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BASELINE RISK ASSESSMENT

HOOKSTON STATION SITE
PLEASANT HILL, CALIFORNIA

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1.0 INTRODUCTION

As directed by the San Francisco Bay Region California Regional Water Quality Control Board (SFRWQCB), this report presents a baseline risk assessment (baseline RA) of chemicals detected on- and off-site near the Hookston Station Site in Pleasant Hill, California. In April 2004, a risk assessment was prepared and submitted to the SFRWQCB using SFRWQCB risk assessment methods (CTEH, 2004). In the April 2004 RA, concentrations of chemicals detected in indoor air, soil, soil vapor, ground water in on-site locations and chemicals detected in indoor air, ground water, and soil vapor in off-site locations were compared to SFRWQCB Environmental Screening Levels (ESLs). As defined by the SFRWQCB, ESLs are conservative levels of chemicals in environmental media that can be assumed to not pose a significant, long-term (chronic) threat to human health and the environment. Chemicals detected in on-site indoor air, soil, soil vapor, and ground water exceeded ESLs. In addition, chemicals detected in off-site indoor air, ground water, and soil vapor exceeded ESLs. The presence of a chemical at a concentration above its ESL does not necessarily indicate that adverse effects to human health or the environment may occur; instead, exceedance of ESLs suggests that additional evaluation is warranted.

This baseline RA is submitted to comply with new Task 8.b. Baseline Risk Assessment ordered by the SFRWQCB on August 12, 2004. The order states that

> The Baseline Human Health Risk assessment, at a minimum, will quantitatively evaluate the cumulative risk to human health posed by exposure to contaminants derived from the subject site in air, soil, and ground water in both on-site and off-site areas.

A baseline RA differs primarily from the April 2004 risk assessment in that human exposure to chemicals of potential concern in each environmental medium is estimated and theoretical estimates of noncancer and lifetime cancer risk are calculated. The baseline RA presents estimates of exposure to on-site individuals in indoor air and soil and off-site individuals exposed to indoor and outdoor air and ground water.

As ordered by the SFRWQCB, the baseline RA evaluates risks posed by contaminants derived from the subject site. The RA also evaluates commingled contaminants derived from sources other than the Hookston Station Site.

Selected figures from the August 2004 Remedial Investigation report (RI) prepared by ERM (ERM, 2004) are attached to the baseline RA. These figures are numbered as they appeared in the RI. Also, data tables presented in the RI are attached to this report on a compact disc.

1.1 Site History and Investigation

This section of the report is largely reproduced from the April 2004 RA. A more detailed discussion of site history and site investigations of the Hookston Station site is presented in the August 2004 Remedial Investigation report (RI) prepared by ERM.

The site is located at the intersection of Hookston and Bancroft Roads in Pleasant Hill, California (RI Figure 1-1). The site covers approximately eight acres, is currently occupied by commercial and light industrial businesses, and is surrounded by a residential neighborhood. RI Figure 1-2 depicts the Hookston Station site.

The site was formerly owned by the Southern Pacific Transportation Company (SPTCo) from June 1891 until September 1983 and was used for a rail line and a station ("Hookston Station"). Between approximately 1965 and 1983, the land was developed into a mixed light industrial business complex. The property was transferred from SPTCo to Mr. Daniel Helix in 1983, and the eastern portion of the site was subsequently purchased by the Contra Costa County Redevelopment Agency (CCCRA) in 1989. Union Pacific merged with SPTCo in 1997 and thereby took over its project responsibilities.

Environmental investigations regarding the presence of chemicals in soil and ground water at the site were initially conducted between 1989 and 1996 by various environmental consulting firms on behalf of Contra Costa County and Mr. Helix. As described below, these investigations discovered the presence of petroleum-based products and chlorinated solvents in the soil and ground water at the site.

The initial environmental investigations by Harding Lawson Associates (HLA, January 1990 and June 1990) were completed for the Contra Costa County Public Works Department in support of the proposed purchase of the eastern portion of the property. Following the discovery of chemical impacts to soil and ground water at the site, Engeo, Inc. (1991 to 1992) and Treadwell & Rollo, Inc. (1993 to 1996) performed additional investigations on behalf of Mr. Helix. UPRR and Mr. Helix contracted with ERM in April 2000 to perform ground water sampling at the site, build a comprehensive project database, and develop a plan for moving the project through final remediation.

Modified Phase I Preliminary Report, HLA, 1990
This October 1989 investigation consisted of the collection of 10 surface soil samples, and focused solely on the presence of petroleum hydrocarbons. As a result of the concentrations of petroleum hydrocarbons found in these samples, HLA recommended a ground water investigation be conducted and additional soil samples be collected.

Remedial Investigation, HLA, 1990
This April/May 1990 investigation consisted of the collection of soil and ground water samples. Four monitoring wells (MW-1, MW-2, MW-3 and MW-4) were installed on site and were subsequently sampled for petroleum hydrocarbons. The laboratory contracted for this investigation alerted HLA of the presence of volatile organic compounds (VOCs), particularly trichloroethylene (TCE), in the ground water samples. Shallow soil samples collected during this investigation were not analyzed for VOCs, but HLA recommended additional soil and ground water samples be collected at the site.

Preliminary Site Characterization, Engeo, 1991
This investigation consisted of the collection of soil and ground water samples and the installation of two shallow monitoring wells (MW-5 and MW-6). In addition, 76 passive soil vapor probes were installed and analyzed. The soil vapor survey served to locate the areas with elevated VOC concentrations at the site. Based on these findings, Engeo recommended further soil and ground water investigation activities.

Report on Ground Water Sampling, Engeo, 1992
This January 1992 investigation consisted of the collection of ground water samples from the six on-site monitoring wells. These samples provided further insight into the extent and concentration of TCE in ground water at the site.

Initial Soil Characterization Study, Engeo, 1992
In June 1991, Engeo suggested that a further vertical delineation of VOCs in soil was needed at the site. This January 1992 investigation consisted of the collection of soil and ground water samples to provide an on-site characterization of VOCs. During this investigation, 21 soil borings were advanced and one grab ground water sample was collected. The 1992 report also discusses sanitary sewer video inspections that were performed in three phases between June 1991 and January 1992.

Subsurface Investigation, Treadwell & Rollo, 1993
This investigation consisted of the collection of 14 off-site grab ground water samples and the installation of two on-site and two off-site monitoring wells. This was the first off-site

investigation; the results indicated that the ground water VOC plume was present up to 2,000 feet downgradient of the site. Three monitoring wells (MW-1D, MW-2D and MW-3D) were installed in the deeper aquifer zone. Sample results from these wells indicated that TCE was also present in the deeper aquifer. This report also identified several off-site private domestic and municipal water wells within the vicinity of the site.

Supplemental Subsurface Investigation, Treadwell & Rollo, 1996
This November 1995 field investigation consisted of the collection of soil and ground water samples from numerous on-site and off-site locations. Several shallow on-site soil samples were collected and analyzed for VOCs. In addition to collecting samples from the 10 existing monitoring wells, Treadwell & Rollo advanced 10 shallow HydroPunch borings to further delineate the shallow ground water TCE plume. This report concluded that the increases of PCE in ground water at wells MW-1 and MW-7 may be caused by an off-site, upgradient contaminant source or unknown on-site sources.

Ground Water Monitoring, ERM, 2000
In June 2000, Environmental Resources Management (ERM) completed ground water monitoring of nine of the 10 monitoring wells on and downgradient of the site. One of the on-site wells (MW-02) was not sampled due to immobile equipment that blocked access to the wellhead. In September 2000, ERM resampled MW-03D to confirm the elevated detections of TCE reported in the June 2000 laboratory data.

Preliminary Risk Evaluation (PRE), ERM, 2002
On October 22, 2002, ERM submitted a Preliminary Risk Evaluation (PRE) for the Hookston Station site to the RWQCB. The PRE was conducted to assess passive exposures to VOCs in ground water underlying the Hookston Station site and nearby neighborhoods.

Development of the PRE focused on the following exposure pathways:

- Inhalation of VOCs released from the ground water table into indoor air;
- Inhalation of VOCs released from the ground water table into outdoor ambient air; and
- Discharge of ground water to the creek, and subsequent exposure by both human and ecological receptors.

Risk-based screening levels were identified or derived for each of these pathways.

To support the PRE, ERM completed surface flux chamber sampling to provide site-specific chemical flux data. These data were used to evaluate potential human health risks associated

with vapor migration into indoor air and outdoor ambient air. In addition to the collection of surface flux data, ERM also collected surface water and sediment data to support evaluation of potential human health and ecological risks associated with the discharge of ground water to Walnut Creek.

Source Area Investigation and Interim Remedial Measures Analysis Report, ERM, 2003
In November 2003, ERM completed a source area investigation. This report concluded TCE is the primary chemical of concern. Generally low concentrations of TCE were found in soils. The soils are isolated from direct human contact and contact with the underlying ground water. The ground water quality was found to be generally stable. This investigation determined chemical concentrations were not detected at concentrations that warrant consideration for an interim remedial measure (IRM).

Further detail of the overall project background, site history, and previous site characterization results can be found in the *Phase I Remedial Investigation Sampling and Analysis Plan* (Phase I RI SAP) (ERM, 2000) and the *Remedial Investigation Progress Report* (ERM, 2002).

Remedial Investigation Report, ERM, 2004
The Remedial Investigation Report (RI) presented the results of the Phase I investigation and the Phase II investigations of the source area and the characterization of ground water. Phase I investigations were conducted for on-site soil vapor (passive methods), on-site and off-site ground water, off-site surface water and sediment in Walnut Creek, and surface flux chamber sampling at both on-site and off-site locations. In addition, residential wells were surveyed in the Hookston Station area.

Phase II investigations of the Hookston Station site evaluated on-site soil and on-site and off-site ground water impacts, soil vapor concentrations of chemicals of potential concern at on-site and off-site locations, and indoor air concentrations of chemicals of potential concern at on-site and off-site locations. These studies completed the dataset necessary to proceed with the Feasibility Study of the Hookston Station site. They also determined that sources of TCE other than the Hookston Station site are impacting area ground water.

1.2 Baseline Risk Assessment Objectives and Scope

The objectives of this baseline RA are to comply with the SFRWQCB order dated August 12, 2004 that requires preparation of a baseline human health RA for the Hookston Station site. The baseline RA presents quantitative estimates of on-site human exposures to chemicals in indoor air and soil and off-site human exposures to indoor air and ground water.

The April 2004 RA presented a screening level evaluation of ground water hypothetically used as a supply of potable water. The baseline RA does not further evaluate potential use of ground water as a potable water supply. Also, possible exposure to chemicals of potential concern in on-site and off-site indoor air that may result from soil or ground water sources are assessed using indoor air data rather than by modeling indoor air concentrations from these possible sources. To evaluate possible contact with chemicals of potential concern in ground water via use for non-potable purposes (i.e., irrigation, filling swimming pools), data from residential wells in the community surrounding Hookston Station are used.

In addition, as directed by the SFRWQCB, hypothetical exposure and risk to ground water from monitoring well MW-14A are also calculated. MW-14A is located east of the Hookston Station site on public land and is the location of the highest concentrations of TCE detected in off-site groundwater. Concentrations of TCE in MW-14A are more than 10 times higher than the highest detected concentrations of TCE in residential wells. MW-14A is not located in the surrounding neighborhood and has not been used for any purpose other than monitoring ground water. Thus, theoretical exposures and risks from contact with ground water from MW-14A represent “worst case” risk calculations. As directed by the SFRWQCB, the baseline RA uses the average concentrations of TCE and other contaminants detected in MW-14A from the quarterly monitoring in 2004.

2.0 DATA EVALUATION

This section presents an evaluation of the data used in the baseline RA of the Hookston Station site. The primary source of data for this baseline RA is the RI (ERM, 2004). However, some on-site soil data is used which results from investigations performed in the 1980s and 1990s. All chemicals detected in indoor air, soil, and residential well ground water were retained as chemicals of potential concern in the baseline RA. Data tables from the RI report are attached to the baseline RA on a compact disc.

2.1 Summary of Analytical Results

2.1.1 On-site Indoor Air Sampling Results

Based on the results of on-site soil vapor sampling, ERM performed on-site indoor air sampling in the office and work space of Hookston Station site businesses in December, 2003. The locations of these samples are presented in Figure 5 from the April 2004 risk assessment. Five indoor air samples (IA-1, IA-2, IA-3, IA-5, and IA-6) were collected at a height of 5 feet using Summa canisters over a period of 8 hours and analyzed for 1,1-dichloroethylene (1,1-DCE), cis-1,2-dichloroethylene (cis-1,2-DCE), and TCE. The volatile organic compounds (VOCs) analyzed in indoor air samples were selected in agreement with the SFRWQCB. Samples IA-1 and IA-6 were collected from enclosed office spaces and samples IA-2, IA-3, and -5 were collected within open warehouse areas. The results of this sampling are presented in Table 2.1.1. In addition, an ambient air sample was collected outdoors at the Hookston Station site (AA-2). 1,1-DCE, cis-1,2-DCE, and TCE were not detected in the ambient air sample at detection limits of <0.065, <0.13, and <0.18 ug/m^3, respectively.

1,1-DCE was not detected in any on-site indoor air sample (detection limits ranging from <0.065 to <0.081 ug/m^3). cis 1,2-DCE was detected in only one sample (1.7 ug/m^3 in IA-2) at a concentration below the RWQCB screening level (10 ug/m^3). Trichloroethylene was detected in all five indoor air samples at concentrations ranging from 0.68 to 4.9 ug/m^3.

2.1.2 On-site Soil Sampling Results

The locations of on-site soil borings are presented in RI Figure 5-2. Prior to evaluating soil sampling data for use in the baseline RA, the soil data were categorized as shallow soil (less than 3 meters and deep soils) or deeper soil (greater than 3 meters bgs). With the exception of the petroleum hydrocarbon soil analyses from the late 1980s and early 1990s, the results of soil

samples collected from a depth of 0 to 10-feet bgs were considered for use in calculating exposures and risks. In studies conducted before the RI (1989, 1990, and 1992), petroleum hydrocarbon analyses were non-specific and reported analyses for parameters such as "oil and grease. In addition, detection limits for petroleum hydrocarbons in the earliest studies of the Hookston Station site were elevated. For these reasons, only petroleum hydrocarbon analyses from the Remedial Investigation performed by ERM are used in the baseline RA. PCBs were not detected in Hookston Station site soils.

Direct contact with chemicals in deeper soils is much less likely than contact with shallow soils. For several reasons, chemicals detected in shallow soils were used to calculate exposure and risks for on-site workers. In addition to the fact that direct contact or disturbance of chemicals in deeper soils is unlikely, concentrations of the chlorinated ethenes are higher in the shallow soils than in deeper soils (see RI Table 7-3). Also, exposures to chemicals in soil resulting from volatilization of chemicals from soil to indoor air and leaching of chemicals from soil to ground water were addressed in the April 2004 RA. Further, soil samples collected for analysis for semivolatile organic compounds (SVOCs) (RI Table 7-5) and metals (RI Table 7-7) were collected from within the 0 to 10 feet below ground surface (bgs) soil depth range. During the RI, soil samples collected and analyzed for petroleum hydrocarbons as diesel fuel, gasoline, and motor oil were collected at the soil surface or at a depth of 2.5 feet bgs (RI Table 7-4).

A summary of the soil sample results for all chemicals detected in 0 to 10 feet bgs soils at the Hookston Station site is presented in Table 2.1.2. All chemicals detected in shallow soil (less than or equal to 10 feet bgs) were retained as chemicals of potential concern in the baseline RA.

2.1.3 Off-site Indoor Air Sampling Results

Indoor air sampling was conducted by ERM at 16 residences in the Hookston Station area. These residences are located approximately 250 to 1000 feet to the northeast of the Hookston Station site boundary. The 16 residences were sampled during the months of January, February, and March 2004. The indoor air in living spaces in homes and in several cases, air within crawl spaces, was sampled. With the exception of one residence, sampling was conducted during the winter season when indoor air levels would likely be higher than at other times of the year. Each air sample was collected over a period of approximately 12 hours. The dates, times, and locations sampled in each residence, indoor and outdoor temperatures, and indoor percent relative humidity are presented in Table 2.1.3a.

Details concerning the collection of indoor air samples were provided to the RWQCB under separate cover to protect the confidentiality of residents. For this reason, Tables 2.1.3a and 2.1.2b do not list addresses of the residences but identify each residence with a number from 1 to 16 and the street where the residence is located. Generally, residents were approached as possible participants in the indoor air study when the home was located directly over the highest concentrations of the ground water plume. Participation in the indoor air study was entirely voluntary. Thus, the indoor air locations sampled were not under the control of Dan Helix, Union Pacific, ERM, or CTEH.

The results of the indoor air sampling are presented in Table 2.1.3b. 1,1-DCE was infrequently detected in indoor air in levels up to 0.13 ug/m^3. Cis-1,2-DCE was not detected in indoor air (detection limits 0.12 to 0.14 ug/m^3). TCE was detected at concentrations up to 5 ug/m^3 in indoor air. Crawl space 1,1-DCE, cis-1,2-DCE, and TCE concentrations were similar to indoor air, ranging up to 0.11, 0.38, and 6.7 ug/m^3, respectively.

Ambient air samples were collected at two off-site locations. 1,1-DCE and cis-1,2-DCE were not detected in either ambient outdoor air sample (detection limits 0.062 and 0.12 μg/m^3, respectively). Trichloroethylene (TCE) was detected in one ambient outdoor sample on Thames Drive at a concentration of 0.21 ug/m^3. Based on the detection of higher concentrations of TCE in indoor air at the same time that the ambient samples were collected, it is unlikely that ambient outdoor air is a significant source of TCE.

2.1.4 Ground Water Sampling Results

Ground water sampling results from monitoring wells and HydroPunch samplers are summarized in RI report in RI Tables 8-1, 8-2, 8-3, and 8-4 for VOCs, SVOCs, petroleum hydrocarbons, and metals, respectively.

As summarized in the RI report, TCE and its breakdown products such as 1,1-dichloroethylene (1,1-DCE), cis-1,2-dichloroethylene (cis-1,2-DCE), and trans-1,2-dichloroethylene (trans-1,2-DCE) have been detected in ground water on- and off-site to depths of up to 70 feet bgs. A source of TCE impacted ground water is near the southwestern corner of the Hookston Station site. Movement of ground water across the site is toward the north to northeast direction. TCE and its breakdown products have been transported in ground water off-site. Isoconcentration maps of A-Zone ground water depict the extent of tetrachloroethylene (PCE), TCE, cis-1,2-DCE, and 1,1-DCE migration (RI Figures 8-5, 8-6, 8-7, and 8-8, respectively). The A-Zone consists of thin, discontinuous sand stringers found above a depth of about 30 feet bgs. The B-Zone is a

relatively continuous sand interval located between 30 and 70 feet bgs. Isoconcentration maps of the occurrence of PCE, TCE, cis-1,2-DCE, and 1,1-DCE occurrence in B-zone ground water are presented in RI Figures 8-13, 8-14, 8-15, and 8-16, respectively.

Although some residential wells exist at off-site locations, there is no evidence of potable ground water use in the Hookston Station area. However, concentrations of chemicals detected in monitoring wells were screened using conservative SFRWQCB ESLs designed for protection of persons drinking ground water. As summarized in the April 2004 RA, on-site groundwater and off-site ground water near the site exceeds ESLs protective of drinking water (CTEH, 2004). In particular, concentrations of PCE, TCE, and its breakdown products exceed drinking water ESLs.

As discussed in the RI, a private well survey was conducted by ERM beginning in February 2003. Details of the survey are discussed in Section 5.2.2 of the RI report. The private wells identified by ERM for which information was available from homeowners are either not used or are used for landscape irrigation. No use of private well water for drinking water was reported.

ERM also sampled 8 of the private wells in the Hookston Station area. Table 2.1.4a lists information concerning the 8 wells sampled. The wells sampled were on Bermuda Drive, Stimel Drive, Gragg Lane, Thames Drive, and Waterloo Court. To protect the confidentiality of the residents whose wells were sampled, the locations are designated (a) through (h) with only the street name given.

TCE and other chlorinated ethenes were detected in several of the sampled private wells. In addition, very low levels of other chemicals not associated with the Hookston Station site were detected. These included acetone, chloromethane, 1,1-dichloroethane, and 1,2-dichloroethane.

The private well data were selected for evaluation in the baseline RA because these data better represent chemical concentrations in ground water to which off-site residents may be exposed. All chemicals detected in the private wells were retained for evaluation as chemicals of potential concern in the baseline RA.

As discussed above, hypothetical exposure and risks are calculated assuming that groundwater from MW-14A is used for non-potable purposes. The data from quarterly ground water sampling of MW-14A are summarized in Table 2.1.4c.

2.1.5 Surface Water Sampling Results

Walnut Creek, the nearest surface water body to the Hookston Station site, is located about 0.5 mile east of the site. Whether chemicals in off-site ground water affect Walnut Creek is not known. Sampling of Walnut Creek surface water in 2001 and 2002 detected the presence of very low concentrations (less than 5 ug/L) of chlorinated solvents such as cis-1,2-DCE (1.4 ug/L and lower), PCE (2.6 ug/L and lower), and TCE (3.3 ug/L) (ERM, 2002). The surface water sampling stations in Walnut Creek are presented in RI Figure 9-1. Sampling results are summarized in RI Table 9-1. Although concentrations of toluene were also detected in Walnut Creek at concentrations less than 1 ug/L and methyl tert-butyl ether (MTBE) was detected at a single location in the creek at 8.3 ug/L, these chemicals have not been associated with the Hookston Station site. For this reason, only cis-1,2-DCE, PCE, and TCE were retained as chemicals of potential concern for the baseline RA.

2.2 Summary of Chemicals of Potential Concern for Baseline Risk Assessment

All chemicals detected in on-site air (Table 2.1.1) and on-site soil (Table 2.1.2) were retained as chemicals of potential concern for the baseline RA.

All chemicals detected in off-site residential indoor air samples (Table 2.1.3b), private well ground water samples (Table 2.1.4b), and MW-14A (Table 2.1.4c) were retained as chemicals of potential concern for the baseline RA. Cis-1,2-DCE, PCE, and TCE were retained as chemicals of potential concern for surface water in Walnut Creek.

3.0 EXPOSURE ASSESSMENT

The objectives of the exposure assessment are to evaluate potential pathways of human exposure to the chemicals of potential concern in indoor air, soil, ground water, and surface water at or near the Hookston Station site. Once complete exposure pathways are identified (for example, ingestion of a chemical in soil), chemical intakes associated with each pathway are calculated for each potential receptor (such as the construction worker). This section analyzes exposure conditions that may exist on-site at the Hookston Station site as well as conditions that exist off-site in the nearby residential areas.

This exposure assessment calculates chemical intakes for potentially exposed populations that are representative of "reasonable maximum exposure" (RME). The RME is defined by the USEPA as "the highest exposure that is reasonably expected to occur at a site" (USEPA, 1989). The intent of the RME scenario is to calculate chemical intakes that do not underestimate exposure under conservative exposure conditions.

Data used to calculate exposures to chemicals in on-site indoor air and on-site soil are summarized in Tables 2.1.1 and 2.1.2, respectively. Data used to calculate exposures to chemicals in off-site residential indoor air are presented in Table 2.1.3b. Data used to calculate exposures to chemicals in off-site private well water and MW-14A are summarized in Tables 2.1.4b and 2.1.4c, respectively. The maximum detected concentrations of cis-1,2-DCE, PCE, and TCE were used to assess possible human exposure to these chemicals in Walnut Creek surface water.

3.1 Exposure Pathway Analysis

As stated by the USEPA, an exposure pathway "describes the course a chemical or physical agent takes from the source to the exposed individual. An exposure pathway analysis links the sources, locations, and types of environmental releases with population locations and activity patterns to determine the significant pathways of human exposure" (USEPA, 1989).

An exposure pathway is made up of four elements. These are:

- A source and mechanism of chemical release,
- A retention or transport medium,
- A point of potential human contact with the contaminated medium, and;
- An exposure route at the contact point.

In the following discussion, exposure pathways to chemicals in on-site indoor air, on-site soil, off-site indoor air, ground water from private wells, and surface water are identified. These exposure pathways are based on current or reasonable future uses of the Hookston Station site. A summary of potential exposure pathways for on-site and off-site persons is presented in Table 3.1. These potential pathways of exposure are discussed below.

3.2 On-site Exposure Pathways

Due to commercial/industrial land use, on-site workers are the primary receptors of potential concern at the Hookston Station site. Although other individuals (business patrons, visitors) may be exposed by these same pathways on-site, the potential for exposure is small relative to that potentially experienced by on-site workers.

On-site workers may spend time both indoors in offices and work areas and outdoors. For the purpose of assessing exposure to chemicals present in on-site indoor air, workers are conservatively assumed to spend the work day indoors.

Typically, direct contact with chemicals in soil is assumed to occur during outdoor activity, although workers may also contact soil as indoor dust during indoor activity. For this reason, on-site commercial/industrial workers are assumed to have direct contact with surface soil or indoor dust as a part of their normal workdays. However, the likelihood of a commercial/industrial worker directly contacting outdoor surface soil is unlikely since much of the Hookston Station site is covered by base rock or asphalt. Nonetheless, possible direct contact with chemicals in soil is considered for the on-site commercial/industrial worker. Exposures to chemicals of potential concern in soils ranging from surface soil to a depth of 10 feet bgs are assessed for the incidental ingestion, skin contact, and inhalation exposure pathways for the on-site commercial/industrial worker. For this exposure to occur, it would be necessary to remove the overlying base rock and asphalt cover and excavate soils to a depth of 10 feet bgs so that it is brought to the surface.

No disturbance of site soils or other construction activity is planned for the Hookston Station site. However, to address the future possibility of future short-term but intensive exposures to chemicals in subsurface soil, a construction worker soil exposure scenario is considered for the Hookston Station site. A future construction worker is assumed to incidentally ingest chemicals in soil, have skin contact with chemicals in soil, and inhale chemicals of potential concern in soils ranging from the surface to 10 feet bgs.

In summary, the following exposure pathways are assumed to be complete for on-site workers:

Commercial/Industrial Workers

- Inhalation of volatile chemicals in indoor air

- Inadvertent ingestion of chemicals in soil
- Skin contact with chemicals in soil
- Inhalation of chemicals in dusts or volatilizing from soil to outdoor air

Construction Workers

- Inadvertent ingestion of chemicals in soil
- Skin contact with chemicals in soil
- Inhalation of chemicals in dusts or volatilizing from soil to outdoor air

3.3 Off-site Exposure Pathways

Due to detection of low levels of 1,1-DCE and TCE in off-site indoor residential air, inhalation of these VOCs is considered to be a complete exposure pathway for an adult and child resident.

Private wells have been used in the area of affected off-site ground water and it is possible that ground water from these wells may be used to water lawns and homegrown produce. The VOCs of interest evaporate rapidly from water and are almost completely released from irrigation water into outdoor air (Berisford et al., 2003). Thus, while individuals may be exposed to chemicals volatilizing from irrigation water into outdoor air, it is unlikely that VOCs will be taken up into vegetables to any significant degree. This topic is discussed in greater detail in the uncertainties section of this report. The inhalation of VOCs from ground water used for irrigation is considered a complete exposure pathway for a child and adult resident. Inhalation of VOCs volatilizing from irrigation water from May to September (when water use is highest) is assumed to occur either when the resident is indoors or outdoors.

In addition to irrigation, it is possible that ground water from private wells may be used for cleaning purposes (car washing, etc.), filling swimming pools, and other uses. Of these uses, use of ground water to fill swimming pools would result in the greater amount of exposure to chemicals in ground water. For this reason, recreational exposure to ground water while swimming in a backyard pool is evaluated for a child resident. A child swimmer is assumed to swim 108 times per year (approximately six days per week from May 15 to September 15).

Exposure pathways evaluated for the child swimmer are incidental ingestion, absorption through the skin, and inhalation of volatilizing chemicals while in the pool.

Very low levels of cis-1,2-DCE, PCE, and TCE may be present in Walnut Creek surface water. Direct contact with these chemicals in surface water is unlikely. Exposure and risks posed by these chemicals through fish consumption was addressed in a Preliminary Risk Evaluation (ERM, 2002) and is not further addressed in the baseline RA. In addition, the concentrations of these VOCs are below even the most stringent SFRWQCB surface water ESLs designed to protect surface water.

An exposure pathway not considered in previous risk assessments is volatilization of VOCs from Walnut Creek and inhalation of the VOCs by nearby residents. Several residential properties are adjacent to the creek and it is possible that nearby residents could inhale chemicals volatilizing from the creek. Although this pathway is considered a minor pathway of exposure, it is evaluated quantitatively in the baseline RA.

In summary, the following exposure pathways are assumed to be complete for off-site residents:

Off-site residents (child and adult resident)

- Inhalation of chemicals in indoor air
- Inhalation of chemicals in air released from lawn irrigation with groundwater
- Skin contact, incidental ingestion, and inhalation of chemicals in backyard swimming pools using ground water (child resident only)
- Inhalation of chemicals in air released from Walnut Creek surface water

3.3 Quantification of Exposure

3.3.1 Estimation of Chemical Intakes

Chemical intakes may be calculated for the on-site and off-site receptors once the concentration of the chemical in air, soil, or ground water is known and the factors associated with human exposure to the medium of concern have been assessed. The 95% upper confidence limit (UCL) on the arithmetic mean soil concentration is typically used to assess reasonable maximum exposures (RME). When the 95% UCL on the arithmetic mean exceeds the maximum

detected concentration, the maximum detected value is often conservatively used to estimate chemical intake (USEPA, 1992). However, due to the location-specific nature of the indoor air results, separate exposures were calculated for each indoor air sample location. In the case of the on-site indoor air results, exposures were calculated for 5 on-site indoor locations. Likewise, exposures were calculated for 11 off-site residences where 1,1-DCE, cis-1,2-DCE, or TCE were detected.

The 95% upper confidence limits (UCLs) on the arithmetic mean concentration for chemicals detected in soil were calculated using the USEPA's ProUCL program (USEPA, 2004). The ProUCL program can be used to calculate UCLs based on several parametric and non-parametric programs. As shown in Table 2.1.2, UCLs were calculated for relatively few chemicals of potential concern. Due to relatively low detection frequencies, calculation of the UCL would not result in a meaningful concentration (due to the large degree of censoring that must be used to evaluate the data). As such, the maximum detected value was often conservatively used as the exposure point concentration (EPC) for calculating soil exposures. The concentration used as the exposure point concentration is bolded in Table 2.1.2. The method used to calculate the UCL (as selected by the ProUCL program) is included in Table 2.1.2.

For the purpose of modeling releases and inhalation exposures to volatile chemicals released from soil, ground water, and surface water, chemicals classified as "volatile" in SFRWQCB guidance (SFRWQCB, 2003) were selected for the development of volatilization factors. Methods and assumptions used to calculate volatilization factors for VOCs released from on-site soil into outdoor air are summarized in Appendix A. Methods and estimated concentrations of chemicals in air resulting from use of ground water for irrigation and to fill a swimming pool are presented in Appendix B. Methods and assumptions used to calculate air concentrations of VOCs resulting from volatilization from Walnut Creek surface water are presented in Appendix C.

Equations and assumptions used to calculate chemical intakes for the on-site commercial/industrial worker inhaling indoor air and the on-site commercial/industrial worker and construction worker exposed to soil are presented in Table 3.2a. Exposure variables used to calculate chemical intakes for off-site residents exposed to VOCs in indoor air, use of ground water for irrigation and filling swimming pools, and VOCs volatilizing from Walnut Creek are presented in Table 3.2b.

Estimates of daily chemical intake are expressed as average daily intakes (ADIs) or lifetime average daily intakes (LADIs). ADIs are calculated over the assumed period of exposure whereas LADIs are calculated over a lifetime (70 years). ADIs and LADIs for ingested and inhaled chemicals of potential concern are expressed as intakes rather than absorbed doses. Dermal contact with chemicals of potential concern in soil and ground water is calculated as an absorbed dose.

ADIs are used to assess noncancer risks whereas LADIs are used to assess lifetime cancer risks.

ADIs were not calculated for lead. Cal-EPA uses the Leadspread exposure model to assess lead exposure and the resulting blood lead concentration resulting from exposure to lead in dust, soil, food, drinking water, and air. Exposure to lead in on-site soil and other environmental media is assessed in Appendix D using the Leadspread 7 model.

ADIs and LADIs for the commercial/industrial worker exposed to VOCs in on-site indoor air are presented in Table 3.3. Soil exposure estimates for the commercial/industrial worker and construction worker are presented in Tables 3.4 and 3.5, respectively.

ADIs and LADIs for off-site residents exposed to VOCs in indoor air, volatilizing from ground water used for irrigation, in swimming pool water, and volatilizing from Walnut Creek surface water are presented in Tables 3.6, 3.7, 3.8, and 3.9, respectively.

4.0 TOXICITY ASSESSMENT

4.1 Noncarcinogenic Risks

The noncarcinogenic effects of the chemicals of concern were assessed by comparing chemical intakes calculated in Section 3 with USEPA reference doses (RfDs). The USEPA considers the RfD to be "an estimate (with uncertainty spanning perhaps an order of magnitude) of the daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a portion of the lifetime" (USEPA, 1997b).

The USEPA derives RfDs for inhalation and oral exposure for subchronic exposures (2 weeks to 7 years) and chronic exposures (7 years and longer) for many chemicals. Only chronic inhalation and oral reference doses were used for assessing risks at the Hookston Station site. Inhalation and oral RfDs are presented in Tables 4-1 and 4-2, respectively. RfDs were identified (in order of preference) from the following sources: the Integrated Risk Information Service online, USEPA Region 9 PRG tables (October 2004), and Table J from the SFRWQCB risk assessment guidance (SFRWQCB, 2003).

The RfDs used in this assessment are generally derived from animal studies. The results of these studies are extrapolated to humans using appropriate factors to adjust for uncertainties resulting from:

- Extrapolation from the results of animal studies to humans,
- Variation within individuals of the same species,
- Extrapolation from the results of short-term animal studies and,
- Extrapolation from exposure levels in animal studies that demonstrate an effect rather than a no-effect level.

For any particular chemical, an intake that exceeds the RfD for that chemical indicates that an adverse health effect may be observed. The intake/RfD is defined by the USEPA to be the hazard quotient (HQ) for a chemical. As a general rule, when the HQ < 1, it is unlikely that an adverse health effect will occur. The chance of observing an effect increases as the HQ increasingly exceeds unity. The USEPA directs that the HQ for each chemical and each route of exposure be summed to calculate a hazard index (HI). This process conservatively assumes that simultaneous exposure to multiple chemicals at intakes below the RfD may produce an adverse health effect if the HI exceeds one. When calculated according to USEPA methods, the HI assumes that the effects of each chemical are additive. The HI is used as a screen to

determine whether or not the effects of intake of multiple chemicals may be of concern. If the HI is less than one, there is little reason to expect that any adverse effect will result from concurrent exposure to all of the chemicals of concern.

The USEPA does not derive dermal RfDs for chemicals. However, since dermal exposure may add to the overall intake of a chemical and possibly cause an adverse effect, the oral RfD was used as the dermal reference dose.

4.2 Carcinogenic Risks

The chemicals detected in indoor air, soil and ground water that are considered by the USEPA and the Cal-EPA to be potentially carcinogenic to humans are presented in Tables 4.1 and 4.2. According to the current USEPA weight of evidence classification scheme, Group A chemicals are considered to be human carcinogens. Group B chemicals are considered to be "probable human carcinogens" primarily based on cancer studies in animals. Chemicals in Group B1 have limited evidence of carcinogenicity in humans while Group B2 chemicals are described as having sufficient evidence of carcinogenicity in animals with inadequate human evidence. Chemicals in Group C are considered "possible human carcinogens" on the basis of limited evidence of carcinogenicity in animals.

The Toxicity Criteria Database (http://www.oehha.ca.gov/risk/ChemicalDB/index.asp) maintained by Cal/EPA and OEHHA was used as the source of slope factors for the potentially carcinogenic chemicals of potential concern. Cal/EPA and USEPA calculate slope factors by applying the linearized multistage or linear model to data from animal carcinogenicity studies or human epidemiological studies. In the absence of data concerning the carcinogenic potential of very low doses of a chemical, these models are used to generate estimates of carcinogenic potency. An inherent conservatism in these models is the provision that there is no dose, no matter how small, that is not associated with some carcinogenic risk. The uncertainties associated with weight-of-evidence classifications and use of the linear and linearized multistage model are addressed in a later section of this report. Multiplication of the lifetime average daily intake by the slope factor [expressed as $(mg/kg/day)^{-1}$] produces a unitless estimate of lifetime cancer risk. Increased lifetime cancer risk calculated by this method is often expressed in terms of 1 in ten thousand (1E-04), 1 in one hundred thousand (1E-05), or 1 in one million (1E-06).

In cases where both the USEPA and DTSC have derived different slope factors for the same chemical, the DTSC slope factor was used.

4.3 Toxicological Effects of Lead

Unlike other chemicals for which human exposure is calculated in terms of chemical intake (intake in milligrams of chemical per kilogram of body weight per day, mg/kg/day), risks associated with exposure to lead are based on blood lead concentrations. Due to the existence of an ever-growing database relating blood lead concentration (typically expressed in terms of micrograms of lead per deciliter of blood, µg/dL) and human toxicity, blood lead concentration is the most direct means by which the toxic effects of lead in humans can be assessed.

The USEPA and others have developed lead exposure models for evaluating blood lead concentrations associated with intake of lead from food, water, air, and soil. The State of California has developed its own lead exposure model to calculate lead exposure in children and adults. The DTSC child and adult lead exposure models were used to calculate blood lead concentrations for workers potentially exposed to lead in soil at the Hookston Station site. These calculations are presented in Appendix D.

4.4 Toxicological Effects of Petroleum Hydrocarbon Mixtures

There is currently no single, universally accepted method for addressing risks posed by petroleum hydrocarbon mixtures in soil or water. For example, although petroleum mixtures in soil at the Hookston Station site were analyzed as “diesel”, “gasoline”, and “motor oil”, there is no reference dose available for estimating the toxicity of these mixtures. The problems associated with the evaluation of risks associated petroleum mixtures in the environment relate to the analytical characterization of petroleum mixtures, the uncertainties associated with a relative lack of toxicological information concerning the toxicity of whole petroleum mixtures, and the effect of weathering on petroleum mixtures in the environment. In the absence of further analytical characterization of the petroleum hydrocarbon fractions in soil, the SFRWQCB conservatively assumes that the petroleum hydrocarbons are the most toxic petroleum hydrocarbon fraction.

5.0 RISK CHARACTERIZATION

The risk characterization portion of the risk assessment integrates the results of the exposure assessment (Section 3) and toxicity assessment (Section 4) to calculate theoretical estimates of noncancer and lifetime cancer risks. In addition, uncertainties associated with the baseline RA are discussed.

Calculated noncancer and theoretical lifetime cancer risks for individual chemicals are summed for each exposure pathway. In addition, summed risks for each exposure pathway are added together to calculate a cumulative risk calculation for each exposure scenario.

Noncancer and theoretical lifetime cancer risks resulting from commercial/industrial worker exposure to on-site indoor air and on-site soil are presented in Tables 5.1 and 5.2, respectively. Risks calculated for the on-site construction worker exposed to soil are presented in Table 5.3.

Noncancer and theoretical lifetime cancer risks for the off-site resident exposed to VOCs in indoor air, VOCs volatilizing from ground water used for irrigation, resident swimming exposure to VOCs in ground water used to fill a pool, and VOCs volatilizing from Walnut Creek surface water are presented in Tables 5.4, 5.5, 5.6, and 5.7, respectively.

These risks are discussed for on-site and off-site receptors below.

5.1 On-Site Exposure to Chemicals in Indoor Air and Soil

Noncancer and theoretical lifetime cancer risks calculated for the commercial/industrial worker exposed to cis-1,2-DCE and TCE in indoor air are presented in Table 5.1. The summed hazard quotients (noncancer risks) were less than one for each on-site indoor air location sampled, indicating that inhalation of on-site indoor air would not result in adverse noncancer health effects. Theoretical lifetime cancer risks associated with inhalation of TCE ranged from 3.3E-07 at location IA-3 to 2.4 E-06 at location IA-2. These risks are well within the range of risks considered to be acceptably low by the USEPA (i.e., 1E-06 to 1E-04) and below the one in 100,000 (1E-05) theoretical lifetime cancer risk level considered to pose “no significant risk” as defined under the State of California’s Proposition 65.

Noncancer and theoretical lifetime cancer risks calculated for the commercial/industrial worker and construction worker exposed to chemicals of potential concern in soil are presented in Tables 5.2 and 5.3, respectively. Summed noncancer risks for the commercial/industrial worker and construction worker exposed to the chemicals of potential concern in soil were below one,

indicating that exposure to chemicals in soil would not result in noncancer health risks to on-site workers. As presented in Appendix D, commercial/industrial worker and construction workers exposed to 104 mg/kg lead in soil would be unlikely to have a blood lead concentration greater than 10 ug/dL, the targeted level of concern for children and women of child-bearing age.

Theoretical lifetime cancer risks for the commercial/industrial worker exposed to chemicals of potential concern in soil were 3.1 E-04 and exceeded the range of risks targeted by the USEPA (1E-06 to 1E-04). Arsenic accounts for 98% of the total lifetime cancer risk calculated and no other chemical exceeded a theoretical lifetime cancer risk of 1E-05. Since publication of the April 2004 RA, OEHHA changed the oral slope factor for arsenic, increasing its carcinogenic potency approximately 6-fold. In addition, the exposure point concentration for arsenic in soil (132 mg/kg) is skewed relatively high on the basis of two samples. Soil samples B-69 (211 mg/kg) and B-84 (76 mg/kg) were collected at locations approximately 500 feet apart on the Hookston Station site. The remaining arsenic soil concentrations are below 10 mg/kg, suggesting that the occurrences of elevated concentrations in surface soils are anomalous. Also, recent evidence indicates that a substantial fraction of arsenic in soil that is ingested may not be absorbed from the gastrointestinal tract. This baseline RA assumes the conservative default condition, i.e., that arsenic in soil is absorbed from the gastrointestinal tract to the same degree as arsenic dissolved in water. The risk assessment uncertainties associated with assessing arsenic bioavailability and risk are discussed in Section 5.3 below.

Theoretical lifetime cancer risks calculated for the construction worker exposed to chemicals of potential concern in soil were 4.3 E-05. This risk is within the range of theoretical lifetime cancer risks considered acceptable by the USEPA. As with the commercial/industrial worker, the risk is almost entirely attributable to arsenic.

5.2 Off-Site Exposure to Chemicals in Indoor Air, Ground Water, and Surface Water

Risks to both off-site child and adult residents were calculated. Noncancer risks are based on exposures calculated for children so as not to underestimate noncancer risks. Theoretical lifetime cancer risks for residents are the sum of the child and adult lifetime cancer risks.

Noncancer risks calculated for the off-site resident exposed to VOCs in indoor air (Table 5.4), VOCs volatilizing from ground water used for irrigation (Table 5.5), VOCs in ground water used to fill a swimming pool (Table 5.6), and VOCs volatilizing from Walnut Creek (Table 5.7) were less than one for all exposures scenarios evaluated except that of a hypothetical swimming pool scenario using groundwater concentrations from MW-14A. This indicates that VOCs detected in residential indoor air, ground water from private wells, and surface water from Walnut Creek do

not pose noncancer adverse health risks. Noncancer risks calculated for the swimming pool exposure scenario for MW-14A exceeded one (9.4) largely as a result of TCE. As explained previously, use of ground water concentrations of TCE and other chemicals in MW-14A results in "worst case" estimates of risk.

For off-site residents exposed to VOCs in indoor air, calculated theoretical lifetime cancer risks were within the acceptable USEPA risk range (1E-06 to 1E-04) and are below the "no significant risk" level for carcinogens of 1E-05 defined under Proposition 65. The highest off-site theoretical lifetime cancer risk calculated was for a resident exposed to VOCs in indoor air (3.9 E-06) was calculated for a location on Hampton Drive (4. Hampton Drive; Table 5.4).

Hypothetical exposures to ground water from MW-14A resulted theoretical lifetime cancer of 6.8E-06 and 1.3E-06 for the irrigation and swimming pool exposure scenarios, respectively. As discussed previously, concentrations of TCE in MW-14A are more than 10 times higher than the highest concentration of TCE detected in residential wells. Thus, risks calculated for hypothetical users of ground water from MW-14A represent "worst case" exposure conditions and not those calculated for residential wells.

The highest theoretical lifetime cancer risk calculated for the irrigation exposure scenario was calculated for a hypothetical user of ground water from MW-14A (6.8E-06). As discussed previously, risks calculated for MW-14A represent hypothetical "worst case" concentrations in ground water. The next highest calculated risk (3.5E-07) was for a private residential well on Bermuda Drive ((a) Bermuda) (Table 5.5). The risk for the well on Bermuda Drive is well below the range of risks considered acceptable by the USEPA.

The calculated theoretical lifetime cancer risk for the swimming pool exposure scenario was highest for the dermal absorption pathway. As in the irrigation exposure scenario, the highest theoretical lifetime cancer risk was calculated for a hypothetical user of ground water from MW-14A (8.1E-06). This risk represents the use of "worst case" concentrations of TCE and other contaminants in off-site ground water. The next highest risk for a private residential well on Bermuda Drive ((a) Bermuda) (Table 5.6) was 6.3 E-07, well below the range of risks considered acceptable by the USEPA.

Calculated theoretical lifetime cancer risk for residents exposed to VOCs volatilizing from surface water were 1.6 E-06, well within the range of risks considered acceptable the USEPA. The exposures and risks calculated for this pathway are particularly conservative since changes in wind direction and distance from the creek are not reflected in the calculations. Further,

maximum detected concentrations of cis-1,2-DCE, PCE, and TCE in Walnut Creek were used to calculate exposure and risks.

5.3 Evaluation of Risk Assessment Uncertainties

Several areas of uncertainty were associated with the estimation of chemical intakes from exposure to air, soil, ground water, and surface water and the characterization of risk. For ease of discussion, uncertainties are discussed as they relate to either the estimation of exposure or the evaluation of chemical toxicity.

5.3.1 Uncertainties Related to Estimation of Exposure

Uncertainties associated with estimation of exposure to the chemicals of concern in soil, ground water, or air primarily relate to:

- the representativeness of indoor air samples collected on- and off-site and the possible changes in indoor air concentrations with the season;
- the modeled air concentrations of VOCs associated with use of ground water for irrigation and volatilization of VOCs from surface water;
- the selection of exposure parameters estimating intakes and frequency and duration of exposure;
- the extent of absorption of chemicals in soil from the digestive tract,
- the possible uptake of VOCs into edible vegetable produce grown in home gardens that are irrigated with ground water

These areas of uncertainty are discussed below.

<u>Indoor Air Uncertainties</u>

Indoor air samples were collected at on-site businesses in December 2003 and in off-site residences in January, February, and March, 2004. The results represent a single air sample collected on a particular day and may not represent indoor air concentrations throughout the year. The concentrations of VOCs in indoor air can be affected by several factors. When a subsurface source of VOCs is considered (i.e., VOCs in ground water), the most important factors that may affect the migration of VOCs from a subsurface source to the indoor air are the depth of the source of VOCs (i.e, the depth of potentially affected ground water), the permeability of nearby soil and the residence to vapors, and the amount of under-pressurization of the residence. Each of these factors may be directly or indirectly influenced by local climate and meteorological conditions.

In winter, there is typically lower air exchange between the indoor and outdoor environment, resulting in relatively higher VOC concentrations in indoor air than those present in summer. In addition, operation of a heating system produces temperature and pressure differences between the indoor and outdoor environments that may draw VOCs into a building. The pressure difference inside and outside of a building is greatest when windows and doors are closed and the heating system is operating. Operation of heating systems may create a "stack" effect in the home in which make-up air is pulled into the home at lower levels, potentially drawing vapors from soil into indoor air. Steady winds on a structure at speeds greater than five miles per hour may also cause under pressurization. Thus, the winter heating season and steady winds may create conditions that increase movement of soil vapor into a home.

In addition, during the wetter seasons of the year, precipitation may fill pores occupied by soil vapor, driving the soil vapor from the wetter soils into the drier soils underneath a home. The shallow ground water may also rise during the wetter seasons of the year and bring VOCs in the water table closer to the building.

As a result of these meteorological and climatological conditions, "worst-case" indoor air concentrations may occur during winter or spring when depth to groundwater is shallow, the building heating system is operating, and the doors and windows of the building are closed (MADEP, 2002). Although the Pleasant Hill/Concord area experiences milder winters than most areas of the country, indoor air concentrations of VOCs measured in December through March in the Pleasant Hill/Concord area are expected to be higher than in the summer and fall months for the reasons described above. Therefore, the results of winter-time indoor air sampling conducted at on- and off-site areas at Hookston Station may overestimate year-round average indoor air concentrations.

Crawl space air samples results from 7 off-site residences provide a conservative upper bound for indoor air concentrations observed in residences. The maximum detected concentration of TCE in Hookston Station area crawl spaces (6.7 ug/m^3) was very similar to the maximum TCE concentration detected in residential indoor air (5 ug/m^3) (Table 2.1.3b). According to studies of radon migration into residential indoor air, indoor air concentrations of radon ranged from 0.36 to 0.60 of crawl space radon concentrations (Nazaroff and Doyle, 1985). This suggests that crawl space air concentrations of VOCs would likely exceed the concentration of VOCs in indoor air if the crawl space is the source of VOCs migrating into the residence. The observation that residential indoor air VOC concentrations are similar to crawl space air concentrations suggests

that the indoor air sampling program has not underestimated the concentration of VOCs migrating into the indoor air of living spaces.

With exception of a voluntary indoor air questionnaire, the possible sources of VOCs in indoor air were not thoroughly investigated. Although migration of soil vapor from ground water may be a source of VOCs in indoor air, indoor use of consumer products containing VOCs may also be a source of VOCs in indoor air. The degree to which other sources of VOCs such as consumer products may be sources of VOCs in indoor air is not known. For example, the Agency for Toxic Substances and Disease Registry estimated that "typical" background concentrations of TCE in air ranged from about 0.5 ug/m^3 to 2.7 ug/m^3 (ATSDR, 1997). CalEPA estimated that the median range of TCE concentrations in California homes ranged from 0.3 ug/m^3 to 0.8 ug/m^3 (CalEPA, 2001b). Thus, it would not be surprising to find TCE in indoor air in a city or suburban area at typical levels that approach or even exceed the RWQCB's residential indoor air screening level of 1.2 ug/m^3.

Concentrations of TCE in residential indoor air are similar to what would be predicted from empirically derived attenuation factors for VOCs in soil vapor and indoor air. Johnson et al. (2002) examined the relationship between soil gas and indoor air concentrations of several chlorinated VOCs. The range of observed attenuation factors between soil vapor and indoor air was 1E-4 to 1E-6 with an average of 3 E-05. Given the range of attenuation factors reported by Johnson et al. and the maximum TCE soil vapor concentration detected off-site near the Hookston Station site (ASV-05; 6,800 ug/m^3) (RI Table 7-2; RI Figure 5-6), indoor air concentrations would be predicted to range from 0.0068 to 0.68 ug/m^3. These concentrations are somewhat lower than the observed concentrations in indoor air in off-site residences.

Air Emissions and Modeling Uncertainties

Air concentrations resulting from modeling use of ground water for irrigation purposes, filling pools, and VOC emissions from surface water are uncertain. To some degree, the potential for human exposure to volatile emissions is maximized by the fact that wind direction is not factored into the analysis. It is highly unlikely that the wind carrying VOC emissions is toward the home of residents 100% of the time. Also, more rapid volatilization of VOCs from irrigation water or swimming pools could result in decreased inhalation exposures. For example, splashing in a pool could result in greater than expected losses of VOCs from surface water.

Exposure Parameters

Exposure periods of 30 years are routinely considered in risk assessments. As is typical with risk assessments, no factor was used to account for the likely decrease in ground water

concentrations over time. Over decades, concentrations of chemicals of potential concern in ground water will likely decrease due to degradation, volatilization, or other mechanisms. Assumption of a constant concentration of the chemicals of potential concern in ground water will likely result in overestimation of chemical exposures and risks.

Indoor air inhalation rates were adjusted downward from the default daily inhalation rates for off-site residents exposed to VOCs in indoor air. A daily indoor inhalation rate of 13.3 m^3/day was used for the adult resident (average of the male and female average daily inhalation rates) and 8.7 m^3 /day used for the 1 to 7 year old child. These rates are average values recommended for use by the USEPA (USEPA, 1997a) for daily inhalation exposure. Inhalation rates less than 20 m^3 /day for adults and 10 m^3 /day for children are justified for indoor air exposures, particularly when it is considered that USEPA recommends that the amount of time spent indoors at a residence is 16.4 hours per day (USEPA, 1997a).

Bioavailability of Chemicals in Soil

The absorption of chemicals in soil from the digestive tract has been the subject of considerable study in recent years. In the calculation of ESLs for direct contact exposure scenarios, the regulatory default is to assume that ingestion of a chemical in soil is absorbed to the same extent as the chemical in food or water. For arsenic, this is clearly not the case. Roberts et al. 2002 evaluated the digestive tract absorption of arsenic in monkeys for soils from five waste sites (one soil sample from an electrical substation, a wood preservative treatment site, and a cattle-dip vat site and two samples from pesticide sites) with arsenic concentrations in soil ranging from 101 to 743 mg/kg arsenic. The absorption of arsenic in soil was measured relative to that of an oral solution of sodium arsenate. The excretion of urinary and fecal arsenic was used to evaluate the bioavailability of arsenic. The monkeys received oral doses of arsenic in soil ranging from 0.3 mg/kg to 1.0 mg/kg. The oral bioavailability of arsenic in soil (relative to sodium arsenate administered orally in water) ranged from 10.7% (pesticide site soil) to 24.7% (cattle dip site soil). Roberts et al. concluded that “These observations, coupled with data in the literature, suggest limited oral bioavailability of arsenic in soils from a variety of types of arsenic-contaminated sites.” In summary, these data sets suggest that arsenic bioavailability in soil and dust is considerably lower than 100%. For this reason, theoretical risks calculated to be associated with direct contact with arsenic in soil are likely overestimated by a factor of about 3.

Uptake of VOCs into Homegrown Produce

Chemicals detected in ground water at the Hookston Station site are volatile, meaning that they evaporate easily at normal temperatures. As a result, VOCs will tend to volatilize during the irrigation process, rather than be taken up or absorbed by plants. Berisford et al. 2003

demonstrated that TCE and tetrachloroethylene (PCE) are readily stripped from ground water when sprayed through mini-sprinklers. These sprinklers, typical of home and garden use, stripped concentrations of TCE and PCE from ground water with an effectiveness of 97% to 100%. Berisford et al. (2003) tested concentrations of PCE and TCE that ranged from hundreds to thousands of ug/L. For this reason, it is likely that lawn or garden irrigation will result primarily in releases of VOCs to air but will not result in significant transfer of VOCs to edible fruits and vegetables. The possible exposure of off-site residents to VOCs in air resulting from lawn irrigation is addressed in Appendix B.

Research demonstrates that if the volatile chemicals manage to reach the plants and if the chemicals are then absorbed by the plants, the VOCs do not accumulate in plant tissues (Davis et al. 1998). Instead, the VOCs are transferred to air through pores in the plants' tissues. The resulting air concentrations do not pose a threat to health because the amounts of chemicals released are very low and they mix readily with surrounding air.

Studies have also shown that chemicals taken up through a plant's root system tend to concentrate in the cells near the surface of the roots (Agustin 1994). In root vegetables such as beets, carrots, and potatoes, these cells are typically lost during washing and peeling of the produce. In above-ground fruits and vegetables (e.g., tomatoes, lettuce, squash, etc.), the roots are not consumed.

Plants are also able to break down or degrade volatile chemicals. Consequently, volatile chemicals taken up by plants may be present temporarily in the roots and stems of the plant, but are much less likely to be present in the leaves or other above-ground, potentially edible parts of the plant (Newman et al. 1997). According to research performed by Schnabel et al. (1997), TCE that is taken up into tomatoes and spinach is degraded to the extent that TCE is not detectable. Schnabel et al. were unable to remove the breakdown products of TCE using a strong solvent or acid, indicating that if the breakdown products in tomatoes or spinach are eaten, it is unlikely that they would be absorbed from the digestive tract. In summary, the literature review indicates that uptake and accumulation of volatile chemicals in plants and subsequent exposures by home gardeners and their families are likely to be negligible.

5.3.2 Uncertainties Related to the Toxicity Assessment

Uncertainties associated with characterization of risks associated with the chemicals of concern primarily relate to the derivation of cancer slope factors and their use in estimating lifetime cancer risk. Perhaps the greatest uncertainty associated with the risk assessment process is the

evaluation of carcinogenic risk due to chemical exposure. The fundamental principles underlying risk assessment for carcinogenic chemicals remain arguable, including the tenet that every potential carcinogen is associated with some degree of carcinogenic risk, no matter how small the dose. The belief that chemically induced cancer is a non-threshold process is a conservative default policy that the EPA assumes to ensure the protection of human health. However, there is little biological basis to support the widespread application of this policy to all potential carcinogens.

The EPA default policy for potential chemical carcinogens mandates that results from high-dose animal studies be extrapolated to exposures in humans which are thousands of times lower. The EPA uses a mathematical model known as the linearized multistage model to extrapolate from high doses to very low doses. As applied by the EPA, the linearized multistage model leads to quantitative estimates of cancer risk which are conservative, upper bound approximations of lifetime cancer risk. The EPA expressed the following uncertainty in using the linearized multistage model to determine carcinogenic risks in humans:

> It should be emphasized that the linearized multistage procedure leads to a plausible upper limit to the risk that is consistent with some proposed mechanisms of carcinogenesis. Such an estimate, however, does not necessarily give a realistic prediction of the risk. The true value of risk is unknown, and may be as low as zero. The range of risks, defined by the upper limit given by the chosen model and the lower limit which may be stated as low as zero, should be explicitly stated. (51 Federal Register 33998)

Thus, according to the EPA commentary cited above, carcinogenic risks estimated using the linearized multistage procedure lead to conservative but not necessarily realistic estimates of risk. The National Research Council has also commented concerning use of the linearized multistage model, stating:

> The linearized multistage model is widely used to estimate cancer risks associated with environmental exposures (EPA, 1987) and is said to provide an upper-limit estimate of low-dose response. To some degree, the model's wide use reflects its mathematical flexibility. However, biologic support for the assumption of linearity at low doses remains largely inferential and probably wrong in a high proportion of cases (emphasis added) (Bailar et al., 1988). (NRC, 1989)

For these reasons, it is likely that the risks calculated in this report will substantially overestimate the actual risks which may be associated with exposure to the chemicals of potential concern in air, soil, ground water, and surface water.

In particular, TCE is regulated by the USEPA and State of California as a potentially carcinogenic substance. TCE is also a chemical of concern at the Hookston Station site. In 2001, the USEPA published a draft evaluation of the toxicity of TCE. Although this document has undergone review by the USEPA's Science Advisory Board, a final version of the report has not been published three years later. Some elements of the draft report are controversial, and apparently the USEPA has asked the National Academy of Sciences to review the report (http://www.hsia.org/updates/nov-dec%202003.htm). The uncertainties associated with assessing the theoretical risks of TCE exposure are addressed in greater detail below.

The 2001 draft USEPA toxicity assessment for TCE proposes that TCE should be considered a more potent potential carcinogen than was previously thought by the USEPA or as is currently considered by the Office of Environmental Health Hazard Assessment (OEHHA) in California. Unlike its previous policy regarding the calculation of TCE cancer risk, the USEPA draft report does not propose a single value for assessing TCE cancer risk, but provides a range of values that varies over 20-fold. Each value is based on endpoints derived from a different human or animal study. The draft report recommends that a slope factor from this range be selected that is appropriate for the risk assessment and exposure scenario under consideration, but does not provide specific guidance on choosing an appropriate factor. Publication of the EPA's draft assessment has generated substantial controversy and criticism. In fact, the EPA's own Scientific Advisory Board (SAB) has suggested that risk assessors wait for resolution of controversial issues before putting the new recommendations into effect. The EPA plans to submit the TCE draft assessment to the National Academy of Sciences for a special expert-panel review. That review is scheduled to be completed in 2006.

Concerns raised during review of the USEPA TCE risk assessment draft included:

- Proper use of the range of slope factors developed
- Inadequate scientific analyses to support the range of values
- Oral to inhalation extrapolation
- Risk assessment at background values
- The inconsistency in the human data for the cancer causing effects of TCE

The new range of slope factors for TCE proposed in the USEPA draft assessment is 0.02 to 0.4 per mg/kg-day. The highest value (0.4 per mg/kg-day) is 36-fold higher than the value applied by EPA and 57 times greater than the value derived by the State of California Office of Human

Health and Environmental Assessment (OEHHA). A number of problems are associated with using the proposed draft range of values.

- There are no guidelines for applying the range in risk assessment.
- All slope factors are given in terms of oral exposure with no specific guidance for extrapolating from oral to inhalation exposures.
- The high end of the USEPA draft range is based on an inappropriate study.

First, the USEPA draft recommends choosing an appropriate slope factor from the new range based on the unique risk factors of each individual risk assessment. However, the USEPA provides no clear guidance on how this should be done.

Second, the draft slope factors are expressed in terms of oral exposure (per mg/kg-day) without specific information on how to assess inhalation exposures using these values. As a result, federal and state agencies have proposed different methods to address this issue, but there is no consensus. Application of the most conservative slope factor results in an inhalation risk that is many-fold higher than the previous value.

Thirdly, the draft high end slope factor (0.4 per mg/kg-day) calculated by the USEPA was based on the results of Cohn et al. (1994). The Cohn study was a proportional mortality (PMR) study that evaluated the incidence of leukemia and non-Hodgkin's lymphoma (NHL) in a population exposed to solvents in drinking water. In general, PMR studies are unreliable in proving an association, cannot be used to prove causation (McLaughlin and Brookmeyer, 1994) and are entirely inappropriate for deriving health-based benchmarks. Although the study reported small, statistically significant increases in NHL in females exposed to the highest levels of TCE, the study is flawed, causing the relatively small increases in relative risk to be suspect. The study provides no information regarding: 1) residential history of the individuals that describes how long they were exposed; 2) the magnitude of TCE exposure; 3) potential confounders for attributing the increased risk of cancer to TCE; 4) medical history of the residents and; 5) exposure to other potentially carcinogenic substances.

The incompatibility of the draft high end slope factor with empirical evidence of TCE carcinogenicity is illustrated by using the draft slope factor to calculate the risks from workplace exposure to TCE. The most highly exposed individuals are those who have worked with TCE for decades and have been exposed at levels that approach or even exceed current occupational exposure limits. The current Occupational Safety and Health Administration Permissible Exposure Limit (OSHA PEL) for TCE is 537 mg/m^3 and the current American

Conference of Governmental Industrial Hygienists Time-Weighted Average Threshold-Limit Value (ACGIH TWA-TLV) for an eight hour work day is 269 mg/m^3.

Using the most conservative draft slope factor in the range of values derived by USEPA (0.4 $mg/kg\text{-}day^{-1}$), 98% or more of all individuals exposed to TCE at current occupational exposure limits would be expected to develop cancer after exposure for 250 days per year for 25 years. This is clearly not the case. Workers have been exposed to TCE at similar levels for over 80 years and yet no conclusive association between TCE and cancer has been determined, much less one of such magnitude. This level of calculated theoretical risk is unrealistically high, particularly when compared to the results of epidemiological data from TCE exposed workers.

In summary, if TCE exposure in workers caused cancer at the levels suggested by calculations using the EPA's draft high end slope factor, the epidemiological data from exposed workers should indicate a clearly elevated, consistent risk of developing cancer (above that which occurs naturally) after an appropriate latency period. The use of the draft high end value is clearly not supported by the scientific literature.

A review of uncertainties associated with the characterization of human health risk posed by exposure to chemicals in air, soil, ground water, and surface water on or near the Hookston Station site indicates that the methods used primarily overestimate exposure and risk.

6.0 RISK ASSESSMENT SUMMARY

The purpose of this baseline RA was to perform an exposure and risk assessment of persons on and near the Hookston Station site that may be exposed to chemicals in indoor air, on-site soil, ground water from off-site private wells, and surface water in Walnut Creek. In addition, theoretical risks from exposure to ground water were assessed for the most affected off-site well, MW-14A. Unlike the residential wells considered in the RA, MW-14A is not located in a neighborhood and has not been used as a source of ground water. However, exposure and risks were calculated based on the results from this well because it contains the highest off-site concentrations of TCE. As such, hypothetical exposure to chemicals detected in MW-14A represents "worst case" conditions. Like all risk assessments of this type, the results cannot be used to accurately predict the actual incidence of human disease for current or future conditions. Risks calculated in the baseline RA rely on conservative but uncertain methods.

The RI report was the source of indoor air, soil, ground water, and surface water data used in evaluating human exposures and risks. The RI data was supplemented with analysis from the last two quarters of monitoring from 2004 for MW-14A..

<u>On-site Exposures and Risks</u>
Evaluation of potentially exposed individuals and possible exposure pathways resulted in selection of the following on-site exposure pathways for consideration in the baseline RA:

Commercial/Industrial Workers
- Inhalation of volatile chemicals in indoor air

- Inadvertent ingestion of chemicals in soil
- Skin contact with chemicals in soil
- Inhalation of chemicals in dusts or volatilizing from soil to outdoor air

Construction Workers
- Inadvertent ingestion of chemicals in soil
- Skin contact with chemicals in soil
- Inhalation of chemicals in dusts or volatilizing from soil to outdoor air

Noncancer risks resulting from commercial/industrial worker to VOCs in indoor air were below one for all 5 on-site indoor air locations sampled, indicating that VOCs in indoor air do not pose a noncancer health risk to workers. Theoretical lifetime cancer risk estimates for commercial/industrial worker inhalation of TCE in indoor air ranged from 3.3 E-07 to 2.4 E-06, below or well-within the range of risks considered acceptable by the USEPA.

Noncancer risks resulting from commercial/industrial worker exposure to chemicals of potential concern in soils to a depth of 0 to 10 feet bgs were also acceptably low (0.55). Theoretical lifetime cancer risks exceeded 1 E-04. The lifetime cancer risk associated with commercial/industrial worker exposure to chemicals in soil was 98% attributable to arsenic. Although arsenic concentrations in 17 out of 19 surface soil samples were below 10 mg/kg, two samples were sufficiently high (211 mg/kg and 76 mg/kg) to skew the exposure point concentration to 132 mg/kg for arsenic in on-site soils. Furthermore, much of the site is covered with rock or asphalt, decreasing the possibility that on-site workers will directly contact arsenic in soil.

Noncancer risks for construction workers ingesting soil, having skin contact with soil, and inhaling chemicals in soil was 0.30, indicating that direct contact with on-site soil does not pose a noncancer health concern for construction workers. The lifetime cancer risk associated with construction worker exposure to chemicals in on-site soil was 4.3 E-05, within the range of acceptable USEPA lifetime cancer risks.

Off-Site Exposure and Risks

Evaluation of potentially exposed individuals and possible exposure pathways resulted in selection of the following off-site exposure pathways for consideration in the baseline RA:

Off-site residents (child and adult resident)

- Inhalation of chemicals in indoor air
- Inhalation of chemicals in outdoor/indoor air released from lawn irrigation with groundwater
- Skin contact, incidental ingestion, and inhalation of chemicals in backyard swimming pools using ground water (child resident only)
- Inhalation of chemicals in outdoor/indoor air released from Walnut Creek surface water

Noncancer risks calculated for the off-site resident exposed to VOCs in indoor air, VOCs volatilizing from ground water used for irrigation, VOCs in ground water used to fill a swimming pool, and VOCs volatilizing from Walnut Creek (were less than one for all exposures scenarios evaluated except that of a hypothetical swimming pool scenario using groundwater concentrations from MW-14A. This indicates that VOCs detected in residential indoor air,

ground water from private wells, and surface water from Walnut Creek do not pose noncancer adverse health risks. Noncancer risks calculated for the swimming pool exposure scenario for MW-14A exceeded one (9.4) largely as a result of TCE. The use of ground water concentrations of TCE and other chemicals in MW-14A to assess exposure results in "worst case" estimates of risk.

Theoretical lifetime cancer risks for the off-site resident exposed to VOCs in indoor air varied with the residential location sampled; the range of theoretical lifetime cancer risk was 1.5 E-07 to 3.9 E-06. All of the calculated theoretical lifetime cancer risk were below or well within the range of risks considered acceptable by the USEPA.

For all 8 private wells sampled near the Hookston Station site, calculated exposures to VOCs in ground water resulting from use of ground water for irrigation and filling swimming pools were below 1 E-06. Calculated theoretical lifetime cancer risks associated with irrigation and swimming pool use of ground water from MW-14A were 6.8 E-06 and 8.1 E-06, respectively. These calculated theoretical lifetime cancer risks are within the acceptable USEPA risk range (1E-06 to 1E-04) and are below the "no significant risk" level for carcinogens of 1E-05 defined under Proposition 65. As discussed, risks calculated for MW-14A represent "worst case" exposure conditions and not those potentially present at off-site residential wells.

Theoretical lifetime cancer risks resulting from volatilization of VOCs from surface water and inhalation by residents was calculated to be 1.6 E-06

An evaluation of exposure and toxicological uncertainties indicated that most of the assumptions and methods used in the baseline RA will result in overestimation, rather than underestimation of risks.

7.0 REFERENCES

ATSDR (Agency for Toxic Substances and Disease Registry). 1997. Toxicological Profile of Trichloroethylene (Update). September 1997.

Berisford YC, Bush PB, Blake JI, Bayer CL. 2003. Use of mini-sprinklers to strip trichloroethylene and tetrachloroethylene from contaminated ground water. J Environ Qual. 32(3): 801-15.

Agustin, R.C. 1994. Analysis of the potential for plant uptake of trichloroethylene and an assessment of the relative risk from different crop types. Thesis. Air Force Institute of Technology. AFIT/GEE/ENV/94S-01 July 1994

CalEPA (California Environmental Protection Agency). 2001a. A Guide to Health Risk Assessment. Office of Environmental Health Hazard Assessment. http://www.oehha.ca.gov

CalEPA (California Environmental Protection Agency). 2001b. Indoor Air Quality Guideline. No. 3. May 2001. Chlorinated Chemicals in Your Home. California Air Resources Board.

Cohn P, Klotz J, Bove F, Berkowtiz M, Fagliano J. 1994. Drinking water contamination and the incidence of leukemia and Non-Hodgkin's lymphoma. Environ Health Perspec 102:556-561.

CTEH (Center for Toxicology and Environmental Health) 2004. Risk Assessment. Hookston Station Site. Pleasant Hill, California April 2004

Davis, L.C., Vanderhoof, S., Dana, J., Selk, K., Smith, K., Goplen, B., and Erickson, L.E. 1998. Movement of chlorinated solvents and other volatile organics through plants monitored by fourier transform infrared (FT-IR) spectrometry. J. Hazardous Substance Research. 1: 4-1 – 4-26

ERM (Environmental Resources Management) 2004. Remedial Investigation Report. Hookston Station Site. Pleasant Hill, California. August 2004

Johnson, P.C. et al. 2002. Migration of soil gas vapors to indoor air: determining vapor attenuation factors using a screening –level model and field data from the CDOT-MTL Denver, Colorado site. American Petroleum Institute. April 2002. No. 16

MADEP (Massachusetts Department of Environmental Protection) 2002. Indoor Air Sampling and Evaluation Guide. WSC POLICY #02-430. April 2002

McLaughlin, J. K. and Brookmeyer, R. Epidemiology and biostatistics. In: McCunney, R. J., Editor. A practical approach to occupational and environmental medicine. 2nd ed. Boston: Little Brown; 1994; pp. 346-357.

Nazaroff, W.W. and Doyle, S.M. 1985. Radon entry into houses having a crawl space. Health Physics 48:265-281.

Newman, L.A. et al. 1997. Uptake and biotransformation of trichloroethylene by hybrid poplars. Environ. Sci. Technol. 31:1062-1067

Roberts, S.M., Weimar, W.R., Vinson, J.R.T., Munson, J.W., and Bergeron, R.J. 2002. Measurement of arsenic bioavailability in soil using a primate model. Toxicol. Sci. 67:303-310.

Schnabel, W.E. et al. 1997. Uptake and transformation of trichloroethylene by edible garden plants. Wat. Res. 31:816-824.

SFRWQCB (San Francisco Regional Water Quality Control Board) 2003. Screening for Environmental Concerns at Sites with Contaminated Soil and Groundwater. Interim Final – July 2003

USEPA. 1989. Risk Assessment Guidance for Superfund. Volume I. Human Health Evaluation Manual (Part A). USEPA/540/1-89/002.

USEPA. 1991. Risk Assessment Guidance for Superfund. Volume 1 Human Health Evaluation Manual. Supplemental Guidance 'Standard Default Exposure Factors'. PB91-921314. March 25, 1991.

USEPA 1992. Supplemental Guidance to RAGS: Calculating the Concentration Term. May 1992. PB92-963373.

USEPA 1997a. Exposure Factors Handbook. Volume I – General Factors. Office of Health and Environmental Assessment.

USEPA 1997b. Health Effects Assessment Summary Tables. FY-1997 Update. July 1997. PB97-921199

USEPA 1997c. Standard Operating Procedures (SOPs) for Residential Exposure Assessments. December 19, 1997. Prepared by The Residential Exposure Assessment Work Group.

USEPA 2001a. Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites. Peer Review Draft. OSWER 9355.4-24. March 2001

USEPA 2001b. Risk Assessment Guidance for Superfund Volume 1: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment Interim) Review Draft for Public Comment. September 2001. EPA/540/R/99/005 PB99-963312

USEPA 2004. ProUCL Version 3.0 User Guide. EPA/600/R04/079.

TABLES