

Explanation

25 → Soil Vapor Sample Point and Depth
 139 Concentrations of Total VOCs (μg/L-Vapor)
 ND Non-Detect @ Laboratory Detection Limit of 1.0 μg/L-Vapor
 P Sample Port Plugged; No Sample Collected
 W Sample Port Waterlogged; No Sample Collected

Contours:

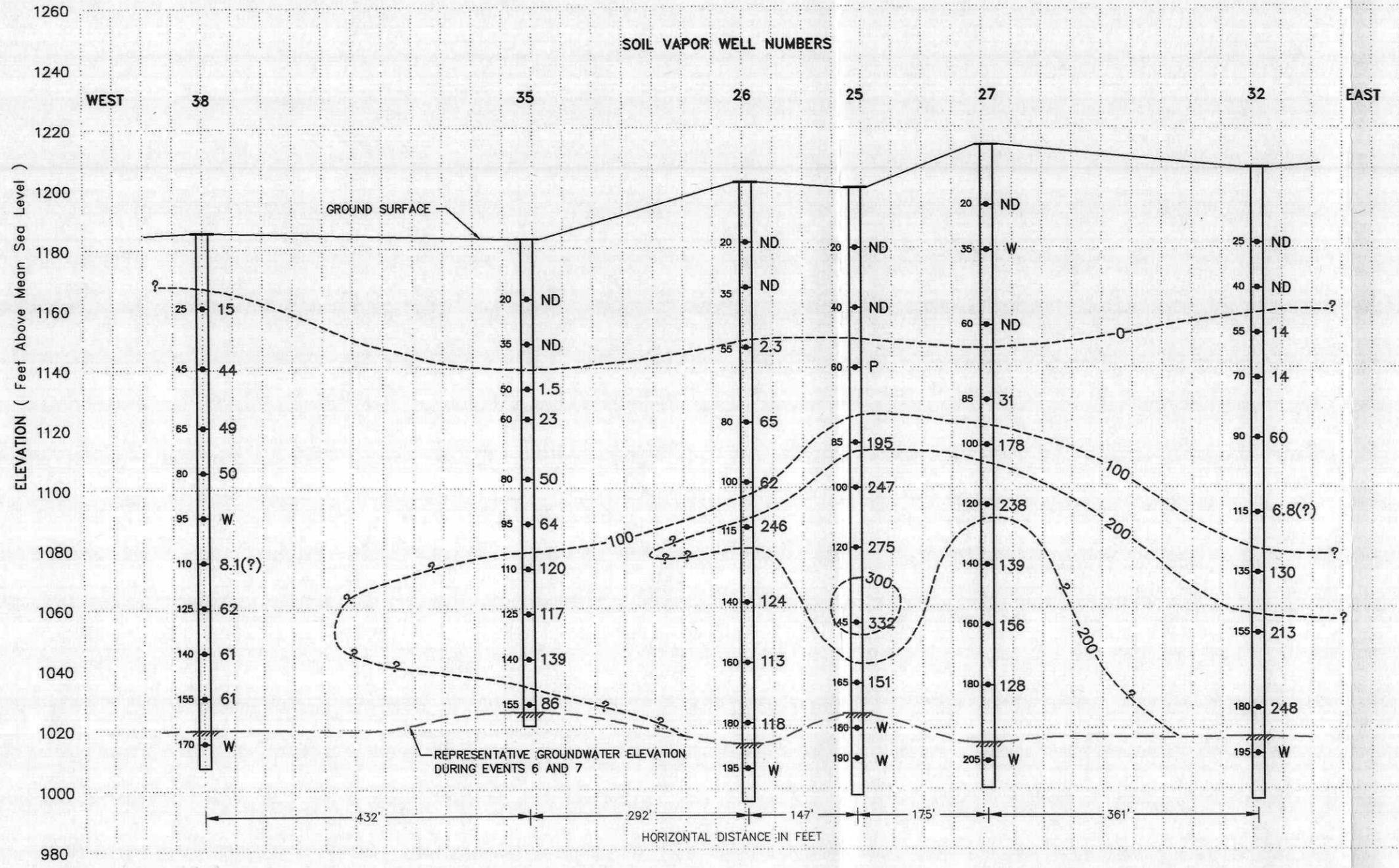
1. Intervals in 100 μg/L-Vapor.
 2. Queried where spatial control is lacking.

Note:

Location of cross-section is shown on Figures 4-17 and 4-26.

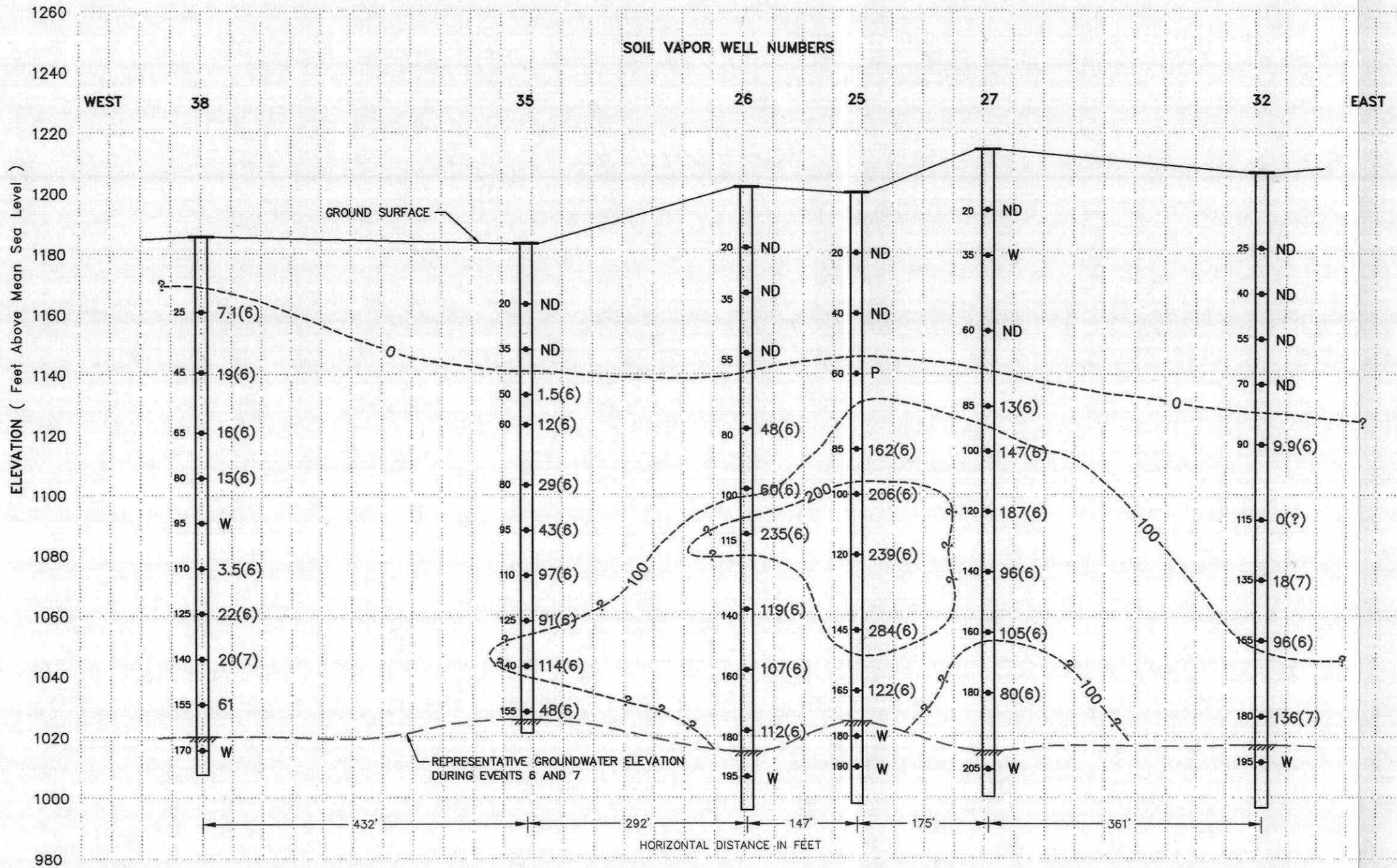
HORIZONTAL SCALE: 1"=160'

VERTICAL SCALE: 1"=40'



NOTE:
 THE CONCENTRATION SUMS PRESENTED INCLUDE THE HIGHEST RESULTS OBTAINED FROM EITHER EVENT.

FIGURE 4-35
 REPRESENTATIVE HORIZONTAL AND VERTICAL
 DISTRIBUTION OF TOTAL VOCs DURING THE TIME
 INTERVAL FOR EVENTS 6 AND 7
 MAY-JUNE, 1998
 Jet Propulsion Laboratory
 Pasadena, California
 FOSTER WHEELER ENVIRONMENTAL CORPORATION



Explanation

- 25 → Soil Vapor Sample Point and Depth
- 187 Concentrations of Carbon Tetrachloride ($\mu\text{g/L}$ -Vapor)
- (6) Indicates Sample Event From Which Results Came
- ND Non-Detect @ Laboratory Detection Limit of 1.0 $\mu\text{g/L}$ -Vapor
- P Sample Port Plugged; No Sample Collected
- W Sample Port Waterlogged; No Sample Collected

Contours:

1. Intervals in 100 $\mu\text{g/L}$ -Vapor.
2. Queried where spatial control is lacking.

Note:

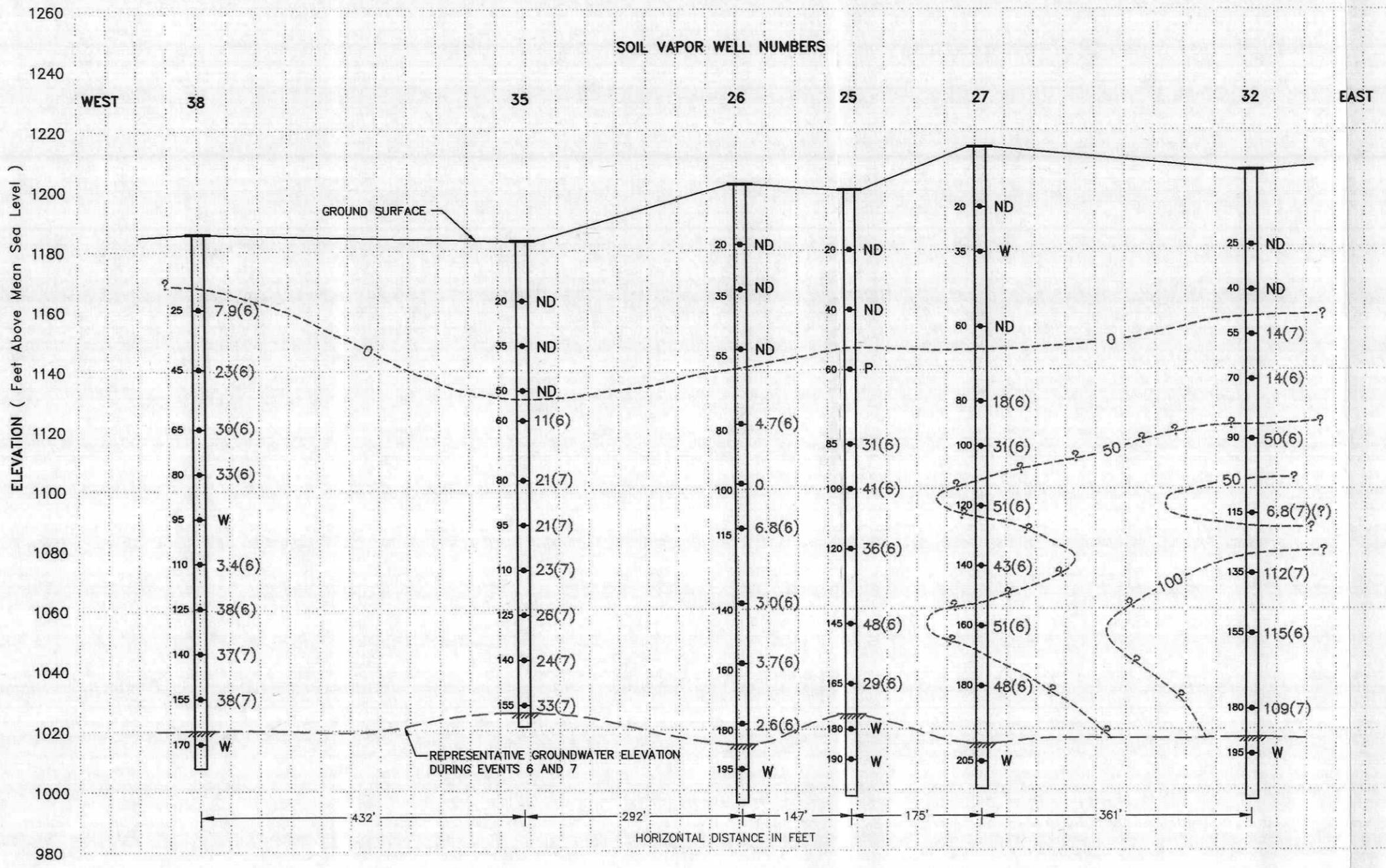
Location of cross-section is shown on Figures 4-17 and 4-26.

HORIZONTAL SCALE: 1"=160'

VERTICAL SCALE: 1"=40'

NOTE:
 HIGHEST CONCENTRATION FROM EITHER EVENT ARE PRESENTED.

FIGURE 4-36
 REPRESENTATIVE HORIZONTAL AND VERTICAL DISTRIBUTION OF TOTAL CARBON TETRACHLORIDE DURING THE TIME INTERVAL FOR EVENTS 6 AND 7 MAY-JUNE, 1998
 Jet Propulsion Laboratory
 Pasadena, California
 FOSTER WHEELER ENVIRONMENTAL CORPORATION



Explanation

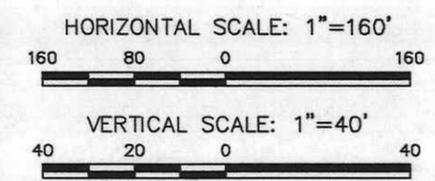
- 25 → Soil Vapor Sample Point and Depth
- 31 Concentrations of Freon 113 ($\mu\text{g/L}$ -Vapor)
- (6) Indicates Sample Event From Which Results Came
- ND Non-Detect @ Laboratory Detection Limit of 1.0 $\mu\text{g/L}$ -Vapor
- P Sample Port Plugged; No Sample Collected
- W Sample Port Waterlogged; No Sample Collected

Contours:

1. Intervals in 50 $\mu\text{g/L}$ -Vapor.
2. Queried where spatial control is lacking.

Note:

Location of cross-section is shown on Figures 4-17 and 4-26.



NOTE:

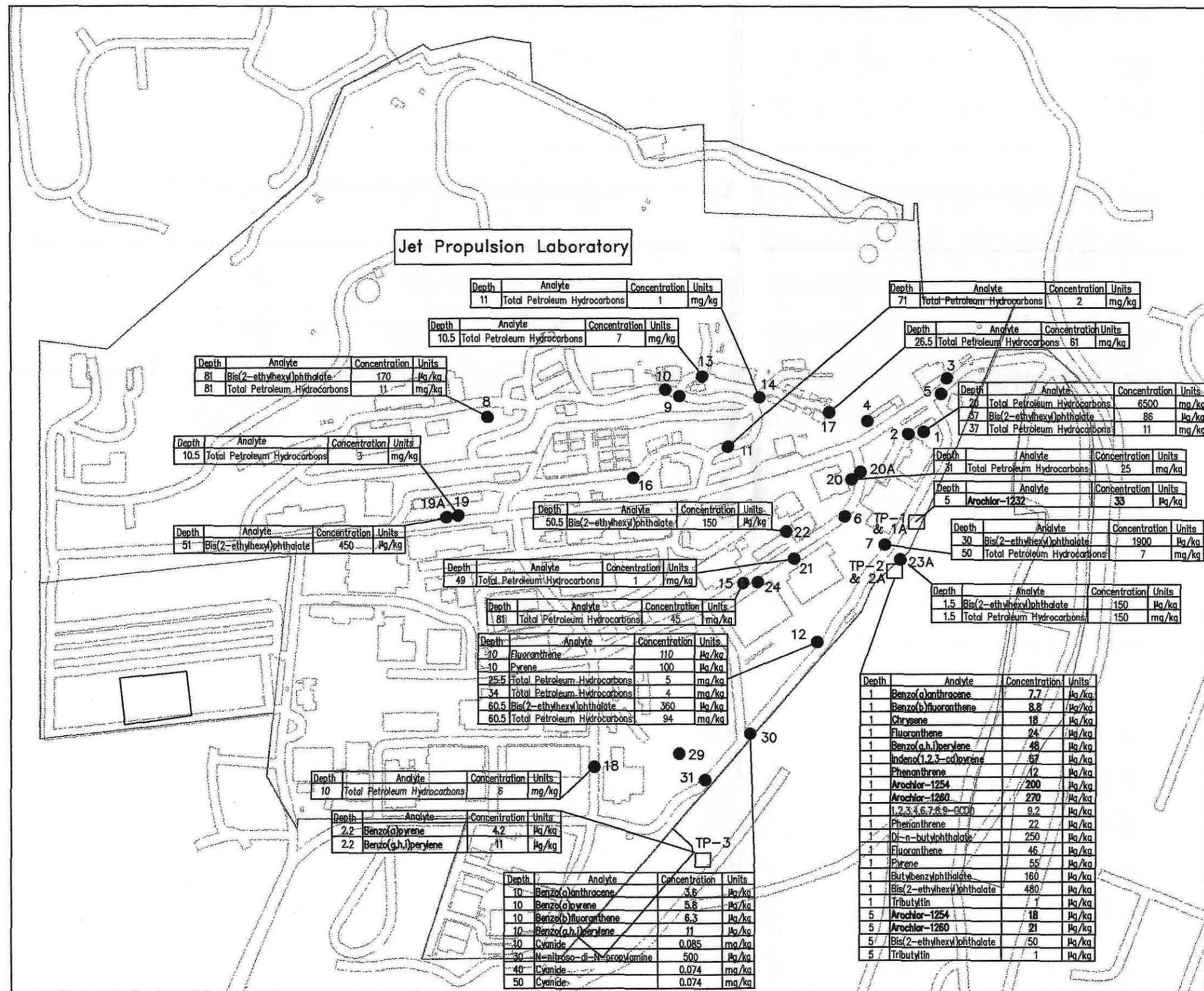
HIGHEST CONCENTRATION FROM EITHER EVENT ARE PRESENTED.

FIGURE 4-37

REPRESENTATIVE HORIZONTAL AND VERTICAL DISTRIBUTION OF TOTAL FREON 113 DURING THE TIME INTERVAL FOR EVENTS 6 AND 7 MAY-JUNE, 1998

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Pasadena, California

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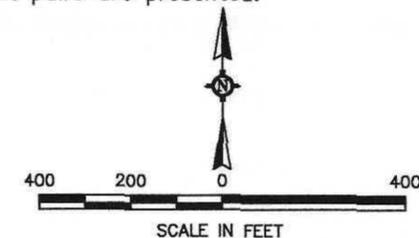


Explanation

- 39 Soil Boring Completed During RI Investigation
- TP-1 & 1A Test Pit Location
- Total Petroleum Hydrocarbons (EPA Method 418.1)
- Semivolatile Organic Compounds (EPA Method 8270)
- Polycyclic Aromatic Hydrocarbons (EPA Method 8310)
- Poly Chlorinated Biphenyls (EPA Method 8081)
- Dioxins (EPA Method 8280)
- Cyanide (EPA Method 335.3)
- Tributyltin (No EPA Method)

mg/kg Milligrams per kilogram
µg/kg Micrograms per kilogram

NOTE:
The higher concentrations from the test pit pairs are presented.



Source: USGS, 7.5 Minute Topographic Map Pasadena, CA 1966, Revised 1988, 1994.

FIGURE 4-38

CONCENTRATIONS OF ORGANIC COMPOUNDS AND CYANIDE DETECTED IN SOIL DURING THE OU-2 RI

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5.0 CONTAMINANT FATE AND TRANSPORT

The fate and transport characteristics of the primary constituents identified in the soil and soil vapor during the OU-2 RI (Section 4.0) are described in this section. These constituents include mainly volatile organic compounds (VOCs) that were quantified in soil-vapor samples. Also included are other organic compounds that were infrequently detected in soil samples at concentrations near their detection limits, including semivolatile organic compounds (SVOCs), [which also include polynuclear aromatic hydrocarbons (PAHs)], three polychlorinated biphenyls (PCBs), one dioxin congener (1,2,3,4,6,7,8,9-OCDD), cyanide (CN⁻), nitrate (NO₃⁻), tributyltin, and total petroleum hydrocarbons (TPH). As discussed in Section 4.3.2, two metals, arsenic (As) and hexavalent chromium [Cr(VI)], were detected at elevated concentrations..

The purpose of this section is to provide an understanding of the factors controlling the environmental fate and transport of contaminants in soil and soil vapor at JPL and to determine the potential for further migration of these compounds. This information will be used in assessment of the potential risk of current and future exposure. This section is organized into four parts as follows:

- **Section 5.1** – Potential contaminant migration pathways at JPL.
- **Section 5.2** – Physical and chemical characteristics of contaminants relevant to environmental fate and transport.
- **Section 5.3** – Fate and transport processes most likely to be present at JPL based on site history, site physical characteristics, and the nature and extent of contamination.
- **Section 5.4** – General conclusions.

5.1 POTENTIAL MIGRATION PATHWAYS

As detailed in Section 4.0, the release of compounds from past activities at JPL has resulted in varying degrees of soil and soil-vapor contamination, which appears to have undergone migration and redistribution in on-site soils, and has impacted groundwater. A summary of the potential migration pathways and fate and transport processes that may be operating at JPL is presented in Figure 5-1. A detailed discussion of these processes with regard to specific site conditions is presented in Section 5.3. In the following discussions, “surface soil” is defined as the upper few inches of soil that may be subject to transport by surface processes such as wind or overland water flow.

As shown in Figure 5-1, contaminants present in surface soil (upper few inches) may be mobilized and transported by wind erosion, volatilization, or episodic overland flow. Contaminants in surface soil may also migrate to subsurface soil (and groundwater) via desorption and leaching processes. Volatile organic compounds in surface soil can migrate into soil vapor or they can volatilize directly to the atmosphere.

Volatile organic compounds in surface soil can migrate into soil vapor or they can volatilize directly to the atmosphere.

If mobilized by surface water runoff, contaminants may eventually re-enter the subsurface environment by infiltration, contaminating subsurface soil and possibly groundwater. In the process of infiltration, organic contaminants may also remain adsorbed to soil particles, where attenuation by photolysis (in surface soils) or biodegradation may occur. Contaminants, in surface soil or sediment, are also subject to biomagnification, potentially impacting plants and animals. Transport by surface water to a standing body of water is also possible. Contaminants mobilized as fugitive dust can be deposited onto surface soil, surface water bodies, or dispersed in local air masses.

Contaminants present in subsurface soil can be released to soil vapor and can eventually reach the atmosphere or seep into basements if the building is directly above or in close proximity to a source; or vapor can migrate to groundwater via desorption and/or leaching. Volatile contaminants that migrate to the atmosphere are subject to dispersal by local air masses; while atmospheric and indoor air vapors may undergo degradation by photolysis and oxidation reactions. Redeposition from the atmosphere to surface soil or surface water bodies may also occur. Contaminants that remain in the soil may be subject to attenuation by chemical and biological degradation processes.

5.2 CONTAMINANT CHARACTERISTICS AND BEHAVIOR

Contaminants identified in the JPL soil and soil vapor (Section 4.0) include select VOCs, SVOCs (including PAHs), three PCBs, one dioxin congener (1,2,3,4,6,7,8,9-OCDD), TPH, tributyltin, CN⁻, NO₃⁻, As, and Cr(VI). Discussed in this section are the generic properties of each contaminant with respect to potential behavior in soil.

The chemical and physical properties of each analyte detected in JPL soil and soil vapor during the OU-2 RI are compiled in Table 5-1. These properties can be used to predict various fate and transport parameters, such as the potential of an analyte to partition between the solid, liquid, and gas phases. For example, partitioning of a particular VOC between water, air, and soil can be estimated using the VOC's aqueous solubility value (water), Henry's law constant (K_H) (water-air), and vapor pressure (air), and its organic carbon partition coefficient (K_{oc}) [which can be estimated by measuring its octanol-water partition coefficient (K_{ow})] (soil).

The aqueous solubility value gives the maximum amount (mass) of a chemical that is soluble within a given volume of water. In general, compounds with solubility values less than 1 mg/L are generally considered insoluble in water, while compounds with values greater than 10,000 mg/L are considered highly soluble.

The vapor pressure of a chemical is a measure of the chemical's tendency to volatilize. Vapor pressures greater than 1 millimeter of mercury (mm Hg) indicate volatility, whereas chemicals with vapor pressures ranging from 1 to 0.001 mm Hg are considered semivolatile, and those with vapor pressures less than 0.001 mm Hg are considered non-volatile. It should be noted that the classification of volatility by vapor pressure does not necessarily correspond to the laboratory

classification of compounds as either volatile or semivolatile (base-neutral-acid extractable) target analyses.

The specific Henry's law constant for a given compound provides a measure of the tendency of that compound to volatilize from an aqueous solution. For volatile compounds, higher values of Henry's law constants are associated with an increased volatilization from water. Chemicals that are readily volatilized from groundwater or surface water have constants exceeding 10^{-3} atmosphere-cubic meters per mole ($\text{atm}\cdot\text{m}^3/\text{mol}$), whereas compounds with low volatility have constants less than 10^{-7} $\text{atm}\cdot\text{m}^3/\text{mol}$.

The single most important characteristic for quantifying adsorption of an organic contaminant by a soil is the organic carbon (C) content in the soil, which is usually estimated in terms of the octanol-water partitioning coefficient, K_{ow} . The K_{ow} defines the potential for a compound to partition into octanol in an octanol-water system. Since octanol is considered to represent the sorptive properties of soil organic matter, the K_{ow} can provide an estimate of the tendency for a chemical to sorb to soil organic matter. The greater the value of K_{ow} [generally expressed as $\text{Log}(K_{ow})$], the greater the tendency for adsorption. Compounds with $\text{Log}(K_{ow})$ values generally greater than 3 are preferentially sorbed into the soil phase in soil-water systems. Compounds with $\text{Log}(K_{ow})$ values less than 1 are considered to weakly partition into the soil phase and values between 1 and 3 denote moderate affinity for the soil phase. Of course, actual partitioning of VOCs into the soil phase will be highly dependent on the organic carbon content of the soil. In the following discussions, it is assumed that because substantial vegetation has historically covered the JPL site, organic matter (such as humic material) is present in the surface soils and to a lesser extent the subsurface soils at JPL. Relevant characteristics of the contaminants and their behavior in environmental systems identified in JPL soils are described in the following subsections.

5.2.1 Volatile Organic Compounds

Relevant physical and chemical properties of the VOCs detected in soil vapor at JPL are listed in Table 5-1. As noted in Section 4.0, carbon tetrachloride (CCl_4), trichloroethene (TCE), 1,1-dichloroethene (1,1-DCE), and 1,1,2-trichloro-1,2,2-trifluoroethane (Freon 113) were the most frequently detected compounds, and were generally detected at the highest concentrations, but this discussion covers all VOCs detected in soil-vapor samples collected during the RI.

With reference to Table 5-1 and the discussion above (Section 5.2), VOCs can be classified as volatile, moderately adsorbing to soil organic carbon, and range in solubility from insoluble to moderately soluble. Their high vapor pressures and moderate to high Henry's law constants suggest a moderate to low affinity for water. Generally moderate $\text{Log}(K_{ow})$ values indicate that partitioning of these compounds into soil organic carbon would likely have an impact on contaminant retardation if soil organic matter were present. In soils such as those at JPL, where organic carbon is not prevalent and coarser-grained materials (such as sands and gravels) are

encountered, retardation will be diminished and the migration of contaminants will occur more readily.

With regard to degradation, VOCs in subsurface soils are typically not subject to hydrolytic reactions, however, non-halogenated VOCs, and to a lesser extent halogenated VOCs, can be degraded biologically via several mechanisms under both aerobic and anaerobic conditions as discussed below.

Oxidation

Oxidation of organic compounds by heterotrophic bacteria is the means by which organisms acquire energy for growth. This process occurs under aerobic conditions, where oxygen serves as the terminal electron acceptor, as well as occurring anaerobically, where oxyanions such as nitrate (or various metals or organic compounds) serve as alternate terminal electron acceptors. Oxidation of most of the chlorinated VOCs listed in Table 5-1 as energy sources is generally not believed to occur, although non-chlorinated and some of the lesser chlorinated compounds (the latter of which are not present at the site) are subject to aerobic microbial oxidation reactions. In addition, the non-chlorinated compounds present at the site, such as benzene, toluene, ethylbenzene, the xylene isomers, and potentially the volatile compounds comprising petroleum hydrocarbons detected in various soil borings (see Sections 4.2.2 and 4.3.7) are also microbially oxidized under aerobic conditions.

Co-metabolism

This is a process whereby organisms fortuitously degrade a non-growth substrate (such as a particular chlorinated organic compound) while growing on a structurally similar substrate. There is no energy derived from the co-metabolized compound, and no known benefit to the organism. The process is believed to occur as a result of enzymes with loose substrate specificity. The best documented example of this process is the fortuitous degradation of TCE by methane-oxidizing organisms (while growing on methane or propane) under aerobic conditions.

Reductive Dechlorination

Reductive dechlorination is a process whereby a chlorinated organic compound serves as a terminal electron acceptor during anaerobic respiration (not as a source of organic carbon). In this process, chlorine (Cl) atoms are removed from the parent compound forming less chlorinated metabolites and the chloride ion (Cl^-). As an example, reductive dechlorination of TCE proceeds sequentially (e.g., from TCE, degrading to dichloroethene, and then possibly to less chlorinated compounds). Depending on environmental conditions, TCE degradation may yield a variety of dichloroethene isomers as well as several dichloroethanes. In order for this process to occur, there must be an appropriate organic carbon source such as natural soil organic matter or petroleum hydrocarbons. Because TCE was commonly used as a solvent while dichloroethenes were not, it is likely that the any dichloroethene detected in JPL soil vapor has resulted from reductive dechlorination of TCE. The presence of dichloroethene isomers is generally an indicator that this process has occurred.

5.2.2 Semi-Volatile Organic Compounds

Polynuclear Aromatic Compounds

PAHs are hydrocarbons with more than one aromatic ring. This group of compounds comprises the largest number of SVOCs detected in soils at JPL. The majority of PAHs are solids at standard temperatures and pressures. Like other SVOCs, PAHs are characterized by low solubilities, moderate to low volatilities, and moderate to high partition coefficients. PAHs are considered relatively immobile in soil-water systems (Howard, 1990). The absence of PAHs in deeper soil intervals or groundwater at JPL reflects the immobility of these compounds.

Volatilization is typically of minor concern for PAHs with more than three-fused aromatic rings, which comprise the majority of PAHs detected in soil at JPL. As a general rule, solubility, volatility, and biodegradation potential decrease with an increasing number of fused aromatic rings. Phenanthrene and pyrene are the most soluble and have the highest vapor pressures, by an order of magnitude or more, compared to the other PAHs detected in soil at JPL. Of the PAHs detected, only one, phenanthrene, has less than four rings.

The PAHs detected in soil at JPL have low aqueous solubilities ranging from 0.00026 mg/L to 0.816 mg/L and $\text{Log}(K_{ow})$ partition coefficients ranging from 4.46 to 7.66 which indicate that these compounds have a high potential to adsorb to soil organic matter, and should not leach from soil into groundwater. In addition, the PAHs detected at the site are not highly susceptible to biodegradation (Howard, 1990).

The depths at which PAHs were detected in the soil (generally near the surface) and their absence in groundwater suggests that these compounds are probably adsorbed to the soil. The isolated occurrence of these chemicals in near-surface soils (from 1 to 5 feet bgs) in test pit No. 2 (TP-2), and soil boring Nos. 12 and 30 (at 10 feet bgs) suggests that these PAHs are associated with discharged waste liquids at DP-2 and asphalt materials in pavement at sample locations. These PAHs are likely immobile at their present locations.

Phthalates and Other SVOCs

Three phthalates [(bis(2-ethylhexyl)phthalate, butylbenzyl phthalate, and di-n-butyl phthalate] and n-nitroso-di-n-propylamine were detected in soil samples at JPL. The majority of detects were in the vicinity of TP-2 at a depth of 1 foot. In general, phthalates are characterized by low solubilities, low volatilities, and moderate to high partition coefficients and are considered relatively immobile in soil-water systems (Howard, 1990). The infrequency of detects in deeper soil intervals or groundwater at JPL reflects the immobility of these compounds.

Bis(2-ethylhexyl)phthalate, butylbenzyl phthalate, and di-n-butyl phthalate have low to moderate solubilities ranging from 0.4 mg/L for bis(2-ethylhexyl)phthalate to 400 mg/L for di-n-butyl phthalate. In addition, their $\text{Log}(K_{ow})$ values, ranging from 4.78 to 5.3, indicate a strong propensity for adsorption to soil organic matter. The infrequency of detects and low concentrations in soil at greater depths, as well as in groundwater (typically at least one order of

magnitude below regulatory limits), suggests that these compounds are adsorbed to surface soil. It is possible that the isolated detection of these chemicals at depth may have resulted from field sampling cross contamination due to the storage of sampling sleeves in plastic garbage bags (these three phthalates are common in plasticizers).

N-nitroso-di-n-propylamine was detected in only one sample, at a depth of 30 feet in soil boring No. 30. This compound has a solubility of 9,900 mg/L, and $\text{Log}(K_{ow})$ of 1.31. N-nitroso-di-n-propylamine has a lower affinity for the solid phase compared to the phthalates detected in soil, but its infrequency of detection and its absence in groundwater suggest that it is of minimal concern.

5.2.3 Polychlorinated Biphenyls

Polychlorinated biphenyls (PCBs) were detected in three soil samples collected at JPL. Arochlor-1254 and Arochlor-1260 were both detected in two samples collected from TP-2 at depths of 1 feet and 5 feet. Arochlor-1232 was detected in one sample from TP-1A at 4.7 feet. Concentrations of Arochlor-1254 and Arochlor-1260 decreased significantly from 1 to 5 feet. All detections of PCBs were within the upper 6 feet of soil sampled at TP-1A and TP-2.

Arochlor-1232, Arochlor-1254, and Arochlor-1260 are characterized by very low solubilities (2.00, 0.031 mg/L, and 0.0027 mg/L, respectively), high $\text{log } K_{ow}$ values (4.84, 6.3, and 6.8, respectively), and low susceptibility to biodegradation in aerobic soils (Montgomery and Welkom, 1990). The absence of PCBs in deeper soil and groundwater at OU-2 reflects their immobility in soil-water systems.

PCBs are expected to be very immobile given the high $\text{Log}(K_{ow})$ values and the fine-grained nature of soil at JPL. As a result of the high affinity for the solid phase, adsorption of PCBs at JPL are expected to be very substantial. As a result, potential migration pathways for PCBs at JPL are probably limited to eolian transport in soil or dust particulates. Degradation processes (both biotic and abiotic) are not expected to be significant for PCBs over the short term in JPL soils. However, these compounds may degrade via various mechanisms over longer periods of time.

5.2.4 Dioxins and Furans

One dioxin congener was detected in JPL soil at a depth of 1 foot in one sample collected from TP-2. Dioxins and were not detected in any other samples collected during the RI, and furans were not detected in any JPL soil samples.

Dioxins are characterized by very low solubilities ranging from 1×10^{-8} mg/L to 1×10^{-5} mg/L, very high $\text{Log}(K_{ow})$ values (7 to 9), and low susceptibility to biodegradation in aerobic soils (Palausky and others, 1986). As a result of the high affinity for the solid phase [high $\text{Log}(K_{ow})$ values], adsorption of the dioxin congener detected at JPL is expected to be very substantial and, therefore, it is expected to be very immobile. The absence of this compound in deeper soils and groundwater

at JPL may reflect its immobility in the JPL soil-water system. As a result, potential migration pathways for this compound are probably limited to airborne or eolian transport in soil or dust particulates. Biodegradation is not expected to be significant.

5.2.5 Tributyltin

Tributyltin compounds are a subgroup of the trialkyl organotin family of compounds and are the main active ingredients in bactericides and fungicides used to control a broad spectrum of organisms in wood preservatives, marine paints, and in industrial water systems (such as cooling tower and refrigeration water systems).

In soil, tributyltin takes one to three months to degrade in aerobic conditions, while in anaerobic soils this compound can persist for more than two years. Degradation depends on temperature and the presence of microorganisms and the ionic form of tin is the final breakdown product. Because of the low water solubility of tributyltin and high partition coefficient, it will bind strongly to suspended material such as organic material or inorganic sediments and precipitate to the bottom sediment. Reported half-lives of the compound in freshwater are 6 to 25 days; in seawater and estuarine locations, it is 1 to 34 weeks, depending on the initial concentration.

5.2.6 Total Petroleum Hydrocarbons

Analysis of TPH was conducted using EPA Method 418.1, which detects a variety of petroleum hydrocarbons with ten or more carbon atoms. These can be branched and unbranched aliphatic compounds (straight chained), or aromatic compounds (containing ring structures). This analysis does not allow for identification of specific compounds; however, PAHs (which have ten or more carbon atoms), were not detected in any of the samples that contained TPH, suggesting that the TPH consists largely of long-chained aliphatic compounds. These types of compounds are generally considered to be sparingly soluble and to have strong affinities for the solid phase, and, therefore, are considered relatively immobile in soil-water systems. They are also typically characterized as having relatively low vapor pressures, and thus, volatilization is generally not considered significant. These compounds are subject to biodegradation via oxidation; however, the rates are dependent upon microbial population dynamics, structural characteristics of the target molecules (such as the degree of branching), and the availability of electron acceptors.

5.2.7 Title 26 Metals

Results from Title 26 metal analysis suggested that arsenic (As) was detected in several locations at levels that may be elevated, but probably reflect the natural mineralogy of the area. Hexavalent chromium [Cr(VI)], which is generally not considered to be naturally occurring, was detected at one location near discharge point No. 2 (DP-2). The chemical and physical properties of these two metals and a description of their behavior in the environment are discussed below.

Arsenic

Arsenic occurs naturally in a variety of oxidation states, which include both negatively charged states occurring in arsenide and sulfide minerals, and the positively charged states As(III) and As(V), that occur within the oxyanions arsenite and arsenate, respectively. Arsenic is subject to chemically and/or microbiologically mediated reduction-oxidation reactions in soil-water systems. In aqueous solutions under oxidizing environmental conditions, dissolved arsenates occur in two primary forms. The monovalent arsenate anion, H_2AsO_4^- , predominates between pH 3 and pH 7, and the divalent species, HAsO_4^{2-} , predominates between pH 7 and pH 11. Under acidic and mildly reducing conditions, the uncharged arsenite ion H_3AsO_3 is stable, but dissociates to the monovalent H_2AsO_3^- and divalent HAsO_3^{2-} at pH values greater than 9 (Hem, 1985).

Arsenic solubility is controlled primarily by the formation of low solubility ferric arsenates and other metal arsenate solids, and by adsorption and co-precipitation with iron (Hem, 1985; Masscheleyn and others, 1991). Arsenic concentrations [as As(V)] in oxidizing environments are often controlled by adsorption to ferric iron solids, but can be remobilized under reducing conditions due to the reductive dissolution of iron (Masscheleyn and others, 1991).

Chromium

Chromium is found in nature in two oxidation states: the trivalent state, Cr(III), and the hexavalent state, Cr(VI). The trivalent form is most common, occurring in several primary and secondary minerals, as well as various oxides and hydroxides such as chromium hydroxide [$\text{Cr}(\text{OH})_3$].

When released to the environment by weathering, Cr(III) is readily adsorbed by clay-sized particles, organic matter, and oxyhydroxides of iron and manganese. Under normal environmental conditions (pH 5 to 9), Cr(III) is highly insoluble, forming oxide and hydroxide precipitates. At a pH of less than 5, Cr(III) is stable as the chromic ion, and at an alkaline pH it forms a soluble complex, $\text{Cr}(\text{OH})_4^-$ (aq). Cr(III) is also known to form soluble complexes with various organic compounds. Consequently, Cr(III) is generally only mobile under very acidic or very alkaline conditions, or in the presence of suitable organic compounds at high enough concentrations. Cr(III) may be naturally oxidized to the hexavalent form by dissolved oxygen, but the reaction is very slow and generally considered negligible, even under highly oxidizing conditions. Oxidation of Cr(III), however, has been shown to occur in soils in the presence of manganese [Mn(IV)].

While Cr(VI) occurs in soil-water systems, it is relatively unstable as compared to the trivalent form unless conditions are highly oxidizing, or unless it occurs as a constituent of primary igneous minerals. When released to the environment, hexavalent chromium occurs as an oxyanion over the entire pH range under oxidizing conditions. As a result, it is very soluble in water and highly mobile. Hexavalent chromium is readily reduced to the trivalent form by several mechanisms including bacterial reduction (in the presence of a suitable organic carbon source), or abiotic reduction by ferrous iron or hydrogen sulfide. The abundance of iron in most

soil may provide a natural source for the conversion of Cr(VI) to Cr(III). Adsorption of Cr(VI) in soil-water systems is not well documented, but may be most significant in low pH conditions when the surface charge of clays and oxyhydroxides tends to be more positive (Moore and Ramamoorthy, 1984; Losi and others, 1994).

5.2.8 Cyanide

Cyanide (CN^-) was detected in one JPL borehole during the OU-2 RI. Cyanide is an anion that readily forms metallo-cyanide complexes with many metals, including alkali, alkaline earth and transition metals. In environmental systems, CN^- can exist as the free anion, and as loosely or strongly complexed metal cyanides. While free CN^- is considered toxic and mobile, the toxicity and mobility of CN^- generally decreases (and the stability of CN^- compounds increases) with the more strongly complexed forms, such as ferrocyanide and ferricyanide, which consists of CN^- complexed with iron (Conner, 1990). Specification of CN^- in JPL soils was not carried out, and therefore, the form that was detected is not known. However, given the wide variety of naturally occurring metals in these soils (including iron), it is likely that the CN^- detected was a complexed form, and, therefore, of minimal concern.

5.2.9 Nitrate

Although ammonium (NH_4^+) in clay minerals can be released and converted to NO_3^- via a microbial process known as nitrification, the presence of NO_3^- in soils (and in groundwater) generally reflects organic deposition. Accordingly, the NO_3^- detected in JPL soils is believed to have resulted from the historic use of agricultural fertilizers on irrigated cropland prior to JPL and prior equestrian activities, JPL's use of fertilizers and irrigation water in landscaped areas, and cesspools on the site. Nitrate is readily soluble and mobile in most soil-water systems, as evidenced by its presence (at levels well below MCLs) in JPL groundwater (FWENC, 1999). Nitrate can also be reduced biologically (by soil bacteria) under anaerobic conditions to form nitrogen gas, provided a suitable carbon source is available.

5.3 CONTAMINANT MIGRATION AT JPL

Based on site conditions and contaminant types and distribution, it appears that several of the fate and transport mechanisms identified in Section 5.1 are considered significant enough to cause further migration and redistribution of contaminants at JPL. Vertical downward flow due to rainfall appears to be the principal contaminant transport mechanism. This mechanism may have contributed to the migration of VOCs, and possibly Cr(VI) into groundwater. This migration pathway was thoroughly addressed during the OU-1/OU-3 RI (FWENC, 1999), and the extent of groundwater contamination is well characterized.

Other contaminant fate and transport processes that may be operating to a minor extent at JPL include the transport and redistribution of metals, SVOCs, PAHs, PCBs, and dioxin in surface soil by wind and surface runoff, volatilization and degradation of VOCs in subsurface soil, and desorption and leaching of metals in surface soil to subsurface soil and groundwater. While

theoretically possible, significant migration of SVOCs, PAHs, PCBs, and dioxin to groundwater by infiltrating precipitation is not indicated by the data (either the OU-2 RI or the OU-1/OU-3 RI), and is unlikely because of the nature of subsurface geologic materials, and the general insolubility of these contaminants.

Summaries of the contaminant transport processes at JPL and how these processes (because of historical releases of contaminants) have affected surface and subsurface soil at the site are presented in the following subsections. Air and soil fate and transport processes at JPL are addressed in this section of the RI report. Groundwater was addressed as a separate operable unit (OU-1/OU-3) and is included here in order to completely show migration pathways and how these may affect the site receptors as addressed in the risk assessment (Section 6.0).

5.3.1 Air

Migration of VOCs because of volatilization to air and into buildings or basements is expected to be of little, if any, significance. This is largely because the depth of contamination is generally greater than 20 feet and the majority of contamination is much deeper. Although the high vapor pressures favor volatilization, the vertical distribution of VOCs in the soil vapor (Section 4.2) indicates that overall movement is in the downward direction, and volatilization of VOCs to the atmosphere is not likely as indicated by the data.

Erosion and subsequent eolian transport of contaminants residing in uncovered surface soil and sediment [primarily SVOCs (including PAHs), PCBs, dioxin, and metals] is possible at JPL, but unlikely. Transport of contaminated soil, sediment, or dust by eolian mechanisms can occur at the site if surface and near-surface soil are disturbed. If surface soil remains undisturbed, or if the contaminated soil lies beneath buildings and paved areas, eolian transport of contaminants via soil particles will be diminished or will not occur. Organic compounds in soil were only detected at very low concentrations and in very isolated instances, and transport is, therefore, not expected to be important.

5.3.2 Surface Soil and Sediment

As outlined in Section 5.1, the presence of contaminants in surface soil and sediment increase the probability of migration by surface runoff mechanisms to surrounding on- and off-site receptors. Most of JPL is covered by pavement and buildings; therefore, surface soils encompass a very limited area at JPL. Migration by surface runoff, especially during periods of rapid rainfall and flash flooding, is not considered a significant migration pathway for metals and relatively stable organics in soil at JPL.

5.3.3 Subsurface Soil

The primary migration pathway for contaminants in subsurface soil is generally limited to desorption and leaching to deeper soil horizons or groundwater. VOCs released at seepage pits and other source areas at JPL have migrated to groundwater as documented in previous investigations

of the site and in the OU-1/OU-3 RI report (FWENC, 1999). Because VOCs are still present in the subsurface soil, it is possible that further migration of this type may continue to impact groundwater beneath the site. However, as noted above, extensive groundwater investigations have been conducted, the extent of the groundwater contamination is reasonably well known, and VOC concentrations appear to be decreasing in the majority of groundwater plume wells (FWENC, 1999). Furthermore, the concentrations of VOCs in groundwater will continue to be monitored regularly over the next few years. Since the concentrations present in groundwater are the final indication of impact, the extent and impact to groundwater has not been estimated separately. The mass transfer rate from soils to groundwater has not been estimated for the same reason. This is further compounded by the fact that ongoing soil-vapor extraction (SVE) pilot testing operations are expected to significantly reduce VOC concentrations in the soil.

Migration, into groundwater, of other organic compounds detected in subsurface soil at the site is considered improbable because of the low concentrations at which they were detected, as well as the extremely low aqueous solubilities of the compounds, their high affinities for the solid phase, and the nature of the soil, which impedes the downward movement of contaminants. Detections of SVOCs, PAHs, PCBs, and dioxins in subsurface soil samples suggest that vertical transport of contaminants from the surface by leaching has occurred only to a minor extent in the past.

It is unlikely that vertical migration of organic contaminants other than VOCs is significant for several reasons. First, these contaminants were detected in a few soil samples collected at depths shallower than 30 feet. The same analytes were not detected in any samples collected deeper than 30 feet or in soil sampled from nearby soil borings, indicating that migration in general has been impeded. Second, the transport mechanism (infiltrating surface water) required to move these contaminants to deeper soil horizons becomes less influential with depth, as certain subsurface soil properties (e.g., increasing soil density, and decreasing occurrence of animal burrows, desiccation cracks, and root holes) become more predominant. Third, the fact that the concentrations of PCBs in TP-2 decreased more than ten-fold between the depths of 1 and 5 feet further supports that migration of SVOCs, PAHs, PCBs, and other similar compounds is impeded.

5.3.4 Groundwater

Although groundwater at JPL is a separate operable unit, this medium is being presented in this report in order to provide a complete discussion of the relationship of all media and how these media have been affected by contaminant releases at JPL.

The final COPCs identified in the risk assessment for OU-1/OU-3 groundwater at JPL included: the organic compounds 1,1-dichloroethene, 1,2-dichloroethane, bromodichloromethane, carbon tetrachloride, chloroform, tetrachloroethene, and trichloroethene; and the inorganic compounds arsenic, hexavalent chromium, lead, nitrate, and perchlorate. The presence of VOC contamination in groundwater has been demonstrated by the presence of VOCs in soil vapor. The presence of the Cr(VI) in groundwater is consistent with Cr(VI) in soil at the site, but occurrences in soil and groundwater are infrequent and very localized. Very low levels of arsenic have also been detected

in groundwater, however, detections are very infrequent, occurring only at significant depth in the aquifer, and are attributable to naturally occurring sources. Metals in groundwater will travel very slowly due to adsorption reactions with the fine-grained minerals in the aquifer matrix that retard movement relative to the groundwater flow velocity.

5.4 ESTIMATES OF MASS OF CONTAMINANTS

The mass of contaminants in the subsurface for OU-2 at JPL was estimated for TCE, DCE, CCl₄, and Freon 113. Two different methods were used in the calculations.

Method 1 used the VOC data presented in Section 4.0 in terms of contours representing the areal distribution of contamination, and soil-vapor concentration data for each of the target compounds. First, the total volume of soil contaminated with the particular constituent was estimated. Next, the pore volume (soil-vapor volume) was calculated using the soil porosity. Finally, the mass of contaminant was determined by multiplying the average concentration in soil vapor by the pore volume of the soil.

Method 2 utilized the same soil characterization data, but involved a more rigorous calculation of the soil concentration. The total soil concentration in the soil was calculated from the soil vapor data presented in Section 4.0 using soil physical parameters for the site and chemical properties for each particular constituent. The total soil concentration was then multiplied by the total volume of the soil estimated from Method 1 to obtain VOC mass.

Method 1

The following procedure was followed to calculate the mass of contaminant:

- The areal extent of contamination for the four target VOCs was estimated from Figures 4-18 through 4-24. The outermost contour, representing the maximum distribution of contamination for the sampling events, was considered.
- The average depth of soil was assumed to be 200 feet (ft).
- The total volume of contaminated soil was calculated by multiplying the area of contamination by the depth of the soil.

$$\text{Volume Soil (ft}^3\text{)} = \text{Area (ft}^2\text{)} \times \text{Depth (ft)} \quad (1)$$

- The pore volume of soil was calculated by multiplying the estimated soil porosity of 0.35 by the volume of soil from (1). Soil porosity taken from RWQCB Interim Site Assessment and Cleanup Guidebook (RWQCB, 1996).

$$\text{Pore Volume} = \text{Volume Soil} \times \text{Porosity} \quad (2)$$

- The soil-vapor concentration for each contaminant was estimated by taking one-half the maximum value reported for Event 6 (Figures 4-19, 4-21, 4-23, and 4-25). These values were reported in units of µg/L in the RI Report.

- The soil-vapor concentration in $\mu\text{g/L}$ was converted into units of lb/ft^3 by multiplying with several conversion factors for mass and volume.

$$C = C_g \times 28.3 \text{ L/ft}^3 \times 10^{-9} \text{ kg/}\mu\text{g} \times 2.205 \text{ lb/kg} \quad (3)$$

Where:

C_g = Soil-vapor concentration ($\mu\text{g/L}$)

C = Soil-vapor concentration (lb/ft^3)

- Finally, the mass of each contaminant in the soil was calculated. The soil-vapor concentration from (3) was multiplied by the pore volume of soil calculated in (2).

Method 2

- The total vapor concentration in soil was calculated from an equation presented in the RWQCB (1996) guidebook.

The equation reads as follows:

$$C_T = C_g \times \{ \theta_w + [(n - \theta_w) \times K_H] + (\rho_b \times f_{oc} \times K_{oc}) \} / (\rho_b \times K_H) \quad (3)$$

Where:

C_T = Total soil concentration ($\mu\text{g/kg}$)

C_g = Soil-vapor concentration ($\mu\text{g/L}$)

θ_w = Soil water content by volume

n = Soil porosity

K_H = Henry's law constant

ρ_b = Soil bulk density (g/cc)

f_{oc} = Soil organic carbon content

K_{oc} = Organic carbon partition coefficient (mL/g)

- C_g data was interpreted in the same manner as in Method 1.
- Attenuation factors for the VOCs [i.e., Henry's law constant and organic carbon partition coefficient, were taken from Appendix A, Table 2, in the RWQCB (1996) guidebook].
- Soil physical parameter data [i.e., soil bulk density, soil water content, soil organic carbon content, and soil porosity, were taken from Appendix A, Table 1, in the RWQCB (1996) guidebook].
- The VOC mass in the soil was calculated by multiplying the result of (3) with the total volume of soil derived in (1), the soil bulk density, and various conversion factors:

$$M = C_T \times \text{Volume Soil (ft}^3) \times \rho_b \text{ (g/cc)} \times 62.43 \left(\frac{\text{lb/ft}^3}{\text{g/cc}} \right) \times 10^{-9} \quad (4)$$

Where:

M = Mass of VOC compound in soil (lb)

Tables 5-2 and 5-3 present the values for the soil and contaminant parameters, including mass in the soil for all four contaminants, for Methods 1 and 2, respectively. As shown in Tables 5-2 and 5-3, the mass of contaminants by the two methods are approximately 2,251 and 5,038 pounds, respectively. The large disparity between the calculated masses is due to the difference inherent in the two methodologies used to calculate the approximate mass.

It should be noted that the significant changes in elevation at OU-2, combined with the fact there might be "clean" pockets of soil pores within the overall contaminant envelopes, make it difficult to accurately estimate the mass of contaminants present in the soils. The above methods are fairly simplistic in nature, and are intended to merely provide an idea of the "order of magnitude" of mass, rather than an actual estimate.

5.5 GENERAL CONCLUSIONS

Migration of VOCs due to volatilization to air is expected to be of little, if any, significance. Although the high vapor pressures favor volatilization, the vertical distribution of VOCs in the soil indicates that overall movement is in the downward direction. This is supported by the OU-1/OU-3 RI groundwater data that shows that VOCs are present, but JPL site data also suggest that this process is predictable and decreasing in significance.

Erosion and subsequent eolian transport of contaminants residing in surface soil and sediment [primarily SVOCs (including PAHs), PCBs, dioxin, and metals] are considered insignificant at JPL because concentrations are generally low, and the affected area is very limited because most of the site is covered by buildings and pavement. Migration of metals and organic contaminants in surface soils and sediments to deeper soil horizons may be possible, although JPL site data do not suggest this is a significant means of transport.

The presence of contaminants in surface soil and sediment increase the probability of migration of surface runoff mechanisms to surrounding on- and off-site receptors, especially during periods of rapid rainfall and flash flooding. However, for the reasons described in the preceding paragraph, environmental impacts associated with surface run-off are expected to be insignificant. Based on available groundwater data, it is evident that VOCs released at seepage pits and other source areas at JPL have migrated to groundwater. However, migration of SVOCs detected in soil at JPL has not occurred.

The transport of VOCs to groundwater beneath JPL has been demonstrated by the presence of VOCs in soil vapor and groundwater. In addition, the presence of the Cr(VI) in groundwater is consistent with Cr(VI) in soil at the site, but occurrences in soil and groundwater are infrequent and very localized. Arsenic has also been detected in groundwater, but these detections were very localized, occurred only in a deep portion of the aquifer, and are attributed to naturally occurring sources.

TABLE 5-1
CHEMICAL AND PHYSICAL PROPERTIES OF ANALYTES
DETECTED IN SOIL AND SOIL-VAPOR SAMPLES DURING THE OU-2 RI

Analytical Group	Analytes Detected in Soil or Soil Vapor	CAS Number	Empirical Formula	Molecular Weight (g/mol)	Physical State (at 25°C)	Density (g/ml)	Aqueous Solubility (mg/l)	Vapor Pressure (mm Hg)	Henry's Law Constant (atm-m ³ /mol)	Octanol-Water Partition Coefficient (Log[K _{ow}])
VOCs	Acetone	67-64-1	C ₃ H ₆ O	58.08	Liquid	0.7899	Miscible	266	4.276 x 10 ⁻⁵	-0.24
	1,1-Dichloroethane	107-06-2	C ₂ H ₄ Cl ₂	99	Liquid	1.22	8520	600	9.79 x 10 ⁻⁴	1.84
	1,1,1-Trichloroethane	71-55-6	C ₂ H ₃ Cl ₃	133.4	Liquid	1.339	4400	100	0.0172	2.47
	1,1,2-Trichloroethane	79-00-5	C ₂ H ₃ Cl ₃	133.4	Liquid	1.4397	4500	25	9.607 x 10 ⁻⁴	2.17
	1,1-Dichloroethene	75-35-4	C ₂ H ₂ Cl ₂	97	Liquid	1.218	2250	591	0.0261	1.48
	1,2-Dichloroethane	107-06-2	C ₂ H ₄ Cl ₂	99	Liquid	1.2351	8520	79	9.79 x 10 ⁻⁴	1.45
	cis-1,2-Dichloroethene	156-59-2	C ₂ H ₂ Cl ₂	96.94	Liquid	1.28	3500	208	0.00408	0.7
	Benzene	71-43-2	C ₆ H ₆	78.11	Liquid	0.8765	1750	95	0.00555	2.13
	Bromodichloromethane	75-27-4	CHBrCl ₂	163.83	Liquid	1.980	4500	50	2.12x10 ⁻³	1.88
	Carbon tetrachloride	56-23-5	CCl ₄	154	Liquid	1.594	793	113	0.0304	2.73
	Chloroform	67-66-3	CHCl ₃	119.4	Liquid	1.49	7920	160	0.00367	1.97
	Ethylbenzene	100-41-4	C ₈ H ₁₀	106.17	Liquid	0.867	169	10	0.00788	3.15
	Freon 113	76-13-1	C ₂ Cl ₃ F ₃	187.38	Liquid	1.5635	0.17	284	0.53	1.66
	Methylene chloride	75-09-2	CH ₂ Cl ₂	84.9	Liquid	1.33	13200	429	0.00219	25
	Tetrachloroethene	127-18-4	C ₂ Cl ₄	165.8	Liquid	1.63	200	19	0.0184	53
	Toluene	108-88-3	C ₇ H ₈	92.14	Liquid	0.8669	526	28	0.00664	2.69
	Trichloroethene	79-01-6	C ₂ HCl ₃	131.39	Liquid	1.46	1100	77	0.0103	53
	Trichlorofluoromethane	75-69-4	CCl ₃ F	137.4	Liquid-Gas	1.494	1100	687	0.097	2.53
	Total Xylenes (a)	1330-20-7	C ₈ H ₁₀	106.17	Liquid	0.86104 - 0.8801	Insoluble	10	0.004184 - 0.006662	2.77 - 3.2

TABLE 5-1
CHEMICAL AND PHYSICAL PROPERTIES OF ANALYTES
DETECTED IN SOIL AND SOIL-VAPOR SAMPLES DURING THE OU-2 RI

Analytical Group	Analytes Detected in Soil or Soil Vapor	CAS Number	Empirical Formula	Molecular Weight (g/mol)	Physical State (at 25°C)	Density (g/ml)	Aqueous Solubility (mg/l)	Vapor Pressure (mm Hg)	Henry's Law Constant (atm-m ³ /mol)	Octanol-Water Partition Coefficient (Log[K _{ow}])
Metals	Antimony	7440-36-0	Sb	121.75	Solid	6.684	Insoluble	1	NA	NA
	Arsenic	7440-38-2	As	74.92	Solid	5.727	Insoluble	1	NA	NA
	Barium	7440-39-3	Ba	137.33	Solid	3.51	Hydrolyzes	10	NA	NA
	Beryllium	7440-41-7	Be	9.012	Solid	1.85	Insoluble	1	NA	NA
	Cadmium	7440-43-9	Cd	112.41	Solid	8.642	Insoluble	NA	NA	NA
	Chromium (b)	7440-47-3	Cr	51.996	Solid	7.2	Insoluble	1	NA	NA
	Cobalt	7440-48-4	Co	58.93	Solid	8.9	Insoluble	30	NA	NA
	Copper	7440-50-8	Cu	63.55	Solid	8.92	Insoluble	1	NA	NA
	Lead	7439-92-1	Pb	207.2	Solid	11.296	Insoluble	1	NA	NA
	Mercury	7439-97-6	Hg	200.59	Liquid	13.594	0.056	100	1.14 x 10 ⁻²	NA
	Molybdenum	7439-98-7	Mo	95.94	Solid	10.28	Insoluble	NA	NA	NA
	Nickel	7440-02-0	Ni	58.69	Solid	8.9	Insoluble	NA	NA	NA
	Silver	7440-22-4	Ag	107.868	Solid	10.49	Insoluble	NA	NA	NA
	Strontium	7440-24-6	Sr	87.62	Solid	2.6	Insoluble	NA	NA	NA
	Thallium	7440-28-0	Tl	204.383	Solid	11.85	Insoluble	NA	NA	NA
Vanadium	7440-62-2	V	509415	Solid	5.96	Insoluble	NA	NA	NA	
Zinc	7440-66-6	Zn	65.38	Solid	7.14	Insoluble	1	NA	NA	

TABLE 5-1
CHEMICAL AND PHYSICAL PROPERTIES OF ANALYTES
DETECTED IN SOIL AND SOIL-VAPOR SAMPLES DURING THE OU-2 RI

Analytical Group	Analytes Detected in Soil or Soil Vapor	CAS Number	Empirical Formula	Molecular Weight (g/mol)	Physical State (at 25°C)	Density (g/ml)	Aqueous Solubility (mg/l)	Vapor Pressure (mm Hg)	Henry's Law Constant (atm-m ³ /mol)	Octanol-Water Partition Coefficient (Log[K _{ow}])
SVOCs	Bis(2-ethylhexyl)phthalate	117-81-7	C ₂₄ H ₃₈ O ₄	390.54	Liquid	0.99	0.4	1.2	3 x 10 ⁻⁷	5.3
	Butylbenzyl phthalate	85-68-7	C ₁₉ H ₂₀ O ₄	312.4	Liquid	1.1	2.9	8.6 x 10 ⁻⁶	NA	4.78
	Di-n-butylphthalate	84-74-2	C ₁₆ H ₂₂ O ₄	278.35	Liquid	1.047	400	0.1	2.8 x 10 ⁻⁷	5.2
	N-Nitroso-di-n-propylamine	621-64-7	C ₆ H ₁₄ N ₂ O	130.19	Liquid	0.9163	9900	0.086	1.4 x 10 ⁻⁶	1.31
PAHs	Benzo(a)anthracene	56-55-3	C ₁₈ H ₁₂	228.29	Solid	1.274	0.01	5 x 10 ⁻⁹	6.6 x 10 ⁻⁷	5.61
	Benzo(a)pyrene	50-32-8	C ₂₀ H ₁₂	252.32	Solid	1.351	0.0038	5 x 10 ⁻⁹	4.9 x 10 ⁻⁷	5.98
	Benzo(b)fluoranthene	205-99-2	C ₂₀ H ₁₂	252.32	Solid	NA	0.0012	5 x 10 ⁻⁷	1.2 x 10 ⁻⁵	6.57
	Benzo(g,h,i)perylene	191-24-2	C ₂₂ H ₁₂	276.34	Solid	NA	2.6 x 10 ⁻⁴	1 x 10 ⁻¹⁰	1.4 x 10 ⁻⁷	7.23
	Chrysene	218-01-9	C ₁₈ H ₁₂	228.29	Solid	1.274	0.002	7.8 x 10 ⁻⁹	1.2 x 10 ⁻⁶	5.521
	Fluoranthene	206-44-0	C ₁₆ H ₁₀	202.26	Solid	1.252	0.265	5.0 x 10 ⁻⁶	6.5 x 10 ⁻⁶	5.33
	Indeno(1,2,3-cd)pyrene	193-39-5	C ₂₂ H ₁₂	276.34	Solid	NA	0.062	1 x 10 ⁻¹⁰	6.95 x 10 ⁻⁸	7.66
	Phenanthrene	85-01-8	C ₁₄ H ₁₀	178.23	Solid	0.98	0.816	1	3.93 x 10 ⁻⁵	4.46
	Pyrene	129-00-0	C ₁₆ H ₁₀	202.26	Solid	1.271	0.16	2.5	5.1 x 10 ⁻⁶	5.18
PCBs	Arochlor-1232	11141-16-5	variable mixture	233	Liquid	1.381	2.00	4.06 x 10 ⁻³	5.9 x 10 ⁻⁴	4.84
	Arochlor-1254	11097-69-1	variable mixture	327 (average)	Liquid	1.495 - 1.505	0.031	7.71 x 10 ⁻⁵	0.0026	6.3
	Arochlor-1260	11096-82-5	variable mixture	376	Resin	1.58	0.0027	4.05 x 10 ⁻⁵	0.74	6.8

TABLE 5-1
CHEMICAL AND PHYSICAL PROPERTIES OF ANALYTES
DETECTED IN SOIL AND SOIL-VAPOR SAMPLES DURING THE OU-2 RI

Analytical Group	Analytes Detected in Soil or Soil Vapor	CAS Number	Empirical Formula	Molecular Weight (g/mol)	Physical State (at 25°C)	Density (g/ml)	Aqueous Solubility (mg/l)	Vapor Pressure (mm Hg)	Henry's Law Constant (atm-m ³ /mol)	Octanol-Water Partition Coefficient (Log[K _{ow}])
Dioxins/Furans	1,2,3,4,6,7,8,9-OCDD	3268-87-9	C ₁₂ Cl ₈ O ₂	460.76	Solid	NA	7.4x10 ⁻⁸	8.25x10 ⁻¹³	7.0x10 ⁻⁹	7.59
Other Parameters	Cyanide (c)	--	CN ⁻	27	Liquid-Gas	0.901	1,000,000	742	1.3 x 10 ⁻⁴	-0.25
	Tributyltin	56573-85-4	(C ₄ H ₉) ₃ SnCl	595.62	Liquid	NA	4	0.1	NA	NA
	Nitrate (d)	14797-55-8	NO ₃ ⁻	80.06 - 101.1	Solid	1.725 - 2.26	0.92 - 2.47	NA	NA	NA
	TPH	--	variable mixture	--	--	--	--	--	--	--

Notes:

- (a) Values represent ranges for the three xylene isomers: m-xylene, o-xylene, and p-xylene.
 (b) Chemical and physical properties for Cr (VI) are represented by the values listed for chromium.
 (c) Parameters are presented for hydrogen cyanide.
 (d) Parameters are presented as ranges of values for nitrate-containing compounds: sodium nitrate, potassium nitrate, and ammonium nitrate.
 NA - Not available.

References for chemical and physical properties include the following:

- 1) Micromedex, 1997.
- 2) American Toxicological Substances and Disease Registry, 1997.
- 3) Burkhard and Kuehl, 1986.
- 4) Howard, 1990.
- 5) EPA Region IX PRG Table, 1998.
- 6) Mabey and others, 1982.

TABLE 5-2
ESTIMATE OF MASS OF CONTAMINANTS IN OU-2
METHOD 1

Compound	Area (ft ²)	Soil Volume (ft ³)	Pore Volume Soil (ft ³)	Soil-Vapor Concentration (µg/L-vapor)	VOC Mass (lb)
TCE	1.12E+06	2.24E+08	7.84E+07	4.1	20.1
DCE	9.20E+05	1.84E+08	6.44E+07	4.9	19.7
CCl ₄	1.96E+06	3.92E+08	1.37E+08	202	1729.4
Freon 113	1.92E+06	3.84E+08	1.34E+08	57.5	482.2
					2251.4

Assumptions:

Soil porosity - 0.35 (RWQCB, 1996).

Depth of soil - 200 feet.

Soil-vapor concentration is 1/2 maximum concentration (from Event 6 profiles).

TABLE 5-3
ESTIMATE OF MASS OF CONTAMINANTS IN OU-2
METHOD 2

Soil Volume (ft ³)	Compound	Mass (lb)	Parameters*							
			C _T	C _G	θ _w	n	K _H	ρ _b	f _{oc}	K _{oc}
2.24E+08	TCE	123.41	5.07	4.1	0.167	0.364	0.371	1.746	0.00247	130
1.84E+08	DCE	15.08	0.75	4.9	0.167	0.364	6.237	1.746	0.00247	65
3.92E+08	CCl ₄	4139.59	97.14	202	0.167	0.364	0.998	1.746	0.00247	110
3.84E+08	Freon 113	759.67	18.20	57.5	0.167	0.364	2.41	1.746	0.00247	160
		5037.75								

Note:

* See Section 5.4 for parameter definitions.

PRIMARY SOURCE

PRIMARY RELEASE MECHANISM

SECONDARY SOURCE

SECONDARY RELEASE MECHANISM

POTENTIAL EXPOSURE MEDIA

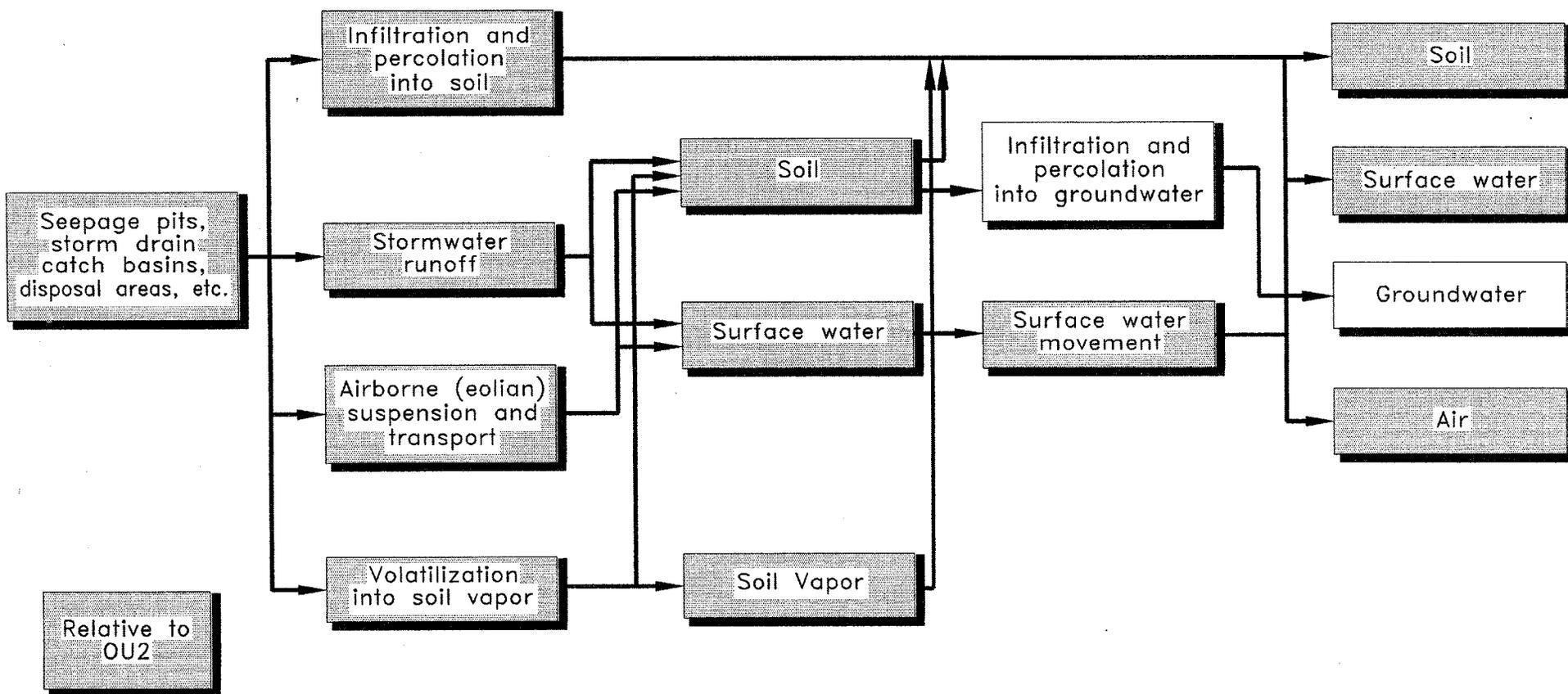


FIGURE 5-1

SITE CONCEPTUAL MODEL FOR FATE AND TRANSPORT OF CONTAMINANTS

Jet Propulsion Laboratory
Pasadena, California



FOSTER WHEELER ENVIRONMENTAL CORPORATION

6.0 BASELINE RISK ASSESSMENT

Presented in this section is the baseline human health risk assessment (HHRA) and the screening-level ecological risk assessment (ERA) prepared for OU-2 at the Jet Propulsion Laboratory. The purpose of this HHRA and the ERA is to define the magnitude and probability of threats to public health and the environment posed by chemicals in soils at the JPL site. Evaluated in the HHRA and ERA are all potentially relevant current and future conditions at the site. The extent of risk is dependent on the degree to which receptors are exposed, which is mainly influenced by the type, frequency, and duration of activities conducted at the site. The HHRA is presented in Section 6.1, and the ERA is presented in Section 6.2.

6.1 HUMAN HEALTH RISK ASSESSMENT

This evaluation was conducted in accordance with State of California Environmental Protection Agency Department of Toxic Substances Control (DTSC) guidance provided in the *Preliminary Endangerment Assessment (PEA) Guidance Manual* (DTSC, 1994) and standard United States Environmental Protection Agency (EPA) guidance, including *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part A)* (EPA, 1989), and *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part D)* (EPA, 1998b).

In addition to the sources cited above, toxicologists from EPA Region IX and DTSC were consulted (Oral communications, D. Stralka, 1998a, and Y. Luthra, 1998b, respectively) during the evaluation process. The letter confirming the results of these consultations is located in Appendix H. Topics discussed during these conversations include the use of soil and soil vapor data to assess exposure pathways; the application of screening levels derived from EPA and DTSC guidance; selection of constituents of potential concern (COPCs); background geochemistry and metals in soil; and the calculation of location-specific risk at seepage pits, waste pits, and discharge points within OU-2. The results of these conversations were used to shape and guide the development of the HHRA.

Presented in the following subsections are a discussion on the evaluation of the OU-2 data, a presentation of the HHRA methodology, and a summary of findings and conclusions of the HHRA. The organization of the discussion is presented below:

- **Section 6.1.1**—Site-Specific Objectives
- **Section 6.1.2**—Selection of Constituents of Potential Concern
- **Section 6.1.3**—Exposure Assessment
- **Section 6.1.4**—Toxicity Assessment
- **Section 6.1.5**—Risk Characterization

- **Section 6.1.6**—Uncertainty Analysis
- **Section 6.1.7**—Risk Assessment Results
- **Section 6.1.8**—Summary

6.1.1 Site-Specific Objectives

The primary objectives of the baseline HHRA include the following:

- Focus the analytical results presented in the Remedial Investigation (RI) report on the COPCs for human health risk.
- Identify potential exposure pathways.
- Identify areas where COPCs pose potential risk to human health under a no-action alternative.

6.1.2 Selection of Constituents of Potential Concern

Reviewed and summarized in this section are the analytical data for on-site soil and soil vapor sampled at the JPL site. It further discusses the selection of the COPCs to be evaluated in the baseline HHRA.

6.1.2.1 Data Reduction

The quantitative assessment of exposure and potential risk for the JPL site is based on the COPCs, which are site-related chemicals that may be associated with adverse effects on human health. COPCs are a subset of the list of all chemicals positively identified at the site. For the purposes of this HHRA, the analytical data collected for the RI for soil (1994 and 1997) and soil vapor (1998) was considered the most representative for current and future conditions that may occur at the site.

Soil Samples

Soil samples were collected during the RI field investigation in 1994 and 1997 at the locations presented in Figure 3-8. Soil samples were collected from soil borings and test pits at depths ranging from 1 foot to 101 feet. Analyses included SVOCs, PAHs, PCBs, dioxins and furans, Title 26 Metals plus strontium and hexavalent chromium, tributyltin, nitrate, cyanide, TPH, gross alpha and beta, and total solids. Samples from the test pits were also analyzed for VOCs. Detailed discussions of the results of soil sampling conducted during the RI are provided in Section 4.3.

For the purposes of this HHRA, analytical data for the upper 15 feet of soil was considered to be a realistic estimate of the soil at which potential receptors would most likely be exposed either through excavation or during on-site construction activities (Oral communications, D. Stralka, 1998a and Y. Luthra, 1998b).

Soil-Vapor Samples

Soil-vapor samples were collected during seven sampling events beginning in 1994 and continuing into 1998 at the locations designated in Figures 4-2 and 4-4. Vapor samples were collected at depths ranging from 5 to 205 feet at the locations shown in Figures 4-2 and 4-4 and analyzed only for VOCs by EPA Method 8010/8020. Detailed discussion of the results of soil-vapor sampling conducted during the RI are discussed in Section 4.2.

For the purposes of this RA, soil-vapor data collected within the upper 30 feet of soil was used to evaluate risk due to exposure to contaminated soil and soil vapor (Oral communications, D. Stralka, 1998a and Y. Luthra, 1998b). This determination was based on the following rationale:

- The shallowest depth at which groundwater is present at the site is approximately 30 feet.
- Excavations or basements where construction workers or on-site employees may be located are not expected to exceed 30-foot depths.
- Volatilized chemicals detected deeper than 30 feet most likely will not migrate upwards through the soil column with subsequent release to the atmosphere.

In order to evaluate risk because of contaminated soil, soil concentrations were extrapolated from soil-vapor concentrations using guidance provided in *Soil Screening Guidance: Technical Background Document* (EPA, 1996). Soil concentrations were calculated for carbon tetrachloride (CCl₄) and trichlorotrifluoroethane (Freon 113) using the following equation:

$$C_s = C_v \times \frac{K_d}{H'}$$

where:

- C_s = Soil concentration (mg/kg)
- C_v = Vapor concentration (mg/L of air)
- K_d = Soil-water distribution coefficient (L/kg)
- H' = Henry's Law Constant (dimensionless)

Comparison to Preliminary Remediation Goals

A comparison to preliminary remediation goals (PRGs) was conducted to provide remedial design staff with long-term targets to use during analysis and selection of remedial alternatives (EPA, 1991a). The maximum detected value of all chemicals positively identified in soil samples taken from the upper 15 feet of soil and in soil-vapor samples taken from the upper 30 feet of soil were compared to PRGs. PRGs were derived based on State of California (DTSC, 1994) and EPA (1989, 1991a, 1998c) guidances and are based on an acceptable target risk of 1×10^{-6} for carcinogens or a hazard quotient of 1.0 for non-carcinogens. PRGs are based on a hypothetical current residential scenario as a conservative estimate of potential on-site risk (see Table 6-1).

PRGs incorporate potential exposure to on-site soils by ingestion, dermal contact, and inhalation. The methodology used in deriving the PRGs is presented in Appendix I and the results of this comparison between the current and future land use scenarios are presented in Tables 6-2 and 6-3.

Chemical-specific toxicity values were unavailable for the following COPCs:

- Chromium
- Cyanide
- 1,2,3,4,6,7,8,9-octachlorodibenzo-p-dioxin (OCDD)
- Thallium
- Tributyltin

Surrogate toxicity values were used to derive conservative PRGs. Toxicity criteria for total chromium, having a 1:6 Cr(VI) to Cr(III) ratio, were used for chromium (EPA, 1998a). Toxicity criteria for free cyanide were used for cyanide (EPA, 1998b). Toxicity criteria for 1,2,3,4,6,7,8,9-OCDD were extrapolated from toxicity criteria developed for tetrachlorodibenzo-p-dioxin based on the assumption of 0.0001 relative toxicity (WHO, 1997). Toxicity criteria for thallium oxide was used for thallium (EPA, 1998b). Toxicity criteria for tributyltin oxide was used for tributyltin (EPA, 1998b)

Comparison to Background Concentrations

A comparison to naturally occurring, or background, concentrations of inorganics was conducted to identify chemicals that may be found at or near the site (DTSC, 1994 and EPA, 1989). For the comparison, all metals identified in soil samples taken from the upper 15 feet of soil were compared to background concentrations determined during RI site activities (refer to Section 4.3.1 for a discussion). The maximum detected value in the site investigative data was compared to the maximum detected value in the background data (DTSC, 1997). In accordance with EPA guidance (EPA, 1989), those inorganic chemicals present on-site at naturally occurring levels were eliminated from the quantitative risk assessment. This comparison is included in Tables 6-2 and 6-3.

6.1.2.2 Results of the Preliminary Data Analysis

All organic chemicals detected at concentrations above the PRGs were considered to be preliminary COPCs. All inorganic chemicals detected at concentrations above the PRGs and above background levels were considered to be preliminary COPCs. For this risk assessment, the list of COPCs included the following chemicals:

- Arochlor-1254
- Arochlor-1260

- Arsenic (As)
- Hexavalent chromium [Cr(VI)]

The COPCs listed above were detected in soil samples during the RI field activities. All chemicals detected in soil-vapor samples were determined to be below PRGs. In June 1998, in response to concerns raised by the Agency of Toxic Substances and Disease Registry (ATSDR), JPL performed indoor air quality sampling at Building 107. This sampling was undertaken because VOC vapors in soil at relatively shallow depths have the potential to collect in the lower levels of buildings where they may pose a health hazard. The sampling results indicated that VOC vapors were not present in the building (ATSDR, 1998). Based on the results of the PRG comparison and the results of the indoor air sampling, no chemicals detected in soil-vapor samples were included as COPCs for further evaluation.

6.1.2.3 Areas of Concern

Based on an evaluation of the nature and extent of contamination due to the above potential COPCs, five areas of concern were identified where contamination and risk should be further evaluated because of the localized occurrence of organic compounds and Cr(VI) in subsurface soil. These locations include Waste Pit No. 1/Discharge Point No. 1 (WP-1/DP-1), Discharge Point No. 2 (DP-2), Discharge Point No. 3 (DP-3), Discharge Point No. 4 (DP-4), and Waste Pit No. 4 (WP-4). The preliminary COPCs detected in these five areas were screened against residential PRGs and background values as discussed above. The results of the screening are included in Tables 6-4 through 6-13 and further focus the HHRA on areas where risk to potential receptors may exist. The five areas of concern were further considered in the exposure assessment and calculation of risks to potential receptors.

6.1.3 Exposure Assessment

The objective of the exposure assessment is to characterize the exposure setting, determine potentially exposed populations, and identify exposure pathways. The identification of exposure pathways entails integrating the variables (contaminant sources, releases, fate and transport mechanisms, and exposure points) that contribute to complete exposure pathways to human receptors. Exposure to chemicals is quantified by calculating exposure-point concentrations for all media and estimating chemical intakes.

A complete exposure pathway consists of four necessary elements: (1) a source and mechanism of contaminant release to the environment; (2) an environmental transport medium (e.g., soil) for a released contaminant; (3) a point of potential contact with the medium (referred to as the exposure point); and (4) an exposure route (e.g., ingestion) at the contact point (EPA, 1989).

6.1.3.1 Exposure Setting and Site Conceptual Model

The exposure setting entails the physical environment, the land use associated with the current and potential future uses of the site, and the soils in the immediate vicinity that have been affected by site activities. Information on the physical characteristics of the site is included in Section 2.0, and this information is used as the basis for identifying the receptors, specific pathways, and input parameters used in the quantitative assessment and presented in Figure 6-1. Refer to Section 3.1 for a detailed discussion of each area of concern.

6.1.3.2 Identification of Potential Receptors

In the baseline HHRA, possible exposures were examined to determine if on-site soil and soil vapor could pose a threat to human health. The risks associated with impacted soils depends not only on chemical concentrations in soil but also on the extent to which people are exposed. Because risks depend upon the concentration of the contaminant and the extent of the exposure, theoretical exposure scenarios are created. The scenarios describe the type of population expected to be exposed and the frequency and length of time people are likely to be exposed.

The identification of potential receptors involves considering current and potential future land uses at the site. Two land-use scenarios were evaluated for the JPL site; Scenario 1 assumes that the site remains as it is with an on-site area for industrial use and Scenario 2 assumes the site is converted into a residential area. The scenarios considered for this HHRA are discussed below and included in Table 6-1.

Off-Site Resident

The off-site resident was considered in this assessment because residential areas border the JPL site. The primary pathway through which off-site residents would be exposed to on-site soil would be via air-borne particulates and vapors blown off site.

On-Site Resident

The on-site resident was considered in this assessment as a potential future receptor. The JPL site is not currently developed for residential use. However, the residential receptor is considered a conservative potential receptor because it includes long-term daily exposure and exposure to children. If risk estimates for a given area are within the acceptable range for residents, it is assumed that risk estimates will be acceptable for all other short-term receptors.

Construction Worker

The construction worker was considered in this assessment as a potential current on-site receptor. The construction worker is potentially involved in activities such as excavation and construction of a basement. It is assumed that the construction worker spends his entire time on site at one area of concern. His exposure duration is assumed to be 1 year and, therefore, is shorter than the other receptors. It is assumed that the exposure to construction workers is the same for current and future land uses.

Commercial Worker

The commercial worker was considered in this assessment as a potential current on-site receptor. It is assumed that the commercial worker spends his or her entire workday indoors in an on-site office or laboratory. The office or laboratory is assumed to be located over or adjacent to one area of concern, and the commercial worker is assumed to be representative of all current and future commercial workers on site.

6.1.3.3 Exposure Pathways

Exposure pathways are descriptions of the ways in which people can potentially be exposed to contaminants at a site. The pathway analysis involves the systematic examination of each potential contaminant source, contaminant transport pathway, and exposed population to determine which combinations should be evaluated quantitatively in HHRA. The combinations that are considered for risk evaluation are those that represent complete current pathways or future pathways (making reasonable assumptions about future land use).

Under current conditions, commercial workers and construction workers may have direct access to the JPL site and any on-site contamination. Under future conditions, residential adults and children may become exposed to on-site contamination. Human receptors and the potential pathways of exposure to affected media under current and future land-use scenarios are listed in Table 6-1. The pathways that represent potentially complete exposure routes for humans include the following:

- Ingestion and dermal contact with soils during work and recreational activities.
- Inhalation of contaminated soil and soil particulates during wind or soil disturbance activities.

The approach for this HHRA was to select human populations that were conservative representatives of the populations that could be exposed to contaminants on-site under current and future land-use scenarios. The following populations were selected to quantitatively model risk to human receptors:

- ***Child and Adult Residents*** - to model exposure to both children and adults under a future on-site residential exposure scenario.
- ***Commercial Worker*** - to model exposure to the commercial and industrial workers that may work on-site currently and in the future.
- ***Construction Worker*** - to model risk to on-site workers during invasive activities (conservative scenario). This approach is conservative because it assumes that the construction worker spends the entire time on-site in a single area of concern.

The off-site resident was not retained for quantitative analysis. Although residential areas border the west side of JPL, the only pathway through which off-site residents would be exposed to on-site soil would be via air-borne particulates migrating off site. While this may be a complete

exposure pathway, the concentrations to which the off-site residents would be exposed are negligible because of wind dispersion that occurs during eolian transport. In addition, the five areas of concern identified in Section 6.1.2.3 are very small areas relative to the overall size of the site. The portion of particulates blowing off-site from the areas of concern, versus areas where all chemical detections are below levels of concern, is minimal.

6.1.3.4 Quantification of Exposure

In this section, assumptions about the behavior of the populations potentially at risk are considered, as well as the concentrations of COPCs at the point of potential human exposure, to estimate the chronic daily intake (CDI) of COPCs for potentially exposed individuals in accordance with DTSC guidance (DTSC, 1994). The CDI is analogous to the average daily dose (ADD) and the lifetime average daily dose (LADD) (EPA, 1989). In the risk characterization step of the assessment, the CDIs are combined with toxicity parameters for COPCs to estimate whether the calculated intake levels pose a threat to human health.

Exposure Point Concentrations

The exposure point concentration (EPC) was determined, following the guidance provided in the PEA manual (DTSC, 1994), to be the maximum contaminant value detected in the upper 15 feet of soil. Data used in this determination are the most recent available and were collected during RI site investigations conducted in 1994 and 1997. EPCs for each area of concern are shown in Tables 6-14 through 6-23.

Quantification of Chronic Daily Intake

To calculate chemical intakes, the following factors must be estimated:

- EPC to which an individual is exposed.
- Amount of chemical taken up by the body via ingestion, dermal absorption, and/or inhalation.
- Frequency and duration of exposures.

These factors are incorporated into the CDI, which represents an estimated average daily dose received via direct contact (soil ingestion and dermal contact) and/or inhalation pathways. CDIs are expressed in units of milligrams of chemical per kilogram of body weight per day (mg/kg-day) and are calculated using the following generic equation:

$$CDI = \frac{C \times IR \times EF \times ED \times AF}{BW \times AT}$$

where:

- AF = absorption fraction
- AT = averaging time; time over which the exposure is averaged
- BW = body weight

C	=	chemical concentration in exposure medium
CDI	=	chronic daily intake
ED	=	exposure duration
EF	=	exposure frequency
IR	=	intake rate; the amount of the medium contacted per unit time

The risks associated with exposure to COPCs depend not only on the concentrations of COPCs but also on the extent to which receptors are exposed. Presented in Tables 6-24 through 6-38 are the exposure parameters used in this assessment for each pathway for each receptor and the medium-specific CDI equation. The exposure assumptions are taken from the PEA manual (DTSC, 1994) and EPA guidance documents (EPA 1989, 1991b, and 1992b). Averaging time for carcinogenic chemicals is based on a 30-year exposure that incorporates a 6-year exposure to children and a 24-year exposure to adults averaged over a lifetime of 70 years. Averaging time for non-carcinogenic chemicals is based on the estimated exposure duration. Absorption via ingestion and inhalation is assumed to be 100 percent because limited chemical-specific information is available. For the residential scenario, the CDI for carcinogenic chemicals is one value that incorporates intake by adults and children using the appropriate exposure parameters for each. Calculating the carcinogenic CDI in this manner ensures that exposure to children, with their greater rate of exposure to on-site soils, is taken into account. The CDI for non-carcinogenic chemicals addresses intake by children only.

6.1.4 Toxicity Assessment

For RA purposes, COPCs were separated into two categories of chemical toxicity, (1) carcinogenic, and (2) non-carcinogenic effects. A discussion of the two effects is presented below.

6.1.4.1 Toxicity Values

Toxicity values, when available, are published by the California Office of Environmental Health Hazard Assessment (COEHHA, 1994), EPA in the on-line Integrated Risk Information System (IRIS) (EPA, 1998a), and in the Health Effects Assessment Summary Tables (HEAST) (EPA, 1997). Reference doses (RfDs) are experimentally derived "no-effect" levels (even for sensitive populations) that are used to quantify the extent of toxic effects (other than cancer) because of exposure to contaminants. A lower value implies a more potent toxicant. Oral and dermal RfDs used for this assessment are listed in Table 6-39; inhalation RfDs are listed in Table 6-40. Cancer slope factors (CSFs) are chemical-specific, experimentally derived potency values that are used to calculate the risk of cancer resulting from exposure to potentially carcinogenic contaminants. Here, a higher value implies a more potent carcinogen. Oral and dermal CSFs used in this HHRA are listed in Table 6-41; inhalation CSFs are listed in Table 6-42. The methodologies used to calculate each of these criteria are discussed below.

Non-Carcinogenic Effects

For effects from non-carcinogenic materials, EPA assumes that a dose threshold exists below which adverse effects are not expected to occur. An RfD is an estimate of a lifetime daily dose of a chemical to humans that is likely to be without appreciable deleterious non-carcinogenic effects, even in sensitive populations. To derive an RfD, a series of professional judgments is made to assess the quality and relevance of the human or animal data and the most critical toxic effect. Data typically used in developing the RfD are the highest no-observable-adverse-effects-levels (NOAELs) for the critical studies and effects of the non-carcinogen. For each factor representing a specific area of uncertainty inherent in the extrapolation from the available data, an uncertainty factor is applied. Chronic RfDs are derived for exposure durations of 7 years or longer. Sub-chronic RfDs are derived for exposure durations ranging from 2 weeks to 7 years.

Four major types of uncertainty factors are typically applied to NOAELs in the derivation of RfDs. These are used to (1) account for the variability between humans, (2) extrapolate from animals to humans, (3) account for a NOAEL based on a sub-chronic study instead of a chronic study, and (4) extrapolate from a lowest-observed-adverse-effects-level (LOAEL) to a NOAEL, if necessary. In addition, a modifying factor (typically set equal to one) can be used to account for adequacy of the database.

To obtain the RfD, all uncertainty factors associated with the NOAEL are multiplied together, and the NOAEL is divided by the total uncertainty factor. Therefore, each uncertainty factor adds a degree of conservatism to the RfD. An understanding of the uncertainties associated with RfDs is important in evaluating the significance of the hazard indices calculated in the risk characterization portion of the HHRA and is further discussed in Section 6.7. All of the COPCs included in this assessment, except for Arochlor-1260, have EPA-established chronic and sub-chronic RfDs.

Carcinogenic Effects

Cancer slope factors (CSFs) are developed from chronic animal studies or, where possible, epidemiological data. Because animal studies use much higher doses over shorter periods of time than do studies for human exposure, the data from these animal studies are adjusted using mathematical models and applying an interspecies scaling factor to derive a comparable low-dose CSFs for humans. The use of these CSFs typically results in an upper-bound estimate of the probability of an individual to develop cancer as a result of exposure to a given level of a potential carcinogen. The actual risks are unlikely to be higher than those predicted using the CSFs, and may actually be considerably lower.

Based on the epidemiological and animal studies available for a given chemical, EPA assigns a weight-of-evidence classification as follows:

- **Group A, Human Carcinogen** - sufficient evidence to support a causal link between chemical exposure and cancer in humans.

- **Group B, Probable Human Carcinogen** - B1, limited evidence of carcinogenicity in humans; B2, sufficient evidence of carcinogenicity in animals, with inadequate or no evidence in humans.
- **Group C, Possible Human Carcinogen** - limited evidence of carcinogenicity in animals and inadequate or no human data.
- **Group D, Not Classifiable as to Human Carcinogenicity** - inadequate or no evidence of carcinogenicity.
- **Group E, Evidence or Non-Carcinogenicity in Humans** - no evidence of carcinogenicity in adequate human or animal studies.

Carcinogenic toxicity criteria are generally developed only for Groups A through C carcinogens. Theoretical carcinogenic risks must be estimated for Group A and Group B carcinogens.

For this HHRA, CSFs developed for PCBs were used to calculate risk to potential receptors from exposure to Arochlor-1254 and Arochlor-1260.

Toxicity Factors Used to Evaluate Dermal Route Exposures

The oral RfD and CSF for chromium (VI) listed in Tables 6-39 and 6-41 were adjusted to derive dermal RfDs and CSFs based on a conversion from an administered dose to an absorbed dose (EPA, 1989). Because arsenic, Arochlor-1254 and Arochlor-1260 are nearly 100 percent absorbed orally, no adjustment to a dermally absorbed dose is necessary. Chemical-specific data to adjust for dermal absorption efficiencies have not been issued by EPA headquarters, EPA Region IX, or the State of California. The following default value of 20 percent for inorganic chemicals was used as recommended by EPA Region IV (EPA, 1995). The CSF is divided by the default value, and the RfD is multiplied by the default factor. The oral to dermal RfD adjustment is shown in Table 6-39. The oral to dermal CSF adjustment is shown in Table 6-41.

6.1.4.2 Toxicity Criteria

The following hierarchy was used to identify toxicity criteria for site COPCs:

Non-Carcinogens:

- IRIS, on-line database (EPA, 1998a).
- HEAST (EPA, 1997).
- Extrapolation from oral to inhalation RfD per Region IX PRGs (EPA, 1998b).
- Extrapolation from inhalation to oral RfD per Region IX PRGs (EPA, 1998b).

Available non-cancer toxicity information is provided in Tables 6-39 and 6-40.

Carcinogens:

- Cancer Potency Factors (COEHHA, 1994).
- IRIS, on-line database (EPA, 1998a).
- HEAST (EPA, 1997).
- Region IX EPA PRGs (EPA, 1998b).

Chemical-specific cancer toxicity information is provided in Tables 6-41 and 6-42. Toxicological profiles for arsenic, Cr(VI), and PCBs are provided in Appendix J.

6.1.5 Risk Characterization

In the final step of the RA, the estimated rate at which human intake of a particular COPC occurs is compared with information about the toxicity of the COPC to estimate the potential risks to human health posed by exposure to the COPC. In this step, known as the risk characterization, cancer risks are evaluated separately from non-cancer health threats. The methods used for assessing cancer risks and non-cancer health effects are discussed below.

6.1.5.1 Methods for Assessing Non-Cancer Health Effects

Potential non-cancer health effects are assessed by comparing the estimated average exposure rate with an exposure level at which no adverse health effects are expected to occur from a long period of exposure. The CDIs derived in Section 6.1.3 and RfDs presented in Section 6.1.4 are compared by dividing the CDI by the RfD to obtain the CDI:RfD ratio [Hazard Quotient (HQ)], as follows:

$$\text{Hazard Quotient} = \text{CDI} \div \text{RfD}$$

where:

CDI = chronic daily intake (mg/kg day)

RfD = reference dose (mg/kg day)

If a person's average exposure is less than the RfD (i.e., if the HQ is less than one), the chemical is considered unlikely to pose a significant non-carcinogenic health hazard to individuals under the given exposure conditions. Unlike carcinogenic risk estimates, an HQ is not expressed as a probability. Therefore, while both cancer and non-cancer risk characterizations indicate a relative potential for adverse effects to occur from exposure to a chemical, a non-cancer health threat estimate is not directly comparable with a cancer risk estimate. If more than one non-carcinogen or pathway is evaluated, the HQs for each chemical and each pathway are summed to determine whether exposure to a combination of pathways and chemicals poses a health concern. This sum of the hazard quotients is known as a hazard index (HI).

$$\text{Hazard Index} = \text{Sum of Hazard Quotients}$$

If necessary, the HI can be refined by summing only those HQs that affect the same target organ. The calculations for estimating the HIs and HQs associated with exposure to on-site chemicals are shown in Tables 6-43 through 6-57.

By using EPA-developed RfDs, along with reasonable maximum estimates of exposure, the risk characterization is likely to be conservative. A conservative risk characterization indicates that the non-cancer health threats are not likely to be underestimated.

6.1.5.2 Methods for Assessing Cancer Risks

In the risk characterization, carcinogenic risk is estimated as the incremental probability of an individual developing cancer over a lifetime as a result of a chemical exposure. Carcinogenic risks are evaluated by multiplying the estimated average exposure rate by the CSF for the chemical. The CSF converts estimated daily intakes averaged over a lifetime to incremental risk of an individual developing cancer. Because cancer risks are averaged over a person's lifetime, longer-term exposure to a carcinogen will result in higher risks than shorter-term exposure to the same carcinogen, if all other exposure assumptions are constant. Theoretical risk associated with low levels of exposure in humans is assumed to be directly related to an observed cancer incidence in animals associated with high levels of exposure. The following equations were used to calculate constituent-specific risks and total risks:

$$\text{Cancer Risk} = \text{CSF} \times \text{CDI}$$

where:

Cancer Risk	=	a unitless probability that an individual will develop cancer attributable to the assumed exposure scenario
CSF	=	cancer slope factor, expressed in $(\text{mg}/\text{kg}\text{-day})^{-1}$
CDI	=	chronic daily intake averaged over 70 years, expressed in $(\text{mg}/\text{kg}\text{-day})$

It is assumed that cancer risks from various exposure routes are additive. The equation to calculate the total carcinogenic risk is shown below:

$$\text{Total Carcinogenic Risk} = \text{Sum of Individual Cancer Risk}$$

Thus, the result of the assessment is a conservative estimate of the total carcinogenic risk. Carcinogenic risk estimates are compared to EPA's acceptable risk range of one in one million (1×10^{-6}) to one in ten thousand (1×10^{-4}). If the estimated risk falls within or below the risk value considered acceptable by EPA, the chemical is considered unlikely to pose an unacceptable carcinogenic health risk to individuals under the given exposure conditions. A risk level of 1×10^{-6} represents a probability of one in one million that an individual could develop cancer from exposure to the potential carcinogen under a defined set of exposure assumptions.

By using COEHHA and EPA-developed CSFs, along with reasonable maximum estimates of exposure, the risk characterization is likely to be conservative. A conservative risk characterization indicates that the cancer health threats are not likely to be underestimated. The calculations for estimating the cancer risk associated with exposure to on-site chemicals are shown in Tables 6-58 through 6-72.

6.1.6 Uncertainty Analysis

Risk estimates have various uncertainties associated with them. These uncertainties are evaluated to provide an indication of the relative degree of uncertainty associated with a risk estimate. Presented in this section is a qualitative discussion of the uncertainties associated with the estimation of risks for the site.

HHRAs are not intended to estimate actual risks to a receptor associated with exposure to contaminants in the environment. In fact, estimating actual risks is impossible because of the variability in the exposed or potentially exposed populations. Therefore, the HHRA is a means of estimating the probability that an adverse health effect will occur in a receptor. The multitude of conservative assumptions used in HHRAs guards against the underestimation of risks.

Risk estimates are calculated by combining site data, assumptions about the individual receptor's exposures to affected media, and toxicity data. The uncertainties in this HHRA can be grouped into four main categories:

- Uncertainties in environmental sampling and analysis.
- Uncertainties in assumptions concerning exposure scenarios.
- Uncertainties in toxicity data and dose-response extrapolations.
- Combinations of sources of uncertainty.

6.1.6.1 Uncertainties in Environmental Sampling and Analysis

This assessment conservatively assumes exposure to a single, maximum chemical concentration in soil. Individuals would more typically be exposed to a wide range of concentrations, potentially resulting in a lower average exposure.

6.1.6.2 Uncertainties in Assumptions Concerning Exposure Scenarios

The selection of exposure pathways is a process that attempts to identify the most probable potentially harmful exposure scenarios. It is possible that risks are not calculated for all of the exposure pathways that may occur, which may cause some underestimation of risk. For example, ingestion of homegrown fruits and vegetables was not evaluated. It is possible that a potential on-site resident may have a garden on impacted soil and plants could take up the contaminants and transfer them to edible portions. This pathway was considered to contribute a negligible amount to the total risk and evaluation was not warranted.

Numerous uncertainties affect the determination of exposure parameters because the behavior patterns of individuals are not always well known. For example, body weights, breathing rates, soil ingestion rates, and dermal contact rates are likely to vary depending on the actual characteristics of the exposed population. Given these uncertainties, reasonable maximum exposure values for both children and adults, as appropriate, were used in the ingestion, dermal contact, and inhalation pathway calculations.

6.1.6.3 Uncertainties in Toxicity Data

The availability and quality of toxicological data is another source of uncertainty. For example, toxicity data for PCBs, as a class of chemicals, was used to calculate the potential carcinogenic risks of Arochlor-1260 and Arochlor-1254. In addition, Arochlor-1260 lacks non-carcinogenic toxicity data. Benzo(g,h,i)perylene and phenanthrene lack both non-carcinogenic and carcinogenic toxicity data. The lack of chemical-specific data and the use of surrogate toxicity values may affect the outcome of the HHRA by either underestimating or overestimating the risks to potential receptors.

Uncertainties associated with animal and human studies can also influence the classification criteria of carcinogens based on the amount of evidence available that suggests human carcinogenicity.

Uncertainties also affect the use of CSFs, which serve as the basis for calculating estimated cancer risks. During the development of CSFs, it is assumed that the dose-response relationship is the same for both test animals and humans and that these factors represent upper-bound estimates of potency. Thus, if an individual's exposure to a chemical is equivalent to the level that defines the potency, there is only a 5 percent chance that the actual risk to that individual will exceed the calculated risk and a 95 percent chance that the risk is at or below the calculated level. Consequently, the actual risks associated with exposure to a potential carcinogen are not likely to exceed the risk estimated using these upper-bound cancer slope factors, and in fact, may be lower.

6.1.6.4 Combinations of Sources of Uncertainty

Uncertainties from different sources are compounded in the risk assessment. For example, if a person's daily intake rate for a given compound is compared to an RfD to determine potential health risks, the uncertainties in the concentration measurements, exposure assumptions, and toxicity will all be expressed in the result. Therefore, by combining all upper-bound numbers, the uncertainty is compounded, and the resulting risk estimate is above the 90th or 95th percentile, perhaps even greater than the 99th percentile.

6.1.7 Risk Assessment Results

To ensure that human health is adequately protected, conservative concentrations, exposure parameters, and toxicity assumptions were used in estimating potential risks. Theoretical risks to human health predicted by this assessment are, therefore, likely to be an overestimation of actual risks.

For each of the exposure populations, the cancer risk or HQ value for each analyte and exposure pathway (ingestion, inhalation, and dermal) was summed to produce total cancer risk and non-cancer risk (HI) values. Presented in Tables 6-73 through 6-87 are the cancer risks and non-cancer HQ by analyte and exposure pathway for each population evaluated for soil exposure.

6.1.7.1 Results for Discharge Point No. 2

None of the soil non-cancer HQ values exceeded the target HQ of 1.0, nor did any of the total HIs. This result indicates the potential non-carcinogenic risk from ingestion, dermal contact, and inhalation exposure to on-site soil in this area is negligible. The on-site resident had the highest risk with an HI of 0.0051; the construction worker had an HI of 0.0012 (Table 6-74) as did the commercial worker (Table 6-75).

None of the soil cancer risks exceeded the target value of 10^{-6} , which indicates the potential carcinogenic risk from ingestion of, dermal contact with, and inhalation of on-site soil is negligible. The on-site resident had the highest risk with a total risk of 7.7×10^{-7} (Table 6-73), the construction worker had the lowest risk with a total risk of 2.2×10^{-8} (Table 6-74), and the commercial worker had a total risk of 5.0×10^{-7} (Table 6-75). This result indicates the potential carcinogenic risk from ingestion, dermal contact, and inhalation exposure to on-site soil in this area is negligible.

6.1.7.2 Results for Discharge Point No. 3

None of the soil non-cancer HQ values exceeded the target HQ of 1.0, nor did any of the total HIs. This result indicates the potential non-carcinogenic risk from ingestion, dermal contact, and inhalation exposure to on-site soil in this area is negligible. The on-site resident had the highest risk with an HI of 0.25 (Table 6-76), the construction worker had an HI of 0.029 (Table 6-77), and the commercial worker had the lowest risk with an HI of 0.013 (Table 6-78).

The soil cancer risks for both the resident and the commercial worker exceeded the lower bound of 1×10^{-6} ; however, calculated risks fell within the target range of 1×10^{-6} to 1×10^{-4} with total risks of 1.5×10^{-5} and 2.3×10^{-6} , respectively (Tables 6-76 and 6-78, respectively). The construction worker had the lowest risk with a total risk of 1.9×10^{-7} (Table 6-77). The results indicate the potential carcinogenic risk from ingestion, dermal contact, and inhalation exposure to on-site soil in this area is negligible.

6.1.7.3 Results for Discharge Point No. 4

None of the soil non-cancer HQ values exceeded the target HQ of 1.0, nor did any of the total HIs. This result indicates the potential non-carcinogenic risk from ingestion, dermal contact, and inhalation exposures to on-site soil in this area is negligible. The on-site resident had the highest risk with an HI of 0.26 (Table 6-79), the construction worker had an HI of 0.030 (Table 6-80), and the commercial worker had the lowest risk with an HI of 0.013 (Table 6-81).

The soil cancer risks for both the resident and the commercial worker exceeded the lower bound of 1×10^{-6} ; however, calculated risks fell within the target range of 1×10^{-6} to 1×10^{-4} with total risks of 1.5×10^{-5} and 2.4×10^{-6} , respectively (Tables 6-79 and 6-81, respectively). The construction worker had the lowest risk with a total risk of 2.0×10^{-7} (Table 6-80). The results indicate the potential carcinogenic risk from ingestion, dermal contact, and inhalation exposure to on-site soil in this area is negligible.

6.1.7.4 Results for Waste Pit No. 1/Discharge Point No. 1

None of the soil non-cancer HQ values exceeded the target HQ of 1.0, nor did any of the total HIs. This result indicates the potential non-carcinogenic risk from ingestion, dermal contact, and inhalation exposure to on-site soil in this area is negligible. The on-site resident had the highest risk with an HI of 0.65 (Table 6-82), the commercial worker had the lowest risk with an HI of 0.058 (Table 6-84), and the commercial worker had an HI of 0.072 (Table 6-83).

The soil cancer risks for both the resident and the commercial worker exceeded the lower bound of the target of 1×10^{-6} ; however, calculated risks fell within the target range of 1×10^{-6} to 1×10^{-4} with total cancer risks of 2.6×10^{-5} and 9.0×10^{-6} , respectively (Tables 6-82 and 6-84, respectively). The construction worker had the lowest risk with a total risk of 4.5×10^{-7} (Table 6-83). This result indicates the potential carcinogenic risk from ingestion, dermal contact, and inhalation exposure to on-site soil in this area is negligible.

6.1.7.5 Results for Waste Pit No. 4

None of the soil non-cancer HQ values exceeded the target HQ of 1.0, nor did any of the total HIs. This result indicates the potential non-carcinogenic risk from ingestion, dermal contact, and inhalation exposure to on-site soil in this area is negligible. The on-site resident had the highest risk with an HI of 0.31 (Table 6-85), and commercial and construction workers had HIs of 0.016 (Tables 6-87 and 6-86, respectively).

The soil cancer risks for both the resident and the commercial worker exceeded the lower bound of the target of 1×10^{-6} ; however, calculated risks fell within the target range of 1×10^{-6} to 1×10^{-4} with total risks of 1.8×10^{-5} and 2.8×10^{-6} , respectively (Tables 6-85 and 6-87, respectively). The construction worker had the lowest risk with a total risk of 2.4×10^{-7} (Table 6-86). This result indicates the potential carcinogenic risk from ingestion, dermal contact, and inhalation exposure to on-site soil in this area is negligible.

6.1.8 Summary

The baseline HHRA evaluated the potential risks to the child and adult on-site resident, the commercial worker, and the construction worker potentially exposed to contaminants in on-site soil at JPL through ingestion, dermal contact, and inhalation pathways. Exposure to off-site residents was not quantified in this baseline HHRA. An off-site resident is potentially exposed primarily through inhalation of on-site soil migrating off the site. Any chemical concentrations to which they would be exposed due to this migration are negligible because of wind dispersion during eolian transport. In addition, the potential on-site receptors that were quantified are considered more conservative than the off-site resident because their exposure to on-site soils is greater. Therefore, because potential risk from ingestion, dermal contact, and inhalation exposure to on-site soil is negligible for on-site receptors, it is also negligible for off-site receptors.

All chemicals detected in soil samples collected in the upper 15 feet of soil and in soil-vapor samples collected in the upper 30 feet of soil were evaluated in this HHRA. The maximum detected values were used to calculate chemical intakes in evaluating lifetime cancer risks and non-cancer risks.

6.1.8.1 Soil Vapor

The final COPC list showed that no volatile chemicals detected in soil-vapor data contributed to risk to potential receptors.

6.1.8.2 Soils

The final COPC list showed Arochlor-1254, Arochlor-1260, arsenic, and Cr(VI) contributing to carcinogenic and non-carcinogenic risks to potential receptors. The potential receptor at greatest risk is the hypothetical on-site resident. It is very unlikely that JPL will ever be used as a residential site, but this scenario is included here as a conservative estimate of risk. All estimated risks for these COPCs were either below the target HQ of 1.0 or within the target risk range of 1×10^{-6} to 1×10^{-4} (EPA, 1989) (see Tables 6-88 through 6-95 for a summary of carcinogenic risks that exceeded the lower bound of the target of 1×10^{-6}). Based on the above target levels and the results of the risk calculations, there is negligible risk to potential receptors, both on-site and off-site, because of exposure to on-site soils at JPL.

6.2 ECOLOGICAL RISK ASSESSMENT

A screening-level ecological risk assessment (ERA) was performed as part of the OU-2 Remedial Investigation for the Jet Propulsion Laboratory in Pasadena, California. The ERA was conducted in accordance with EPA *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments* (EPA, 1997a), as well as other pertinent guidance documents (DTSC, 1996a and 1996b). The purpose of the ERA was to evaluate whether site-specific contaminant levels in soils pose a potential risk to ecological receptors at the site.

The ERA has been organized to present the data collected, discuss the data assessment, and summarize the findings and conclusions. The report format is as follows:

- **Section 6.2.1**—Site Background and Ecological Setting
- **Section 6.2.2**—Selection of Ecological Constituents of Potential Concern
- **Section 6.2.3**—Exposure Pathways and Potential Receptors
- **Section 6.2.4**—Analysis
- **Section 6.2.5**—Results
- **Section 6.2.6**—Uncertainty
- **Section 6.2.7**—Summary

6.2.1 Site Background and Ecological Setting

Presented in the following sections is information pertaining to the description and history of the site, the ecological setting of the site, and species of special concern that could be located on the site. The description of the physical setting of the JPL site is based on field observations and information from previous investigations.

6.2.1.1 Site Background

JPL is located within the cities of Pasadena and La Canada-Flintridge, California. The site is situated in the foothills and along the base of the southern edge of the east-west trending San Gabriel Mountains and at the northern edge of the metropolitan Los Angeles area. A site location map is included as Figure 1-1. The Arroyo Seco, an intermittent stream bed, lies immediately to the east and southeast of the site.

The first permanent structures at JPL were constructed in 1940. The southern half of the site is used by JPL for project support, testing, and storage facilities and houses most of the personnel, administrative, management, laboratory, and project functions of JPL. Further development of JPL is constrained because of steeply sloping terrain to the north, the Arroyo Seco wash to the south and east, and residential development to the west.

Today, under a prime contract, CalTech performs research and development tasks at facilities provided by NASA. For JPL to accomplish the research and development tasks under their purview, chemicals and materials have been utilized during the operational history of the site. The general types of materials used and produced include a variety of solvents, solid and liquid rocket propellants, cooling-tower chemicals, and chemical laboratory wastes. For more information about the site and its history, refer to Section 1.3.

6.2.1.2 Ecological Setting

JPL is located along the northern edge of the San Gabriel Valley in the central portion of Los Angeles County. The San Gabriel Valley is bounded on the north by the San Gabriel Mountains, which consist of relatively steep, rocky ridges with numerous canyons.

The northernmost portion of JPL consists of Gould Mesa, a flat-topped southern promontory of the San Gabriel Mountains that rises 300 feet above the main area of the JPL complex. The remainder of the site is moderately sloping to the south.

JPL has a semi-arid Mediterranean climate, which is characterized by mild, rainy winters and warm dry summers. Rainfall in the vicinity of JPL averages about 20 inches per year. Temperatures at JPL are relatively mild, with August typically the warmest month and January the coolest.

Within the JPL site, there are several habitat types including urban landscape, chaparral, riparian, wetlands, and desert wash. The Arroyo Seco (mostly riparian and desert wash habitat) borders the east side of the JPL site.

The predominate habitat at the JPL site is urbanized landscape with paved roads, parking lots, and buildings. Vegetation used in the landscape includes native and non-native plant species.

Chaparral is one of the best developed xeric plant communities in southern California. It covers the convex slopes of the mesa in the northern section of the JPL site and along the upland banks of the Arroyo Seco east of the site.

The Arroyo Seco Creek intermittently flows through the Arroyo Seco wash on the east side of the JPL site. The Arroyo Seco collects runoff from the north, east, and west. Several groundwater recharge ponds are located on the east side of the Arroyo Seco and west of the extended parking area.

Riparian areas are located directly northeast and east of the JPL site along the Arroyo Seco Creek. Riparian trees are thicker at the drain outfalls on the east boundary of the JPL site where runoff from landscape areas and pavement is year-round.

Desert wash habitats are dry, sandy water courses leading from desert mountain canyons that collect runoff and rainwater during rainstorms. The Arroyo Seco is approximately 1,000 feet wide and is intersected by the Devil's Gate Dam approximately 1 mile south of JPL. The Arroyo Seco has chaparral and riparian areas interspersed within its banks.

6.2.1.3 Species of Special Concern

A review was completed of several data sources for species of special concern that might be present on the site. Species of special concern are those species which have been identified by Federal or state agencies as threatened, endangered, or candidate species, and are known or

suspected to occur within the area covered by the USGS 7.5 minute quadrangle map for Pasadena. The California Department of Fish and Game (CDF&G) Natural Diversity Data Base (CDF&G, 1995) and the California Native Plant Society (CNPS) list of rare, threatened, or endangered plant species (CNPS, 1994) was examined for species of special concern that may occur in the project area. The following species of special concern have been identified as potentially occurring in the vicinity of the site:

- Southwestern arroyo toad
- Southwestern pond turtle
- San Diego horned lizard
- Peregrine falcon
- Bank swallow
- Western yellow-billed cuckoo
- Least Bell's vireo

These species have not been identified at the JPL site. Their presence on the above list is only an indication that there may be suitable habitat within the general area.

6.2.2 Selection of Ecological Constituents of Potential Concern

Ecological constituents of potential concern are those chemicals that may potentially induce an adverse response in ecological receptors. In order to focus the assessment on those chemicals with the highest potential to have adverse effects on ecological receptors, the list of chemicals to be evaluated is narrowed through a COPC selection process. The COPC selection process (represented in Figure 6-2) evaluates the following criteria: detection in site soils or soil-vapor, comparison to background concentrations, and comparison to ecological PRGs. Each of these criteria is discussed in more detail in the following subsections.

6.2.2.1 Detection in Site Soils

The first step of the COPC selection process determined which chemicals had been detected in site soils and soil-vapor. For the purposes of this ERA, the analytical data collected for the RI for soil (1994 and 1997) and soil vapor (1998) were considered the most representative for current and future conditions that may occur at the site.

Soil Samples

Soil samples were collected during the RI field investigations in 1994, 1997, and 1999 at the locations presented in Figure 3-8. Soil samples were collected from soil borings and test pits at depths ranging from 1 foot to 101 feet. Analyses included SVOCs, PAHs, PCBs, dioxins and furans, Title 26 Metals plus strontium and hexavalent chromium, tributyltin, nitrate, cyanide, TPH, gross alpha and beta, and total solids. Samples from the test pits were also analyzed for

VOCs. Detailed discussions of the results of soil sampling conducted during the RI are provided in Section 4.3.

For the purposes of this ERA, analytical data for the upper 5 feet of soil were considered to be a realistic estimate of the soil at which potential receptors would most likely be exposed. This depth accounts for potential exposure to burrowing animals and to plant roots. Soil samples were evaluated from the surface (surface to 2-foot depth interval) and the subsurface (2- to 5-foot depth interval). Sampling locations evaluated in this ERA include WP-1/DP-1, DP-2, DP-3, DP-4, WP-4, and WP-5. These locations are situated along the east and southeast boundary of the JPL site.

Soil-Vapor Samples

Soil-vapor samples were collected during seven sampling events beginning in 1994 and continuing into 1998 at the locations designated in Figures 4-2 and 4-4. Vapor samples were collected at depths ranging from 5 to 205 feet and analyzed only for VOCs by EPA Method 8010/8020. Detailed discussion of the results of soil-vapor sampling conducted during the RI are discussed in Section 4.2.

For the purposes of this ERA, soil-vapor data collected within the upper 15 feet of soil were used to evaluate risk due to exposure to contaminated soil and soil vapor. There were no chemicals positively identified in soil-vapor samples collected from this interval.

6.2.2.2 Comparison to Background Concentrations

The second step in the COPC selection process was a comparison to naturally occurring, or background, concentrations of inorganics to identify chemicals that may be found naturally at or near the site (DTSC, 1994, and EPA, 1989). For the comparison, all metals identified in surface and subsurface soil samples were first compared to background concentrations determined during RI site activities (refer to Section 4.3.1). The maximum detected value in the site-investigative data was compared to the maximum detected concentration in the background data (DTSC, 1997). Those inorganic chemicals present on-site at naturally occurring levels were eliminated from further evaluation in the ERA. This comparison is included in Tables 6-96 and 6-97.

6.2.2.3 Comparison to Ecological Preliminary Remediation Goals

The third step of the COPC selection process compared the maximum detected value of each chemical positively identified in surface and subsurface soil samples at each location to ecological PRG values. The results of these comparisons are included in Tables 6-96 (surface soil) and 6-97 (subsurface soil).

For this comparison, the concentration of 1,2,3,4,6,7,8,9-OCDD was adjusted based on the toxicity equivalency factor (TEF) for dioxins established for humans, wild mammals, fish, and birds [Eastern Research Group (ERG), 1997]. This method assumes a 0.0001 relative toxicity of

OCDD to 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD). Because PRGs are only available for TCDD, the concentration of OCDD is converted to a toxic equivalent (TEQ) of TCDD. The TEQ concentration for 1,2,3,4,6,7,8,9-OCDD was determined using the following equation:

$$\text{TEQ} = \text{Detected Concentration} \times \text{TEF}$$

$$\text{TEQ} = 0.0092 \frac{\text{mg}}{\text{kg}} \times 0.0001$$

$$\text{TEQ} = 0.00000092 \frac{\text{mg}}{\text{kg}}$$

PRG values were extracted primarily from *Preliminary Remediation Goals for Ecological Endpoints* developed by Oak Ridge National Laboratory (Efroymsen and others, 1997). Ecological PRGs are upper concentration limits for specific chemicals in specific media that are anticipated to protect the environment. In general, PRGs correspond to small effects on individual organisms, which would be expected to cause minimal effects on populations and communities. Efroymsen and others (1997) chose their PRGs for soil by comparing toxicological benchmarks for plants and earthworms to calculated PRGs for wildlife. Efroymsen and others (1997) derived wildlife PRGs by iteratively calculating exposure estimates using different soil concentrations and soil-to-biota contaminant uptake models. Because different diets may dramatically influence exposures and sensitivity to contaminants varies among species, PRGs were developed for six species present on the Oak Ridge Reservation: short-tailed shrew, white-footed mouse, red fox, white-tailed deer, American woodcock, and red-tailed hawk. The lowest value available was adopted as the PRG.

PRGs were unavailable from Efroymsen and others (1997) for the PAHs including benzo(b)fluoranthene, benzo(g,h,i)perylene, fluoranthene, phenanthrene, and pyrene and for di-n-butyl-phthalate. Region III's *Interim Ecological Risk Assessment Guidelines* (EPA, 1995a) was used as a secondary source for toxicological information for these chemicals. Region III used toxicity values developed for benzo(a)pyrene as surrogate values for the PAHs.

Toxicity values for acetone, bromodichloromethane, chloroform, methylene chloride, nitrate, strontium, and tributyltin were not available from either of the above two sources. The toxicity of acetone, bromodichloromethane, chloroform, and methylene chloride to small mammals (i.e., mice and rats) is discussed qualitatively below. The EPA (1986b) document reported an acetone no-effects level of 2,000 mg/kg of acetone based on a 90-day study. No significant effects to rats were observed at this level. The maximum acetone concentration detected on site (0.0063 mg/kg) is substantially lower than the above level. Therefore, no risk to potential mammalian receptors is expected from exposure to acetone.

The National Toxicology Program (NTP) (1986) reported a bromodichloromethane no-effect dose for rats of approximately 700 mg/kg. This dose is based on a study during which male and female rats received doses of 19 to 300 mg/kg/day of bromodichloromethane, male mice received doses of 6.25 to 100 mg/kg/day, and female mice received doses of 25 to

400 mg/kg/day for 5 days a week. Doses above the no-effect level produced kidney lesions and depressed body weight in male mice. The maximum bromodichloromethane concentration detected on site (0.0032 mg/kg) is substantially lower than the no-effect level. Therefore, no risk to potential mammalian receptors is expected from exposure to bromodichloromethane.

Palmer and others (1979) reported a chloroform no-effect dose for rats of approximately 3,000 mg/kg based on a 13-week study. No significant effects were observed at this dose. The maximum chloroform concentration detected on site (0.0052 mg/kg) is substantially lower than the above dose. Therefore, no risk to potential mammalian receptors is expected from exposure to chloroform.

The National Coffee Association (NCA) (1982) reported a methylene chloride no-effect dose for rats of approximately 120 mg/kg for 2 years. No significant effects were observed at this dose. The maximum methylene chloride concentration detected on site (0.005 mg/kg) is substantially lower than the above dose. Therefore, no risk to potential mammalian receptors is expected from exposure to methylene chloride.

No toxicity information for avian receptors was available for acetone, bromodichloromethane, chloroform, or methylene chloride. However, based on the discussion of toxicity to small mammals above, no adverse effects are expected in avian receptors. The concentrations of these chemicals detected on site are extremely low relative to the toxicity information available for small mammals. It is unlikely that these low concentrations will have an adverse impact on birds. Therefore, acetone, bromodichloromethane, chloroform, and methylene chloride were eliminated as COPCs for the evaluated sites.

Nitrate was not considered further in this ERA because of its low toxicity as documented in *The Health Effects of Nitrate, Nitrite, and N-Nitroso Compounds* (ALS, 1981). This document reported no-effect levels for the chronic feeding of nitrate to be 10,000 mg/kg for 2 years and 20,000 mg/kg for 105 to 125 days in rats and dogs, respectively. The concentrations of nitrate detected at JPL, ranging from 0.21 mg/kg to 28.8 mg/kg, are considerably less than the no-effect level and are not expected to pose risk to potential environmental receptors.

Strontium was evaluated qualitatively relative to published background concentrations for California and the western United States (Bradford and others, 1996; Shacklette and others, 1984). Concentrations of strontium at the evaluated sites ranged from 17.6 mg/kg (WP-4) to 108 mg/kg (WP-1/DP-1). While this range exceeds the site background concentration of 26.7 mg/kg, it falls below the reported arithmetic mean of naturally occurring strontium in California (130 mg/kg) and in the western United States (200 mg/kg). Therefore, strontium was eliminated as a COPC for the evaluated sites.

Tributyltin was evaluated qualitatively relative to available toxicity information. Tributyltin compounds are considered moderately toxic to birds. This conclusion is based on the results of a 13-week study of toxic effects of tributyltin oxide in Japanese quail. At dietary levels of

150 ppm no treatment-related mortality was observed; at 375 ppm, egg production, eggshell thickness, fertility, and hatchability were reduced. Reported LD₅₀ values for tributyltin oxide range from 55 to 87 mg/kg in mice and rats. Dermal LD₅₀ values are 200 mg/kg in rats and mice and 900 mg/kg in rabbits (EXTOXNET, 1999). The tributyltin concentration detected on site (0.001 mg/kg) is substantially lower than any of the above toxic effect levels. Therefore, no risk to potential receptors is expected from exposure to tributyltin; it was eliminated as a COPC for the evaluated sites.

Chemicals identified as COPCs based on the above three steps include chromium, lead, mercury, molybdenum, vanadium, and zinc.

6.2.3 Exposure Pathways and Potential Receptors

A complete exposure pathway between a receptor and an affected environmental media is necessary for potential ecological risk to occur. For example, chemical contamination existing in soils at depths equal to 30 feet are not expected to pose risk to deer because there is no complete exposure pathway between the deer and soils at that depth. However, if a plant species with tap roots greater than 30 feet exists on site, then a complete exposure pathway would exist to the plant and potentially to wildlife that ingest the foliage of that plant.

As shown in the site conceptual model for risk assessment (Figure 6-1), the principal media of ecological concern for this ERA are surface and subsurface soils. Potential exposure routes to chemicals in soils may include one or more of the following:

- Inhalation
- Ingestion
- Dermal absorption

Ingestion of soil, plants, or prey was considered the primary route of exposure for this ERA. Inhalation and dermal absorption are potential routes of exposure, but for this ERA they are not likely to significantly contribute to the total exposure. In addition, methods are not adequately developed to quantitatively evaluate these pathways. Exposure through drinking water is also expected to be insignificant due to the limited presence of surface water. Therefore, ingestion of soil, plants, or prey were the only routes of exposure considered in this evaluation.

Receptors that are evaluated to provide a determination of whether there is potential ecological risk at the site are called assessment endpoints and are selected from the potential receptors occurring at the site. Criteria pertaining to exposure potential were used to identify assessment endpoints with the most significant potential for exposure-related impacts. The biological receptor selection criteria were obtained from the *Risk Assessment Handbook Volume II: Environmental Evaluation* (USACE, 1996) and include the following:

- Likelihood of contacting chemical contamination
- Key component of ecosystem structure or function
- Listing as rare, threatened, or endangered, or critical habitat for such
- Sensitivity to chemicals
- Recreational or commercial value
- Site residency
- Size of home range

By evaluating significant endpoints such as reproduction, mortality, and health at the species level, conclusions regarding population can also be presented.

The deer mouse (*Peromyscus maniculatus*) and American kestrel (*Falco sparverius*) were the receptors chosen as assessment endpoints at JPL and conservatively represent the key elements of the trophic webs in each of the major habitat types included in this ERA. Assessment endpoint species are assumed to have uniform body size, metabolism, diet, home ranges, and habitat requirements (Sample and Suter, 1994).

The deer mouse represents small rodents, which are ubiquitous to all habitats on JPL. Deer mice can be found in a wide variety of habitats, including grasslands and disturbed areas overgrown by weedy vegetation (Armstrong, 1987). The dietary fractions of deer mice vary seasonally, but have been found to average about 38.5 percent insects, with the remainder composed primarily of seeds and plants, over the year in semiarid grasslands of Colorado (EPA, 1993b). For purposes of this ERA, the dietary concentrations of COPCs for the deer mouse was conservatively estimated to be equal to the concentrations of the COPCs in soil. This approach overestimates the COPC intake of the deer mouse because it assumes its diet is composed entirely of food with COPC concentrations equal to the soil concentration. In reality, the COPC intake by the deer mouse would be much less because its intake is dependent on the residual COPC concentrations in the plants and insects it ingests. These plants and insects are potentially exposed to COPCs in soil through a variety of pathways. They absorb and retain a portion of the COPC, which is then ingested by the deer mouse when it eats the plant or insect. Also, incidental soil ingestion was included as part of the ingestion pathway in addition to the ingestion of food. The rate of incidental soil ingestion was conservatively estimated at 2 percent of the ingestion rate of dry food matter based on data for the white-footed mouse (Beyer and others, 1994). Therefore, the total dry matter (i.e., food and soil) ingestion rate for the deer mouse is 102 percent of the ingestion rate for dry food matter. It was assumed all dry food matter ingested by the deer mouse is obtained from the sample site.

The American kestrel is modeled as a predator of the deer mouse and is the most common falcon in open and semi-open areas throughout North America. Kestrels inhabit open deserts, semi-open areas, edges of groves, and urban areas. For purposes of this ERA, 100 percent of the dietary intake of the kestrel was conservatively estimated to be deer mice although they are likely

to take a wide variety of prey. COPC intake was estimated based on the estimated COPC deer mouse tissue concentration (see Section 6.2.4.2). Incidental soil ingestion was also included as part of the ingestion pathway in addition to the ingestion of food. However, no information is available on the incidental soil ingestion rate for the American kestrel. Therefore, the rate of incidental soil ingestion was estimated at 10.4 percent of the ingestion rate of dry food matter based on data for the American woodcock (Beyer and others, 1994). This is probably a conservative estimate because the woodcock uses its bill to probe into the soil for prey. Therefore, the total dry matter ingestion rate (i.e., food and soil) for the American kestrel is 110.4 percent of the ingestion rate for dry food matter.

6.2.4 Analysis

The purpose of the analysis is to estimate the nature, extent, and magnitude of potential exposure of receptors to COPCs present at each location. This section describes toxicity values, exposure assessment methods, and dose calculations.

6.2.4.1 Ecological Effects Evaluation

This screening-level ERA is intended to identify chemical contaminants that may pose potential ecological risk to plants and wildlife. Chemical contamination that is determined to potentially cause ecological risk may require additional evaluation in a more detailed quantitative assessment.

Dose estimates were compared to conservative toxicity reference values (TRVs) obtained from literature sources to determine if COPCs are present on site at concentrations that may be detrimental to species selected as assessment endpoints (EPA, 1999, and Sample and others, 1996). TRVs are based on a no-observed-adverse-effects level (NOAEL) specific to both chemicals and organisms. NOAEL-based TRVs were applied because they are believed to be from the most comprehensive studies, they are conservative, and they represent maximum concentrations that are believed to be nonhazardous. San Francisco Bay Regional TRVs (U.S. Navy, undated draft) were used when available. These TRVs are not species specific; they are developed for mammals and for birds. No additional extrapolation or uncertainty factors have been applied to the Regional TRVs. If a Regional TRV was not available for a specific COPC, TRVs from Sample and others (1996) were used. TRVs for the deer mouse and the American kestrel are listed in Table 6-98.

The exceedance of TRVs in this assessment does not imply certain ecological risk; rather, the exceedance indicates contamination may be sufficient to warrant further investigation.

6.2.4.2 Exposure Assessment

This section describes how the chemical data discussed in Section 6.2.2.1 and the toxicological data discussed in Section 6.2.4.1 are combined with species-specific parameters to estimate exposure and risk to each of the potential biological receptors. Doses were estimated for the deer

mouse and the American kestrel for each site for which COPCs were identified. Doses were estimated based on the maximum concentration reported in surface and subsurface soils.

Exposure Estimate for the Deer Mouse

Potential exposure to the deer mouse was estimated using the following equation, as appropriate (based on Sample and Suter, 1994):

$$Exposure\ Estimate = \frac{C_{max} \times IR \times BA}{BW_{deer\ mouse}}$$

where:

BA	=	bioavailability, the fraction of a chemical available to illicit an effect (unitless)
BW _{deer mouse}	=	body weight for the deer mouse (kilograms [kg])
C _{max}	=	the maximum detected COPC concentration in soil at each location (milligrams per kilogram [mg/kg])
Exposure Estimate	=	the estimated oral dose of the COPC to the receptor (mg/kg-day)
IR	=	intake rate (kg/day)

Incidental soil ingestion was included as part of the ingestion pathway in addition to the ingestion of food. The total intake rate was calculated using the following equation:

$$IR_o = [1 + IF_s] \times FIR$$

where:

IF _s	=	soil ingestion fraction (unitless)
FIR	=	food intake rate (kg/day)

Food intake rates (FIRs) vary with many factors, including metabolic rate, the energy devoted to growth and reproduction, and composition of the diet. In addition, metabolic rates vary with fluctuating ambient temperatures, activity levels, and body weights. The following equation was used to account for this variation (Nagy, 1987):

$$FIR_{rodents} = 0.621 \times BW_{deer\ mouse}^{0.564}$$

The FIR was first calculated in grams per day, then converted to kg/day. Table 6-99 includes the specific exposure parameters that were used in the calculation above.

Exposure Estimate for the American Kestrel

After the TRVs specific to the American kestrel were determined, potential exposure was estimated using the following equation, as appropriate (based on Sample and Suter, 1994):

$$\text{Exposure Estimate} = \frac{BA \times [(C_{\max} \times IF_s \times FIR) + (C_{\text{mouse}} \times FIR)]}{BW_{\text{American kestrel}}}$$

where:

BA	=	bioavailability, the fraction of a chemical available to illicit an effect (unitless)
BW _{American kestrel}	=	body weight for the American kestrel (kg)
C _{max}	=	the maximum detected COPC concentration in soil at each location (mg/kg)
C _{mouse}	=	estimated tissue COPC concentration in the deer mouse, dry weight (mg/kg)
IF _s	=	soil ingestion fraction (unitless)
FIR _{non-passerine birds}	=	food intake rate (kg/day)

Passerine birds are songbirds (order Passeriformes); non-passerine refers to all other orders of birds. American kestrels are therefore considered non-passerine birds.

Because food ingestion varies with a number of environmental factors, the following equation (Nagy, 1987) was used to estimate the FIR for the American kestrel:

$$FIR_{\text{non-passerine birds}} = 0.301 \times BW^{0.751}$$

The COPC concentration in deer mouse tissue was estimated based on a food-to-muscle transfer factor derived for modeling chemical concentrations in beef. Food-to-muscle transfer factors are based on a dry-weight to wet-weight concentration conversion. The following equation was used to estimate the COPC concentration in dry deer mouse tissue:

$$C_{\text{deer mouse}} = TF_{\text{fm}} \times C_{\text{food}} \times 3.125$$

where:

3.125	=	the wet-weight to dry-weight conversion factor, based on a water content of 68% (EPA, 1993b)
C _{max}	=	the maximum detected COPC concentration in soil at each location (mg/kg)
TF _{fm}	=	food-to-muscle transfer factor (unitless)

Food-to-muscle transfer factors for the inorganic COPCs were estimated as the maximum reported value from the International Atomic Energy Agency (IAEA, 1994), National Council on Radiation Protection and Measurements (NCRP, 1989), or Baes and others (1984) (Table 6-100). Table 6-99 includes other exposure parameters for the American kestrel.

Risk Characterization

The potential for risk to ecological receptors was determined by estimating a hazard quotient (HQ). HQs are specific to a particular receptor for exposure to a particular COPC. HQs were determined by dividing the calculated exposure estimate by the species-specific toxicity reference value (TRV), as in the following equation:

$$HQ = \frac{\text{Exposure Estimate}}{TRV}$$

where:

Exposure Estimate	=	the estimated oral dose of the COPC for the receptor (mg/kg-day)
HQ	=	the hazard quotient (unitless)
TRV	=	the TRV for the COPC and the receptor (mg/kg-day)

HQs greater than 1.0 indicate potential risk to an ecological receptor and may indicate the need for further evaluation using more site-specific information. HQs less than 1.0 indicate no potential ecological risk. Therefore, COPCs with HQs less than 1.0 can be removed from further consideration due to the inherent and conservative assumptions applied to derive the HQ. Estimated HQs are included for each receptor in Section 6.2.5.

6.2.5 Results

Risks were evaluated for sampling locations WP-1/DP-1, DP-2, DP-3, DP-4, WP-4, and WP-5. The following sections describe each of the sample locations evaluated and include a brief site description and an evaluation of potential ecological risk.

6.2.5.1 Waste Pit No. 1/Discharge Point No. 1

Waste Pit No. 1/Discharge Point No. 1 is reported to have received an uncharacterized yellow oily substance from a large corrugated iron pipe located south of Building 103. This site also contains an erosion gully where solvents, and potentially mercury, were reportedly disposed. Four soil samples were collected at this location—two from surface soil (1 to 1.5 feet in depth) (soil boring No. 23A and test pit No. 2) and two from subsurface soil (5-foot depth) (test pit No. 2 and test pit No. 2A).

Soil Boring No. 23A

A surface soil sample from soil boring No. 23A was collected at a depth of 1.5 feet. Lead, mercury, molybdenum, and zinc were identified as COPCs for this sample location and were quantitatively evaluated for the deer mouse and American kestrel based on the methodology presented in Section 6.2.4.

Lead had an HQ of approximately 8,000 for the deer mouse and 50 for the American kestrel (Tables 6-101 and 6-102, respectively). These HQs are considered elevated and may pose risk to potential receptors at this location. However, because lead is ubiquitous in the environment and is a characteristic trace constituent in rocks, soils, water, plants, animals, and air, a meaningful comparison can be made to on-site background levels and regional naturally occurring levels. Although the on-site lead concentration of 71.6 mg/kg is greater than the site background concentration of 6.2 mg/kg, it falls within the reported ranges of naturally occurring lead in California (12 to 97 mg/kg) and in the western United States (less than 10 to 700 mg/kg) (see Table 6-103). Therefore, the lead concentration at this location is well within concentrations expected in this area.

Eisler (1988) reports that the effects of lead are substantially modified by numerous physical, chemical, and biological variables. For example, organolead compounds are generally more toxic than inorganic lead compounds. The lead TRVs recommended by EPA Region IX (0.0015 and 0.014 mg/kg-day for mammals and birds, respectively) are based on lead acetate, an organolead compound. Although the form of lead on-site is unknown, the most common form of lead in nature is the inorganic ion Pb^{2+} . Site conditions are not likely to support the existence of organolead compounds because of the low organic content of the soils. Therefore, the TRV used in this assessment likely overestimates the toxicity of the lead in on-site soils. Substituting the mammalian TRV developed by Sample and others (1996) (8 mg/kg-day) into the HQ equation results in an HQ of 1.5, approximately four orders of magnitude less than when the EPA Region IX TRV is used. The TRV developed by Sample and others (1996) is also based on the toxicity of lead acetate. When the avian TRV developed by Sample and others (1996) based on the toxicity of metallic lead (3.85 mg/kg-day) is used to estimate the HQ for the American kestrel, the result is an HQ of 0.18.

The highest lead HQ was for the deer mouse. Another source of overestimation for this HQ, in addition to the sources discussed above, is the assumption that the dietary consumption of lead by the deer mouse is equal to the lead concentration in soil. In nature, approximately 61.5 percent of the diet of the deer mouse is composed of plants and seeds (EPA, 1993b). Because the lead uptake by terrestrial plants is limited by the low bioavailability of lead from soils (Eisler, 1988), the amount of lead being contributed to the overall diet of deer mouse because of plant and seed ingestion is expected to be much smaller than the concentration in soil.

Eisler (1988) reports that ingestion of spent lead shot by migratory waterfowl and other birds is a significant cause of mortality in these species, and also in raptors that eat waterfowl killed or wounded by hunters. Forms of lead other than shot are unlikely to cause clinical signs of lead poisoning in birds except for certain alkyllead compounds that bioconcentrate in aquatic food items (Eisler, 1988). Neither of these factors are concerns at the JPL site. In addition, the food chain biomagnification of lead is negligible. Therefore, because the diet of the American kestrel was modeled based on a diet composed almost entirely of deer mice, as lead ingestion by the deer mouse becomes more representative of actual conditions in nature so will estimates of lead ingestion by the American kestrel. In addition, because the American kestrel has a large home range, it would potentially obtain only a small fraction of its diet from this location.

Mercury had an HQ less than 1.0 for both the deer mouse and the American kestrel (Tables 6-101 and 6-102, respectively). Therefore, no risk to potential receptors is expected from mercury exposure at this location.

Molybdenum and zinc had HQs between 1.0 and 10 for the deer mouse (Table 6-101). Chemicals with HQs within this range are not expected to pose risk to potential receptors due to the conservatism of the exposure parameters used in this ERA. For example, the ERA assumes that the dietary COPC concentration for the deer mouse is equal to the maximum COPC concentration in soil. In reality, the dietary concentration would be much less. In addition, it assumes all exposure and diet are from that location. Molybdenum and zinc had HQs of less than 1.0 for the American kestrel (Table 6-102). Therefore, no risk to potential receptors is expected due to molybdenum or zinc exposure at this location.

Test Pit Nos. 2 and 2A

Soil samples from test pit Nos. 2 and 2A were collected at a depth of 1 foot and 5 feet. Chromium, lead, mercury, vanadium, and zinc were identified as surface soil COPCs for this site. Chromium, mercury, and zinc were identified as subsurface COPCs for this site. These COPCs were quantitatively evaluated for the deer mouse and American kestrel based on the methodology presented in Section 6.2.4.

In surface soil, mercury and vanadium had HQs less than 1.0 for the deer mouse (Table 6-101). Chromium and zinc had HQs between 1.0 and 10 for the deer mouse. Chemicals with HQs within this range are not expected to pose risk to potential receptors due to the conservatism of the exposure parameters used in this ERA. For example, the ERA assumes that the dietary COPC concentration for the deer mouse is equal to the maximum COPC concentration in soil. In reality, the dietary concentration would be much less. In addition, it assumes all exposure and diet are from that location. Chromium, mercury, vanadium, and zinc all had HQs less than 1.0 for the American kestrel (Table 6-102). Therefore, no risk to potential receptors is expected from exposure to these COPCs at this location.

Lead in surface soil had HQs of approximately 8,100 for the deer mouse and 51 for the American kestrel, respectively. These HQs are considered elevated and may pose risk to potential receptors at this location. However, because lead is ubiquitous in the environment and is a characteristic trace constituent in rocks, soils, water, plants, animals, and air, a meaningful comparison can be made to on-site background levels and regional naturally occurring levels. Although the on-site lead concentration of 72.1 mg/kg is greater than the site background concentration of 6.2 mg/kg, it falls within the reported ranges of naturally occurring lead in California (12 to 97 mg/kg) and in the western United States (less than 10 to 700 mg/kg) (see Table 6-103). Therefore, the lead concentration at this location is well within concentrations expected in this area.

Eisler (1988) reports that the effects of lead are substantially modified by numerous physical, chemical, and biological variables. For example, organolead compounds are generally more toxic than inorganic lead compounds. The lead TRVs recommended by EPA Region IX (0.0015 and 0.014 mg/kg-day for mammals and birds, respectively) are based on lead acetate, an organolead compound. Although the form of lead on-site is unknown, the most common form of lead in nature is the inorganic ion Pb^{2+} . Site conditions are not likely to support the existence of organolead compounds because of the low organic content of the soils. Therefore, the TRV used in this assessment likely overestimates the toxicity of the lead in on-site soils. Substituting the mammalian TRV developed by Sample and others (1996) (8 mg/kg-day) into the HQ equation results in an HQ of 1.5, approximately four orders of magnitude less than when the EPA Region IX TRV is used. The TRV developed by Sample and others (1996) is also based on the toxicity of lead acetate. When the avian TRV developed by Sample and others (1996) based on the toxicity of metallic lead (3.85 mg/kg-day) is used to estimate the HQ for the American kestrel, the result is an HQ of 0.18.

The highest lead HQ was for the deer mouse. Another source of overestimation for this HQ, in addition to the sources discussed above, is the assumption that the dietary consumption of lead by the deer mouse is equal to the lead concentration in soil. In nature, approximately 61.5 percent of the diet of the deer mouse is composed of plants and seeds (EPA, 1993b). Because the lead uptake by terrestrial plants is limited by the low bioavailability of lead from soils (Eisler, 1988), the amount of lead being contributed to the overall diet of deer mouse because of plant and seed ingestion is expected to be much smaller than the concentration in soil.

Eisler (1988) reports that ingestion of spent lead shot by migratory waterfowl and other birds is a significant cause of mortality in these species, and also in raptors that eat waterfowl killed or wounded by hunters. Forms of lead other than shot are unlikely to cause clinical signs of lead poisoning in birds except for certain alkyllead compounds that bioconcentrate in aquatic food items (Eisler, 1988). Neither of these factors are concerns at the JPL site. In addition, the food chain biomagnification of lead is negligible. Therefore, because the diet of the American kestrel was modeled based on a diet composed almost entirely of deer mice, as lead ingestion by the deer mouse becomes more representative of actual conditions in nature so will estimates of lead ingestion by the American kestrel. In addition, because the American kestrel has a large home range, it would potentially obtain only a small fraction of its diet from this location.

In subsurface soils, mercury had an HQ less than 1.0 for the deer mouse and all COPCs had HQs less than 1.0 for the American kestrel (Tables 6-104 and 6-105, respectively). Mercury and zinc had HQs between 1.0 and 10 for the deer mouse. Chemicals with HQs within this range are not expected to pose risk to potential receptors due to the conservatism of the exposure parameters used in this ERA as described above. Therefore, no risk to potential receptors is expected from exposure to these COPCs at this location.

6.2.5.2 Discharge Point No. 2

Subsurface soil was sampled at DP-2 in soil boring No. 29 at a depth of 4 feet. DP-2 is located where a main north-south drainage through JPL enters the Arroyo Seco near the southern extremities of the facility. The drainage channel is blackened with a deposit of dark, odorless, pigment-like material. It was reported that considerable flow occurred at this location when combustion chambers were washed down.

Mercury and zinc were identified as COPCs for this sample location and were quantitatively evaluated for the deer mouse and American kestrel based on the methodology presented in Section 6.2.4. Both of these COPCs had HQs less than 1.0 for the deer mouse and the American kestrel (Tables 6-104 and 6-105, respectively). Therefore, no risk to potential ecological receptors is anticipated at this location.

6.2.5.3 Discharge Point No. 3

Subsurface soil was sampled in test pit Nos. 3 and 3A at DP-3 at depths of 2 feet and 5 feet. A yellow-colored waste is known to have been discharged in this area into the Arroyo Seco from a JPL storm drain. The discharges originated as bleedoff, containing sodium chromate, from cooling tower No. 118 and emptied into the Arroyo Seco from the storm-drain outfall south of the Southern California Edison substation.

Chromium, mercury, vanadium, and zinc were identified as COPCs for this sample location and were quantitatively evaluated for the deer mouse and American kestrel based on the methodology presented in Section 6.2.4. All of these COPCs had HQs less than 1.0 for the deer mouse and the American kestrel (Tables 6-104 and 6-105, respectively). Therefore, no risk to potential ecological receptors is anticipated at this location.

6.2.5.4 Discharge Point No. 4

Subsurface soil was sampled at depths of 2.2 feet and 5 feet in test pit Nos. 1 and 1A at the location of DP-4. Discharge to this location is reportedly from a drain that originates north of Building 103, passes under Building 103, and discharges at the Arroyo Seco bank. The reported discharge consisted of a black, coal-tar-like substance with a strong objectionable odor that resembled petroleum derivatives. The discharge was in a small sump area and was reportedly not of sufficient quantity to reach the streambed.

Mercury, vanadium, and zinc were identified as COPCs for this sample location and were quantitatively evaluated for the deer mouse and American kestrel based on the methodology presented in Section 6.2.4. All of these COPCs had HQs less than 1.0 for the deer mouse and the American kestrel (Tables 6-104 and 6-105, respectively). Therefore, no risk to potential ecological receptors is anticipated at this location.

6.2.5.5 Waste Pit No.4

Subsurface soil was sampled at the location of WP-4 in soil boring No. 30 at a depth of 5 feet. WP-4 is located where EPA identified a trench from an aerial photograph. EPA suggested that this trench, located in the southeast portion of the site adjacent to the Arroyo Seco, may indicate past waste disposal activities. Because the trench was outside of the JPL boundary at the time the aerial photograph was taken and was not part of JPL's operation, historical information on its use and contents is not available. WP-4 is now covered by an asphalt paved parking lot and a 10-foot-wide, maintained gravel equestrian trail that parallels the edge of the parking lot. Therefore, this area is unavailable as habitat for potential environmental receptors.

Analytical results from WP-4 showed no analytes detected at concentrations greater than both PRGs and background concentrations (see Table 6-97). Therefore, risk to potential environmental receptors is negligible in this area.

6.2.5.6 Waste Pit No. 5

Subsurface soil was sampled at a depth of 5 feet in soil boring No. 31 at the WP-5 location. WP-5 is where EPA identified a trench from an aerial photograph. EPA suggested that this trench, located in the southeast portion of the site adjacent to the Arroyo Seco, may represent past waste disposal activities. Because the trench was outside of the JPL boundary at the time the aerial photograph was taken and was not part of JPL's operation, historical information on its use and contents is not available. The location of WP-5 is now covered by an asphalt paved parking lot. Therefore, this area is unavailable as habitat for potential environmental receptors.

Mercury was identified as a subsurface COPC for this sample location. This COPC was quantitatively evaluated for the deer mouse and American kestrel based on the methodology presented in Section 6.2.4. Mercury had HQs less than 1.0 for the deer mouse and the American kestrel (Tables 6-104 and 6-105, respectively). Therefore, no risk to potential ecological receptors is anticipated at this location.

6.2.6 Uncertainty

In considering the results of the screening-level ERA it is important to emphasize that there are uncertainties associated with the characterization of potential risk to terrestrial organisms associated with the JPL site. These include uncertainties in exposure point concentrations, exposure assumptions, the toxicity literature values used, food chain transfer factors, and the relative availability and chemical form of the potential contamination at the site. In light of these

uncertainties, this screening-level assessment uses conservative assumptions that are likely to overestimate potential risk rather than underestimate potential risk.

The modeling of soil exposure using the maximum detected concentration as representative of all dietary exposures is a very conservative approach, which usually overestimates risk. The use of the maximum detected chemical concentration is conservative, particularly for free-roaming animals that are more likely to encounter different areas of the site that possess no chemical concentrations in the soil. Such free-roaming animals, especially birds, are not likely to forage only at the site, and, therefore, will spend some of their feeding time at areas not affected by the contamination at the site.

There are also uncertainties associated with the PRGs used in this ERA. Efroymsen and others (1997) acknowledge the following limitations of their PRGs:

- For many chemicals, only one or two organisms have been studied.
- A limited number of studies have been completed and/or biological endpoints identified of almost all contaminants.
- The contaminant uptake models used in developing the PRGs do not account for soil and biota properties.

Several sources of uncertainty are present in the ERA, which were addressed by the conservative approach used to estimate risk. The conservative treatment will tend to overestimate risk for potential environmental receptors.

6.2.7 Summary

This screening-level ERA was conducted using conservative criteria for potential ecological receptors. The approach is conservative because it employs conservative assumptions for each step of the process including the PRG values and using the maximum soil concentration to represent dietary intake.

Because no TRVs exist for acetone, bromodichloromethane, chloroform, methylene chloride, nitrate, strontium, or tributyltin, they were eliminated as COPCs and qualitatively evaluated relative to regional background levels and available toxicity information. On-site concentrations of strontium were found to be within published regional background levels. Acetone, bromodichloromethane, chloroform, methylene chloride, nitrate, and tributyltin were detected on site at concentrations well below levels for which toxic effects have been reported. No risk due to exposure to these chemicals is expected at JPL.

Chemicals identified as COPCs for this screening-level ERA include chromium, lead, mercury, molybdenum, vanadium, and zinc. All COPCs were quantitatively evaluated for the deer mouse and American kestrel. Lead concentrations at WP-1/DP-1 had HQs exceeding 10 for both the deer mouse and the American kestrel. Uncertainties regarding the form of lead at the site versus the form used to derive the TRV and the conservatism of exposure parameters likely

overestimate the risk at this location. Animals with large home ranges, such as the American kestrel, are not likely to be at risk since they would potentially obtain only a small fraction of their diet from this location. Although the HQs are elevated at this location, it is important to note that lead concentrations are within the range of background values for Californian and the western U.S. soils. Thus, potential ecological risks are likely to be lower than indicated by the estimated HQ values.

All other COPC concentrations had HQs either less than 1.0 or between 1.0 and 10 for both the deer mouse and the American kestrel. Therefore, no risk from exposure to the evaluated COPCs is expected at JPL.

TABLE 6-1
SELECTION OF EXPOSURE PATHWAYS
Jet Propulsion Laboratory -- Operable Unit-2

Scenario Timeframe	Medium	Exposure Medium	Exposure Point	Receptor Population	Receptor Age	Exposure Route	On-Site/ Off-Site	Type of Analysis	Rationale for Selection or Exclusion of Exposure Pathway
Current	Soil	Soil	Sitewide	Resident	Child/Adult	Ingestion	Off-Site	None	Future on-site resident considered to be a more conservative pathway.
						Dermal	Off-Site	None	Future on-site resident considered to be a more conservative pathway.
						Inhalation	Off-Site	None	Future on-site resident considered to be a more conservative pathway.
			Sitewide	Resident	Child/Adult	Ingestion	On-Site	None	Not currently developed for residential use.
						Dermal	On-Site	None	Not currently developed for residential use.
						Inhalation	On-Site	None	Not currently developed for residential use.
			Discharge Point 2	Construction Worker	Adult	Ingestion	On-Site	Quant	Construction worker potential receptor during on-site activities.
						Dermal	On-Site	Quant	Construction worker potential receptor during on-site activities.
						Inhalation	On-Site	Quant	Construction worker potential receptor during on-site activities.
				Commercial Worker	Adult	Ingestion	On-Site	Quant	Commercial Worker potential receptor during on-site activities.
						Dermal	On-Site	Quant	Commercial Worker potential receptor during on-site activities.
						Inhalation	On-Site	Quant	Commercial Worker potential receptor during on-site activities.
			Discharge Point 3	Construction Worker	Adult	Ingestion	On-Site	Quant	Construction worker potential receptor during on-site activities.
						Dermal	On-Site	Quant	Construction worker potential receptor during on-site activities.
						Inhalation	On-Site	Quant	Construction worker potential receptor during on-site activities.
				Commercial Worker	Adult	Ingestion	On-Site	Quant	Commercial Worker potential receptor during on-site activities.
						Dermal	On-Site	Quant	Commercial Worker potential receptor during on-site activities.
						Inhalation	On-Site	Quant	Commercial Worker potential receptor during on-site activities.
			Waste Pit 1/ Discharge Point 1	Construction Worker	Adult	Ingestion	On-Site	Quant	Construction worker potential receptor during on-site activities.
						Dermal	On-Site	Quant	Construction worker potential receptor during on-site activities.
						Inhalation	On-Site	Quant	Construction worker potential receptor during on-site activities.
Commercial Worker	Adult	Ingestion		On-Site	Quant	Commercial Worker potential receptor during on-site activities.			
		Dermal		On-Site	Quant	Commercial Worker potential receptor during on-site activities.			
		Inhalation		On-Site	Quant	Commercial Worker potential receptor during on-site activities.			
Waste Pit 4	Construction Worker	Adult	Ingestion	On-Site	Quant	Construction worker potential receptor during on-site activities.			
			Dermal	On-Site	Quant	Construction worker potential receptor during on-site activities.			
			Inhalation	On-Site	Quant	Construction worker potential receptor during on-site activities.			
	Commercial Worker	Adult	Ingestion	On-Site	Quant	Commercial Worker potential receptor during on-site activities.			
			Dermal	On-Site	Quant	Commercial Worker potential receptor during on-site activities.			
			Inhalation	On-Site	Quant	Commercial Worker potential receptor during on-site activities.			

TABLE 6-1
SELECTION OF EXPOSURE PATHWAYS
Jet Propulsion Laboratory -- Operable Unit-2

Scenario Timeframe	Medium	Exposure Medium	Exposure Point	Receptor Population	Receptor Age	Exposure Route	On-Site/ Off-Site	Type of Analysis	Rationale for Selection or Exclusion of Exposure Pathway
Future	Soil	Soil	Sitewide	Resident	Child/Adult	Ingestion	On-Site	Quant	Residential development not excluded by permit.
						Dermal	On-Site	Quant	Residential development not excluded by permit.
						Inhalation	On-Site	Quant	Residential development not excluded by permit.
			Discharge Point 2	Resident	Child/Adult	Ingestion	On-Site	Quant	Residential development not excluded by permit.
						Dermal	On-Site	Quant	Residential development not excluded by permit.
						Inhalation	On-Site	Quant	Residential development not excluded by permit.
				Construction Worker	Adult	Ingestion	On-Site	None	Current on-site construction worker considered to be a more conservative pathway.
						Dermal	On-Site	None	Current on-site construction worker considered to be a more conservative pathway.
						Inhalation	On-Site	None	Current on-site construction worker considered to be a more conservative pathway.
				Commercial Worker	Adult	Ingestion	On-Site	None	Current on-site Commercial Worker considered to be a more conservative pathway.
						Dermal	On-Site	None	Current on-site Commercial Worker considered to be a more conservative pathway.
						Inhalation	On-Site	None	Current on-site Commercial Worker considered to be a more conservative pathway.
			Discharge Point 3	Resident	Child/Adult	Ingestion	On-Site	Quant	Residential development not excluded by permit.
						Dermal	On-Site	Quant	Residential development not excluded by permit.
						Inhalation	On-Site	Quant	Residential development not excluded by permit.
				Construction Worker	Adult	Ingestion	On-Site	None	Current on-site construction worker considered to be a more conservative pathway.
						Dermal	On-Site	None	Current on-site construction worker considered to be a more conservative pathway.
						Inhalation	On-Site	None	Current on-site construction worker considered to be a more conservative pathway.
				Commercial Worker	Adult	Ingestion	On-Site	None	Current on-site Commercial Worker considered to be a more conservative pathway.
						Dermal	On-Site	None	Current on-site Commercial Worker considered to be a more conservative pathway.
						Inhalation	On-Site	None	Current on-site Commercial Worker considered to be a more conservative pathway.
			Waste Pit 1/ Discharge Point 1	Resident	Child/Adult	Ingestion	On-Site	Quant	Residential development not excluded by permit.
						Dermal	On-Site	Quant	Residential development not excluded by permit.
						Inhalation	On-Site	Quant	Residential development not excluded by permit.

TABLE 6-1
SELECTION OF EXPOSURE PATHWAYS
Jet Propulsion Laboratory -- Operable Unit-2

Scenario Timeframe	Medium	Exposure Medium	Exposure Point	Receptor Population	Receptor Age	Exposure Route	On-Site/ Off-Site	Type of Analysis	Rationale for Selection or Exclusion of Exposure Pathway
				Construction Worker	Adult	Ingestion	On-Site	None	Current on-site construction worker considered to be a more conservative pathway.
						Dermal	On-Site	None	Current on-site construction worker considered to be a more conservative pathway.
						Inhalation	On-Site	None	Current on-site construction worker considered to be a more conservative pathway.
				Commercial Worker	Adult	Ingestion	On-Site	None	Current on-site Commercial Worker considered to be a more conservative pathway.
						Dermal	On-Site	None	Current on-site Commercial Worker considered to be a more conservative pathway.
						Inhalation	On-Site	None	Current on-site Commercial Worker considered to be a more conservative pathway.
			Waste Pit 4	Resident	Child/Adult	Ingestion	On-Site	Quant	Residential development not excluded by permit.
						Dermal	On-Site	Quant	Residential development not excluded by permit.
						Inhalation	On-Site	Quant	Residential development not excluded by permit.
				Construction Worker	Adult	Ingestion	On-Site	None	Current on-site construction worker considered to be a more conservative pathway.
						Dermal	On-Site	None	Current on-site construction worker considered to be a more conservative pathway.
						Inhalation	On-Site	None	Current on-site construction worker considered to be a more conservative pathway.
Commercial Worker	Adult	Ingestion	On-Site	None	Current on-site Commercial Worker considered to be a more conservative pathway.				
		Dermal	On-Site	None	Current on-site Commercial Worker considered to be a more conservative pathway.				
		Inhalation	On-Site	None	Current on-site Commercial Worker considered to be a more conservative pathway.				

Definitions: Quant = Quantitative

TABLE 6-2
 OCCURRENCE, DISTRIBUTION AND SELECTION OF CHEMICALS OF POTENTIAL CONCERN
 Jet Propulsion Laboratory – Operable Unit-2

Scenario Timeframe: Current
 Medium: Soil
 Exposure Medium: Soil
 Exposure Point: Sitewide

CAS Number	Chemical	Minimum Concentration ⁽¹⁾	Minimum Qualifier	Maximum Concentration ⁽¹⁾	Maximum Qualifier	Units	Location of Maximum Concentration	Detection Frequency	Range of Detection Limits	Concentration Used for Screening ⁽²⁾	Background Value ⁽³⁾	Screening Toxicity Value ⁽⁴⁾	Potential ARAR/TBC Value	Potential ARAR/TBC Source	COPC Flag	Rationale for Contaminant Deletion or Selection ⁽⁵⁾
67-64-1	Acetone	0.0054	J,B	0.0063	J	mg/kg	Test Pit #1A	3/12	N/P	0.0063	N/A	1300	N/A	N/A	No	BSL
7440-36-0	Antimony	0.7		3.2	J	mg/kg	Test Pit #2A	6/31	N/P	3.2	1.5	28	N/A	N/A	No	BSL
11141-16-5	Arochlor-1232 (6)	0.033	J	0.033	J	mg/kg	Test Pit #2A	1/22	N/P	0.033	N/A	0.11	N/A	N/A	No	BSL
11097-69-1	Arochlor-1254 (6)	0.018		0.20		mg/kg	Test Pit #2	2/16	N/P	0.2	N/A	0.11	N/A	N/A	Yes	ASL
11096-82-5	Arochlor-1260 (6)	0.021		0.27		mg/kg	Test Pit #2	2/16	N/P	0.27	N/A	0.11	N/A	N/A	Yes	ASL
7440-38-2	Arsenic	1.1		5.6		mg/kg	B-30	31/31	N/P	5.6	2.8	0.31	N/A	N/A	Yes	ASL
7440-39-3	Barium	21.3		199		mg/kg	B-4	31/31	N/P	199	180	4900	N/A	N/A	No	BSL
56-55-3	Benzo(a)anthracene	0.0036		0.0077	J	mg/kg	B-30	21/49	N/P	0.0077	N/A	0.19	N/A	N/A	No	BSL
50-32-8	Benzo(a)pyrene	0.0042		0.0058		mg/kg	B-30	2/49	N/P	0.0058	N/A	0.019	N/A	N/A	No	BSL
205-99-2	Benzo(b)fluoranthene	0.0063		0.0088		mg/kg	Test Pit #2A	3/49	N/P	0.0064	N/A	0.19	N/A	N/A	No	BSL
191-24-2	Benzo(g,h,i)perylene	0.011		0.048		mg/kg	Test Pit #2	3/49	N/P	0.048	N/A	N/A	N/A	N/A	No	NTX
7440-41-7	Beryllium	0.25		0.85		mg/kg	B-18	15/31	N/P	0.85	0.58	140	N/A	N/A	No	BSL
117-81-7	Bis(2-ethylhexyl)phthalate	0.15		0.48		mg/kg	Test Pit #2A	4/33	N/P	0.48	N/A	35	N/A	N/A	No	BSL
75-27-4	Bromodichloromethane	0.0028	J	0.0032	J	mg/kg	Test Pit #2A	3/12	N/P	0.0032	N/A	0.17	N/A	N/A	No	BSL
85-68-7	Butylbenzyl phthalate (7)	0.075	J	0.16		mg/kg	Test Pit #2	2/33	N/P	0.16	N/A	930	N/A	N/A	No	BSL
7440-43-9	Cadmium (8)	0.8	J	3.4	J	mg/kg	Test Pit #2A	3/31	N/P	3.4	N/A	9	N/A	N/A	No	BSL
56-23-5	Carbon tetrachloride	0.00197		0.00238		mg/kg	B-38	2/8	N/P	0.00238	N/A	0.055	N/A	N/A	No	BSL
67-66-3	Chloroform	0.0045	J	0.0052	J	mg/kg	Test Pit #2A	3/12	N/P	0.0052	N/A	0.24	N/A	N/A	No	BSL
7440-47-3	Chromium (9)	3.7		33.9		mg/kg	Test Pit #2A	31/31	N/P	33.9	12.4	570	N/A	N/A	No	BSL
7440-47-3	Chromium (VI) (8)	0.011		0.84		mg/kg	Test Pit #2A	9/41	N/P	0.84	N/A	0.20	N/A	N/A	Yes	ASL
218-01-9	Chrysene	0.018	J	0.018	J	mg/kg	Test Pit #2A	1/49	N/P	0.018	N/A	0.019	N/A	N/A	No	BSL
7440-48-4	Cobalt	3.2		10.3		mg/kg	Test Pit #3	27/31	N/P	10.3	8.2	3100	N/A	N/A	No	BSL
7440-50-8	Copper	5.6		22.7		mg/kg	B-23A	31/31	N/P	22.7	11.5	2600	N/A	N/A	No	BSL
57-12-5	Cyanide (10)	0.085		0.085		mg/kg	B-30	1/32	N/P	0.085	N/A	1400	N/A	N/A	No	BSL
84-74-2	Di-n-butylphthalate	0.25		0.25		mg/kg	Test Pit #2	1/33	N/P	0.25	N/A	3900	N/A	N/A	No	BSL
206-44-0	Fluoranthene	0.024		0.11		mg/kg	B-12	3/49	N/P	0.11	N/A	1300	N/A	N/A	No	BSL
193-39-5	Indeno(1,2,3-cd)pyrene	0.067		0.067		mg/kg	Test Pit #2	1/49	N/P	0.067	N/A	0.19	N/A	N/A	No	BSL
7439-92-1	Lead (8)	1.5		72.1		mg/kg	Test Pit #2	31/31	N/P	72.1	5.2	130	N/A	N/A	No	BSL
7487-94-7	Mercury	0.06		0.3		mg/kg	Test Pit #1	29/31	N/P	0.3	0.09	21	N/A	N/A	No	BSL
75-09-2	Methylene chloride	0.003	J,B	0.005	J,B	mg/kg	Test Pit #2	6/12	N/P	0.005	N/A	6.0	N/A	N/A	No	BSL
7439-98-7	Molybdenum	0.29		2.5		mg/kg	B-23A	2/31	N/P	2.5	N/A	360	N/A	N/A	No	BSL
7440-02-0	Nickel (8)	2.7		12.0		mg/kg	Test Pit #2	25/31	N/P	12.0	6.9	150	N/A	N/A	No	BSL

TABLE 6-2
 OCCURRENCE, DISTRIBUTION AND SELECTION OF CHEMICALS OF POTENTIAL CONCERN
 Jet Propulsion Laboratory – Operable Unit-2

Scenario Timeframe: Current
 Medium: Soil
 Exposure Medium: Soil
 Exposure Point: Sitewide

CAS Number	Chemical	Minimum Concentration ⁽¹⁾	Minimum Qualifier	Maximum Concentration ⁽¹⁾	Maximum Qualifier	Units	Location of Maximum Concentration	Detection Frequency	Range of Detection Limits	Concentration Used for Screening ⁽²⁾	Background Value ⁽³⁾	Screening Toxicity Value ⁽⁴⁾	Potential ARAR/TBC Value	Potential ARAR/TBC Source	COPC Flag	Rationale for Contaminant Deletion or Selection ⁽⁵⁾
3268-87-9	1,2,3,4,6,7,8,9-OCDD (11)	0.0092		0.0092		mg/kg	Test Pit #2	2/22	N/P	0.0092	N/A	0.036	N/A	N/A	No	BSL
85-01-8	Phenanthrene	0.022		0.022		mg/kg	Test Pit #2	2/49	N/P	0.022	N/A	N/A	N/A	N/A	No	NTX
129-00-0	Pyrene	0.055		0.1		mg/kg	B-12	2/49	N/P	0.1	N/A	940	N/A	N/A	No	BSL
7440-22-4	Silver	0.42		0.42		mg/kg	B-4	1/31	N/P	0.42	N/A	360	N/A	N/A	No	BSL
7440-24-6	Strontium	5.2		108		mg/kg	Test Pit #2A	31/31	N/P	108	29.8	43000	N/A	N/A	No	BSL
7446-18-6	Thallium (12)	0.15		0.86	J	mg/kg	Test Pit #2A	7/31	N/P	0.86	5.2	5.0	N/A	N/A	No	BKG, BSL
688-73-3	Tributyltin	0.001		0.001	J	mg/kg	Test Pit #2A	2/36	N/P	0.001	N/A	16	N/A	N/A	No	BSL
76-13-1	Trichlorotrifluoroethane (7)	8.19E-06		8.19E-06		mg/kg	B-38	1/8	N/P	0.0000819	N/A	5600	N/A	N/A	No	BSL
7440-62-2	Vanadium	14.2		67.6		mg/kg	Test Pit #2A	31/31	N/P	67.6	50.5	500	N/A	N/A	No	BSL
7440-66-6	Zinc	21.8		279		mg/kg	Test Pit #2A	31/31	N/P	279	54.1	21000	N/A	N/A	No	BSL

- (1) Minimum/maximum detected concentration
- (2) Maximum concentration used as screening value
- (3) Refer to Section 6.3.14 for a discussion of the comparison to background
- (4) Screening toxicity value derived in accordance with State of California Department of Toxic Substances Control Preliminary Endangerment Assessment Guidance Manual (DTSC 1994) and USEPA Risk Assessment Guidance for Superfund (USEPA 1989). See Appendix I for methodology.
- (5) Rationale Codes Selection Reason: Above Screening Levels (ASL)
 Background Levels (BKG)
 Deletion Reason: No Toxicity Information (NTX)
 Below Screening Level (BSL)
- (6) Screening toxicity value based on cancer potency of polychlorinated biphenyls
- (7) USEPA Region IX Preliminary Remediation Goal used for screening toxicity value based on derivation of soil saturation limit (USEPA 1998b)
- (8) USEPA 1998b
- (9) Screening toxicity value based on the cancer potency of total chromium (1/6 ratio Cr VI/Cr III)
- (10) Toxicity screening value based on toxicity of free cyanide
- (11) Toxicity screening value based on toxicity of tetrachlorodibenzo-p-dioxin
- (12) Toxicity screening value based on toxicity of thallium oxide

Definitions:

8.1E-6 = 8.1×10^{-6} or 0.0000081

ARAR/TBC = Applicable or Relevant and Appropriate Requirement/To Be Considered

CAS = Chemical Abstract Service

COPC = Chemical of Potential Concern

mg/kg = milligrams per kilogram

N/A = Not applicable

N/P = Not provided by the laboratory performing the analyses

OCDD = octachlorodibenzo-p-dioxin

J = Estimated result; value is lower than reporting limit

B = Compound detected in method blank

TABLE 6-3
 OCCURRENCE, DISTRIBUTION AND SELECTION OF CHEMICALS OF POTENTIAL CONCERN
 Jet Propulsion Laboratory – Operable Unit-2

Scenario Timeframe: Future
 Medium: Soil
 Exposure Medium: Soil
 Exposure Point: Sitewide

CAS Number	Chemical	Minimum Concentration ⁽¹⁾	Minimum Qualifier	Maximum Concentration ⁽¹⁾	Maximum Qualifier	Units	Location of Maximum Concentration	Detection Frequency	Range of Detection Limits	Concentration Used for Screening ⁽²⁾	Background Value ⁽³⁾	Screening Toxicity Value ⁽⁴⁾	Potential ARAR/TBC Value	Potential ARAR/TBC Source	COPC Flag	Rationale for Contaminant Deletion or Selection ⁽⁵⁾
67-54-1	Acetone	0.0054	J,B	0.0063	J	mg/kg	Test Pit #1A	3/12	N/P	0.0063	N/A	1300	N/A	N/A	No	BSL
7440-36-0	Antimony	0.7		3.2	J	mg/kg	Test Pit #2A	6/31	N/P	3.2	1.5	28	N/A	N/A	No	BSL
11141-16-5	Arochlor-1232 (6)	0.033	J	0.033	J	mg/kg	Test Pit #2A	1/22	N/P	0.033	N/A	0.11	N/A	N/A	No	BSL
11097-69-1	Arochlor-1254 (6)	0.018		0.20		mg/kg	Test Pit #2	2/16	N/P	0.2	N/A	0.11	N/A	N/A	Yes	ASL
11096-82-5	Arochlor-1260 (6)	0.021		0.27		mg/kg	Test Pit #2	2/16	N/P	0.27	N/A	0.11	N/A	N/A	Yes	ASL
7440-38-2	Arsenic	1.1		5.6		mg/kg	B-30	31/31	N/P	5.6	2.8	0.31	N/A	N/A	Yes	ASL
7440-39-3	Barium	21.3		199		mg/kg	B-4	31/31	N/P	199	180	4900	N/A	N/A	No	BSL
56-55-3	Benzo(a)anthracene	0.0036		0.0077	J	mg/kg	B-30	21/49	N/P	0.0077	N/A	0.19	N/A	N/A	No	BSL
50-32-8	Benzo(a)pyrene	0.0042		0.0058		mg/kg	B-30	2/49	N/P	0.0058	N/A	0.019	N/A	N/A	No	BSL
205-99-2	Benzo(b)fluoranthene	0.0063		0.0088		mg/kg	Test Pit #2A	3/49	N/P	0.0064	N/A	0.19	N/A	N/A	No	BSL
191-24-2	Benzo(g,h,i)perylene	0.011		0.048		mg/kg	Test Pit #2	3/49	N/P	0.048	N/A	N/A	N/A	N/A	No	NTX
7440-41-7	Beryllium	0.25		0.85		mg/kg	B-18	15/31	N/P	0.85	0.58	140	N/A	N/A	No	BSL
117-81-7	Bis(2-ethylhexyl)phthalate	0.15		0.48		mg/kg	Test Pit #2A	4/33	N/P	0.48	N/A	35	N/A	N/A	No	BSL
75-27-4	Bromodichloromethane	0.0028	J	0.0032	J	mg/kg	Test Pit #2A	3/12	N/P	0.0032	N/A	0.17	N/A	N/A	No	BSL
85-68-7	Butylbenzyl phthalate (7)	0.075	J	0.16		mg/kg	Test Pit #2	2/33	N/P	0.16	N/A	930	N/A	N/A	No	BSL
7440-43-9	Cadmium (8)	0.8	J	3.4	J	mg/kg	Test Pit #2A	3/31	N/P	3.4	N/A	9	N/A	N/A	No	BSL
56-23-5	Carbon tetrachloride	0.00197		0.00238		mg/kg	B-38	2/8	N/P	0.00238	N/A	0.055	N/A	N/A	No	BSL
67-66-3	Chloroform	0.0045	J	0.0052	J	mg/kg	Test Pit #2A	3/12	N/P	0.0052	N/A	0.24	N/A	N/A	No	BSL
7440-47-3	Chromium (9)	3.7		33.9		mg/kg	Test Pit #2A	31/31	N/P	33.9	12.4	570	N/A	N/A	No	BSL
7440-47-3	Chromium (VI) (8)	0.011		0.84		mg/kg	Test Pit #2A	9/41	N/P	0.84	N/A	0.20	N/A	N/A	Yes	ASL
218-01-9	Chrysene	0.018	J	0.018	J	mg/kg	Test Pit #2A	1/49	N/P	0.018	N/A	0.019	N/A	N/A	No	BSL
7440-48-4	Cobalt	3.2		10.3		mg/kg	Test Pit #3	27/31	N/P	10.3	8.2	3100	N/A	N/A	No	BSL
7440-50-8	Copper	5.6		22.7		mg/kg	B-23A	31/31	N/P	22.7	11.5	2600	N/A	N/A	No	BSL
57-12-5	Cyanide (10)	0.085		0.085		mg/kg	B-30	1/32	N/P	0.085	N/A	1400	N/A	N/A	No	BSL
84-74-2	Di-n-butylphthalate	0.25		0.25		mg/kg	Test Pit #2	1/33	N/P	0.25	N/A	3900	N/A	N/A	No	BSL
206-44-0	Fluoranthene	0.024		0.11		mg/kg	B-12	3/49	N/P	0.11	N/A	1300	N/A	N/A	No	BSL
193-39-5	Indeno(1,2,3-cd)pyrene	0.067		0.067		mg/kg	Test Pit #2	1/49	N/P	0.067	N/A	0.19	N/A	N/A	No	BSL
7439-92-1	Lead (8)	1.5		72.1		mg/kg	Test Pit #2	31/31	N/P	72.1	5.2	130	N/A	N/A	No	BSL
7487-94-7	Mercury	0.06		0.3		mg/kg	Test Pit #1	29/31	N/P	0.3	0.09	21	N/A	N/A	No	BSL
75-09-2	Methylene chloride	0.003	J,B	0.005	J,B	mg/kg	Test Pit #2	6/12	N/P	0.005	N/A	6.0	N/A	N/A	No	BSL
7439-98-7	Molybdenum	0.29		2.5		mg/kg	B-23A	2/31	N/P	2.5	N/A	360	N/A	N/A	No	BSL
7440-02-0	Nickel (8)	2.7		12.0		mg/kg	Test Pit #2	25/31	N/P	12.0	6.9	150	N/A	N/A	No	BSL

TABLE 6-3
 OCCURRENCE, DISTRIBUTION AND SELECTION OF CHEMICALS OF POTENTIAL CONCERN
 Jet Propulsion Laboratory – Operable Unit-2

Scenario Timeframe: Future
 Medium: Soil
 Exposure Medium: Soil
 Exposure Point: Sitewide

CAS Number	Chemical	Minimum Concentration ⁽¹⁾	Minimum Qualifier	Maximum Concentration ⁽¹⁾	Maximum Qualifier	Units	Location of Maximum Concentration	Detection Frequency	Range of Detection Limits	Concentration Used for Screening ⁽²⁾	Background Value ⁽³⁾	Screening Toxicity Value ⁽⁴⁾	Potential ARAR/TBC Value	Potential ARAR/TBC Source	COPC Flag	Rationale for Contaminant Deletion or Selection ⁽⁵⁾
3268-87-9	1,2,3,4,6,7,8,9-OCDD (11)	0.0092		0.0092		mg/kg	Test Pit #2	2/22	N/P	0.0092	N/A	0.036	N/A	N/A	No	BSL
85-01-8	Phenanthrene	0.022		0.022		mg/kg	Test Pit #2	2/49	N/P	0.022	N/A	N/A	N/A	N/A	No	NTX
129-00-0	Pyrene	0.055		0.1		mg/kg	B-12	2/49	N/P	0.1	N/A	940	N/A	N/A	No	BSL
7440-22-4	Silver	0.42		0.42		mg/kg	B-4	1/31	N/P	0.42	N/A	360	N/A	N/A	No	BSL
7440-24-6	Strontium	5.2		108		mg/kg	Test Pit #2A	31/31	N/P	108	29.8	43000	N/A	N/A	No	BSL
7446-18-6	Thallium (12)	0.15		0.86	J	mg/kg	Test Pit #2A	7/31	N/P	0.86	5.2	5.0	N/A	N/A	No	BKG, BSL
688-73-3	Tributyltin	0.001		0.001	J	mg/kg	Test Pit #2A	2/36	N/P	0.001	N/A	16	N/A	N/A	No	BSL
76-13-1	Trichlorotrifluoroethane (7)	8.19E-06		8.19E-06		mg/kg	B-38	1/8	N/P	0.0000819	N/A	5600	N/A	N/A	No	BSL
7440-62-2	Vanadium	14.2		67.6	*	mg/kg	Test Pit #2A	31/31	N/P	67.6	50.5	500	N/A	N/A	No	BSL
7440-66-6	Zinc	21.8		279		mg/kg	Test Pit #2A	31/31	N/P	279	54.1	21000	N/A	N/A	No	BSL

- (1) Minimum/maximum detected concentration
- (2) Maximum concentration used as screening value
- (3) Refer to Section 6.3.14 for a discussion of the comparison to background
- (4) Screening toxicity value derived in accordance with State of California Department of Toxic Substances Control Preliminary Endangerment Assessment Guidance Manual (DTSC 1994) and USEPA Risk Assessment Guidance for Superfund (USEPA 1989). See Appendix I for methodology.
- (5) Rationale Codes Selection Reason: Above Screening Levels (ASL)
 Background Levels (BKG)
 Deletion Reason: No Toxicity Information (NTX)
 Below Screening Level (BSL)
- (6) Screening toxicity value based on cancer potency of polychlorinated biphenyls
- (7) USEPA Region IX Preliminary Remediation Goal used for screening toxicity value based on derivation of soil saturation limit (USEPA 1998b)
- (8) USEPA 1998b
- (9) Screening toxicity value based on the cancer potency of total chromium (1/8 ratio Cr VI/Cr III)
- (10) Toxicity screening value based on toxicity of free cyanide
- (11) Toxicity screening value based on toxicity of tetrachlorodibenzo-p-dioxin
- (12) Toxicity screening value based on toxicity of thallium oxide

Definitions: 8.1E-6 = 8.1 x 10⁻⁶ or 0.0000081
 ARAR/TBC = Applicable or Relevant and Appropriate Requirement/To Be Considered
 CAS = Chemical Abstract Service
 COPC = Chemical of Potential Concern
 mg/kg = milligrams per kilogram
 N/A = Not applicable
 N/P = Not provided by the laboratory performing the analyses
 OCDD = octachlorodibenzo-p-dioxin
 J = Estimated result, value is lower than reporting limit
 B = Compound detected in method blank

TABLE 6-4
 OCCURRENCE, DISTRIBUTION AND SELECTION OF CHEMICALS OF POTENTIAL CONCERN
 Jet Propulsion Laboratory – Operable Unit-2

Scenario Timeframe: Current
Medium: Soil
Exposure Medium: Soil
Exposure Point: Discharge Point 2

CAS Number	Chemical	Minimum Concentration ⁽¹⁾	Minimum Qualifier	Maximum Concentration ⁽¹⁾	Maximum Qualifier	Units	Location of Maximum Concentration	Detection Frequency	Range of Detection Limits	Concentration Used for Screening ⁽²⁾	Background Value ⁽³⁾	Screening Toxicity Value ⁽⁴⁾	Potential ARAR/TBC Value	Potential ARAR/TBC Source	COPC Flag	Rationale for Contaminant Deletion or Selection ⁽⁵⁾
7440-38-2	Arsenic	1.2		2.1		mg/kg	B-29	4/4	N/P	2.1	2.2	0.31	N/A	N/A	No	BKG
7440-47-3	Chromium (VI) (6)	0.011		0.28		mg/kg	B-29	3/4	N/P	0.28	N/A	0.20	N/A	N/A	Yes	ASL

- (1) Minimum/maximum detected concentration.
 (2) Maximum concentration used as screening value
 (3) Refer to Section 6.3.14 for a discussion of the comparison to background
 (4) Screening toxicity value derived in accordance with State of California Department of Toxic Substances Control Preliminary End Assessment Guidance Manual (DTSC 1994) and USEPA Risk Assessment Guidance for Superfund (USEPA 1989). See Appendix I for methodology
 (5) Rationale Codes Selection Reason: Above Screening Levels (ASL)
 Deletion Reason: Background Levels (BKG)
 (6) USEPA 1998b

Definitions: ARAR/TBC = Applicable or Relevant and Appropriate Requirement/To Be Considered
 CAS = Chemical Abstract Service
 COPC = Chemical of Potential Concern
 mg/kg = milligrams per kilogram
 N/A = Not applicable
 N/P = Not provided by the laboratory performing the analyses

TABLE 6-5
 OCCURRENCE, DISTRIBUTION AND SELECTION OF CHEMICALS OF POTENTIAL CONCERN
 Jet Propulsion Laboratory – Operable Unit-2

Scenario Timeframe: Future
Medium: Soil
Exposure Medium: Soil
Exposure Point: Discharge Point 2

CAS Number	Chemical	Minimum Concentration ⁽¹⁾	Minimum Qualifier	Maximum Concentration ⁽¹⁾	Maximum Qualifier	Units	Location of Maximum Concentration	Detection Frequency	Range of Detection Limits	Concentration Used for Screening ⁽²⁾	Background Value ⁽³⁾	Screening Toxicity Value ⁽⁴⁾	Potential ARAR/TBC Value	Potential ARAR/TBC Source	COPC Flag	Rationale for Contaminant Deletion or Selection ⁽⁵⁾
7440-38-2	Arsenic	1.2		2.1		mg/kg	B-29	4/4	N/P	2.1	2.2	0.31	N/A	N/A	No	BKG
7440-47-3	Chromium (VI) (6)	0.011		0.28		mg/kg	B-29	3/4	N/P	0.28	N/A	0.20	N/A	N/A	Yes	ASL

(1) Minimum/maximum detected concentration.

(2) Maximum concentration used as screening value

(3) Refer to Section 6.3.14 for a discussion of the comparison to background

(4) Screening toxicity value derived in accordance with State of California Department of Toxic Substances Control Preliminary Endang Assessment Guidance Manual (DTSC 1994) and USEPA Risk Assessment Guidance for Superfund (USEPA 1989). See Appendix I for methodology

(5) Rationale Codes Selection Reason: Above Screening Levels (ASL)

Deletion Reason: Background Levels (BKG)

(6) USEPA 1998b

Definitions:

ARAR/TBC = Applicable or Relevant and Appropriate Requirement/To Be Considered

CAS = Chemical Abstract Service

COPC = Chemical of Potential Concern

mg/kg = milligrams per kilogram

N/A = Not applicable

N/P = Not provided by the laboratory performing the analyses

TABLE 6-7
 OCCURRENCE, DISTRIBUTION AND SELECTION OF CHEMICALS OF POTENTIAL CONCERN
 Jet Propulsion Laboratory -- Operable Unit-2

Scenario Timeframe: Future
Medium: Soil
Exposure Medium: Soil
Exposure Point: Discharge Point 3

CAS Number	Chemical	Minimum Concentration ⁽¹⁾	Minimum Qualifier	Maximum Concentration ⁽¹⁾	Maximum Qualifier	Units	Location of Maximum Concentration	Detection Frequency	Range of Detection Limits	Concentration Used for Screening ⁽²⁾	Background Value ⁽³⁾	Screening Toxicity Value ⁽⁴⁾	Potential ARAR/TBC Value	Potential ARAR/TBC Source	COPC Flag	Rationale for Contaminant Deletion or Selection ⁽⁵⁾
7440-38-2	Arsenic	2.0		4.5		mg/kg	Test Pit #3	4/4	N/P	4.5	2.2	0.31	N/A	N/A	Yes	BKG
7440-47-3	Chromium (VI)	0.078		0.15		mg/kg	Test Pit #3	2/4	N/P	0.15	N/A	0.20	N/A	N/A	No	BSL

- (1) Minimum/maximum detected concentration
- (2) Maximum concentration used as screening value
- (3) Refer to Section 6.3.14 for a discussion of the comparison to background
- (4) Screening toxicity value derived in accordance with State of California Department of Toxic Substances Control Preliminary Endangerment Assessment Guidance Manual (DTSC 1994) and USEPA Risk Assessment Guidance for Superfund (USEPA 1989) See Appendix I for methodology.
- (5) Rationale Codes
 - Selection Reason: Background Levels (BKG)
 - Deletion Reason: Below Screening Levels

Definitions:

- ARAR/TBC = Applicable or Relevant and Appropriate Requirement/To Be Considered
- CAS = Chemical Abstract Service
- COPC = Chemical of Potential Concern
- mg/kg = milligrams per kilogram
- N/A = Not applicable
- N/P = Not provided by the laboratory performing the analyses

TABLE 6-8
 OCCURRENCE, DISTRIBUTION AND SELECTION OF CHEMICALS OF POTENTIAL CONCERN
 Jet Propulsion Laboratory – Operable Unit-2

Scenario Timeframe:	Current
Medium:	Soil
Exposure Medium:	Soil
Exposure Point:	Discharge Point 4

CAS Number	Chemical	Minimum Concentration ⁽¹⁾	Minimum Qualifier	Maximum Concentration ⁽¹⁾	Maximum Qualifier	Units	Location of Maximum Concentration	Detection Frequency	Range of Detection Limits	Concentration Used for Screening ⁽²⁾	Background Value ⁽³⁾	Screening Toxicity Value ⁽⁴⁾	Potential ARAR/TBC Value	Potential ARAR/TBC Source	COPC Flag	Rationale for Contaminant Deletion or Selection ⁽⁵⁾
7440-38-2	Arsenic	2.2		4.7		mg/kg	Test Pit #1A	4/4	N/P	4.7	2.2	0.31	N/A	N/A	Yes	ASL
7440-47-3	Chromium (VI) (6)	0.07		0.13		mg/kg	Test Pit #1A	2/4	N/P	0.13	N/A	0.20	N/A	N/A	No	BKG

- (1) Minimum/maximum detected concentration.
 (2) Maximum concentration used as screening value
 (3) Refer to Section 6.3.14 for a discussion of the comparison to background
 (4) Screening toxicity value derived in accordance with State of California Department of Toxic Substances Control Preliminary Endang Assessment Guidance Manual (DTSC 1994) and USEPA Risk Assessment Guidance for Superfund (USEPA 1989). See Appendix I for methodology
 (5) Rationale Codes Selection Reason: Above Screening Levels (ASL)
 Deletion Reason: Background Levels (BKG)
 (6) USEPA 1998b

Definitions:
 ARAR/TBC = Applicable or Relevant and Appropriate Requirement/To Be Considered
 CAS = Chemical Abstract Service
 COPC = Chemical of Potential Concern
 mg/kg = milligrams per kilogram
 N/A = Not applicable
 N/P = Not provided by the laboratory performing the analyses