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RISK ASSESSMENT REPORT
ELECTRO-COATINGS, INC. FACILITY
EMERYVILLE, CALIFORNIA

December 1996

Prepared for

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Provided by GERAGHTY & MILLER, INC.

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EXECUTIVE SUMMARY

The purpose of this risk assessment is to evaluate potential human health and ecological risks associated with detected constituent concentrations in subsurface soil and shallow groundwater at the facility in Emeryville, California. The facility consists of two parcels (the "Site"), 1401 Park Avenue which is owned by Electro-Coatings, Inc. and 1421 Park Avenue which is owned by 1421 Park Avenue Associates. Analytical soil and groundwater data from the Site were reviewed, and constituents of potential concern (COPCs) were selected for each medium based on comparison with U.S. Environmental Protection Agency (USEPA) Region IX Preliminary Remediation Goals (PRGs).

Past, current, and potential future conditions and uses at the Site were considered in selecting appropriate human exposure scenarios to include in the risk assessment calculations. Potential exposure scenarios for subsurface soil include: (1) site worker exposure to surface soil (conservatively assuming that hypothetical future construction activity at the Site brings the current subsurface soil concentrations to the surface, where typical site workers could contact the soil constituents on a daily basis); (2) hypothetical excavation worker exposure to subsurface soil; and (3) site worker exposure to indoor air affected by vapor intrusion of volatile constituents from subsurface soil. The first scenario (site worker exposure to surface soil) is particularly unlikely because the primary COPCs in soil are highly volatile and likely would be removed by the soil agitation and aeration associated with construction activities, and because no such construction activity is planned for the Site. Potential exposure scenarios for the shallow groundwater include: (1) hypothetical excavation worker exposure, and (2) site worker exposure to indoor air affected by vapor intrusion of volatile constituents from the groundwater. Conservative exposure assumptions were used in all of the risk calculations.

Calculated risks for cancer and non-cancer effects in the above-listed exposure scenarios were all below the benchmarks for acceptable cancer (10^{-6}) and non-cancer (1) risks. Total site risks for the two hypothetical receptors (site worker and excavation worker) were calculated by summing the total risks from each exposure scenario involving that receptor. The total site cancer risk for the site worker (1×10^{-6}, summing results from all the soil and groundwater exposure scenarios) is equal to the acceptable level of cancer risk, and the total site non-cancer risk (0.08) is well below the acceptable level for non-cancer risk (1). The total site cancer and non-cancer risks for the excavation worker (summing the results from the soil and groundwater exposure scenarios) were 2×10^{-7} and 0.4, respectively, both of which are below the benchmarks for acceptable risks. These results indicate that the site-related soil and groundwater concentrations do not pose unacceptable human health risks under the assumed exposure conditions.

There are no current exposure pathways for ecological receptors at the Site. However, if groundwater constituents from the Site were to discharge into San Francisco Bay, aquatic life in the bay might be affected. To evaluate this potential exposure pathway, a simple groundwater transport model was used to estimate the groundwater concentrations at the point of discharge into the bay. The effects of dilution by discharge into the waters of the bay were not included in the calculations. The model results indicated that the concentrations of the organic constituents at the point of discharge would be 0 (zero) milligrams per liter (mg/L). The transported concentration of hexavalent chromium (0.07 mg/L) slightly exceeded the chronic criteria for marine aquatic life (0.05 mg/L), but did not exceed the acute criteria (1.1 mg/L). The transport calculations for hexavalent chromium did not consider the effects of the natural reduction to trivalent chromium (less toxic, more stable, and less mobile) because suitable half-life data were not available. This reduction process is expected to bring the hexavalent chromium concentration below the criteria levels well before it reaches the bay, and dilution effects due to discharge into the waters of the bay (also not considered in the model) are expected to further decrease the constituent concentrations. With these considerations, the ecological risk assessment concludes that groundwater constituents from the Site do not pose a threat to aquatic life in the bay.

Potential risks associated with detected subsurface soil and groundwater constituents at the Site were evaluated in the risk assessment. The results of the risk assessment calculations indicate that there is no threat to human health or the environment at or in the vicinity of the Site.

In the event that future site investigation(s) involve the collection of additional analytical data at the Site, risk-based concentration goals (RBGs) were derived for use in screening the new data. The RBGs presented here are based on the theoretical risks calculated for the hypothetical site worker and excavation worker exposure scenarios. For potential cancer effects, the RBGs were derived based on a 10^{-6} to 10^{-4} range of acceptable cancer risk; for non-cancer effects, the RBGs were based on an acceptable risk of 1. The calculated RBGs for the COPCs in subsurface soil and groundwater are summarized in Table E-1. The soil RBGs based on direct exposure for a site worker (assuming future excavation brings subsurface soil to the surface, retaining current subsurface concentrations) are omitted from this summary table because of the highly unlikely nature of the exposure scenario; however, those RBG values are presented in the risk assessment report. For constituents with potential cancer and non-cancer effects, the lesser (more protective) RBG value (or range of values) is presented. Details of the calculations are presented in the body of the risk assessment report. Future exceedances of these RBG levels do not necessarily imply that unacceptable levels of risk are present; however, it may indicate the need for additional review of potential risks at the Site.

Table E-1. Summary of Calculated Risk-Based Goals, Electro-Coatings, Inc., Emeryville, California.

	Groundwater RBGs (mg/L)				Soil RBGs (mg/kg)			
Constituent	Site Worker (Vapor Intrusion)		Excavation Worker (Direct Contact)		Site Worker (Vapor Intrusion)		Excavation Worker (Direct Contact)	
		C or NC *		C or NC *		C or NC *		C or NC *
VOCs								
Chlorobenzene	50,000	NC	10	NC	–	–	–	–
1,1-Dichloroethene	30 - 3,000	C	3 - 20	C [a]	–	–	–	–
cis-1,2-Dichloroethene	90,000	NC	300	NC	–	–	–	–
trans-1,2-Dichloroethene	90,000	NC	500	NC	–	–	–	–
Tetrachloroethene	20,000 - 100,000	C [a]	10 - 90	C [a]	–	–	–	–
1,1,1-Trichloroethane	700,000	NC	2,000	NC	–	–	–	–
Trichloroethene	2,000 - 20,000	C [a]	10	NC	70 - 900	C [a]	600	NC
Vinyl chloride	20 - 2,000	C	2 - 200	C	6 - 600	C	50 - 5,000	C
Inorganics								
Chromium (total)	NAP	–	70,000	NC	NAP	–	200,000	NC
Chromium (hexavalent)	NAP	–	1,000	NC	NAP	–	4,000	NC

* 'C' indicates the RBG is based on cancer effects (using a target cancer risk range of 10^{-6} to 10^{-4}); 'NC' indicates the RBG is based on non-cancer effects (using a target hazard index of 1).

[a] The upper level of the range is based on non-cancer effects (RBC_{NC}) because the RBC_C for a target cancer risk of 10^{-4} exceeds this level.

ELCR	Excess lifetime cancer risk
HI	Hazard index.
mg/kg	Milligrams per kilogram.
NAP	Not applicable.
RBG	Risk-based concentration goal for soil.

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1.0 INTRODUCTION

This risk assessment was prepared on behalf of Electro-Coatings, Inc. (ECI), of Martinez, California. The purpose of the work is to evaluate potential human health and environmental risks at ECI's facility in Emeryville, California. This document provides a brief description and history of the Site followed by discussions of site data, exposure assessment, toxicity assessment, and risk characterization. This risk assessment includes an explanation of the methodology and assumptions that were used to evaluate potential risks posed by site-related constituents that have been encountered at the Site.

The risk assessment methodology is based on the Risk Assessment Guidance for Superfund (U.S. Environmental Protection Agency [USEPA], 1989a) and conforms to USEPA guidance for baseline risk assessments (USEPA, 1991a,b,c; 1989a,b,c). This risk assessment follows the Risk Assessment Work Plan (Geraghty & Miller, 1996), which was reviewed and approved by the California Regional Water Quality Control Board (CRWQCB). All departures from the Work Plan were approved in telephone communications with a representative of the CRWQCB (November 1 and 4, 1996; telephone communications of Dr. Shawn L. Sager and Ms. Amy H. Bass [Geraghty & Miller] with Mr. Sumadhu Arigala [CRWQCB]).

The data collected at the Site during the various phases of site investigation were statistically summarized for the development of this risk assessment. The risk assessment focuses on site-related constituents: chlorinated volatile organic compounds (VOCs), nickel, and chromium (total and hexavalent). The baseline risk assessment is based on the assumption that no remedial (corrective) action will take place at the Site; therefore, the Site was evaluated as it existed at the time of environmental sampling.

2.0 SITE CHARACTERIZATION

The ECI facility is in a highly industrialized area of Emeryville, California, north of Interstate 580-Highway 24 and east of Interstate 80 (Figure 2-1). The facility consists of two parcels (the "Site"), 1401 Park Avenue which is owned by Electro-Coatings, Inc. and 1421 Park Avenue which is owned by 1421 Park Avenue Associates. Buildings are adjacent to the northern and eastern property boundaries; parking and paved areas are south and west of the primary buildings (Figure 2-2). The Site is bordered by Park Avenue to the north, a lumber yard and parking area to the south, a dirt alley with a buried railroad track to the east, and a clothing outlet and a crematorium to the west. The dirt alley east of the Site reportedly is scheduled to be improved as an extension of Holden Street between Park Avenue and 40th Street. The Southern Pacific Railroad right-of-way, about 140 feet to the south, is being reconstructed as an extension of 40th Street. Horton Street lies approximately 80 feet west of the Site, and San Francisco Bay is approximately 2,500 feet west.

ECI began metal plating operations at the Site in 1963 when they purchased the assets of Industrial Hard Chrome Plating Corporation, which operated a chrome plating facility at the Site since 1952 and began nickel plating in the late 1950s. ECI performed hard chrome plating until 1989 and nickel plating until 1994. The facility currently is not in operation. Trichloroethene (TCE) was used by Industrial Hard Chrome Plating Corporation prior to 1963 and by ECI until 1973, when it was replaced with 1,1,1-trichloroethane (111-TCA). These solvents were used to vapor degrease metal parts prior to nickel plating. In 1992, vapor degreasing was discontinued and replaced with a liquid alkaline soak process.

The area surrounding the Site currently is zoned I-C (Custom Manufacturing), which does not allow any residential use of property. In September 1994, the City of Emeryville Zoning Ordinance Revision Committee conducted a public workshop as part of the city's effort to update the land-use policies and design guidelines for the creation of a Revitalization Strategy/Zoning Overlay District for five blocks along Park Avenue, including the ECI facility. The city has expressed the intent to preserve the character of this district while allowing new uses by non-industrial commercial businesses. According to the property owner, there currently are no plans to redevelop the Site.

2.1 HYDROGEOLOGY

The Site generally is underlain by clays and silty clays to approximately 15 feet below land surface (ft bls). The sediments become coarser, consisting of layers of sand and gravel with varying silt and clay content, between about 15 and 30 ft bls. This coarser zone comprises the water-bearing unit and shallow aquifer. The shallow aquifer is semi-confined to confined, with a potentiometric surface roughly 6 to 9 ft bls and a hydraulic gradient to the west and northwest. Measured aquifer permeability for the shallow aquifer is 28 cubic feet per day per square foot ($ft^3/day/ft^2$), which is typical for sand and gravel aquifers (ENTRIX, Inc. [ENTRIX], 1994).

Underlying the shallow aquifer is an extensive blue clay with small lenses of sand and gravel. The potentiometric surface of the deeper wells (3A and 18A) reveals a slight vertically downward hydraulic head, while Monitor Well (MW) 20 shows an upward vertical head of about 3 feet above the shallow potentiometric surface. This upward head indicates that groundwater constituents are not likely to migrate below the shallow aquifer under natural conditions (ENTRIX, 1994). Empirical data indicate that there has been no downward movement of the constituents.

Groundwater from beneath the Site flows to the west and northwest, ultimately discharging into San Francisco Bay. Groundwater is not in use at the Site or in the vicinity of the Site. Drinking water to the City of Emeryville is provided by East Bay Municipal Utilities District.

2.2 POTENTIAL SOURCE AREAS

Potential constituent source areas were identified at the Site. The chromium waste storage area, directly behind the 1401 Park Avenue building in the southeast corner of the facility, was identified as a likely source of chromium contamination. A leaking concrete vault or tank was reported in that area sometime in either 1974 or 1977 (records are unclear), and groundwater quality data indicate that elevated chromium concentrations probably originated in this area (ENTRIX, 1994). Nickel plating was performed only on the 1421 Park Avenue parcel, and chrome plating was performed only on the 1401 Park Avenue parcel. All metal degreasing operations (associated with the nickel plating operations) were performed in the southwest portion of the facility on the 1421 Park Avenue parcel. TCE was used as the degreasing solvent until 1973, when it was replaced with 111-TCA. Vapor degreasing was discontinued in 1992. The vapor degreasing area is the only potential on-site source of the elevated levels of TCE which were measured in the groundwater; no solvent leaks or spills were reported in this area. A 500-gallon gasoline underground storage tank (UST) reportedly exists west of the 1421 Park Avenue building. No investigation has been performed to locate or assess the integrity of this UST; however, analytical data have not indicated any detectable quantities of benzene, toluene, ethylbenzene, or xylenes (BTEX), which are commonly found in gasoline. The absence of these constituents indicates that there probably has been no significant release of gasoline at the Site.

3.0 DATA SUMMARY

This section describes the occurrence of constituents detected in environmental media at the Site. Prior to statistical analyses, these data were separated into two groups according to medium: (1) on-site groundwater and (2) on-site subsurface soil. The following sections summarize the data reduction procedure and the occurrence of constituents in these media.

3.1 DATA REDUCTION

The data were reduced and analyzed for use in the risk assessment according to the guidelines provided by USEPA (1989a) guidance, as described below:

- Constituents that have never been detected in a data group were eliminated from further analysis for that group;
- All analytical results reported as detects, including laboratory estimated (J-qualified) data, were used at the reported value;
- For constituents within a data group reported as non-detected (non-detects), one-half of the sample quantitation limit (SQL) was used as a proxy concentration rather than using zero or eliminating the data point. In instances where one-half of the SQL exceeded the maximum detected concentration for that constituent in that data group (i.e., an unusually high SQL), the maximum detect was used as the proxy value for that non-detect.

The results of the statistical analyses are presented in the constituent occurrence tables (Tables 3-1 [groundwater data] and 3-2 [soil data]). The information in these tables includes, for each detected constituent, the frequency of detection (ratio of the number of detects to the total number of relevant samples in that group), the range of SQLs for non-detects in the dataset, the range of detected values, the average detected value, the arithmetic mean, the one-tailed 95 percent upper confidence level (UCL) on the arithmetic mean (assuming a normal distribution), USEPA Region IX preliminary remediation goals (PRGs), and the exposure point concentration (EPC) to be used in the risk calculations for constituents of potential concern (COPCs). The mean and UCL concentrations were calculated using appropriate proxy concentrations for non-detects.

The UCL is a statistical number 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} 95 percent upper confidence level for the mean; and

$\bar{x}$ sample mean (average).

Assuming the samples were selected randomly from the Site, statistical theory asserts that there is a 95 percent probability that the true mean concentration for the Site lies below the UCL concentration. 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.

3.2 OCCURRENCE IN GROUNDWATER SAMPLES

Groundwater samples have been collected at the Site since 1977. In samples collected prior to March 1985, analyses were performed only for total and hexavalent chromium. Since March 1985, groundwater samples have been analyzed for chlorinated solvents, and most were also analyzed for total and hexavalent chromium. The most recent groundwater data were collected in September 1996. All available data were included in the statistical analyses to select COPCs and to calculate the UCLs for use in the risk assessment calculations.

Table 3-1 presents occurrence information for constituents detected in groundwater samples collected at the Site. Samples collected from MW-1, MW-2, MW-8, and MW-21 are designated as background and were not included in the site-related data. As shown in the table, 11 VOCs, all classified as chlorinated solvents, were detected in the on-site groundwater. 1,2-Dichlorobenzene (12-DCB) was detected in only 3 of 66 samples; 1,2-dichloroethane (12-DCA) was detected in only 4 of 66 samples; and chlorobenzene was detected in only 5 of 66 samples. All other VOCs listed in the table were detected in 18 or more on-site samples. Chromium was detected as hexavalent chromium in 97 of 125 samples and as total chromium (hexavalent and trivalent) in 131 of 148 samples. Throughout the risk assessment, total chromium results are evaluated as trivalent chromium since that is the predominant form in nature and since hexavalent chromium concentrations are available.

All but two of the detected VOCs (chlorobenzene and 12-DCB) were also detected in the background samples. 12-DCA was detected at a slightly higher concentration (0.0056 milligrams per liter [mg/L]) in the background data than the maximum detected on-site concentration (0.0029 mg/L).

3.3 OCCURRENCE IN SOIL SAMPLES

Six soil samples collected by Geraghty & Miller in May 1995 and 53 soil samples collected by ENTRIX in 1980 through 1985 (ENTRIX, 1994) were used to represent current Site conditions. The ENTRIX samples, although collected over 10 years ago, were included to improve the representation of chromium contamination at the Site. Geraghty & Miller collected two subsurface soil samples from each of three locations at the Site: (1) the piping manifold area, (2) beneath the former vapor degreaser, and (3) the former chromium storage area. Four of the Geraghty & Miller samples (the piping manifold and vapor degreaser samples) were analyzed for VOCs and for nickel. The samples from the former chromium storage area were analyzed for total and hexavalent chromium. All of the ENTRIX samples were analyzed for total chromium, and 10 of those samples were also analyzed for hexavalent chromium.

Table 3-2 presents the analytical results for the subsurface soil samples. Five chlorinated VOCs were detected in the Geraghty & Miller soil samples. 1,1,1-Trichloroethane (111-TCA) and vinyl chloride were detected only once in the four samples, and 1,1-dichloroethane (11-DCA) and trichloroethene (TCE) were detected twice. cis-1,2-Dichloroethene (c12-DCE) was detected in all four samples. Total chromium and nickel were detected in all samples analyzed for those parameters. Hexavalent chromium was detected in 4 of 12 samples, but was not detected in either of the samples collected by Geraghty & Miller from the former chromium storage area. The normal background concentration of chromium in soils in the San Francisco area ranges from 100 to 2,000 milligrams per kilogram (mg/kg), with a national average of 54 mg/kg (U.S. Geological Survey [USGS], 1984). For nickel, the normal background concentration range is 30 to 700 mg/kg, with a national average of 19 mg/kg (USGS,. 1984). The maximum detected concentration for total chromium at this site (6,700 mg/kg), exceeds the USGS range, but the maximum detected nickel concentration (310 mg/kg) is within the USGS background range for this area. Throughout the risk assessment, total chromium results are evaluated as trivalent chromium since that is the predominant form in nature and since hexavalent chromium concentrations are available.

3.4 SELECTION OF CONSTITUENTS OF POTENTIAL CONCERN

Identification of the COPCs for the human-health risk assessment was accomplished following USEPA (1989a) guidance. The term "constituent of potential concern" does not indicate that risk is attributable to the constituent discussed at the concentration detected during sampling. The term is used to describe those constituents on which the risk assessment focuses. Conclusions concerning risk should be made only following the quantitative risk assessment.

The occurrence data and the USEPA Region IX PRGs in Tables 3-1 and 3-2 were used to select the COPCs for the risk assessment. Table 3-1 presents the USEPA Region IX PRGs for tap water (USEPA, 1996). Use of tap water PRGs for the selection of COPCs at this site is very conservative since there is no ingestion of or direct exposure to groundwater in the area. Comparison of the maximum detected concentrations to the USEPA Region IX PRGs indicates that all detected concentrations of 12-DCB, 11-DCA, and 12-DCA were below the PRGs for those constituents. Therefore, those three constituents were eliminated from the list of COPCs for the groundwater. Table 3-2 presents the USEPA Region IX PRGs for industrial soil (USEPA, 1996). Comparison of those PRGs to the maximum detected concentrations in soil indicates that all detected concentrations for 11-DCA, c12-DCE, 111-TCA, and nickel were below the PRGs for those constituents. Therefore, these constituents were eliminated from the list of COPCs for soil. Table 3-3 presents the list of COPCs for the sampled media (groundwater and soil) at the Site.

3.5 PHYSICAL AND CHEMICAL PROPERTIES

The environmental fate and transport of constituents are dependent on the physical and chemical properties of the constituents, the environmental transformation processes affecting the constituents, and the media through which they are migrating. The following subsections briefly describe the primary physical and chemical properties of the constituents and their influence on the potential for migration of the COPCs. Then, the mechanisms of migration for the COPCs are discussed.

The physical and chemical properties summarized in Table 3-4 for the organic COPCs include molecular weight, water solubility, specific gravity, vapor pressure, Henry's Law Constant, diffusivity, organic carbon partition coefficient (K_{oc}), octanol-water partition coefficient (K_{ow}), and half-life ($T_{1/2}$) in groundwater and soil.

The water solubility of a substance is an important property affecting environmental fate. Solubility is expressed in terms of the number of milligrams of a constituent dissolving in one liter of water (mg/L; parts per million [ppm]) at a specified temperature and pressure. The solubilities in Table 3-4 were measured under standard conditions of 25 degrees Centigrade (°C) and one atmosphere of pressure, unless noted otherwise. The higher the value of the solubility, the greater the tendency of a constituent to dissolve in water. Highly soluble constituents are generally mobile in groundwater, soil, and surface water. Soluble compounds may be leached from soils and become mobile in groundwater. In general, 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). All of the organic COPCs are fairly soluble chlorinated VOCs, with solubility ranges from a low end of 150 mg/L (150 to 485 mg/L) for tetrachloroethene (also known as perchloroethene [PCE]) to a high of 6,400 mg/L (273 to 6,400 mg/L) for 1,1-dichloroethene (11-DCE). This indicates that these COPCs are relatively mobile in the environment, with a tendency to leach from soil to groundwater or surface water.

The specific gravity of a substance expresses its density relative to that of water. Since densities are temperature-dependent, the relevant temperatures must be specified. The values in Table 3-4 are the densities at 20 °C relative to the density of water at 4 °C. If the specific gravity of a liquid is less than one, it is less dense than water; liquids with specific gravities greater than one are more dense than water. For a separate phase product, a liquid less dense than water will form a layer floating on the water while a liquid less dense that water will form a layer below the water layer. The specific gravity of the pure form of a constituent, relative to water, affects the migrational behavior of the constituent. All of the chlorinated VOCs in Table 3-4, except for vinyl chloride, have a higher specific gravity than water. The pure forms of these chlorinated VOCs are referred to as dense nonaqueous phase liquids (DNAPLs). If these constituents reach the water table in pure form, they will continue to migrate vertically through the saturated zone as DNAPLs.

Volatilization of a constituent from an environmental medium depends on the vapor pressure, water solubility, and diffusion coefficient. Vapor pressure, a relative measure of the volatility of constituents in their pure state, is an indication of the rate of volatilization. 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 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 vapor pressures in Table 3-6 range from a low of 11.8 mm Hg for chlorobenzene to a high of 2,660 mm Hg for vinyl chloride.

The Henry's Law Constant (H), 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} atmosphere × cubic meter 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 (e.g., the remaining organic COPCs) 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 only volatilize from water slowly and to a limited extent (Howard, 1989; Lyman et al., 1990). All of the organic COPCs at this site are in the first two classes, with 111-TCA being the most volatile (H of 0.0162 atm-m^3/mol) and PCE being the least volatile (H of 0.00287 atm-m^3/mol). These H values indicate significant volatility for all of the organic COPCs.

The diffusion coefficient can be used as a means to predict the rate at which a compound moves through the atmosphere. Molecular diffusion is determined both by molecular properties (e.g., size and weight) and by the presence of a concentration gradient, which means that molecules of a chemical migrate from an area of high concentration to an area of low concentration. Diffusivities in Table 3-4 range from a low of 0.07193 square centimeters per second (cm^2/sec) for chlorobenzene to a high of 0.10726 cm^2/sec for vinyl chloride.

Constituent partitioning between soil and water generally is represented by the soil-water distribution coefficient (K_d) and the organic carbon partition coefficient (K_{OC}). Higher K_d and K_{OC} 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 and K_{OC} 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}):

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

Low values of K_{OC} (i.e., less than 1,000 milliliters per gram [mL/g]) and f_{OC}, coupled with high solubility, characterize constituents with a high potential to migrate through soils or aquifer, and these constituents tend to migrate through soil to groundwater. All of the organic COPCs in Table 3-4 fall into this category, with K_{OC} values ranging from 48 mL/g (48 to 331 mL/g) for chlorobenzene to 363 mL/g for PCE (210 to 363 mL/g). A range of K_{OC} values is often presented since the value is sensitive to soil qualities which are also highly variable. For constituents represented by a range of K_{OC} values in Table 3-4, the midpoint of the range was used in the risk calculations.

The octanol-water partition coefficient (K_{OW}) often is used to estimate the extent to which a chemical partitions from water into lipophilic parts of organisms, for example, animal fat. The K_{OW} also can be used to estimate a constituent's permeability coefficient, which is used to model the amount of the constituent adsorbed through the skin in dermal absorption from water. The log K_{OW} presented in Table 3-4 ranges from a low of 0.60 for vinyl chloride to a high of 3.30 for TCE (range of 2.29 to 3.30).

The half-life of a chemical is the time it takes to reduce the chemical by one-half the original amount, measured from the time of its introduction to the environment. The half-lives in Table 3-4 are presented in ranges because the rate of degradation depends on concentration and environmental factors. Biodegradation is the biological process by which microorganisms break down organic chemicals. Environmental factors such as oxygen levels, soil moisture, pH, temperature, and available nutrients affect the rate of biodegradation. Constituents with simple chemical structures (lacking halogens), high water solubility, low adsorption tendencies, and low K_{OW} values will biodegrade (Ney, 1990). Microorganisms naturally occurring in groundwater and soil are able to use several organics as a food source, degrading the components ultimately to carbon dioxide and water (Kostecki and Calabrese, 1989).

3.6 MECHANISMS OF MIGRATION

There are several mechanisms through which constituents may migrate from the Site to the surrounding area. The constituent-containing soils can act as a source of constituents to other environmental media. Migration into the air potentially can occur via volatilization or fugitive dust emissions; migration into groundwater potentially can occur by direct vertical migration of DNAPLs or by percolation of infiltrating rain water that dissolves COPCs present in soil; and transport within groundwater also can occur. San Francisco Bay lies approximately 2,500 feet west of the Site. If affected groundwater were to discharge into the bay, constituents could reach the surface water. The mechanisms of migration for constituents in air, soil, groundwater, and surface water 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.

3.6.1 Migration Into Air

There are two processes controlling migration of constituents into air. Organic constituents in soil or groundwater 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 depends on other competing processes which would hinder this migration. Vapor pressure, K_{OC}, and water solubility govern the extent to which a chemical volatilizes into air under ambient conditions. For example, if a constituent is strongly adsorbed to soil particles, it is 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. The VOCs of concern have these properties, and are therefore expected to migrate to air via volatilization.

As with volatilization, chemical and physical properties can 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 mL/g) 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. The VOCs of concern fall into this category and are unlikely to be emitted in dust. Chromium, however, is not volatile and tends to remain adsorbed to soil. Inorganic COPCs can either form insoluble precipitates with compounds found in soil or adsorb to soil particles. These processes result in metal constituents persisting in soils, thereby increasing their potential to be present in fugitive dust emissions. However, fugitive dust emissions at this site are limited because the constituents were detected at depth. Therefore, unless excavation activities occur, constituents are not expected to migrate via fugitive dust emissions.

3.6.2 Migration Into Groundwater

The potential for COPCs to leach from soil to groundwater depends on various physical and chemical properties of the constituents and the medium through which they are migrating including solubility, sorption properties, chemical species, soil properties, topography, climate, and vegetation. Migration in soil is influenced by soil characteristics. Clay and minerals exhibit adsorptive behavior, while organic matter is capable of both adsorption and absorption. Coarse sand and gravel are generally poor at sorbing chemicals.

Solubility and the tendency to bind to soil materials and/or organic carbon are two of the most important properties affecting constituent migration from soil to groundwater. When a constituent enters the soil environment, some of it binds to soil particles through the process of sorption; some dissolves in the water contained in the spaces between soil particles (pore water); and some volatilizes. The term "sorption" includes adsorption (constituents bound on the outside of soil particles) and absorption (constituent distributed throughout the particle matrix). Sorption to soil reduces volatilization, leaching, and biodegradation. Constituents which are water soluble, such as VOCs, tend not to be sorbed well and vice-versa. The more soluble constituents may migrate from soil with infiltrating precipitation to the groundwater. Typically, organic constituents with high water solubilities and low K_{OC}s are particularly susceptible to this phenomenon. Volatilization is the primary loss mechanism for the VOCs at this site; however, due to their high solubilities and low sorption potentials, migration to groundwater also is likely.

Inorganic metal constituents tend to sorb to soil materials or form insoluble precipitates, especially under neutral or alkaline conditions. In soil, inorganics tend to adsorb to soil particles and can be released or desorbed from soils with changing conditions in oxidation-reduction potential of pH. Rain water typically is mildly acidic; therefore, the potential exists for the constituents to be leached to groundwater with infiltrating precipitation.

In addition to the leaching of dissolved constituents, COPCs can migrate to and through groundwater as phase-separated NAPLs. DNAPLs, primarily the chlorinated VOCs, can migrate vertically through soil. On encountering the water table, DNAPLs tend to continue migrating downward through the network of fractures, under the influence of gravity. As the DNAPLs migrate downward, they become diaggregated, forming globules and droplets, and adhere to fracture surfaces, rock fragments, the size of the individual DNAPL bodies, and the depth of penetration into the aquifer depends on the amount of product released and the timing of the release. Once present as globules or droplets below the water table, DNAPLs serve as a source of COPCs to be dissolved in groundwater. Typically, a steep concentration gradient forms in a downgradient direction from the DNAPL below the water table, as groundwater migrates through the DNAPL and dissolves the DNAPL constituents. Near the DNAPL, concentrations approach the solubility limits of the individual COPCs (in the case of chlorinated VOCs, solubilities are on the order of 150 to 6,400 mg/L); concentrations typically drop off rapidly in the downgradient direction. An equilibrium typically becomes established; however, the stability of this equilibrium and the distribution of dissolved chlorinated VOCs in groundwater can be greatly impacted by pumping stresses.

In the subsurface environment, constituents may remain dissolved in groundwater or adsorb to soil. Typically, organic constituents with high water solubilities and low K_{OC}s (i.e., VOCs) are highly mobile. Migration in groundwater is expected to be the primary transport mechanism for VOCs. Volatilization could be a significant removal mechanism for VOCs in shallow groundwater. All the organic COPCs are subject to biodegradation to some extent.

The inorganic COPCs in groundwater tend to sorb to clay and rock particles that form the matrix of the aquifer. Their mobility depends on the cation and anion exchange capacities (that is, the interaction between positively and negatively charged ions), the fraction of organic matter, pH, and oxidation-reduction potential. In general, metal constituents with a positive charge (cations) are bound by clays exhibiting an overall negative charge. Chromium III and VI exist as cations and tend to adsorb to soil materials or form insoluble precipitates, especially under neutral or basic conditions.

3.6.3 Migration in Surface Water

San Francisco Bay lies approximately 2,500 feet west of the Site. Constituents in groundwater may migrate to the bay and discharge into the surface water with the groundwater. Processes which tend to retard this migration pathway include sorption to aquifer materials, volatilization, and natural degradation and attenuation. The VOCs detected at the Site are relatively mobile and have a greater potential to migrate to surface water than does the chromium, which tends to remain sorbed to aquifer materials. The risk assessment includes a simple groundwater transport to determine the maximum concentrations of the COPCs that potentially could be released into the bay. Upon release to surface water, all of the organic VOCs are expected to volatilize rapidly (Hazardous Substances Databank [HSDB]).

3.6.4 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 groundwater. 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. In most cases, an organic constituent is not broken down completely to carbon dioxide and water by bacterium but is metabolized to an intermediate, which in turn is degraded further. The metabolites isolated depend primarily on the time at which the reaction is stopped. Factors that contribute to the degree to which biodegradation occurs include biodegradability rates, toxicity to microbial populations, available nutrients and dissolved oxygen, pH, production of intermediates, and the effects of mixtures. In general, the intermediates isolated are more soluble than the parent compound and are therefore more mobile.

Biodegradation of organic constituents can be relatively rapid, provided adequate amounts of oxygen, moisture, and nutrients (e.g., nitrogen and phosphorous) 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 anaerobic (oxygen-deficient) respiration, or other types of microorganisms may become active in metabolizing the constituent (USEPA, 1989d).

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

The inorganics do not undergo degradation in soil and groundwater and may persist, although their form may change depending on the pH and availability of their ions. However, elevated inorganic concentrations typically decrease with time as a result of transport and associated dispersion processes.

4.0 TOXICITY ASSESSMENT

Risk associated with exposure to chemical constituents is a function of the toxicity and exposure dose. In assessing human-health risks, a distinction is made between non-carcinogenic and carcinogenic effects. This section discusses these two categories of toxic effects and the toxicity values used to calculate human-health risk.

4.1 GENERAL TOXIC EFFECTS

A distinction is made between carcinogenic and non-carcinogenic effects. For potential carcinogens, the current regulatory guidelines (USEPA, 1989a) use an extremely conservative approach in which it is assumed that any level of exposure to a carcinogen hypothetically could cause cancer. This is contrary to the traditional toxicological approach, which still is applied to non-carcinogenic chemicals where finite thresholds are identified, below which toxic effects have not occurred. This traditional approach still is applied to non-carcinogenic chemicals.

4.2 NON-CARCINOGENIC EFFECTS

For many non-carcinogenic effects, protective mechanisms 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. A single compound might elicit several adverse effects depending on the dose, the exposure route, and the duration of exposure. Chemicals may exhibit their toxic effects at the point of application or contact (local effect), or they may exhibit systemic effects after they have been distributed throughout the body. Most chemicals that produce systemic toxicity do not cause similar degrees of toxicity in all organs, rather they exhibit the major toxicity on one or two target organs. The non-carcinogenic effects can be estimated by comparing a calculated exposure dose to a toxicity value for each individual chemical constituent. A discussion of the toxicity values to be used in the risk assessment is included in Section 4.4.

4.3 CARCINOGENIC EFFECTS

The induction of cancer in humans and in animals by chemicals proceeds through a complex series of reactions and processes. As with non-carcinogenic effects, chemicals may exhibit their toxic effects at the point of application or contact (local effect), or they may exhibit systemic effects after they have been distributed throughout the body. In the case of carcinogens, the target organ is the site of tumor formation.

Chemical constituents are classified as known, probable, or possible human carcinogens based on a USEPA weight-of-evidence scheme in which chemicals are systematically evaluated for their ability to cause cancer in humans or laboratory animals. The USEPA classification scheme (USEPA, 1989a) contains six classes 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.

Constituents in Classes A, B1, B2, and C generally are included in risk assessments as potential human carcinogens; however, Class C carcinogens may be evaluated on a case-by-case basis (USEPA, 1989a). In this risk assessment, Class C carcinogens are evaluated in the same manner as the Class A and Class C carcinogens.

4.4 TOXICITY VALUES

Toxicity values for non-carcinogenic and carcinogenic effects have been developed for many chemicals. When applied to calculated exposure doses, these values can yield an estimate of the potential risk to human health.

For a given chemical, the dose or concentration 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 referred to as the no observed effect level (NOEL). The NOEL is used to establish non-carcinogenic toxicity values (called reference doses [RfDs] for oral or dermal exposures and reference concentrations [RfCs] for inhalation exposure). Available RfDs and RfCs for the COPCs are presented in Table 4-1. The RfD and RfC are estimates of a daily exposure level that is unlikely to cause non-carcinogenic health effects. Therefore, exposure levels must exceed a threshold dose to produce toxic effects. Chronic RfDs and RfCs are used to assess long-term exposures ranging from 7 years to a lifetime. Subchronic RfDs and RfCs are used to evaluate the potential for adverse health effects associated with exposure to chemicals during a period of a few days to 7 years. Subchronic RfDs are used to evaluate potential excavation worker exposure.

While the RfD is an estimated dose of a chemical that will not cause adverse health effects, the RfC is an estimated concentration in air that will not cause adverse health effects. The RfC considers the dynamics of the respiratory system, diversity between species, and the difference in physicochemical properties of chemical constituents. Therefore, parameters such as deposition, clearance mechanisms, and the physicochemical properties of the inhaled agent are considered in the determination of the effective dose delivered to the target organ. RfD and RfC values used in this risk assessment were obtained from USEPA's Integrated Risk Information System (IRIS) (1996), the Health Effects Assessment and Summary Tables (HEAST) (USEPA, 1995), or the USEPA Region IX PRG memorandum (USEPA, 1996). If toxicity values were not available from these sources, USEPA's National Center for Environmental Assessment (NCEA), formerly the Environmental Criteria and Assessment Office (ECAO), was contacted for recommendations.

Currently, the USEPA uses the linearized multistage model for extrapolating cancer risk from high doses associated with occupational exposure or laboratory animal studies to low doses typically associated with environmental exposures. The model provides a 95 percent upperbound estimate of cancer incidence at a given dose. The slope of the extrapolated curve, called the cancer slope factor (CSF), is used to calculate the probability of cancer associated with an ingested dose. Inhalation exposures are evaluated using the unit risk factor (UR_i). Available CSFs and UR_is for the carcinogenic COPCs are presented in Table 4-2. The unit risk is the expected excess cancer risk resulting from continuous, lifetime exposure to air containing 1 microgram per cubic meter (mg/m^3) of the chemical constituent. CSFs and inhalation unit risks used in this risk assessment are taken from IRIS (1996), HEAST (USEPA, 1995), the Region IX PRG memorandum (USEPA, 1996), or USEPA/NCEA communications. CSFs and UR_is are derived from the assumption that any dose level has a probability of causing cancer. The cumulative dose, regardless of the exposure period, determines the risk; therefore, separate CSFs and UR_is are not derived for subchronic and chronic exposure periods.

Whenever possible, route-specific toxicity values are used; however, toxicity values for dermal exposure are not available (appropriate toxicity data are scarce). Therefore, the oral toxicity values were used to estimate potential risks due to dermal exposure as well as oral exposure. Following USEPA Region IX recommendations (USEPA, 1996), route-to-route extrapolation was used in some cases where inhalation toxicity values were lacking but oral toxicity values were available. Instances of this oral-to-inhalation route-to-route extrapolation are indicated by footnotes on Tables 4-1 and 4-2. Dermal absorption factors (used to estimate dermal absorption from soil) and permeability constants (used to estimate dermal absorption from water) for the COPCs at this site are presented in Table 4-3.

The toxicity of TCE and PCE currently is being reviewed by the USEPA Carcinogenicity Risk Assessment Verification Endeavor (CRAVE) work group. There are no final RfDs or CSFs for TCE, and no CSFs for PCE. The values used in this risk assessment are provisional values (USEPA, undated [a],[b],[c]) provided by the USEPA/NCEA. As was stated previously, the total chromium concentrations are evaluated as trivalent chromium since that is the predominant form in nature and since hexavalent chromium concentrations are available.

5.0 EXPOSURE ASSESSMENT

This section addresses the potential for human and ecological exposure to constituents detected in groundwater and soil in the vicinity of the Site and identifies the exposure pathways considered in the risk assessment. An exposure pathway is considered complete only if the potential exists for a receptor to directly contact released constituents or if a mechanism exists for the released constituents to be transported to a receptor. Without exposure, there is no risk; therefore, the exposure assessment is one of the key elements of a risk assessment.

An exposure pathway is defined by four elements: (1) a source or 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) a receptor exposure route at the exposure point. The purpose of the exposure assessment is to identify the reasonable maximum exposure (RME) for each potential receptor. The RME is defined by the USEPA (1989a) as the maximum exposure that is reasonably expected to occur at a site. Typically, this involves measuring or estimating constituent concentrations at the expected exposure points, contact rates, exposure frequencies, and exposure durations. Determining the RME requires the use of site data and professional judgment. In many cases, standard, conservative USEPA default exposure assumptions are used.

RME EPCs typically are based on the lesser of the UCL or maximum detected concentration (USEPA, 1989a) and are assumed to remain constant over the expected exposure period; however, environmental fate and transport data may be used to provide a more thorough estimate of EPCs. This risk assessment follows the more conservative approach in which the EPCs are assumed to remain constant over the 25- or 30-year exposure period, ignoring the natural attenuation effects that are expected to reduce the constituent concentrations over time.

5.1 CONCEPTUAL SITE MODEL

The purpose of the conceptual site model is to provide an overview of the release sources, release mechanisms, exposure pathways, exposure points, and potential receptors. Both current and future site conditions are considered in the conceptual model.

The conceptual model assumes the source area for chromium was the chrome waste storage area, and the source area for solvents was the vapor degreasing area (see Section 2.2, Potential Source Areas). A leaking concrete vault or tank, reported sometime in 1974 or 1977, may have released chromium waste in the vapor degreasing area. Solvents (primarily TCE and 111-TCA) were used at the Site until 1992. No solvent leaks or spills have been reported at the Site; however, these and other solvents have been detected in on-site soil and groundwater.

Currently, groundwater is not used on site or in the vicinity of the Site, and no mechanism for contact with constituents in the groundwater exists. Therefore, no current exposure pathway exists for on-site or off-site groundwater. However, groundwater from the Site probably discharges to San Francisco Bay (approximately 2,500 feet west of the Site), which is a potential exposure point for aquatic life in the bay. The ecological risk assessment evaluates this exposure pathway qualitatively and semi-quantitatively by comparison of potential release concentrations for the bay to appropriate aquatic life criteria.

Potential exposure pathways for current and future site workers are considered in the risk assessment. It is assumed that, at some time in the future, subsurface soil is brought to the surface in such a manner that future on-site workers could regularly come in contact with the affected soils. Therefore, site worker exposure to soils via incidental ingestion (oral), dermal contact, and inhalation of released vapors and particulates to ambient air is evaluated in the risk assessment. A second site worker exposure pathway involves the transport of volatile constituents from groundwater and subsurface soil into a building occupied by the worker. This vapor intrusion pathway is evaluated using a vapor transport model by Daugherty (1991).

A hypothetical future potential exposure pathway is represented by an excavation worker working on redevelopment of the property coming in direct contact with soil and with groundwater, due to its semi-shallow nature (generally 6 to 9 ft bls across the Site). While direct contact with groundwater at this depth by an excavation worker is unlikely, this hypothetical future exposure pathway is considered by the risk assessment as a conservative measure in evaluating potential future risk at the Site.

In summary, potentially complete future soil exposure pathways include hypothetical future site worker and excavation worker exposure to subsurface soils, assuming redevelopment of the Site results in subsurface soils being brought to the surface. Other potentially complete exposure pathways include site worker exposure to indoor air affected by vapor intrusion of volatile constituents from subsurface soil and groundwater, and direct contact exposure to shallow groundwater by a hypothetical excavation worker.

5.2 EXPOSURE PATHWAYS, ASSUMPTIONS, AND EQUATIONS

This section presents the exposure assumptions that are used to estimate average daily intakes and risks posed by the COPCs identified in Section 3.0. The receptor-specific exposure parameters used in the risk calculations are summarized in Table 5-1. Unless otherwise noted in Table 5-1, standard USEPA default exposure assumptions were used where appropriate; however, site data and professional judgment were used to develop some exposure assumptions. The exposure assumptions are consistent with the RME concept currently recommended by the USEPA (1989a).

A basic assumption underlying all exposure calculations was that the EPCs would remain constant throughout the exposure period. Natural attenuation processes were not considered. Therefore, using the lesser of the current maximum detected concentration or the UCL concentration as the representative EPC over the entire exposure period should result in conservative estimates (or overestimates) of exposure.

5.2.1 On-Site Worker

As discussed above, the site worker may directly contact constituents in surface soil or may inhale vapors migrating from subsurface soils or groundwater into a building. This section presents details regarding the evaluation of these hypothetical exposure pathways.

5.2.1.1 Surface Soil

The potential exists for the Site to be redeveloped in the future, although there currently are no such plans by the owner. As part of the hypothetical redevelopment of the Site, subsurface soils could be brought to the surface. If the subsurface soils were brought to the surface, future site workers could be exposed to the affected surface soil through incidental ingestion, dermal contact, and vapor/particulate inhalation. Hypothetical future site worker exposure assumptions for surface soil exposure reflect current USEPA default values (USEPA, 1989a,b; 1991a,b; 1992a; 1996). The exposure assumptions for hypothetical future site worker exposed to surface soil are summarized in Table 5-1. The equations used to estimate site worker exposure to soil and a sample calculation are shown in Table 5-2.

5.2.1.2 Groundwater and Subsurface Soil

Groundwater in the vicinity of the Site currently is not used for any purpose, and there are no known plans for any future use of groundwater in this area. Therefore, there is negligible potential for direct exposure to groundwater constituents at or near the Site. However, volatile constituents were detected in the groundwater, and the potential exists for those COPCs to migrate to the soil surface and enter the indoor air of a building occupied by site workers. Volatile COPCs from subsurface soil also may affect indoor air via the vapor intrusion pathway. The vapor intrusion model published by Seth Daugherty (1991) of the Orange County, California, Health Care Agency was used to evaluate this potential exposure pathway. The equations used to estimate potential indoor air concentrations and associated risks for a site worker based on the Daugherty (1991) model and sample calculations are presented in Table 5-3. The exposure assumptions for a site worker are provided in Table 5-1.

It was assumed that exposure occurs within the north-most building on the adjacent downgradient property. Vapors are assumed to enter the building through a 0.5-centimeter (cm) crack around the foundation perimeter at the floor/wall seam. Model parameters representing the building in which exposure occurs are as follows:

(1) Building dimensions of 50 feet by 110 feet, with a ceiling height of 10 feet.

(2) Building air exchange rate of 1 volume per hour (hr^{-1}).

(3) Depth to groundwater from the building floor equal to 6 feet (approximately 180 cm); depth to contaminated soil equal to 2 feet (60 cm).

Application of the vapor intrusion model requires knowledge of certain soil parameters which affect the movement of vapors through the soil (i.e., soil bulk density, total porosity, and moisture content). Currently, site-specific values for these soil parameters are not available. Therefore, representative literature values which best represent the clays and silty clays encountered in the upper 15 feet of soil at the Site were used (Illinois Environmental Protection Agency [IEPA], 1996).

5.2.2 Hypothetical Excavation Worker

During hypothetical future construction activities at the Site, construction or excavation workers could come into contact with affected subsurface soil or groundwater. This section presents details of the evaluation of these exposure pathways.

5.2.2.1 Soil Exposure

The potential exists for excavation workers to be exposed to constituents in subsurface soil at the Site during future excavation activities. Construction and contracting firms report that the time required to install building footings or build a foundation varies depending on the size of the building and other site-specific factors. Excavation activities associated with installing underground cables or piping would require less time than installing a building foundation. An exposure duration of 6 weeks is expected to be a RME exposure duration for a hypothetical future excavation worker at the Site. The exposure assumptions for the hypothetical future site worker exposed to soil and groundwater are summarized in Table 5-1. The equations used to estimate excavation worker exposure to soil are the same equations as are used to evaluate site worker exposure to soil, as shown in Table 5-2.

5.2.2.2 Groundwater Exposure

During hypothetical future excavation activities, excavation workers could come in contact with groundwater. The depth to groundwater is approximately 6 to 9 ft bls; therefore, an assumption of any future excavation reaching groundwater is very conservative (protective). Exposure assumptions for excavation workers presented earlier remain the same except that the exposure time for groundwater contact is assumed to be 1 hour per day, and the exposed skin surface area is assumed to be 1,980 cm^2, representing exposure of the arms and hands. The exposure time for groundwater contact is expected to be reduced because, if groundwater were to begin seeping into the excavation pit during the excavation activities, the work would cease and workers would leave the pit until dewatering operations could remove the groundwater. Therefore, actual exposure time would probably be on the order of a few minutes, rather than a full hour per day. Table 5-4 shows the equations that used to estimate excavation worker exposure to groundwater through incidental ingestion, dermal contact, and inhalation of released vapors into a 1 square meter (m^2) area surrounding the worker. The exposure parameters applied in the evaluation of this pathway are presented in Table 5-1.

6.0 RISK CHARACTERIZATION

As stated in a previous section, a distinction is made between non-carcinogenic and carcinogenic effects, and two general criteria are used to describe risk: the hazard quotient (HQ) for non-carcinogenic effects and the excess lifetime cancer risk (ELCR) (for Class A, B, or C carcinogens). HQs and ELCRs, calculated for all COPCs for each receptor and exposure pathway are presented and summarized in this section. A brief discussion of HQs, ELCRs, and the criteria for interpreting these values is provided below.

The HQ is the ratio of the estimated exposure dose and the RfD or RfC. If the HQ exceeds 1, there may be concern for potential non-carcinogenic effects. However, the HQ does not provide the probability of an adverse effect as does the ELCR. An HQ greater than 1 indicates that the estimated exposure dose for that constituent exceeds the RfD, but it does not necessarily imply that adverse health effects will occur, because RfDs typically are set an order of magnitude or more below the NOEL (as discussed in Section 4.4). Furthermore, the level of concern does not increase linearly with increasing HQs because RfDs have different levels of confidence, are based on different toxic effects, and do not consider the slope of the dose-response curve. HQs may be summed to derive the hazard index (HI). Current regulatory methodology (USEPA, 1989a) advises summing HIs across exposure routes for all media to derive a "Total Site HI" for each receptor. However, if the HI exceeds 1, constituents may be grouped according to critical toxic effects, and HIs may be calculated separately for each effect.

The ELCR is an estimate of the increased risk or probability of developing cancer and is an indication of the increased risk that may result from exposure to affected media. The ELCR is an upperbound estimate; therefore, it is likely that the true risk is less than that predicted by the model. Current regulatory methodology assumes that ELCRs can be summed across routes and media of exposure and COPCs to derive a "Total Site Risk" for each receptor (USEPA, 1989a). ELCRs in the target range of 10^{-4} to 10^{-6} generally do not require remediation (USEPA, 1991c).

6.1 SITE WORKER

As discussed in the previous sections, the site worker exposure scenarios included in the risk assessment include (1) direct soil contact, (2) vapor intrusion from shallow groundwater, and (3) vapor intrusion from subsurface soil. The following subsections present the calculated risks for these potential site worker exposure scenarios.

6.1.1 Soil Contact

The risk calculations for site worker exposure to subsurface soil via incidental ingestion, dermal contact, and inhalation of vapors and dust are presented in Table 6-1. This exposure scenario conservatively assumed that the subsurface soil is, at some time in the future, brought to the surface by some means, and that the resulting surface soil concentrations are equivalent to the measured subsurface soil concentrations. These assumptions are very conservative for the following reasons:

- There currently are no plans to perform any excavation activities at the Site that would bring significant amounts of subsurface soil to the surface. In particular, there are no plans to remove buildings from the Site, which makes it very unlikely that subsurface soils sampled beneath existing buildings would be disturbed.
- The passage of time is expected to reduce the current VOC concentrations through volatilization, biodegradation, and other natural attenuation processes.
- If subsurface soils were brought to the surface, the process would agitate and aerate the soil enough to greatly reduce or remove the existing concentrations of VOCs in the soil.

The calculated risks for this exposure scenario are presented in Table 6-1. As shown there, the total cancer risk (Total ELCR) is 8×10^{-7}, which is below the USEPA target risk range (10^{-6} to 10^{-4}), and the total non-cancer risk (Total HI) is 0.04, which is well below the level of acceptable non-cancer risk (1). Most of the calculated cancer risk comes as a result of the current subsurface soil VOC concentrations, which are unlikely to be present in the surface soil if the hypothetical excavation activity were to occur. Neglecting the VOC contribution to cancer risk, the Total ELCR is 7×10^{-10}, which is well below the acceptable level for cancer risk. Therefore, this hypothetical exposure scenario, if it were to occur, is not expected to present unacceptable risks to site workers.

6.1.2 Vapor Intrusion

The risk calculations for site worker inhalation exposure to indoor air affected by vapor intrusion from shallow groundwater and subsurface soil are presented in Tables 6-2 and 6-3, respectively. As shown in Table 6-2, the Total ELCR based on vapor intrusion from groundwater is 1×10^{-8}, and the Total HI is 0.0001, both of which are below the relevant risk benchmarks. The total cancer and non-cancer risks based on vapor intrusion from subsurface soil (Table 6-3) are 6×10^{-7} and 0.04, respectively, which also are below the acceptable risk levels. These vapor intrusion calculations were based on conservative exposure and transport assumptions which are expected to result in overestimates of actual indoor air concentrations and associated inhalation risks. Therefore, the vapor intrusion exposure pathways are not expected to present significant risk to indoor workers at the Site.

6.2 EXCAVATION WORKER

The risk assessment calculations included consideration of hypothetical future excavation worker exposure to subsurface soil and shallow groundwater. The following subsections present the results of the risk calculations.

6.2.1 Soil Contact

Table 6-4 presents the risk calculations for hypothetical future excavation worker exposure to subsurface soil via incidental ingestion, dermal contact, and inhalation of vapors and dust released from the exposed soil. The calculated Total ELCR is 1×10^{-8}, and the Total HI is

0.07. These risk levels are below acceptable cancer and non-cancer risks, implying that this hypothetical future exposure scenario is unlikely to present significant risks to the workers.

6.2.2 Groundwater Contact

The risk calculations for hypothetical future excavation worker contact with shallow groundwater are presented in Table 6-5. The Total ELCR for this exposure scenario is 1×10^{-7}, and the Total HI is 0.3. As with the other exposure scenarios, these risks are below the acceptable levels of cancer and non-cancer risk, implying that this exposure scenario, if it were to occur, is unlikely to present significant risk to the workers.

7.0 ECOLOGICAL RISK ASSESSMENT

The objectives of the ecological assessment are: (1) to evaluate data collected at the Site and determine potential site-related ecological effects, and (2) to determine whether further evaluation is warranted based on the results of the first objective. The potential for ecological receptors to be exposed to constituents in soil and groundwater at the Site is minimal. The majority of the Site is covered by pavement and buildings, and surface soil (0 to 2 ft bls) is not a medium of concern for the Site. Depth to groundwater is approximately 6 to 9 ft bls; therefore, there are no direct exposure routes for ecological receptors. Ecological receptors potentially could be indirectly exposed to affected groundwater if it were to discharge into San Francisco Bay. Therefore, the ecological assessment focuses on potential exposure of aquatic organisms to groundwater COPCs in San Francisco Bay.

The existing beneficial uses of San Francisco Bay coastal waters include contact recreation; noncontact water recreation; industrial services supply; navigation; marine habitat; shellfish harvesting; ocean, commercial, and sport fishing; and preservation of rare and endangered species (CRWQCB, San Francisco Bay Region, 1995). Surface-water samples have not been collected adjacent to the Site as part of this investigation; however, in an attempt to determine whether potential impacts to surface-water quality and aquatic receptors exist, estimated groundwater constituent discharge concentrations were calculated and compared to available water quality criteria for the protection of aquatic species.

The estimated groundwater constituent discharge concentrations were calculated using a simple groundwater transport model presented in the American Society for Testing and Material (ASTM) standard for risk-based corrective action (RBCA) (ASTM, 1995). The model equations are presented in Table 7-1. This model is based only on the concentration attenuation and constituent degradation during groundwater transport; the dilution effect of groundwater discharge into the waters of San Francisco Bay is not considered. In addition, the degradation of hexavalent chromium due to reduction to trivalent chromium is not included because no suitable half-life data were available. These omissions from the model cause the estimated discharge concentrations to be significantly over-estimated, probably by several orders of magnitude.

The calculated groundwater concentrations and comparison concentrations are presented in Table 7-2. Comparison values consist of CRWQCB and USEPA criteria for the protection of marine aquatic life (CRWQCB, 1995; USEPA, 1991d). The CRWQCB sets objectives and criteria for the protection of the water quality in various water bodies and drainages associated with San Francisco Bay. These objectives and criteria were used to evaluate potential impacts to surface-water quality associated with potential groundwater discharge from the Site. USEPA ambient water-quality criteria and lowest observed effects levels (LOELs) for the protection of marine aquatic life were used where CRWQCB values were not available.

The modeled transport of constituent concentrations to San Francisco Bay demonstrates that there is essentially no discharge of organic constituents to the bay. The comparison of estimated groundwater constituent concentrations potentially discharged to San Francisco Bay with available comparison criteria for the protection of marine aquatic species (Table 7-2) indicates that, with the possible exception of hexavalent chromium, no estimated constituent concentrations exceed the available comparison criteria. The hexavalent chromium concentration estimated to discharge to the bay (0.07 mg/L) does not exceed the CRWQCB and USEPA acute criteria (1.1 mg/L), but does slightly exceed the CRWQCB and USEPA chronic criteria (0.05 mg/L) for the protection of aquatic organisms (Table 7-2). As stated earlier, the transported concentration of hexavalent chromium is expected to be significantly overestimated for two reasons: (1) the reduction to trivalent chromium (less toxic, more stable, and less mobile) is not considered in the model, and (2) the dilution effect of discharge into the waters of the bay are not included.

The groundwater constituent discharge concentration calculations do not include the effect of dilution upon discharge to San Francisco Bay; therefore, actual constituent concentrations in the bay associated with groundwater discharge from the Site are expected to be much lower than those estimated. Additionally, trivalent chromium (Chromium III) and hexavalent chromium (Chromium VI) are readily interconvertible under natural conditions with trivalent chromium representing the more stable form under redox conditions normally found in natural waters (USEPA, 1979). Therefore, the estimated concentration of hexavalent chromium

8.0 RISK-BASED CONCENTRATION GOALS

This section presents a summary of the calculated human health risks, total site risks for each human receptor considered in the risk assessment, and risk-based concentration goals for groundwater and subsurface soil based on the relevant exposure scenarios.

8.1 TOTAL SITE RISKS

Table 8-1 presents a summary of the total calculated cancer and non-cancer risks for each exposure scenario included in the risk assessment. Consistent with USEPA guidance, total site risks are presented for each of the human receptors considered in the risk assessment. For the site worker, the total site risks are a summation of the total ELCRs and total HIs for the soil contact (Table 6-1), vapor intrusion from shallow groundwater (Table 6-2), and vapor intrusion from subsurface soil (Table 6-3). This summation assumes that the hypothetical site worker is exposed via all three exposure scenarios, which is particularly unlikely given the conservative nature of the soil contact exposure scenario. As shown in Table 8-1, the total site ELCR for the site worker exposed via all three exposure scenarios is 1×10^{-6}, and the total site HI is 0.08. The total site ELCR is equal to the lower end of the USEPA target risk range (10^{-6} to 10^{-4}), and the total site HI is well below the level of acceptable non-cancer risks (1). Given the conservative nature of the exposure assumptions and these calculated risk levels, the Site groundwater and subsurface soil concentrations are not expected to present unacceptable risks to current or future site workers.

The total site risks for an excavation worker assume that the worker is exposed to both subsurface soil and shallow groundwater under the assumed conservative exposure conditions. The total site ELCR for the hypothetical excavation worker is calculated as 2×10^{-7}, and the total site HI is calculated as 0.4. Both of these risk levels are below the acceptable levels of cancer and non-cancer risk, implying that there is no significant risk associated with the measured groundwater and soil concentrations.

8.2 RISK-BASED CONCENTRATION GOALS

The calculated risks for every relevant exposure scenario at the Site are below acceptable levels or cancer and non-cancer risk. Therefore, the measured groundwater and soil concentrations are not expected to present significant risks to human receptors at the Site and no remedial actions are implicated based on the results of the risk assessment. However, in the event that future investigations at the Site result in additional analytical data, risk-based concentration goals (RBGs) are presented here for comparison with measured groundwater and soil concentrations for the COPCs. RBG values are derived for shallow groundwater and subsurface soil based on each of the exposure scenarios included in the risk assessment.

Once risks have been derived for an exposure scenario, the calculation of RBGs for that scenario are straightforward since the calculated risks are linear with concentration. For each COPC, the RBGs for cancer and non-cancer effects are calculated as shown below:

CANCER EFFECTS:

$$RBG_{C} = TCR \times \frac{EPC}{ELCR}$$

NON-CANCER EFFECTS:

$$RBG_{NC} = THI \times \frac{EPC}{HI}$$

where:

ELCR	Calculated cancer risk for the constituent.
EPC	Exposure point concentration used in the risk calculations.
HI	Calculated non-cancer risk for the constituent.
RBG	Calculated risk-based concentration goal.
TCR	Target cancer risk (10^{-6} to 10^{-4}).

THI Target hazard index (1).

The selected RBG for each COPC is the minimum of the values calculated for cancer and non-cancer effects (RBG_C and RBG_{NC}, respectively). The RBC_C values were calculated for a range of target risks (10^{-6} to 10^{-4}), and the RBC_{NC} values were calculated for a target hazard index of 1. The calculated RBCs for shallow groundwater are presented in Tables 8-2 (based on site worker exposure via vapor intrusion to indoor air) and 8-3 (based on excavation worker exposure). The calculated RBCs for subsurface soil are presented in Tables 8-4 (based on site worker and excavation worker contact) and 8-5 (based on site worker exposure via vapor intrusion to indoor air). For RBCs based on cancer effects of the COPC, a range of values based on target cancer risks of 10^{-6} to 10^{-4} is presented in the tables. In cases where the upper limit of this range (the RBC_C based on a target cancer risk of 10^{-4}) exceeds the RBC_{NC} value, the upper limit of the range is the (lesser) RBC_{NC} value.

Comparison of the calculated groundwater RBCs in Tables 8-2 and 8-3 to the measured groundwater concentrations in Table 3-1 indicates that all of the calculated EPCs are below the RBC values. The maximum detected concentration of 11-DCE (3.8 mg/L) falls within the RBC range (3 to 30 mg/L) based on excavation worker exposure and was the only detected concentration of that COPC within that range. This analytical result is from the sample collected from MW-10 in 1991; the most-recently collected sample from that monitor well (April 1995) was reported at 1.2 mg/L, which is below the range of RBC values. The maximum detected TCE concentration (22 mg/L, from MW-16) exceeds the RBC value for the excavation worker exposure scenario (10 mg/L). Groundwater samples from two monitor wells (MW-10 and MW-16) have reported TCE concentrations exceeding this RBC value; however, the most recent results from these two wells (10 mg/L from MW-10 in November 1991; 11 mg/L from MW-16 in September 1996) were approximately equal to the RBC value (10 mg/L, which was 13 mg/L before rounding to one significant figure). As for the other groundwater COPCs, the EPCs for these two constituents are below the calculated RBC values.

Comparison of the calculated soil RBCs in Tables 8-4 and 8-5 to the measured soil concentrations in Table 3-2 indicates that the calculated EPCs and maximum detected concentrations for all of the COPCs are below the RBC values.

9.0 UNCERTAINTIES

The risk estimates presented here are conservative estimates of the risks associated with exposure to constituents detected in shallow groundwater and subsurface soil at the Site. Uncertainty is inherent in the risk assessment process, and a discussion of these uncertainties is presented in this section. In general, conservative assumptions were made in the risk assessment process to bias the risk assessment towards protectiveness. Each of the three basic building blocks for risk assessment (monitoring data, exposure scenarios, and toxicity values) contribute uncertainties, as discussed in the following paragraphs.

Environmental sampling itself introduces uncertainty, largely because of the potential for uneven distribution of constituents in the environment, and the fact that more samples are collected in areas of suspected contamination, biasing the risk assessment results toward higher risk. This risk assessment is based on the assumption that the available monitoring data adequately describe the occurrence of constituents in environmental media at the Site. The samples are representative of site conditions at the time the samples were taken; however, it is reasonable to assume that, as a result of natural processes such as volatilization and biodegradation, constituent concentrations have decreased. Nevertheless, the risk assessment calculations conservatively assume that constituent concentrations remain as measured.

Environmental sampling itself introduces uncertainty. This source of uncertainty can be reduced through a well designed sampling plan, use of appropriate sampling techniques, and implementation of laboratory data validation and quality assurance/quality control (QA/QC). The data used in this report meet these requirements and are appropriate for use in a risk assessment.

Exposure scenarios and constituent transport models also contribute uncertainty to the risk assessment. Exposure intakes were calculated based on the assumption that the current conditions would remain stable (i.e., no biodegradation) throughout the exposure period. This assumption can produce uncertainties because natural attenuation processes are expected to substantially reduce constituent concentrations over time. Exposure scenarios were developed based on site-specific information, USEPA exposure guidance documents, and professional judgment. Although uncertainty is inherent in the exposure assessment, the exposure assumptions also were chosen to err on the side of conservatism.

The toxicity values and other toxicological information (i.e., health effects) used in this report are associated with significant uncertainty. Many toxicity values are developed using results of studies in which laboratory animals are 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 diets, occupations, pharmaceuticals, and other factors. When human epidemiological data are available, a different set of uncertainties is present. For instance, exposure dose is seldom well characterized in epidemiological studies.

Recent research on the mechanisms of carcinogenesis suggests that USEPA's use of the linearized multistage model may overestimate the cancer risks associated with exposure to low doses of chemicals. At higher doses, many chemicals cause large-scale cell alteration which stimulates replacement by cellular division. Dividing cells are more subject to mutations than quiescent or non-dividing cells; thus, there is an increased potential for tumor formation. It is possible that administration of these same chemicals at lower doses would not increase cell division and thus would not increase mutations. This would suggest that the current methodology may overestimate cancer risk.

Toxicity values are not available from the USEPA for all of the COPCs in media at the Site. The USEPA is in the process of developing many inhalation toxicity values. In the absence of inhalation RfCs, route-to-route extrapolation was used to calculate an RfC based on the RfD value, if available. Dermal toxicity values are not available. Therefore, oral toxicity values were used to estimate potential risks due to dermal uptake. This approach introduces additional uncertainty to the risk calculations but reduces the possibility that potential risks are underestimated.

There is a great deal of uncertainty in the TCE CSF and in the calculated ELCRs for potential exposures to TCE in soil and groundwater at the Site. As discussed in the toxicity assessment, the USEPA has withdrawn the carcinogenicity assessment of TCE in which this chemical had been classified as a probable human carcinogen (i.e., Class B2). The carcinogenicity assessment has been withdrawn in response to the growing weight of evidence that indicates that the mechanism of the induction of liver tumors observed in mice may not be relevant to the assessment in humans (NRC, 1994). This suggests that the risks calculated for exposure to TCE and presented in this report probably overestimate actual risks associated with exposure to TCE.

10.0 SUMMARY AND CONCLUSIONS

This risk assessment was performed to evaluate whether constituent concentrations detected in shallow groundwater and subsurface soil at the Site present unacceptable risks to human health or the environment. COPCs for groundwater and soil were selected by screening the maximum detected concentrations of each constituent against the USEPA Region IX PRGs for tap (drinking) water and industrial soil, respectively. Use of the tap water PRGs as screening values for this site is highly conservative since there is no beneficial use of the shallow groundwater in the vicinity, and use of the industrial soil PRGs as screening values at this site is also conservative since all the affected soil exists only in the subsurface. Based on the results of the screening process, 12-DCB, 12-DCA, and 11-DCA were eliminated as COPCs for groundwater, and 11-DCA, c12-DCE, 111-TCA, and nickel were eliminated as COPCs in subsurface soil. The following constituents were retained as COPCs for the risk assessment:

Shallow Groundwater
chlorobenzene
1,1-dichloroethane
cis-1,2-dichloroethene
trans-1,2-dichloroethene
tetrachloroethene
1,1,1-trichloroethane
trichloroethene
vinyl chloride
chromium (total)
chromium (hexavalent)

Subsurface Soil
trichloroethene
vinyl chloride
chromium (total)
chromium (hexavalent)

Potential human health risks for the Site were evaluated based on the following receptors and exposure pathways/scenarios:

Site Worker:
Direct contact with subsurface soil
Inhalation exposure due to vapor intrusion from shallow groundwater to indoor air
Inhalation exposure due to vapor intrusion from subsurface soil to indoor air

Excavation Worker:
Direct contact with subsurface soil
Direct contact with shallow groundwater

The hypothetical scenario in which site workers come into direct contact with subsurface is based on the assumption that, at some time in the future, the Site would undergo reconstruction that brings the subsurface soil to the surface in such a manner that the currently-measured subsurface soil concentrations are representative of hypothetical future surface soil concentrations. The exposure calculations for this scenario (as in all the risk assessment exposure scenarios) assume that the constituent concentrations are constant throughout the entire exposure period -- 25 years in this case. This is very unlikely to occur in reality. There currently are no plans by the owners to redevelop the Site. If reconstruction activity were to occur, the constituent concentrations, particularly for the volatile constituents, would be greatly reduced or eliminated due to the agitation and aeration of the soils.

The calculated cancer and non-cancer risks for all of the exposure scenarios included in the risk assessment were below the target levels of acceptable risks (10^{-6} to 10^{-4} for cancer risk; 1 for non-cancer risk). The total site risks for the two hypothetical human receptors (summing the risks from all the relevant exposure scenarios for each) were as follows:

	Total Site ELCR	Total Site HI
Site Worker	1×10^{-6}	0.08
Excavation Worker	2×10^{-7}	0.4

The total site cancer risks are at or below the lowest level of potentially acceptable cancer risk (10^{-6}), and the total site non-cancer risks are both below the level of acceptable non-cancer risk (1). Therefore, based on these results and the conservative nature of the risk assessment, this Site is not expected to present unacceptable cancer or non-cancer risks to human receptors.

Potential risks to ecological receptors also were considered in the risk assessment. There are no complete exposure pathways for ecological receptors at the Site since the affected media are in the subsurface at depths that are unlikely to be encountered by digging creatures. However, if affected groundwater from the Site were to discharge into San Francisco Bay, aquatic life in the bay potentially could be affected by the groundwater constituents. To evaluate potential risks associated with this indirect exposure pathway, a simple groundwater transport model was used to estimate the groundwater concentrations at the point of release into the bay.

This model considers only the effects of the groundwater transport; dilution effects of the release of the groundwater into the bay were not included. This approach is expected to result in significant overestimates of the discharge concentrations, probably by several orders of magnitude. The results of the model indicated that the transported groundwater concentrations for the organic constituents are essentially 0 (zero). The estimated hexavalent chromium concentration (0.07 mg/L) slightly exceeds the aquatic criteria for chronic exposure (0.05 mg/L) but is below the criteria for acute exposure (1.1 mg/L). The effects of dilution are expected to bring the actual discharge concentration well below these levels. In addition, the calculations did not account for the reduction of hexavalent chromium to trivalent chromium (less toxic, more stable, and less mobile form), which also is expected to greatly decrease the transported concentration of hexavalent chromium. With these considerations, the ecological risk assessment concludes that the observed on-site groundwater concentrations do not pose a threat to aquatic life in the bay.

The results of the human-health and ecological risk assessments indicate that the Site does not present significant risks to human health or the environment at or in the vicinity of the Site. Future investigations at the Site may involve additional sampling of groundwater and soil; therefore, the results of this risk assessment were used to generate site-specific RBGs. The RBGs for cancer effects were derived based on a range of 10^{-6} to 10^{-4} for acceptable cancer risk, and the RBGs for non-cancer effects were derived based on an acceptable non-cancer risk of 1. Tables in the risk assessment present the results of these RBG calculations for each relevant exposure scenario.

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Table 3-1. Occurrence Summary for Groundwater Samples, Electro-Coatings, Inc., Emeryville, California.

Constituent	Frequency Detects / Total	Range of SQLs Min - Max	Range of Detects Min - Max	Average Detect	Mean	UCL	Region IX PRG	EPC
VOCs								
Chlorobenzene	5 / 66	0.0005 - 1 *	0.0051 - 0.052	0.025	0.014	0.018	0.039	0.018
1,2-Dichlorobenzene	3 / 66	0.0005 - 1 *	0.015 - 0.028	0.020	0.010	0.013	0.37	–
1,1-Dichloroethane	18 / 98	0.0005 - 1 *	0.0006 - 0.042	0.011	0.011	0.013	0.81	–
1,2-Dichloroethane	4 / 66	0.0005 - 1 *	0.001 - 0.0029	0.0018	0.0020	0.0022	0.12	–
1,1-Dichloroethene	29 / 98	0.0005 - 1	0.0016 - 3.8	0.32	0.11	0.18	0.000046	0.18
cis-1,2-Dichloroethene	38 / 66	0.0005 - 1	0.0036 - 2.5	0.48	0.29	0.42	0.061	0.42
trans-1,2-Dichloroethene	43 / 98	0.0005 - 1	0.0014 - 2.299	0.15	0.083	0.13	0.12	0.13
Tetrachloroethene	41 / 98	0.0005 - 1	0.00073 - 0.85	0.041	0.036	0.054	0.0011	0.054
1,1,1-Trichloroethane	27 / 98	0.0005 - 1	0.00066 - 6.5	0.36	0.12	0.23	1.3	0.23
Trichloroethene	85 / 103	0.0005 - 0.05	0.00056 - 22	2.4	2.0	2.7	0.0016	2.7
Vinyl chloride	19 / 96	0.0005 - 2 *	0.0022 - 0.73	0.16	0.064	0.090	0.00002	0.090
Metals								
Chromium (total)	131 / 148	0.001 - 0.05	0.014 - 892	110	99	120	NA	120
Chromium (hexavalent)	97 / 125	0.005 - 0.5	0.006 - 877	120	97	120	0.18	120

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

*	For non-detects with one-half the SQL greater than the maximum detected concentration, the maximum detect (rather than SQL/2) was used as the proxy concentration.
–	Not a constituent of potential concern in this medium.
EPC	Exposure point concentration (lesser of the UCL and the maximum detected concentration) for the constituents of potential concern.
Mean	Arithmetic average of the total number of samples, using proxy concentrations for non-detects.
NA	Not available.
PRG	Preliminary Remediation Goal; USEPA Region IX PRGs for tap water (USEPA, 1996).
SQL	Practical sample quantitation limit.
UCL	95 percent upper confidence limit (one-tailed) on the mean, assuming a normal distribution.

Table 3-2. Occurrence Summary for Soil Samples, Electro-Coatings, Inc., Emeryville, California.

	Frequency	Range of SQLs	Range of Detects	Average			Region IX	
Constituent	Detects / Total	Min - Max	Min - Max	Detect	Mean	UCL	PRG	EPC
VOCs								
1,1-Dichloroethane	2 / 4	0.5 - 1.0	0.18 - 0.86	0.52	0.45	0.81	1,700	–
cis-1,2-Dichloroethene	4 / 4	NA	2.6 - 10	4.9	4.9	9.0	100	–
1,1,1-Trichloroethane	1 / 4	0.1 - 1.0 *	0.15	0.15	0.10	0.17	3,000	–
Trichloroethene	2 / 4	0.1 - 0.10	22 - 37	30	15	36	7.0	36
Vinyl chloride	1 / 4	0.2 - 2.0 *	0.20	0.20	0.18	0.23	0.035	0.20
Metals								
Chromium (total)	55 / 55	NA	24.1 - 6,700	510	510	810	450	810
Chromium (hexavalent)	4 / 12	0.2 - 5.0	0.4 - 91	34	12	26	64	26
Nickel	4 / 4	NA	34 - 310	140	140	290	34,000	–

Concentrations are reported in milligrams per kilogram (mg/kg).

*	For non-detects with one-half the SQL greater than the maximum detected concentration, the maximum detect (rather than SQL/2) was used as the proxy concentration.
–	Not a constituent of potential concern in this medium.
EPC	Exposure point concentration (lesser of the UCL and the maximum detected concentration) for the constituents of potential concern.
Mean	Arithmetic average of the total number of samples, using proxy concentrations for non-detects.
NA	Not available.
PRG	Preliminary Remediation Goal; USEPA Region IX PRGs for industrial soil (USEPA, 1996).
SQL	Practical sample quantitation limit.
UCL	95 percent upper confidence limit (one-tailed) on the mean, assuming a normal distribution.
VOCs	Volatile organic compounds.

Table 3-3. Constituents of Potential Concern, Electro-Coatings, Inc., Emeryville, California.

Constituent	Medium	
	Groundwater	Soil
VOCs		
Chlorobenzene	X	–
1,1-Dichloroethene	X	–
cis-1,2-Dichloroethene	X	–
trans-1,2-Dichloroethene	X	–
Tetrachloroethene	X	–
1,1,1-Trichloroethane	X	–
Trichloroethene	X	X
Vinyl chloride	X	X
Metals		
Chromium (total)	X	X
Chromium (hexavalent)	X	X

–	Not a constituent of potential concern for that medium.
X	Constituent of potential concern for that medium.

Table 3-4. Physical and Chemical Properties of Organic Constituents of Potential Concern, Electro-Coatings, Inc., Emeryville, California.

Constituent	Molecular Weight (g/mol)	Water Solubility (mg/L 25 °C)	Specific Gravity	Vapor Pressure (mm Hg 25 °C)	Henry's Law Constant (atm-m³/mol) (25 °C)	Diffusivity (cm²/sec)	Koc (mL/g)	Log Kow	Groundwater T ½ Low - High (days)	Soil T ½ Low - High (days)
VOCs										
Chlorobenzene	113	295 - 500	1.1	11.8	4.45E-03	0.07193	48 - 331	2.71 - 2.98	136 - 300	68 - 150
1,1-Dichloroethene	97	273 - 6,400	1.22	591	1.50E-02	0.10077	65	1.48 - 2.13	56 - 132	28 - 180
cis-1,2-Dichloroethene	97	3,500	1.28	200	3.37E-03	0.09980	49	1.86	56 - 2,850	28 - 180
trans-1,2-Dichloroethene	97	6,300	1.25	270 (20 °C)	6.74E-03	0.09980	59	2.09	56 - 2,850	28 - 180
Tetrachloroethene	166	150 - 485	1.6	19	2.87E-03	0.07404	210 - 363	2.1 - 2.88	360 - 730	180 - 365
1,1,1-Trichloroethane	133	300 - 1,334	1.34	124	1.62E-02	0.07965	104 - 151	2.17 - 2.49	140 - 546	140 - 273
Trichloroethene	131	1,100 - 1,500	1.46	73	9.90E-03	0.08116	65 -126	2.29 - 3.30	321 - 1,643	180 - 365
Vinyl chloride	63	1,100 - 2,700	0.91	2,660	1.07E-02	0.10726	56	0.60	56 - 2,850	28 - 180

References: Howard et al., 1991; Howard, 1990 and 1989; Lyman et al., 1990; Montgomery and Welkom, 1990; Shen, 1982; Verschueren, 1983.

atm-m³/mol	Atmospheres-cubic meters per mole.	mg/L	Milligrams per liter.
°C	Degrees Celsius.	mL/g	Milliliters per gram.
cm²/sec	Square centimeters per second.	mm Hg	Millimeters of mercury.
g/mol	Grams per mole.	T ½	Half-life.
Koc	Organic carbon partition coefficient.	VOCs	Volatile organic compounds.
Kow	Octanol-water partition coefficient.		

Table 4-1. Oral Reference Doses, Inhalation Reference Concentrations, Target Sites, and Confidence Levels for Constituents of Potential Concern, Electro-Coatings, Inc., Emeryville, California.

Constituent	RfDo (mg/kg/day) Subchronic	RfDo (mg/kg/day) Chronic	RfC (mg/m^3) Subchronic	RfC (mg/m^3) Chronic	Target Sites Oral	Target Sites Inhalation	Confidence Level/ Uncertainty Factor
VOCs							
Chlorobenzene	2.0E-01 [w]	2.0E-02	7.0E-01 [r]	2.0E-02 [w]	liver, kidney	liver, kidney	medium/1000
1,1-Dichloroethene	9.0E-03	9.0E-03	3.2E-02 [r]	3.2E-02 [r]	liver	NA	medium/1000
cis-1,2-Dichloroethene	1.0E-01	1.0E-02	3.5E-01 [r]	3.5E-02 [r]	red blood cells	NA	NA/3000
trans-1,2-Dichloroethene	2.0E-01	2.0E-02	7.0E-01 [r]	7.0E-02 [r]	serum enzymes	NA	low/1000
Tetrachloroethene	1.0E-01	1.0E-02	3.5E-01 [r]	3.5E-02 [r]	liver	NA	medium/1000
1,1,1-Trichloroethane	9.0E-01 [w]	9.0E-02 [w]	1.0E+00	1.0E+00	NA	liver	NA
Trichloroethene	6.0E-03	6.0E-03	2.1E-02 [r]	2.1E-02 [r]	liver	NA	low/3000
Vinyl chloride	NA	NA	NA	NA	NA	NA	NA
Inorganics							
Chromium (trivalent) *	1.0E+00	1.0E+00	NA	NA	liver	NA	low/100
Chromium (hexavalent)	2.0E-02	5.0E-03	NA	NA	NR	NA	low/500

References: IRIS, 1996; USEPA, 1995, USEPA, 1992c; USEPA, undated [c].

* Chromium (trivalent) used to represent total chromium.

[r] The RfC is not available; route-to-route extrapolation was used to calculate an RfC from the oral RfD value: RfC = RfDo × (70 kg) / (20 m^3/day)

[w] Value has been withdrawn from the USEPA database(s) pending review.

mg/kg/day	Milligrams per kilogram per day.
mg/m^3	Milligrams per cubic meter.
NA	Not available.
RfC	Inhalation reference concentration.
RfDo	Oral reference dose.
VOCs	Volatile organic compounds.

Table 4-2. Oral Cancer Slope Factors, Inhalation Unit Risks, Tumor Sites, and USEPA Cancer Classifications for Constituents of Potential Concern, Electro-Coatings, Inc., Emeryville, California.

Constituent	Oral CSF (kg-day/mg)	Inhalation Unit Risk ($m^3/\mu g$)	Tumor site		USEPA Classification
			Oral	Inhalation	
VOCs					
1,1-Dichloroethene	6.0E-01	5.0E-05	adrenal gland	kidney	C
Tetrachloroethene	5.2E-02	5.8E-07	liver	liver	C-B2
Trichloroethene	1.1E-02	1.7E-06	liver	lung	C-B2
Vinyl chloride	1.9E+00	8.4E-05	lung	liver	A
Inorganics					
Chromium (hexavalent)	NAP	1.2E-02	NA	lung	A

References: IRIS (1996); USEPA (1995); USEPA (undated [a], [b]).

CSF	Cancer slope factor.
kg-day/mg	Kilograms-day per milligram.
$m^3/\mu g$	Cubic meters per microgram.
NA	Not available.
NAP	Not applicable, since it is carcinogenic by inhalation.
PCE	Tetrachloroethene.
TCE	Trichloroethene.
VOCs	Volatile organic compounds.

Table 4-3. Dermal Absorption Efficiencies and Permeability Constants for Constituents of Potential Concern Electro-Coatings, Inc., Emeryville, California.

Constituents	Dermal Absorption Factor [a]	Permeability Constant [b] (cm/hour)
VOCs		
Chlorobenzene	0.1	4.1E-02
1,1-Dichloroethene	0.1	1.6E-02
cis-1,2-Dichloroethene	0.1	1.0E-02 [c]
trans-1,2-Dichloroethene	0.1	1.0E-02
Tetrachloroethene	0.1	4.8E-02
1,1,1-Trichloroethane	0.1	1.7E-02
Trichloroethene	0.1	1.6E-02
Vinyl chloride	0.1	7.3E-03
Inorganics		
Chromium	0.01	1.6E-04 [d]

[a]	USEPA (1996).
[b]	USEPA (1992a).
[c]	Calculated using the adjusted Bronaugh equation (USEPA, 1992a).
[d]	Assumed equal to the estimated permeability constant for water (USEPA, 1992a).
cm/hour	Centimeters per hour.
VOCs	Volatile organic compounds.

Table 5-1. Receptor-Specific Exposure Parameters, Electro-Coatings, Inc., Emeryville, California.

Parameter	(units)	Site Worker		Excavation Worker	
		Surface Soil	Vapor Intrusion	Subsurface Soil	Groundwater
APc	(days)	25,550	25,550	25,550	25,550
APnc	(days)	9,125	9,125	42	42
BW	(kg)	70	70	70	70
EF	(days/year)	250	250	–	–
EF	(days/week)	–	–	5	5
EP	(years)	25	25	–	–
EP	(weeks)	–	–	6	6
ET	(hours/day)	8	8	8	1
IR$_S$	(mg/day)	50	–	480	–
IRw	(L/day)	–	–	–	0.001
SSA	(cm^2)	3,160	–	3,160	1,980

References: USEPA (1989a,b; 1991a,b; 1992a; 1996)

APc	Averaging period for cancer risk.
APnc	Averaging period for non-cancer risk.
BW	Body weight.
cm^2	Square centimeters.
EF	Exposure frequency.
EP	Exposure period.
ET	Exposure time.
IRs	Incidental ingestion rate of soil.
IRw	Incidental ingestion rate of groundwater during excavation work.
kg	Kilogram.
L	Liter.
mg	Milligram.
SSA	Exposed skin surface area.

Table 5-2. Risk Equations for Worker Exposure to Soil, Electro-Coatings, Inc., Emeryville, California.

ROUTE-SPECIFIC RISKS:

Oral:

$$\text{ELCR}_o \text{ or } \text{HQ}_o = \frac{\text{EPC}_S \times \text{IR}_S \times \text{EF} \times \text{EP}}{(10^6 \text{ mg/kg}) \times \text{BW} \times (\text{AP}_C \textit{ or } \text{AP}_{NC}) \times [(1/\text{CSF}_o) \textit{ or } \text{RfD}_o]}$$

Dermal:

$$\text{ELCR}_d \text{ or } \text{HQ}_d = \frac{\text{EPC}_S \times \text{SSA} \times \text{SAR} \times \text{ABS} \times \text{EF} \times \text{EP}}{(10^6 \text{ mg/kg}) \times \text{BW} \times (\text{AP}_C \textit{ or } \text{AP}_{NC}) \times [(1/\text{CSF}_o) \textit{ or } \text{RfD}_o]}$$

Inhalation:

$$\text{ELCR}_i \text{ or } \text{HQ}_i = \frac{\text{EPC}_S \times [1/(\text{VF} \textit{ or } \text{PEF})] \times \text{ET} \times \text{EF} \times \text{EP}}{(24 \text{ hr/day}) \times (\text{AP}_C \textit{ or } \text{AP}_{NC}) \times \left[\left(\frac{0.001 \text{mg}/\mu\text{g}}{\text{UR}_i}\right) \textit{ or } \text{RfC}\right]}$$

VF for volatiles
PEF for non – volatiles

where:

$$\text{VF} = \text{Q/C} \times \frac{(3.1416 \times \alpha \times \text{T})^{1/2}}{2 \times \text{Dei} \times \text{Pa} \times \text{Kas}} \times (0.0001 \text{ m}^2/\text{cm}^2)$$ for volatiles

$$\text{PEF} = \text{Q/C} \times \frac{3{,}600 \text{ sec/hr}}{\text{RPF} \times (1-\text{G}) \times (\text{Um/Ut})^3 \times \text{F}_X}$$ for non-volatiles

$$\text{Q/C} = \left(\exp\left\{\left[(0.1004 \times \ln[\text{A}]) - 5.3466\right] + (2.92 \times \text{sY})\right\}\right)^{-1}$$

$$\text{sY} = 0.02685 \times \left(0.25 + \frac{[\ln(\text{A}) - 11.0509]^2}{26.3608}\right)$$

$$\alpha = \frac{\text{Dei} \times \text{Pa}}{\text{Pa} + [\rho\text{s} \times (1-\text{Pa})/\text{Kas}]}$$

$$\text{Dei} = \text{Di} \times (\text{Pa}^{3.33}/\text{P}_T^{\,2})$$

$$\text{Kas} = \text{H}/(\text{RT} \times \text{Kd})$$

CANCER RISK:

$$\text{ELCR} = \text{ELCR}_o + \text{ELCR}_d + \text{ELCR}_i$$

Table 5-2. Risk Equations for Worker Exposure to Soil, Electro-Coatings, Inc., Emeryville, California.

NON-CANCER RISK:

$$HI = HQ_o + HQ_d + HQ_i$$

where:

α	Alpha; calculation intermediate (cm^2/sec).
A	Contiguous area of contamination (2,025 m^2 ; default).
ABS	Dermal absorption efficiency.
AP_C	Averaging period for cancer effects (25,550 days).
AP_{NC}	Averaging period for non-cancer effects (days) (EP × 365 days/year for a site worker; EP × 7 days/week for an excavation worker) .
BW	Body weight (kg).
CSF_o	Cancer slope factor for oral/dermal exposure (kg-day/mg; inverse of mg/kg/day).
Dei	Effective diffusivity (cm^2/sec).
Di	Diffusivity in air (cm^2/sec).
EF	Exposure frequency (days/year for a site worker; days/week for an excavation worker).
ELCR	Excess lifetime cancer risk (unitless).
EPCs	Exposure point concentration in soil (mg/kg).
EP	Exposure period (years for a site worker; weeks for an excavation worker).
ET	Exposure time (hours/day).
F_X	Function of Ut/Um (0.008865) (unitless); $F_X = 0.18 \times [\ 8x^3 + 12x\ ] \times \exp[-(x^2)]$, where $x = 0.886 \times (Ut/Um)$.
Foc	Fraction organic carbon in soil (unitless) (0.02, default).
G	Fraction of vegetative cover (unitless); conservatively assumed as zero.
H	Henry's Law Constant (atm-m^3/mol).
HI	Hazard index (unitless); sum of the HQs.
HQ	Hazard quotient (unitless).
IR_S	Ingestion rate of soil (mg/day).
Kas	Soil-air partition coefficient (g soil/cm^3 air).
Kd	Soil-water partition coefficient (cm^3/g or mL/g). Kd is calculated as Foc × Koc for organics.
Koc	Organic carbon partition coefficient (cm^3/g or mL/g).
Pa	Air-filled soil porosity (unitless).
PEF	Particulate emission factor (m^3/kg) for non-volatile constituents (Henry's Law Constant less than 10^{-5} atm-m^3/mol or molecular weight greater than 200 grams per mole).
P_T	Total soil porosity (unitless).
ρs	True soil or particle density (2.65 g/cm^3).
Q/C	Emission flux per unit concentration (g/m^2/sec)/(kg/m^3).
RfC	Reference concentration for inhalation exposure (mg/m^3).
RfD_o	Reference dose for oral/dermal exposure (mg/kg/day).
RPF	Respirable particle fraction (0.036 g/m^2/hr) (USEPA 1991b).
RT	Product of the ideal gas constant (8.206×10^{-5} atm-m^3/mol/K) and the Kelvin temperature (298 K at 25 °C) = 0.02445 atm-m^3/mol.
SAR	Soil adherence rate (mg/cm^2/day).
SSA	Exposed skin surface area (cm^2).
sY	Intermediate value for calculation of Q/C.
T	Exposure interval (7.9×10^8 sec).
UR_i	Unit cancer risk for inhalation exposure (m^3/mg).
Um	Wind speed (3.9 m/sec) (NOAA, 1975).
Ut	Equivalent threshold value of windspeed at 10 meters (12.8 m/sec).
VF	Volatilization factor (m^3/kg) for volatile constituents (Henry's Law Constant greater than 10^{-5} atm-m^3/mol and molecular weight less than 200 grams per mole).

x Intermediate value in calculation of PEF; $x = 0.886 \times (Ut/Um) = 2.91$.

SAMPLE CALCULATION: Trichloroethene

$$sY = 0.02685 \times \left(0.25 + \frac{[\ln(2{,}025\ m^2) - 11.0509]^2}{26.3608}\right) = 0.01875$$

$$Q/C = \left(\exp\left\{\left[(0.1004 \times \ln[2{,}025\ m^2]) - 5.3466\right] + (2.92 \times 0.01875)\right\}\right)^{-1} = 92.52\ (g/m^2/sec)/(kg/m^3)$$

$$F_X = 0.18 \times \left[\left(8 \times 2.91^3\right) + \left(12 \times 2.91\right)\right] \times \exp\left[-(2.91^2)\right] = 0.008865$$

$$PEF = 92.52\,\frac{g/m^2/sec}{kg/m^3} \times \frac{3{,}600\ sec/hr}{(0.036\ g/m^2/hr) \times (1-0) \times \left(\dfrac{3.9\ m/sec}{12.8\ m/sec}\right)^3 \times 0.008865} = 3.69 \times 10^{10}\ m^3/kg$$

$$Dei = (0.08116\ cm^2/sec) \times (0.2^{3.33}/0.35^2) = 0.003116\ cm^2/sec$$

$$Kd = \frac{65\ cm^3/g + 126\ cm^3/g}{2} \times 0.02 = 1.91\ cm^3/g$$

$$Kas = (0.00990\ atm \cdot m^3/mol)/(0.02445\ atm \cdot m^3/mol \times 1.91\ cm^3/g) = 0.212\ g/cm^3$$

$$\alpha = \frac{(0.003116\ cm^2/sec) \times 0.2}{0.2 + [(2.65\ g/cm^3) \times (1-0.2)/(0.212\ g/cm^3)]} = 6.11 \times 10^{-5}\ cm^2/sec$$

$$VF = 92.52\,\frac{g/m^2/sec}{kg/m^3} \times \frac{[3.1416 \times (6.11 \times 10^{-5}\ cm^2/sec) \times (7.9 \times 10^8\ sec)]^{1/2}}{2 \times (0.003116\ cm^2/sec) \times 0.2 \times (0.212\ g/cm^3)} \times (0.0001\ m^2/cm^2)$$

$$= 13{,}635\ m^3/kg$$

CANCER RISK:

$$ELCR_o = \frac{(36\ mg/kg) \times (50\ mg/day) \times (250\ days/yr) \times (25\ yr)}{(10^6\ mg/kg) \times (70\ kg) \times (25{,}550\ days) \times [1/(0.011\ kg \cdot day/mg)]}$$

$$= 6.9 \times 10^{-8}$$

Table 5-2. Risk Equations for Worker Exposure to Soil, Electro-Coatings, Inc., Emeryville, California.

$$\mathrm{ELCR_d} = \frac{(36\ \mathrm{mg/kg}) \times (3{,}160\ \mathrm{cm^2}) \times (0.2\ \mathrm{mg/cm^2/day}) \times 0.1 \times (250\ \mathrm{days/yr}) \times (25\ \mathrm{yr})}{(10^6\ \mathrm{mg/kg}) \times (70\ \mathrm{kg}) \times (25{,}550\ \mathrm{days}) \times [1/(0.011\ \mathrm{kg \cdot day/mg})]}$$

$$= 8.7 \times 10^{-8}$$

$$\mathrm{ELCR_i} = \frac{(36\ \mathrm{mg/kg}) \times [1/(13{,}635\ \mathrm{m^3/kg})] \times (8\ \mathrm{hr/day}) \times (250\ \mathrm{days/yr}) \times (25\ \mathrm{yr})}{(24\ \mathrm{hr/day}) \times (25{,}550\ \mathrm{days}) \times \left(\dfrac{0.001\ \mathrm{mg}/\mu\mathrm{g}}{1.7 \times 10^{-6}\ \mathrm{m^3}/\mu\mathrm{g}}\right)}$$

$$= 3.7 \times 10^{-7}$$

$$\mathrm{ELCR} = (6.9 \times 10^{-8}) + (8.7 \times 10^{-8}) + (3.7 \times 10^{-7}) = 5.2 \times 10^{-7}$$

NON-CANCER RISK:

$$\mathrm{HQ_o} = \frac{(36\ \mathrm{mg/kg}) \times (50\ \mathrm{mg/day}) \times (250\ \mathrm{days/yr}) \times (25\ \mathrm{yr})}{(10^6\ \mathrm{mg/kg}) \times (70\ \mathrm{kg}) \times (9{,}125\ \mathrm{days}) \times (0.006\ \mathrm{mg/kg/day})}$$

$$= 0.0029$$

$$\mathrm{HQ_d} = \frac{(36\ \mathrm{mg/kg}) \times (3{,}160\ \mathrm{cm^2}) \times (0.2\ \mathrm{mg/cm^2/day}) \times 0.1 \times (250\ \mathrm{days/yr}) \times (25\ \mathrm{yr})}{(10^6\ \mathrm{mg/kg}) \times (70\ \mathrm{kg}) \times (9{,}125\ \mathrm{days}) \times (0.006\ \mathrm{mg/kg/day})}$$

$$= 0.0037$$

$$\mathrm{HQ_i} = \frac{(36\ \mathrm{mg/kg}) \times [1/(13{,}635\ \mathrm{m^3/kg})] \times (8\ \mathrm{hr/day}) \times (250\ \mathrm{days/yr}) \times (25\ \mathrm{yr})}{(24\ \mathrm{hr/day}) \times (9{,}125\ \mathrm{days}) \times (0.021\ \mathrm{mg/kg/day})}$$

$$= 0.029$$

$$\mathrm{HI} = (0.0029) + (0.0037) + (0.029) = 0.035$$

Table 5-3. Risk Equations for Vapor Intrusion from Groundwater and Subsurface Soil, Electro-Coatings, Inc, Emeryville, California.

Vapor Intrusion from Groundwater:

$$EPC_{air} = \frac{C_{GW} \times (H/RT) \times D_{gw}^{eff} \times A_b \times IR \times (10{,}000\ cm^2/m^2) \times (3{,}600\ sec/hr)}{L_{GW} \times AER \times V \times (1{,}000\ cm^3/L)}$$

Vapor Intrusion from Soil:

$$EPC_{air} = \frac{C_S \times (H/RT) \times D_s^{eff} \times A_b \times IR \times (10{,}000\ cm^2/m^2) \times (3{,}600\ sec/hr)}{K_{OC} \times F_{OC} \times L_S \times AER \times V \times (1{,}000\ cm^3/L)}$$

where:

$$D_s^{eff} = D^{air} \times \left(\frac{\theta_{as}^{3.33}}{\theta_T^2}\right)$$

$$D_{cap}^{eff} = D^{air} \times \left(\frac{\theta_{acap}^{3.33}}{\theta_T^2}\right)$$

$$D_{gw}^{eff} = L_{GW} \times \left[\frac{h_{cap}}{D_{cap}^{eff}} + \frac{h_v}{D_s^{eff}}\right]^{-1}$$

CANCER RISK:

$$ELCR = EPC_{air} \times \frac{ET \times EF \times EP}{(24\ hr/day) \times AP_C} \times \frac{UR_i}{0.001\ mg/\mu g}$$

NON-CANCER RISK:

$$HQ = EPC_{air} \times \frac{ET \times EF \times EP}{(24\ hr/day) \times AP_{NC}} \times \frac{1}{RfC}$$

where:

A_b	Building area (511 square meters [m^2]).
AER	Enclosed-space air exchange rate (1 volume per hour [hr^{-1}]).
AP_C	Averaging period for cancer effects (25,550 days [70 years]).
AP_{NC}	Averaging period for non-cancer effects (days) (EP × 365 days/year).
C_S	Constituent concentration in subsurface soil (mg/kg).
D^{air}	Diffusion coefficient in air (square centimeters per second [cm^2/sec]).
D_{cap}^{eff}	Effective diffusion coefficient in the capillary fringe soil (cm^2/sec).
D_s^{eff}	Effective diffusion coefficient in vadose zone soil (cm^2/sec).
D_{gw}^{eff}	Effective diffusion coefficient between groundwater and the soil surface (cm^2/sec).
EP	Exposure period (years).

Table 5-3. Risk Equations for Vapor Intrusion from Groundwater and Subsurface Soil, Electro-Coatings, Inc, Emeryville, California.

EPC_{air}	Calculated indoor air concentration based on vapor intrusion from subsurface soil (mg/m^3).
EF	Exposure frequency (days/year).
ELCR	Excess lifetime cancer risk (unitless).
F_{OC}	Fraction organic carbon in soil (0.01) (unitless).
H	Henry's Law Constant (atmosphere × cubic meter per mole [atm-m^3/mol]).
h_{cap}	Thickness of capillary fringe (5 centimeters [cm]).
HQ	Hazard quotient for non-cancer risk (unitless).
h_v	Thickness of vadose zone ($h_v = L_{GW} - h_{cap}$) (117 cm).
IR	Infiltration ratio; ratio of crack area to foundation area (5×10^{-4} [Daugherty, 1991]).
K_{OC}	Organic carbon partition coefficient (cm^3/g = L/kg); constituent specific.
L_{GW}	Depth to groundwater from building foundation (183 cm [6 feet]).
L_S	Depth to affected subsurface soil from building foundation (61 cm [2 feet]).
RfC	Reference concentration for inhalation exposure (mg/m^3).
RT	Product of the ideal gas constant ($R = 8.206 \times 10^{-5}$ atm-m^3/mol/°K) and the Kelvin temperature (T = 293K at 20°C) (RT = 0.02404 atm-m^3/mol).
θ_{acap}	Air-filled porosity in capillary fringe soil (0.036; assumed $0.1 \times \theta_T$) (unitless).
θ_{as}	Air-filled porosity in vadose zone soil (0.19; assumed based on clay soil type [IEPA, 1996]) (unitless).
θ_T	Total soil porosity (0.36; assumed based on clay soil type [IEPA, 1996]) (unitless).
UR_i	Unit cancer risk for inhalation exposure (m^3/μg).
V	Volume of building (approximately 1,557 m^3).

SAMPLE CALCULATION: Trichloroethene

$$D_s^{eff} = (0.08117\ \mathrm{cm^2/sec}) \times \left(\frac{0.19^{3.33}}{0.36^2}\right) = 0.00248\ \mathrm{cm^2/sec}$$

$$D_{cap}^{eff} = (0.08117\ \mathrm{cm^2/sec}) \times \left(\frac{0.036^{3.33}}{0.36^2}\right) = 9.755 \times 10^{-6}\ \mathrm{cm^2/sec}$$

$$D_{gw}^{eff} = (183\ \mathrm{cm}) \times \left(\frac{5\ \mathrm{cm}}{9.755 \times 10^{-6}\ \mathrm{cm^2/sec}} + \frac{178\ \mathrm{cm}}{0.00248\ \mathrm{cm^2/sec}}\right)^{-1} = 0.000313\ \mathrm{cm^2/sec}$$

Vapor Intrusion from Groundwater:

$$EPC_{air} = \frac{(2.7\ \mathrm{mg/L}) \times \left(\frac{0.0099}{0.02404}\right) \times (0.000313\ \mathrm{cm^2/sec}) \times (511\ \mathrm{m^2}) \times 0.0005 \times (10{,}000\ \mathrm{cm^2/m^2}) \times (3{,}600\ \mathrm{sec/hr})}{(183\ \mathrm{cm^2}) \times 1 \times (1{,}557\ \mathrm{m^3}) \times (1{,}000\ \mathrm{cm^3/L})}$$

$$= 1.12 \times 10^{-5}\ \mathrm{mg/m^3}$$

CANCER RISK:

$$ELCR = \left(1.12 \times 10^{-5}\ \frac{\mathrm{mg}}{\mathrm{m^3}}\right) \times \left(\frac{(8\ \mathrm{hr/day}) \times (250\ \mathrm{day/yr}) \times (25\ \mathrm{yr})}{(24\ \mathrm{hr/day}) \times (25{,}550\ \mathrm{days})}\right) \times \left(\frac{1.7 \times 10^{-6}\ \mathrm{m^3}/\mu g}{0.001\ \mathrm{mg}/\mu g}\right) = 1.6 \times 10^{-9}$$

Table 5-3. Risk Equations for Vapor Intrusion from Groundwater and Subsurface Soil, Electro-Coatings, Inc, Emeryville, California.

NON-CANCER RISK:

$$HQ = \left(1.12 \times 10^{-5}\ \frac{mg}{m^3}\right) \times \left(\frac{(8\ hr/day) \times (250\ day/yr) \times (25\ yr)}{(24\ hr/day) \times (9{,}125\ days)}\right) \times \left(\frac{1}{0.021\ mg/m^3}\right) = 1.2 \times 10^{-4}$$

Vapor Intrusion from Subsurface Soil:

$$EPC_{air} = \frac{(36\ mg/kg) \times \left(\frac{0.0099}{0.02404}\right) \times (0.00248\ cm^2/sec) \times (511\ m^2) \times 0.0005 \times (10{,}000\ cm^2/m^2) \times (3{,}600\ sec/hr)}{(95.5\ L/kg) \times 0.01 \times (61\ cm^2) \times 1 \times (1557\ m^3) \times (1{,}000\ cm^3/L)}$$

$$= 0.00373\ mg/m^3$$

CANCER RISK:

$$ELCR = \left(0.00373\ \frac{mg}{m^3}\right) \times \left(\frac{(8\ hr/day) \times (250\ day/yr) \times (25\ yr)}{(24\ hr/day) \times (25{,}550\ days)}\right) \times \left(\frac{1.7 \times 10^{-6}\ m^3/\mu g}{0.001\ mg/\mu g}\right) = 5.2 \times 10^{-7}$$

NON-CANCER RISK:

$$HQ = \left(0.00373\ \frac{mg}{m^3}\right) \times \left(\frac{(8\ hr/day) \times (250\ day/yr) \times (25\ yr)}{(24\ hr/day) \times (9{,}125\ days)}\right) \times \left(\frac{1}{0.021\ mg/m^3}\right) = 0.041$$

Table 5-4. Risk Equations for Excavation Worker Exposure to Groundwater, Electro-Coatings, Inc., Emeryville, California.

ROUTE-SPECIFIC RISKS:

Oral:

$$\text{ELCR}_o \text{ or } \text{HQ}_o = \frac{\text{EPCgw} \times \text{IR}_W \times \text{EF} \times \text{EP}}{\text{BW} \times (\text{AP}_C \text{ or } \text{AP}_{NC}) \times [(1/\text{CSF}_o) \text{ or } \text{RfD}_o]}$$

Dermal:

$$\text{ELCR}_d \text{ or } \text{HQ}_d = \frac{\text{EPCgw} \times \text{SSA} \times \text{PC} \times (0.001\text{L}/\text{cm}^3) \times \text{ET} \times \text{EF} \times \text{EP}}{\text{BW} \times (\text{AP}_C \text{ or } \text{AP}_{NC}) \times [(1/\text{CSF}_o) \text{ or } \text{RfD}_o]}$$

Inhalation:

$$\text{ELCR}_i \text{ or } \text{HQ}_i = \frac{\text{EPC}_V \times \text{ET} \times \text{EF} \times \text{EP}}{(24\,\text{hr}/\text{day}) \times (\text{AP}_C \text{ or } \text{AP}_{NC}) \times \left[\left(\frac{0.001\,\text{mg}/\mu\text{g}}{\text{UR}_i}\right) \text{or RfC}\right]}$$

where:

$$\text{EPC}_V = \frac{\text{EPCgw} \times (10^3\ \text{L}/\text{m}^3)}{1/k_l + [\text{RT}/(k_g \times \text{H})]} \times \frac{\text{SA}}{\text{Hb} \times \text{Wb} \times \text{U}}$$

CANCER RISK:

$$\text{ELCR} = \text{ELCR}_o + \text{ELCR}_d + \text{ELCR}_i$$

NON-CANCER RISK:

$$\text{HI} = \text{HQ}_o + \text{HQ}_d + \text{HQ}_i$$

where:

AP_C	Averaging period for cancer effects (days).
AP_{NC}	Averaging period for non-cancer effects (days); EP × 7 days/week.
BW	Body weight (kg).
CSF_o	Cancer slope factor for oral/dermal exposure (kg-day/mg; inverse of mg/kg/day).
EF	Exposure frequency (days/week).
ELCR	Excess lifetime cancer risk (unitless).
ET	Exposure time (hours/day).
EP	Exposure period (weeks).
EPCgw	Exposure point concentration in groundwater (mg/L).
EPC_V	Exposure point concentration in the vapor phase (mg/m^3).
H	Henry's Law Constant (atm-m^3/mol).
Hb	Height of mixing zone (2 m).
HI	Hazard index (unitless); sum of the HQs.
HQ	Hazard quotient (unitless).
IR_W	Incidental ingestion rate of groundwater during excavation (L/day).
k_g	Gas-phase mass transfer coefficient (m/sec) ~ $(8.3 \times 10^{-3}$ m/sec$) \times [(18 \text{ g/mol})/\text{MW}]^{1/2}$.

Table 5-4. Risk Equations for Excavation Worker Exposure to Groundwater, Electro-Coatings, Inc., Emeryville, California.

k_l	Liquid-phase mass transfer coefficient (m/sec) ~ (5.6×10^{-5} m/sec) × $[(44\ \text{g/mol})/\text{MW}]^{1/2}$.
MW	Molecular weight (g/mol).
PC	Permeability constant (cm/hour).
RfC	Reference concentration for inhalation exposure (mg/m^3).
RfD_o	Reference dose for oral/dermal exposure (mg/kg/day).
RT	Product of the universal gas constant (R = 8.206×10^{-5} atm-m^3/mol/K) and the relevant Kelvin temperature (T = 293 K); RT = 0.02404 atm-m^3/mol.
SA	Source area (1 m^2).
SSA	Exposed skin surface area (cm^2).
U	Mean wind speed (m/sec); assumed 1 m/sec in the excavation pit.
UR_i	Unit cancer risk for inhalation exposure (m^3/mg).
Wb	Width of mixing zone (1 m).

SAMPLE CALCULATION: vinyl chloride

$$k_g = (8.3 \times 10^{-3}\ \text{m/sec}) \times [(18\ \text{g/mol})/(63\ \text{g/mol})]^{1/2} = 4.4 \times 10^{-3}\ \text{m/sec}$$

$$k_l = (5.6 \times 10^{-5}\ \text{m/sec}) \times [(44\ \text{g/mol})/(63\ \text{g/mol})]^{1/2} = 4.7 \times 10^{-5}\ \text{m/sec}$$

$$\text{EPC}_V = \frac{(0.090\ \text{mg/L}) \times (1000\ \text{L/m}^3)}{\left(\frac{1}{4.7 \times 10^{-5}\ \text{m/sec}}\right) + \left[\frac{0.02404\ \text{atm}\cdot\text{m}^3/\text{mol}}{(4.4 \times 10^{-3}) \times (0.0107\ \text{atm}\cdot\text{m}^3/\text{mol})}\right]} \times \frac{1\ \text{m}^2}{(2\ \text{m}) \times (1\ \text{m}) \times (1\ \text{m/sec})}$$

$$= 2.1 \times 10^{-3}\ \text{mg/m}^3$$

Cancer Risk:

$$\text{ELCR}_o = \frac{(0.090\ \text{mg/L}) \times (0.001\ \text{L/day}) \times (5\ \text{day/wk}) \times (6\ \text{wk})}{(70\ \text{kg}) \times (25{,}550\ \text{days}) \times (1/1.9\ \text{kg}\cdot\text{day/mg})} = 2.9 \times 10^{-9}$$

$$\text{ELCR}_d = \frac{(0.090\ \text{mg/L}) \times (1{,}980\ \text{cm}^2) \times (7.3 \times 10^{-3}\ \text{cm/hr}) \times (0.001\ \text{L/cm}^3) \times (1\ \text{hr/day}) \times (5\ \text{day/wk}) \times (6\ \text{wk})}{(70\ \text{kg}) \times (25{,}550\ \text{days}) \times (1/1.9\ \text{kg}\cdot\text{day/mg})}$$

$$= 4.1 \times 10^{-8}$$

$$\text{ELCR}_i = \frac{(0.0021\ \text{mg/m}^3) \times (5\ \text{day/wk}) \times (6\ \text{wk})}{(24\ \text{hr/day}) \times (25{,}550\ \text{days}) \times (0.001\ \text{mg}/\mu\text{g})/(8.4 \times 10^{-5}\ \text{m}^3/\mu\text{g})} = 8.5 \times 10^{-9}$$

Table 5-4. Risk Equations for Excavation Worker Exposure to Groundwater, Electro-Coatings, Inc., Emeryville, California.

$$\text{ELCR} = \left(2.9 \times 10^{-9}\right) + \left(4.1 \times 10^{-8}\right) + \left(8.5 \times 10^{-9}\right) = 5.3 \times 10^{-8}$$

Non-Cancer Risk

$$\text{HQ}_o = \frac{(0.090\ \text{mg/L}) \times (0.001\ \text{L/day}) \times (5\ \text{day/wk}) \times (6\ \text{wk})}{(70\ \text{kg}) \times (42\ \text{days}) \times NA} = NA \begin{pmatrix}\text{Not available;} \\ \text{insufficient toxicity information}\end{pmatrix}$$

$$\text{HQ}_d = \frac{(0.090\ \text{mg/L}) \times \left(1{,}980\ \text{cm}^2\right) \times \left(7.3 \times 10^{-3}\ \text{cm/hr}\right) \times \left(0.001\ \text{L/cm}^3\right) \times (1\ \text{hr/day}) \times (5\ \text{day/wk}) \times (6\ \text{wk})}{(70\ \text{kg}) \times (42\ \text{day}) \times NA}$$

$$= NA \begin{pmatrix}\text{Not available;} \\ \text{insufficient toxicity information}\end{pmatrix}$$

$$\text{HQ}_i = \frac{\left(0.0021\ \text{mg/m}^3\right) \times (8\ \text{hr/day}) \times (5\ \text{day/wk}) \times (6\ \text{wk})}{(24\ \text{hr/day}) \times (42\ \text{day}) \times NA} = NA \begin{pmatrix}\text{Not available;} \\ \text{insufficient toxicity information}\end{pmatrix}$$

HI = *N*A (Not available; insufficient toxicity information)

Table 6-1. Risk Calculations for Site Worker Exposure to Soil, Electro-Coatings, Inc., Emeryville, California.

		CANCER RISK				**NON-CANCER RISK**			
	EPCs	Route-Specific Risks			Calculated	Route-Specific Risks			Calculated
Constituent	(mg/kg)	Oral	Dermal	Inhalation	Risk	Oral	Dermal	Inhalation	Risk
		ELCRo	ELCRd	ELCRi	ELCR	HQo	HQd	HQi	HI
VOCs									
Trichloroethene	36	6.9E-08	8.7E-08	3.7E-07	5.2E-07	2.9E-03	3.7E-03	2.9E-02	3.5E-02
Vinyl chloride	0.20	6.6E-08	8.4E-08	1.6E-07	3.1E-07	NA	NA	NA	NA
Metals									
Chromium (total)	810	NC	NC	NC	NC	4.0E-04	5.0E-05	NA	4.5E-04
Chromium (hexavalent)	26	NAP	NAP	6.9E-10	6.9E-10	2.5E-03	3.2E-04	NA	2.9E-03
				TOTAL ELCR	**8E-07**			**TOTAL HI**	**0.04**

ELCR	Excess lifetime cancer risk.	NA	Not available; insufficient toxicity data.
EPCs	Exposure point concentration in surface soil (mg/kg) (Table 3-1).	NAP	Not applicable; carcinogenic only via inhalation.
HI	Hazard index; sum of the HQs.	NC	Not a suspected carcinogen.
HQ	Hazard quotient.	VOCs	Volatile organic compounds.
mg/kg	Milligrams per kilogram.		

Table 6-2. Risk Calculations for a Site Worker Based on Vapor Intrusion from Groundwater, Electro-Coatings, Inc., Emeryville, California.

			CANCER RISK		NON-CANCER RISK	
Constituent	Cgw (mg/L)	Cair (mg/m^3)	URi (m^3/µg)	ELCR	RfC (mg/m^3)	HQ
<u>VOCs</u>						
Chlorobenzene	0.018	2.99E-08	NC	NC	2.0E-02	3.4E-07
1,1-Dichloroethene	0.18	1.41E-06	5.0E-05	5.7E-09	3.2E-02	1.0E-05
cis-1,2-Dichloroethene	0.42	7.32E-07	NC	NC	3.5E-02	4.8E-06
trans-1,2-Dichloroethene	0.13	4.53E-07	NC	NC	7.0E-02	1.5E-06
Tetrachloroethene	0.054	5.95E-08	5.8E-07	2.8E-12	3.5E-02	3.9E-07
1,1,1-Trichloroethane	0.23	1.54E-06	NC	NC	1.0E+00	3.5E-07
Trichloroethene	2.7	1.12E-05	1.7E-06	1.6E-09	2.1E-02	1.2E-04
Vinyl chloride	0.090	5.35E-07	8.4E-05	3.7E-09	NA	NA
			TOTAL ELCR	**1E-08**	**TOTAL HI**	**0.0001**

Cair	Estimated indoor air concentrations based on vapor intrusion from groundwater (Daugherty, 1991).
Cgw	Concentration in groundwater beneath the building.
ELCR	Calculated excess lifetime cancer risk.
HI	Hazard index (sum of the hazard quotients).
HQ	Calculated hazard quotient for non-cancer risk.
m^3/µg	Cubic meters per microgram.
mg/L	Milligrams per liter.
mg/m^3	Milligrams per cubic meter.
NA	Not available; insufficient toxicity data.
NC	Not evaluated as a carcinogen.
RfC	Reference concentration for inhalation exposure.
URi	Inhalation unit risk.

Table 6-3. Risk Calculations for a Site Worker Based on Vapor Intrusion from Subsurface Soil, Electro-Coatings, Inc., Emeryville, California.

			CANCER RISK		**NON-CANCER RISK**	
Constituent	Cs (mg/kg)	Cair (mg/m^3)	URi (m^3/µg)	ELCR	RfC (mg/m^3)	HQ
VOCs						
Trichloroethene	36	3.73E-03	1.7E-06	5.2E-07	2.1E-02	4.1E-02
Vinyl chloride	0.20	5.05E-06	8.4E-05	3.5E-08	NA	NA
			TOTAL ELCR	**6E-07**	**TOTAL HI**	**0.04**

Cair	Estimated indoor air concentrations based on vapor intrusion from subsurface soil (Daugherty, 1991).
Cs	Concentration in subsurface soil.
ELCR	Calculated excess lifetime cancer risk.
HI	Hazard index (sum of the hazard quotients).
HQ	Calculated hazard quotient for non-cancer risk.
m^3/µg	Cubic meters per microgram.
mg/kg	Milligrams per kilogram.
mg/m^3	Milligrams per cubic meter.
NA	Not available; insufficient toxicity data.
NC	Not evaluated as a carcinogen.
RfC	Reference concentration for inhalation exposure.
URi	Inhalation unit risk.

Table 6-4. Risk Calculations for Excavation Worker Exposure to Soil, Electro-Coatings, Inc., Emeryville, California.

		CANCER RISK				NON-CANCER RISK			
		Route-Specific Risks			Calculated Risk	Route-Specific Risks			Calculated Risk
Constituent	EPCs (mg/kg)	Oral	Dermal	Inhalation		Oral	Dermal	Inhalation	
		ELCRo	ELCRd	ELCRi	ELCR	HQo	HQd	HQi	HI
VOCs									
Trichloroethene	36	3.2E-09	4.2E-10	1.8E-09	5.4E-09	2.9E-02	3.9E-03	3.0E-02	6.3E-02
Vinyl chloride	0.20	3.1E-09	4.0E-10	7.6E-10	4.2E-09	NA	NA	NA	NA
Metals									
Chromium (total)	810	NC	NC	NC	NC	4.0E-03	5.2E-05	NA	4.0E-03
Chromium (hexavalent)	26	NAP	NAP	3.3E-12	3.3E-12	6.4E-03	8.4E-05	NA	6.5E-03
				TOTAL ELCR	**1E-08**			**TOTAL HI**	**0.07**

ELCR	Excess lifetime cancer risk.
EPCs	Exposure point concentration in surface soil (mg/kg) (Table 3-1).
HI	Hazard index; sum of the HQs.
HQ	Hazard quotient.
mg/kg	Milligrams per kilogram.
NA	Not available; insufficient toxicity data.
NAP	Not applicable; carcinogenic on via inhalation.
NC	Not a suspected carcinogen.
VOCs	Volatile organic compounds.

Table 6-5. Risk Calculations for Excavation Worker Exposure to Groundwater, Electro-Coatings, Inc., Emeryville, California.

			CANCER RISK				NON-CANCER RISK			
			Route-Specific Risks			Calculated Risk	Route-Specific Risks			Calculated Risk
Constituent	EPCgw (mg/L)	EPCv (mg/m³)	Oral	Dermal	Inhalation		Oral	Dermal	Inhalation	
			ELCRo	ELCRd	ELCRi	ELCR	HQo	HQd	HQi	HI
VOCs										
Chlorobenzene	0.018	3.0E-04	NC	NC	NC	NC	9.2E-07	1.7E-03	1.3E-05	1.7E-03
1,1-Dichloroethene	0.18	3.3E-03	1.8E-09	5.7E-08	8.2E-09	6.7E-08	2.0E-04	6.5E-03	3.2E-03	9.8E-03
cis-1,2-Dichloroethene	0.42	7.4E-03	NC	NC	NC	NC	4.3E-05	8.7E-04	6.3E-04	1.5E-03
trans-1,2-Dichloroethene	0.13	2.4E-03	NC	NC	NC	NC	6.6E-06	1.3E-04	1.0E-04	2.4E-04
Tetrachloroethene	0.054	7.2E-04	4.7E-11	4.5E-09	2.0E-11	4.5E-09	5.5E-06	5.2E-04	6.1E-05	5.9E-04
1,1,1-Trichloroethane	0.23	3.6E-03	NC	NC	NC	NC	2.6E-06	NA	1.1E-04	1.1E-04
Trichloroethene	2.7	4.3E-02	5.0E-10	1.6E-08	3.6E-09	2.0E-08	4.6E-03	1.5E-01	6.1E-02	2.1E-01
Vinyl chloride	0.090	2.1E-03	2.9E-09	4.1E-08	8.5E-09	5.3E-08	NA	NA	NA	NA
Metals										
Chromium (total)	120	–	NC	NC	–	NC	1.2E-03	3.9E-04	–	1.6E-03
Chromium (hexavalent)	120	–	NAP	NAP	–	NAP	6.1E-02	1.9E-02	–	8.1E-02
					TOTAL ELCR	1E-07			TOTAL HI	0.3

ELCR	Excess lifetime cancer risk.	mg/m³	Milligrams per cubic meter.
EPCgw	Exposure point concentration in the groundwater (mg/L).	mg/L	Milligrams per liter.
EPCv	Exposure point concentration in the vapor phase (mg/m³).	NA	Not available.
HI	Hazard index (sum of HQs).	NC	Not evaluated as a carcinogen.
HQ	Hazard quotient.	VOCs	Volatile organic compounds.

Table 7-1. Groundwater Transport Model Equations Used to Estimate Potential Groundwater Constituent Concentrations at San Francisco Bay, Electro-Coatings, Inc., Emeryville, California.

$$C(X) = C_O \times \exp\left[\frac{X}{2 \times \alpha_x}\left(1 - \sqrt{1 + \frac{4\lambda \times \alpha_x}{U}}\right)\right] \times erf\left(\frac{S_W}{4\sqrt{\alpha_y \times X}}\right) \times erf\left(\frac{S_d}{4\sqrt{\alpha_Z \times X}}\right)$$

where:

$$\alpha_X = 0.10 \times X$$

$$\alpha_y = \frac{\alpha_X}{3}$$

$$\alpha_z = \frac{\alpha_X}{20}$$

$$U = \frac{K \times I}{\theta_T}$$

where:

C_o	Constituent concentration at the source (presumed to be on-site concentration) (mg/L).
$C(X)$	Calculated constituent concentration at distance X from the source (mg/L).
erf()	Error function (unitless). Mathematical function; values obtained from a software look-up table.
I	Hydraulic gradient (cm/cm; unitless) (0.0067 [ENTRIX, 1994]).
K	Aquifer hydraulic conductivity (cm/day) (0.01 cm/day; estimated from representative values for clay and silty clay [Freeze and Cherry, 1979]).
S_d	Source width perpendicular to groundwater flow direction in the vertical plane (cm) (estimated as 15 feet ≈ 450 cm).
S_W	Source width perpendicular to groundwater flow direction in the horizontal plane (cm) (estimated as 250 feet ≈ 4,570 cm for organic COPCs; 40 feet ≈ 1,220 cm for chromium).
U	Specific discharge (cm/day).
X	Distance along the centerline of the groundwater plume emanating from the source (cm). The x-direction is the direction of groundwater flow (2,500 feet ≈ 76,200 cm).
α_X	Longitudinal dispersivity (cm).
α_y	Transverse dispersivity (cm).
α_Z	Vertical dispersivity (cm).
λ	First-order degradation constant (day^{-1}); constituent-specific.
θ_T	Total soil porosity (cm^3/cm^3; unitless) (0.36; representative value for clayey soil [IEPA, 1996]).

SAMPLE CALCULATION: (chlorobenzene)

$$\alpha_X = 0.10 \times (76{,}200\,\text{cm}) = 7{,}620\,\text{cm}$$

$$\alpha_y = \frac{7{,}620\,\text{cm}}{3} = 2{,}540\,\text{cm}$$

Table 7-1. Groundwater Transport Model Equations Used to Estimate Potential Groundwater Constituent Concentrations at San Francisco Bay, Electro-Coatings, Inc., Emeryville, California.

$$\alpha_Z = \frac{7{,}620\text{ cm}}{20} = 381\text{ cm}$$

$$U = \frac{(0.01\text{ cm / day}) \times 0.0067}{0.36} = 0.000186\ \text{ cm / day}$$

$$erf\left(\frac{S_W}{4\sqrt{\alpha_y \times X}}\right) = erf\left(\frac{4{,}570\text{ cm}}{4\sqrt{(2{,}540\text{ cm}) \times (76{,}200\text{ cm})}}\right) = erf\ (0.0821) \approx 0.092$$

$$erf\left(\frac{S_d}{4\sqrt{\alpha_Z \times X}}\right) = erf\left(\frac{450\text{ cm}}{4\sqrt{(381\text{ cm}) \times (76{,}200\text{ cm})}}\right) = erf\ (0.0209) \approx 0.024$$

$$\exp\left[\left(\frac{X}{2 \times \alpha_X}\right) \times \left(1 - \sqrt{1 + \frac{4 \times \lambda \times \alpha_X}{U}}\right)\right] = \exp\left[\left(\frac{76{,}200\text{ cm}}{2 \times (7{,}620\text{ cm})}\right) \times \left(1 - \sqrt{1 + \frac{4 \times\ (0.0023) \times (7{,}620\text{ cm})}{(0.000186\text{ cm / day})}}\right)\right]$$

$$= \exp(-3{,}065) = \quad 0 \quad (\textit{zero})$$

$$C(X) = (0.018\text{ mg / L}) \times (0) \times (0.092) \times (0.024) = 0\ (\textit{zero})\text{ mg / L}$$

Table 7-2. Comparison of Groundwater Concentrations with Water-Quality Criteria, Electro-Coatings, Inc., Emeryville, California.

Constituent	On-Site Groundwater EPC (mg/L)	1st-Order Degradation Constant * ($days^{-1}$)	Estimated Transport oncentration (mg/L)	Comparison Criteria			
				FWQC [Marine]		CRWQCB	
				Acute [a] (mg/L)	Chronic [b] (mg/L)	1-Hour Average (mg/L)	4-Hour Average (mg/L)
<u>Organics</u>							
Chlorobenzene	0.018	0.0023	0	0.16	0.129	NA	NA
1,2-Dichlorobenzene	0.013	0.0019	0	1.97	NA	NA	NA
1,1-Dichloroethane	0.013	0.0019	0	NA	NA	NA	NA
1,2-Dichloroethane	0.0022	0.0019	0	NA	NA	NA	NA
1,1-Dichloroethene	0.18	0.0053	0	224	NA	NA	NA
cis-1,2-Dichloroethene	0.42	0.00024	0	224	NA	NA	NA
trans-1,2-Dichloroethene	0.13	0.00024	0	224	NA	NA	NA
Tetrachloroethene	0.054	0.00096	0	10.2	0.45	NA	NA
1,1,1-Trichloroethane	0.23	0.0013	0	31.2	NA	NA	NA
Trichloroethene	2.7	0.00042	0	2	NA	NA	NA
Vinyl chloride	0.090	0.00024	0	NA	NA	NA	NA
<u>Inorganics</u>							
Chromium (total)	120	0	0.07	10.3	NA	NA	NA
Chromium (hexavalent)	120	0	0.07	1.1	0.05	1.1	0.05

* IEPA (1996).

mg/L	Milligrams per liter.
CRWQCB	California Regional Water Quality Control Board (CRWQCB, 1995).
EPC	Exposure point concentration (Table 3-1).
FWQC	Federal Water Quality Criteria (USEPA, 1991d).
NA	Not available.
[a]	Insufficient data to develop Federal Water Quality Criteria (FWQC). Value presented is USEPA Lowest observed effect level (LOEL) via acute exposure (USEPA, 1991d), unless otherwise specified.
[b]	Insufficient data to develop Federal Water Quality Criteria (FWQC). Value presented is USEPA Lowest observed effect level (LOEL) via chronic exposure (USEPA, 1991d), unless otherwise specified.

Table 8-1. Summary of Calculated Risks, Electro-Coatings, Inc., Emeryville, California.

Scenario	Risk Table	Cancer Risk Total ELCR	Non-Cancer Risk Total HI
<u>Site Worker</u>			
Soil Contact	Table 6-1	8E-07	0.04
Vapor Intrusion from Groundwater	Table 6-2	1E-08	0.0001
Vapor Intrusion from Soil	Table 6-3	6E-07	0.04
		==========	==========
TOTAL SITE RISK:		1E-06	0.08
<u>Excavation Worker</u>			
Soil Contact	Table 6-4	1E-08	0.07
Groundwater Contact	Table 6-5	1E-07	0.3
		==========	==========
TOTAL SITE RISK:		2E-07	0.4

ELCR	Excess lifetime cancer risk.
HI	Hazard index.

Table 8-2. Calculated Risk-Based Goals for Groundwater Based on Site Worker Exposure via Vapor Intrusion to Indoor Air, Electro-Coatings, Inc., Emeryville, California.

Constituent	Current Groundwater Concentration (mg/L)	Calculated Risks Cancer Risk	 Non-Cancer Risk	RBG (mg/L)	C or NC *
	Table 3-1	Table 6-2			
VOCs		ELCR	HI		
Chlorobenzene	0.018	NC	3.4E-07	50,000	NC
1,1-Dichloroethene	0.18	5.7E-09	1.0E-05	30 - 3,000	C
cis-1,2-Dichloroethene	0.42	NC	4.8E-06	90,000	NC
trans-1,2-Dichloroethene	0.13	NC	1.5E-06	90,000	NC
Tetrachloroethene	0.054	2.8E-12	3.9E-07	20,000 - 100,000	C [a]
1,1,1-Trichloroethane	0.23	NC	3.5E-07	700,000	NC
Trichloroethene	2.7	1.6E-09	1.2E-04	2,000 - 20,000	C [a]
Vinyl chloride	0.090	3.7E-09	NA	20 - 2,000	C
Inorganics					
Chromium (total)	120	NAP	NAP	NAP	–
Chromium (hexavalent)	120	NAP	NAP	NAP	–

* 'C' indicates the RBG is based on cancer effects (using a target cancer risk range of 10^{-6} to 10^{-4}); 'NC' indicates the RBG is based on non-cancer effects (using a target hazard index of 1).

[a] The upper level of the range is based on non-cancer effects (RBC_{NC}) because the RBC_C for a target cancer risk of 10^{-4} exceeds this level.

ELCR	Excess lifetime cancer risk
HI	Hazard index.
mg/L	Milligrams per liter.
NAP	Not applicable.
RBG	Risk-based concentration goal for groundwater.

Table 8-3. Calculated Risk-Based Goals for Groundwater Based on Excavation Worker Exposure, Electro-Coatings, Inc., Emeryville, California.

Constituent	Current Groundwater Concentration (mg/L)	Calculated Risks Cancer Risk	 Non-Cancer Risk	RBG (mg/L)	C or NC *
	Table 3-1	Table 6-5			
VOCs		ELCR	HI		
Chlorobenzene	0.018	NC	1.7E-03	10	NC
1,1-Dichloroethene	0.18	6.7E-08	9.8E-03	3 - 20	C [a]
cis-1,2-Dichloroethene	0.42	NC	1.5E-03	300	NC
trans-1,2-Dichloroethene	0.13	NC	2.4E-04	500	NC
Tetrachloroethene	0.054	4.5E-09	5.9E-04	10 - 90	C [a]
1,1,1-Trichloroethane	0.23	NC	1.1E-04	2,000	NC
Trichloroethene	2.7	2.0E-08	2.1E-01	10	NC
Vinyl chloride	0.090	5.3E-08	NA	2 - 200	C
Inorganics					
Chromium (total)	120	NC	1.6E-03	70,000	NC
Chromium (hexavalent)	120	NAP	8.1E-02	1,000	NC

* 'C' indicates the RBG is based on cancer effects (using a target cancer risk range of 10^{-6} to 10^{-4}); 'NC' indicates the RBG is based on non-cancer effects (using a target hazard index of 1).

[a] The upper level of the range is based on non-cancer effects (RBC_{NC}) because the RBC_C for a target cancer risk of 10^{-4} exceeds this level.

ELCR	Excess lifetime cancer risk
HI	Hazard index.
mg/L	Milligrams per liter.
NAP	Not applicable.
RBG	Risk-based concentration goal for groundwater.

Table 8-4. Calculated Risk-Based Goals for Soil Based on Site Worker and Excavation Worker Exposure, Electro-Coatings, Inc., Emeryville, California.

		RBGs Based on Site Worker Exposure				RBGs Based on Excavation Worker Exposure			
		Calculated Risks				Calculated Risks			
Constituent	Current Soil Concentration (mg/kg)	Cancer Risk	Non-Cancer Risk	RBG (mg/kg)	C or NC *	Cancer Risk	Non-Cancer Risk	RBG (mg/kg)	C or NC *
	Table 3-2	Table 6-1				Table 6-4			
VOCs		ELCR	HI			ELCR	HI		
Trichloroethene	36	5.2E-07	3.5E-02	70 - 1,000	C [a]	5.4E-09	6.3E-02	600	NC
Vinyl chloride	0.20	3.1E-07	NA	0.7 - 70	C	4.2E-09	NA	50 - 5,000	C
Inorganics									
Chromium (total)	810	NC	4.5E-04	2,000,000	NC	NC	4.0E-03	200,000	NC
Chromium (hexavalent)	26	6.9E-10	2.9E-03	9,000	NC	3.3E-12	6.5E-03	4,000	NC

* 'C' indicates the RBG is based on cancer effects (using a target cancer risk range of 10^{-6} to 10^{-4}); 'NC' indicates the RBG is based on non-cancer effects (using a target hazard index of 1).

[a] The upper level of the range is based on non-cancer effects (RBC_{NC}) because the RBC_{C} for a target cancer risk of 10^{-4} exceeds this level.

ELCR	Excess lifetime cancer risk
HI	Hazard index.
mg/kg	Milligrams per kilogram.
NAP	Not applicable.
RBG	Risk-based concentration goal for soil.

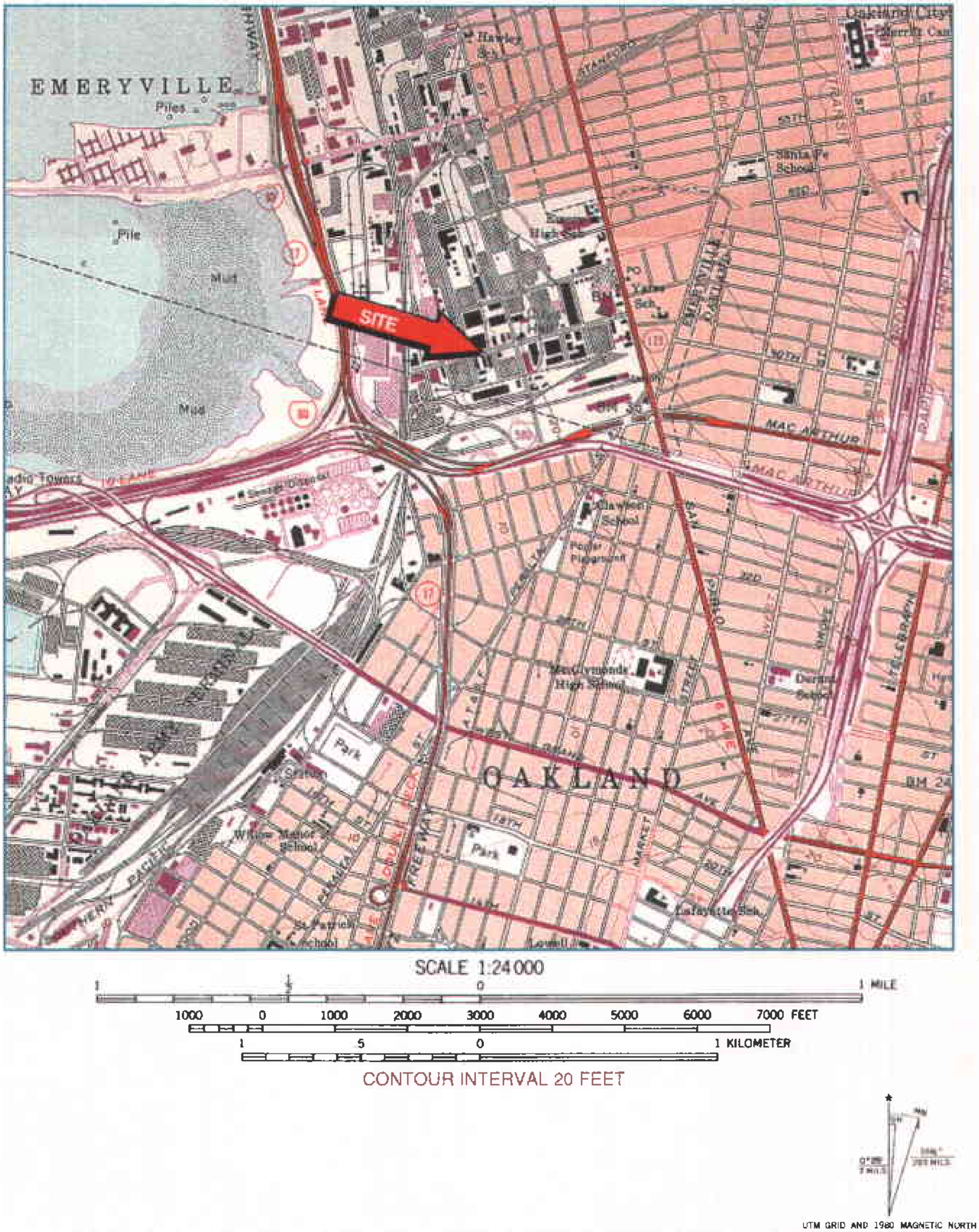
Table 8-5. Calculated Risk-Based Goals for Soil Based on Site Worker Exposure via Vapor Intrusion to Indoor Air, Electro-Coatings, Inc., Emeryville, California.

		Calculated Risks			
Constituent	Current Soil Concentration (mg/kg)	Cancer Risk	Non-Cancer Risk	RGB (mg/kg)	C or NC *
	Table 3-2	Table 6-3			
VOCs		ELCR	HI		
Trichloroethene	36	5.2E-07	4.1E-02	70 - 900	C [a]
Vinyl chloride	0.20	3.5E-08	NA	6 - 600	C
Inorganics					
Chromium (total)	810	NAP	NAP	NAP	–
Chromium (hexavalent)	26	NAP	NAP	NAP	–

* 'C' indicates the RBG is based on cancer effects (using a target cancer risk range of 10^{-6} to 10^{-4}); 'NC' indicates the RBG is based on non-cancer effects (using a target hazard index of 1).

[a] The upper level of the range is based on non-cancer effects (RBC_{NC}) because the RBC_{C} for a target cancer risk of 10^{-4} exceeds this level.

ELCR	Excess lifetime cancer risk
HI	Hazard index.
mg/kg	Milligrams per kilogram.
NAP	Not applicable.
RBG	Risk-based concentration goal for soil.



Reference: U.S.G.S. 7.5-minute Quadrangle Oakland West, California, 1959 photorevised 1980.

GERAGHTY & MILLER, INC.
Environmental Services
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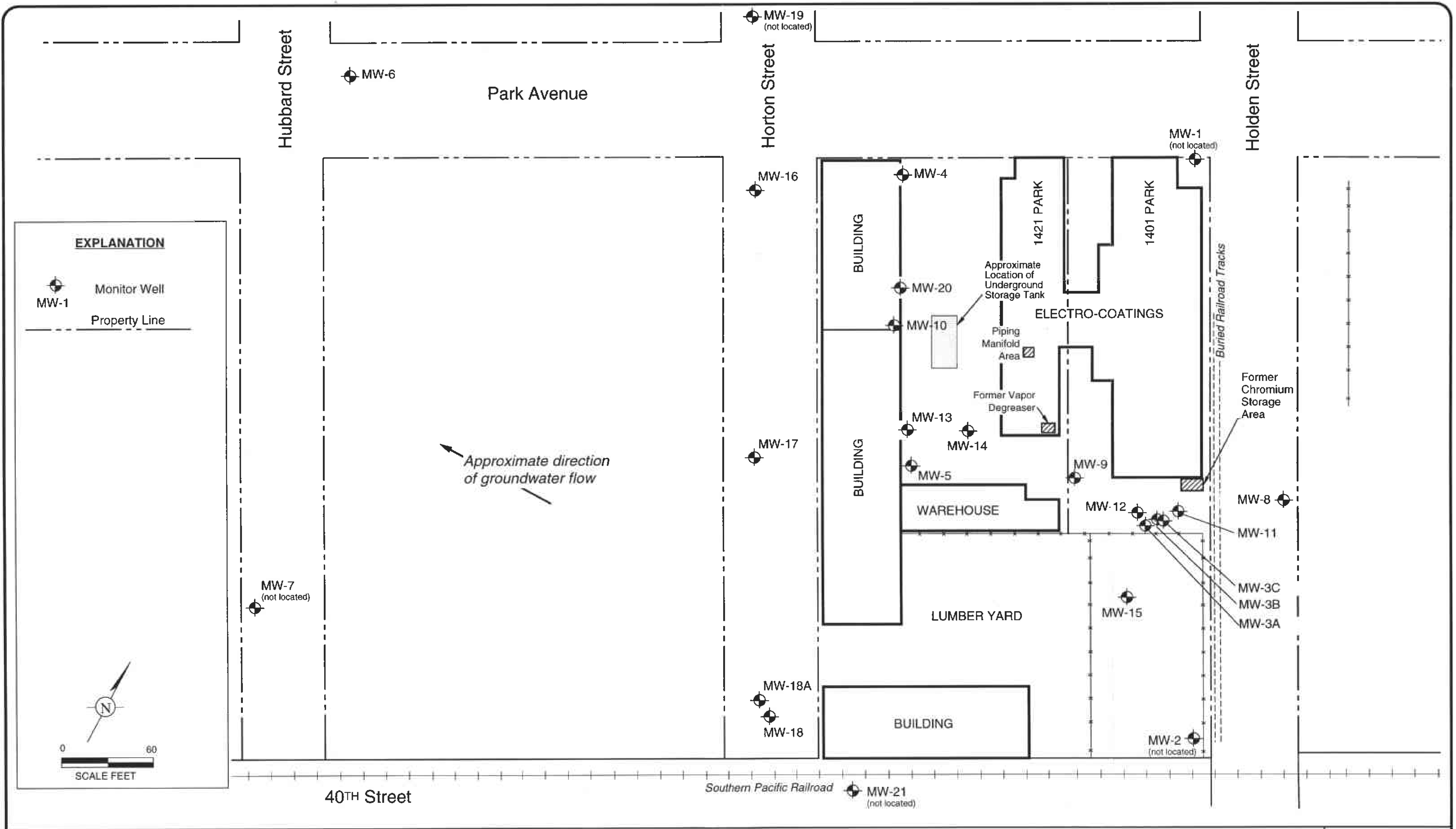
SITE LOCATION MAP

Electro-Coatings, Inc.
1401 and 1421 Park Avenue
Emeryville, California

FIGURE
1



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GERAGHTY & MILLER, INC.
Environmental Services
A **Heidemij** Company

Project No. RC0304.000

SITE PLAN
Electro-Coatings, Inc.
1401 and 1421 Park Avenue
Emeryville, California

FIGURE
2

REVISION:
DECEMBER 16, 1996