RISK ASSESSMENT FOR THE FORMER CHEVRON ASPHALT PLANT EMERYVILLE, CALIFORNIA

July 28, 1992

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Geraghty & Miller, Inc., is submitting this report to Chevron U.S.A. Products Company for work performed at the former Chevron asphalt plant, Emeryville, California. The report was prepared in conformance with Geraghty & Miller's strict quality assurance/quality control procedures to ensure that the report meets the highest standards in terms of the methods used and the information presented. If you have any questions or comments concerning this report, please contact one of the individuals listed below.

Respectfully submitted,

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EXECUTIVE SUMMARY

This risk assessment, prepared by Geraghty & Miller, Inc., for Chevron U.S.A. Products Company, evaluated the potential threat to human health and the environment for constituents detected in soils and ground water at the former Chevron asphalt plant in Emeryville, California, in the event that the site is redeveloped for commercial or retail uses. From the early 1950s until June 1987, the Chevron asphalt plant operated as a laboratory and test facility. The laboratory tested asphalt composition and experimented with asphalt-based surface coats. A portion of the site was used as a storage and transfer facility for petroleum products. Another area of the site was leased to a solvent handler. Information regarding Chevron's tenants' use of chemicals on site was not available. The buildings at the former Chevron asphalt plant were demolished and the site is now a vacant lot.

Various site investigations at the property have indicated the presence of chlorinated solvents and petroleum hydrocarbons in soil and ground water. Remedial activities have occurred at the site involving the removal of contaminated soil. The calculated health-based cleanup goals were compared to currently measured concentrations of constituents in soil and ground water to aid in the development of any additional remedial strategies.

The constituents of concern identified in soil and/or ground water were benzene, chloroform, 1,1-dichloroethane, 1,1-dichloroethene, cis-1,2-dichloroethene, trans-1,2-dichloroethene, ethylbenzene, tetrachloroethene, toluene, total petroleum hydrocarbons (TPH) as diesel, TPH as gasoline, 1,1,1-trichloroethane, trichloroethene, vinyl chloride, and xylenes.

The purpose of this report was to develop health-based cleanup goals based on the most probable future land-use at the site. The former Chevron asphalt plant may be developed for commercial purposes. The original site development drawings showed three buildings on the site with the remainder of the site paved over as parking lot. Assuming future development of the site, health-based cleanup goals were calculated evaluating exposure of future users of the property inhaling volatile organic constituents (VOCs) migrating from soil and ground water into buildings at the site. Ground water in the vicinity of the site is not used as a water supply source. Ground water discharges into San Francisco Bay downgradient of the site. Therefore, the nearest downgradient beneficial use of ground water would be the bay. The most recent ground-water data (collected in April) were compared to water quality criteria for the protection of aquatic life to evaluate whether discharging current concentrations of the constituents of concern would degrade San Francisco Bay or pose a threat to aquatic life in the bay.

The methodologies used in this risk assessment were designed to be constituent with guidelines established by the California Regional Water Quality Control Board (RWQCB), San Francisco Bay Region (RWQCB, 1990) and the U.S. Environmental Protection Agency (USEPA; 1989a, 1991a,b) for risk assessments in general and the development of remedial goals specifically.

The risk assessment process included derivation of numerical estimates of the health-based remediation goals designed to be protective of human health and the environment for human and environmental receptors from potential exposure to constituents detected in environmental media (e.g., soils) at or adjacent to the former Chevron asphalt plant. Exposure to detected constituents was evaluated by considering hypothetical future conditions. Health-based remediation goals were derived based on protection of an on-site worker assuming direct contact exposure to soils during construction activities. In addition, health-based remediation goals were derived based on protection of an on-site worker assuming inhalation exposure to constituents originating in soils or ground water beneath the building and migrating into the building. An evaluation of exposures to environmental receptors also was conducted using the ground-water data and assuming these concentrations discharged into San Francisco Bay, the nearest downgradient ground-water discharge point.

Standard numerical parameters for quantifying human intakes were used to derive the health-based remediation goals for potentially exposed populations. Constituent- and route-specific intakes were estimated, and toxicity criteria (established by the USEPA) were used in the derivation to account for potential non-carcinogenic health effects and potential cancer risk from the hypothetical exposure scenarios. USEPA-established reference doses (RfDs) were used to derive health-based remediation goals for constituents classified as non-carcinogens. An RfD represents the constituent- and route-specific dose to which a human receptor may be exposed over a lifetime without experiencing adverse health effects. USEPA-established cancer slope factors (CSFs) were used to derive health-based remediation goals for constituents classified as potential carcinogens. A CSF represents an upperbound estimate of the probability of developing cancer from constituent exposure over a lifetime and is derived from a mathematical model that extrapolates from the high doses in animal studies to the low doses characterizing human exposure.

An environmental assessment was conducted as part of this risk assessment to evaluate the potential impacts to environmental receptors potentially exposed to site-related constituents. The approach used in the environmental assessment approximately parallel those used to conduct human health assessments. Following identification of all potentially exposed populations, the nearest downgradient receptor location was assumed to be San Francisco Bay, ambient water quality criteria derived by USEPA and based on information on exposure and toxicity were used to derive qualitative estimates of potential ecological impacts.

Comparisons were made between the health-based remediation goals and the detected levels of constituents at the former Chevron asphalt plant. To evaluate exposure of aquatic life, currently detected ground-water concentrations were compared with ambient water quality criteria. The currently measured levels of the constituents of concern in soil and ground water were all below the health-based remediation goals or ambient water quality criteria. As a result, further remediation at the site does not appear to be warranted.

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1.0 INTRODUCTION

Geraghty & Miller, Inc., has been contracted to evaluate the potential threat to human health and the environment for constituents detected in soils and ground water at the former Chevron asphalt plant, Emeryville, California in the event that the site is redeveloped for commercial or retail uses. The risk evaluation was performed by developing health-based cleanup goals for soil and ground water. Various site investigations at the property have indicated the presence of chlorinated solvents and petroleum hydrocarbons in soil and ground water. Remedial activities involving the removal of contaminated soil have occurred at the site. The calculated health-based cleanup goals were compared to currently measured concentrations of constituents in soil and ground water to aid in the development of any additional remedial strategies.

The purpose of this report was to develop health-based cleanup goals based on the most probable future land uses at the site. The former Chevron asphalt plant may be developed for commercial purposes. The original site development drawings showed three buildings on the site, with the remainder of the site paved over as a parking lot. Assuming future development of the site, health-based cleanup goals were calculated evaluating exposure of future users of the property inhaling volatile organic compounds (VOCs) migrating from soil and ground water into buildings at the site. Ground water in the vicinity of the site is not used as a water-supply source. Ground water discharges into San Francisco Bay downgradient of the site. Therefore, the nearest downgradient beneficial use of ground water would be the bay. The most recent ground-water data were compared to water-quality criteria for the protection of aquatic life to evaluate whether discharging current concentrations of the constituents of concern would degrade San Francisco Bay or pose a threat to aquatic life in the bay.

The methodologies used in this risk assessment were designed to be consistent with guidelines established by the California Regional Water Quality Control Board (RWQCB), San

Francisco Bay Region (RWQCB, 1990), and the U.S. Environmental Protection Agency ((USEPA (1989a, 1991a,b) for risk assessments in general and the development of remedial goals specifically. The report is organized as follows:

- Section 2, Site Characterization, describes the former Chevron asphalt plant, provides a summary of the history of the site, and describes the data collected to date.

- Section 3, Constituent Characterization, identifies and summarizes the occurrence of constituents in soil and ground water

- Section 4, Toxicity Assessment, identifies and presents summaries of the inherent toxicological properties of the constituents detected at the site.

- Section 5, Exposure Assessment, discusses the physical and chemical properties influencing constituent migration, potential exposure routes, and potential receptors used in the derivation of health-based remediation goals.

- Section 6, Derivation of Health-Based Remediation Goals, presents the derivation of health-based cleanup goals. The remediation goals are compared to the concentrations of the constituents of concern measured in soil and ground water.

- Section 7, Uncertainties in the Risk Assessment, discusses the uncertainties in the health-based cleanup goal derivations.

- Section 8, Summary and Conclusions, summarizes the results of the risk assessment.

- Appendix A, Calculation of Health-Based Remediation Goals, provides the volatilization model used to calculate ground-water remediation goals.

2.0 SITE CHARACTERIZATION

This section describes the former Chevron asphalt plant and surrounding area, the geology and hydrogeology, and observations obtained from site investigations conducted to date, and the geology, hydrology, and meteorology of the site.

2.1 SITE DESCRIPTION AND HISTORY

The former Chevron asphalt plant is in the City of Emeryville, Alameda County, California. The site encompasses approximately 3 acres. The site is bordered to the east and south by Landregan Street and Powell Street, respectively, and to the west by the Southern Pacific Railroad right-of-way (as seen in Figure 2-1). The plant was used previously as a storage and transfer facility for petroleum products. The site is currently vacant.

Beginning in the early 1950s, the Chevron asphalt plant operated as a laboratory and test facility. It was closed in June 1987. The laboratory tested asphalt composition and experimented with asphalt-based surface coats. A portion of the land was leased to a solvent handler during this same period. Information regarding Chevron's tenants' use of on-site chemicals was not available.

In 1985, Chevron's Marketing Department conducted a field investigation to assess potential soil and ground-water contamination at the site. Nine ground-water monitoring wells were installed and sampled by McKesson Environmental Services (McKesson, 1985). Several VOCs, including benzene, chlorobenzene, trans-1,2-dichloroethene, trichloroethene, and vinyl chloride were detected in monitoring well MW-1, and polycyclic aromatic hydrocarbons (PAHs) were detected in MW-5. The other wells did not contain any constituents.

In October 1987, the above-ground fuel storage tanks and associated piping were removed to allow for subsurface analysis. Blaine Technical Services, Inc., (Blaine, 1987) sampled monitoring wells MW-1 through MW-9. (Monitoring wells MW-4, MW-5, and MW-6 were destroyed in 1989, during a soil remediation effort; MW-9 was destroyed earlier). Chloroethane was detected in monitoring well MW-4, and benzene, trans-1,2-dichloroethene, and vinyl chloride were detected in MW-1. The other monitoring wells did not show any contamination.

In 1988, both the loading dock and barrel storage area were removed to allow for further subsurface analysis. Soil was sampled to identify any petroleum contamination at the aboveground tanks, truck loading ramp, or drum staging/storage platforms (Harding Lawson Associates [HLA], 1988). Soil samples contained xylenes and trichloroethene as well as petroleum hydrocarbons other than gasoline, diesel, and kerosene within the C6 to C15 boiling range. Ground water also was sampled and analyzed for VOCs, total petroleum hydrocarbons (TPH), and inorganics. Monitoring well MW-1 contained benzene, 1,2-dichloroethene, trichloroethene, vinyl chloride, and the inorganics, barium, molybdenum, nickel, and zinc. 1,2-Dichloroethene and trichloroethene were detected in MW-10. Tetrachloroethene was found in MW-11 and MW-12. Trace levels of trichloroethene were found in MW-11. Petroleum hydrocarbons were detected in MW-1, MW-4, MW-5, and MW-6.

Approximately 10,400 cubic yards of soils (Figure 2-1) containing hydrocarbons were excavated to a depth of 6 feet (Western Geologic Resources [WGR], 1990a). Soils were removed until halocarbons were no longer detected using a portable gas chromatograph. Excavated soils were transported to the American Rock and Asphalt Facility in Richmond, California (WGR, 1990). The excavated area was lined with 10-mil Visqueen plastic sheeting; then it was backfilled with 1.5 inches of clean crushed rock and covered with graded sub-base material.

An additional 256 cubic yards of contaminated soil were excavated and removed from four other locations. Three were within the southwest office/lab building, and the other one was just outside the building area. The excavated areas were backfilled and covered in the same manner as discussed previously.

The former laboratory building was demolished in late 1991. The garage, paint shop, and office/lab building were demolished in May 1992. Due to the presence of stained soils, soil samples were collected from beneath the garage. The presence of hydrocarbons was verified and soil excavation was conducted. Approximately 15 cubic yards of soil were removed (Geraghty & Miller, Inc., 1992).

A USEPA Superfund site owned by Westinghouse is directly north of the site at 6121 Hollis Street. The site contains soils contaminated with polychlorinated biphenyls (PCBs). The soil is covered with a clay and asphalt cap. A remedial action has been initiated that includes surrounding the contaminated soils with a continuous slurry cutoff wall tied into the underlying bay mud. Ground water is monitored quarterly at the Westinghouse site and does not show any migration of PCBs into ground water off-site. This is verified by quarterly monitoring sampling results conducted at the former Chevron asphalt plant indicating PCBs were not detected.

2.2 ENVIRONMENTAL CHARACTERISTICS

2.2.1 Regional Geology

The site lies approximately 10 feet above mean sea level (msl) and slopes to the west toward the San Francisco Bay. The site is located on 5 feet of fill, with the upper 2 feet consisting of imported gravelly sands, and the lower 3 feet is composed of recompacted locally derived sandy clay. Alluvial deposits of sandy gravel and clayey sands underlie the fill to a depth of 17 feet below land surface (bls). Below the deposits is stiff clay which was measured at 17 bls (HLA, 1988).

2.2.2 Regional Hydrology

Ground-water levels at the site are relatively shallow, ranging from 6 feet to 10.5 feet. The direction of the ground-water flow is southwest, toward the San Francisco Bay. There are no known wells downgradient from the site.

The nearest surface-water body is the San Francisco Bay, 0.4 mile west of the site.

2.2.3 Meteorology

The climate of Emeryville is mild with mean monthly temperatures ranging from 48 degrees Fahrenheit (°F) in January to 65°F in September (National Oceanic and Atmospheric Administration [NOAA], 1974). Monthly high average temperatures range from 55°F in January to 75°F in September, while average monthly low temperatures range from 41°F to 56°F in January and August, respectively. The annual precipitation for the area is 17.93 inches (NOAA, 1974). The mean wind speed is 3.6 meters per second (m/sec) in a westward direction (NOAA, 1974).

3.0 CONSTITUENT CHARACTERIZATION

This section describes the occurrence of constituents in the soil and ground water at the former Chevron asphalt plant. The results of the various site investigations are summarized below. To focus the assessment on the constituents associated with the greatest potential risk, all sampling data were reviewed. Since soil remediation has occurred at the site, only analytical data collected following soil removal represent current site conditions. After considering the frequency of detection, toxicity, and physical and chemical properties of the constituents, constituents of concern were identified. The term "constituents of concern" does not imply that exposure to these constituents poses a threat to human health. Rather, it is a term used to identify constituents to be used in the determination of health-based remediation goals.

3.1 SOIL

As discussed above, soil remediation has occurred at the site. Soil sampling at the site was conducted in conjunction with or following soil removal efforts. The various sampling events, described in Section 2.1, occurred at different times. In an effort to characterize the current conditions in soils at the site, analytical data for soil samples from different sampling events were used to describe the occurrence of constituents at the former Chevron asphalt plant.

Twenty-four soil samples were collected from beneath the former Chevron facility laboratory in February 1991. Five of the samples contained TPH as diesel, with a maximum concentration of 250 milligrams per kilogram (mg/kg). Several VOCs were detected in the soils. Trichloroethene, detected in 14 samples, was the most prevalent constituent and was detected at the greatest concentration, 2.3 mg/kg. As a point of comparison, detected benzene and xylenes concentrations ranged from 0.015 mg/kg to 0.14 mg/kg, with positive detections in 3 of the 24 samples collected (WGR, 1991a). In April 1991, soils beneath the storeroom, garage, and office buildings (see Figure 2-1) were sampled and analyzed for VOCs, benzene, toluene, ethylbenzene, and xylenes (BTEX), and TPH as gasoline. TPH as gasoline were detected in the storeroom at a concentration of 53 mg/kg and tetrachloroethene was detected beneath the garage at a concentration of 0.007 mg/kg (WGR, 1991b). Toluene was detected in 12 of 17 samples collected with a maximum concentration of 0.011 mg/kg found beneath the garage. Xylenes were detected in all but 1 of the 17 samples collected, with a maximum concentration of 0.16 mg/kg detected beneath the storeroom (WGR, 1991b).

Soil sampling occurred along the laboratory building and the former tank area. The samples were analyzed for TPH as diesel and gasoline. TPH as diesel were detected in the vicinity of the laboratory building at a concentration of 3,500 mg/kg, but were not detected in other areas sampled (WGR 1990b). TPH as gasoline were detected in the former tank area at a concentration of 230 mg/kg, but were not detected in other areas sampled (WGR, 1990b).

In April 1990, soil sampling was conducted at the site along the property line, the boundary of the 10,400 cubic yards of soil excavation (see Figure 2-1), and former laboratory building (WGR, 1990c). TPH and several VOCs, including BTEX, trans-1,2-dichloroethene, and trichloroethene, were detected.

The maximum concentrations detected are presented in Table 3-1. The maximum VOC concentrations were detected near the former laboratory building. The maximum TPH as gasoline concentration was detected near the Southern Pacific Railroad tracks (WGR, 1990c). The maximum TPH as diesel concentration reported in Table 3-1 was collected in the vicinity of the laboratory building during the 1990 sampling event discussed above (WGR, 1990b).

Soil sampling from 1988 (Ground Water Technology, Inc., 1988; HLA, 1988) indicated the presence of trichloroethene, TPH, and xylenes near the former laboratory and barrel platform areas. VOC concentrations were below the maximum concentration reported in Table 3-1. TPH concentrations were previously higher along the property line near the Southern Pacific Railroad tracks than currently detected concentrations; however, these soils have been removed, as discussed in Section 2.1.

The constituents of concern for soil are benzene, trans-1,2-dichloroethene, ethylbenzene, toluene, TPH as diesel, TPH as gasoline, trichloroethene, and xylenes.

3.2 GROUND WATER

The first nine ground-water monitoring wells (MW-1 through MW-9) were installed at the site in 1985 (McKesson, 1985). Three additional wells (MW-10 through MW-12) were installed in 1988 (HLA, 1988). During a ground-water sampling event in 1988, MW-9 could not be located and was thought to have been destroyed. During soil excavation in 1989, monitoring wells MW-4, MW-5, and MW-6 were destroyed. In February 1990, seven additional monitoring wells (MW-13 through MW-19) were installed (WGR, 1990d). The monitoring wells at the former Chevron asphalt plant are sampled quarterly. The most recent round of sampling occurred in April 1992.

All existing monitoring wells (MW-1, MW-2, MW-3, and MW-7 through MW-19) were sampled in April 1992. PCBs were not detected in any of the monitoring wells. On-site ground water, collected from monitoring wells MW-1, MW-2, and MW-7 through MW-15, contained detectable concentrations of BTEX, TPH as gasoline, and other VOCs (1,1-dichloroethane; 1,1-dichloroethene; cis-1,2-dichloroethene; trans-1,2-dichloroethene; trichloroethene; and vinyl chloride). The VOCs were found predominantly in monitoring wells adjacent to the former laboratory building (MW-1, MW-10, and MW-11), supporting historical data, as discussed in Section 2.1 and below. BTEX; chloroform; cis-1,2-dichloroethene; trans-1,2-dichloroethene; tetrachloroethene; 1,1,1-trichloroethane; trichloroethene; and TPH as gasoline were detected in off-site monitoring wells (MW-16 through MW-19).

Tables 3-2 and 3-3 summarize the maximum ground-water concentrations for on- and off-site (downgradient) monitoring wells and the location of the maximum detections from the April 1992 sampling round. Concentrations of cis- and trans-1,2-dichloroethene and TPH as gasoline were greater on-site than off-site. Chloroform, tetrachloroethene, and 1,1,1-trichloroethane were not detected in on-site ground water but were detected off-site. 1,1-Dichloroethane; 1,1-

dichloroethene; and vinyl chloride were detected on-site, but not off-site. BTEX and trichloroethene were detected at slightly greater concentrations off-site than on-site.

Historical data were compared to evaluate the trend in constituent concentrations in on-site ground water. Table 3-4 summarizes the VOC concentrations in MW-1, the well with the highest constituent concentrations for sampling events in 1985 (McKesson, 1985), in 1987 (Blaine Technical Services, Inc., 1987), and in 1988 (HLA, 1988). Concentrations of benzene, chlorobenzene, trichloroethene, and vinyl chloride have been decreasing over time.

Constituents of concern for ground water were those detected during the April 1992 ground-water sampling round. Other VOCs (chloroethane; 1,2-dichlorobenzene; 1,2-dichloroethane; 1,2-dichloropropane; trans-1,3-dichloropropane; methylene chloride; 1,1,2,2-tetrachloroethane; and trichlorofluoromethane) were detected in ground water infrequently (i.e., once or twice in samples collected between 1985 and 1992). These constituents were detected at concentrations ranging from 0.001 milligrams per liter (mg/L) to 0.011 mg/L (Sierra Analytical, 1992). Because these additional constituents were detected infrequently (less than 5 percent) and at relatively low concentrations (less than or equal to 0.011 mg/L), they were not considered to be constituents of concern.

4.0 TOXICITY ASSESSMENT

The risks associated with exposure to constituents detected at the former Chevron asphalt plant are a function of the inherent toxicity (hazard) of the constituents and exposure dose. This section addresses the inherent toxicological properties of the constituents. The probability of exposure and possible exposure pathways are identified in the Exposure Assessment, Section 5.0, which follows. In Section 6.0, Derivation of Health-Based Remediation Goals, the exposure and toxicity information are combined to calculate the remediation goals.

A distinction is made between carcinogenic and non-carcinogenic effects, and two general criteria are used to describe risk: excess lifetime cancer risk for constituents which are thought to be potential human carcinogens and the hazard quotient (HQ) for constituents that cause non-carcinogenic effects. For potential carcinogens, the current regulatory guidelines (USEPA, 1989a) use an extremely conservative approach in which it is assumed that any level of exposure to a carcinogen could hypothetically cause cancer. This is contrary to the traditional toxicological approach to toxic chemicals, in which finite thresholds are identified, below which toxic effects have not occurred. This traditional approach still is applied to non-carcinogenic chemicals. Table 4-1 summarizes the recognized toxic responses associated with the constituents of concern at the former Chevron asphalt plant.

4.1 CARCINOGENIC EFFECTS

Identification of constituents as known, probable, or possible human carcinogens is based on a USEPA weight-of-evidence classification scheme in which chemicals are systematically evaluated for their ability to cause cancer in mammalian species, and conclusions are reached about the potential to cause cancer in humans. The USEPA classification scheme, discussed in USEPA (1989a) and utilized on the Integrated Risk Information System (IRIS), contains six groups based on the weight of available evidence, as follows:

A known human carcinogen;

B1	probable human carcinogen -- limited evidence in humans;
B2	probable human carcinogen -- sufficient evidence in animals and inadequate data in humans;
C	possible human carcinogen -- limited evidence in animals;
D	inadequate evidence to classify; and
E	evidence of non-carcinogenicity.

Some chemicals in group D may have the potential to cause cancer, but adequate data are not currently available to change the classification. In this risk assessment, evaluations of the likelihood of a carcinogenic effect include constituents in groups A, B1, B2, and C.

The toxicity value used to describe the potency of a group A, B1, B2, or C carcinogen is the cancer slope factor (CSF) (previously called the cancer potency factor). The CSF is generated by USEPA using a mathematical model that extrapolates from the high doses in animal studies to the low doses that characterize human exposures. The CSF represents the 95 percent upper confidence limit on the slope of the curve generated by the model. Thus, CSFs typically overestimate risk.

4.2 NON-CARCINOGENIC EFFECTS

For many non-carcinogenic effects, protective mechanisms in the human body must be overcome before the effect is manifested. Therefore, a finite dose (threshold), below which adverse effects will not occur, is believed to exist for non-carcinogens. Non-carcinogenic health effects include birth defects, organ damage, behavioral effects, and many other health impacts. A single compound might elicit several adverse effects, depending on the dose, the exposure route, and the duration of exposure. For a given constituent, the administered dose that elicits no effect when evaluating the most sensitive response (the adverse effect which occurs at the lowest dose) in the most sensitive species is used to establish an acceptable dose (toxicity value) for non-carcinogenic effects. Acceptable doses that are sanctioned by the USEPA are called verified reference doses (RfDs) for oral exposure and verified reference concentrations (RfCs) for inhalation exposure. The RfD and RfC are uncertain values and do not represent a strict demarcation between toxic and non-toxic responses. For ease in calculating health-based remediation goals, RfCs have been converted to RfDs by a unit conversion, that is, the RfC was multiplied by 20 cubic meters per day (m^3/day) and divided by 70 kilograms (kg) (USEPA, 1992a).

The chronic RfD should be used to assess the potential non-carcinogenic effects associated with long-term exposure periods (i.e., greater than 7 years), while the sub-chronic RfD can be used for exposure periods between 2 weeks and 7 years (USEPA, 1989a). In this risk assessment, the chronic RfDs will be used to assess the potential for non-carcinogenic effects because, for most constituents, the sub-chronic RfD is the same as the chronic RfD. For some constituents, the sub-chronic RfD is higher than the chronic RfD (a higher RfD indicates lesser toxicity). Therefore, this approach is expected to result in an overestimate of the actual risk. Although not used in the risk assessment, subchronic RfDs were presented in Table 4-3 for comparison purposes.

4.3 TOXICITY PROFILES

A brief summary of the potential health effects of the constituents of concern considered in this report is provided in Table 4-1.

4.4 TOXICITY VALUES

In general, CSFs, cancer classifications, RfDs, and RfCs are taken from IRIS (1992), or, in the absence of IRIS data, the USEPA Health Effects Assessment Summary Tables (HEAST) (USEPA, 1992a). Because toxicity values (i.e., RfDs and CSFs) for dermal exposure are rarely available (appropriate toxicity data are scarce), the oral RfD and CSF are adjusted to an absorbed dose, using the constituent-specific oral absorption efficiency, as recommended by the USEPA (1989a), to derive an adjusted RfD and CSF to assess dermal exposure. Derivations of the adjusted RfDs and CSFs for the constituents of concern are shown in Table 4-2. RfDs for the constituents of concern are presented in Table 4-3. CSFs, cancer type or tumor sites, and carcinogen classifications for the constituents of concern at the site are presented in Table 4-4.

TPH are mixtures of hydrocarbons. Toxicity values were not available for TPH. As a result, the composition of TPH as gasoline and TPH as diesel was reviewed and a surrogate selected to evaluate toxicity of TPH. Criteria for selection were the percentage of a constituent present in TPH and the availability of a toxicity value. The RfD for n-hexane was used to evaluate the potential for non-cancer adverse health effects associated with exposure to TPH as gasoline. Naphthalene was used as the surrogate for TPH as diesel.

5.0 EXPOSURE ASSESSMENT

An exposure assessment was conducted as part of the risk assessment to evaluate the potential exposure pathways that may occur at the former Chevron asphalt plant. An exposure pathway is defined by four elements: (1) a source and mechanism of constituent release to the environment; (2) an environmental transport medium for the released constituent; (3) a point of potential contact with the contaminated medium (the exposure point); and (4) an exposure route at the exposure point. The purpose of the exposure assessment is to estimate the way a population potentially might be exposed to constituents originating at a site. Typically this involves projecting concentrations along hypothetical pathways between sources and receptors. The projection usually is accomplished using site-specific data and, if necessary as in this case, mathematical modeling.

Migration of the constituents of concern from the former Chevron asphalt plant is dependent on the physical and chemical properties of the constituents and the characteristics of the surrounding environment. This section discusses the physical and chemical properties of the constituents and their influence on the potential for migration of the constituents of concern in soil and ground water at the former Chevron asphalt plant, and outlines the scenarios used in this risk assessment to evaluate potential human health impacts from exposure to the constituent of concern.

5.1 PHYSICAL AND CHEMICAL PROPERTIES INFLUENCING CONSTITUENT MIGRATION

The environmental fate and transport of constituents are dependent on the physical and chemical properties of those constituents, the environmental transformation processes affecting them, and the media through which they are migrating. Physical and chemical properties of the constituents of concern are summarized in Table 5-1.

The water solubility of a substance is an important property affecting environmental fate. Highly soluble constituents are generally mobile in ground and surface water. Solubility is expressed in terms of the number of milligrams of a constituent dissolving in one liter of water (mg/L) under standard conditions of 25 degrees Centigrade (°C) and one atmosphere of pressure (atm). Solubilities range from less than 1 mg/L to totally miscible, with most common organic chemicals falling between 1 mg/L and 1,000,000 mg/L (Lyman et al., 1990). The higher the value of the solubility, the greater the tendency of a constituent to dissolve in water.

Volatilization of a constituent from an environmental medium will depend on its vapor pressure, water solubility, and diffusion coefficient. Highly water-soluble compounds generally have lower volatilization rates from water than do compounds with lower solubilities unless the former compounds also have high vapor pressures. Vapor pressure, a relative measure of the volatility of constituents in their pure state, ranges from about 0.001 to 760 millimeters of mercury (mm Hg) for liquids, with solids ranging down to less than 10^{-10} mm Hg.

The Henry's Law Constant, combining vapor pressure with solubility and molecular weight, can be used to estimate releases from water to air. Compounds with Henry's Law Constants in the range of 10^{-3} atmospheres-cubic meters per mole (atm-m^3/mol) and larger can be expected to volatilize readily from water; those with values ranging from 10^{-3} to 10^{-5} atm-m^3/mol are associated with possibly significant, although not as readily as more volatile compounds, volatilization, while compounds with values less than 10^{-5} atm-m^3/mol will only volatilize from water slowly and to a limited extent (Howard, 1989; Lyman et al., 1990). All of the constituents of concern, with the exception of naphthalene used as a surrogate for TPH as diesel, have Henry's Law Constants greater than 10^{-3} atm-m^3/mol. n-Hexane is used as a surrogate to evaluate TPH as gasoline and has a very high Henry's Law Constant of 0.77 atm-m^3/mol. While n-hexane is very volatile, most of the hydrocarbons remaining at the former Chevron asphalt plant are likely to be longer-chain hydrocarbons, which are not considered as volatile as n-hexane.

The diffusion coefficient can be used as a means to predict the rate at which a compound moves through the environment. Molecular diffusion is determined by both molecular properties (e.g., size and weight) and by the presence of a concentration gradient, which means that molecules of a chemical will migrate to areas deficient in molecules of that compound.

The octanol-water partition coefficient (K_{ow}) often is used to estimate the extent to which a chemical will partition from water into lipophilic parts of organisms, for example, animal fat. The organic carbon partition coefficient (K_{oc}) reflects the propensity of a compound to adsorb to the organic matter found in the soil or sediments. The normal range of K_{oc} values is from 1 to 10^7, with higher values indicating greater adsorption potential.

Constituent partitioning between soil and water generally is represented by the soil-water distribution coefficient, K_d. As with the K_{oc}, higher K_d values indicate that a larger percentage of the constituent is associated with the soil solids, and the constituent therefore is less mobile in the subsurface environment. The K_d may be determined empirically or may be estimated using constituent-specific and soil-specific parameters. The parameters most often used to calculate K_d for organic constituents are the K_{oc} and the fraction of organic carbon in soil (f_{oc}), since K_d commonly is expressed as the product of the K_{oc} and f_{oc} (USEPA, 1989b). Low values of K_{oc} (i.e., less than 1,000) and f_{oc}, coupled with high solubility, characterize constituents with a high potential to migrate through soils or aquifer materials, such as those found at the former Chevron asphalt plant, and these constituents tend to migrate through soil to ground water.

5.2 COMPOSITION OF TPH

TPH as gasoline and TPH as diesel are complex mixtures of petroleum-derived hydrocarbons with 4 to 11 carbon atoms and 9 to 22 carbon atoms, respectively, in their molecular structures (California Leaking Underground Fuel Tank [LUFT] Manual, 1989; California State Water Resources Control Board, 1991; Millner et al., 1992). The hydrocarbons fall into four major classes: paraffins or alkanes (straight- or branched-chain hydrocarbons), cycloalkanes (ring structures), alkenes, and aromatics (containing benzene rings) (Bergamini, 1992).

When gasoline or diesel enters the soil and/or ground-water environments, changes in its composition, referred to as "weathering," begins immediately. Volatilization of the lighter compounds occurs at a higher rate than heavier compounds, resulting in a shift in the composition of the weathered gasoline toward heavier compounds. The solubilities of the heavier hydrocarbons are generally lower and the adsorption characteristics are stronger than those of the lighter gasoline compounds. Therefore, these heavier compounds tend to remain adsorbed to soil organic matter for longer periods of time, while the more soluble components partition into soil moisture and/or ground water more quickly and/or more completely. Rates of biotransformation also are different; short-chain alkanes are generally biodegraded more readily than aromatics, cycloalkanes, and heavier alkanes (USEPA, 1989b). Transformation products are generally more mobile in soil and ground water than the original compounds. The net result of these weathering processes with respect to the soil TPH analytical results is that the TPH concentrations reported will reflect a greater proportion of the heavier gasoline components than fresh gasoline. These heavier components are largely comprised of cycloalkanes and straight- and branched-chain alkanes (Andrews and Snyder, 1991).

For the purposes of this discussion, the fate and transport characteristics of TPH as gasoline will at times be compared to those of n-hexane, although n-hexane only comprises from 0.24 percent to 3.5 percent by weight of fresh gasoline (California LUFT Manual, 1989). Using n-hexane to describe the fate and transport behavior of gasoline in soil represents a realistic approach because n-hexane is as soluble, if not more soluble, than most of the heavier hydrocarbons and has weaker adsorption characteristics than the heavier hydrocarbons which comprise the majority of weathered gasoline. The fate and transport characteristics of TPH as diesel will be compared to those of naphthalene,

5.3 MECHANISMS OF MIGRATION

There are several mechanisms through which constituents may migrate from the former Chevron asphalt plant to the surrounding area. The constituent-containing soils can act as a source of constituents to other environmental media. Migration into the air can occur via volatilization or fugitive dust emissions; migration into ground water can occur by percolation of infiltrating rainwater; and transport into San Francisco Bay can occur via ground-water discharge. The mechanisms of migration for constituents in soils at the former Chevron asphalt plant are discussed in this section from a conceptual standpoint, together with a discussion of constituent persistence and transformations that may occur in the source or transport media.

5.3.1 Migration Into Air

There are two processes controlling migration of constituents into air. Organic constituents may volatilize and migrate into the air. Constituents adsorbed to soil may migrate into the air through the generation of dust either by wind erosion or mechanical means.

Volatilization is the mass transfer of an organic compound from a specific medium (i.e., soil) to the air. The ability for this transfer or migration to occur will depend on other competing processes which should hinder this migration. For example, if a constituent is strongly adsorbed to soil particles, it will be less likely to volatilize into the air. Environmental factors that affect volatilization include temperature, soil porosity, soil water content, soil organic carbon content, and depth of contamination (Jury et al., 1983).

Generally, organic constituents with high vapor pressures (greater than 10 mm Hg) or high Henry's Law Constants (greater than 10^{-3} atm-m^3/mol) are expected to volatilize readily from soil and water. All of the constituents of concern except naphthalene (used as a surrogate for TPH as diesel) have these properties. Ethylbenzene and xylenes have low vapor pressures but high Henry's Law Constants. Naphthalene is expected to have lesser but still substantial tendencies to volatilize, although other processes may be more important in controlling its ultimate migration into air.

Fugitive dust emissions from wind or vehicle disturbances may occur from unpaved or unvegetated areas of the former Chevron asphalt plant site. The environmental factors that influence wind erosion are wind speed, moisture content of soil, vegetative cover, and soil composition. Factors affecting vehicle-related emissions include soil composition and moisture content, vehicle design (e.g., weight and number of wheels), and speed of travel. Chemical and physical properties can also be used to estimate a constituent's potential to be emitted in dust. Constituents with relatively low organic carbon partition coefficients (K_{oc} values less than 10^4) and moderate to high water solubility (greater than 1 mg/L) are more likely to be associated with the water or air phases than to remain in surface soils, and thus are unlikely to be emitted in dust. All of the constituents of concern fall into this category.

5.3.2 Migration Into Ground Water

The more soluble constituents may migrate from soil with infiltrating precipitation to the ground water. Typically, organic constituents with high water solubilities and low K_{oc}s are particularly susceptible to this phenomenon. The more volatile constituents or those strongly adsorbed to soil may migrate into air, as discussed in the previous section. Most of the constituents of concern at the former Chevron asphalt plant site are expected to behave in this manner. Since TPH is a mixture of compounds, the behavior of TPH in soils and ground water is dependent on the composition of the TPH present at the site.

When TPH as gasoline or diesel enters the soil and/or ground-water environments, changes in its composition, referred to as weathering, begins immediately. Volatilization of the lighter compounds occurs at a faster rate than for the heavier compounds, resulting in a shift in the composition of weathered TPH toward the heavier hydrocarbons. The solubilities of the heavier hydrocarbons generally are lower and the adsorption characteristics are stronger than those of the lighter TPH components. Therefore, these heavier compounds tend to remain adsorbed to the soil organic matter for longer periods of time, while the more soluble components partition into soil moisture and/or ground water more quickly and/or more completely.

5.3.3 Migration Into Surface Water

Constituent migration into surface water may occur through ground-water recharge. The nearest downgradient surface-water body is San Francisco Bay, approximately 0.4 mile from the site. The bay is the discharge point for ground water in the area of the site. Constituents with high water solubilities and low K_{oc} values may be transported with the ground-water runoff into the Bay. Upon reaching surface water, constituents may remain in the water column, volatilize, or adsorb to bottom or suspended sediments. The constituents of concern likely to have a high tendency to volatilize have been described above. Constituents with low water solubilities and/or high K_{oc}s, such as naphthalene, will tend to associate with sediments, if they reach the bay. Due to the distance from the former Chevron asphalt plant to San Francisco Bay, the constituents detected in ground water at the site may not reach the bay because of volatilization, adsorption, or biodegradation, especially if the transport time is relatively long allowing for these other processes to occur.

5.3.4 Biodegradation and Biotransformation Processes

Biological and chemical processes occurring in soil can be important in determining the ultimate fate of the constituents in soils and ground water at the former Chevron asphalt plant. The extent and rates of these reactions, however, are difficult to predict for each individual site. Microorganisms naturally occurring in soils are able to use several organics as a food source, degrading the components ultimately to carbon dioxide and water (Kostecki and Calabrese, 1989).

BTEX may be degraded aerobically (i.e., in the presence of oxygen) in soils (Kostecki and Calabrese, 1989). In surficial soils, biodegradation can be relatively rapid, provided adequate amounts of oxygen, moisture, and nutrients (e.g., nitrogen, phosphorus) are available. Aerobic metabolism of constituents under these conditions may result in the total depletion of oxygen. When this happens, the microorganisms may begin utilizing inorganic ions, such as nitrate or sulfate, and continue aerobic respiration, or other types of microorganisms may become active in metabolizing the constituent (USEPA, 1989b).

Under anaerobic or oxygen-depleted conditions, chlorinated aliphatic constituents (e.g., tetrachloroethene, trichloroethene) have been found to undergo reductive dechlorination reactions, that is, reactions which remove chlorine from and add hydrogen to the constituent (Bouwer et al., 1981; Kobayashi and Rittmann, 1982). One exception to this is the aerobic degradation of trichloroethene in the presence of methane (Wilson and Wilson, 1984). The transformation is sequential with, for example, tetrachloroethene (an ethene molecule with four chlorines), yielding trichloroethene (an ethene molecule with three chlorines), which in turn yields 1,1-dichloroethene (an ethene molecule with two chlorines), and ultimately vinyl chloride (an ethene molecule with one chlorine) (Parsons et al., 1984; Cline and Viste, 1984).

Naphthalene also can be biodegraded. Factors which contribute to the degree to which biodegradation occurs include biodegradability rates, production of intermediates, and the effects of mixtures. In general, smaller PAHs with 2 (i.e., naphthalene) or 3 rings (e.g., phenanthrene) are more readily degraded than larger PAHs (McKenna and Heath, 1976).

The rate of biodegradation of TPH is dependent on the constituent. Short-chain alkanes generally are biodegraded more quickly than aromatics, cycloalkanes, and heavier alkanes (USEPA, 1989b). The net result is that the TPH detected at the former Chevron asphalt plant most likely contain heavier components of diesel and gasoline. These heavier components are comprised largely of cycloalkanes and straight- and branched-chain alkanes (Andrews and Snyder, 1991).

5.4 EXPOSURE PATHWAYS

Exposure can occur only when the potential exists for a receptor to contact released constituents directly or if there is a mechanism for released constituents to be transported to a receptor. Without exposure, there can be no risk. Therefore, the evaluation of exposure pathways is a key element in evaluating potential risks at a site. The site is not used currently, but there are plans to develop the site for commercial, retail, or industrial uses in the future.

Constituents spilled onto the ground surface have acted as the source of contamination of soils and ground water at the former Chevron asphalt plant. Migration into ground water has occurred. The majority of the contaminated soils at the site have been removed and as a result, exposure to constituents in soils will occur only in areas with residual soil contamination through either direct contact with soil or inhalation of dusts or vapors. Exposure to constituents in ground water will occur only if ground water is used as a drinking-water source or if individuals inhale volatiles released from the ground water.

Soils at the site are unpaved and unvegetated. Although the site is not being used currently, the potential exists for individuals using the site in the future to contact the soils through incidental ingestion or dermal (skin) contact. The most likely scenario would involve exposure of construction workers working on the development of the property to contact soils. The potential also exists for individuals to inhale fugitive dusts or vapors generated during construction activities. Additionally, if the site were to be redeveloped, soils containing VOCs could act as a source of volatiles which could migrate into buildings build on the property.

Exposure to the constituents detected in ground water is not occurring currently. The area surrounding the site is supplied with water from the local water authority and, should the site be redeveloped, water would be supplied by the municipal water-supply system. Ground water flows beneath the site in a south to southwesterly direction and was found at depths of approximately 5 feet bls. There are no water-supply wells in the vicinity of the site and drinking water is provided by East Bay Municipal Utilities District. Volatile constituents in ground water could migrate from ground water into soil gas to the ambient indoor and outdoor air. If this migration pathway occurred, individuals outdoors at the site, or in buildings at or downgradient of the site could become exposed to constituents through the inhalation exposure route.

Exposure of environmental receptors to site-related constituents is not likely to occur because the former Chevron asphalt plant does not support a complex ecosystem. The area surrounding the site is developed. There are few areas with vegetative cover sufficient to provide a habitat for these receptors. As a result, terrestrial wildlife are not likely to find the site to be a suitable habitat, and hence will not become exposed to constituents present in soils at the site.

If ground water originating at the former Chevron asphalt plant discharged into San Francisco Bay, aquatic life living in the Bay could become exposed to these constituents. This population was determined to be the closest downgradient sensitive potential receptor. To evaluate whether or not currently detected concentrations of the ground-water constituents of concern could pose a threat to aquatic life, the April 1992 sampling data were compared with ambient water-quality criteria, as seen in Table 5-2. The currently detected ground-water concentrations were all less than the available criteria.

6.0 DERIVATION OF HEALTH-BASED REMEDIATION GOALS

On-site current exposure pathways were not identified for either soils or ground water since the former Chevron asphalt plant is not currently used. Health-based remediation goals, essentially a "back" calculation of potential risk, were calculated based on future hypothetical exposure of a construction worker to soil or of an office or retail worker to constituents in ground water, assuming inhalation of vapors migrating from ground water into buildings. A health-based remediation goal was calculated to derive a constituent concentration considered to be protective of human health if exposure were to occur.

The former Chevron asphalt plant may be redeveloped in the future. The area is zoned commercial/industrial, indicating that development of the site for residential use is not expected to occur. The site is currently a vacant lot. For the purposes of this assessment, it was assumed a building would be constructed over one-third of the site, and the other two-thirds of the site would be paved for parking. Using these potential use scenarios, health-based remediation goals were calculated for workers engaged in construction activities as well as those working in the building once the site was redeveloped. The site-specific human health-based remediation goals were calculated to evaluate whether or not additional remediation of soils or ground water was required at the former Chevron asphalt plant assuming the above-mentioned future land uses.

Guidance provided by USEPA (1991a) was followed, in conjunction with guidance from the RWQCB (1990). This approach combines constituent-specific hazard information with conservative (i.e., health protective) assumptions about medium-specific exposure in order to derive medium-specific concentrations that will be protective of human health. In calculating remediation goals, equations were developed (based on the above referenced guidance) in which the potential cancer risk or non-cancer health effect was set at a level that would not require remediation. Consistent with USEPA guidance for potential carcinogens, the risk levels were set at an excess lifetime cancer risk of 10^{-6} for each constituent in each medium and, for non-carcinogens, a hazard quotient (HQ) of 1 for each constituent in each medium. The proposed health-based remediation goal for potential carcinogens is the lesser of the health-based remediation goal for carcinogenic and non-carcinogenic effects. For non-carcinogenic, only the non-cancer health-based remediation goal was calculated. Information on the inherent hazard of each constituent was used in the equations, as were parameters representing conservative exposure scenarios. The equations were solved for the medium-specific concentration of each constituent not requiring remediation. It should be noted that the approach described above differs from RWQCB guidance (1990) in that the RWQCB provides the option to use a higher target-risk level than does the USEPA (1991a) based on the relative carcinogenicity of each constituent. To be conservative, however, the target risk level was set at 10^{-6} for each potential carcinogen.

6.1 REMEDIATION GOALS BASED ON CONSTRUCTION WORKER EXPOSURE

Health-based remediation goals were derived assuming that during the construction activities conducted as part of the redevelopment of the site, the potential would exist for the use of heavy equipment and related traffic in and around contaminated soils, disturbing the soil and producing particulate emissions. Because the constituents of concern are volatile, vapor emissions also could occur as part of the construction activities.

USEPA (1991a,b) guidance was used to develop soil exposure assumptions. In calculating the health-based remediation goals for constituents in soil, an exposure frequency of 250 days per year for one year was selected assuming construction activities at the site would require 1 year to complete. It was assumed construction on the site would be completed in phases with construction of a building covering one-third of the site being completed first, followed by construction of the parking lot covering the remainder of the site. Construction workers were assumed to contact only soil, and construction activities were not assumed to involve contact with ground water. Additional exposure assumptions were:

(1) an inhalation rate of 20 m^3/day;

(2) a soil ingestion rate of 480 milligrams per day (mg/day);

(3) an exposed skin surface area of 3,900 square centimeters (cm^2), assuming forearms and hands would be exposed;

(4) a soil adherence factor of 1 milligram per square centimeter per day (mg/cm^2-day);

(5) a body weight of 70 kg;

(6) an exposure frequency of 250 days per year with an exposure duration of 1 year; and

(7) a target excess individual lifetime cancer risk of 1×10^{-6} or a hazard quotient of 1.

The equations and assumptions used to calculate health-based remediation goals based on exposure of a construction worker and an example calculation are provided in Tables 6-1 and 6-2 for potential carcinogens and non-carcinogens, respectively. Tables 6-3 and 6-4 provide equations for input parameters into the remediation goal calculations. The calculation for the soil-to-air volatilization factor is summarized in Table 6-3. The calculation for the particulate emission factor is provided in Table 6-4. The health-based remediation goals based on a construction worker exposure scenario are summarized in Table 6-5 for the potential carcinogens and in Table 6-6 for the non-carcinogens.

6.2 REMEDIATION GOALS BASED ON OFFICE WORKER EXPOSURE

Once redevelopment of the property has been completed, the site may be used for commercial purposes such as an office building. Workers at the office building will not contact soils at the site, since the soils will be covered either by a parking lot or by the office building itself. Volatile constituents present in ground water beneath the site may vaporize and migrate through the soil to the ground surface and into the building. If this were to occur, individuals working in the building could be exposed via inhalation to any constituents in the vapors. This scenario would apply also to any downgradient office buildings which the ground-water plume flows under moving towards San Francisco Bay.

A volatilization model, described in Appendix A, was used to estimate the health-based remediation goal for ground water assuming a volatile constituent vaporized and migrated through the soil and into a building covering one-third of the site. The exposure assumptions used to calculate the health-based remediation goals were the following:

(1) an inhalation rate of 20 m^3/day;

(2) an exposure frequency of 250 days/year;

(3) an exposure duration of 25 years (based on the 90th-percentile value for time spent at one job);

(4) a body weight of 70 kg; and

(5) a target excess individual lifetime cancer risk of 1×10^{-6} or a hazard quotient of 1.

The equations and assumptions used to calculate health-based remediation goals based on exposure of an office worker are provided in Table 6-7 for potential carcinogens and non-carcinogens. The health-based remediation goals for ground water based on an office worker exposure scenario are summarized in Table 6-8. Also provided in Table 6-8 is a soil health-based remediation goal, using the method described in Appendix A.

6.3 REMEDIATION GOALS BASED ON RETAIL WORKER EXPOSURE

Once redevelopment of the property has been completed, the site may be used for retail purposes such as a strip mall composed of a restaurant or several shops facing a parking lot, or an enclosed mall. Workers at the mall will not contact soils at the site since the soils will be covered either by a parking lot or by buildings. In the strip-mall configuration, there may be several smaller buildings rather than one large building, as described for the commercial development. As described above, volatile constituents present in ground water beneath the site may vaporize and migrate through the soil to the ground surface and into the building with subsequent inhalation exposure by individuals working in the building to any constituents in the vapors.

The volatilization model, described in Appendix A, again was used to estimate the health-based remediation goal for ground water assuming a volatile constituent vaporized and migrated through the soil and into one or several building(s) covering one-sixth of the site. The exposure assumptions used to calculate the health-based remediation goals described in Section 6.2 also were used to describe exposure of these workers. The major differences in the office and retail worker exposure scenarios were the air exchange rate for the building and the size of the building. The air exchange rate will be greater for the retail space, since doors will be opened and closed frequently as individuals come and go from the retail space. The building size is likely to be smaller for retail space although there may be several smaller buildings.

The equations and assumptions used to calculate health-based remediation goals based on exposure of a retail worker were provided in Table 6-7 for potential carcinogens and non-carcinogens. The ground-water health-based remediation goals based on a retail worker exposure scenario are summarized in Table 6-9. Soil health-based remediation goals are provided in Table 6-9 and were calculated using the method described in Appendix A.

7.0 UNCERTAINTIES IN THE RISK ASSESSMENT

The health-based remediation goals presented here for the former Chevron asphalt plant are conservative estimates of soil and ground-water concentrations which would not cause adverse non-carcinogenic health effects or potential carcinogenic risks at the 10^{-6} or 1 in a million level. If the exposure scenarios were to occur, in the absence of further remediation, actual risks experienced by the potentially exposed population are almost certainly lower than those presented in this report. It is important to realize that considerable uncertainty is inherent in the risk assessment process. Sources of uncertainty include monitoring data, exposure models, and values of the variables used to calculate intakes.

Exposure scenarios contribute uncertainty to the risk assessment. Exposure doses were calculated based on the assumption that the current conditions with respect to constituent concentraitons would remain constant throughout the exposure period. If the source is eliminated, natural attenuation processes will reduce constituent concentrations and the likelihood of exposure, thus reducing risks for the hypothetical future exposure scenarios. This is especially true for a situation such as this one, in which remediation goals have been derived, since comparisons between remediation goals and detected concentrations will be used to evaluate whether or not further remediation is warranted at the site. The concentrations of constituents at the site have been reduced over time through soil removal efforts as well as natural degradation processes.

The toxicity values and other toxicological (health effects) information used in this report are associated with significant uncertainty. Most health effects information has been developed using laboratory animals exposed to high doses. Although species differences in absorption, distribution, metabolism, excretion, and target organ sensitivity are well documented, available data are not sufficient to allow compensation for these differences. Most laboratory studies strictly control as many factors as possible, yet the human population is genetically diverse and affected by a variety of dietary, occupational, pharmaceutical, and other factors. When human epidemiologic data are available, a different set of uncertainties is present. For instance, exposure dose is seldom well characterized in epidemiologic studies.

There is also considerable uncertainty associated with the toxicity of mixtures. For the most part, data about the toxicity of chemical mixtures are unavailable. Rather, toxicity studies are generally performed using a single chemical. Constituents present in a mixture can interfere with the absorption, distribution, metabolism, or excretion of other compounds. Constituents also may act by the same mechanism on the same target organ or can act completely independently.

8.0 SUMMARY AND CONCLUSIONS

This risk assessment was prepared to evaluate whether soils or ground water at the former Chevron asphalt plant could pose a threat to human health should the site be redeveloped for commercial or retail purposes. Health-based remediation goals were calculated for constituents detected in environmental sampling data using intake assumptions to protect against potential non-carcinogenic adverse health effects and potential carcinogenic health risks associated with exposure to human receptor populations. Measured ground-water data were compared to ambient water-quality criteria for the protection of aquatic life to evaluate whether or not ground water discharging into San Francisco Bay would affect aquatic life in the bay.

The constituents of concern identified in soil and/or ground water were benzene; chloroform; 1,1-dichloroethane; 1,1-dichloroethene; cis-1,2-dichloroethene; trans-1,2-dichloroethene; ethylbenzene; tetrachloroethene; toluene; TPH as diesel; TPH as gasoline; 1,1,1-trichloroethane; trichloroethene; vinyl chloride; and xylenes. Other chlorinated compounds detected during historical sampling were not included due to a low frequency of detection (less than 5 percent) and low concentration (no greater than 0.011 mg/L) detected).

Soil removal has occurred in several areas of the former Chevron asphalt plant, and all the buildings have been torn down. The site is not presently in use and is a vacant lot. In the future, the property may be redeveloped as an office building or retail shops. Hypothetical future exposures could occur if construction were undertaken at the site. Additionally, once the site is developed, constituents originating in ground water could form vapors which then could migrate through soils and into the buildings. Individuals working in the office building or retail space then could inhale these vapors. Both of these hypothetical exposure scenarios were considered in developing health-based remediation goals.

Comparisons were made between the health-based remediation goals and the detected levels of constituents at the former Chevron asphalt plant. As seen in Tables 8-1 and 8-2 for soil and ground water respectively, the currently measured levels of the constituents of concern are all below the health-based remediation goals. As a result, further remediation at the site does not appear to be warranted.

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Table 6-8. Health-Based Remediation Goals Based Upon Office Building Exposure to VOCs from Ground Water, Former Chevron Asphalt Plant, Emeryville, California.

Constituent	Koc (mL/g)	H (atm-m³/mol)	Do (cm²/s)	Ds (cm²/s)	Toxicity Value	Ground-Water HBG (mg/L)	Soil HBG [a] (mg/kg)
Semi-VOCs							
TPH as diesel [b]	940	4.2E-04	0.08205	0.0326	4.0E-03	2.1E+06	2.0E+07
TPH as gasoline [c]	1265	7.7E-01	0.07461	0.0296	5.7E-03	8.0E+02	1.0E+04

[a]	Soil HBG calculated by: ground-water HBG × Koc × foc.
[b]	TPH as diesel evaluated as naphthalene using California Air Resources Board inhalation toxicity value (CAPCOA, 1992).
[c]	TPH as gasoline evaluated as n-hexane.
---	Insufficient data; HBG could not be calculated due to lack of toxicity information.
CSF	Cancer slope factor for inhalation exposure (kg-day/mg).
Do	Diffusion coefficient in air (cm²/s).
Ds	Effective vapor-phase diffusion coefficient in soil (cm²/s) = Do × 0.547.
foc	Fraction organic carbon in the soil; assumed value of 0.01 (1 percent organic carbon).
H	Henry's Law Constant (atm-m³/mol).
HBG	Health-based remediation goal (mg/L for water; mg/kg for soil).
Koc	Organic carbon partition coefficient (mL/g).
NA	Not available.
RfD	Reference dose for inhalation exposure (mg/kg-day).
TPH	Total petroleum hydrocarbons.

Table 6-9. **Health-Based Remediation Goals Based Upon Retail Building Exposure to VOCs from Ground Water, Former Chevron Asphalt Plant, Emeryville, California.**

Constituent	Koc (mL/g)	H (atm-m^3/mol)	Do (cm^2/s)	Ds (cm^2/s)	Toxicity Value	Ground-Water HBG (mg/L)	Soil HBG [a] (mg/kg)
CANCER EFFECTS					CSF (kg-day/mg)		
VOCs							
Benzene	74.5	5.5E-03	0.0932	0.0370	2.9E-02	1.5E+04	1.1E+04
Chloroform	44	3.8E-03	0.08868	0.0352	8.1E-02	5.1E+03	2.2E+03
1,1-Dichloroethane	30	5.7E-03	0.0959	0.0381	NA	---	---
1,1-Dichloroethene	65	1.5E-01	0.10077	0.0400	1.2E+00	2.9E+01	1.9E+01
Tetrachloroethene	286.5	2.3E-02	0.07404	0.0294	1.8E-03	9.1E+03	2.6E+04
Trichloroethene	95.5	8.9E-03	0.08116	0.0322	1.7E-02	4.9E+03	4.7E+03
Vinyl Chloride	2.5	6.9E-01	0.10726	0.0426	2.9E-01	4.9E+01	1.2E+00
NON-CANCER EFFECTS					RfD (mg/kg-day)		
VOCs							
Benzene	74.5	5.5E-03	0.0932	0.0370	NA	---	---
Chloroform	44	3.8E-03	0.08868	0.0352	2.9E+00	4.2E+08	1.9E+08
1,1-Dichloroethane	30	5.7E-03	0.0959	0.0381	1.0E-01	2.0E+07	6.0E+06
1,1-Dichloroethene	65	1.5E-01	0.10077	0.0400	NA	---	---
cis-1,2-Dichloroethene	49	6.6E-03	0.0998	0.0396	NA	---	---
trans-1,2-Dichloroethene	59	5.7E-03	0.0998	0.0396	NA	---	---
Ethylbenzene	177.5	1.5E-01	0.08503	0.0337	2.9E-01	7.3E+05	1.3E+06
Tetrachloroethene	286.5	2.3E-02	0.07404	0.0294	NA	---	---
Toluene	132.5	6.7E-03	0.07828	0.0311	5.7E-01	1.7E+07	2.3E+07
1,1,1-Trichloroethane	127.5	2.8E-02	0.07965	0.0316	3.0E-01	2.5E+06	3.2E+06
Trichloroethene	95.5	8.9E-03	0.08116	0.0322	NA	---	---
Vinyl Chloride	2.5	6.9E-01	0.10726	0.0426	NA	---	---
Xylenes	854	6.3E-02	0.07164	0.0284	8.6E-02	1.5E+05	1.2E+06

Footnotes appear on page 2.

Table 6-9. Health-Based Remediation Goals Based Upon Retail Building Exposure to VOCs from Ground Water, Former Chevron Asphalt Plant, Emeryville, California.

Constituent	Koc (mL/g)	H (atm-m³/mol)	Do (cm²/s)	Ds (cm²/s)	Toxicity Value	Ground-Water HBG (mg/L)	Soil HBG [a] (mg/kg)
Semi-VOCs							
TPH as diesel [b]	940	4.2E-04	0.08205	0.0326	4.0E-03	2.8E+06	2.6E+07
TPH as gasoline [c]	1265	7.7E-01	0.07461	0.0296	5.7E-03	1.1E+03	1.3E+04

[a] Soil HBG calculated by: ground-water HBG × Koc × foc.

[b] TPH as diesel evaluated as naphthalene using California Air Resources Board inhalation toxicity value (CAPCOA, 1992).

[c] TPH as gasoline evaluated as n-hexane.

---	Insufficient data; HBG could not be calculated due to lack of toxicity information.
CSF	Cancer slope factor for inhalation exposure (kg-day/mg).
Do	Diffusion coefficient in air (cm²/s).
Ds	Effective vapor-phase diffusion coefficient in soil (cm²/s) = Do × 0.574
foc	Fraction organic carbon in the soil; assumed value of 0.01 (1 percent organic carbon).
H	Henry's Law Constant (atm-m³/mol).
HBG	Health-based remediation goal (mg/L for water; mg/kg for soil).
Koc	Organic carbon partition coefficient (mL/g).
NA	Not available.
RfD	Reference dose for inhalation exposure (mg/kg-day).
TPH	Total petroleum hydrocarbons.

Table 8-1. Comparison of Maximum Soil Data to Health-Based Remediation Goals, Former Chevron Asphalt Plant, Emeryville, California.

Constituent	Maximum Soil Concentration (mg/kg)	Health-Based Remediation Goal (mg/kg)
VOCs		
Benzene	0.5	5.2
Chloroform	ND	1.7
1,1-Dichloroethane	ND	1,500
1,1-Dichloroethene	ND	0.057
cis-1,2-Dichloroethene	ND	12,000
trans-1,2-Dichloroethene	1.7	23,000
Ethylbenzene	0.68	970
Tetrachloroethene	ND	94
Toluene	0.007	1,500
1,1,1-Trichloroethane	ND	4,700
Trichloroethene	15	22
Vinyl Chloride	ND	0.0056
Xylenes	3.1	470,000
Semi-VOCs		
TPH as diesel (a)	3,500	4,500
TPH as gasoline (b)	1,900	70,000

(a)	TPH as diesel evaluated using naphthalene as a surrogate.
(b)	TPH as gasoline evaluated using n-hexane as a surrogate.
ND	Not detected.
TPH	Total petroleum hydrocarbons.

Table 8-2. Comparison of Ground-Water Sampling Data to Health-Based Remediation Goals, Former Chevron Asphalt Plant, Emeryville, California.

Constituent	Concentration (mg/L)		Health-Based Remediation Goal (mg/L) [a]
	On-Site	Off-Site	
VOCs			
Benzene	0.019	0.021	12,000
Chloroform	ND	0.003	3,900
1,1-Dichloroethane	0.0028	ND	15,000,000
1,1-Dichloroethene	0.0007	ND	22
cis-1,2-Dichloroethene [b]	1.9	0.023	24,000
trans-1,2-Dichloroethene [c]	0.033	0.0017	39,000
Ethylbenzene	0.0012	0.0095	560,000
Tetrachloroethene	ND	0.13	6,900
Toluene	0.0026	0.027	13,000,000
1,1,1-Trichloroethane	ND	0.0015	1,900,000
Trichloroethene	0.0074	0.13	3,800
Vinyl Chloride	0.26	ND	37
Xylenes	0.004	0.041	110,000
Semi-VOCs			
TPH as diesel [d]	ND	ND	2,100,000
TPH as gasoline [e]	0.42	0.27	800

[a] Several of the health-based remediation goals are physically impossible concentrations, which were derived from the mathematical model used.

[b] Health-based remediation goal calculated by: soil remediation goal/(Koc x foc) = 12,000 mg/kg / (49 L/kg x 0.01).

[c] Health-based remediation goal calculated by: soil remediation goal/(Koc x foc) = 23,000 mg/kg / (59 L/kg x 0.01).

[d] Health-based remediation goal derived using naphthalene as a surrogate for TPH as diesel.

[e] Health-based remediation goal derived using n-hexane as a surrogate for TPH as gasoline. The TPH remediation goal is less than that of benzene, because n-hexane is more volatile than benzene, a factor significantly influencing the result of the calculation.

foc	Fraction of organic carbon in the soil; assumed value of 0.01 (1 percent).
Koc	Organic carbon partition coefficient (L/kg).
L/kg	Liters per kilogram.
mg/kg	Milligrams per kilogram.
mg/L	Milligrams per liter.
ml/g	Milligrams per gram.
ND	Not detected.
TPH	Total petroleum hydrocarbons.

Table 3-1. Maximum Soil Concentrations, Former Chevron Asphalt Plant, Emeryville, California.

Constituent	Soil Concentration (mg/kg)
Benzene	0.5
trans-1,2-Dichloroethene	1.7
Ethylbenzene	0.68
Toluene	0.007
TPH as diesel	3,500
TPH as gasoline	1,900
Trichloroethene	15
Xylenes	3.1

mg/kg	Milligrams per kilogram.
TPH	Total petroleum hydrocarbons.

Table 3-2. Maximum On-Site Ground-Water Concentrations, Former Chevron Asphalt Plant, Emeryville, California.

Constituent	Concentration (mg/L)	Monitoring Well
Benzene	0.019	MW-1
1,1-Dichloroethane	0.0028	MW-10
1,1-Dichloroethene	0.0007	MW-10
cis-1,2-Dichloroethene	1.9	MW-1
trans-1,2-Dichloroethene	0.033	MW-11
Ethylbenzene	0.0012	MW-1
Toluene	0.0026	MW-15
TPH as gasoline	0.42	MW-1
Trichloroethene	0.0074	MW-1
Vinyl chloride	0.26	MW-1
Xylenes	0.004	MW-1

mg/L	Milligrams per liter.
TPH	Total petroleum hydrocarbons.

Table 3-3. Maximum Off-Site Ground-Water Concentrations, Former Chevron Asphalt Plant, Emeryville, California.

Constituent	Concentration (mg/L)	Monitoring Well
Benzene	0.021	MW-16
Chloroform	0.003	MW-19
cis-1,2-Dichloroethene	0.023	MW-19
trans-1,2-Dichloroethene	0.0017	MW-19
Ethylbenzene	0.0095	MW-16
Tetrachloroethene	0.13	MW-19
Toluene	0.027	MW-16
TPH as gasoline	0.27	MW-16
1,1,1-Trichloroethane	0.0015	MW-19
Trichloroethene	0.13	MW-18
Xylenes	0.041	MW-17

mg/L	Milligrams per liter.
TPH	Total petroleum hydrocarbons.

Table 3-4. Summary of Volatile Organic Compounds Detected in Monitoring Well MW-1, Former Chevron Asphalt Plant, Emeryville, California.

	Sampled by McKesson Environmental 4/26/85 (μg/L)	Sampled by Blaine Technical Services 9/11/87 (μg/L)	Sampled by HLA 7/7/88 (μg/L)	Sampled by Sierra 4/17/92 (μg/L)
Benzene	99	63	55	19
Chlorobenzene	20	ND	ND	ND
1,1-Dichloroethene	3	ND	ND	ND
trans-1,2-Dichloroethene	1,200	700	1,050	26
Trichloroethene	160	ND	45	ND
Vinyl chloride	1,500	990	560	260

ND Not detected.
μg/L Micrograms per Liter.

Table 4-1. Toxicity Summaries for Constituents of Concern, Former Chevron Asphalt Plant, Emeryville, California.

Constituent	Acute Toxicity Summary	Chronic Toxicity Summary	Cancer Potential	Other
<u>VOCs</u>				
Benzene	**Critical Effects:** Drowsiness, dizziness, headache, vertigo, moderately toxic by ingestion.	**Critical Effects:** Pancytopenia, hearing impairment, polyneuritis. **Data Summary:** Not available.	Class A; human carcinogen. The cancer slope factor was derived from human data in which leukemia rates increased.	**Developmental:** No evidence suggesting any adverse effects even when the mother exhibits toxicity. **Reproductive:** Ovarian hypofunction. **Mutagenicity:** Chromosomal aberrations in human lymphocytes.
Chloroform	**Critical Effects:** Irritability, burning urination, anesthetic effects, arrhythmias.	**Critical Effects:** Enlarged liver, hepatitis, nephrosis. **Data Summary:** The oral RfD is based on a LOAEL in dogs of 12.9 mg/kg/day. Fatty cyst formations were seen in the liver.	Class B2; probable human carcinogen. Kidney tumors reported in rats.	**Developmental:** Increases in resorption rates and decreases in litter sizes were seen. **Reproductive:** Increases in abnormal sperm in mice. **Mutagenicity:** Positive and negative results were seen in sister chromatid exchange assays in humans.

Footnotes appear on page 8.

Table 4-1. Toxicity Summaries for Constituents of Concern, Former Chevron Asphalt Plant, Emeryville, California.

Constituent	Acute Toxicity Summary	Chronic Toxicity Summary	Cancer Potential	Other
1,1-Dichloroethane	**Critical Effects:** Cardiac arrhythmias, anesthetic effects.	**Critical Effects:** No data available. **Data Summary:** Both oral and inhalation RfDs are based on cat and rat studies in which the animals were exposed to 138 mg/kg/day.	Class C; probable human carcinogen.	**Developmental:** Decreases in maternal food consumption and body weight were seen in rats. **Reproductive:** No data available. **Mutagenicity:** Positive results were seen in animal assays for DNA binding.
1,1-Dichloroethene	**Critical Effects:** Anesthetic effects, respiratory and eye irritation.	**Critical Effects:** Liver dysfunction, kidney, and histological changes. **Data Summary:** The oral RfD is based on a LOAEL of 9 mg/kg/day in rats.	Class C; possible human carcinogen. Results show it causes adrenal pheochromocytoma in rats.	**Developmental:** Soft tissue anomalies seen in mice. **Reproductive:** An increase in resorptions was seen in mice. **Mutagenicity:** No data available.
cis-1,2-Dichloroethene	**Critical Effects:** Eye irritation and narcotic effects.	**Critical Effects:** No data available. **Data Summary:** The oral RfD is based on a rat study in which a NOAEL of 32 mg/kg/day was determined.	Class D; inadequate evidence of carcinogenicity.	**Developmental:** No data available. **Reproductive:** No data available. **Mutagenicity:** No data available.

Footnotes appear on page 8.

Table 4-1. Toxicity Summaries for Constituents of Concern, Former Chevron Asphalt Plant, Emeryville, California.

Constituent	Acute Toxicity Summary	Chronic Toxicity Summary	Cancer Potential	Other
trans-1,2-Dichloroethene	**Critical Effects:** Eye irritation, nausea, drowsiness, fatigue, vertigo.	**Critical Effects:** Swelling of the myocardium. **Data Summary:** The oral RfD is based on a study in mice in which a NOAEL of 17 mg/kg/day was determined.	Class D; inadequate evidence of carcinogenicity.	**Developmental:** No data available. **Reproductive:** No data available. **Mutagenicity:** Negative results were seen in various *S. typhirium* assays.
Ethylbenzene	**Critical Effects:** Throat irritation, chest constriction, eye irritation, dizziness, vertigo.	**Critical Effects:** Increases in kidney to body weight ratios were seen in rats. **Data Summary:** The oral RfD is based on a NOEL of 97 mg/kg/day in rats. The inhalation RfD is based on a NOEL of 100 ppm in rats.	Class D; inadequate evidence of carcinogenicity.	**Developmental:** Increases in the incidence of fetal anomalies were seen in rats, mice, and rabbits. **Reproductive:** No data available. **Mutagenicity:** Negative results were seen in various *S. typhirium* assays.

Footnotes appear on page 8.

Table 4-1. Toxicity Summaries for Constituents of Concern, Former Chevron Asphalt Plant, Emeryville, California.

Constituent	Acute Toxicity Summary	Chronic Toxicity Summary	Cancer Potential	Other
Tetrachloroethene	**Critical Effects:** Eye irritation, headache, dizziness, hypertension.	**Critical Effects:** Cirrhosis, hepatitis, fatty degeneration of the liver, renal dysfunction. **Data Summary:** The RfD is based on a NOAEL of 14 mg/kg/day in mice.	Class B2; probable human carcinogen.	**Developmental:** Increases in fetal resorptions were seen in rats. **Reproductive:** No effects reported. **Mutagenicity:** Negative results reported for human chromosome aberrations.
Toluene	**Critical Effects:** Narcosis, CNS dysfunction, eye and skin irritation. **Comments:** Toluene is abused for its narcotic effects. This usually occurs with sniffing toluene-based glue.	**Critical Effects:** Decreased blood leukocytes, renal tubular acidosis, ataxia, tremors, impaired speech, hearing, and vision. **Data Summary:** The oral RfD was derived from a 13-week rat gavage study. A NOAEL of 223 mg/kg/day was developed. Changes in liver and kidney weights were seen at a LOAEL of 446 mg/kg/day. The inhalation RfD is based on human data in which a LOAEL of 88 ppm caused CNS toxicity.	Class D; no evidence of carcinogenicity.	**Developmental:** CNS anomalies, growth retardation. **Reproductive:** No evidence. **Mutagenicity:** Results were negative or inconclusive for various tests.

Footnotes appear on page 8.

Table 4-1. Toxicity Summaries for Constituents of Concern, Former Chevron Asphalt Plant, Emeryville, California.

Constituent	Acute Toxicity Summary	Chronic Toxicity Summary	Cancer Potential	Other
1,1,1-Trichloroethane	**Critical Effects:** Respiratory depression, cardiac arrhythmias, nausea, CNS depression, vomiting, diarrhea.	**Critical Effects:** Heart damage, fatty liver. **Data Summary:** The RfDs are based on a 6-month inhalation study in guinea pigs. A NOAEL of 90 mg/kg/day was developed. Liver toxicity was noted at a LOAEL of 120 mg/kg/day.	Class D; inadequate evidence of carcinogenicity.	**Developmental:** No evidence. **Reproductive:** No evidence. **Mutagenicity:** No data available.
Trichloroethene	**Critical Effects:** Irritation of eyes and skin, CNS depression, gastrointestinal distress, liver toxicity, cardiac failure. **Comments:** Mildly toxic to humans by ingestion or inhalation. Inhalation exposures to concentrations as low as 27 mg/kg have caused drowsiness and mucous membrane irritation in humans.	**Critical Effects:** CNS disturbances, liver and kidney toxicity, hematological changes. **Data Summary:** The oral RfD is based on a NOAEL of 250 mg/kg. The inhalation RfD is based on a LOAEL of 100 ppm for CNS toxicity in rats. **Comments:** Exposure to alcohol can potentiate liver and kidney toxicity.	Class B2; probable human carcinogen.	**Developmental:** Inhalation and oral exposure in rats have resulted in fetotoxicity and developmental effects at 100 mg/kg (inhalation) or 150 mg/kg (diet). **Reproductive:** Sperm abnormalities in mice (2,000 mg/kg). No significant effects from oral studies (NOAEL 1,000 mg/kg/day). **Mutagenicity:** Human data are inconclusive. Some evidence from *in vitro* and in vivo studies suggest that trichloroethene is a weak indirect mutagen.

Footnotes appear on page 8.

Table 4-1. Toxicity Summaries for Constituents of Concern, Former Chevron Asphalt Plant, Emeryville, California.

Constituent	Acute Toxicity Summary	Chronic Toxicity Summary	Cancer Potential	Other
Vinyl chloride	**Critical Effects:** Dizziness, ataxia, headache, narcosis.	**Critical Effects:** Liver damage, circulatory disturbances in extremities.	Class A; human carcinogen. The cancer slopes are based on both inhalation and ingestion studies in rats.	**Developmental:** No data available. **Reproductive:** Sexual dysfunction was reported in women. **Mutagenicity:** Human chromosome aberrations reported.
Xylenes	**Critical Effects:** Dyspnea, nose, skin, and throat irritation, nausea, vomiting, CNS depression, moderately toxic.	**Critical Effects:** Increased hepatic weights in rats, renal toxicity, tremors, labored breathing. **Data Summary:** The oral RfD was based on a chronic rat gavage study in which a NOAEL of 250 mg/kg/day was reported. At higher doses, hyperactivity occurred. The RfC was based on a NOAEL of 27 mg/m^3 from human epidemiological data.	Class D; inadequate evidence of carcinogenicity.	**Developmental:** Fetal hemorrhages and decreased fetal weights in rats. **Reproductive:** No evidence exists. **Mutagenicity:** Negative results were seen in various tests.

Footnotes appear on page 8.

Table 4-1. Toxicity Summaries for Constituents of Concern, Former Chevron Asphalt Plant, Emeryville, California.

Constituent	Acute Toxicity Summary	Chronic Toxicity Summary	Cancer Potential	Other
Semi-VOCs				
n-Hexane	**Critical Effects:** Hallucinations after inhalation, paresthesia, muscle weakness. **Comments:** Used as a surrogate for C_9 to C_{20} hydrocarbons.	**Critical Effects:** Motor neuropathies, anorexia. **Data Summary:** The oral RfD is derived from a rat study in which NOAEL of 570 mg/kg/day was reported. A NOAEL of 58 ppm from human epidemiological studies was used to derive an inhalation RfD.	**Cancer Effects:** Class D; inadequate evidence of carcinogenicity.	**Developmental** No data available. **Reproductive:** Reproductive dysfunction in men. **Mutagenicity:** No data available.
Naphthalene	**Critical Effects:** Eye and skin irritation, nausea, headache, vomiting; mildly toxic. **Comments:** Naphthalene toxicity is the surrogate for the non-carcinogenic PAHs.	**Critical Effects:** Hemolytic anemia. **Data Summary:** The RfD is based on a rat study in which the NOAEL was 50 mg/kg/day.	Class D; inadequate evidence of carcinogenicity.	**Developmental:** Crosses the placenta barrier causing hemolytic anemia in the fetus. **Reproductive:** No data available. **Mutagenicity:** Negative results were seen *in vitro*.

Footnotes appear on page 8.

Table 4-1. Toxicity Summaries for Constituents of Concern, Former Chevron Asphalt Plant, Emeryville, California.

Constituent	Acute Toxicity Summary	Chronic Toxicity Summary	Cancer Potential	Other

References: ATSDR 1990; GAP, 1991; IRIS, 1992; Sax and Lewis, 1989; USEPA, 1992a.

CNS	Central nervous system.
LOAEL	Lowest observed adverse effect level.
mg/kg/day	Milligrams per kilogram per day.
mg/kg	Milligrams per kilogram.
mg/m^3	Milligrams per cubic meter.
NOAEL	No observed adverse effect level.
NOEL	No observed effect level.
ppm	Parts per million.
RfC	Reference concentration.
RfD	Reference dose.

Table 4-2. Adjusted Toxicity Values Used to Assess Dermal Exposure for Constituents of Concern, Former Chevron Asphalt Plant, Emeryville, California.

Constituent	RfDo (mg/kg/day)		CSFo	Oral Absorption	Reference	RfDa (mg/kg/day)		CSFa
	Subchronic	Chronic	(mg/kg/day)	Efficiencies		Subchronic	Chronic	(mg/kg/day)
<u>VOCs</u>								
Benzene	NA	NA	2.9E-02	1.00	a	NA	NA	2.9E-02
Chloroform	1.0E-02	1.0E-02	6.1E-03	1.00	a	1.0E-02	1.0E-02	6.1E-03
1,1-Dichloroethane	1.0E+00	1.0E-01	NA	1.00	a	1.0E+00	1.0E-01	NA
1,1-Dichloroethene	9.0E-03	9.0E-03	6.0E-01	1.00	a	9.0E-03	9.0E-03	6.0E-01
cis-1,2-Dichloroethene	1.0E-01	1.0E-02	NA	1.00	a	1.0E-01	1.0E-02	NA
trans-1,2-Dichloroethene	2.0E-01	2.0E-02	NA	1.00	a	2.0E-01	2.0E-02	NA
Ethylbenzene	1.0E+00	1.0E-01	NA	1.00	a	1.0E+00	1.0E-01	NA
Tetrachloroethene	1.0E-01	1.0E-02	5.2E-02	1.00	a	1.0E-01	1.0E-02	5.2E-02
Toluene	2.0E+00	2.0E-01	NA	1.00	a	2.0E+00	2.0E-01	NA
1,1,1-Trichloroethane	9.0E-01	9.0E-02	NA	1.00	a	9.0E-01	9.0E-02	NA
Trichloroethene	NA	NA	1.1E-02	1.00	a	NA	NA	1.1E-02
Vinyl chloride	NA	NA	1.9E+00	1.00	a	NA	NA	1.9E+00
Xylenes	4.0E+00	2.0E+00	NA	1.00	a	4.0E+00	2.0E+00	NA
<u>Semi-VOCs</u>								
TPHs as gasoline [a]	6.0E-01	6.0E-02	NA	1.00	a	6.0E-01	6.0E-02	NA
TPHs as diesel [b]	4.0E-02	4.0E-02	NA	0.9	b	3.6E-02	3.6E-02	NA

References:	IRIS, 1992; USEPA, 1992a,b.
[a]	Used as a surrogate for total petroleum hydrocarbons as gasoline.
[b]	Used as a surrogate for total petroleum hydrocarbons as diesel.
a	Assumed.
b	Value not given; benzo(a)pyrene is used as a surrogate (ATSDR, 1990).
CSFa	Adjusted cancer slope factor.
CSFo	Oral cancer slope factor.
mg/kg/day	Milligrams per kilogram per day.
NA	Not available.
RfDa	Adjusted reference dose.
RfDo	Oral reference dose.

Table 4-3. Reference Doses, Target Sites, and Confidence Levels for Constituents of Concern, Former Chevron Asphalt Plant, Emeryville, California.

Constituent	RfDo (mg/kg/day) Subchronic	RfDo (mg/kg/day) Chronic	RfDi (mg/kg/day) Subchronic	RfDi (mg/kg/day) Chronic	Target Sites Oral	Target Sites Inhalation	Confidence Level/ Uncertainty Factor
<u>VOCs</u>							
Chloroform	1.0E-02	1.0E-02	NA	NA	liver	NA	medium/1000
1,1-Dichloroethane	1.0E+00	1.0E-01	1.4E+00	1.4E-01	none	kidney	1000
1,1-Dichloroethene	9.0E-03	9.0E-03	NA	NA	liver	NA	medium/1000
cis-1,2-Dichloroethene	1.0E-01	1.0E-02	NA	NA	red blood cells	NA	3000
trans-1,2-Dichloroethene	2.0E-01	2.0E-02	NA	NA	serum enzymes	NA	low/1000
Ethylbenzene	1.0E+00	1.0E-01	2.9E-01	2.9E-01	liver, kidney	developmental	low/1000
Tetrachloroethene	1.0E-01	1.0E-02	NA	NA	liver	NA	medium/1000
Toluene	2.0E+00	2.0E-01	5.7E-01	1.1E-01	liver, kidney	CNS	medium/1000
1,1,1-Trichloroethane	9.0E-01	9.0E-02	2.9E+00	2.9E-01	liver	liver	medium/1000
Trichloroethene	NA	NA	NA	NA	NA	NA	NA
Vinyl chloride	NA	NA	1.3E-03	1.3E-03	NA	NA	NA
Xylenes	4.0E+00	2.0E+00	NA	NA	hyperactivity	NA	medium/100
<u>Semi-VOCs</u>							
TPHs as gasoline [a]	6.0E-01	6.0E-02	5.7E-02	5.7E-02	CNS, testicles	CNS	medium/300
TPHs as diesel [b]	4.0E-02	4.0E-02	NA	NA	decreased weight gain	NA	1000

References:	IRIS, 1992; USEPA, 1992a.
[a]	Used as a surrogate for total petroleum hydrocarbons as gasoline.
[b]	Used as a surrogate for total petroleum hydrocarbons as diesel.
CNS	Central nervous system.
mg/kg/day	Milligrams per kilogram per day.
NA	Not available.
RfDi	Inhalation reference dose.
RfDo	Oral reference dose.

Table 4-4. Cancer Slope Factors, Tumor Sites, and USEPA Cancer Classifications for Constituents of Concern, Former Chevron Asphalt Plant, Emeryville, California.

Constituent	CSF (mg/kg/day)-1		Tumor site		USEPA Classification
	Oral	Inhalation	Oral	Inhalation	
<u>VOCs</u>					
Benzene	2.9E-02	2.9E-02	leukemia	leukemia	A
Chloroform	6.1E-03	8.1E-02	kidney	liver	B2
1,1-Dichloroethane	NA	NA	heart	NA	C
1,1-Dichloroethene	6.0E-01	1.2E+00	adrenal gland	kidney	C
Tetrachloroethene	5.2E-02	2.0E-03	NA	NA	B2
Trichloroethene	1.1E-02	6.0E-03	NA	NA	B2
Vinyl Chloride	1.9E+00	3.0E-01	lung	liver	A

References:	IRIS, 1992; USEPA,1992a,b.
mg/kg/day	Milligrams per kilogram per day.
NA	Not available.

Table 5-1. Physical and Chemical Properties of Constituents of Concern, Former Chevron Asphalt Plant, Emeryville, California.

Constituent	Molecular Weight (g/mol)	Water Solubility (mg/L 25°C)	Specific Gravity	Vapor Pressure (mm Hg 25°C)	Henry's Law Constant (atm-m^3/mol) (25°C)	Diffusivity (cm^2/sec)	K_{oc} (mL/g)	Log K_{ow}	Fish BCF (L/kg)
<u>VOCs</u>									
Benzene	78	1,780	0.88	9.5E+01	5.5E-03	9.3E-02	49 - 100	1.56 - 2.15	5.2
Chloroform	119	7,222-9,600	1.48	2.0E+02	3.2E-03	8.9E-02	44	1.90 - 1.97	3.8
1,1-Dichloroethane	99	5,060	1.17	2.3E+02	5.9E-03	9.6E-02	30	1.78 - 1.79	1.2
1,1-Dichloroethene	97	273-6,400	1.22	5.9E+02	1.5E-02	1.0E-01	65	1.48 - 2.13	5.6
cis-1,2-Dichloroethene	97	3,500	1.28	2.0E+02	3.4E-03	1.0E-01	49	1.86	15
trans-1,2-Dichloroethene	97	6,300	1.25	2.7E+02 (20°C)	6.7E-03	1.0E-01	59	2.09	1.58
Ethylbenzene	106	152-208	0.87	9.5E+00	8.7E-03	6.7E-02	95 - 260	3.05-3.15	37.5
Tetrachloroethene	166	150-485	1.6	1.9E+01	2.9E-03	7.4E-02	210-363	2.1 - 2.88	30.6
Toluene	92	490-627	0.87	2.8E+01	6.7E-03	7.8E-02	115-150	2.11 - 2.80	10.7
1,1,1-Trichloroethane	133	300-1,334	1.34	1.2E+02	1.6E-02	8.0E-02	104-151	2.17 - 2.49	5.6
Trichloroethene	131	1,100-1,500	1.46	7.3E+01	9.9E-03	8.1E-02	65-126	2.29 - 3.30	10.6
Vinyl chloride	63	1,100-2,700	0.91	2.7E+03	5.6E-02	1.1E-01	2.5	0.60	1.17
Xylenes (total)	106	162-200	0.87	6.6E+00-8.8E+00	6.3E-03	7.2E-02	128-1,580	2.77 - 3.20	134
<u>Semi-VOCs</u>									
TPHs (Naphthalene)[a]	128	30 - 34	1.16	2.3E-01 - 8.7E-01	4.6E-04	8.2E-02	550 - 3,160	3.2 - 4.7	10.5
TPHs (n-Hexane)[b]	86	18 (20 C)	0.66	1.20E+02 (20C)	7.7E-01	7.5E-02	890	2.77	ND

References: Howard et al., 1991; Howard, 1990 and 1989; Lugg, 1968; Lyman et al., 1990; Mackay and Shiu, 1981; Montgomery and Welkom, 1990; RTI, 1987; Shen, 1982; USEPA, 1991; Veith and Kosain, 1982; and Verschueren, 1983.

[a] Naphthalene used as a surrogate for TPH as diesel.

[b] Hexane used as a surrogate for TPH as gasoline.

atm-m^3/mol	Atmospheres-cubic meter per mole.	L/kg	Liters per kilogram.
BCF	Bioconcentration factor.	mg/L	Milligrams per liter.
C	Degrees Celsius.	mL/g	Milliliters per gram.
cm^2/sec	Square centimeters per second.	mm Hg	Millimeters of mercury.
g/mol	Grams mole.	NA	Not applicable.
K_{oc}	Organic carbon partition coefficient.	ND	No data.
K_{ow}	Octanol-water partition coefficient.	TPH	Total petroleum hydrocarbons.

Table 5-2. Maximum On- and Off-Site Ground-Water Concentrations and California Water-Quality Goals, Former Chevron Asphalt Plant, Emeryville, California.

	Ground-Water Concentration		California Water-Quality Goals[a]	
Constituent	On-Site (mg/L)	Off-Site (mg/L)	Marine (mg/L)	Freshwater (mg/L)
Benzene	0.019	0.021	0.70[b]	5.3[c]
Chloroform	ND	0.003	6.4[d]	1.24[c]
1,1-Dichloroethane	0.0028	ND		
1,1-Dichloroethene	0.0028	ND		
cis-1,2-Dichloroethene	1.9	0.023	224e[e]	11.6[e]
trans-1,2-Dichloroethene	0.033	0.0017	224[e]	11.6[e]
Ethylbenzene	0.0012	0.0095	0.43[c]	32[c]
Tetrachloroethene	ND	0.13	0.45[b]	0.84[b]
Toluene	0.0026	0.027	5.0[b]	17[c]
TPH as gasoline (e)	0.42	0.27	NA	NA
1,1,1-Trichloroethane	ND	0.0015	31.2[c]	18[c]
Trichloroethene	0.0074	0.13	2.0[c]	21.9[c]
Vinyl chloride	0.26	ND	NA	NA
Xylenes	0.004	0.041	0.040[g]	0.070[g]

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a From "A Compilation of Water-Quality Goals," State of California Environmental Protection Agency, Regional Water Quality Control Board, Central Valley Region, September 1991.
b USEPA chronic lowest observed effect level (LOEL) (USEPA, 1986).
c USEPA acute LOEL (USEPA, 1986).
d USEPA chronic lowest observed effect level (LOEL) for sum of halomethanes (USEPA, 1986).
e USEPA acute LOEL for sum of dichloroethenes (USEPA, 1986).
f TPH as gasoline evaluated using n-hexane as a surrogate.
g Applied action level for aquatic life (AAL List, No. 91-1, 7/1/91).

mg/L	Milligrams per liter.
NA	Not available.
ND	Not detected.

Table 6-1. Calculation of Human Health-Based Soil Remediation Goals for a Construction Worker for Exposure to Carcinogens in Soil, Former Chevron Asphalt Plant, Emeryville, California.

<u>Carcinogens</u>

$$\text{HBG (mg/kg)} = \frac{\text{TR} \times \text{BW} \times \text{AT} \times \text{UCF1}}{\text{EF} \times \text{ED} \times ([\text{CSF}_o \times \text{UCF2} \times \text{IR}_{soil}] + [\text{CSF}_a \times \text{ABS} \times \text{SSA} \times \text{SA} \times \text{UCF2}] + [\text{CSF}_i \times \text{IR}_{air} \times ([1/\text{VF}] + [1/\text{PEF}])])}$$

ABS	Dermal absorption efficiency (constituent-specific).
AT	Averaging time for non-carcinogenic effects (70 yr).
BW	Adult body weight (70 kg).
CSF_a	Adjusted cancer slope factor (constituent-specific, kg-mg/day).
CSF_i	Inhalation cancer slope factor (constituent-specific, kg-mg/day).
CSF_o	Oral cancer slope factor (constituent-specific, kg-mg/day).
ED	Exposure duration (1 yr).
EF	Exposure frequency (250 days/yr).
HBG	Health-based remediation goal (mg/kg).
IR_{air}	Inhalation rate (20 m^3/day).
IR_{soil}	Soil ingestion rate (480 mg/day).
kg	Kilograms.
m^3	Cubic meters.
mg	Milligrams.
PEF	Particulate emission factor (1.16×10^{11} m^3/kg; from Table 6-4).
SSA	Skin surface area (3,900 cm^2, hands and arms).
SA	Soil adherence rate (1 mg/cm^2-day).
TR	Target excess individual lifetime cancer risk (1×10^{-6}).
UCF1	Unit conversion factor (365 days/yr).
UCF2	Unit conversion factor (1×10^{-6}).
VF	Soil-to-air volatilization factor (area and constituent-specific, m^3/kg; from Table 6-3).
yr	Years.

Sample calculation appears on page 2.

Table 6-1. Calculation of Human Health-Based Soil Remediation Goals for a Construction Worker for Exposure to Carcinogens in Soil, Former Chevron Asphalt Plant, Emeryville, California.

Sample calculation of HBG for chloroform:

$$\text{HBG} = \frac{1 \times 10^{-6} \times 70\ \text{kg} \times 70\ \text{yr} \times 365\ \text{days/yr}}{250\ \text{days/yr} \times 1\ \text{yr} \times ([0.0061\ \text{kg-day/mg} \times 1 \times 10^{-6}\ \text{kg/mg} \times 50\ \text{mg/day}] + [0.0061\ \text{kg-day/mg} \times 0.25 \times 3{,}900\ \text{cm}^2 \times 1\ \text{mg/cm}^2\text{-day}] + [0.081\ \text{kg-day/mg} \times 20\ \text{m}^3\text{/day} \times ([1/383\ \text{m}^3\text{/kg}] + [1/1.16 \times 10^{11}\ \text{m}^3\text{/kg}])])}$$

$$\text{HBG} = 1.68\ \text{mg/kg}$$

Reference: USEPA, 1991a.

Table 6-2. **Calculation of Human Health-Based Soil Remediation Goals for a Construction Worker for Exposure to Non-Carcinogens in Soil, Former Chevron Asphalt Plant, Emeryville, California.**

Non-Carcinogens

$$\mathrm{HBG\ (mg/kg)} = \frac{\mathrm{THI \times BW \times AT \times UCF1}}{\mathrm{EF \times ED \times ([(1/RfD_o) \times UCF2 \times IR_{soil}] + [(1/RfD_a \times ABS \times SSA \times SA \times UCF2] + [(1/RD_i) \times IR_{air} \times ([1/VF] + [1/PEF])])}}$$

ABS	Dermal absorption efficiencies (constituent-specific).
AT	Averaging time for non-carcinogenic effects (1 yr).
BW	Adult body weight (70 kg).
ED	Exposure duration (1 yr).
EF	Exposure frequency (250 days/yr).
HBG	Health-based remediation goal (mg/kg).
IR_{air}	Inhalation rate (20 m^3/day).
IR_{soil}	Soil ingestion rate (480 mg/day).
kg	Kilograms.
mg	Milligrams.
PEF	Particulate emission factor (1.16×10^{11} m^3/kg; from Table 6-4).
RfD_a	Adjusted reference dose (constituent-specific, mg/kg/day).
RfD_i	Inhalation reference dose (constituent-specific, mg/kg/day).
RfD_o	Oral reference dose (constituent-specific, mg/kg/day).
SSA	Skin surface area (3,900 cm^2).
SA	Soil adherence rate (1 mg/cm^2-day).
THI	Target hazard index (1).
UCF1	Unit conversion factor (365 days/yr).
UCF2	Unit conversion factor (1×10^{-6} kg/mg).
VF	Soil-to-air volatilization factor (area and constituent-specific, m^3/kg; from Table 6-3).
yr	Years.

Sample calculation appears on page 2.

Table 6-2. Calculation of Human Health-Based Soil Remediation Goals for a Construction Worker for Exposure to Non-Carcinogens in Soil, Former Chevron Asphalt Plant, Emeryville, California.

Sample calculation of Health-Based Remediation Goal for 1,1-dichloroethane:

$$\text{HBG} = \frac{1 \times 70\ \text{kg} \times 25\ \text{yr} \times 365\ \text{days/yr}}{250\ \text{days/yr} \times 1\ \text{yr} \times \left(\left[(1/1\ \text{mg/kg/day}) \times 10^{-6}\ \text{kg/mg} \times 480\ \text{mg/day}\right] + \left[(1/1\ \text{mg/kg/day}) \times 3{,}900\ \text{cm}^2 \times 1\ \text{mg/cm}^2 \times 10^{-6}\ \text{kg/mg}\right] + \left[(1/1.4\ \text{mg/kg/day}) \times 20\ \text{m}^3/\text{day} \times \left([1/215\ \text{m}^3/\text{kg}] + [1/1.16 \times 10^{11}\ \text{m}^3/\text{kg}]\right)\right]\right)}$$

$$\text{HBG} = 1{,}500\ \text{mg/kg}$$

Reference: USEPA, 1991a.

Table 6-3. Calculation of Soil-to-Air Volatilization Factor for Exposure to Constituents in Soil, Former Chevron Asphalt Plant, Emeryville, California.

$$\text{VF (m}^3\text{/kg)} = \frac{\text{LS x V x DH}}{\text{A}} \quad \text{x} \quad \frac{(\text{3.14 x alpha x T})^{0.5}}{\text{2 x Dei x E x Kas x UC}}$$

where:

$$\text{alpha (cm}^2\text{/s)} = \frac{\text{Dei x E}}{\text{E + (Ps x [1 - E]/Kas)}}$$

$$\text{Dei (cm}^2) = \text{Di x E}^{0.33}$$

$$\text{Kas (g soil/cm}^3\text{ air)} = \text{(H/Kd)/41}$$

Where:

A	Area of contamination (33,444,000 cm^2).
alpha	Intermediate value.
atm-m^3/mol	Atmospheres-cubic meters per mole.
cm^2	Square centimeters.
cm^3	Cubic centimeters.
Dei	Effective diffusivity (Di x $E^{0.33}$ cm^2/s).
DH	Diffusion height (2 m).
Di	Molecular diffusivity (cm^2/s; Table 5-1).
E	True soil porosity (0.5).
g	Gram.
H	Henry's Law Constant (atm-m^3/mol; Table 5-1).
Kas	Soil-air partition coefficient ([H/Kd] x 41 g soil/cm^3 air, where 41 is a unit conversion factor).
Kd	Soil-water partition coefficient (cm^3/g, 0.01; x Koc).
kg	Kilograms.
Koc	Organic carbon partition coefficient (cm^3/g; Table 5-1).
LS	Length of side of contaminated area (61 m).
m	Meters.
m^3	Cubic meters.
Ps	True soil density or particulate density (2.65 g/cm^3).
s	Second.
T	Exposure interval (3.2 x 10^7 s = 1 year).
UC	Unit conversion factor (0.001 kg/g).
V	Wind speed in mixing zone (1.8 m/s).
VF	Volatilization factor (m^3/kg).

Sample calculation appears on page 2.

Table 6-7. Equations Used to Calculate Health-Based Remediation Goals for Ground Water, Based Upon Volatilization of Ground-Water Constituents into Building Air, Former Chevron Asphalt Plant, Emeryville, California.

D_o	vapor diffusion coefficient (cm^2/s) = constituent-specific value;
D_s	apparent steady-state vapor diffusion coefficient in soil (cm^2/s) = $0.5^{4/3} \times D_o$;
EF	exposure frequency (days/yr) = 250 days/year;
EP	exposure period (yr) = 25 years;
H	Henry's Law Constant (atm-m^3/mol) = constituent-specific value;
HBG	health-based remediation goal (mg/L);
IR	inhalation rate (daily average) (m^3/day) = 20 m^3/day;
L	depth to ground water (cm) = 154.2 cm = 5 feet;
LT	expected lifetime (averaging period for cancer effects) (yr) = 70 years;
n	number of data points;
RfD	reference dose for inhalation exposure (mg/kg-day) = constituent-specific value;
RT	universal gas constant x soil temperature (atm-m^3/mol) = 0.02445 atm-m^3/mol (assumed T = 298 K);
t	diffusion time (seconds) = 2.592×10^6 s = 1 month;
TCR	target cancer risk (unitless) = 10^{-6};
THQ	target hazard index for non-cancer risk (unitless) = 1;
UC_1	unit conversion = 365 days/year;
UC_2	unit conversion = 10^{-3} L/cm^3;

Table 6-8. Health-Based Remediation Goals Based Upon Office Building Exposure to VOCs from Ground Water, Former Chevron Asphalt Plant, Emeryville, California.

Constituent	Koc (mL/g)	H (atm-m³/mol)	Do (cm²/s)	Ds (cm²/s)	Toxicity Value	Ground-Water HBG (mg/L)	Soil HBG [a] (mg/kg)
CANCER EFFECTS					CSF (kg-day/mg)		
VOCs							
Benzene	74.5	5.5E-03	0.0932	0.0370	2.9E-02	1.2E+04	8.7E+03
Chloroform	44	3.8E-03	0.08868	0.0352	8.1E-02	3.9E+03	1.7E+03
1,1-Dichloroethane	30	5.7E-03	0.0959	0.0381	NA	---	---
1,1-Dichloroethene	65	1.5E-01	0.10077	0.0400	1.2E+00	2.2E+01	1.4E+01
Tetrachloroethene	286.5	2.3E-02	0.07404	0.0294	1.8E-03	6.9E+03	2.0E+04
Trichloroethene	95.5	8.9E-03	0.08116	0.0322	1.7E-02	3.8E+03	3.6E+03
Vinyl Chloride	2.5	6.9E-01	0.10726	0.0426	2.9E-01	3.7E+01	9.3E-01
NON-CANCER EFFECTS					RfD (mg/kg-day)		
VOCs							
Benzene	74.5	5.5E-03	0.0932	0.0370	NA	---	---
Chloroform	44	3.8E-03	0.08868	0.0352	2.9E+00	3.2E+08	1.4E+08
1,1-Dichloroethane	30	5.7E-03	0.0959	0.0381	1.0E-01	1.5E+07	4.5E+06
1,1-Dichloroethene	65	1.5E-01	0.10077	0.0400	NA	---	---
cis-1,2-Dichloroethene	49	6.6E-03	0.0998	0.0396	NA	---	---
trans-1,2-Dichloroethene	59	5.7E-03	0.0998	0.0396	NA	---	---
Ethylbenzene	177.5	1.5E-01	0.08503	0.0337	2.9E-01	5.6E+05	9.9E+05
Tetrachloroethene	286.5	2.3E-02	0.07404	0.0294	NA	---	---
Toluene	132.5	6.7E-03	0.07828	0.0311	5.7E-01	1.3E+07	1.7E+07
1,1,1-Trichloroethane	127.5	2.8E-02	0.07965	0.0316	3.0E-01	1.9E+06	2.4E+06
Trichloroethene	95.5	8.9E-03	0.08116	0.0322	NA	---	---
Vinyl Chloride	2.5	6.9E-01	0.10726	0.0426	NA	---	---
Xylenes	854	6.3E-02	0.07164	0.0284	8.6E-02	1.1E+05	9.5E+05

Footnotes appear on page 2.

Table 6-7. Equations Used to Calculate Health-Based Remediation Goals for Ground Water, Based Upon Volatilization of Ground-Water Constituents into Building Air, Former Chevron Asphalt Plant, Emeryville, California.

UC_3 unit conversion = 10^4 cm^2/m^2;

UC_4 unit conversion = 3,600 seconds/hour;

V volume of building (m^3) = 10,149 m^3 for the office building; 5,097 m^3 for the retail building; and

z point just below the surface, from which diffusion into the air is assumed to occur = 0.1 cm (same as d).

Table 6-3. Calculation of Soil-to-Air Volatilization Factor for Exposure to Constituents in Soil, Former Chevron Asphalt Plant, Emeryville, California.

Sample calculation of volatile emission factor for benzene:

$$\text{VF (m}^3\text{/kg)} = \frac{61 \text{ m x } 1.8 \text{ m/s x } 2 \text{ m}}{33{,}444{,}000 \text{ cm}^2} \text{ x } \frac{(3.14 \text{ x alpha x } 3.2 \text{ x } 10^7 \text{ s})^{0.5}}{2 \text{ x } 0.074 \text{ cm}^2 \text{ x } 0.5 \text{ x } 0.11 \text{ g/cm}^3 \text{ x } 0.001 \text{ kg/g}}$$

where:

$$\text{alpha (cm}^2\text{/s)} = \frac{0.074 \text{ cm}^2\text{/s x } 0.5}{0.5 + (2.65 \text{ g/cm}^3 \text{ x } [1 - 0.5]/0.11 \text{ g/cm}^3)}$$

$$\text{Dei (cm}^2) = 0.093 \text{ x } (0.5)^{0.33}$$

$$\text{Kas (g soil/cm}^3 \text{ air)} = (0.0055/2) \text{ x } 41$$

VF = 434 m^3/kg

where:

alpha = $3.02 \text{ x } 10^{-3} \text{ cm}^2\text{/s}$

Dei = 0.074 cm^2

Kas = 0.11 g soil/cm^3 air

Reference: USEPA, 1991a.

Table 6-4. Calculation of Particulate Emission Factor for Exposure to Constituents in Soil, Former Chevron Asphalt Plant, Emeryville, California.

$$\text{PEF} = \frac{\text{LS} \times \text{V} \times \text{DH} \times \text{UCF1}}{\text{A}} \times \frac{\text{UCF2}}{\text{RF} \times (1\text{-G}) \times (\text{Um/Ut})^3 \times \text{F(x)}}$$

where:

A	Area of contamination (3,344 m^2).
DH	Diffusion height (2 m).
F(x)	Function dependent on Um/Ut (0.0025) (USEPA, 1991a).
G	Fraction of vegetative cover (0).
g	Grams.
hr	Hour.
kg	Kilograms.
LS	Length of side of contaminated area (61 m).
m^2	Square meters.
m^3	Cubic meters.
PEF	Particulate emission factor (1.16 x 10^{11} m^3/kg).
RF	Respirable fraction (0.036 g/m^2/hr).
s	Seconds.
Um	Mean annual wind speed (3.6 m/s).
Ut	Equivalent threshold value of wind speed at 10 m (12.8 m/s).
UCF1	Unit conversion factor (3,600 s/hr).
UCF2	Unit conversion factor (1,000 g/kg).
V	Wind speed in mixing zone (1.8 m/s).

Sample calculation of particulate emission factor from soil:

$$\text{PEF} = \frac{61\text{ m} \times 1.8\text{ m/s} \times 2\text{ m} \times 3{,}600\text{ s/hr}}{3{,}344\text{ m}^2} \times \frac{1{,}000\text{ g/kg}}{0.036\text{ g/m}^2\text{-hr} \times (1\text{-}0) \times (3.6\text{ m/s}/\ 12.8\text{ m/s})^3 \times 0.0025}$$

$$\text{PEF} = 1.16 \times 10^{11}\text{ m}^3\text{/kg}$$

Reference: USEPA, 1991a.

Table 6-5. Carcinogenic Health-Based Remediation Goals for a Construction Worker for Exposure to Constituents in Soil, Former Chevron Asphalt Plant, Emeryville, California.

			Toxicity Values			Cancer Effects
Constituent	alpha	VF	CSFo (kg-day/mg)	CSFa (kg-day/mg)	CSFi (kg-day/mg)	HBG (mg/kg)
VOCs						
Benzene	3.02E-03	4.34E+02	2.9E-02	2.9E-02	2.9E-02	5.2
Chloroform	3.77E-03	3.83E+02	6.1E-03	6.1E-03	8.1E-02	1.7
1,1-Dichloroethane	1.01E-02	2.15E+02	NA	NA	NA	NA
1,1-Dichloroethene	1.21E-02	1.92E+02	6.0E-01	6.0E-01	1.2E+00	0.057
cis-1,2-Dichloroethene	4.05E-03	3.70E+02	NC	NC	NC	NC
trans-1,2-Dichloroethene	6.42E-03	2.85E+02	NC	NC	NC	NC
Ethylbenzene	1.34E-03	6.60E+02	NC	NC	NC	NC
Tetrachloroethene	3.62E-04	1.30E+03	5.2E-02	5.2E-02	2.0E-03	94
Toluene	2.07E-03	5.27E+02	NC	NC	NC	NC
1,1,1-Trichloroethane	4.82E-03	3.31E+02	NC	NC	NC	NC
Trichloroethene	3.69E-03	3.85E+02	1.1E-02	1.1E-02	6.0E-03	22
Vinyl chloride	8.27E-02	4.71E+00	1.9E+00	1.9E+00	3.0E-01	0.0056
Xylenes	1.76E-04	1.87E+03	NC	NC	NC	NC
Semi-VOCs						
TPHs as gasoline [a]	NAP	NAP	NC	NC	NC	NC
TPHs as diesel [b]	NAP	NAP	NC	NC	NC	NC

References:	IRIS, 1992; USEPA, 1992a,b.
[a]	n-Hexane used as a surrogate for TPH as gasoline.
[b]	Naphthalene used as a surrogate for TPH as diesel.
alpha	Intermediate value used to calculate VF.
CSFa	Adjusted cancer slope factor.
CSFi	Inhalation cancer slope factor.
CSFo	Oral cancer slope factor.
HBG	Health-based remediation goal.
kg-day/mg	Kilograms day per milligram.
mg/kg	Milligrams per kilogram.
NA	Not available.
NAP	Not applicable.
NC	Not carcinogenic.
TPH	Total petroleum hydrocarbons.
VF	Soil-to-air volatilization factor, cubic meters per kilogram (m^3/kg).

Table 6-6. Non-Carcinogenic Health-Based Remediation Goals for a Construction Worker for Exposure to Constituents in Soil, Former Chevron Asphalt Plant, Emeryville, California.

			Toxicity Values			Non-Cancer
Constituent	alpha	VF	RfDo (mg/kg/day)	RfDa (mg/kg/day)	RfDi (mg/kg/day)	Effects HBG (mg/kg)
<u>VOCs</u>						
Benzene	3.02E-03	4.34E+02	NA	NA	NA	NA
Chloroform	3.77E-03	3.83E+02	1.0E-02	1.0E-02	NA	1,200
1,1-Dichloroethane	1.01E-02	2.15E+02	1.0E+00	1.0E+00	1.4E+00	1,500
1,1-Dichloroethene	1.21E-02	1.92E+02	9.0E-03	9.0E-03	NA	1,100
cis-1,2-Dichloroethene	4.05E-03	3.70E+02	1.0E-01	1.0E-01	NA	12,000
trans-1,2-Dichloroethene	6.42E-03	2.85E+02	2.0E-01	2.0E-01	NA	23,000
Ethylbenzene	1.34E-03	6.60E+02	1.0E+00	1.0E+00	2.9E-01	970
Tetrachloroethene	3.62E-04	1.30E+03	1.0E-01	1.0E-01	NA	12,000
Toluene	2.07E-03	5.27E+02	2.0E+00	2.0E+00	5.7E-01	1,500
1,1,1-Trichloroethane	4.82E-03	3.31E+02	9.0E-01	9.0E-01	2.9E+00	4,700
Trichloroethene	3.69E-03	3.85E+02	NA	NA	NA	NA
Vinyl chloride	8.27E-02	4.71E+00	NA	NA	NA	NA
Xylenes	1.76E-04	1.87E+03	4.0E+00	4.0E+00	NA	470,000
<u>Semi-VOCs</u>						
TPHs as gasoline [a]	NAP	NAP	6.0E-01	6.0E-01	5.7E-02	70,000
TPHs as diesel. [b]	NAP	NAP	4.0E-02	3.6E-02	NA	4,500

References:	IRIS, 1992; USEPA, 1992a,b.
[a]	n-Hexane used as a surrogate for TPH as gasoline.
[b]	Naphthalene used as a surrogate for TPH as diesel.
alpha	Intermediate value used to calculate VF.
HBG	Health-based remediation goal.
mg/kg	Milligrams per kilogram.
mg/kg/day	Milligrams per kilogram per day.
NA	Not available.
NAP	Not applicable.
RfDa	Adjusted reference dose.
RfDi	Inhalation reference dose.
RfDo	Oral reference dose.
TPH	Total petroleum hydrocarbons.
VF	Soil-to-air volatilization factor, cubic meters per kilogram (m^3/kg).

Table 6-7. Equations Used to Calculate Health-Based Remediation Goals for Ground Water, Based Upon Volatilization of Ground-Water Constituents into Building Air, Former Chevron Asphalt Plant, Emeryville, California.

$$\sum_o = \exp\left[\frac{-D_s \pi^2 t}{4L^2}\right] \cos\left[\frac{\pi (L-z)}{2L}\right]$$

For cancer risk:

$$HBG = \frac{TCR \times \pi \times d \times RT \times ACH \times V \times BW \times LT \times UC_1}{H \times \sum_o \times 4D_o \times A \times CSF \times IR \times EF \times EP \times UC_2 \times UC_3 \times UC_4}$$

For noncancer risk:

$$HBG = \frac{THQ \times RfD \times \pi \times d \times RT \times ACH \times V \times BW \times UC_1}{H \times \sum_o \times 4D_o \times A \times IR \times EF \times UC_2 \times UC_3 \times UC_4}$$

where:

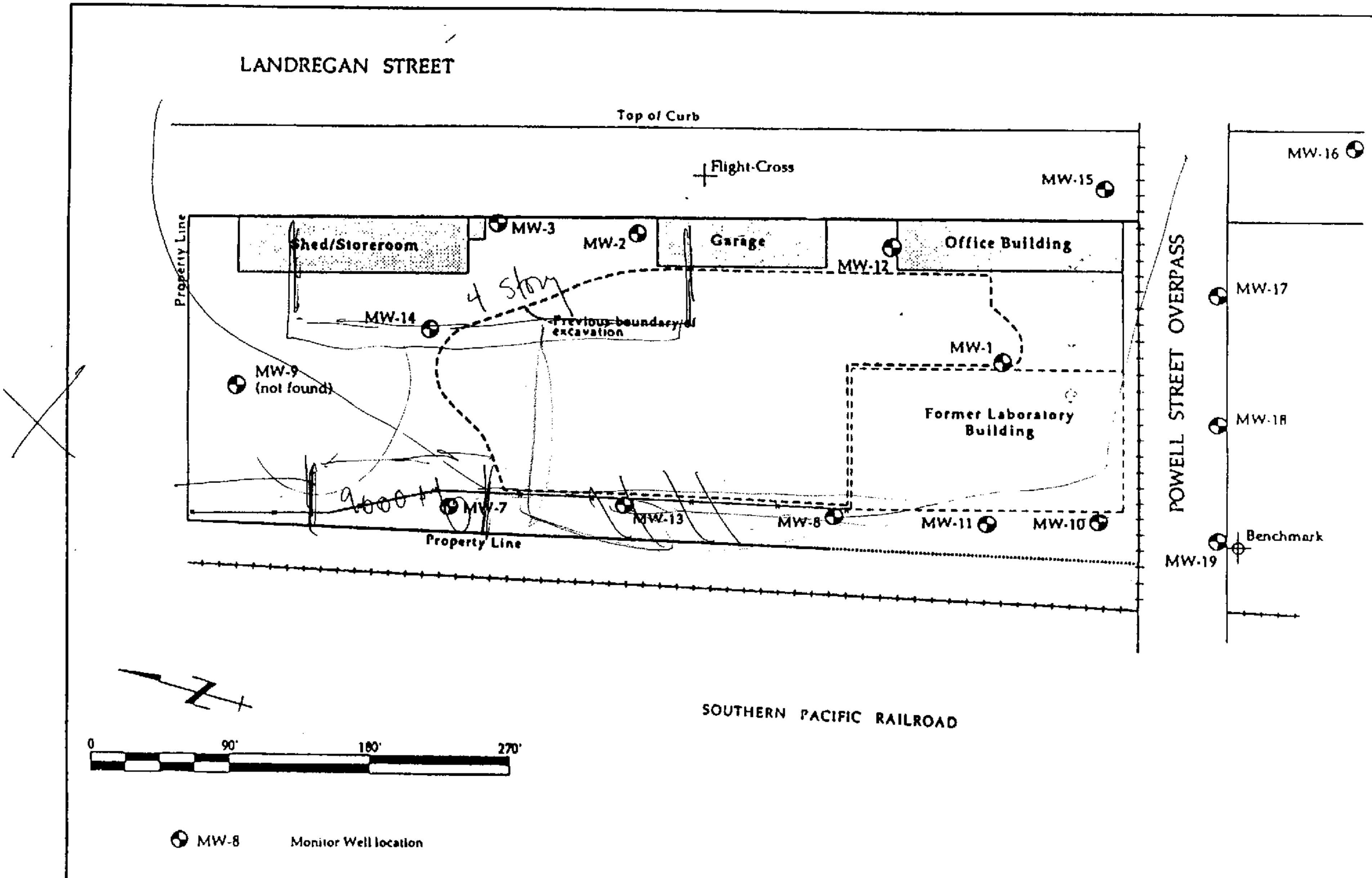
A area of infiltration (m^2) = 1.158 m^2 for the office building; 0.8839 m^2 for the retail building;

ACH air exchange rate (hr^{-1}) = 1 hr^{-1} for the office building; 2 hr^{-1} for the retail building;

BW adult body weight (kg) = 70 kg;

CSF cancer slope factor for inhalation exposure (kg-day/mg) = constituent-specific value;

d diffusion distance (cm) = 0.1 cm;



Site Map, Former Chevron Asphault Plant, Emeryville, California
(from Western Geologic Resources, Inc., 1991b)

Figure
2-1

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APPENDIX A

CALCULATION OF HEALTH-BASED REMEDIAL GOALS

INTRODUCTION

This appendix presents the model used in deriving the equation shown in Table 6-7 and used to calculate the health-based remedial goals (HBGs) in Tables 6-8 and 6-9. The calculation of HBGs for ground water was based upon a model in which constituents in the ground water volatilize, diffuse to the soil surface, and then diffuse into the hypothetical building through the foundation. The model is presented in the "forward" direction first, and those results are then applied to the calculation of HBGs for the office and retail building scenarios.

GROUND-WATER VOLATILIZATION MODEL

The conceptual exposure model consists of the partitioning of a volatile organic compound (VOC) between soil and ground water, from which it volatilizes into the air-filled pore spaces in the soil. The vapor-phase VOC diffuses upward until it encounters the concrete slab foundation, diffuses through the concrete or through cracks in the concrete, and is dispersed in the building air.

In a soil system, a VOC is in equilibrium between the vapor, aqueous (solubilized in water), and adsorbed phases. The phase change from aqueous to vapor phase provides the emission source for the volatilization flux through the soil. If the volatilization process is assumed to be at steady state, the extent of volatilization of a constituent from the ground water to the gas phase can be evaluated using equilibrium partitioning. The distribution coefficient is the constituent-specific dimensionless Henry's Law Constant, which is calculated by dividing the Henry's Law Constant by the product of the universal gas constant and the soil temperature (Lyman et al., 1990). The value of the vapor phase equilibrium concentration in the soil was calculated by:

$$C_o = \left(\frac{H}{RT}\right) \times C_{gw} \times \left(10^{-3}\ L/cm^3\right) \tag{1}$$

where:

C_{gw} = ground-water concentration (milligrams per liter [mg/L]);

C_o = vapor phase equilibrium concentration (milligrams per cubic centimeter [mg/cm^3]);

H = Henry's Law Constant (atmospheres × cubic meters per mole [atm-m^3/mol]);

R = universal gas constant (8.204×10^{-5} atmospheres × cubic meters per mole per degree Kelvin [atm-m^3/mol-K); and

T = soil temperature (K).

If C_o is the concentration in soil gas at the source, which is located a distance L from the soil surface, the concentration in the soil gas at a distance z below the soil surface can be estimated using diffusion theory (Mayer et al., 1974):

$$C(z) = \frac{4C_o}{\pi} \sum_{n=0}^{\infty} \frac{(-1)^n}{(2n+1)} \exp\left[\frac{-D_s(2n+1)^2\pi^2 t}{4L^2}\right] \cos\left[\frac{(2n+1)\pi(L-z)}{2L}\right] \tag{2}$$

where:

C_o = concentration in the soil vapor at depth L (mg/cm^3);

C(z) = concentration in the soil vapor at depth z (mg/cm^3);

D_s = apparent steady-state vapor diffusion coefficient in soil (square centimeters per second [cm^2/s]);

L = depth to ground water (cm);

n = summation index (n = integers from 0 to infinity);

t = diffusion time (s); and

z = depth below the soil surface (cm).

Two boundary conditions were used in obtaining this solution. First, there was a soil/ground-water layer at depth L which was treated uniformly with a constituent at initial concentration C_o. Second, it was assumed that the constituent was removed quickly, maintaining a zero concentration at the ground surface (z=0).

The apparent steady-state diffusion coefficient (D_s) in Equation 2 accounts for the effects of soil on vapor phase diffusion. The value of D_s is a function of soil geometry and air-filled pore space, both of which are affected by the soil water content. The value of D_s was calculated using a model developed by Millington and Quirk (1961) incorporating these factors, which has been verified in other studies on organic vapor phase diffusion through soil (Jury et al., 1984). Using the Millington and Quirk model and assuming that the air-filled porosity in the soil is equal to the total soil porosity, the apparent vapor phase diffusion was determined by:

$$D_s = D_o \times P_t^{4/3} \tag{3}$$

where:

D_o = vapor phase diffusion coefficient (cm^2/s);

D_s = apparent steady-state vapor diffusion coefficient in soil (cm^2/s); and

P_t = total soil porosity (unitless) (assumed value of 0.5 = upper range of porosity for loess [Freeze and Cherry, 1979]).

Equation 2 can be used to calculate the constituent concentration at any depth z between the surface (z=0) and the ground water (z=L). A small value of z (e.g., 0.1 cm) was used to give the concentration just below the soil surface, Cs. It was assumed that this was the source concentration for diffusion through the soil surface. Soil/air interface effects were ignored (a conservative assumption since there is generally an adsorption affinity effect), so that the flux through the surface was given by:

$$J = \left(\frac{D_o \times C_s}{d} \right) \times \left(10^4 \ \frac{cm^2}{m^2} \right) \tag{4}$$

where:

C_s = vapor concentration in the air at the soil surface (mg/cm^3);

d = diffusion distance (cm);

D_o = vapor diffusion coefficient (cm^2/s); and

J = flux of constituent through the soil surface (mg/m^2-s).

Assuming this was the flux of constituent diffusing through the cracks in the concrete foundation, the indoor air concentration was calculated as follows:

$$IAC = \frac{J \times A}{\left(\frac{ACH}{3{,}600 \ s/hr} \right) \times V} \tag{5}$$

where:

A = area of infiltration (m^2);

ACH = air exchanges per hour (hr^{-1});

IAC = indoor air concentration (mg/m^3);

J = flux of constituent through the foundation (mg/m^2-s); and

V = volume of air in the building (m^3).

CALCULATION OF EXPOSURE DOSE AND RISK

The calculated IAC was used to estimate exposure dose and risks (cancer and noncancer effects) for a worker inside the building. The following equation was used to calculate the worker's average daily exposure dose to vapors released from the ground water into the building:

$$ExD = \frac{IAC \times IR \times EF \times EP}{BW \times AP \times (365\ days/yr)} \qquad (6)$$

where:

AP = averaging period (equal to EP for non-cancer risk; expected lifespan for cancer risk) (yr);

BW = average adult body weight (kg);

EF = exposure frequency (days/yr);

EP = exposure period (yr);

ExD = average daily exposure dose (mg/kg-day);

IAC = indoor air concentration (mg/m^3); and

IR = inhalation rate (daily average) (m^3/day).

This derivation can be condensed into a single equation, as shown below:

$$ExD = \frac{C_{gw} \times \left(10^{-3}\ \frac{L}{cm^3}\right) \times \left(\frac{H}{RT}\right) \times \sum_o \times 4D_o \times \left(10^4\ \frac{cm^2}{m^2}\right) \times A \times IR \times EF \times EP}{\pi \times d \times \left(\frac{ACH}{3{,}600\ s/hr}\right) \times V \times BW \times AP \times (365\ days/yr)} \qquad (7)$$

where Σ_o represents the summation defined in Equation 2, neglecting terms with $n > 0$:

$$\sum_o = \exp\left[\frac{-D_s \pi^2 t}{4L^2}\right] \cos\left[\frac{\pi (L - z)}{2L}\right] \tag{8}$$

The risks for cancer and non-cancer effects were calculated using the following equations:

$$\begin{aligned} \textit{CANCER EFFECTS}: &\quad ELCR = ExD \times CSF \\ \textit{NON-CANCER EFFECTS}: &\quad HQ = \frac{ExD}{RfD} \end{aligned} \tag{9}$$

where:

ELCR = excess lifetime cancer risk (unitless);

CSF = cancer slope factor for inhalation exposure (kg-day/mg);

ExD = average daily exposure dose (mg/kg-day);

HQ = hazard quotient (unitless); and

RfD = reference dose for inhalation exposure (mg/kg-day).

HEALTH-BASED REMEDIAL GOALS (HBGs) FOR GROUND WATER

HBGs were calculated to meet acceptable risk criteria, based upon the exposure dose associated with the building worker exposure scenario. In order to calculate HBGs, an acceptable risk must be set. The USEPA generally regards excess lifetime cancer risks (ELCRs) within the 10^{-4} to 10^{-6} range, and non-cancer risks (HQs) less than or equal to 1 to be acceptable (USEPA, 1991). The "target" cancer risk was conservatively set at 10^{-6}, and the "target" HQ was set to 1. Using the derived equations for exposure dose and risk, and solving for the ground-water concentration (which becomes the remediation goal for the "target" risk levels), the following equations were obtained for the cancer and non-cancer HBGs for ground water:

For cancer risk:

$$HBG = \frac{TCR \times \pi \times d \times RT \times ACH \times V \times BW \times LT \times UC_1}{H \times \sum_o \times 4D_o \times A \times CSF \times IR \times EF \times EP \times UC_2 \times UC_3 \times UC_4} \tag{10}$$

For non-cancer risk:

$$HBG = \frac{THQ \times RfD \times \pi \times d \times RT \times ACH \times V \times BW \times UC_1}{H \times \sum_o \times 4D_o \times A \times IR \times EF \times UC_2 \times UC_3 \times UC_4} \tag{11}$$

where:

A = area of infiltration (m^2);

ACH = air exchange rate (hr^{-1});

BW = adult body weight (kg);

CSF = cancer slope factor for inhalation exposure (kg-day/mg);

d = diffusion distance (cm);

D_o = vapor diffusion coefficient (cm^2/s);

EF = exposure frequency (days/yr);

EP = exposure period (yr);

H = Henry's Law Constant (atm-m^3/mol);

HBG = health-based remedial goal (mg/L);

IR = inhalation rate (daily average) (m^3/day);

LT = expected lifetime (averaging period for cancer effects) (yr);

RfD = reference dose for inhalation exposure (mg/kg-day);

RT = universal gas constant x soil temperature (atm-m^3/mol);

Σ_o = first term of infinite series in Equation 2, as defined in Equation 8;

TCR = target cancer risk (unitless);

THQ = target hazard index for non-cancer risk (unitless); and

UC_1 = unit conversion = 365 days/year.

UC_2 = unit conversion = 0.001 L/cm^3.

UC_3 = unit conversion = 1,000 cm^2/m^2.

UC_4 = unit conversion = 3,600 seconds/hour.

V = volume of building (m^3).

For carcinogenic constituents, the more conservative HBG was selected as the minimum of the two HBGs calculated for cancer and non-cancer effects. For noncarcinogens, only the non-cancer HBG was calculated.

HEALTH-BASED REMEDIAL GOALS FOR SOIL

The soil HBGs were calculated from the ground-water HBGs using the assumption that the soil and aqueous phases are in equilibrium, so that the constituent concentrations in the two phases are related by:

$$C_{soil} = C_{gw} \times K_d$$

where:

C_{soil} = constituent concentration in the soil (mg/kg); and

K_d = soil-water partition coefficient (mL/g = L/kg).

For VOCs, the literature generally provides the organic-carbon partition coefficient (K_{oc}) rather than K_d. K_{oc} was used to approximate the K_d using the following relationship:

$$K_d = K_{oc} \times f_{oc}$$

where f_{oc} represents the fraction of organic carbon in the soil, which was assumed to be 0.01 (1 percent organic carbon).

EXPOSURE PARAMETERS

This subsection presents the two exposure scenarios used in calculating the HBGs and the selected parameter values. The two scenarios pertain to the type of building which was modeled in the calculation of indoor air concentration (Equation 5). In the office building scenario, the hypothetical building dimensions were 180 feet x 200 feet (assuming the building covered one-third of the site), and the air exchange rate was 1 hr^{-1} (assuming the room had windows or exterior doors on at least one but possibly two sides [Wadden and Scheft, 1983]). In the retail building scenario, the hypothetical building dimensions were 90 feet x 200 feet (assuming the building covered one-sixth of the site), and the air exchange rate was 2 hr^{-1} (assuming the shop was similar to an entrance hall [Wassen and Scheft, 1983]). All of the other variables in the HBG calculations were given the same values in both scenarios, as discussed below:

A	The area of infiltration (A) was assumed to be a half-centimeter crack around the circumference of the building foundation. Thus $A = 1.158\ m^2$ for the office building and $0.8839\ m^2$ for the retail building.
AER	The air exchange rate was assumed to be 1 hr^{-1} for the office building and 2 hr^{-1} for the retail building.
BW	Average adult body weight = 70 kg.
d	The diffusion distance was set equal to z, at 0.1 cm.
D_s	The apparent steady-state vapor diffusion coefficient in soil was calculated as $0.5^{4/3} \times D_o$;

EF	An exposure frequency of 250 days/year (5 days/week for 50 weeks/year) was assumed for the office worker.
EP	An exposure period of 25 years was used.
IR	The daily average inhalation rate was assumed to be 20 m^3/day.
L	The depth to ground water (used to calculate Σ_o) was set at 5 feet, or 152.4 cm.
LT	The average lifetime (the averaging period for cancer effects) was 70 years.
RT	A soil temperature of 298 K was assumed, giving a value of 0.02445 atm-m^3/mol for RT.
t	A diffusion time of 1 month (2.6×10^6 s) was used to calculate Σ_o.
V	A 10-foot ceiling height was assumed, so that volumes of 10,149 m^3 and 5,097 m^3 were obtained for the office and retail buildings, respectively.
z	The volatilization depth below the soil surface (used to calculate Σ_o) was set at 0.1 cm (same value as d).

The variables which had constituent-specific values (CSF, D_o, D_s, H, K_{oc}, and RfD) are shown in Tables 6-8 and 6-9. The diffusion time of 1 month (2.592×10^6 s) was assumed as a conservatively small estimate of the minimum time it might take to complete the hypothetical building and have finished office or retail space available for occupancy. This assumption is very conservative since actual construction time may take as long as 1 year. Also note that this model accounts for source attenuation by upward diffusion only. Other attenuation processes (e.g., dispersion and natural degradation) simultaneously should reduce the source concentration.

SAMPLE CALCULATION

This sample calculation of the ground-water HBG is for chloroform, using the office-building scenario. Constituent-specific parameters for chloroform are as follows:

K_{oc} = 44 mL/g = 44 L/kg

H = 0.0038 atm-m^3/mol

D_o = $0.08868\ cm^2/s$

D_s = $D_o \times 0.5^{4/3} = 0.0352\ cm^2/s$

CSF = 0.081 kg-day/mg

RfD = 2.9 mg/kg-day

The value of the summation term is needed first:

$$\sum\nolimits_o = \exp\left[\frac{-0.0352\frac{cm^2}{s} \times \pi^2 \times 2.592x10^6 s}{4 \times (152.4cm)^2}\right] \times \cos\left[\frac{\pi \times (152.4cm - 0.1cm)}{2 \times 152.4cm}\right]$$
$$= 6.362x10^{-8}$$

For cancer risk (units are omitted for clarity):

$$HBG = \frac{10^{-6} \times \pi \times 0.1 \times 0.02445 \times 1 \times 10{,}149 \times 70 \times 70 \times 365}{0.0038 \times 6.362x10^{-8} \times 4 \times 0.08868 \times 1.158 \times 0.081 \times 20 \times 250 \times 25 \times 3.6x10^4}$$
$$= 3{,}850\ \frac{mg}{L}$$

For non-cancer risk:

$$HBG = \frac{1 \times 2.9 \times \pi \times 0.1 \times 0.02445 \times 1 \times 10{,}149 \times 70 \times 365}{0.0038 \times 6.362x10^{-8} \times 4 \times 0.08868 \times 1.158 \times 20 \times 250 \times 3.6x10^4}$$
$$= 3.23x10^8\ \frac{mg}{L}$$

The more conservative HBG value is the lower of these two results, or 3,850 mg/L. The soil HBG calculated from the ground-water HBG for cancer risk is:

$$HBG_{soil} = 3{,}850\ \frac{mg}{L} \times 44\ \frac{L}{kg} \times 0.01 = 1.70x10^3\ \frac{mg}{kg}$$

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