RISK-BASED ANALYSIS FOR THE FORMER CHEVRON SERVICE STATION #9-3864, 5101 TELEGRAPH AVENUE OAKLAND, CALIFORNIA

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FOR THE FORMER CHEVRON
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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 Service Station #9-3864, 5105 Telegraph Avenue, Oakland, 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 from potential exposure to petroleum hydrocarbon-related constituents detected in soils and ground water at the former Chevron Service Station #9-3864, 5105 Telegraph Avenue, Oakland, California in the event the site is redeveloped for residential uses. Chevron began leasing the site in 1970 and currently holds the lease. A service station was established in 1970 and closed in 1991, when the building was demolished and the underground storage tanks removed. The site is now vacant.

The constituents of concern identified in soil and/or ground water were benzene, ethylbenzene, toluene, xylenes, total petroleum hydrocarbons (TPH) as diesel (in soil only), TPH as gasoline, and lead (in soil only). Health-based remediation goals (HBGs) were calculated and compared to currently-measured concentrations of constituents in soil and ground water to aid in the development of remedial strategies. The methodologies used in this risk assessment were designed to be consistent with risk assessment guidelines established by the Regional Water Quality Control Board's (RWQCB) San Francisco Bay Region (RWQCB, 1990) and the U.S. Environmental Protection Agency (USEPA) (1989a; 1991a,b).

The risk assessment process included derivation of HBGs designed to be protective of human health in the event of exposure to constituents detected in soil and ground water at the former Chevron Service Station #9-3864. Since the site is vacant, current exposure is not occurring on site. Therefore, only hypothetical future uses were considered. Evaluated in this assessment were exposure of hypothetical future on-site construction workers, and hypothetical future on-site adult and child residents.

Soil HBGs calculated for construction workers and residents were compared to currently-measured concentrations. The HBGs for all the constituents of concern in soil (benzene, ethylbenzene, lead, toluene, TPH as diesel, TPH as gasoline, and xylenes) were greater than the maximum detected soil concentrations, indicating remediation is not necessary for protection of human health.

Ground water in the vicinity of the site is not used as a water supply source because the East Bay Municipal Utility District provides water to the area. HBGs for hypothetical future residential exposure were developed assuming volatile constituents in ground water (benzene, ethylbenzene, toluene, xylenes, and TPH as gasoline) would migrate into a home on the site. The calculated HBGs were greater than the measured on-site ground-water concentrations. As a result, exposure to ground water does not appear to pose a threat to human health.

A one-dimensional ground-water model was used to predict concentrations of constituents discharging into San Francisco Bay, the nearest downgradient discharge point. The modeling results indicated that the site-related constituents of concern would not reach the bay. As a result, exposure of aquatic life in the bay was not evaluated.

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1.0 INTRODUCTION

Geraghty & Miller, Inc., has been contracted to evaluate the potential threat to human health for constituents detected in soils and ground water at the former Chevron Service Station #9-3864 at 5101 Telegraph Avenue in Oakland, California in the event that the site is redeveloped for residential use. Excavation activities involving the removal of underground gasoline and waste oil storage tanks and hydrocarbon-impacted soil have occurred at the site. Soil samples collected as a part of the excavation and ground-water samples collected from four on-site monitoring wells have indicated the presence of constituents typically associated with hydrocarbon contamination (benzene, toluene, ethylbenzene, xylenes [BTEX], lead, and "total petroleum hydrocarbons" [TPH]).

The risk evaluation was performed by developing health-based remediation goals (HBGs) for soil and ground water. HBGs are constituent-specific concentrations which will not present a risk to human health, based upon site-specific exposure scenarios and acceptable levels of risk (i.e., a target cancer risk of 1 in 1,000,000 or 10^{-6} and a target non-cancer hazard quotient of 1). The calculated HBGs 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 HBGs based on the most conservative (from a risk perspective) potential future land use at the site. The former Chevron service station site may be developed for other purposes (e.g., commercial or retail), but goals set based upon a conservative residential scenario also will be protective of these other uses.

Assuming future residential development of the site, HBGs for soil were calculated based upon future exposure for construction workers and upon hypothetical future residential exposure. HBGs for ground water were calculated based upon exposure of future hypothetical residents of the property inhaling volatile organic compounds (VOCs) migrating from ground water into their homes. Ground water in the vicinity of the site is not used as a water-supply source, as the area is provided with water by the East Bay Municipal Utility District. Ground water discharges into San Francisco Bay, approximately 1.9 miles downgradient of the site. Ground water transport modeling was used to examine the potential for constituents detected beneath the site to be released into the bay. Conservative exposure assumptions were used in all of these calculations.

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 Service Station #9-3864, 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 HBGs.
- Section 6, Derivation of Health-Based Remediation Goals: presents the derivation of HBGs. 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 HBG derivations.

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

- Appendix A, Calculation of Health-Based Remediation Goals for Ground Water: provides the ground water vapor intrusion model used to calculate ground-water HBGs.

2.0 SITE CHARACTERIZATION

This section describes the former Chevron Service Station #9-3864 and surrounding area, the geology, hydrogeology, and meteorology of the site.

2.1 SITE DESCRIPTION AND HISTORY

The former Chevron Service Station #9-3864 is at 5101 Telegraph Avenue in the City of Oakland, Alameda County, California. The site encompasses approximately one-half acre. The site is triangular in shape, bordered by 52nd Street (north of the site), Telegraph Avenue (east), and 51st Street (southwest). The site map presented in Figure 2-1 indicates the former locations of the Service Station #9-3864 building and service islands; the site currently is vacant. Chevron began leasing this site in 1970 and currently maintains the lease. The former Service Station #9-3864, established in 1970, was demolished and all underground storage tanks removed in 1991.

2.1.1 Tank Removal and Soil Excavation

In 1970, four underground storage tanks were installed at the site: two 10,000-gallon product tanks, one 5,000-gallon product tank, and one 1,000-gallon waste oil tank. Each tank was constructed of coated steel, with cathodic leak protection. The last tank integrity test on November 15, 1990 indicated the tanks were tight, with no leaks. When the tanks were removed on September 18, 1991, a detailed inspection of the tanks was conducted and likely failure points were probed. No holes were observed in any of the tanks. When the tanks were removed, the soils at the fill pipe end of the gasoline tanks was noticeably discolored, which could be attributed to chronic overfilling.

The former tank locations and the areas of the soil excavation are indicated in Figure 2-2. The tank removal and initial excavation occurred on September 18, 1991. On that day, approximately 45 cubic yards of soil were excavated from the waste oil tank pit, and approximately 300 cubic yards of soil were excavated from the gasoline tank pit. This soil was temporarily stockpiled on site, adjacent to the excavation pits. Following this excavation event, confirmatory soil samples were collected according to Regional Water Quality Control Board (RWQCB) standards (Blaine Tech Services, 1991). Interface samples were taken from the native soil at both ends of each storage tank location, from the sidewalls of the gasoline tank pit, and from the soil underlying the product line that conducted fuel from the underground storage tanks to the dispenser pumps. A total of 15 samples were collected from the native soils remaining in the excavated areas. A four-part composite soil sample was collected from the waste oil tank excavation stockpile, and 6 four-part composite soil samples were collected from the gasoline storage tank excavation stockpile.

Analytical results from the first excavation event identified five areas of the gasoline tank pit and one area in the product line trench containing detectable hydrocarbon concentrations (0.046 to 1.3 mg/kg). Therefore, additional excavation was performed on September 26, 1991 (Blaine Tech Services, 1991). The gasoline tank pit depth was increased from 13.0-13.5 feet to 17.5-18.0 feet (2.0-2.5 feet below ground water). Additional excavation in the product line trench increased the depth to 5 feet below grade. Six new soil samples were collected in the newly excavated areas in the gasoline tank pit and the product line trench. Approximately 600 cubic yards of soil was generated from the second excavation, of which, approximately 300 cubic yards was disposed at the BFI Landfill in Livermore, California. Two new stockpiles, each containing approximately 150 cubic yards of soil, were generated with soil excavated on this date. Three four-part composite soil samples were collected from each of the two new stockpiles. The stockpiles generated during the first excavation event were aerated (agitated and tilled) following the second excavation event.

On October 10, 1991, the stockpiled soil from the gasoline tank pit was re-sampled. Three four-part composite soil samples were collected from the two newer stockpiles. Fifteen discrete samples were collected from the stockpiled soil from the initial tank removal work (the soil which had been aerated on September 26, 1991). The analytical results for the discrete samples were "non-detect" (ND) for all the BTEX compounds and for TPH. The stockpiled soil from the waste oil tank pit was not re-sampled. Following the aeration and sampling, the stockpiled soil was used as backfill along with clean imported soil.

2.1.2 Ground-Water Monitoring Wells

On November 14 and 15, 1990, four soil borings (C-1 through C-4) were drilled and completed as ground-water monitoring wells. The locations of these wells are shown in Figure 2-1. Field work and laboratory analyses were performed in compliance with RWQCB guidance for investigations related to underground storage tanks. Details of the installation and sampling are presented in the Well Installation Report (GeoStrategies, 1991).

Soil borings C-1 through C-4 were drilled with 8-inch-diameter hollow-stem augers to total depths of 30.5 to 35.5 feet below existing grade. Soil samples were collected from the 10.5 and 15.5 foot depths in Borings C-2 through C-4 and from the 15.5 foot depth from Boring C-1. A total of 7 soil boring samples were collected on November 14 and 15, 1990.

The first round of ground-water samples from monitor wells C-1 through C-4 was collected on December 6, 1990. Subsequent sampling has occurred at approximate 6-month intervals, with the most recent analytical results obtained from sampling performed on September 16, 1992 (Sierra Analytical, 1992). The site is currently on a quarterly monitoring schedule.

2.1.3 Off-Site Ground Water Sampling

On November 30 and December 1, 1992, Pacific Environmental Group installed five temporary ground-water wells using a drive core sampling system. Two of the wells were installed upgradient of the site, locations TC-4 and TC-5 in Figure 2-2, one was installed cross gradient (TC-3), and two were located downgradient, TC-1 and TC-2. The temporary wells were sampled and then filled in and abandoned.

2.2 ENVIRONMENTAL CHARACTERISTICS

2.2.1 Regional Geology

The former Chevron Service Station #9-3864 site is on the westward sloping alluvial plain in Oakland, California. According to Radbruch (1957, 1969), the area is underlain by the Quaternary Temescal Formation, which is composed of sand with lenses and silty clayey sand and clay. The Temescal Formation is underlain by the Alameda Formation containing several hundred feet of marine gravel, sand, silt, and clay. Upland areas to the east are composed of Mesozoic and Cenozoic metamorphic and sedimentary rocks and some igneous rocks, all of which have been highly deformed by folding and faulting (GeoStrategies, 1990).

2.2.2 Regional Hydrology

Ground-water levels at the site range from 15 feet to 18 feet. The direction of the ground-water flow is west-northwest, toward San Francisco Bay. There are no known wells downgradient from the site (Tim Collins, East Bay Municipal Utility District). The nearest downgradient surface-water body is San Francisco Bay, approximately 1.9 miles from the site.

2.2.3 Meteorology

The climate of Oakland 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 westerly direction (NOAA, 1974).

3.0 CONSTITUENT CHARACTERIZATION

This section describes the occurrence of constituents in the soil and ground water at the former Chevron Service Station #9-3864. To focus the assessment on the constituents associated with the current conditions at the site, only the most recent ground-water monitoring data (collected September, 16, 1992) and relevant soil samples are presented. Since soil excavation has occurred at the site, only analytical data collected following soil removal represent current site conditions. Soil samples are not considered representative of current conditions if the associated soil was removed in the subsequent excavation activities. For the stockpile samples, only the most recent data collected from each stockpile were used.

Selected data were analyzed in accordance with USEPA guidance for risk assessments (USEPA, 1989a). These analysis guidelines are outlined as follows:

- Constituents that were never detected in a data set are not included in the list of potential constituents of concern.
- Analytical results reported as detects are used at the reported value.
- For non-detects, one-half the associated sample quantitation limit (SQL) (the minimum detectable concentration for the analysis) is used as a proxy concentration (rather than using zero or eliminating the data point). Exceptions to this rule occur whenever this proxy value (one-half the SQL) exceeds the maximum detect for that constituent in that data set. When this occurs, the maximum detected concentration is substituted as the proxy concentration for that non-detect.
- When duplicate samples are analyzed, the higher detected concentration of the two results is used for the reported value. If one is a non-detect, the detected

concentration is used. If both results are non-detects, one-half the lower SQL is used as the proxy concentration.

The results of the statistical analyses for each data group are presented in Tables 3-1 (soil) and 3-2 (ground water). The information in these tables includes, for each detected constituent, the frequency of detect (ratio of the number of detects to the total number of samples analyzed for that constituent), the SQL(s), the range of detected concentrations, the average (mean) concentration, and the 95 percent upper confidence limit (UCL) on the mean. Both the mean and the UCL are calculated using proxy concentrations for the non-detects.

The one-sided UCL is a statistic calculated using the following formula:

$$UCL_{95} = \bar{x} + \frac{s \times t_{0.05,n-1}}{\sqrt{n}}$$

where:

n	sample size (number of data points);
s	sample standard deviation;
$t_{0.05,\,n-1}$	0.05 critical value for the t_{n-1} distribution;
UCL_{95}	upper 95 percent confidence level for the mean; and
$\bar{x}$	sample mean (average).

We can be 95 percent confident that the true mean concentration for the site lies below the UCL concentration if the samples were randomly selected from the site, there are no outliers, and the data fit a normal distribution. A high level of confidence (95 percent) is used to compensate for the uncertainty involved in representing the site conditions with a finite number of samples. The USEPA recommends the UCL as the reasonable maximum exposure concentration for use in risk assessments (USEPA, 1989a). An exception to this recommendation arises when the calculated UCL exceeds the maximum detected value, which indicates large uncertainty in the calculated

UCL (due to small sample size or large standard deviation). When this occurs, the maximum detect is a more reliable reasonable maximum exposure point concentration (USEPA, 1989a). For each constituent in each medium at this site, the calculated UCL was less than the maximum detected concentration.

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 included in the determination of HBGs.

3.1 SOIL

As discussed above, soil excavation 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 Service Station #9-3864.

A total of 40 soil samples were included in this data set. All seven soil boring samples taken during the monitoring well installation on November 14 and 15, 1991 were used. Four confirmatory soil samples taken from the dispenser pump island and product line area on September 18 and 26, 1991 were included (2-PL, 10-DP, 11-DP, and 12-PL). One sample taken in this area on September 18 (13-PL) was eliminated because of additional excavation in the immediate area of that sample; it was superseded by Sample 2-PL. The soil data set also includes 2 confirmatory soil samples taken from the waste oil tank pit and 1 composite soil sample taken from the waste oil pit stockpile, all of which were collected on September 18, 1991. Five post-excavation confirmatory soil samples from the gasoline tank pit (collected following the second excavation event on September 26, 1991) were included in the data set. Twenty-one samples were included from the gasoline tank pit stockpile re-sampling on October 10, 1991. Twenty-two other soil samples were excluded from the data set because the associated soil areas were subsequently excavated or, for some of the earlier stockpile samples, because they sere superseded by later samples.

The results of statistical analysis of the soil samples are presented in Table 3-1. BTEX and TPH as gasoline were analyzed for in all 40 samples; soluble lead was analyzed for in seven of the samples; and TPH as diesel, barium, cadmium, chromium, lead, and silver were analyzed for in one sample. Soluble lead was analyzed as the concentration (mg/L) lead in liquid extract, according to California Administrative Code Title 22, Paragraph 66700. Of the BTEX and TPH as gasoline, all were detected in less than half of the samples. Three other constituents (TPH as diesel, barium, and soluble lead) were detected in each of the relevant samples. Cadmium, chromium, lead, and silver were not detected. Reviewing the results, the following were selected as constituents of concern for soil: benzene, ethylbenzene, toluene, xylenes, TPH as diesel, TPH as gasoline, and soluble lead. Barium is not included as a constituent of concern because of its low toxicity and because there is no reason to suspect it as a site-related contaminant (barium is not a hydrocarbon-related constituent).

3.2 GROUND WATER

3.2.1 On-Site Ground Water

The four on-site ground-water monitoring wells (C-1 through C-4) were installed at the site on November 14 and 15, 1990 (GeoStrategies, 1991). The monitoring wells at the former Chevron Service Station #9-3864 have been sampled at approximate 6-month intervals since the installation of the wells. Ground-water monitoring at the site is now conducted on a quarterly schedule. The well locations are shown on Figure 2-1.

The statistical summary for the most recent set of data (collected in September 1992) is presented in Table 3-2. The samples collected from C-1, C-2, and C-3 contained detectable concentrations of BTEX and TPH as gasoline; the C-4 sample contained detectable levels of benzene, ethylbenzene, and xylenes, but toluene and TPH as gasoline were not detected. The maximum detected concentrations for each constituent occurred in the C-3 sample (benzene, 0.13 milligrams per liter [mg/L]; ethylbenzene, 0.012 mg/L; toluene, 0.026 mg/L; xylenes, 0.030 mg/L; and TPH as gasoline, 7.1 mg/L) (Sierra Analytical, 1992). The historical maximum concentrations are shown below:

Constituent	Maximum Detect (mg/L)	Collection Date	Sample Location
Benzene	0.34	06-Jun-91	C-2
Ethylbenzene	0.019	06-Jun-91	C-2
Toluene	0.17	02-Jun-92	C-1
Xylenes	0.083	02-Jun-92	C-1
TPH as gasoline	7.1	16-Sep-92	C-3

Constituents of concern for ground water are all those detected during the September 1992 ground-water sampling round: benzene, ethylbenzene, toluene, xylenes, and TPH as gasoline.

3.2.2 Off-Site Ground-Water

Five temporary ground-water wells were installed up-, down-, and crossgradient of the former Chevron Service Station #9-3864 on November 30 and December 1, 1992. The wells were sampled and the results are summarized and compared to on-site concentrations in Table 3-3. BTEX and TPH as gasoline were not detected in the down- or crossgradient temporary wells. Ethylbenzene, xylenes, and TPH as gasoline were detected in well TC-4, located adjacent to a former service station. Xylenes and TPH as gasoline were detected in well TC-5 located across Telegraph Avenue from the former Chevron Service Station #9-3864. The concentrations detected at TC-4 were greater than any of the other on- or off-site monitoring or temporary ground-water wells.

The presence of BTEX and TPH in upgradient wells indicates that the former Chevron Service Station #9-3864 is not the sole source of hydrocarbon contamination in the area. The high concentrations (relative to on-site concentrations) detected in TC-4 indicate the existence of an off-site source. It is unclear whether that off-site source is impacting ground water beneath the former Chevron Service Station #9-3864 site, considering the apparent ground-water flow direction.

Neither BTEX compounds nor TPH were detected in the downgradient wells. This observation may be due to natural degradation of the constituents within the transport distance. It is also possible that the constituent plume encountered beneath the site has not yet reached those off-site sampling points.

4.0 TOXICITY ASSESSMENT

The risks associated with exposure to constituents detected at the former Chevron Service Station #9-3864 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 cancer and non-cancer 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-cancer 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 Service Station #9-3864.

4.1 CANCER 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-CANCER EFFECTS

For many non-cancer 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-cancer 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-cancer 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 HBGs, 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-cancer effects associated with long-term exposure periods (i.e., greater than 7 years), while the subchronic 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-cancer effects because, for most constituents, the subchronic RfD is the same as the chronic RfD. For some constituents, the subchronic 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). In the absence of IRIS and HEAST data, RfCs were obtained from the California Air Pollution Control Officers Association's (CAPCOA) Air Toxics "Hot Spots" Program Risk Assessment Guidelines (CAPCOA, 1992). 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. Dermal and oral absorption efficiencies 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 Service Station #9-3864. 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 Service Station #9-3864 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 Service Station #9-3864, 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 Service Station #9-3864 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 milliliters per gram (mL/g) or cubic centimeters per gram (cm^3/g), 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 Service Station #9-3864, 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 weathered gasoline in soil represents a conservative 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, comprising 0.13 percent by weight of fresh diesel (California LUFT Manual, 1989). Naphthalene is one of the more mobile constituents in diesel fuel. Therefore, using naphthalene as a surrogate for TPH as diesel will predict as great or greater mobility of TPH as diesel than is likely to occur at the site.

5.3 MECHANISMS OF MIGRATION

There are several mechanisms through which constituents may migrate from the former Chevron Service Station #9-3864 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 Service Station #9-3864 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 in soil or ground water 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, such as adsorption to soil, 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 Service Station #9-3864 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. The exceptions are the longer-chain and heavier TPH constituents which are not highly volatile or soluble and tend to remain adsorbed to soil.

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 Service Station #9-3864 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 1.9 miles 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 Service Station #9-3864 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 Service Station #9-3864. 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).

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 polycyclic aromatic hydrocarbons (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 Service Station #9-3864 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.

It does not appear that there is a single source of contamination at this site. Off-site ground-water sampling has indicated similar (but not identical) contamination upgradient of the site. Therefore, it is reasonable to assume that some of the on-site ground-water contamination may be originating off site. During the tank removal activities, the soils at the fill pipe end of the gasoline tanks was noticeably discolored, which could be attributed to chronic over-fill problems. During the excavation, fuel-saturated soil was removed to a depth of 1.5 to 2 feet below ground water (Blaine Tech Services, 1991). The majority of the contaminated soils at the site have been removed. However, residual soil contamination exists in the capillary fringe, and exposure to these constituents can occur through either direct contact with the soil or inhalation of dusts or vapors from the soil. Exposure to constituents in ground water will occur only via inhalation of volatilized components since ground water in the area is not used as a drinking-water source and there are no non-potable uses of the water anticipated at the site.

Although the site currently is not being used, there is interest in developing the site. Therefore, 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 these 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 on the property. To be conservative, it is assumed here that the property will be developed for residential use. These hypothetical future residents potentially would be exposed to soil contaminants via ingestion, dermal contact, and inhalation of dust and vapors, and to ground-water contaminants via inhalation of volatilized constituents which infiltrate the homes.

There are no water-supply wells in the vicinity of the site and drinking water is provided by East Bay Municipal Utility District. 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 west-northwesterly direction and was found at depths of approximately 15 to 17 feet below land surface (bls). Volatile constituents in ground water could volatilize from ground water into soil gas and then migrate to the ambient indoor and outdoor air. Since contaminants in the home can concentrate in the indoor air, and since many people spend most of their time inside their homes, this exposure pathway is considered to be a potentially significant source of exposure to ground-water constituents.

Exposure of environmental receptors to site-related constituents is not likely to occur because the former Chevron Service Station #9-3864 does not support a complex ecosystem. The area surrounding the site is developed. 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 or ground water at the site.

If ground water originating at the former Chevron Service Station #9-3864 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 the ground-water constituents of concern for the site could be released into the bay, ground-water transport modeling was used to determine the maximum distance that on-site contamination might be transported.

5.5 MODELING OF FATE AND TRANSPORT OF BTEX AND TPH IN GROUND WATER

The goal of this modeling effort was to evaluate the maximum future extent of BTEX and TPH in ground water at the former Chevron Service Station #9-3864 site. Benzene was selected to represent BTEX and TPH because it is very mobile and has a low biodegradation rate relative to the other constituents. The analytical solution to the one-dimensional advection-dispersion equation with decay and a constant concentration boundary condition (Bear, 1972) was used to assess the fate and transport of benzene. This analytical solution simulates the processes of advection, dispersion, retardation, and degradation of dissolved constituents in ground water.

Conservative values were used for each of the model input parameters. The source was assumed to be continuous with a dissolved benzene concentration fixed at the highest observed benzene concentration of 340 micrograms per liter (μg/L) in observation well C-2 on June 6, 1991. Reasonable maximum values of ground-water flow velocity and dispersivity were used in order to determine the greatest possible downgradient migration distance from the source area.

5.5.1 Conceptual Model

The subsurface geology at the site consists of clay, silt, and clayey silty gravel, and sand to the total depth explored of 35.5 feet (GeoStrategies, 1991). From depths of approximately 1 to 9 feet bls the lithology consisted of silt and clayey silt, and from 9 to 30 feet bls primarily interbedded clayey, silty gravel, and sand deposits (GeoStrategies, 1991). The material in the 9 to 30 feet interval is believed to comprise the uppermost aquifer beneath the site (GeoStrategies, 1991). There appears to be a basal aquitard beneath the site, as evidenced by the presence of a sandy clay layer (in each of the borings C-1, C-2, and C-4) at a depth of approximately 29 to 30 feet. The water table is approximately 15 to 16.5 feet beneath the site. The saturated thickness of the shallow water-bearing zone is approximately 15 feet based on the distance from the water table to the basal aquitard.

Water-table maps indicate that ground-water flow beneath the site is to the west-northwest with an average horizontal hydraulic gradient of 0.038 ft/ft between monitoring wells C-1 and C-4 (GeoStrategies, 1991). No pump tests or slug tests have been conducted at the site from which to determine the hydraulic conductivity. Thus, the hydraulic conductivity was estimated to be 50 feet/day, which is mid-range value for silty sand, clean sand, and gravel (Freeze and Cherry, 1979). Using the estimated value of 50 feet/day for the hydraulic conductivity and an effective porosity of 0.25 (de Marsily, 1986), the maximum average linear ground-water velocity is calculated to be 7.6 feet/day. Table 5-2 provides a summary of the ground-water transport model parameter values and the calculation results.

Ground-water samples were collected semi-annually from December 1989 to June 1992, with an additional sampling event in September 1992. These samples were analyzed for BTEX and TPH compounds. The most recent analytical results for benzene (September 1992) show that concentrations are greatest near C-3 (130 μg/L) and decrease to 1.4 μg/L in C-4, downgradient of C-3. The analytical results from ground-water samples collected from off-site temporary wells TC-2 and TC-3, which are downgradient of permanent monitoring well C-4 and C-3, respectively, indicate no benzene (or any other constituent) were detected. Temporary monitoring well TC-2 is approximately 100 feet downgradient of C-4 and approximately 145 feet downgradient of C-3.

5.5.2 Model Description and Assumptions

The solute transport model for this site uses the analytical solution to the one-dimensional advection dispersion equation with a constant concentration boundary condition (Bear, 1972). The main assumptions for this solute transport model are: (1) a uniform ground-water velocity; (2) homogeneous and isotropic aquifer properties; (3) advection, dispersion, sorption, and first-order degradation (decay rate proportional to concentration of constituent) are the main physical and chemical processes affecting constituent transport; and (4) the source release is continuous as a point source in which the benzene concentration reaches its highest observed concentration at the instant of release.

Because the saturated thickness is small compared to the area of interest (from the source to maximum downgradient migration distance), ground-water flow and the migration of BTEX and TPH as gasoline and diesel are primarily horizontal. It should be noted that a one-dimensional model provides more conservative results (higher concentrations and greater transport distances) than a multi-dimensional model. The one-dimensional model is more conservative because it assumes that all constituents are transported in the direction of ground-water flow with no decrease in concentrations due to vertical and lateral dispersion. Therefore, the one-dimensional model was considered to be applicable and was used to assess the fate and transport of BTEX and TPH as gasoline and diesel in ground water at the site.

Benzene was chosen as the simulated constituent because it is more mobile and has a slower biodegradation rate than the other BTEX compounds. Furthermore, benzene is the only carcinogen detected at the site and has the highest detected concentrations compared to the other constituents. Therefore, the results of this fate and transport model for benzene will be conservative while also ensuring that the results are applicable to the other BTEX compounds and TPH as gasoline.

5.5.3 Model Parameters

The parameters used for this ground-water solute transport model are summarized in Table 5-2. Site-specific model parameter values were used whenever possible, and conservative values from the literature were used when site-specific data were not available. For example, the source is assumed to be continuous with its concentration fixed at the highest ever observed benzene concentration (340 µg/L, in monitoring well C-3 on June 6, 1991) at the site. In addition, the longitudinal dispersivity was estimated to be 115 feet, which is at the high end range for field-scale dispersivity values (Anderson 1984).

Adsorption of constituents onto the aquifer materials causes the constituent plume center of mass to migrate at a fraction of the rate that ground water moves. Based on lithology, values of 30 percent total porosity (de Marsily, 1986) and 1.75 grams per cubic centimeter (g/cm^3) for the aquifer soil bulk mass density (Freeze and Cherry, 1979) were used to calculate the retardation factor (Baetsle, 1967) for benzene. Using the K_{oc} reported value for benzene of 83 milliliters per gram (mL/g) (USEPA, 1986a), and an estimated total organic carbon content in the aquifer materials of 0.25, the retardation factor for benzene is calculated to be 2.21 (see Table 5-2).

Dispersion is an important physical process which influences the transport of dissolved constituents at this site. For this site, the longitudinal dispersivity was conservatively assumed to be 115 feet. This dispersivity value is a very high estimate when compared to actual field determined values for sand and gravel deposits (Anderson, 1984). Higher dispersivity values cause benzene to disperse even further downgradient and therefore tend to overestimate the calculated migration distance.

The other chemical processes which affect the transport of dissolved constituents are degradation processes. Degradation is a general term which includes the effects of biodegradation, photolysis, oxidation-reduction, and hydrolysis. For the former Chevron Service Station #9-3864 site, the degradation half-life of benzene in ground water was assumed to be 6 months (Howard et al., 1991). This value was based on unacclimated aqueous anaerobic biodegradation screening test data (Horowitz et al., 1982). Although degradation processes can cause significant reductions in benzene concentrations, other physical process such as volatilization and recharge dilution can also cause decreases in dissolved benzene concentrations. In this modeling analysis, these effects are neglected to provide conservative results.

5.5.4 Model Results

In this model, it is assumed that dissolved benzene is continuously released from the source and migrates downgradient until it is removed from solution by degradation processes. The maximum downgradient distance that the plume migrates occurs when steady state conditions are achieved. At steady state, the rate that benzene is released at the source equals the rate that it is removed from solution by degradation processes. Model calculations show that steady state conditions are reached after approximately 9 years (3,305 days or 9.05 years).

Figure 5-1 shows the benzene concentration vs. distance traveled along the ground-water flow direction from the source for 1 to 9 years using the model parameter values listed in Table 5-2. As expected, the concentrations are greatest near the source and decrease downgradient from the source. It also is apparent that at later times the benzene plume moves downgradient with its front edge becoming more dispersed. Furthermore, degradation causes the benzene plume to reach a steady-state configuration (linear on log-scale) in approximately 9 years. Benzene was predicted to be present above its detection limit (0.4 μg/L) at a maximum downgradient distance of 6,640 feet. The distance along the ground-water flow direction from the gasoline tank pit and pump island to San Francisco Bay (10,030 feet) is greater than the maximum transport distance indicated by the model (6,640 feet). Therefore, the model predicts that the benzene (and by extension, ethylbenzene, toluene, xylene, and TPH) plume hypothetically originating from the site will not reach San Francisco Bay.

5.5.5 Model Summary

In summary, the results of this BTEX and TPH transport modeling effort indicate that the maximum distance that benzene concentrations will be above the laboratory detection limit of 0.4 μg/L is 6,640 feet (using conservative input parameters in the model). Because benzene is the most mobile and has the slowest degradation rate of the BTEX and TPH compounds, these results also were conservative estimates of maximum migration distance for the other BTEX constituents and TPH. These results indicate that BTEX and TPH plumes will not reach San Francisco Bay, which is approximately 10,030 feet downgradient of the former Chevron Service Station #9-3864.

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 Service Station #9-3864 site currently is not used. HBGs for soil were calculated based on exposure of a construction worker or a hypothetical future resident (adult and child) to constituents in soil contaminants via ingestion, dermal absorption, and inhalation of dust and vapors from the soil. HBGs for ground water were calculated based on hypothetical future exposure of residents (adult and child) to ground-water contaminants, assuming inhalation of vapors migrating from ground water into homes built on the site. HBGs were calculated to derive constituent concentrations considered to be protective of human health if exposure were to occur. Using these potential use scenarios, HBGs were calculated for construction workers engaged and for hypothetical residents living in the homes once the site is redeveloped. The site-specific HBGs were calculated to evaluate whether or not additional remediation of soils or ground water was required at the former Chevron Service Station #9-3864 site.

The HBGs were calculated following guidance provided by USEPA (1991a) and 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 "target" risk levels were set at an target excess lifetime cancer risk (TCR) of 10^{-6} for each potential carcinogen in each medium and, for all constituents in each medium, a target hazard quotient (THQ) of 1. The more conservative HBG for potential carcinogens is the lesser of the HBGs for cancer and non-cancer effects. For non-carcinogens, only the non-cancer HBG 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 TCR was set at 10^{-6} for each potential carcinogen.

6.1 SOIL REMEDIATION GOALS

6.1.1 Construction Worker Scenario

HBGs 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 some of 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. The assumed exposure period for this construction project was 12 weeks, although foundations for homes typically require less than 12 weeks to complete. Assuming a 12-week exposure period is conservative and makes the HBGs protective of a larger, more involved construction project. Therefore, in calculating soil HBGs for a hypothetical construction worker, an exposure time of 72 days (12 weeks × 6 days/week) and averaging period of 84 days (12 weeks × 7 days/week) were used. The following is a list of the exposure assumptions used for the construction worker scenario:

- inhalation rate of 20 cubic meters per day (m^3/day) (USEPA, 1991a);
- soil ingestion rate of 480 milligrams per day (mg/day) (USEPA, 1991a);
- exposed skin surface area of 2,940 square centimeters (cm^2), assuming face, forearms, and hands would be exposed (Federal Register [FR], 1988);

- soil adherence factor of 1 milligram per square centimeter per day (mg/cm^2/day) (USEPA, 1992b);

- body weight of 70 kg (USEPA, 1991a);

- exposure time of 72 days (12 weeks × 6 days/week); and

- averaging period of 84 days (12 weeks × 7 days/week) for non-cancer effects, and 25,550 days (70 years) for cancer effects.

The equations and assumptions used to calculate HBGs 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 HBG calculation results. 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 6-5. The HBGs for a construction worker exposure scenario are summarized in Table 6-6 for the potential carcinogens and in Table 6-6 for the non-carcinogens.

6.1.2 Adult and Child Resident Scenarios

Soil HBGs were also derived for hypothetical future adult and child residents at the site. Residents would be exposed to soil via ingestion, dermal contact, and inhalation of particulates and vapors generated from VOCs in the soil. Exposure assumptions for the hypothetical residents were as follows:

- inhalation rate of 20 m^3/day (USEPA, 1991a);

- soil ingestion rate of 100 mg/day for an adult, and 200 mg/day for a child (USEPA, 1991a);

- exposed skin surface area of 3,160 cm^2 (face, head, forearms, and neck) for an adult, and 3.652 cm^2 (head, arms, face, lower legs, and feet) for a child (USEPA, 1989c);

- soil adherence factor of 1 mg/cm^2/day (USEPA, 1992b);

- body weight of 70 kg for an adult (USEPA, 1991a), and 15 kg for a child (USEPA, 1989c);

- exposure frequency of 350 days/year (USEPA, 1991a); and

- exposure duration of 30 years for an adult, and 6 years for a child.

The equations and assumptions used to calculate soil HBGs and an example calculation are provided in Table 6-7. Soil HBGs for an adult resident are shown in Table 6-8. Soil HBGs for a child resident are shown in Table 6-9.

6.1.3 Soil Remediation Goal for Lead

6.1.3.1 Construction Worker

Currently, there are no USEPA accepted toxicity values (CSFs and RfDs) for lead. However, because of the correlation between lead exposures and increases in blood lead levels and the health effects associated with these levels, soil HBGs can be developed for adults using methodology derived similar to that described in the USEPA Uptake Biokinetic (UBK) model (Sager et al., 1992). A theoretically safe level of intake (TSLI) for adults was calculated based on how much lead an adult would have to absorb daily to reach but not exceed an "acceptable" blood lead level. Background exposures to lead from non-soil related sources were subtracted from the TSLI to obtain the "acceptable" contribution of the site. This revised TSLI (TSLIr) was used to calculate a soil HBG for lead based on the amount of soil an adult may ingest or inhale without their resultant blood lead levels exceeding acceptable blood levels of 10 micrograms per deciliter (μg/dL) (FR, 1991).

To convert an acceptable blood lead concentration to a TSLI, the effective absorption of lead must be approximated. For adults, the blood lead level increase for every microgram of lead ingested per day was found to be 0.05 μg/dL per μg/day (USEPA, 1986b). The TSLI was calculated by dividing the acceptable blood lead level (10 μg/dL) by this blood lead slope factor (0.05 μg/dL per μg/day).

$$\mathrm{TSLI} = \frac{\mathrm{ABLL}}{\mathrm{BLSF}} = \frac{10\ \mu\mathrm{g/dL}}{0.05\ \frac{\mu\mathrm{g/dL}}{\mu\mathrm{g/day}}} = 200\ \mu\mathrm{g/day}$$

where:

TSLI	theoretically safe level of intake of lead (200 μg/day);
ABLL	acceptable blood lead level of lead (10 μg/dL); and
BLSF	blood lead slope factor of lead (0.05 μg/dL per μg/day).

A revised theoretically safe level of intake (TSLIr) was calculated by subtracting the daily background intakes of lead in water, food, and ambient air from the TSLI. An average water intake of 4.5 μg/day was calculated by multiplying the 15 μg/L action level for lead in drinking water (FR, 1991) by an ingestion rate of 2 L/day (USEPA, 1991a) and by an absorption factor of 15 percent (USEPA, 1986b). An average dietary intake of 31 μg/day was obtained from the U.S. Food and Drug Administration (FDA) (1990). An average inhalation intake of 2.5 μg/day was calculated by multiplying a background air concentration of 0.25 micrograms per cubic meter (μg/m^3) by a daily inhalation rate of 20 cubic meters per day (m^3/day) and by a 50 percent absorption rate (USEPA, 1986b). These background levels of lead were subtracted from the TSLI to calculate the TSLIr.

$$\begin{aligned} TSLIr &= TSLI - (Water_{lead} + Food_{lead} + Air_{lead}) \\ &= 200\ \mu g/day - (4.5\ \mu g/day + 31\ \mu g/day + 2.5\ \mu g/day) \\ &= 162\ \mu g\ Pb/day \end{aligned}$$

where:

TSLIr	revised theoretically safe level of intake (μg/day);
$Water_{lead}$	average background water intake of lead (4.5 μg/day);
$Food_{lead}$	average background dietary intake of lead (31 μg/day) (FDA, 1990);
Air_{lead}	average background inhalation intake of lead (2.5 μg/day) (USEPA, 1989d).

The HBG for lead was calculated using the following equation:

$$\begin{aligned} HBG &= \frac{TSLIr \times UC_1}{[IR_o + (IR_i \times SRP)] \times UC_2} \\ &= \frac{162\ \mu g/day \times 10^6\ mg/kg}{[480\ mg/day + (20\ m^3/day \times 0.075\ mg/m^3)] \times 10^3\ \mu g/mg} \\ &= 340\ mg/kg \end{aligned}$$

where:

HBG	Health-based soil remediation goal for lead (mg/kg);
TSLIr	revised theoretically safe level of intake (162 μg Pb/day);
IR_o	soil ingestion rate (480 mg/day) (USEPA, 1991a);
IR_i	inhalation rate (20 m^3/day) (USEPA, 1991a);
SRP	suspended respirable particulates (0.075 mg/m^3) (FR, 1988);
UC_1	unit conversion factor of 10^6 mg/kg; and
UC_2	unit conversion factor of 10^3 μg/mg.

Using these assumptions, a soil HBG of 340 mg/kg was obtained. The results are presented in Table 6-10.

For a hypothetical future adult resident exposure scenario, a soil ingestion rate of 100 mg/day was used with the same methodology to obtain a soil HBG of 1,600 mg/kg. Since the construction worker scenario results in a lower (more protective) HBG, it is presented as the adult reasonable maximum exposure value in Table 6-10.

6.1.3.2 Child Resident

The current approach to assessing the toxicity of lead is based on the effect associated with a specified concentration of lead in the blood (blood lead level). To assess non-cancer effects of lead exposure, the USEPA has developed a biokinetic/uptake model for lead called "LEAD5" (USEPA, 1991c). LEAD5 is a program that estimates total lead uptake (in μg Pb/day) resulting from diet; inhalation and ingestion of soil, dust, water, and paint; and placental transport to the fetus. The current program (LEAD5) calculates the uptake and blood lead levels for the most sensitive subpopulation, children aged 0 to 6 years.

The USEPA has identified 10 μg/dL as a level of potential concern for health effects in children (FR, 1991). The results of a LEAD5 model run are the geometric mean blood lead level and the percentages of the population above and below a set blood lead level. Setting the soil concentration at 200 mg/kg and all other parameters to their default (background) conditions, 100 percent of the receptor population are expected to have blood lead levels below 10 μg/dL. Therefore, this analysis results in a HBG for lead of 200 mg/kg in soil.

6.2 GROUND-WATER REMEDIATION GOALS

Residential use was assumed here since residents would receive the most exposure to the site, making it the most conservative assumption from a risk standpoint. Construction workers are not likely to have significant exposure to constituents from the ground water since most, or all the work would be outdoors, the exposure time is short, and they are unlikely to contact the ground water directly. For the hypothetical future residential exposure scenario, volatile constituents present in ground water beneath the site may volatilize into the soil gas and migrate through the soil to the ground surface and into the homes. If this were to occur, residents in the homes would be exposed via inhalation of the indoor air. This scenario would apply also to any downgradient buildings which the ground-water plume flows under, but the concentrations will be lower due to dispersion and natural degradation effects.

A ground-water vapor intrusion model, described in Appendix A, was used to estimate the HBGs for ground water. This model assumes volatile constituents in the ground water volatilize into the soil gas and migrate through the soil and into a home built on the site. TPH as gasoline was included in this calculation, using n-hexane as a surrogate compound. This is a very conservative approximation since weathered gasoline is expected to be less volatile than n-hexane.

The exposure assumptions used to calculate the ground-water HBGs for the hypothetical future adult resident scenario were as follows:

- inhalation rate of 20 m^3/day (USEPA, 1991a);
- exposure frequency of 350 days/year (USEPA, 1991a);
- exposure duration of 30 years (USEPA, 1991a);

- body weight of 70 kg (USEPA, 1991a); and

- TCR of 10^{-6} and THQ of 1.

In addition, HBGs were calculated based upon exposure of a child resident to ground-water constituents migrating into the indoor air of the home. Exposure assumptions for this hypothetical child resident were the same as for the adult resident, except for the following parameters:

- exposure duration of 6 years; and

- average body weight of 15 kg (USEPA, 1989c).

The equations and assumptions used to calculate ground-water HBGs based on exposure of hypothetical future adult and child residents are summarized in Table 6-11. A detailed presentation of the model and parameter values is provided in Appendix A. The calculated ground-water HBGs based on the hypothetical future adult and child resident exposure scenarios are presented in Tables 6-12 and 6-13, respectively.

7.0 UNCERTAINTIES IN THE RISK ASSESSMENT

The HBGs presented here for the former Chevron Service Station #9-3864 are conservative estimates of soil and ground-water concentrations which would not cause adverse non-cancer health effects or potential cancer risks at the 10^{-6} (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 generally considered unacceptable by the USEPA. 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.

Uncertainty always exists in using a finite set of monitoring data to represent site conditions. Because of this uncertainty, the calculated HBG was compared to both the UCL (the USEPA-recommended reasonable maximum exposure concentration) and the maximum detected site-related concentration. One source of uncertainty particularly relevant to the risk assessment occurs with inappropriately high SQLs associated with non-detects. The SQL for a constituent is considered inappropriately high if detected concentrations at the SQL would present an unacceptable health risk. To avoid this problem, the selected analytical methods for all constituents should report SQLs below the concentrations which would present unacceptable risk. This criterion was met for all analytical data used in this risk assessment; all the SQLs for all the constituents were less than the calculated HBGs.

Exposure scenarios contribute uncertainty to the risk assessment. HBGs were calculated based on the assumption that the current conditions with respect to constituent concentrations 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 through 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 Service Station #9-3864 could pose a threat to human health should the site be redeveloped for commercial, retail, or residential purposes. HBGs were calculated for constituents detected in environmental sampling data using intake assumptions to protect against potential non-cancer adverse health effects and potential cancer risks associated with exposure of human receptor populations. Ground-water transport modeling was used to evaluate whether site-related constituent concentrations could be discharged into San Francisco Bay. The constituents of concern identified in soil and/or ground water were benzene, ethylbenzene, toluene, xylenes, TPH as diesel, TPH as gasoline, and lead.

The site currently is vacant and is not in use. In the future, the property may be redeveloped, and hypothetical future exposures could occur if construction were undertaken at the site. Additionally, once the site is developed, constituents originating in ground water could volatilize and migrate through soils and into the buildings. Residents in homes on the site then could inhale these vapors. Both of these hypothetical exposure scenarios were considered in developing HBGs.

Comparisons were made between the HBGs and the detected levels of constituents at the former Chevron Service Station #9-3864 in Table 8.1. Site-related concentrations of the constituents of concern in soil and ground water are all below the derived HBGs. This indicates no further remediation is necessary for protection of human health since current constituent concentrations in soil and ground water at the site do not pose a threat to human health.

The former Chevron Service Station #9-3864 does not support an ecosystem. Ground water originating at the site discharges into San Francisco Bay. A ground-water transport model was used to predict the concentrations potentially reaching the bay. Using benzene as a representative compound, site-related constituent concentrations were not found to discharge into the bay.

9.0 REFERENCES

Agency for Toxic Substances and Disease Registry (ATSDR), 1990. Draft Toxicological Profile for Polycyclic Aromatic Hydrocarbons (PAHs). Public Health Service, U.S. Department of Health and Human Services, GA.

Anderson, M.P., 1984. Movement of Contaminants in Groundwater: Ground-Water Transport-Advection and Dispersion. In Groundwater Contamination. National Academy Press. Wash., D.C.

Andrews, L.S., and R. Snyder, 1991. Toxic Effects of Solvents and Vapors. In: Casarett and Doull's Toxicology. The Basic Science of Poisons. Fourth Ed. Amdur, M.O., J. Doull, and C.D. Klaasen, Eds. Macmillan Publishing Co., New York, NY.

Baetsle, L.H., 1967. Computational Methods for the Prediction of Underground Movement of Radionuclides. J. Nuclear Safety, 8, No. 6.

Bear, J., 1972. Dynamics of Fluids in Porous Media. American Elsevier, New York.

Bergamini, 1992. Petroleum Product Chemistry. Underground Tank Technology Update. Vol. 6, No. 2.

Blaine Technical Services, Inc., 1991. Multiple Event Sampling Report 911010-C-1. Chevron Service Station No. 93864, 5101 Telegraph Avenue, Oakland, California. September 11.

California Air Pollution Control Officers Association (CAPCOA), 1992. Air Toxics "Hot Spot" Program Risk Assessment Guidelines. Prepared by the Risk Assessment Committee of CAPCOA. January.

California Leaking Underground Fuel Tank (LUFT) Task Force, 1989. Leaking Underground Fuel Tank Field Manual: Guidelines for Site Assessment, Cleanup, and Underground Storage Tank Closure. October.

California Regional Water Quality Control Board (RWQCB), San Francisco Bay Region, 1990. Guidance Document for the Development of Health-Based Remedial Clean-up Levels for the South Bay Multi-Site Cooperative Superfund Program. June 20.

California Water Resources Control Board, 1991. Final Article II, Corrective Action Regulations. December.

de Marsily, G., 1986. Quantitative Hydrogeology. Academic Press, New York, 440 pp.

Federal Register (FR), 1991. Maximum Contaminant Level Goals and National Primary Drinking-Water Regulations for Lead and Copper; Final Rule. 56:26460-26564.

Federal Register (FR), 1988. Hazardous Waste Management System; Identification and Listing of Hazardous Waste; Final Exclusion. 53(148):29038-29045.

Freeze, R.A., and J.A. Cherry, 1979. Groundwater. Prentice-Hall, Englewood Cliffs, NJ.

Genetic Activity Program (GAP), 1991. U.S. Environmental Protection Agency, Health Effects Research Laboratory, Genetic Toxicology Division, Research Triangle Park, NC.

GeoStrategies, Inc., 1991. Well Installation Report, Chevron Service Station No. 3864, 5101 Telegraph Avenue, Oakland, California. January 17.

GeoStrategies, Inc. 1990. Trace Element Occurrence in Soil and Groundwater, Chevron Service Station No. 0338, 5500 Telegraph Avenue, Oakland, California. October, 19.

Horowitz, A., D.R. Shelton, C.P. Cornell, and J.M. Tiedje, 1982. Anaerobic Degradation of Aromatic Compounds in Sediment and digested sludge. Dev. Ind. Microbiol. 23: 435-44.

Howard, P.H., R.S. Boethling, W.F. Jarvis, W.M. Meylan, and E.M. Michalenko, 1991. Handbook of Environmental Degradation Rates. Lewis Publishers, Inc., Chelsea, MI. 725 pp.

Howard, P.H., 1990. Handbook of Environmental Fate and Exposure Data for Organic Chemicals, Volume II, Solvents. Lewis Publishers, Inc., Chelsea, MI. 546 pp.

Howard, P.H., 1989. Handbook of Environmental Fate and Exposure Data for Organic Chemicals. Volume I: Large Production and Priority Contaminants. Lewis Publishers, Inc., Chelsea, MI. 574 pp.

Integrated Risk Information System (IRIS), 1992. U.S. Environmental Protection Agency, Office of Health and Environmental Assessment, Cincinnati, OH.

Jury, W.A., W.F. Spencer, and W.J. Farmer, 1983. Behavior Assessment Model for Trace Organics in Soil: I. Model Description. J. Environ. Qual. 12:558-564.

Karickhoff, S.W., 1985. Pollutant Sorption in Environmental Systems. Environmental Exposure Form Chemicals, Vol. I, eds. W.B. Neely and G.E. Blau: Fla.; Boca Raton, CRC Press, p. 49-62.

Kostecki, P.J., and E.J. Calabrese, 1989. Petroleum Contaminated Soils. Volume I. Remediation Techniques, Environmental Fate, and Risk Assessment. Lewis Publishers, Inc., Chelsea, MI.

Lyman, W.J., W.G. Reehl, and D.H. Rosenblatt, 1990. Handbook of Chemical Property Estimation Methods: Environmental Behavior of Organic Compounds. American Chemical Society, Washington, DC.

McKenna, E.J., and R.D. Heath, 1976. Biodegradation of Polynuclear Aromatic Hydrocarbon Pollutants by Soil and Water Microorganisms. Water Resources Center, University of Illinois, Research Report No. 113. UILV-WEC-76-0113.

Millner, C.G., R.C. James, and A.C. Nye, 1992. Human Health-Based Soil Cleanup Guidelines for Diesel Fuel No. 2. J. Soil Contam. 1:103-157.

Montgomery, J.H., and L.M. Welkom, 1990. Ground Water Chemicals Desk Reference. Lewis Publishers, Inc., Chelsea, MI. 640 pp.

National Oceanic and Atmospheric Administration (NOAA), 1974. Climates of the States, Volume II, Western States. Water Information Center, Inc., Port Washington, NY.

Radbruch, D.H., 1957. Areal and engineering geology of the Oakland West Quadrangle, California. U.S. Geological Survey, Geologin Quandrangle, GQ-769.

Radbruch, D.H., 1969. Areal and Engineering Geology of the Oakland East Quadrangle: U.S. Geological Survey, Geologic Quadrangle, GQ-769.

Ryan, E.A., E.T. Hawkins, B. Magee, and S.L. Santos, 1987. Assessing Risk from Dermal Exposure at Hazardous Waste Sites. Superfund Procedures of the Eighth National Conference, Washington, DC, November 16-18.

Sager, S.L., L.J. Lawton, M.K. Jones, 1992. Evaluation of Exposure to Lead in Soil Considering Decreasing Background Lead Concentrations. An Abstract in The Toxicologist.

Sax, N.I., and R.J. Lewis, Sr., 1989. Dangerous Properties of Industrial Materials. Seventh Ed. Van Nostrand Reinhold, New York, NY.

Shen, T.J., 1982. Air Quality Assurance for Land Disposal of Industrial Waste. Environ. Mgmt. 6:297-305.

Sierra Analytical, 1992. Quarterly Ground Water Sampling Report. Former Chevron Asphalt Plants Terminal #1001067, 1520 Powell Street, Emeryville, California. SES Project #1-191-04. April 20.

U.S. Environmental Protection Agency (USEPA), 1992a. Health Effects Assessment Summary Tables, Annual FY-1992. Office of Research and Development, Office of Solid Waste and Emergency Response, Washington, DC. OHEA ECAO-CIN-821. DERR 9200.6-303(92-1). NTIS No. PB 92-921199. March.

U.S. Environmental Protection Agency (USEPA), 1992b. Dermal Exposure Assessment: Principles and Applications. Office of Reasearch and Development. Washington, DC. EPA/600/8-91/011B. January.

U.S. Environmental Protection Agency (USEPA), 1991a. Risk Assessment Guidance for Superfund, Human Health Evaluation Manual, Supplemental Guidance: Standard Default Exposure Factors. Office of Solid Waste and Emergency Response, Washington, DC. OSWER Directive 9285.6-03. March 25.

U.S. Environmental Protection Agency (USEPA), 1991b. Risk Assessment Guidance for Superfund, Human Health Evaluation Manual, Part B: Development of Risk-based Preliminary Remediation Goals. Office of Solid Waste and Emergency Response, Washington, DC. OSWER Directive 9285.7-01B. December 13.

U.S. Environmental Protection Agency (USEPA), 1991c. Users Guide for Lead: A PC Software Application of the Uptake/Biokinetic Model, Version 5.0 Environmental Criteria and Assessment Office, Cincinnati, OH.

U.S. Environmental Protection Agency (USEPA), 1989a. Risk Assessment Guidance for Superfund, Human Health Evaluation Manual, Volume 1, Part A. Interim Final. Office of Solid Waste and Emergency Response, Washington, DC. EPA/540/1-89/002. December.

U.S. Environmental Protection Agency (USEPA), 1989b. Transport and Fate of Contaminants in the Subsurface. Seminar Publication, Center for Environmental Research Information, Cincinnati, OH.

U.S. Environmental Protection Agency (USEPA), 1989c. Exposure Factors Handbook. Exposure Assessment Group, Office of Health and Environmental Assessment, Washington, DC. EPA 600/8-83/028a-d.

U.S. Environmental Protection Agency (USEPA), 1989d. Air Quality Criteria for Lead: Supplement to the 1986 Addendum. Office of Health and Environmental Assessment, Washington, DC. EPA/600/8-89/049F. August.

U.S. Environmental Protection Agency (USEPA), 1986a. Superfund Public Health Evaluation Manual, August 1986. EPA 540/1-86.

U.S. Environmental Protection Agency (USEPA), 1986b. Air Quality Criteria for Lead, Volumes I - IV Office of Research and Development, Research Triangle Park, NC. EPA/600/8-83/028.

U.S. Food and Drug Administration (FDA), 1990. Memorandum to Elizabeth Campbell, Division of regulatory Guidance from Contaminants Team, Division of Toxicological Review and Evaluation. Public Health Service.

Table 3-1. Occurrence Summary for Soil, Former Chevron Service Station #9-3864, 5101 Telegraph Avenue, Oakland, California.

Constituent	Frequency Detects / Total	Range of SQLs Min – Max	Range of Detects Min – Max	Mean	UCL
VOCs					
Benzene	5 / 40	0.005 – 0.25 *	0.0060 – 0.069	0.016	0.022
Ethylbenzene	16 / 40	0.005 – 0.005	0.0060 – 2.5	0.25	0.39
Toluene	17 / 40	0.005 – 0.005	0.0090 – 2.7	0.20	0.34
Xylenes	18 / 40	0.005 – 0.005	0.0060 – 5.5	0.60	0.93
TPH					
TPH as Diesel	1 / 1	1.0	78	78	#N/A
TPH as Gasoline	15 / 40	1.0 – 1.0	2.0 – 980	82	130
Metals					
Barium	1 / 1	0.50	0.80	0.80	#N/A
Lead, soluble (mg/L)	7 / 7	0.50 – 0.50	0.20 – 0.60	0.30	0.43

Concentrations are reported in milligrams per kilogram (mg/kg), except as noted.

*	When ½ the SQL for a nondetect exceeded the maximum detect for the data set, the maximum detect was used as the proxy value for that nondetect. This occurred only once, in the 15.5-ft sample from the installation of monitoring well C-3 (15-Nov-90).
Mean	Arithmetic average of the total number of samples, using proxy concentrations for non-detects.
mg/L	Milligrams per liter (concentration units for soluble lead).
#N/A	Number is not available; UCL cannot be calculated for only one value.
SQL	Sample quantitation limit.
TPH	Total petroleum hydrocarbons.
UCL	95 percent upper confidence limit (one-tailed) on the mean, assuming a normal distribution.
VOCs	Volatile organic compounds.

Table 3-2. Occurrence Summary for Ground Water, Former Chevron Service Station #9-3864, 5101 Telegraph Avenue, Oakland, California.

Constituent	Frequency Detects / Total	SQL	Range of Detects Min – Max	Mean	UCL
VOCs					
Benzene	4 / 4	0.0005	0.0014 – 0.13	0.038	0.11
Ethylbenzene	3 / 4	0.0005	0.0020 – 0.012	0.0044	0.011
Toluene	4 / 4	0.0005	0.0018 – 0.026	0.012	0.025
Xylenes	4 / 4	0.0005	0.0011 – 0.030	0.011	0.026
TPH as Gasoline	3 / 4	0.05	0.81 – 7.1	2.7	6.5

Concentrations are reported in milligrams per liter (mg/L).

Mean	Arithmetic average of the total number of samples, using proxy concentrations for non-detects.
SQL	Sample quantitation limit.
TPH	Total petroleum hydrocarbons.
UCL	95 percent upper confidence limit (one-tailed) on the mean, assuming a normal distribution.
VOCs	Volatile organic compounds.

Table 3-3. Comparison of Analytical Results for On- and Off-Site Ground-Water Sampling, Former Chevron Service Station #9-3864, 5101 Telegraph Avenue, Oakland, California.

	Off-Site Up-/Cross-Gradient			On-Site (Most Recent Data)				Off-Site Down-Gradient	
Constituent	TC-3	TC-4	TC-5	C-1	C-2	C-3	C-4	TC-1	TC-2
<u>VOCs</u>									
Benzene	< 0.0004	< 0.20	< 0.0020	0.0058	0.016	0.13	0.0014	< 0.0004	< 0.0004
Ethylbenzene	< 0.0003	0.50	< 0.0020	0.0057	0.015	0.026	0.0018	< 0.0003	< 0.0003
Toluene	< 0.0003	< 0.20	< 0.0020	0.0020	0.0034	0.012	< 0.00050	< 0.0003	< 0.0003
Xylenes	< 0.0004	0.40	0.0030	0.0063	0.0075	0.030	0.0011	< 0.0004	< 0.0004
TPH as Gasoline	< 0.050	120	2.4	0.81	3.0	7.1	< 0.050	< 0.050	< 0.050

Concentrations are given in milligrams per liter (mg/L).

Off-site ground-water samples were collected on 01-Dec-92; on-site samples were collected on 16-Sep-92.

<	Constituent was not detected. The number following the "<" is the sample quantitation limit.
TPH	Total petroleum hydrocarbons.
VOCs	Volatile organic compounds.

Table 4-1. Toxicity Summaries for Constituents of Concern, Former Chevron Service Station #9-3864, 5101 Telegraph Avenue, Oakland, 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.
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.

References appear on page 5.

Table 4-1. Toxicity Summaries for Constituents of Concern, Former Chevron Service Station #9-3864, 5101 Telegraph Avenue, Oakland, California.

Constituent	Acute Toxicity Summary	Chronic Toxicity Summary	Cancer Potential	Other
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 NOAEL of 88 ppm rrresulted in 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.

References appear on page 5.

Table 4-1. Toxicity Summaries for Constituents of Concern, Former Chevron Service Station #9-3864, 5101 Telegraph Avenue, Oakland, California.

Constituent	Acute Toxicity Summary	Chronic Toxicity Summary	Cancer Potential	Other
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.	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.

References appear on page 5.

Table 4-1. Toxicity Summaries for Constituents of Concern, Former Chevron Service Station #9-3864, 5101 Telegraph Avenue, Oakland, California.

Constituent	Acute Toxicity Summary	Chronic Toxicity Summary	Cancer Potential	Other
<u>TPH</u>				
n-Hexane	**Critical Effects:** Hallucinations after inhalation, parasthesia, muscle weakness. **Comments:** Used as a surrogate for C_8 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:** Used as a surrogate for TPH as diesel.	**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*.

References appear on page 5.

Table 4-1. Toxicity Summaries for Constituents of Concern, Former Chevron Service Station #9-3864, 5101 Telegraph Avenue, Oakland, California.

Constituent	Acute Toxicity Summary	Chronic Toxicity Summary	Cancer Potential	Other
Lead	**Critical Effects:** Reversible kidney damage. **Comments:** Toxicity is dependent on its accumulation in the blood.	**Critical Effects:** Brain encephalopathy, peripheral neuropathies, kidney damage, learning disabilities, anemia. **Data Summary:** There is no RfD for lead. A blood lead model is used to determine toxicity. **Comments:** Children have a greater risk of toxicity due to greater absorption and less developed blood brain barrier.	Class B2; probable carcinogen. No slope factor exists.	**Developmental:** A relationship in the decreased gestation period and fetal weights to maternal blood lead levels was seen. **Reproductive:** Increases in spontaneous abortions were detected in women living near smeltering plants. In men, decreases in sperm count were detected. **Mutagenicity:** Positive results in sister chromatid exchange and chromosomal aberrations.

References: ATSDR documents; 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.
NOAEL	No observed adverse effect level.
NOEL	No observed effect level.
ppm	Parts per million.
RfD	Reference dose.

Table 4-2. Dermal and Oral Absorption Efficiencies for Constituents of Concern, Former Chevron Service Station #9-3864, 5101 Telegraph Avenue, Oakland, California.

Constituent	Absorption Efficiencies			
	Dermal		Oral	
VOCs	0.25	a	1.00	b
TPH				
n-Hexane [a]	0.10	a	1.00	b
Naphthalene [b]	0.03	c	0.85	c

a Ryan et al. (1987).

b Assumed.

c ATSDR (1990).

[a] n-Hexane is used as a surrogate for TPH as gasoline.

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

TPH Total petroleum hydrocarbons.

VOCs Volatile organic compounds.

Table 4-3. Reference Doses, Target Sites, and Confidence Levels for Constituents of Concern, Former Chevron Service Station # 9-3864, 5101 Telegraph Avenue, Oakland, California.

	RfDo (mg/kg/day)		RfDa (mg/kg/day)*		RfDi (mg/kg/day)		Target Sites		Confidence Level/
Constituent	Subchronic	Chronic	Subchronic	Chronic	Subchronic	Chronic	Oral	Inhalation	Uncertainty Factor
VOCs									
Benzene	NA	NA	NA	NA	2.0E-02	2.0E-02	NA	NA	NA
Ethylbenzene	1.0E+00	1.0E-01	1.0E+00	1.0E-01	2.9E-01	2.9E-01	liver, kidney	developmental	low/1000
Toluene	2.0E+00	2.0E-01	2.0E+00	2.0E-01	5.7E-01	1.1E-01	liver, kidney	CNS	medium/1000
Xylenes	4.0E+00	2.0E+00	4.0E+00	2.0E+00	8.6E-02	8.6E-02	hyperactivity	NA	medium/100
TPH									
n-Hexane [a]	6.0E-01	6.0E-02	6.0E-01	6.0E-02	5.7E-02	5.7E-02	CNS, testicles	CNS	medium/300
Naphthalene [b]	4.0E-02	4.0E-02	3.4E-02	3.4E-02	4.0E-03	4.0E-03	decreased weight gain	NA	low/1000

References: IRIS, 1992; USEPA, 1992a.

*	The adjusted RfD is calculated by multiplying the oral RfD by the constituent-specific oral absorption efficiency (Table 4-2).
[a]	n-Hexane is used as a surrogate for TPH as gasoline.
[b]	Naphthalene is used as a surrogate for TPH as diesel.
CNS	Central nervous system.
NA	Not available.
RfDa	Adjusted reference dose.
RfDi	Inhalation reference dose.
RfDo	Oral reference dose.
TPH	Total petroleum hydrocarbons.
VOCs	Volatile organic compounds.

Table 4-4. Cancer Slope Factors, Tumor Sites, and USEPA Cancer Classifications for Constituents of Concern, Former Chevron Service Statation # 9-3864, 5101 Telegraph Avenue, Oakland, California.

Constituent	CSF (kg-day/mg)			Tumor site		USEPA Classification
	Oral	Adjusted *	Inhalation	Oral	Inhalation	
VOC						
Benzene	2.9E-02	2.9E-02	2.9E-02	leukemia	leukemia	A

References: IRIS, 1992.

*	The adjusted CSF is calculated by dividing the oral CSF by the constituent-specific oral absorption efficiency (Table 4-2).
CSF	Cancer slope factor.
VOC	Volatile organic compound.

Table 5-1. Physical and Chemical Properties for Constituents of Concern, Former Chevron Service Station #9-3864, 5101 Telegraph Avenue, Oakland, 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-m³/mol) (25 °C)	Diffusivity (cm²/sec)	Koc (mL/g)	Log Kow	Soil T ½ Low - High (days)	Ground Water T ½ Low - High (days)
VOCs										
Benzene	78	1,780	0.88	95	5.5E-03	0.09320	49 - 100	1.56 - 2.15	5 - 16	10 - 180
Ethylbenzene	106	152 - 208	0.87	9.5	8.7E-03	0.06667	95 - 260	3.05 - 3.15	3 - 10	6 - 228
Toluene	92	490 - 627	0.87	28	6.7E-03	0.07828	115 - 150	2.11 - 2.80	4 - 22	7 - 28
Xylenes (total)	106	162 - 200	0.87	6.6 - 8.8	6.3E-03	0.07164	128 - 1,580	2.77 - 3.20	7 - 28	14 - 360
TPH										
TPH as diesel [a]	128	30 - 34	1.16	0.2 - 0.87	4.6E-04	0.08205	550 - 3,160	3.2 - 4.7	16.6 - 48	1 - 258
TPH as gasoline [b]	86	18 (20°C)	0.66	120 (20°C)	7.7E-01	0.07461	890	2.77	ND	ND

References: Howard et al., 1991; Howard, 1990 and 1989; Lugg, 1968; Montgomery and Welkom, 1990; Shen, 1982; and Horowitz et al., 1982.

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

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

°C	Degrees Celsius.	ND	No data.
Koc	Organic carbon partition coefficient.	T ½	Half-life.
Kow	Octanol-water partition coefficient.	TPH	Total petroleum hydrocarbons.
mm Hg	Millimeters of mercury.	VOCs	Volatile organic compounds.

Table 5-2. Summary of Ground Water Transport Model Parameter Values and Calculation Results, Former Chevron Station #9-3864, 5101 Telegraph Avenue, Oakland, California.

Model Parameter	Value
Hydraulic Conductivity (K) (estimated from the lithologic data)	50 ft/day
Average Horizontal Hydraulic Gradient (i)	0.038 ft/ft
Effective Porosity (n_e)	0.25
Total Porosity (n)	0.30
Total Organic Carbon (f_{oc})	0.25 percent
Longitudinal Dispersivity (a_L)	115 feet
Benzene Degradation Half-Life ($\tau_{1/2}$)	0.5 years
Soil Bulk Mass Density (ρ_b)	1.75 g/cm^3
Soil-Water Partition Coefficient for Benzene (K_{oc})	83 mL/g
Concentration at Source (C_o)	340 μg/L
Distribution Coefficient (K_d)	0.2075 mL/g

(1) Average Linear Ground Water Velocity (v)

$$v = \frac{K \times i}{n_e}$$

$$v = \frac{\left[50 \ \frac{ft}{day}\right]\left[0.038 \ \frac{ft}{ft}\right]}{0.25} = 7.6 \ \frac{ft}{day}$$

(2) Retardation Factor (R_d) of Benzene

$$R_d = 1 + \frac{\rho_b}{n} K_d$$ (Baetsle, 1967; Freeze & Cherry, 1979)

$$K_d = K_{oc} \ f_{oc}$$ (Karickhoff, 1984)

$$R_d = \frac{1 + \rho_b}{n} K_{oc} \ f_{oc}$$

$$R_d = \frac{\left[1 + 1.75 \frac{g}{cm^3}\right]}{0.30} \left[83 \ \frac{mL}{g}\right] (0.0025) \left[\frac{1 \ cm^3 \ solution}{1 \ mL \ solution}\right] = 2.21$$

(3) Benzene Plume Velocity

$$v_b = \frac{v}{R_d} = \frac{7.6 \ ft/day}{2.21} = 3.4 \ ft/day$$

Table 6-1. Equation for Human Health-Based Soil Remediation Goals for a Construction Worker, Cancer Effects, Former Chevron Service Station #9-3864, 5101 Telegraph Avenue, Oakland, California.

Cancer Effects

$$\mathrm{HBG} = \frac{\mathrm{TCR} \times \mathrm{BW} \times \mathrm{AP}}{\mathrm{ET} \times \left[(\mathrm{CSF_o} \times \mathrm{UCF} \times \mathrm{IR_{soil}}) + (\mathrm{CSF_a} \times \mathrm{ABS} \times \mathrm{SSA} \times \mathrm{SAR} \times \mathrm{UCF}) + (\mathrm{CSF_i} \times \mathrm{IR_{air}} \times [\mathrm{VF}^{-1} + \mathrm{PEF}^{-1}])\right]}$$

where:

ABS	Dermal absorption efficiency (constituent-specific).
AP	Averaging period for carcinogenic effects (70 yr × 365 days/yr = 25,550 days).
BW	Adult body weight (70 kg).
$\mathrm{CSF_a}$	Adjusted cancer slope factor (constituent-specific, kg-mg/day).
$\mathrm{CSF_i}$	Inhalation cancer slope factor (constituent-specific, kg-mg/day).
$\mathrm{CSF_o}$	Oral cancer slope factor (constituent-specific, kg-mg/day).
ET	Exposure time (12 weeks × 6 days/week = 72 days).
HBG	Health-based remediation goal (mg/kg).
$\mathrm{IR_{air}}$	Inhalation rate (20 m^3/day).
$\mathrm{IR_{soil}}$	Soil ingestion rate (480 mg/day).
PEF	Particulate emission factor (2.48×10^{11} m^3/kg; from Table 6-4).
SSA	Skin surface area (2,940 cm^2, hands, forearms, and face).
SAR	Soil adherence rate (1 mg/cm^2/day).
TCR	Target excess individual lifetime cancer risk (10^{-6}).
UCF	Unit conversion factor (10^{-6} kg/mg).
VF	Soil-to-air volatilization factor (area- and constituent-specific, m^3/kg; from Table 6-3).

Sample Calculation: HBG for benzene (units omitted)

$$\mathrm{HBG} = \frac{10^{-6} \times 70 \times 25{,}550}{72 \times \left[(0.029 \times 10^{-6} \times 480) + (0.029 \times 0.25 \times 2{,}940 \times 1 \times 10^{-6}) + (0.029 \times 20 \times [(469)^{-1} + (2.48 \times 10^{11})^{-1}])\right]}$$

$$= 20 \text{ mg/kg}$$

Table 6-2. Equation for Human Health-Based Soil Remediation Goals for a Construction Worker, Non-Cancer Effects, Former Chevron Service Station #9-3864, 5101 Telegraph Avenue, Oakland, California.

Non-Cancer Effects

$$HBG = \frac{THQ \times BW \times AP}{ET \times \left[(RfD_o^{-1} \times UCF \times IR_{soil}) + (RfD_a^{-1} \times ABS \times SSA \times SAR \times UCF) + (RfD_i^{-1} \times IR_{air} \times [VF^{-1} + PEF^{-1}])\right]}$$

where:

ABS	Dermal absorption efficiency (constituent-specific).
AP	Averaging period for non-carcinogenic effects (12 weeks × 7 days/week = 84 days).
BW	Adult body weight (70 kg).
ET	Exposure time (12 weeks × 6 days/week = 72 days).
HBG	Health-based remediation goal (mg/kg).
IR_{air}	Inhalation rate (20 m^3/day).
IR_{soil}	Soil ingestion rate (480 mg/day).
PEF	Particulate emission factor (2.48×10^{11} m^3/kg; from Table 6-4).
RfD_a	Subchronic adjusted reference dose (constituent-specific, mg/kg/day).
RfD_i	Subchronic inhalation reference dose (constituent-specific, mg/kg/day).
RfD_o	Subchronic oral reference dose (constituent-specific, mg/kg/day).
SSA	Skin surface area (2,940 cm^2, hands, forearms, and face).
SAR	Soil adherence rate (1 mg/cm^2/day).
THQ	Target hazard quotient (1).
UCF	Unit conversion factor (10^{-6} kg/mg).
VF	Soil-to-air volatilization factor (area- and constituent-specific, m^3/kg; from Table 6-3).

Sample Calculation: HBG for toluene (units omitted)

$$HBG = \frac{1 \times 70 \times 84}{72 \times \left[(2^{-1} \times 10^{-6} \times 480) + (2^{-1} \times 0.25 \times 2{,}940 \times 1 \times 10^{-6}) + (0.57^{-1} \times 20 \times [(569)^{-1} + (2.48 \times 10^{11})^{-1}])\right]}$$

$$= 1{,}300 \text{ mg/kg}$$

Table 6-3. Equations for Soil-to-Air Volatilization Factor, Former Chevron Service Station #9-3864, 5101 Telegraph Avenue, Oakland, California.

$$VF = \frac{LS \times V \times DH}{A} \times \frac{(3.14 \times \alpha \times T)^{0.5}}{2 \times Dei \times E \times Kas \times UCF}$$

where:

$$\alpha = \frac{Dei \times E}{E + \left(P_s \times \frac{1 - E}{Kas}\right)}$$

$$Dei = Di \times E^{0.33}$$

$$Kas = \frac{H}{RT \times Kd}$$

where:

A	Area of contamination (18,000,000 cm^2).
α	Intermediate value used in calculating VF.
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	Soil porosity (0.4).
H	Henry's Law Constant (atm-m^3/mol; Table 5-1).
Kas	Soil-air partition coefficient (g soil/cm^3 air).
Kd	Soil-water partition coefficient (cm^3/g; 0.02 × Koc, where 0.02 is the assumed organic carbon content of the soil).
Koc	Organic carbon partition coefficient (cm^3/g; maximum value from Table 5-1 was used).
LS	Length of side of contaminated area (70 m).
Ps	Soil density or particulate density (2.65 g/cm^3).
RT	Universal gas constant × absolute temperature $= 8.206 \times 10^{-5}$ atm-m^3/mol/K × 298 K = 0.02445 atm-m^3/mol
T	Exposure duration in seconds (84 days × 24 hrs/day × 3,600 sec/hr = 7,257,600 sec).
UCF	Unit conversion factor (0.001 kg/g).
V	Wind speed in mixing zone (½ mean wind speed = 3.6/2 = 1.8 m/sec).
VF	Volatilization factor (m^3/kg).

Sample calculation appears on page 2.

Table 6-3. Equations for Soil-to-Air Volatilization Factor, Former Chevron Service Station #9-3864, 5101 Telegraph Avenue, Oakland, California.

Sample Calculation: VF for benzene

Dei, Kas, and α must be calculated first:

$$\mathrm{Dei} = 0.0932\ \mathrm{cm^2/sec} \times 0.4^{0.33}$$

$$= 0.0689\ \mathrm{cm^2/sec}$$

$$K_{as} = \frac{0.0055\ \mathrm{atm\text{-}m^3/mol}}{0.02445\ \mathrm{atm\text{-}m^3/mol} \times 100\ \mathrm{cm^3/g} \times 0.02}$$

$$= 0.113\ \mathrm{g\ soil/cm^3\ air}$$

$$\alpha = \frac{0.0689\ \mathrm{cm^2/sec} \times 0.4}{0.4 + \left(2.65\ \mathrm{g/cm^3} \times \dfrac{1 - 0.4}{0.133\ \mathrm{g/cm^3}}\right)}$$

$$= 1.90 \times 10^{-3}\ \mathrm{cm^2/sec}$$

$$\mathrm{VF} = \frac{70\ \mathrm{m} \times 1.8\ \mathrm{m/sec} \times 2\ \mathrm{m}}{18{,}000{,}000\ \mathrm{cm^2}} \times \frac{(3.14 \times 1.90 \times 10^{-3}\ \mathrm{cm^2/sec} \times 7{,}257{,}600\ \mathrm{sec})^{0.5}}{2 \times 0.0689\ \mathrm{cm^2/sec} \times 0.4 \times 0.133\ \mathrm{g/cm^3} \times 0.001\ \mathrm{kg/g}}$$

$$= 469\ \mathrm{m^3/kg}$$

Table 6-4. Equation for Soil Particulate Emission Factor, Former Chevron Service Station #9-3864, 5101 Telegraph Avenue, Oakland, California.

$$\mathrm{PEF} = \frac{\mathrm{LS} \times \mathrm{V} \times \mathrm{DH} \times \mathrm{UCF}_1}{\mathrm{A}} \times \frac{\mathrm{UCF}_2}{\mathrm{RF} \times (1 - \mathrm{G}) \times (\mathrm{U}_m/\mathrm{U}_t)^3 \times \mathrm{F(x)}}$$

where:

A	Area of contamination (1,800 m^2).
DH	Diffusion height (2 m).
F(x)	Function dependent on Um/Ut (0.00254).
G	Fraction of vegetative cover (0 assumed).
LS	Length of side of contaminated area (70 m).
PEF	Particulate emission factor (m^3/kg).
RF	Respirable fraction (0.036 g/m^2/hr).
Um	Mean annual wind speed (3.6 m/sec).
Ut	Equivalent threshold value of wind speed at 10 m (12.8 m/sec).
UCF_1	Unit conversion factor (3,600 sec/hr).
UCF_2	Unit conversion factor (1,000 g/kg).
V	Wind speed in mixing zone (½ mean annual wind speed = 1.8 m/sec).

Calculation:

$$\mathrm{PEF} = \frac{70\,\mathrm{m} \times 1.8\,\mathrm{m/sec} \times 2\,\mathrm{m} \times 3{,}600\,\mathrm{sec/hr}}{1{,}800\,\mathrm{m}^2} \times \frac{1{,}000\,\mathrm{g/kg}}{0.036\,\mathrm{g/m^2/hr} \times (1 - 0) \times \left(\frac{3.6\,\mathrm{m/sec}}{12.8\,\mathrm{m/sec}}\right)^3 \times 0.0}$$

$$= 2.48 \times 10^{11}\ \mathrm{m^3/kg}$$

Table 6-5. Health-Based Soil Remediation Goals for a Construction Worker, Cancer Effects, Former Chevron Service Station #9-3864, 5101 Telegraph Avenue, Oakland, California.

Constituent	alpha (cm^2/sec)	VF (m^3/kg)	Toxicity Values (kg-day/mg) CSFo	CSFa	CSFi	Cancer Effects HBG (mg/kg)
VOCs						
Benzene	1.90E-03	469	2.9E-02	2.9E-02	2.9E-02	20
Ethylbenzene	8.36E-04	715	NC	NC	NC	NC
Toluene	1.30E-03	569	NC	NC	NC	NC
Xylenes	1.09E-04	2,010	NC	NC	NC	NC
TPH						
TPH as diesel	NAP	NAP	NC	NC	NC	NC
TPH as gasoline	NAP	NAP	NC	NC	NC	NC

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.
NAP	Not applicable.
NC	Not carcinogenic.
TPH	Total petroleum hydrocarbons.
VF	Soil-to-air volatilization factor.
VOCs	Volatile organic compounds.

Table 6-6. Health-Based Soil Remediation Goals for a Construction Worker, Non-Cancer Effects, Former Chevron Service Station #9-3864, 5101 Telegraph Avenue, Oakland, California.

Constituent	alpha (cm^2/sec)	VF (m^3/kg)	Subchronic Toxicity Values (mg/kg/day) RfDo	RfDa	RfDi	Non-Cancer Effects HBG (mg/kg)
VOCs						
Benzene	1.90E-03	469	NA	NA	2.0E-02	38
Ethylbenzene	8.36E-04	715	1.0E+00	1.0E+00	2.9E-01	800
Toluene	1.30E-03	569	2.0E+00	2.0E+00	5.7E-01	1,300
Xylenes	1.09E-04	2,010	4.0E+00	4.0E+00	8.6E-02	700
TPH						
TPH as diesel	NAP	NAP	4.0E-02	3.4E-02	4.0E-03	5,600
TPH as gasoline	NAP	NAP	6.0E-01	6.0E-01	5.7E-02	63,000

alpha	Intermediate value used to calculate VF.
HBG	Health-based remediation goal.
NA	Not available.
NAP	Not applicable.
RfDa	Adjusted reference dose, subchronic.
RfDi	Inhalation reference dose, subchronic.
RfDo	Oral reference dose, subchronic.
TPH	Total petroleum hydrocarbons.
VF	Soil-to-air volatilization factor.
VOCs	Volatile organic compounds.

Table 6-7. Equations for Health-Based Soil Remediation Goals for Residential Exposure, Former Chevron Service Station #9-3864, 5101 Telegraph Avenue, Oakland, California.

$$HBG = (RC_o + RC_d + RC_i)^{-1}$$

where:

$$RC_o = \frac{IR \times EF \times ED}{RSD_o \times BW \times AP \times UC_1}$$

$$RC_d = \frac{SSA \times SAR \times ABS \times EF \times ED}{RSD_d \times BW \times AP \times UC_1}$$

$$RC_i = \frac{BR \times H \times PGV \times UC_2 \times EF \times ED}{RSD_i \times BW \times Kd \times W \times AP \times RT \times UC_3} \qquad \text{(VOCs)}$$

or

$$= \frac{SPM \times BR \times FIP \times EF \times ED}{RSD_i \times BW \times AP \times UC_1} \qquad \text{(TPH)}$$

where:

ABS	Dermal absorption efficiency, constituent-specific (Table 4-2).
AP	Averaging period (days); 25,550 days (70 yrs x 365 days/yr) for cancer effects, 10,950 days (30 yrs x 365 days/yr) for non-cancer effects for an adult, or 2,190 days (6 years x 365 days/year) for non-cancer effects for a child aged 0 to 6 years.
BR	Breathing rate (20 m^3/day).
BW	Body weight (kg); 70 kg for an adult, or 15 kg for a child aged 0 to 6 years.
CSF_a	Cancer slope factor for dermal exposure, adjusted for absorbed dose (kg-day/mg).
CSF_i	Cancer slope factor for inhalation exposure (kg-day/mg).
CSF_o	Cancer slope factor for oral exposure (kg-day/mg).
ED	Exposure duration (years); 30 years for an adult, or 6 years for a child aged 0 to 6 years.
EF	Exposure frequency (350 days/year).
FIP	Fraction inhaled particulates (unitless); 0.125.
H	Henry's Law Constant (atm-m^3/mol); constituent-specific (Table 5-1).
HBG	Health-based remediation goal (mg/kg).
IR	Incidental ingestion rate for soil (mg/day); 100 mg/day for an adult, or 200 mg/day for a child aged 0 to 6 years.
Kd	Soil-water partition coefficient (cm^3/g); calculated as the maximum Koc in Table 5-1 × 0.02, where 0.02 is the assumed carbon content of the soil.
PGV	Pore gas velocity (1.63×10^{-5} m/sec).
RC_d	Dermal route component (kg/mg); .
RC_i	Inhalation route component (kg/mg).
RC_o	Oral route component (kg/mg).
RfD_a	Reference dose adjusted to an absorbed dose (mg/kg/day).
RfD_i	Reference dose for inhalation exposure (mg/kg/day).
RfD_o	Reference dose for oral exposure (mg/kg/day).
RSD_d	Dermal risk specific dose (mg/kg/day); calculated as ($10^{-6}/CSF_a$) for cancer risk, or RfD_a for non-cancer risk.
RSD_i	Inhalation risk specific dose (mg/kg/day); calculated as ($10^{-6}/CSF_i$) for cancer risk, or RfD_i for non-cancer risk.

Table 6-7. Equations for Health-Based Soil Remediation Goals for Residential Exposure, Former Chevron Service Station #9-3864, 5101 Telegraph Avenue, Oakland, California.

RSD_o	Oral risk specific dose (mg/kg/day); calculated as ($10^{-6}/CSF_o$) for cancer risk, or RfD_o for non-cancer risk.
RT	Universal gas constant × absolute temperature $= 8.206 \times 10^{-5}$ atm-m^3/mol/K × 298 K = 0.02445 atm-m^3/mol
SAR	Soil adherence rate (1 mg/cm^2/day).
SPM	Suspended particulate matter (0.075 mg/m^3).
SSA	Exposed skin surface area (cm^2); 3,160 cm^2 for an adult, or 3,652 cm^2 for a child.
TCR	Target cancer risk (unitless); 10^{-6}.
THQ	Target hazard quotient (unitless); 1.
UC_1	Unit conversion 1 (10^6 mg/kg).
UC_2	Unit conversion 2 (10^6 cm^3/m^3).
UC_3	Unit conversion 3 (10^3 g/kg).
W	Wind speed (3.6 m/sec).

<u>Sample Calculation</u>: benzene, cancer effiects, adult resident exposure

$$RC_o = \frac{100\text{ mg/day} \times 350\text{ days/yr} \times 30\text{ yr}}{[10^{-6}/(0.029\text{ kg-day/mg})] \times 70\text{ kg} \times 25{,}550\text{ days} \times 10^6\text{ mg/kg}}$$

$$= 0.0170\text{ kg/mg}$$

$$RC_d = \frac{3{,}160\text{ cm}^2 \times 1\text{ mg/cm}^2\text{/day} \times 0.25 \times 350\text{ days/yr} \times 30\text{ yr}}{[10^{-6}/(0.029\text{ kg-day/mg})] \times 70\text{ kg} \times 25{,}550\text{ days} \times 10^6\text{ mg/kg}}$$

$$= 0.134\text{ kg/mg}$$

$$RC_i = \frac{20\text{ m}^3\text{/day} \times 0.0055\text{ atm-m}^3\text{/mol} \times (1.63 \times 10^{-5}\text{ m/sec}) \times 10^6\text{ cm}^3\text{/m}^3 \times 350\text{ days/yr} \times 30\text{ yr}}{[10^{-6}/(0.029\text{ kg-day/mg})] \times 70\text{ kg} \times 2\text{ cm}^3\text{/g} \times 3.6\text{ m/sec} \times 25{,}550\text{ days} \times 0.02445\text{ atm-m}^3\text{/mol} \times 10^3\text{ g/kg}}$$

$$= 1.73\text{ kg/mg}$$

$$HBG = [(0.0170\text{ kg/mg}) + (0.134\text{ kg/mg}) + (1.73\text{ kg/mg})]^{-1}$$

$$= 0.53\text{ mg/kg}$$

<u>Sample Calculation</u>: TPH as diesel, non-cancer effiects, child resident exposure

$$RC_o = \frac{200\text{ mg/day} \times 350\text{ days/yr} \times 6\text{ yr}}{0.040\text{ mg/kg/day} \times 15\text{ kg} \times 2{,}190\text{ days} \times 10^6\text{ mg/kg}}$$

$$= 3.196 \times 10^{-4}\text{ kg/mg}$$

$$RC_d = \frac{3{,}652\text{ cm}^2 \times 1\text{ mg/cm}^2\text{/day} \times 0.03 \times 350\text{ days/yr} \times 6\text{ yr}}{0.034\text{ mg/kg/day} \times 15\text{ kg} \times 2{,}190\text{ days} \times 10^6\text{ mg/kg}}$$

$$= 2.060 \times 10^{-4}\text{ kg/mg}$$

Table 6-7. Equations for Health-Based Soil Remediation Goals for Residential Exposure, Former Chevron Service Station #9-3864, 5101 Telegraph Avenue, Oakland, California.

$$RC_1 = \frac{0.075\,\text{mg/m}^3 \times 20\,\text{m}^3\text{/day} \times 0.125 \times 350\,\text{days/yr} \times 6\,\text{yr}}{0.0040\,\text{mg/kg/day} \times 15\,\text{kg} \times 2{,}190\,\text{days} \times 10^6\,\text{mg/kg}}$$

$$= 2.997 \times 10^{-6}\,\text{kg/mg}$$

$$HBG = \left[(3.196\times10^{-4}\,\text{kg/mg}) + (2.060\times10^{-4}\,\text{kg/mg}) + (2.997\times10^{-6}\,\text{kg/mg})\right]^{-1}$$

$$= 1{,}900\,\text{mg/kg}$$

Table 6-8. **Health-Based Soil Remediation Goals for a Hypothetical Future Adult Resident, Former Chevron Service Station #9-3864, 5101 Telegraph Avenue, Oakland, California.**

Constituent	Toxicity Values			RCo (kg/mg)	RCd (kg/mg)	RCi (kg/mg)	HBG (mg/kg)
CANCER EFFECTS	CSFo (kg-day/mg)	CSFa (kg-day/mg)	CSFi (kg-day/mg)				
VOC							
Benzene	2.9E-02	2.9E-02	2.9E-02	1.7E-02	1.3E-01	1.7E+00	0.53
NON-CANCER EFFECTS	RfDo (mg/kg/day)	RfDa (mg/kg/day)	RfDi (mg/kg/day)				
VOCs							
Benzene	NA	NA	2.0E-02	NA	NA	7.0E-03	140
Ethylbenzene	1.0E-01	1.0E-01	2.9E-01	1.4E-05	1.1E-04	2.9E-04	2,400
Toluene	2.0E-01	2.0E-01	1.1E-01	6.8E-06	5.4E-05	9.8E-04	960
Xylenes	2.0E+00	2.0E+00	8.6E-02	6.8E-07	5.4E-06	1.2E-04	8,100
TPH							
TPH as diesel	4.0E-02	3.4E-02	4.0E-03	3.4E-05	3.8E-05	6.4E-07	14,000
TPH as gasoline	6.0E-02	6.0E-02	5.7E-02	2.3E-05	7.2E-05	4.5E-08	11,000

The proposed health-based remediation goal is the lesser concentration of the HBGs for cancer effects and non-cancer effects.

CSFa	Adjusted cancer slope factor.	RCo	Oral route component.
CSFi	Inhalation cancer slope factor.	RfDa	Adjusted reference dose.
CSFo	Oral cancer slope factor.	RfDi	Inhalation reference dose.
HBG	Health-based remediation goal.	RfDo	Oral reference dose.
NA	Not available.	TPH	Total petroleum hydrocarbons.
RCd	Dermal route component.	VOC	Volatile organic compound.
RCi	Inhalation route component.		

Table 6-9. **Health-Based Soil Remediation Goals for a Hypothetical Future Child Resident, Former Chevron Service Station #9-3864, 5101 Telegraph Avenue, Oakland, California.**

Constituent	Toxicity Values			RCo (kg/mg)	RCd (kg/mg)	RCi (kg/mg)	HBG (mg/kg)
CANCER EFFECTS	CSFo (kg-day/mg)	CSFa (kg-day/mg)	CSFi (kg-day/mg)				
VOC							
Benzene	2.9E-02	2.9E-02	2.9E-02	3.2E-02	1.5E-01	1.6E+00	0.56
NON-CANCER EFFECTS	RfDo (mg/kg/day)	RfDa (mg/kg/day)	RfDi (mg/kg/day)				
VOCs							
Benzene	NA	NA	2.0E-02	NA	NA	3.3E-02	31
Ethylbenzene	1.0E-01	1.0E-01	2.9E-01	1.3E-04	5.8E-04	1.4E-03	480
Toluene	2.0E-01	2.0E-01	1.1E-01	6.4E-05	2.9E-04	4.8E-03	190
Xylenes	2.0E+00	2.0E+00	8.6E-02	6.4E-06	2.9E-05	5.5E-04	1,700
TPH							
TPH as diesel	4.0E-02	3.4E-02	4.0E-03	3.2E-04	2.1E-04	3.0E-06	1,900
TPH as gasoline	6.0E-02	6.0E-02	5.7E-02	2.1E-04	3.9E-04	2.1E-07	1,700

The proposed health-based remediation goal is the lesser concentration of the HBGs for cancer effects and non-cancer effects.

CSFa	Adjusted cancer slope factor.
CSFi	Inhalation cancer slope factor.
CSFo	Oral cancer slope factor.
HBG	Health-based remediation goal.
NA	Not available.
RCd	Dermal route component.
RCi	Inhalation route component.
RCo	Oral route component.
RfDa	Adjusted reference dose.
RfDi	Inhalation reference dose.
RfDo	Oral reference dose.
TPH	Total petroleum hydrocarbons.
VOC	Volatile organic compound.

Table 6-10. Health-Based Soil Remediation Goal for Lead in Soil for a Construction Worker, Former Chevron Service Station #9-3864, 5101 Telegraph Avenue, Oakland, California.

	Acceptable Blood Lead Level (a) (µg Pb/dL)	Intake to Blood Lead Level Factor (b) (µg Pb/dL per µg/day)	Theoretically Safe Level of Intake (c) (µg/day)	Background Levels			Revised Theoretically Safe Level of Intake (c) (µg/day)	HBG (mg/kg)
				Average Dietary Intake (µg/day)	Average Water Intake (µg/day)	Average Inhalation Intake (µg/day)		
RME Adult	10	0.05	200	31	4.5	2.5	162	340

$$\text{Soil Criterion} = \frac{\text{Revised Theoretically Safe Level of Intake} \times 1{,}000{,}000 \text{ mg/kg}}{(\text{Soil Ingestion Rate} + [\text{Inhalation Rate} \times \text{Suspended Respirable Particulates}]) \times 1{,}000\ \mu\text{g/mg}}$$

Adult soil ingestion rate =	480 mg/day
Inhalation rate =	20 m^3/day
Suspend respirable particulates =	0.075 mg/m^3

(a) Concentration given in micrograms of lead per deciliter (µg Pb/dL) of blood.
(b) The Slope estimate for blood lead increase in response to lead exposure.
(c) Theoretically safe level of intake calculated by dividing the acceptable blood lead level by the slope factor.

HBG Health-based remediation goal.
RME Reasonable maximum exposure.

Table 6-11. Equations for Health-Based Ground-Water Remediation Goals, Former Chevron Service Station #9-3864, 5101 Telegraph Avenue, Oakland, California.

EF	exposure frequency (days/yr) = 350 days/year;
EP	exposure period (yr) = 30 years for an adult, or 6 years for a child;
H	Henry's Law Constant (atm-m^3/mol) = constituent-specific value;
HBG	health-based remediation goal for ground water (mg/L);
IR	inhalation rate (daily average) (m^3/day) = 20 m^3/day;
L	depth to ground water (cm) = 15 feet = 457.2 cm;
LT	expected lifetime (averaging period for cancer effects) (yr) = 70 years;
n	number of data points;
P_t	total porosity (untiless) = 0.4;
RfD	reference dose for inhalation exposure (mg/kg/day) = constituent-specific value;
RT	universal gas constant × soil temperature (atm-m^3/mol) = 0.02404 atm-m^3/mol (assumed T = 293 K);
t	diffusion time (sec) = 2.0736×10^7 sec = 8 months;
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;
UC_3	unit conversion = 10^4 cm^2/m^2;
UC_4	unit conversion = 3,600 sec/hour;

Table 6-11. Equations for Health-Based Ground-Water Remediation Goals, Former Chevron Service Station #9-3864, 5101 Telegraph Avenue, Oakland, California.

V	volume of building (m^3) = 425 m^3; and
z	point just below the surface, from which diffusion into the air is assumed to occur = 0.1 cm (same as d).

<u>Sample Calculation</u> (benzene, adult resident):

$$\Sigma_o = \exp\left[\frac{(-0.0275\,\mathrm{cm}^2/\mathrm{s})\,\pi^2\,(2.0736\times10^7\,\mathrm{sec})}{4\,(457.2\,\mathrm{cm})^2}\right]\cos\left[\frac{\pi\,(457.2\,\mathrm{cm}-0.1\,\mathrm{cm})}{2\,(457.2\,\mathrm{cm})}\right]$$

$$= 4.0996\times10^{-7}$$

For cancer risk: (units omitted)

$$\mathrm{HBG} = \frac{(1\times10^{-6})\times\pi\times0.1\times0.02404\times1.5\times425\times70\times70\times365}{0.0055\times(4.0996\times10^{-7})\times4\times0.0932\times0.2438\times0.029\times20\times350\times30\times10^{-3}\times10^{4}\times3600}$$

$$= 192\ \mathrm{mg/L}$$

For noncancer risk:

$$\mathrm{HBG} = \frac{1\times0.020\times\pi\times0.1\times0.02404\times1.5\times425\times70\times365}{0.0055\times(4.0996\times10^{-7})\times4\times0.0932\times0.2438\times20\times350\times10^{-3}\times10^{4}\times3600}$$

$$= 47{,}640\ \mathrm{mg/L}$$

The lower of these two (190 mg/L) is selected as the more conservative HBG value.

Table 6-12. Health-Based Ground-Water Remediation Goals for a Hypothetical Future Adult Resident, Former Chevron Service Station #9-3864, 5101 Telegraph Avenue, Oakland, California.

Constituent	H (atm-m³/mol)	Do (cm²/s)	Ds (cm²/s)	Toxicity Value	Ground-Water HBG (mg/L)
CANCER EFFECTS				CSFi (kg-day/mg)	
VOC					
Benzene	5.5E-03	0.0932	0.0275	2.9E-02	190
NON-CANCER EFFECTS				RfDi (mg/kg/day)	
VOCs					
Benzene	5.5E-03	0.0932	0.0275	2.0E-02	47,000
Ethylbenzene	8.7E-03	0.06667	0.0196	2.9E-01	89,000
Toluene	6.7E-03	0.07828	0.0231	1.1E-01	87,000
Xylenes	6.3E-03	0.07164	0.0211	3.6E-02	20,000
TPH as gasoline [a]	7.7E-01	0.07461	0.0220	5.7E-02	310

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

CSFi	Cancer slope factor for inhalation exposure (kg-day/mg).
Do	Diffusion coefficient in air (cm²/sec).
Ds	Effective vapor-phase diffusion coefficient in soil (cm²/sec).
H	Henry's Law Constant (atm-m³/mol).
HBG	Health-based remediation goal for ground water (mg/L).
RfDi	Reference dose for inhalation exposure (mg/kg/day).
TPH	Total petroleum hydrocarbons.
VOC	Volatile organic compound.

Table 6-13. Health-Based Ground-Water Remediation Goals for a Hypothetical Future Child Resident, Former Chevron Service Station #9-3864, 5101 Telegraph Avenue, Oakland, California.

Constituent	H (atm-m³/mol)	Do (cm²/s)	Ds (cm²/s)	Toxicity Value	Ground-Water HBG (mg/L)
CANCER EFFECTS				CSFi (kg-day/mg)	
VOC					
Benzene	5.5E-03	0.0932	0.0275	2.9E-02	200
NON-CANCER EFFECTS				RfDi (mg/kg/day)	
VOCs					
Benzene	5.5E-03	0.0932	0.0275	2.0E-02	10,000
Ethylbenzene	8.7E-03	0.06667	0.0196	2.9E-01	19,000
Toluene	6.7E-03	0.07828	0.0231	1.1E-01	19,000
Xylenes	6.3E-03	0.07164	0.0211	3.6E-02	4,400
TPH as gasoline [a]	7.7E-01	0.07461	0.0220	5.7E-02	70

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

CSFi	Cancer slope factor for inhalation exposure (kg-day/mg).
Do	Diffusion coefficient in air (cm²/sec).
Ds	Effective vapor-phase diffusion coefficient in soil (cm²/sec).
H	Henry's Law Constant (atm-m³/mol).
HBG	Health-based remediation goal for ground water (mg/L).
RfDi	Reference dose for inhalation exposure (mg/kg/day).
TPH	Total petroleum hydrocarbons.
VOC	Volatile organic compound.

Table 8-1. Comparison of Calculated Health-Based Remediation Goals to Site-Related Concentrations, Former Chevron Service Station #9-3864, 5101 Telegraph Avenue, Oakland, California.

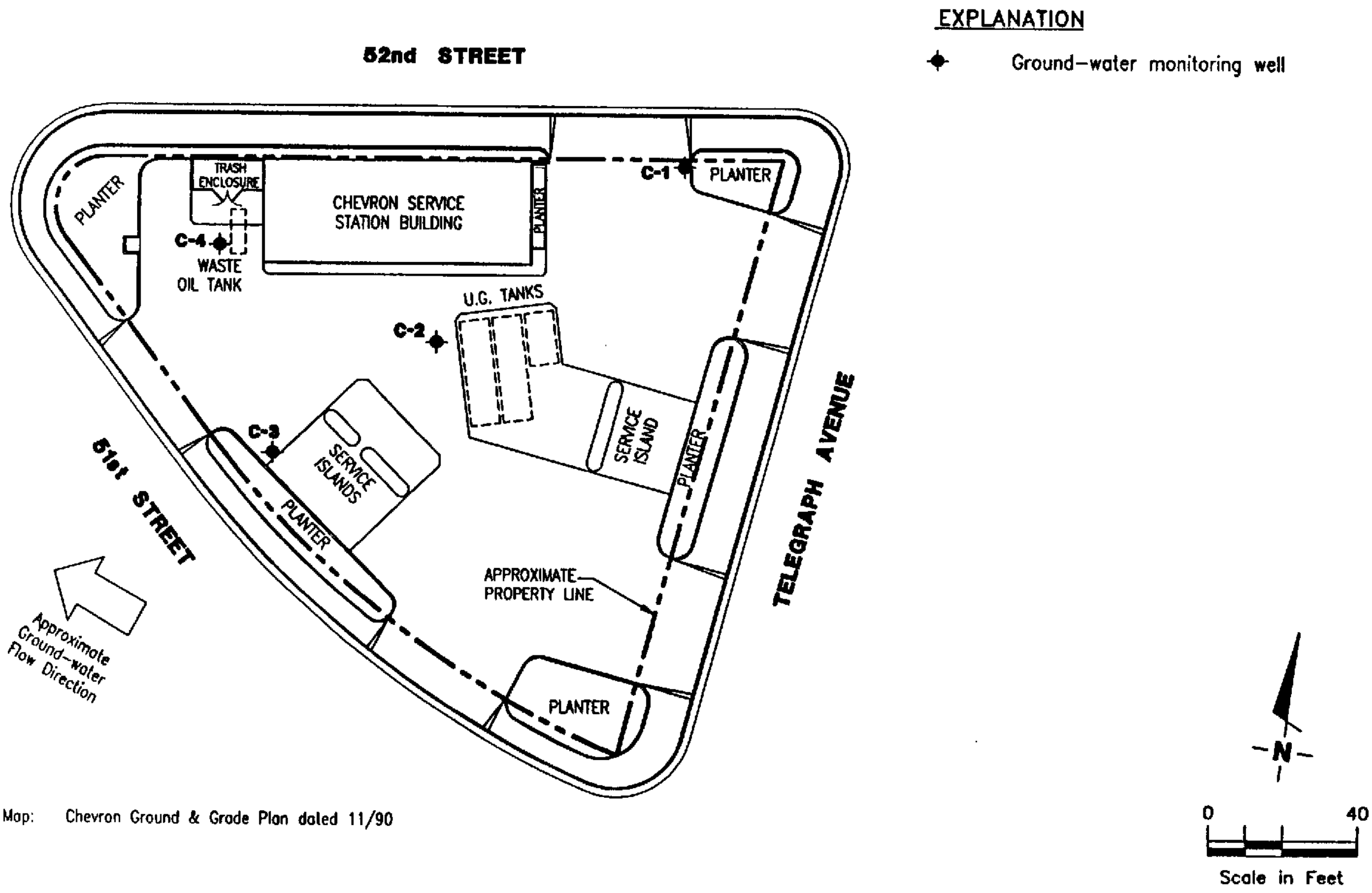
	Calculated HBGs				Site-Related Concentrations			
					Current Data			
Constituent	Construction Worker	Adult Resident	Child Resident	Minimum HBG	UCL	Maximum	Historical Maximum	Does Site Exceed HBG ?
SOIL								
VOCs								
Benzene	20	0.53	0.56	0.53	0.022	0.069	NA	No
Ethylbenzene	800	2,400	480	480	0.39	2.5	NA	No
Toluene	1,300	960	190	190	0.34	2.7	NA	No
Xylenes	700	8,100	1,700	700	0.93	5.5	NA	No
TPH								
TPH as diesel	5,600	14,000	1,900	1,900	#N/A	78	NA	No
TPH as gasoline	63,000	11,000	1,700	1,700	130	980	NA	No
Metal								
Lead *	340	1,600	200	200	0.43	0.60	NA	No
GROUND WATER								
VOCs								
Benzene	NE	190	200	190	0.11	0.13	0.34	No
Ethylbenzene	NE	89,000	19,000	19,000	0.011	0.012	0.019	No
Toluene	NE	87,000	19,000	19,000	0.025	0.026	0.17	No
Xylenes	NE	20,000	4,400	4,400	0.026	0.030	0.083	No
TPH as Gasoline	NE	310	70	70	6.5	7.1	7.1	No

Footnotes appear on page 2.

Table 8-1. Comparison of Calculated Health-Based Remediation Goals to Site-Related Concentrations, Former Chevron Service Station #9-3864, 5101 Telegraph Avenue, Oakland, California.

Soil concentrations are reported in milligrams per kilogram (mg/kg); ground-water concentrations are reported in milligrams per liter (mg/L).

*	HBGs for lead were calculated using the biokinetic/uptake model.
HBG	Health-based remediation goal.
NA	Historical maximum concentrations are not relevant for soil, only for ground water.
NE	Not evaluated. Ground water exposure was not evaluated for the construction worker since the residential exposure is a more significant potential exposure scenario.
TPH	Total petroleum hydrocarbons.
UCL	Upper 95 percent confidence limit on the mean.
VOCs	Volatile organic compounds.



Base Map: Chevron Ground & Grade Plan dated 11/90

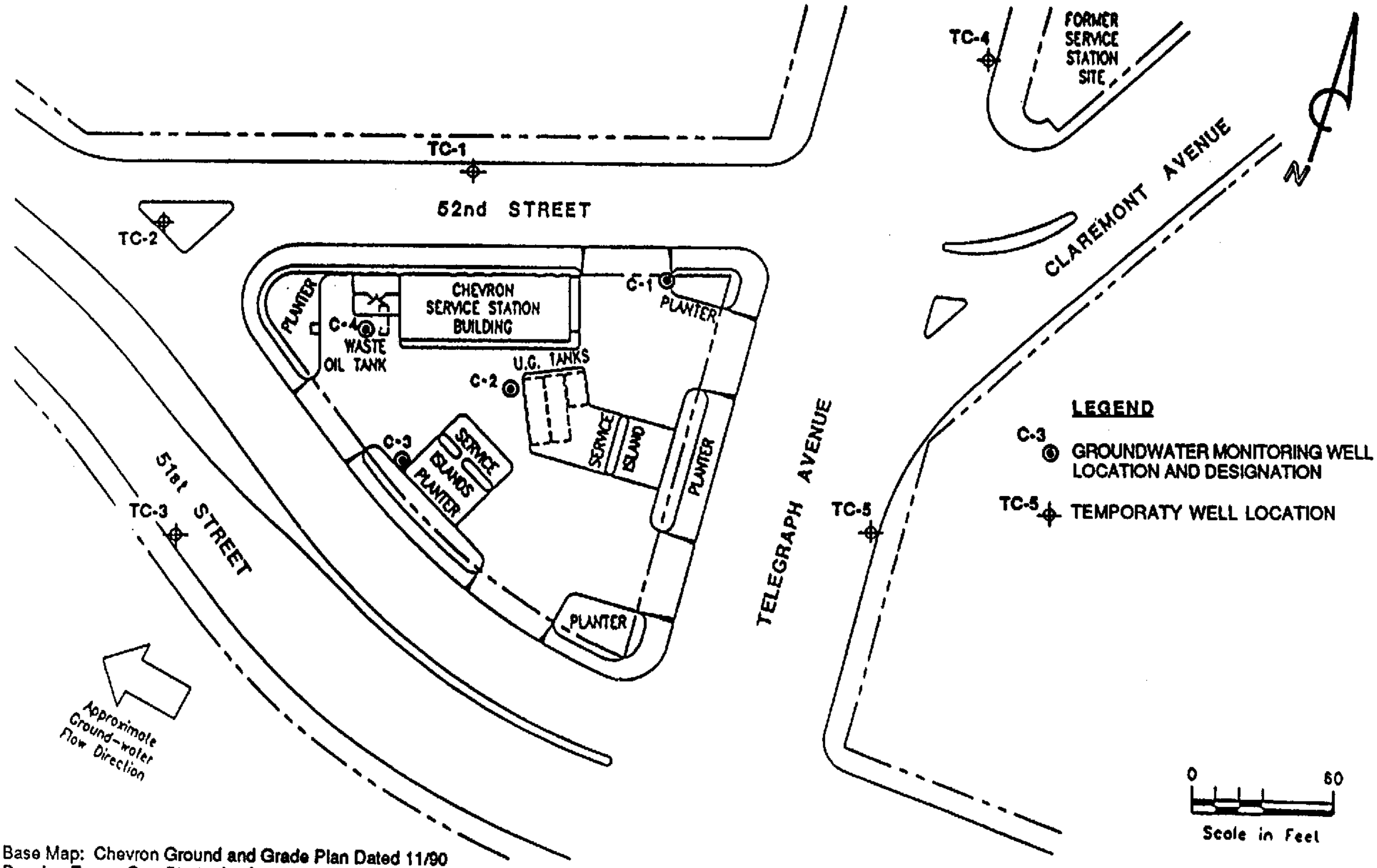
GeoStrategies Inc.

SITE PLAN

Former Chevron Service Station #9-3864
5101 Telegraph Avenue, Oakland, California

Figure 2-1

JOB NUMBER	REVIEWED BY	DATE	REVISED DATE
727702-2	DHP	1/91	



Base Map: Chevron Ground and Grade Plan Dated 11/90
Drawing From: Geo-Strategies Inc.

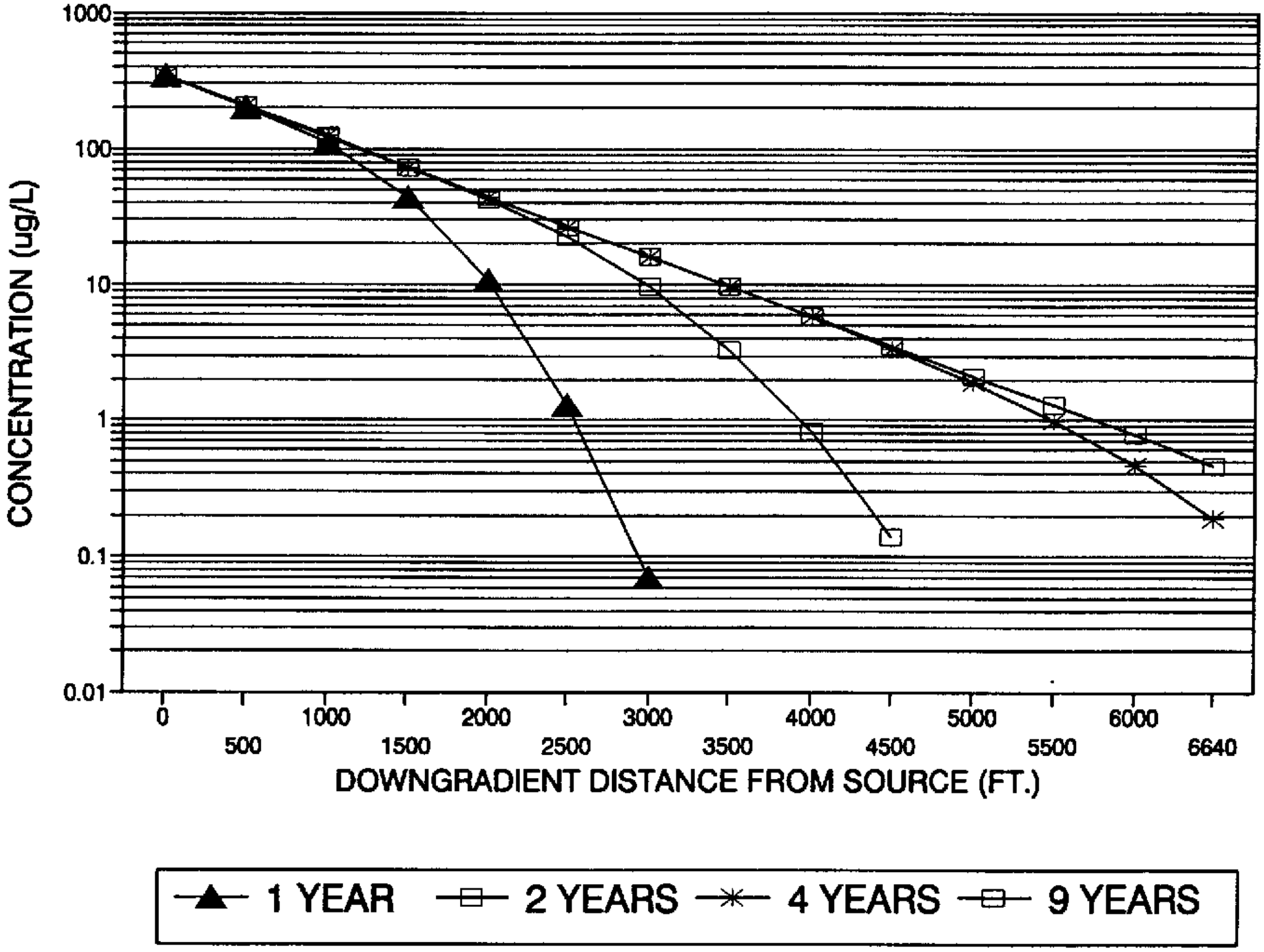
PACIFIC
ENVIRONMENTAL
GROUP, INC.

CHEVRON SERVICE STATION 9-3864
5101 Telegraph Avenue
Oakland, California

SITE PLAN SHOWING OFF-SITE WELL LOCATIONS

Figure 2-2

BENZENE CONC. (ug/L) VS. DISTANCE FROM THE SOURCE FOR VARIOUS TIMES



GERAGHTY & MILLER, INC.
Environmental Services

RESULTS OF GROUND WATER TRANSPORT MODELING
Former Chevron Service Station #9-3864
5101 Telegraph Avenue, Oakland, California

Figure
5-1

APPENDIX A

CALCULATION OF HEALTH-BASED REMEDIAL GOALS

INTRODUCTION

This appendix presents the model used in deriving the equation shown in Table 6-10 and used to calculate the health-based remedial goals (HBGs) in Tables 6-11 and 6-12. 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 a 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 a residential scenario.

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:

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

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 (8.206×10^{-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):

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

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/sec]);

L = depth to ground water (cm);

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

t = diffusion time (sec); 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 (conservatively assuming no moisture in the soil), the apparent vapor phase diffusion was determined by:

$$D_s = D_o \times P_t^{4/3} \qquad (3)$$

where:

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

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

P_t = total soil porosity (unitless) (assumed value of 0.4 = mid-range of porosities for silt [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.

$$C_s = C(z) \quad \text{for } z = 0.1 \text{ cm} \tag{4}$$

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 a surface adsorption effect is expected), so that the flux through the surface was given by:

$$J = \left(\frac{D_o \times C_s}{d}\right) \times \left(10^4 \ \frac{cm^2}{m^2}\right) \tag{5}$$

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/sec); and

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

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

$$\text{IAC} = \frac{\text{J} \times \text{A}}{\left(\frac{\text{ACH}}{3{,}600 \text{ sec/hr}}\right) \times \text{V}} \tag{6}$$

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/sec); 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:

$$\mathrm{ExD} = \frac{\mathrm{IAC} \times \mathrm{IR} \times \mathrm{EF} \times \mathrm{EP}}{\mathrm{BW} \times \mathrm{AP} \times (365\ \mathrm{days/yr})} \tag{7}$$

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:

$$\mathrm{ExD} = \frac{C_{gw} \times \left(10^{-3}\ \frac{\mathrm{L}}{\mathrm{cm}^3}\right) \times \left(\frac{H}{RT}\right) \times \sum_o \times 4D_o \times \left(10^4\ \frac{\mathrm{cm}^2}{\mathrm{m}^2}\right) \times A \times \mathrm{IR} \times \mathrm{EF} \times \mathrm{EP}}{\pi \times d \times \left(\frac{\mathrm{ACH}}{3{,}600\ \mathrm{sec/hr}}\right) \times V \times \mathrm{BW} \times \mathrm{AP} \times (365\ \mathrm{days/yr})} \tag{8}$$

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

$$\sum_o = \exp\left[\frac{-D_s \pi^2 t}{4L^2}\right] \cos\left[\frac{\pi (L - z)}{2L}\right] \tag{9}$$

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

$$\text{CANCER EFFECTS:} \quad ELCR = ExD \times CSF$$

$$\text{NON-CANCER EFFECTS:} \quad HQ = \frac{ExD}{RfD} \tag{10}$$

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 REMEDIATION GOALS FOR GROUND WATER

Health-based remediation goals (HBGs) were calculated to meet acceptable risk criteria, based upon the exposure dose associated with a residential 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 (TCR) was conservatively set at 10^{-6}, and the "target" hazard quotient (THQ) 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:

$$HBG = \frac{TCR \times \pi \times d \times RT \times ACH \times V \times BW \times LT \times UC_1}{H \times \sum_o \times 4D_o \times A \times CSF \times IR \times EF \times EP \times UC_2 \times UC_3 \times UC_4} \quad (11)$$

For non-cancer risk:

$$HBG = \frac{THQ \times RfD \times \pi \times d \times RT \times ACH \times V \times BW \times UC_1}{H \times \sum_o \times 4D_o \times A \times IR \times EF \times UC_2 \times UC_3 \times UC_4} \quad (12)$$

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/sec);

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 9;

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 = 10,000 cm^2/m^2.

UC_4 = unit conversion = 3,600 sec/hr.

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.

EXPOSURE PARAMETERS

This subsection presents the residential exposure scenarios used in calculating the HBGs and the selected parameter values. The two scenarios pertain to an adult and a child resident living in the home which was modeled in the calculation of indoor air concentration (Equation 6). Assuming any new homes built on the site would be similar to other homes in the area, the hypothetical building dimensions were 30 feet × 50 feet (1,500 square feet) (a represesentative size obtained from an aerial photograph of the site). For an adult resident, an average body weight of 70 kg and an exposure period (residence time) of 30 years were used. For a child resident (aged 0 to 6 years), an age-averaged body weight of 15 kg and an exposure period of 6 years were used. All of the variables in the HBG calculations and their values are presented below:

A	The area of vapor infiltration (cm) was assumed to be a half-centimeter crack around the circumference of the building foundation: $A = 2 \times (30\ \text{ft} + 50\ \text{ft}) \times 0.3048\ \text{m/ft} \times 0.5\ \text{cm} \times 0.01\ \text{m/cm} = 0.2438\ \text{m}^2$.
AER	The air exchange rate was assumed to be 1.5 hr^{-1}.
BW	Average body weight = 70 kg for an adult, or 15 kg for a child.
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 $D_s = P_t^{4/3} \times D_o$ (conservatively assuming zero moisture in the soil);
EF	An exposure frequency of 350 days/year (7 days/week for 50 weeks/year) was assumed for both residential scenarios.
EP	An exposure period of 30 years (reasonable maximum residency period) was used for the adult resident, and an exposure period of 6 years was used for the child aged 0 to 6 years..
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 15 feet, or 457.2 cm.
LT	The average lifetime (the averaging period for cancer effects) was 70 years.
RT	A soil temperature of 293 K was assumed, giving a value of 0.02404 atm-m^3/mol for RT.
t	A diffusion time of 8 months (2.0736×10^7 sec) was used to calculate Σ_o. An explanation is provided below.
V	A 10-foot ceiling height was assumed, so that a building volume of 425 m^3 was obtained: $V = (30\ \text{ft} \times 50\ \text{ft} \times 10\ \text{ft}) \times (0.3048\ \text{m/ft})^3 = 425\ \text{m}^3$.
z	The volatilization depth below the soil surface (used to calculate Σ_o) was set at 0.1 cm (same value as d).

The diffusion time of 8 months (2.0736×10^7 sec) was calculated based upon the currently measured benzene concentration and the assumed soil parameters. Using the benzene

UCL concentration of 0.11 mg/L, a source soil vapor concentration (C_o) of 2.5×10^{-5} mg/m^3 was calculated using Equation 1. A typical detection limit for benzene in air is 0.005 mg/m^3 (although this depends upon measuring technique and aquisition time). Using this detection limit as C_s and the calculated C_o, Equation 2 was solved for a t value of approximately 9 months. To be conservative, a diffusion time of 8 months was selected.

The variables which had constituent-specific values (H, D_o, D_s, CSF, and RfD) are shown along with the calculated HBGs for the adult and child residents in Tables 6-11 and 6-12, respectively.

APPENDIX A REFERENCES

Freeze, R. A., and J. A. Cherry, 1979. Groundwater. Prentice-Hall, Inc. Englewood Cliffs, NJ.

Jury, W.A., W.F. Spencer, and W.J. Farmer, 1984. Behavior Assessment Model for Trace Organics in Soil: IV. Review of Experimental Evidence. J. Environ. Qual. 13:580-586.

Lyman, W.J., W.F. Reehl, and D.H. Rosenblatt, 1990. Handbook of Chemical Property Estimation Methods. American Chemical Society, Washington, DC.

Mayer, P., J. Letey, and W.J. Farmer, 1974. Models for Predicting Volatilization of Soil-Incorporated Pesticides. Soil. Sci. Soc. Amer. Proc. 38:523-568.

Millington, R.J., and J.P Quirk, 1961. Permeability of Porous Solids. Trans. Faraday Soc. 57:1200-1207, as cited by Lyman et al., 1990.

U.S. Environmental Protection Agency (USEPA), 1991. Role of the Baseline Risk Assessment in Superfund Remedy Selection Decisions. OSWER Directive 9355.0-30. April 22.