5.0 SOIL AND SEDIMENT: MONITORING AND CONTAMINANT MIGRATION

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5.1 Soil and Sediment Monitoring Studies

Soil and sediment monitoring studies were conducted in four main areas off the SSFL site. These include the Brandeis-Bardin Institute (BBI) (McLaren/Hart, 1993; 1995), the Santa Monica Mountains Conservancy (SMMC) (McLaren/Hart, 1993; 1995), Ahmanson Ranch (Klinefelder, 2000), and the Bell Canyon areas (Ogden, 1998a). Samples were analyzed for a variety of chemicals and radionuclides.[5.1] Although sampling in offsite areas was limited, the detection of radionuclide and chemical contaminants in the samples suggests that contaminants migrated from SSFL to these offsite locations (Appendix H).

In the 1995 McLaren/Hart study, soil and sediment samples were collected from BBI, SMMC and along NPDES drainage channels northwest of Area I (McLaren/Hart, 1995). Figure 5.1 depicts offsite soil contamination detected in the vicinity of SSFL for a select number of chemicals. Tables H-6 and H-9 in Appendix H summarize offsite samples in which contaminants were detected above health-based standards from the McLaren/Hart study (1995), as well as the standards used for comparison.[5.2]

Arsenic was detected in soil samples at significant levels above health-based standards (residential soil screening levels or RSSLs) at the SMMC, and the BBI. However, arsenic levels in various California soils are naturally high (McLaren/Hart, 1993, 1995; Appendix H); it occurs in soil and groundwater as a result of releases from erosion of mineral deposits, though human activities can also lead to substantial contamination (ATSDR, 1990). Background concentrations of arsenic in California can be as high as 2.3 to 11 mg/kg (, according to 1986 California soil samples (<2.5 from surface) (Hunter, P., 2005). While SSFL area soil samples contained approximately 1 to 24 mg/kg of arsenic (see Table 6-4), it is still not possible to ascertain whether these levels are comparable to natural background soil conditions or are due to activities associated with SSFL such as waste incineration. The largest anthropogenic sources of inorganic arsenic emissions to the atmosphere are waste combustion and high-temperature processes (ARB, 1998).

Soil contamination by lead, beryllium, and cesium-137 was also detected south of SSFL at the Bell Canyon and Ahmanson Ranch properties (Ogden, 1998a; Klinefelder, 2000; Appendix H). The perchlorate dose ratios (DRs, see Chapter 6) associated with contaminated groundwater in Simi Valley were generally low: they ranged from about 0.05 to 2, even assuming 30 years of exposure at maximum detected levels. See Appendices H and R for offsite levels of perchlorate used in the analysis and the resulting DRs (Table R-5). However, DRs above 1 were determined for inhalation exposure to TCE and hydrazine (and its derivatives) in multiple receptor locations around the SSFL facility (Table 6-6). The implications of the DR values for the identification of areas of exposure concern are discussed in Chapter 6.

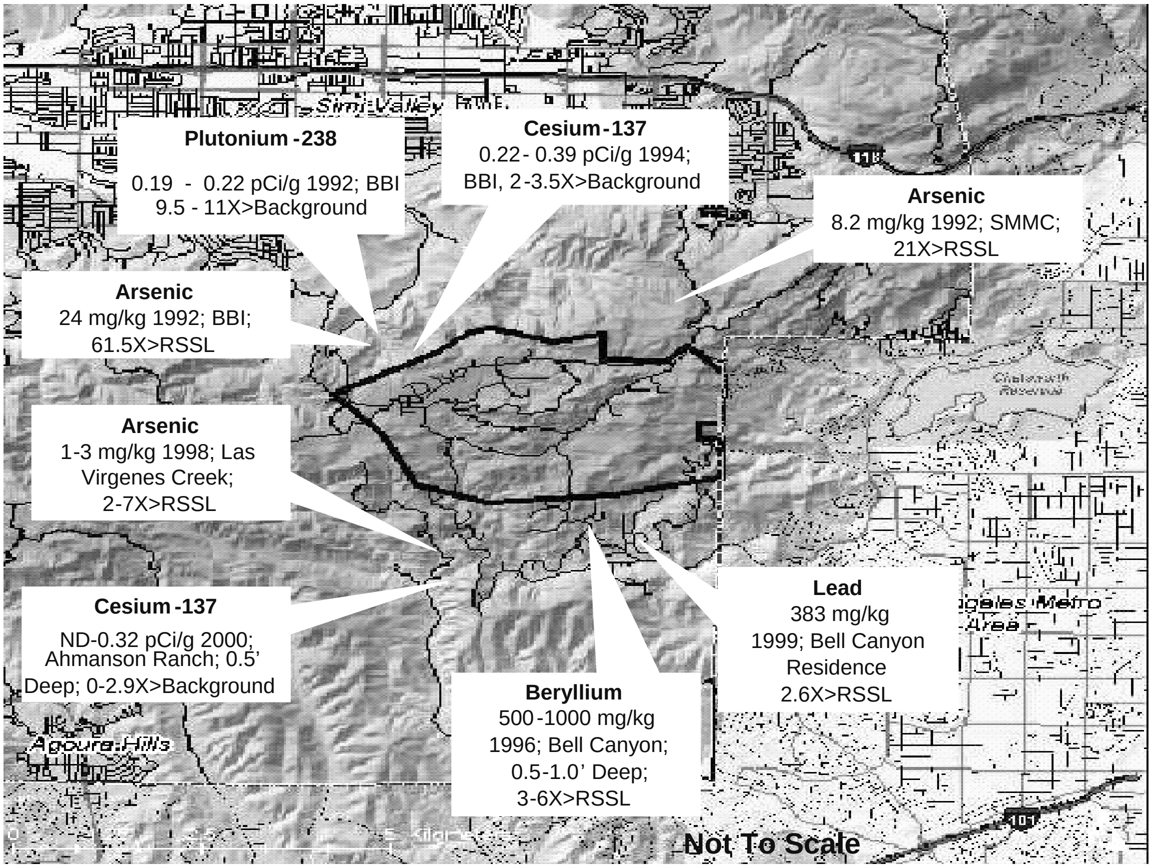
[5.1] See Chapter 2 for a discussion of radionuclide contamination.

[5.2] Note that methylene chloride and toluene were detected in soil samples collected at SMMC but not in background samples collected 2.5 to 12 miles away (McLaren/Hart, 1993, 1995; Appendix H).

5.2 Chemical Migration from Contaminated Soil and Sediment

Soil contaminants can migrate from SSFL in three ways: (1) volatilization from the soil subsurface and subsequent air dispersion, (2) wind re-suspension of contaminated soil particles and subsequent air dispersion and deposition onto offsite soil and (3) surface runoff of soil contaminants from (in SSFL's particular case) NPDES release pathways or natural surface streams with subsequent release to surface water or accumulation in sediment (ATSDR, 1999). Surface water pathways do exist that could be responsible, in part, for offsite transport of soil by intermittent runoff.

Figure 5-1. Offsite Soil Contamination at Levels Above Health-Based Standards and Background Levels



Note: Data collected from 1992 to 1994. Concentration, date detected, location of detection, depth of detection, and exceedence of a health-based standard or background concentration are presented. Depth presented where provided in monitoring reports. (Detections assumed to be at surface level for the purpose of exposure assessment unless otherwise stated in original monitoring report.)

Soil and sediment samples were collected in areas of Bell Canyon that were likely to have been impacted by surface water flow from the SSFL site[5.3] (Ogden, 1998a,b). Note that beryllium was

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[5.3] TCE is discussed in Section 5.3.

detected (up to 1000 mg/kg in soil) above health-based standards (150 mg/kg RSSL) at depths of 0.5 to 1.0 feet (Figure 5-1; Appendix H). Atmospheric deposition is unlikely to have caused contamination at such depths. It is more plausible that the beryllium migrated to offsite areas via runoff and sediment transport during periods of rainfall: at such times, surface water from SSFL flows primarily in (1) a northerly direction via two channels that ultimately discharge at NPDES-permitted outfalls at the northwest property boundary and (2) a southerly direction via two channels that ultimately discharge at two NPDES-permitted outfalls at the southern property boundary (ATSDR, 1999). Note also that soil and sediment sampling along NPDES drainage channels within the BBI and SMMC suggests that PCBs, TCDD (dioxins), and mercury may have migrated in drainages from the Sodium Disposal Facility to offsite areas (McLaren/Hart, 1995).

A clear pattern of topsoil contamination at and away from SSFL would be indicative of potential migration via wind soil re-suspension. However, it is not feasible to establish a clear pattern since there is a concern regarding the adequacy of background samples collected in the late 1990s[5.4] from undeveloped portions of Bell Canyon in areas thought not to be impacted by surface drainage (Ogden, 1998a). Some of these background samples were taken from locations between Bell Canyon and SSFL, in areas which could have been impacted by air dispersion and deposition from SSFL; thus rendering these background samples inadequate for comparison purposes. For example, *n*-nitrosodiphenylamine (NDPA) was detected above analytical reporting limits in background surface soils between SSFL and Bell Canyon at a maximum concentration of 36 µg / kg.[5.5] NDPA is not a naturally occurring substance; it is a man-made chemical that was used in rubber compounding and production. As NDPA was not detected in samples collected along drainage channels, its' presence in background soil samples between SSFL and Bell Canyon suggests that it was transported via air dispersion (Ogden, 1998a; McLaren/Hart, 1993; Boeing, 1990–2003). Indeed, it has been argued that NDPA releases from SSFL would have occurred as air emissions (ATSDR, 1993). Although the concentrations detected off site were all well below the RSSL of 99 mg / kg set by EPA Region 9 (EPA, 1996b),[5.6] offsite detection in areas distant from drainage channels suggests the possibility of migration of soil-bound NDPA particles via air dispersion from SSFL. In support of this possibility, analysis of wind patterns in the SSFL region indicates that the general wind pattern is north-northwest from the ocean during the day.[5.7] Therefore, the potential for wind re-suspended contaminant migration from SSFL cannot be discounted (ATSDR, 1993).

Contaminants found in offsite soil that potentially originated from SSFL and were found in areas of potential exposure include lead, beryllium, arsenic, methylene chloride, toluene, cesium-137, and plutonium-238. These contaminants were found above health-based standards in a number of

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[5.4] Background samples were collected for the following chemicals and radionuclides: As, Ba, Be, Cr, Pb, NDMA, NDPA, PCBs, PAHs, TCDD-TEQ, perchlorate, K-40, Ra-226, Th-228/230/232, H-3, and U-233/234/235/238.

[5.5] The exact location of this sample could not be discerned from the information received, therefore consideration of terrain obstacles to wind dispersion could not be considered in the discussion of background sample appropriateness.

[5.6] EPA has not reported an inhalation reference concentration or an oral reference dose for NDPA. It is not known if exposure to NPDA by breathing or skin contact can affect the health of humans or animals. NDPA has been classified as a probable human carcinogen for exposure via the ingestion route and has been demonstrated to cause adverse health effects in animals (NDPA has a B2 carcinogen listing; EPA, 1995a).

[5.7] The general diurnal winds are predominantly north-northwest, blowing from the ocean; the direction reverses to the east-southeast during the night (Rutherford, 1999).

locations, including residential and recreational areas immediately north and south of the facility (Figure 5.1). Lead and beryllium were detected in soils samples south of SSFL in Bell Canyon, at levels exceeding RSSL standards (Ogden, 1998a). Arsenic and cesium-137 were detected south of SSFL at the Ahmanson Ranch at levels exceeding RSSLs and reported backgrounds respectively (Klinefelder, 2000; Appendix H, Table H-4). Cesium-137, plutonium-238, and arsenic were detected north of SSFL, albeit on border property since purchased by Boeing from the BBI, at levels exceeding background levels and soil standards for arsenic. Background levels for lead and beryllium were not reported with the monitoring data for these chemicals (Appendix H, Table H-4). Background ranges for cesium-137 and plutonium-239 were averaged soil radiation levels in East Ventura and West LA Counties. However, as these background concentrations were derived from Ogden (1998a,b) given the inadequacy of the background sample locations, comparison to these reported background levels may not accurately represent the extent of the radionuclide contamination. Methylene chloride and toluene were detected in soil samples collected at SMMC but not in background samples 2.5 to 12 miles away (McLaren/Hart, 1993, 1995; Appendix H, Table H-6). Although arsenic was detected at significant levels (1-24 mg/kg) above health-based standards in soil samples (2-62x> RSSL) at SMMC, BBI, and Las Virgenes Creek, it is unclear if the arsenic levels were above natural area background levels given that high natural levels in various California soils (2.3-11 mg/kg, Air Force, 2002), and the inadequacy of background samples collected from areas between Bell Canyon and SSFL (McLaren/Hart, 1993; 1995; Appendix H).

In summary, based on information reviewed (McLaren/Hart, 1993, 1995; Ogden, 1998a; Rockwell International, 1992a; GRC, 1993; ICF Kaiser, 1995; ITC, 1999), it is plausible that contaminants that have been detected in offsite soil samples have been transported to offsite locations from SSFL.

5.3 Soil TCE Gas Monitoring and TCE Soil Emission Estimates

5.3.1 Overview of TCE Soil Monitoring Data

A number of studies have been carried out to characterize the SSFL site and assess the extent of TCE contamination and migration (Montgomery Watson, 2000a, 2000b, 2002; GRC, 1986–2000; Ogden, 1999). It is estimated that a significant volume of the TCE used for cleaning rocket engines[5.8] infiltrated the soil and contaminated the aquifer below SSFL (GRC, 1999). When a nonaqueous-phase liquid, such as TCE, migrates through the unsaturated soil zone, a fraction of it remains as a residual phase that adheres to the soil. (Due to the heterogeneous soil formation at SSFL, part of the TCE could be entrapped as free phase in local areas of low permeability.) TCE can volatilize from the soil subsurface, so an assessment of the expected magnitude of the TCE volatilization flux is warranted.

[5.8] It has been estimated (see Section 7.3, particularly 7.3.2) that about 400,000 to 800,000 gallons of TCE were used for washing rocket engines at the SSFL. Estimates of the amount of TCE that has infiltrated the soil range from 139,000 gallons to about 313,000 gallons (CH2M Hill, 1993; Section 7.1).

Monitoring of the soil vapor phase at SSFL[5.9] revealed a significant presence of TCE at various depths surrounding the Instrument and Equipment Laboratories in Area I (Figure 5.2; Ogden, 1999; Montgomery Watson, 2002). The presence of TCE in the soil vapor phase, reported in two separate monitoring data sets (Ogden, 1999; Montgomery Watson, 2002), indicates active transport of TCE in the soil matrix and thus suggests that TCE volatilized to the atmosphere from the above area. The samples were taken from areas northwest of building 301 (Montgomery Watson, 2002), and in an adjacent area south of building 301 (Ogden, 1999). Soil vapor monitoring reported on February 26, 1998 (Ogden, 1999) is presented for TCE concentrations at 18 sampling locations, south of building 301 (Figure 5.2). Data reported in a vapor concentration map dated June 20, 2001, (Montgomery Watson, 2002) provide TCE concentrations at 23 sample locations (Figure 5.2). In each sampling location, TCE concentrations were reported at different depths ranging from 5 to 30 feet. A common characteristic of the data is the high variability of vapor phase concentrations for a given depth at different locations, or for different depths at the same location. In some of the locations, in fact, different concentration values have been reported for the same depth. For example, at sample location identified as ILSV01 (Montgomery Watson, 2002, Map 2), 21 TCE concentration values, ranging from 87 to 220 µg/L, are reported for a depth of 15 feet. The variability in reported TCE vapor phase concentration is illustrated in Figure 5.2. Clearly, the data do not reveal a definitive trend of concentration variation with depth; this suggests that TCE contamination could be distributed throughout the unsaturated soil zone. Note that, for both data sets (Montgomery Watson, 2002; Ogden, 1999), with the exception of one sample, TCE vapor phase concentrations were not reported for the top 5 feet of soil.

5.3.2 TCE Volatilization from the Soil Subsurface

A lower limit of TCE volatilization flux can be estimated if one assumes the top 5 feet of soil to be a TCE-free zone for which TCE monitoring data are unavailable. A reasonable estimate of TCE volatilization flux can be obtained, assuming a homogeneous soil from the surface to a depth of 5 feet, pseudo-steady-state conditions, and that diffusion through the air-soil matrix is the dominant TCE transport mode from a depth of 5 feet to the surface. Given the above approximations, the volatilization flux at the surface, J (µg TCE/m^2 s), can be calculated as

$$J = D_{eff}\frac{C_L}{L} \qquad [5.1]$$

where C_L is the average TCE vapor concentration (µg TCE/m^3) at a depth L (m) below the surface. In Equation 5.1 it is implicit that TCE emission flux is low enough that wind sweeps the chemical as it emerges from the soil, leading to a TCE surface concentration that is several orders of magnitude lower than C_L. The effective TCE diffusion coefficient in the soil void space, D_{eff}, can be estimated as $D_{eff} = \theta_a D_a / \tau_a$, where θ_a is the volumetric air content, $D_a = 8.1 \times 10^{-6}$ m^2/s is the diffusion coefficient of TCE in air (Grifoll and Cohen, 1994), and τ_a is the tortouosity. The tortuosity was estimated from the Millington and Quirk model, $\tau_a = \phi^{2/3}/\theta_a$, where ϕ is the soil porosity (Jin and Jury, 1996). Under dry soil condition, $\theta_a = \phi$ and thus $\tau_a = \theta_a^{-1/3}$.

[5.9] Ogden (1999), Environmental and Energy Services (February 26, 1998), and Montgomery Watson (June 20, 2002) reported analysis of a number of different volatile organics in the soil gas phase.

Following the above approach, the study team estimated the volatilization flux using Equation 5.1 and an average TCE vapor phase concentration (C_L) at 5 feet. This volatilization flux was based on samples analyzed by Ogden (1999) and Montgomery Watson (2002) which are listed in the soil vapor monitoring maps (Ogden, 1999, Map 1; Montgomery Watson, 2002, Map 2). The soil area for TCE volatilization was estimated as the minimum rectangular area that encompasses all locations sampled in each area. The resulting volatilization fluxes, for soil porosity values of 0.15 and 0.3, are given in Tables 5.1 and 5.2. The volatilization flux from the two areas for the porosity range of 0.15 to 0.30 differs by about 30%. The estimated TCE volatilization rate from the two areas ranges from 135 to 345 g/day.

Table 5-1. TCE Volatilization from Soil for Soil Porosity of 0.15

	θ_a	**Average Concentration at 5 Feet (μg/L)**	**Volatilization Flux (g/m^2 day)**	**Surface Area (m^2)**	**TCE Volatilization Rate (g/day)**
Map 1 02/26/98	0.15	274	0.010	6500	65
Map 2 06/20/01	0.15	198	0.0074	9500	70
				Total	135

Although the above TCE volatilization estimates are based on sampling carried out in 1998 and 2001 in the area about building 301, the actual TCE-contaminated area is unknown and could be larger. It is important to note that TCE emission fluxes are proportional to the aerial size of the contaminated area. Given that TCE soil vapor monitoring data are available for only part of the SSFL area, it is not possible, at present, to accurately ascertain the actual TCE volatilization flux or flux changes since the last known monitoring period.

Table 5-2. TCE Volatilization from Soil for Soil Porosity of 0.30

	θ_a	**Average Concentration at 5 Feet (μg/L)**	**Volatilization Flux (g/m^2 day)**	**Surface Area (m^2)**	**TCE Volatilization Rate (g/day)**
Map 1 02/26/98	0.30	274	0.026	6500	169
Map 2 06/20/01	0.30	198	0.019	9500	176
				Total	345

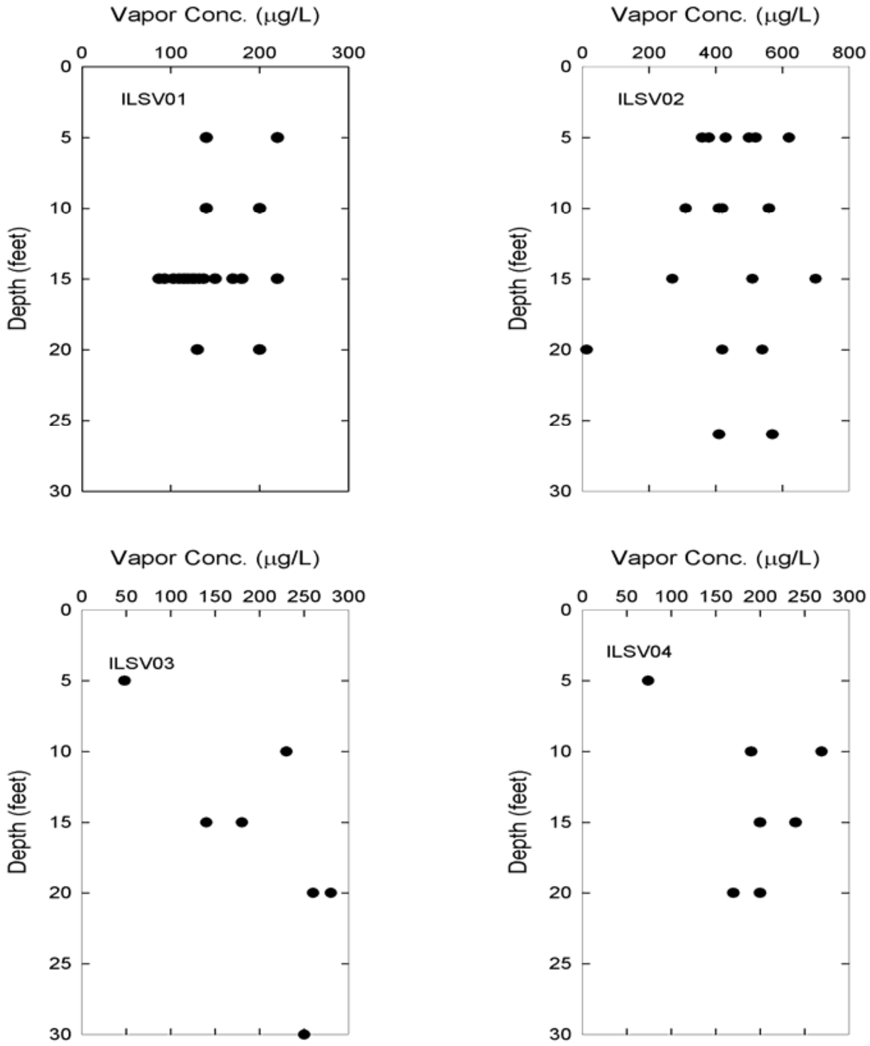
In summary, monitoring data on soil vapor phase in Area I indicate the presence of TCE in the soil vapor at significant concentrations. Cleanup standards based exclusively on gas or soil concentrations have drawbacks, as the distribution of contaminants in the subsurface is not uniform. The American Conference of Governmental and Industrial Hygienists (ACGIH) has created threshold limit values (TLV) or time-weighted averages to express the concentration of a substance to which most workers can be exposed without adverse effects. The ACGIH TLV for TCE is 270 µg/L (270 ppb). This advisory standard is exceeded on site in sample ILSV02 (Figure 5.2) at depths of 5 to 25 feet beneath the surface. Other standards for TCE include Cal-EPA's REL (Recommended Exposure Limit) and ATSDR's intermediate MRL (Minimal Risk Level for 15–364 day exposure). These standards for TCE are 0.6 µg/L and 0.5 µg/L, respectively, and are exceeded in all samples presented in Figure 5.2 below. Finally, the volatilization for TCE and subsequent dispersion via the air pathway is addressed in Chapter 3.

5.4 Soil Exposure Issues

Due to ongoing development and the existence of hiking paths, horse trails, children's camps, and private gardens (see Chapter 6), local residents, visitors, or workers could be exposed to soil contaminants via inhalation, incidental ingestion, dermal contact, and (secondarily) exposure through bioaccumulation and vegetable ingestion. The study team considered these exposures (see Section 6 and Appendices O and T) for contaminants detected in offsite soil (Ogden, 1998a,b; McLaren/Hart, 1993, 1995) above health-based standards. (For the regulatory and advisory standards used, see Appendix N.) In general, the contribution of soil to offsite exposure was found to be low compared to that of other pathways, as discussed in Section 6. The issue of onsite exposure to soil contaminants is nonetheless of greater significance, as soil cleanup is still ongoing.

Contaminants found in onsite soil above health-based standards include lead, mercury, arsenic, chromium, TCE, tetrachloroethylene, PCBs, carbon tetrachloride, 1,2-dichloroethylene, cesium-137, and plutonium-238. Even with effective surface soil cleanup, volatilization of TCE from the soil subsurface is likely to continue. Clearly, assessment of cumulative exposures associated with onsite activities, for single and multiple chemicals and for all exposure pathways, will be of importance especially for areas where mixtures of hazardous wastes were disposed of (Areas I, III, and IV). If onsite land is to be used for residential or even recreational activities, a thorough review of onsite contamination and cleanup targets is warranted, with careful consideration of future land use.

Figure 5-2. TCE Vapor Phase Concentration Profiles in Soil Gas Phase: Area I, Sample Locations ILSV01, ILSV02, ILSV03, and ILSV04



Sources: Ogden, 1999; Montgomery Watson, 2002