis. Because of the repeated nature of such contact, the human exposure does not really occur at a fixed point but rather at a variety with equal likelihood that any given point within the exposure area will be the contact location on any given day. Thus, the EPCs should be the arithmetic averages of the chemical concentrations at various points within the exposure area.

For this HHRA, two types of EPCs were estimated. Groundwater EPCs were calculated to evaluate the ingestion and dermal contact exposure pathways. Air EPCs for groundwater vapors while showering were calculated from the groundwater EPCs.

3.2.1 Groundwater Exposure Point Concentrations

The EPA (*1989*) recommends using an estimate of the upper confidence limit (UCL) on the mean as an EPC for prolonged exposures where it is appropriate to group data. Three types of 95 percent UCLs were calculated in this HHRA for each COPC within each data set (Table 6): (1) arithmetic 95 percent UCL on the mean (*Gilbert, 1987*); (2) 95 percent UCL by Land's method (*Gilbert, 1987*); and (3) bootstrap estimate of the 95 percent UCL (*Manly, 1997*). The equations are provided below for each method. More detailed information on these methods can be found on EPA's website at: http://www.epa.gov/superfund/programs/risk/ragsa/ucl.pdf.

Arithmetic 95 Percent UCL (*Gilbert, 1987*) for a Normal Distribution

$$Arithmetic 95\%UCL = \bar{x} + t_{(a,n-1)} \times \frac{SD}{\sqrt{n}}$$

Where:

$\bar{x}$ =	sample mean
$t_{(a, n-1)}$ =	t score for alpha level (alpha and degrees of freedom = n-1), from table published in Gilbert (*1987*)
SD =	sample standard deviation
n =	number of samples

95 Percent UCL by Land's method (*Gilbert, 1987*) for a Lognormal Distribution

$$Land's 95\%UCL = e^{\bar{x}+0.5sy^2+\frac{sy \times H}{\sqrt{n-1}}}$$

Where:

e =	constant (base of the natural log, equal to 2.718)
$\bar{x}$ =	minimum variance unbiased estimator of the sample mean
sy =	minimum variance unbiased estimator of the sample variance
H =	H value, determined from a table derived by Land and published in Gilbert (*1987*)
n =	number of samples

Bootstrap Estimate of the 95 Percent UCL (*Manly, 1997*) for a Non-Parametric Distribution

The boostrap-t method cannot be explained by an equation, but is rather a process used to derive the 95 percent UCL using an advanced computer program. A detailed explanation of the bootstrap-t can be found in Section 4.9.5 of Appendix A of *ProUCL Version 3.0 User Guide*, EPA/600/R04/079 (*EPA, 2004a*), available on-line at: http://www.epa.gov/nerlesd1/tsc/images/proucl3apr04.pdf. The bootstrap method is used for non-parametric data sets (i.e., data sets that do not fit a normal or log-normal distribution). A bootstrap-t, also known as a bootstrap-pivot algorithm, was used to estimate the bootstrap 95 percent UCL in accordance with the following four steps: 1) The data set was randomly re-sampled with replacement to create a synthetic sample of the same size as the original data set; 2) The arithmetic mean, standard error and "T" value for the synthetic data set were calculated according to Section 3.6 of Manly (*1997*); 3) Steps 1 and 2 were performed 500,000 times and the resulting "T" values were ranked; and 4) The 95th percentile value of the 500,000 "T" values created during Step 3 was selected and used in Equation 3.12 of Manly (*1997*) to derive the bootstrap estimate of the 95 percent UCL on the mean of the original data set.

For non-detect samples, a concentration equal to one-half of the sample-specific reporting limit was used in the 95 percent UCL calculations.

The Shapiro-Wilk W-test (*Algorithm R94, Appl. Statist., 1995*) was conducted for each COPC within each data set to determine if the data set was normally or log-normally distributed with 95 percent confidence. Based on the results of the W-test, the EPC for each COPC within each data set was derived as follows:

- If the W-test for normality did not fail, the data set was assumed to be normally distributed. The EPC was selected as the lesser of the arithmetic 95 percent UCL on the mean and the maximum detected value.
- If the W-test for normality failed and the W-test for log-normality did not fail, the data set was assumed to be log-normally distributed. The EPC was selected as the lesser of the Land's 95 percent UCL on the mean and the maximum detected value.

- If both the W-test for normality and the W-test for log-normality failed, the data set was assumed to be neither normally nor log-normally distributed. The EPC was selected as the lesser of the bootstrap estimate of the 95 percent UCL on the mean and the maximum detected value.

Table 7 provides the results of the W-test, the estimated 95 percent UCLs, and the EPC for each COPC and data set for groundwater.

3.2.2 Air Exposure Point Concentrations from Showering

To estimate EPCs in air from groundwater vapors while showering, a transfer factor, which estimates the ratio of the chemical concentration in indoor air in the bathroom from bathroom water use to the chemical concentration in groundwater, was calculated using the McKone and Bogen equation (*McKone and Bogen, 1992*) as described in Cal/EPA's *CalTOX, A Multimedia Total Exposure Model for Hazardous Waste Sites; Part III: The Multiple Pathway Exposure Model* (*Cal/EPA, 1993*). The transfer factor was multiplied by the groundwater EPC in order to calculate the air EPC. The transfer factor was calculated using the following equation:

$$TF(q \rightarrow bathair) = f_q \times \frac{W_{bath} \times f_x(bath)}{VR_{bath}}$$

where:

TF(q? bathair)	=	The ratio of chemical concentration in indoor air in the bathroom from bathroom water use to the chemical concentration in groundwater liter per cubic meter; (L/m^3);
f_q	=	The fraction of tap water provided by groundwater (unitless);
W_{bath}	=	Water use rate for showering/bathing (rate at which water enters the shower; L/hour);
VR_{bath}	=	Average bathroom ventilation rate (rate at which air leaves the bathroom; cubic meter per hour; m^3/hour); and,
$f_x(bath)$	=	The mass transfer efficiency of a chemical from water to air in the bathroom (unitless).

The mass transfer efficiency indicates how readily the chemical volatilizes from running water according to McKone's (*1987*) equation as described in Cal/EPA (*1993*). The mass transfer efficiency was calculated using the following equation.

$$f(bath) = 0.6 \times \frac{3 \times 10^6 (m^2/s)^{-2/3}}{\frac{2.5}{D_l^{2/3}} + \frac{RT}{H \times D_a^{2/3}}}$$

where:

D_l	=	contaminant diffusion coefficient in water (meters squared per second; m^2/s);
D_a	=	contaminant diffusion coefficient in air (m^2/s);
R	=	universal gas constant (pascals liter per mole Kelvin; Pa-L/mol-K);
T	=	temperature (Kelvin); and,
H	=	Henry's law constant (Pa-L/mol).

Table 8 shows the derivation of air EPCs for each COPC in each data set. Default values from Cal/EPA's CalTOX Model were used for all input values, with the exception of temperature. The water temperature was assumed to be 40^o Celsius or 313.15 Kelvin.

3.3 Intake Estimates

EPA and Cal/EPA-DTSC recommended procedures and exposure assumptions were used to estimate the daily intake (DI), or average daily dose, for each groundwater pathway evaluated in the HHRA (*EPA 1991a, 1997a; Cal/EPA, 1992*). A DI represents an estimate of a chemical dose that a receptor might receive on a daily basis. Standard exposure factors recommended by EPA (*1989, 1991a; 1997a*) and Cal/EPA (*1992*) were used to estimate the DIs.

Two exposure scenarios were evaluated in this HHRA: a reasonable maximum exposure (RME) and an average exposure (AE). RME, as defined by EPA, is the "highest exposure that is reasonably expected to occur" and is estimated using a combination of average and upper-bound values for human exposure assumptions (*EPA, 1989*). For the RME scenario, it was assumed that residents would be exposed to VOCs for 350 days per year for a total duration of 30 years. These are conservative assumptions considering that residents do not typically reside at one place for a total of 30 years and spend the entire time at home. For the AE scenario, exposure durations of 9 and 6 years were assumed for adult and child residents, respectively.

3.3.1 Intake Estimates for Ingestion of Groundwater

The chronic DI for the ingestion of groundwater exposure pathway was calculated according to the following equation:

$$LADD\ or\ ADD = \frac{EPC \times CF \times IR_{ing} \times EF \times ED}{BW \times (AT_c\ or\ AT_{nc})}$$

where:

LADD	=	Lifetime average daily dose for cancer risk (milligrams per kilogram per day [mg/kg-day]);
ADD	=	Average daily dose for noncancer effects (mg/kg-day);
EPC	=	Exposure point concentration of chemical in groundwater (µg/L);

CF	=	Conversion factor (mg/µg);
IR_{ing}	=	Ingestion rate (liter/day);
EF	=	Exposure frequency (days/year);
ED	=	Exposure duration (years);
BW	=	Body weight (kilograms);
AT_c	=	Averaging time (days; toxic effect assessment-determined variable, equal to 70 years or 25,550 days for cancer risk); and
AT_{nc}	=	Averaging time (days; toxic effect assessment-determined variable, equal to ED for noncancer effects).

Table 9 presents the exposure assumptions used in the equation. The estimated DIs for groundwater ingestion for each COPC and data set are presented in Tables 13 and 14.

3.3.2 Intake Estimates for Dermal Exposure to Groundwater

EPA recommended procedures and exposure assumptions were used to estimate the dermally absorbed dose (DAD), or average daily dose, via dermal exposure to groundwater (*EPA, 2004b*). A DAD represents an estimate of a chemical dose that a receptor might receive on a daily basis during showering or bathing. The dermally absorbed dose per event (DA_{event}), an estimate of the total dose dissolved in the skin at the end of exposure, was calculated using the following equation:

$$If\ t_{event} \le t^*,\ then: DA_{event} = 2 \times FA \times K_p \times EPC \sqrt{\frac{6 \times t\ \times t_{event}}{p}}$$

$$If\ t_{event} > t^*,\ then: DA_{event} = FA \times K_p \times EPC \left[\frac{t_{event}}{1+B} + 2 \times t \left(\frac{1+3B+3B^2}{(1+B)^2} \right) \right]$$

where:

t_{event}	=	Event duration (hr/event);
t^*	=	Time to reach steady-state (hr) = 2.4t;
DA_{event}	=	Dermally absorbed dose per event milligram per centimeter squared per event; (mg/cm^2-event);
FA	=	Fraction absorbed water (dimensionless);
K_p	=	Dermal permeability coefficient of compound in water centimeter per hour; (cm/hr);
EPC	=	Exposure point concentration of chemical in groundwater milligram per cubic centimeter; (mg/cm^3);
t	=	Lag time per event (hr/event); and
B	=	Dimensionless ratio of the permeability coefficient of a compound through the stratum corneum relative to its permeability coefficient across the viable epidermis (ve) (dimensionless).

Table 10 provides the derivation of the DA_{event} for each COPC and data set. According to EPA (*2004b*), several of the COPCs evaluated in this HHRA do not need to be assessed via the dermal route because the ratio of groundwater dermal exposure is expected to be 10 percent or less than the groundwater ingestion exposure and therefore, would not contribute significantly to the estimated cumulative risks. These COPCs are 1,2-DCA, bromodichloromethane, chloroform, chloromethane, and dibromochloromethane. For this HHRA, however, all COPCs were conservatively evaluated for the dermal exposure route (Table 10).

The chronic DAD for the dermal exposure to groundwater pathway was calculated according to the following equation:

$$DAD = \frac{DA_{event} \times EV \times ED \times EF \times SA}{BW \times (AT_c \text{ or } AT_{nc})}$$

where:

DAD	=	Dermally absorbed dose (mg/kg-day);
DA_{event}	=	Dermally absorbed dose per event (mg/cm^2-event);
EV	=	Event frequency (events/day);
EF	=	Exposure frequency (days/year);
ED	=	Exposure duration (years);
SA	=	Skin surface area centimeter squared; (cm^2);
BW	=	Body weight (kilograms);
AT_c	=	Averaging time (days; toxic effect assessment-determined variable, equal to 70 years or 25,550 days for cancer risk); and
AT_{nc}	=	Averaging time (days; toxic effect assessment-determined variable, equal to ED for noncancer effects).

Table 9 presents the exposure assumptions used in the equation. The estimated DADs for each COPC and data set are presented in Tables 15 and 16.

3.3.3 Intake Estimates for Inhalation of Groundwater Vapors While Showering

The chronic DI for the inhalation of groundwater vapors while showering exposure pathway was calculated according to the following equation:

$$LADD \text{ or } ADD = \frac{C_{air} \times CF \times IR_{inh} \times EF \times ET \times ED}{BW \times (AT_c \text{ or } AT_{nc})}$$

where:

LADD	=	Lifetime average daily dose for cancer risk mg/kg-day;
ADD	=	Average daily dose for noncancer effects (mg/kg-day);

EPC_{air}	=	Exposure Point Concentration of contaminant in air (µg/m^3);
CF	=	Conversion factor (mg/µg);
IR_{inh}	=	Inhalation rate (m^3/hour):
EF	=	Exposure frequency (days/year);
ED	=	Exposure duration (years);
ET	=	Exposure time (hours/day);
BW	=	Body weight (kilograms);
AT_c	=	Averaging time (days; toxic effect assessment-determined variable, equal to 70 years or 25,550 days for cancer risk); and
AT_{nc}	=	Averaging time (days; toxic effect assessment-determined variable, equal to ED for noncancer effects).

Table 9 presents the exposure assumptions used in the equation. The estimated DIs for inhalation of groundwater vapors for each COPC and data set are presented in Tables 17 and 18.

3.4 Vapor Intrusion Assessment

To evaluate vapor intrusion to indoor air, the DTSC version of the Johnson and Ettinger (J&E) Model was used. The Johnson and Ettinger model is a one-dimensional analytical solution that incorporates both advective and diffusive mechanisms of vapor transport into indoor air (*Cal/EPA, 2005*). It calculates an attenuation coefficient (a) that relates vapor concentration in indoor air to the vapor concentration at the source of contamination in either subsurface soils or groundwater located directly beneath the building. By inputting the soil gas concentrations, the model estimates the associated indoor air concentration. Through the use of specific exposure and toxicity values, the model results are provided as an estimate of the incremental risk associated with site-specific chemical concentrations. The DTSC version of the model uses toxicity criteria developed by OEHHA, and also utilizes certain soil properties that are more representative of the soil types encountered at sites within California (*Cal/EPA, 2005*).

The attenuation factor represents a ratio between indoor air concentration and soil gas concentration, and is calculated as follows (*Cal/EPA, 2005*):

$$a = \frac{C_{indoorair}}{C_{soilgas}}$$

where:

a	=	Attenuation factor;
$C_{indoorair}$	=	Indoor air concentration (micrograms per cubic meter [µg/m^3]); and
$C_{soilgas}$	=	Soil gas concentration (µg/m^3).

The following site-specific parameters were used:

Soil type	=	sand
Groundwater temperature	=	18^{o} Celsius
Sampling depth below grade	=	Sampling location specific (Tables 1 and 5).

Two exposure scenarios were evaluated for the vapor intrusion evaluation: a RME and an AE. For the RME scenario, it was assumed that residents would be exposed to VOCs for 350 days per year for a total duration of 30 years, 24 years for an adult and 6 years for a child. For the AE scenario, exposure durations of 9 and 6 years were assumed for adult and child residents, respectively.

The indoor air concentrations and associated risks are presented on Table 19 and 20, and the J&E Model spreadsheets are presented in Appendix A.

4.0 TOXICITY ASSESSMENT

Toxicity assessment is the process of using the existing toxicity information from human and/or animal studies to identify potential health risks at various dose levels in exposure populations (*EPA, 1989*). To estimate these potential health risks, the relationship between exposure to a chemical (in terms of chronic DI for individuals) and an adverse effect (in terms of bodily response to a specific intake dose level) must be quantified. The methodologies used to develop toxicity factors differ, depending on whether the COPC is a potential carcinogen (i.e., has the potential to cause cancer) and/or has noncancer adverse effects.

Both California and EPA-derived toxicity values were compiled for the HHRA. For California, the Cal/EPA's Office of Environmental Health Hazard Assessment (OEHHA) online toxicity database (*Cal/EPA, 2004*) and chronic Reference Exposure Level (REL) tables (*Cal/EPA, 2003*) were consulted. The EPA values were compiled from EPA's Integrated Risk Information System (IRIS), an online database (*EPA, 2004d*), the National Center for Environmental Assessment (NCEA), provided in EPA's preliminary remediation goal (PRG) tables (*EPA, 2004c*), provided in EPA's PRG tables (*EPA, 2004c*). IRIS is updated regularly based on toxicity and exposure studies. If a toxicity value was not available in any of these sources, EPA's Health Effects Assessment Summary Tables (HEAST; *EPA, 1997b*) were consulted; however, HEAST has not been updated since 1997.

The toxicity values for the COPCs are discussed below and presented in Tables 11 and 12. The uncertainty associated with use of toxicity factors in this assessment is discussed in Section 6.3.

4.1 Cancer Dose-Response Assessment Methodology and Toxicity Criteria

Some chemicals have been shown, and many more are assumed to be, potential human carcinogens. To be health protective, the EPA (*1989*) assumes that a relatively small number of molecular events can elicit changes in a cell, ultimately resulting in uncontrolled cell proliferation and cancer. Based on this theory, the EPA uses a two-part process in evaluating the potential cancer risk of contaminants: (1) assigning a weight-of-evidence classification and (2) calculating a cancer slope factor (SF) for oral exposures and/or inhalation unit risk (IUR) for inhalation exposures.

The EPA (*1986*) weight-of-evidence classification system for carcinogenicity is as follows:

- A Known human carcinogen;
- B1 or B2 Probable human carcinogen;

- C Possible human carcinogen;
- D Not classifiable as to human carcinogenicity; and
- E Evidence of noncarcinogenicity in humans.

The weight-of-evidence classification is based on the source of the data (human epidemiology study or animal bioassay) and whether cancer has been observed in more than one animal species. These alphanumeric classifications are currently being phased out by EPA as toxicity data are reviewed and revised under the *Guidelines for Carcinogenic Risk Assessment* (*EPA, 1999*). Under the revised guidelines, a greater emphasis is placed on the conditions under which the observed effects may be expressed, such as whether the potential for carcinogenicity appears limited to a specific route of exposure, or whether carcinogenic activity may be secondary to another toxic effect. The current weight-of-evidence system is a narrative classification, as follows (*EPA, 1999; EPA, 2003*):

- Carcinogenic to humans;
- Likely to be carcinogenic to humans;
- Suggestive evidence of carcinogenicity, but not sufficient to assess human carcinogenic potential;
- Data are inadequate for an assessment of human carcinogenic potential; and
- Not likely to be carcinogenic to humans.

Tables 11 and 12 present the EPA (*1986*) alphanumeric classification system for the COPCs, as well as the revised EPA (*1999 and 2003*) narrative classification for the COPCs that have been reassessed under the revised Guidelines for Carcinogenic Risk Assessment.

In general, slope factors (SFs) and/or IURs have been calculated and are available for potential carcinogens in Groups A, B1, and B2, but are calculated only on a case-by-case basis for Group C (*EPA, 1989*). The SF is defined as a plausible upper-bound estimate on the probability of a response per unit intake of a chemical over a lifetime, and is based on an assumption of continuous exposure and a linear nonthreshold extrapolation model. The SF is expressed as risk per mg/kg-day, or $(mg/kg\text{-}day)^{-1}$. Because the SF is often an upper 95^{th} percentile confidence limit on the probability of response based on experimental animal data used in the linearized multistage model, the cancer risk estimate will generally be an upper-bound estimate. Thus, one can be reasonably confident that the true risk will not exceed the risk estimate derived using this model. Instead, the EPA has stated that the true risk is likely to be less, and may even be zero (*EPA, 1989*). The IUR is used to evaluate inhalation exposure and is considered an upper-bound excess lifetime cancer risk estimated to result from continuous exposure to an agent at a concentration of 1 micrograms per cubic meter ($\mu g/m^3$) in air; the IURs can be converted to SFs for risk calculation purposes by multiplying the IUR by body weight (70 kilograms) divided by intake rate (20 cubic meters per day). IURs have been developed for known, likely, or suggestive evidence carcinogens for which inhalation assessments have been conducted and reviewed by EPA.

The oral SFs complied for the COPCs are presented in Table 11. In the absence of dermal toxicity factors, EPA recommends using oral SFs with no adjustment to evaluate the dermal exposure pathways for the COPCs evaluated in this HHRA. This is because organic chemicals are generally well absorbed (>50 percent) across the gastrointestinal (GI) tract (*EPA, 2004b*). A cutoff of 50 percent GI absorption is recommended by EPA (*2004b*) to reflect the intrinsic variability in the analysis of absorption studies. This cutoff level obviates the need to make comparatively small adjustments in the toxicity value that would otherwise impart on the process a level of accuracy that is not supported by the scientific literature (*EPA, 2004b*).

The Cal/EPA-OEHHA inhalation SFs and the EPA IURs for the COPCs are presented in Table 12. The EPA IURs were converted to inhalation SFs for risk calculation purposes (the equation and assumptions are provided in Table 12).

The most conservative (i.e., highest) of the Cal/EPA-OEHHA and EPA SFs were selected for use in the HHRA. For dibromochloromethane, an inhalation SF was not available in the literature. In this case, the oral SF was used as a surrogate value.

4.2 Noncancer Dose-Response Assessment Methodology and Toxicity Criteria

Chemically caused toxic endpoints other than cancer and gene mutations are health effects pertaining to the function of various organ systems, and are referred to as systemic or noncancer effects. Based on the scientific understanding of homeostatic and adaptive mechanisms, systemic or noncarcinogenic toxicity is assumed to have an identifiable threshold for both the individual and the population, which means that the organisms or receptors can tolerate a range of exposures without adverse effects. The benchmark value for this threshold for inhalation exposure is the Cal-EPA-OEHHA's chronic REL expressed in units of $\mu g/m^3$ or EPA's inhalation reference concentration (RfC) in units of milligrams per cubic meter (mg/m^3) and for oral exposure is the EPA's chronic reference dose (RfD) in units of mg/kg-day. The REL or RfC is the estimated daily concentration that is considered to pose no appreciable risk of deleterious effects to humans, including sensitive subgroups. The RfD is a numerical estimate of a daily oral exposure or intake that is not likely to cause harmful effects during a lifetime including to sensitive subgroups such as children. Typically, the REL or RfC and RfD are derived from the no-observed-adverse-effect level (NOAEL), which is the highest experimental dose of a chemical at which there is no biologically significant increase in frequency or severity of adverse effects between the exposed population and its appropriate control. For a limited number of chemicals, RELs or RfCs and RfDs are derived based on observations of toxic endpoints in humans that have been exposed in a non-experimental setting.

Uncertainty factors and modifying factors are applied to the NOAEL to address variation in interspecies sensitivity, sensitive subpopulations, using data from a subchronic rather than a chronic study, or using a lowest-observed-adverse-effect level (LOAEL) rather than a NOAEL. Use of these uncertainty and modifying factors add conservatism into the derivation of the REL or RfC and RfD.

The oral RfDs complied for the COPCs are presented in Table 11. In the absence of dermal toxicity factors, EPA recommends using oral RfDs with no adjustment to evaluate the dermal exposure pathways for the COPCs evaluated in this HHRA (similar to that described above in Section 4.1). Therefore, oral RfDs were used to evaluate both oral and dermal exposures in this HHRA.

Cal-EPA-OEHHA's chronic inhalation RELs and EPA's chronic inhalation RfCs are presented in Table 12. The chronic REL and RfC were converted to the inhalation RfD, expressed as mg/kg-day, for risk calculation purposes (the equation and assumptions are provided in Table 12).

The most conservative (i.e., lowest) of the Cal/EPA-OEHHA and EPA RfDs were selected for used in the HHRA. For bromodichloromethane and dibromochloromethane, inhalation RfDs were not available in the literature. In these cases, the oral RfDs were used as surrogate values. Similarly, an inhalation RfD was used for chloromethane which lacks an oral RfD.

5.0 RISK CHARACTERIZATION

The risk characterization integrates the COPC selection, exposure assessment, and toxicity assessment to describe the risks to individuals in terms of the nature and likelihood of potential adverse health risks to occur. The risk characterization process involved integrating the exposure intakes and toxicity values to estimate both cancer risk and noncancer hazards to potential residential receptors from exposure to COPCs in groundwater at the site. Because cancer risk and noncancer effects are quantified differently, separate methods were used to evaluate these effects, as described below.

5.1 Cancer Risk Characterization Methodology

Cancer risk is expressed as an increased probability of developing cancer over a lifetime as a result of the estimated exposure. Cancer risk characterization methodology is predicated on the regulatory assumption that cancer induction does not have a threshold, and any dose, no matter how small, is associated with some incremental or excess cancer risk.

For a given COPC and data set, the excess lifetime cancer risk (ECLR) associated with exposure to the COPC in groundwater was estimated per pathway by multiplying the DI by the SF, according to the following equation (*EPA, 1989*):

$$ECLR = (LADD \text{ or } DAD) \times SF$$

where:

ECLR	=	Excess lifetime cancer risk (unitless);
LADD	=	Lifetime average daily dose, averaged over a lifetime of 70 years (mg/kg-day);
DAD	=	Dermally absorbed dose (mg/kg-day); and
SF	=	Cancer slope factor $(mg/kg\text{-}day)^{-1}$; oral SF used for oral and dermal exposures and inhalation SF used for inhalation exposure.

The ECLR values are expressed in terms such as one-in-ten-thousand (1E-04) or one-in-one-million (1E-06). An excess cancer risk of 1E-06 means that an exposed individual may have an added one-in-one-million chance of developing cancer than would an unexposed individual.

To address exposure to multiple chemicals and exposure pathways within each data set, chemical-specific and pathway specific risks were summed to provide a total theoretical excess risk. To evaluate risks potentially associated with a residential RME scenario, risks for child and adult residents were summed to account for a total exposure duration of 30 years (i.e., 6 years as a child and 24 years as an adult). For the

AE scenario, child and adult cancer risks were evaluated separately because the total exposure duration was assumed to be 9 years as an adult or 6 years as a child.

The chemical- and pathway-specific ECLR estimates for each data set are presented in Tables 13 through 20. Table 21 summarizes the cumulative ECLR estimates from all exposure pathways for each data set. The cancer risk estimates are discussed below in Section 5.3

5.2 Noncancer Effects Characterization Methodology

The potential for noncancer effects was evaluated by comparing the average daily dose with the chronic RfD to arrive at a ratio called the hazard quotient (HQ). For a given COPC and data set, the HQ associated with exposure to the COPC in groundwater was estimated by dividing the DI by the RfD, according to the following equation (*EPA, 1989*):

$$HQ = \frac{(ADD \text{ or } DAD)}{RfD}$$

where:

HQ	=	Hazard quotient (unitless);
ADD	=	Average daily dose (mg/kg-day);
DAD	=	Dermally absorbed dose (mg/kg-day); and
RfD	=	Chronic reference dose (mg/kg-day); oral RfD used for oral and dermal exposures and inhalation RfD used for inhalation exposure.

This ratio is termed the HQ, or in other words, the HQ is the ratio of the exposure level to the noncancer toxicity factor. The HQ approach assumes that there is a level of exposure (e.g., RfD) below which it is unlikely that even sensitive populations would experience adverse health effects. If the exposure level exceeds the threshold (i.e., if HQ exceeds one or unity), there may be concern for potential noncancer effects.

The potential additivity of noncancer hazard due to exposure to multiple substances is quantified as a hazard index (HI), which is the sum of all possible chemical-specific HQs for the data set (*EPA, 1989*). Usually, if the total HI is greater than unity or one, meaning the exposure level exceeds the threshold RfD, a potential for adverse noncancer health effects may exist. If the HI is equal to or less than one, exposures to the COPCs are not expected to result in a systemic toxic response. It should be noted that HQs and HIs are not statistical probabilities, such as excess cancer risks, and the level of concern does not increase linearly as the RfD is approached or exceeded. If the route-specific or cumulative exposure HI is greater than one, segregation of the HI, based on the type of effects, target organ specificity, or mechanisms of action, can be considered (*EPA, 1989*).

The chemical- and pathway-specific HQs and HI estimates for the data sets are presented in Tables 13 through 20. Table 21 summarizes the cumulative HI estimates from all exposure pathways for each data set. The noncancer HI estimates are discussed below in Section 5.3.

5.3 Summary of Estimated Cancer Risks and Noncancer Hazards

This section provides a summary and discussion of the estimated cancer risks and noncancer hazards with respect to groundwater and soil gas related risk.

5.3.1 Summary of Estimated Cancer Risks for Domestic Use of Groundwater

Table 21 summarizes the total cancer risks estimated by aquifer for all exposure pathways associated with domestic use of groundwater evaluated in the HHRA (i.e., groundwater ingestion, groundwater dermal contact, and inhalation of groundwater vapors while showering). The following table summarizes the total cancer risk estimates by aquifer.

Summary of Total Estimated Cancer Risks for Domestic Use of Groundwater (1)

Aquifer	Total Adult + Child RME Risk (30 Year Exposure)	Adult AE Risk (9 Year Exposure)	Child AE Risk (6 Year Exposure)
A-Aquifer	1E-05	2E-06	3E-06
Upper 180 Foot	4E-06	6E-07	9E-07
Lower 180-400 Foot	2E-06	4E-07	6E-07

(1) From Table 21.

As shown above and in Table 21, the total adult and child resident RME risks estimated for the aquifers range from 2E-06 to 1E-05. Under AE conditions, the maximum risks decreased to 2E-06 and 3E-06 for the adult and child resident, respectively. The A-Aquifer was associated with the highest risk, followed by the Upper 180 Foot-Aquifer and then the Lower 180-400 Foot-Aquifer.

5.3.2 Summary of Estimated Noncancer Hazards for Domestic Use of Groundwater

Table 21 summarizes the total noncancer hazards estimated by aquifer for all exposure pathways associated with domestic use of groundwater evaluated in the HHRA (i.e., groundwater ingestion, groundwater dermal contact, and inhalation of groundwater vapors while showering). The following table summarizes the total noncancer hazard estimates by aquifer.

Summary of Total Estimated Noncancer Hazards for Domestic Use of Groundwater (1)

Aquifer	Adult RME Hazard (24 Year Exposure)	Child RME Hazard (6 Year Exposure)	Adult AE Hazard (9 Year Exposure)	Child AE Hazard (6 Year Exposure)
A-Aquifer	0.2	0.5	0.2	0.4
Upper 180 Foot	0.06	0.1	0.04	0.1
Lower 180-400 Foot	0.03	0.07	0.02	0.05

(1) From Table 21.

As shown in Table 21, the total RME hazards estimated for the aquifers range from 0.03 to 0.2 for the adult resident and 0.07 to 0.5 for the child resident. Under AE conditions, the hazards for the aquifers decreased to 0.02 to 0.2 for the adult resident and 0.05 to 0.4 for the child resident. These cumulative noncancer hazard estimates for groundwater exposure are below the noncancer HI value of one.

5.3.3 Summary of Estimated Cancer Risks for Vapor Intrusion to Indoor Air

Tables 19 and 20 summarizes the total estimated cancer risks by sample location for vapor intrusion to indoor air. These results are summarized in the following table:.

Summary of Total Estimated Cancer Risks for Vapor Intrusion to Indoor Air (1)

Sample Location	Total Adult + Child RME Risk (30 Year Exposure)	Adult AE Risk (9 Year Exposure)	Child AE Risk (6 Year Exposure)
CTP-SGP-35	5E-08	1E-08	1E-08

(1) From Tables 19 and 20.

As shown above and in Table 19 and 20, the total adult and child resident estimated RME risk at CTP-SGP-35 is 5E-08. Under AE conditions, the estimated risks are 1E-08 for the adult and child resident.

5.3.4 Summary of Estimated Noncancer Hazards for Vapor Intrusion to Indoor Air

Tables 19 and 20 lists the total noncancer hazards estimated by sample location for vapor intrusion to indoor air. These results are summarized in the following table:

Summary of Total Estimated Noncancer Hazards for Vapor Intrusion to Indoor Air (1)

Sample Location	Adult RME Hazard (24 Year Exposure)	Child RME Hazard (6 Year Exposure)	Adult AE Hazard (9 Year Exposure)	Child AE Hazard (6 Year Exposure)
CTP-SGP-35	0.00007	0.00002	0.00002	0.00002

(1) From Tables 19 and 20.

As shown in Tables 19 and 20, the total estimated RME hazards at CTP-SGP-35 is 0.00007 for the adult resident, and 0.00002 for the child resident. Under AE conditions, the hazards are 0.00002 for the adult and child resident.

5.3.5 Summary of Estimated Cancer Risks

Table 21 summarizes the total cancer risks estimated by aquifer for all exposure pathways quantitatively evaluated in the HHRA. These results are summarized in the following table:

Summary of Total Estimated Cancer Risks (1)

Aquifer	Total Adult + Child RME Risk (30 Year Exposure)	Adult AE Risk (9 Year Exposure)	Child AE Risk (6 Year Exposure)
A-Aquifer	1E-05	2E-06	3E-06
Upper 180 Foot	4E-06	6E-07	9E-07
Lower 180-400 Foot	2E-06	4E-07	6E-07

(1) From Table 21.

As shown above and in Table 21, the total adult and child resident estimated RME risks for each aquifer ranged from 2E-06 to 1E-05. Under AE conditions, the estimated risks range from 4E-07 and 2E-06 for the adult and range from 6E-07 to 3E-06 for child resident. The A-Aquifer was associated with the highest risk, followed by the Upper 180 Foot-Aquifer, and the Lower 180-400 Foot-Aquifer.

Ingestion of groundwater contributes to the greatest potential risk, contributing approximately 76 to 81 percent of the total risk (Table 21). Dermal contact contributed approximately 17 to 23 percent of the estimated risk, and vapor intrusion to indoor air contributed to 0.4 to 2 percent of the estimated risk. The total contribution from inhalation of vapors while showering was negligible.

The total risks by COPC and pathway for each aquifer are presented in Tables 13 through 18, and in Tables 19 and 20 for each specific sample location.

For ingestion of groundwater, the following COPCs were identified as risk drivers (i.e., those COPCs contributing to 10 percent or greater of the total risk):

- A-Aquifer: CT (63 percent) and PCE (22 percent)
- Upper 180 Foot-Aquifer: CT (96 percent)
- Lower 180-400 Foot-Aquifer: 1,2-DCA (21 percent) and CT (73 percent), though the ingestion risk from 1,2-DCA was below 1E-06.

Risk drivers associated with dermal contact are as follows:

- A-Aquifer: CT (54 percent) and PCE (42 percent)
- Upper 180 Foot-Aquifer: CT (98 percent), though the total dermal risk was below 1E-06
- Lower 180-400 Foot-Aquifer: CT (92 percent), though the total dermal risk was below 1E-06.

5.3.6 Summary of Estimated Noncancer Hazards for Direct Contact with Groundwater

Table 21 summarizes the total estimated noncancer hazards by aquifer for all exposure pathways associated with direct contact with groundwater evaluated in the HHRA. These results are summarized in the following table.

Summary of Total Estimated Noncancer Hazards for Direct Contact with Groundwater [(1)]

Aquifer	Adult RME Hazard (24 Year Exposure)	Child RME Hazard (6 Year Exposure)	Adult AE Hazard (9 Year Exposure)	Child AE Hazard (6 Year Exposure)
A-Aquifer	0.2	0.5	0.2	0.4
Upper 180 Foot	0.06	0.1	0.04	0.1
Lower 180-400 Foot	0.03	0.07	0.02	0.05

(1) From Table 21.

As shown in Table 21, the total estimated RME hazards for the aquifers ranged from 0.06 to 0.2 for the adult resident and 0.07 to 0.5 for the child resident. Under AE conditions, the estimated hazards are 0.02 to 0.2 for the adult resident and 0.05 to 0.4 for the child resident, respectively.

6.0 UNCERTAINTY ANALYSIS

Uncertainty is inherent in many aspects of the risk assessment process. All HHRAs involve the use of assumptions, judgments, and incomplete data to varying degrees that may contribute to the uncertainty associated with the final risk estimates. Uncertainties may result from both the use of assumptions or models in lieu of actual data and from the error inherent in the estimation of exposure parameters. These uncertainties may result in the potential over-or underestimation of risks. However, because direct measurements are not available for many of the criteria upon which the risk estimates are dependent, conservative assumptions and methodologies are generally employed to eliminate the possibility of underestimating risk.

Consideration of the uncertainty associated with the components of the risk assessment process allows for a more meaningful interpretation of the results and a better understanding of the potential for adverse effects on human health. Some of the major potential uncertainties and the effects of these uncertainties on the HHRA risk estimates are discussed below.

6.1 Data Sets and COPC Selection

This section discusses the uncertainties associated with the data used in the HHRA and COPC selection process.

6.1.1 Groundwater Data Sets

The groundwater data were divided into four aquifer zones: A-aquifer, upper-180 foot, lower 180 – 400 foot, and 400 foot. The most recent sampling events that occurred from August 2003 to September 2004 were evaluated in this HHRA. The use of the most current groundwater monitoring events from August 2003 to September 2004 is considered most representative of current site conditions (*EPA, 1993*). Using the most current groundwater monitoring events from August 2003 to September 2004 may result in overestimation or underestimation in risk. An overestimation in risk can result from using groundwater data where the chemicals have not been regularly detected. However, the FOD criterion of 2.5 percent in the COPC selection process was used to account for this potential overestimation of risk by eliminating chemicals that have not been detected frequently in the OUCTP. An underestimation of risk can result if chemicals were not detected recently in the OUCTP plume, but are present currently in groundwater; however, this underestimation is unlikely given that CT and its expected breakdown products, chloromethane and chloroform, were detected in most aquifers and evaluated in the HHRA.

6.1.2 Analytical Methods

Error in chemical analyses may result from several sources including errors inherent in the sampling and analytical procedures. Analytical accuracy or sampling errors can result in the rejection of data, which decreases the available data for use in the HHRA, or in the qualification of data, which increases the uncertainty in the detected chemical concentrations.

6.1.3 COPC Selection

A COPC selection process was used to focus the HHRA on the chemicals in groundwater that, based on concentration and toxicity, are most likely to contribute significantly to risks. Chemicals with a FOD greater than 2.5 percent were selected as COPCs. This criterion was used to select the chemicals that would be most representative of current and future groundwater exposure conditions. Acetone, MEK, and VC were excluded from the data sets in cases where the FOD was greater than 2.5 percent because the results are suspect, as described in Section 2.2.

6.2 Exposure Assessment

Exposure assessment is a single step in the HHRA process that uses a wide array of information sources and techniques. In the absence of reliable sources of data, assumptions and inferences are often made that lead to varying degrees of uncertainties, mostly on the conservative side of the HHRA. Sources of uncertainty in exposure assessment include the degrees of completeness and confidence in (1) chemical concentration estimation (related to field measurement and modeling parameter estimation); (2) time of contact identification (for example, exposure scenario characterization, target population identification, and population stability over time); and (3) the methodology for chemical intake calculation. Variability or heterogeneity in exposure routes and exposure dynamics, such as age, gender, behavior, genetic constitution, state of health, and random movement of the potentially exposed populations, also contribute to the uncertainty of the exposure estimates.

6.2.1 Source of Exposure

This HHRA assumed that residents directly pump the groundwater from the OUCTP aquifers for domestic use. However, domestic water supply in the Fort Ord area is provided by the MCWD. MCWD groundwater is pumped from wells that are located in the City of Marina and not have been impacted by contaminants related to the OUCTP. Groundwater within the OUCTP is located in a “prohibition zone,” which is an area overlying or adjacent to a contaminant plume where water well construction is prohibited and applications for water supply wells will not be accepted. However, it was conservatively assumed in

this HHRA that current and future residents would be exposed to groundwater within the OUCTP during domestic use.

6.2.2 Exposure Point Concentrations

For this HHRA, 95 percent UCL concentrations were calculated and used as EPCs in the risk calculations if they were less than the maximum detected value of the data set. The use of 95 percent UCL concentrations (which are upper-bound estimates of averages) as EPCs was considered to be appropriate because it accounts for the likelihood that human receptors will contact various points throughout the exposure area, rather than a fixed point. This is considered representative of groundwater exposure because, if used for domestic purposes, the groundwater would be blended before being supplied to residences in the area.

When a chemical-specific result was reported at a concentration below the reporting limit, but above the MDL, the result was qualified as J, or estimated. The uncertainty associated with J-qualified values generally is not great, because the MDL and reporting limits differed by less than three-fold. Results were only reported as U, or non-detect, when the result was reported below the MDL. While the concentration may be highly uncertain for substances below the MDL, it does not necessarily mean that the concentration is zero (*EPA, 1989*). In this HHRA, a simple substitution method was used to address non-detect data, and the non-detected values were assigned a proxy value of one-half the reporting limit. The substitution approach of one-half the reporting limit may result in under- or overestimation of the expected true mean concentrations and, therefore, under- or overestimation of risk.

Because direct measurements were not available for shower air, a modeling approach was used to estimate air EPCs. The shower model was used to predict shower air EPCs from groundwater EPCs under assumed exposure conditions. The majority of input parameters in the model were chemical-specific parameters that are measured values and have a low degree of error. Exposure assumptions used in the model, including water use rate and bathroom inhalation rate, and the assumption of transfer efficiency in the model itself, may have resulted in an underestimation or overestimation of risk.

6.2.3 Exposure Assumptions and Intake Estimates

The goal of characterizing the time of contact is to develop estimates of contact rate and frequency and duration of exposure. This was done indirectly by use of national demographic data and behavior observation, which is, in some instances, not site-specific and may lead to over- or underestimation of exposure. For this HHRA, most of the exposure assumptions were selected to be conservative and health protective. For example, for the RME scenario, it was assumed that residents would be exposed to VOCs

in groundwater for 350 days per year for 30 years. This is conservative given that most humans are not likely to reside at one location for a total of 30 years.

6.2.4 Vapor Intrusion Assessment

The risks and HIs for the vapor intrusion pathway were calculated using the DTSC version of the J&E Model. The J&E Model uses the conservation of mass principle and is based on the following assumptions (Cal/EPA, 2005):

- Steady-state conditions exist;
- An infinite source of contamination exists;
- The subsurface is homogeneous;
- Air mixing in the building is uniform;
- Preferential pathways do not exist;
- Biodegradation of vapors does not occur;
- Contaminants are homogeneously distributed;
- Contaminant vapors enter a building primarily through cracks in the foundation and walls;
- Buildings are constructed on slabs or with basements; and
- Ventilation rates and pressure differences are assumed to remain constant.

Assumptions that may result in a risk or hazard greater than the calculated value are:

- An assumption that preferential pathways do not exist: The model does not account for preferential pathways that would facilitate the movement of soil vapors into indoor air spaces, such as, the presence of permeable fill material below foundations, openings in the foundation slab for electrical conduits, plumbing, drainage, and heating and cooling equipment.
- Ventilation rates and pressure differences are assumed to remain constant.
- Decreases in ventilation rates could lead to a buildup of contaminant vapors in indoor air intruding from the subsurface.
- Degradation to more toxic daughter products (i.e., PCE to vinyl chloride) is not occurring.

Assumptions that may result in a risk or hazard lower than the calculated value are:

- An infinite source of contamination exists: The mass of chemicals available for volatilization into soil pore spaces decreases over time due to biodegradation, and cleanup of contamination.
- The subsurface is homogeneous: The subsurface in the model was assumed to be sand, which is based on boring logs of the area, and does not take into consideration any fine grained lenses of soil that were encountered.

Additionally, when the model is calculating risk and HIs, the body weight for an adult and intake rate of 20 cubic meters per day are used when estimating risks and hazards for child receptors, which create an underestimation of exposure for child receptor.

A soil gas sample was collected at 85 feet bgs at CTP-SGP-66, which is located downgradient from the potential source area at the northern most point of Preston Drive. No analytes were detected by EPA Method TO-15. The closest groundwater monitoring well, MW-BW-53-A, is a distance of approximately 125 feet crossgradient from CTP-SGP-66. The measured depth to groundwater at MW-BW-53-A is approximately 96 feet bgs. Reported contaminant concentrations at MW-BW-53-A are 15 µg/L CT, 1.8 µg/L chloroform, and 6.4 µg/L TCE. The proximity of the two sampling locations, and the fact that no contaminants were detected at concentrations greater than reporting limits in soil gas suggests that off gassing from groundwater is not significant.

In March 2004, prior to the implementation of SVE, the air in Building 6277 in Lexington Court was sampled to evaluate the potential of VOCs in groundwater as a source of VOC contamination in indoor air (*Shaw, 2004b*). The J&E model was used to estimate indoor air concentrations using soil gas data collected immediately below the slab foundation and at 6 feet bgs. Indoor air concentrations were calculated for carbon tetrachloride, 1,3-butadiene, benzene, chloroform, PCE, and TCE, which were the only contaminants detected in either the sub-slab or 6-foot bgs samples. The modeled indoor air concentrations were between 1 and 3 orders of magnitude less than the measured indoor air concentrations, and measured indoor air concentrations were within the range of concentrations measured in outdoor air during the Ft. Ord outdoor air monitoring. Measured indoor air concentrations were also comparable with concentrations in outdoor air samples collected at Lexington Court. While far from conclusive, these results suggest that groundwater contamination does not appear to be a significant source of contamination to indoor air. For this HHRA, soil gas data collected at CTP-SGP-35 represent data closest to Building 6277 with the highest concentration post-Phase I SVE pilot study. Utilizing data collected at 6 feet bgs, modeled indoor air concentrations are approximately 2 orders of magnitude less

than measured indoor air concentrations (modeled versus measured indoor air concentrations are, respectively, 0.003 and 0.6 µg/m^3 carbon tetrachloride, 0.0001 and 0.1 µg/m^3 chloroform, 0.0006 and 0.3 µg/m^3 PCE, and 0.0006 and 0.09 µg/m^3 TCE). Hence, even using conservative default inputs, indoor air concentrations estimated using the J&E Model are substantially less than those observed through actual indoor air sampling. This further suggests that any contribution to VOC concentrations in indoor air arising from groundwater and/or subsurface contamination is negligible relative to VOC concentrations in outdoor air.

6.3 Toxicity Criteria

Risks and HIs were calculated using Cal/EPA and EPA-derived dose-response criteria. These health effects criteria are conservative and designed to be protective of sensitive subpopulations, such as children and the elderly. The health criteria used in the evaluation of chronic or long-term exposures, such as RfDs and SFs, are based on concepts and assumptions that may bias an evaluation and potentially result in the overestimation of risks and HIs. As stated by EPA (*1986*):

> *There are major uncertainties in extrapolating both from animals to humans and from high to low doses. There are important species differences in uptake, metabolism, and organ distribution of carcinogens, as well as species and strain differences in target site susceptibility. Human populations are variable with respect to genetic constitution, diet, occupational and home environment, activity patterns, and other cultural factors.*

Basing the SFs on the slope of the 95 percent UCL low dose response curve and using uncertainty factors for RfDs address these concerns. The assumptions used in this HHRA provide a plausible estimate of the upper limit of risk. In other words, it is not likely that the true risk would be higher than the estimated risk but could very well be considerably lower, even approaching zero. More refined modeling in the area of dose-response calculation (i.e., using maximum likelihood dose-response values rather than the 95 percent UCL) would be expected to substantially lower the risk estimates.

There are varying degrees of confidence in the weight-of-evidence of carcinogenicity of a given chemical. EPA's weight-of-evidence classification provides information that can indicate the level of confidence or uncertainty in the data obtained from studies in humans or experimental animals. Cancer SFs were available and applied in the HHRA for all chemicals considered to be Class A, B2, or C carcinogens.

For several chemicals, route-to-route extrapolation was used where route-specific toxicity values were unavailable (i.e., oral toxicity values were applied as inhalation toxicity values and inhalation toxicity values were applied as oral toxicity values). This could have resulted in an under- or overestimation of risks for these chemicals because the assumed toxicity criterion may under- or overestimate the toxic potential for the compound. However, it is noted that for the cancer risk driving pathways (oral and

dermal), no route-to-route extrapolation was used for oral SFs; therefore, significant under- or overestimation of risk due to route-to-route extrapolation is unlikely.

7.0 SUMMARY AND CONCLUSIONS

This HHRA for the OUCTP was conducted to evaluate potential risks to residents based on exposure to VOCs detected in groundwater and soil gas from the OUCTP using groundwater and soil gas data collected at the site. This evaluation was accomplished by reviewing the groundwater and soil gas data collected at the site, identifying COPCs, selecting appropriate exposure assumptions and toxicity criteria, and estimating human health risks and hazards. Child and adult residents were evaluated assuming that they could potentially be exposed to contamination in soil gas and groundwater due to vapor intrusion to the indoor air, and from use of contaminated groundwater for household purposes such as showering and bathing, and as a source drinking water. As part of the toxicity assessment, cancer and noncancer toxicity values were compiled for each COPC for use in the risk characterization process.

The risk characterization step combined results from the exposure and toxicity assessments to estimate cancer risks and noncancer hazards. The risks and hazards were estimated for two exposure scenarios. For the RME scenario, it was assumed that an onsite resident would be exposed to VOCs in groundwater 350 days per year for a total duration of 30 years. These are conservative assumptions considering that residents do not typically reside at one place for a total of 30 years. For the AE scenario, it was assumed that adult and child residents would be exposed for a total duration of 9 and 6 years, respectively.

The following conclusions were drawn from the risk characterization:

- The A-Aquifer was associated with the highest cancer risk, followed by, the Upper 180 Foot-Aquifer and then the Lower 180-400 Foot-Aquifer.
- The groundwater ingestion pathway contributed the greatest amount of excess cancer risk with a RME cancer risk estimate range from 2E-06 to 1E-05, followed by dermal exposure with a RME cancer risk estimate range from 4E-07 to 3E-06, and then groundwater vapor intrusion exposure with a RME cancer risk estimate range of 5E-08. The cancer risk estimated for inhalation of groundwater vapors during showering was negligible with a RME cancer risk estimate range from 6E-17 to 2E-16.
- The following COPCs were risk drivers: CT and PCE in the A-Aquifer; CT in the Upper 180 Foot-Aquifer; and 1,2-DCA and CT in the 180-400 Foot-Aquifer.
- The cumulative noncancer hazards did not exceed one.
- VOCs concentrations in indoor air arising from groundwater and/or subsurface contamination were estimated using the Johnson and Ettinger model. The calculated concentrations were negligible relative to measured VOC concentrations in outdoor air and indoor air.

The estimated risks and hazards are hypothetical as groundwater from the OUCTP is not currently used as either a source of drinking water or for other household uses.

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TABLES

PLATE

APPENDIX A

Johnson and Ettinger Model Spreadsheets