

## **Extreme Short-Range Variability in VOC-Contaminated Soils**

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**ABSTRACT:** To accurately characterize volatile organic compound (VOC) distribution in contaminated soils for the purpose of ascertaining the need for site remediation, horizontal and vertical concentration fluctuations must be taken into account when designing the sampling program. Soils at two Superfund sites were collected to examine VOC concentration and soil property variability over extremely short distances ( $\leq 15$  cm). Differences in VOC concentrations between the upper and lower core sections (15 cm apart) were generally on the same order (1 to 4 times different) as the differences found for the TOC, sand, and clay contents; however, several notably larger variations in VOC concentrations were found. Relative percent differences (RPDs) up to 161, 96, 117, and 191% were found for TOC, sand content, clay content, and VOC concentrations between upper and lower core sections, respectively. These elevated RPDs correspond to maximum concentration differences between upper and lower core sections of 25.5 and 72.5%, 5.8 and 22.0%, 0.29 and 2.71%, and 78 and 3371 ng/g for TOC, sand content, clay content, and VOC concentrations, respectively. The large differences in soil properties and VOC concentrations that can occur over extremely short distances must be taken into account during site characterization. Without knowing the magnitude of the extreme short-range variability, erroneous interpretations of contaminant concentrations and distributions can lead to costly remediation when it is not necessary (i.e., false positives) or the leaving behind of a significant threat to human health and the environment when not detected (i.e., false negatives).

**KEY WORDS:** chlorinated solvents, 1,1,1-trichloroethane, trichloroethylene, perchloroethylene.

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## **INTRODUCTION**

Volatile organic compounds (VOCs) are the most common and the most mobile subsurface contaminants encountered at Superfund and other hazardous waste sites (1). The distribution of subsurface VOC concentrations must be established to assess the environmental risk posed by soil contamination, to develop restoration strategies, and to verify the effectiveness of the remediation strategy (2). The sampling design developed must address both the long- and short-range variability of VOCs and soil properties in the field. “The variability of soil properties affects the way we sample and the number of samples required to estimate summary statistics, such as the mean with a known degree of precision and certainty” (3). In general, soil variables that change most dynamically, such as soil moisture, soluble nutrients, and soil microbial activity are associated with a relatively high degree of spatial variability.

The spatial variability of VOCs in the field is affected by the natural variability of numerous soil properties and is exacerbated by the multi-phasic nature of the VOCs (4). Spatial variability results from inherent soil property differences from point to point even within relatively homogeneous deposits (5). For example, significant changes in organic carbon content, clay content, pH, cation exchange capacity, and exchangeable Ca, Mg, and K concentrations have been found in Carolina bays (depressional wetlands) along elevation

gradients measured in 10-cm rises (6). Of potential importance to VOC distributions are the changes in organic carbon and clay content (the primary VOC sorption sites in soil) with organic carbon contents varying laterally from 4.7% to 2.7% from the center of the bay to the rim (approximate distances of 75 to 150 m) and clay contents ranging from 9.7% to 4.5% over the same area (6). In the same Carolina bays, vertical variations of 4.7% to 0.9% and 9.7% to 20% were found between the surface A and subsurface B horizon organic carbon and clay contents, respectively.

The natural variability of soil properties affects the movement of both liquid phase and gas phase plant nutrients as well as site contaminants. For example, in a study of cadmium distribution in an agricultural field to which sewage sludge had been extensively applied, leached cadmium concentrations were found to be spatially dependent and anisotropic (7). The spatial variability of Cd and other soil parameters affecting Cd mobility resulted in fluctuations in Cd concentrations ranging from 0.17 to 1.27 mg/kg at a sampling distance of 100 m between sampling points. When sampling points were separated by only 10 m, Cd concentrations ranged from 0.05 to 0.35 mg/kg while organic carbon contents varied from 0.63 to 2.43% over the same sampling scale.

Key soil properties that influence the movement of the gas phase in soils include structure and texture (8). The interaction of the gas phase with soil moisture is also affected by soil permeability, gas diffusivity, and tortuosity (9). Nitrous oxide fluxes from soil samples collected 0.2 to 16 m apart had large coefficients of variation ranging from 123% to 187% (10). These large coefficients represented concentrations that ranged from 0.3 to 250  $\mu\text{L/L}$   $\text{N}_2\text{O}$  when samples were collected at a fixed depth of 10 cm below the ground surface.

The variability of VOCs in soils is expected to be high due to the variability in contamination events or VOC introduction to the soil. At a waste oil and solvent land treatment unit covering approximately 650 m<sup>2</sup>, total VOC concentrations, in 176 samples collected from 21 borings approximately 10 m apart, ranged from 6 to 154000 µg VOC/kg (11). Similarly, at a different land treatment unit located in southern Ohio, the concentrations of trichloroethylene (TCE), 1,1,1-trichloroethane (TCA), 1,1-dichloroethene, 1,1-dichloroethane, *cis*-1,2-dichloroethene, and methylene chloride varied from nondetectable to 40000 µg/kg across the site when samples were collected 10 m apart (2). The wide range in VOC concentrations were associated with coefficients of variation ranging from 144% to 384%. In the same study (2), duplicate samples were collected from within the same 30 cm core section to examine short-range variability. Total VOC concentrations were significantly different (up to 8.7-times different) between duplicate samples collected from the same core section. West et al. (2) attributed the high variability in both long- and short-range samples to the nonuniform release of VOCs to the subsurface and spatial heterogeneities in soil properties that affect the distribution and retention of VOCs.

With few exceptions, most studies examining spatial variability are performed at scales with sampling points that range from a meter to hundreds of meters apart. The objective of this study was to assess the extreme short-range variability of VOC concentrations within the soil column. Extreme short-range variability in this study is the variability between co-located samples collected within the same core section and between routine samples collected from the same core within a vertical distance of 15 cm or less.

## Experimental Section

**Soil Sampling.** VOC-contaminated soils were collected at two Superfund sites: one in Kent, Washington; and the other in Portland, Oregon (Table 1). Initial pilot holes were drilled to a depth of 91 cm below ground surface using a hollow-stem auger. A 46 cm long, 7.5 cm internal diameter split spoon sampler was then pushed from the bottom of the pilot hole to approximately 137 cm to collect the soils. The split spoon sampler was lined with 15, 7.5, 7.5, 7.5, and 7.5 cm brass rings, from top to bottom, to help maintain sample integrity and to reduce sample exposure and consequent VOC loss to the atmosphere during subsampling (Fig. 1). Samples of approximately 5, 20, and 120 g were collected volumetrically using disposable plastic syringes (10 mL for the 5 and 20 g samples and 60 mL for the 120 g samples) with the tips cut off. Samples were collected from pairs of 7.5 cm brass rings to represent the upper and lower 15 cm of the soil column. The 120 g samples were collected from the first and third or the second and fourth 7.5 cm brass rings, alternating between sampling holes, while the 5 and 20 g samples (both collected from the same ring) were collected from the remaining two brass rings (Fig. 1).

Samples were collected from freshly exposed core surfaces as quickly as possible by a 2 person sampling team with all samples being collected within 1 minute of atmospheric exposure. All samples were placed directly into either 5, 20, or 120 mL of methanol, depending upon sample weight, to obtain an approximate 1:1 soil:methanol ratio. Co-located samples of either 5 or 20 g were routinely collected by reinserting the syringe into the same brass ring used to collect the initial 5 and 20 g samples. Field blanks, vials containing methanol left open during the collection of the 5, 20, and 120 g samples, were collected to monitor cross contamination.

Soil remaining after collection of the VOC samples was transferred to plastic bags for determination of particle-size distribution and total organic carbon content. Upper and lower 15-

cm sections were bagged separately. Soil moisture samples were collected at the same depths but from separate holes drilled approximately 46 cm away from the hole used for the collection of the VOC samples.

**Field Procedures.** Soil:methanol mixtures were shaken by hand until thoroughly mixed and the soil dispersed (visual inspection). After approximately 20 hr at ambient temperatures, the vials were opened and subsampled by pipette to remove approximately 2 mL of the clear methanol supernatant. The supernatants were transferred to 2 mL minivials, crimp-sealed with Teflon™-lined rubber septa, and stored cold (4° C) until analyzed.

Soil moisture contents were determined gravimetrically in the field. Moisture samples were weighed in their field moist condition, dried overnight in an oven at 105° C, reweighed, and discarded. Soil samples collected for the determination of particle-size and total organic carbon contents were air dried in the field for at least 24 hr prior to rebagging and shipping to the laboratory for analysis.

**Analytical Procedures.** Methanol aliquots (50 µL, or less, depending upon sample concentrations) were analyzed for VOCs following modified EPA SW-846 methods 5035 and 8021 (12). A five-point calibration curve was generated prior to analysis of routine samples. An instrument blank (water) and mid-range calibration standard preceded and followed every fifteenth sample. A system monitoring compound (SMC), *cis* 1,3-dichloropropane, was added to every sample, standard, and blank at a concentration of 50 ng/sample. The SMC was used to evaluate the consistency of the detector response and effectiveness of each purge.

All samples were analyzed on a Hewlett-Packard Series II Model 5890 gas chromatograph with an electron capture detector and a J&W DB-624, 75 m, 0.53 mm i.d. fused

silica column. Sample introduction was performed using a Dynatech PTA-30 Autosampler and Tekmar LSC-2 Purge-and-Trap system.

Total organic carbon (TOC) contents were determined by dry combustion using a LECO® CNS-2000 analyzer (13). Sand and clay contents were determined by the hydrometer method on the <2 mm fraction after H<sub>2</sub>O<sub>2</sub> pretreatment to remove organic matter (14). Duplicate samples, collected from the homogenized bulk sample for each core section, were analyzed to assess within-section precision.

**Data Presentation and Statistical Procedures.** Data are reported on a dry weight basis. To determine if statistically significant differences were present between upper and lower core sections, the Anderson-Darling normality test was used to determine if the data were normally distributed (15). The normality test failed and consequently, the non-parametric Wilcoxon signed rank test was performed on paired data with a null hypothesis that there was no statistically significant difference between VOC concentrations at the 95% confidence level (16). Paired data examined consisted of the same sample size (i.e., 5, 20, or 120 g) collected from the upper and lower sets of 7.5 cm brass rings.

## **Results**

### **Soil Property Variability**

Soil properties within the two sites varied widely (Table 1). Although a wide range in particle-size distributions was observed, a majority of the soils ( $\geq 75\%$ ) were coarse-textured and fell into the sand, loamy sand, or sandy loam textural classes. The remaining soils were loams, silt loams, or silty clay loams.

Precision among duplicate samples (i.e., two samples taken from the same bag) was good with relative percent differences (RPDs) of less than 10% for sand and clay contents (Table 2)

and RPDs of about 20% for silt contents (data not shown). Silt imprecision is expected to be higher than sand and clay imprecision since silt content is determined by difference and all sampling and analytical errors are confounded in this measurement. In contrast, when examining differences in sand and clay contents between the upper and lower 15 cm core sections (Table 3), RPDs ranged from 0 to 96% and 0 to 117%, respectively (Table 4). These large differences may be the result of sand or clay lenses (i.e., natural heterogeneity) within the sampling zone, sample collection across soil horizons, anthropogenic site disturbance, or method imprecision (including sample heterogeneity and subsampling bias). Method imprecision has been ruled out as a possible cause for the differences due to the small RPDs found between duplicate samples which were collected and analyzed following the same procedures as the routine samples.

Similar to differences in sand and silt contents, TOC content precision between duplicate samples was good with RPDs ranging from 4% to 10% indicating good method precision (Table 2). However, when TOC contents were compared between the upper and lower 15 cm core sections, the RPDs ranged from 13 to 105% and 0 to 161% for Kent and Portland samples, respectively (Table 4). These elevated RPDs represent changes in TOC content of up to 9-times difference between upper and lower core sections (Table 3).

### **VOC Concentration Variability**

VOC concentrations varied widely within and between sites with an overall range from non-detectable to 10420 ng/g VOC (Table 5). Within the hot spot at Kent (samples K05 and K07), TCE, perchloroethylene (PCE), and TCA concentrations in all samples ranged from 2230 to 6750, 374 to 2252, and 1275 to 4439 ng/g, respectively. In contrast, in the less contaminated zone at the Kent site, concentration ranges of 77 to 767, 44 to 2440, and 93 to 1266 were found for TCE, PCE, and TCA, respectively. Similarly, in the hot spot at Portland (samples P05, P07,



P09, and P11), TCE and PCE concentrations in all samples ranged from 74 to 3371 ng/g, and non-detected to 10420 ng/g, respectively, with the less contaminated area concentrations ranging from non-detected to 55 ng/g and 12 to 122 ng/g for TCE and PCE, respectively.

While the overall range in VOC concentrations was large, the RPDs among co-located samples were generally within the project quality objectives of a  $RPD \leq 30\%$  (Table 2). For the 5 g co-located samples, RPDs ranged from 1 to 52% where detectable quantities of a given VOC were found in both the upper and lower core sections. Similarly, for the 20 g co-located samples, RPDs ranged from 2 to 37%. A majority (82%) of the co-located samples had  $RPDs \leq 30\%$  indicating that the sample collection, preparation, and analytical phases of VOC determination were in control.

In marked contrast to the relatively good precision found among co-located samples, the variability between upper and lower core sections was much greater. RPDs between the upper and lower core sections ranged from approximately 0 to 163% and 0 to 191% at Kent and Portland, respectively (Table 6). Removing the highly contrasting results found at the P07 sample (Table 5), Portland site RPDs still ranged from 0 to 102%. Of importance is that these large RPDs represent concentration changes of up to an order of magnitude (or up to 43-times different in the P07 sample) within the 15 cm distance between the upper and lower core sections (Table 5).

### **Statistical Analysis**

To explain the large variability between upper and lower core sections, the influence of particle-size distribution and TOC on VOC concentrations was examined. These two parameters were selected since they are the two dominant factors believed to influence VOC sorption in soils. While no statistically significant trends were found, indicating a lack of a dominant

controlling factor, a general trend was identified. At the Portland site, whenever the clay content RPDs between upper and lower core sections were  $\geq 40\%$ , the greatest differences in TCE and PCE contents were found with differences up to 43- and 25-times different, respectively, between core sections (Tables 4 and 5). Further, when radical differences (RPDs  $>90\%$ ) between clay contents existed, such as in the P07 sample, orders of magnitude concentration differences were found between upper and lower core sections. At the Kent site, a similar trend was found where, if the clay content RPD values were  $>30\%$ , a majority of the larger differences (i.e., 2 to 4-times differences) were found for TCE, PCE, and TCA concentrations between upper and lower core sections. No similar general trends were identified when examining TOC variability influences on VOC concentration variability.

VOC concentrations between the upper and lower core sections were statistically examined to determine if the upper or lower core sections had consistently higher VOC concentrations (Table 5). While not statistically significant for the whole dataset, presumably due to the large variability associated with the paired data, the general trend was that the lower core sections tended to have greater concentrations of TCE and PCE than their corresponding upper sections at both sites. A statistically significant difference (at the probability ( $P$ )  $\leq 0.05$  level) was identified at the Kent site. In Kent, TCA concentrations were found to be greater in the lower core sections than their associated upper core sections.

## **Discussion**

The results of this study conducted at Superfund sites in Kent, Washington; and Portland, Oregon; present some disturbing findings on the extent and magnitude of variability in soil properties and VOC concentrations that may occur over extremely short distances. At both sites, the sample collection, preparation, and analytical precision was within project acceptance limits

as indicated by the small RPDs between duplicate or co-located samples. However, when the distance between the samples increased to as short as 15 cm, the natural variability inherent in the soil markedly increased. This extreme short-range variability had maximum range differences of 0.29 to 2.71%, 25.5 to 72.5%, and 5.8 to 22.0%, for TOC, sand content, and clay content, respectively (Table 3). In conjunction with the large variations in soil properties between upper and lower core sections, similar differences were found between VOC concentrations. Generally, the differences in VOC concentrations between the upper and lower core sections were on the same order (1 to 4 times different) as the differences in TOC, sand, and clay contents. However, several notably larger differences were found in VOC concentrations with a maximum relative difference of 43-times and a maximum absolute difference ranging from 423 to 10420 ng/g VOC between upper and lower core sections (Table 6).

While the exact causes of the differences are not completely known, several explanations are possible, including: (a) the presence of clay or sand lenses at the sampling depths, (b) sample collection across pedogenic horizons, (c) irregular flow and subsequent accumulation of spilled VOC-containing liquids, (d) selection of non-typical, highly variable sites, and (e) anthropogenic site disturbance. The first two possible explanations account for the inherent soil heterogeneity. Soil formation processes, either through *in situ* weathering or deposition, have been shown to result in marked differences in physical soil properties across relatively short spatial differences (e.g., the formation of argillic horizons (17)). Since these physical property changes can affect the flow patterns of water, spilled VOC-containing liquid wastes, and vapors, these changes can also affect VOC distributions in the soil. If, for example, a clay content increase was significant enough to retard the flow of a spilled VOC-containing liquid, a subsequent accumulation of the VOCs may occur above the restricting layer. The VOC accumulation would result in a

correspondingly high concentration at or near that interface when compared to VOC concentrations some distance above or below the restricting layer.

Little can be done to address the latter two possible explanations. The sites were selected on the basis of site access and known contaminant presence and concentration levels. No *a priori* set of conditions was established or known at the onset of the study. Additional studies on short-range variability are needed to further assess the causes and extent of contaminant variability in soils.

As a result of the large absolute and relative differences in soil properties and VOC concentrations, when planning any soil investigation, and particularly those involving the collection of VOC-contaminated soils, the investigator needs to be aware of where the soil sample is being collected in the soil profile. Sampling at a fixed depth below the surface without regard to position within the soil profile or without knowledge of the variability of soil properties at the site, may result in erroneous interpretations of the VOC concentrations and distributions. For example, a single soil sample may be collected to represent a given site area and depending on exactly where the sample was collected, large differences in VOC concentrations can be obtained. The erroneous interpretations can, in turn, lead to costly remediation of large areas where perhaps the contamination was highly localized or, conversely, not remediating a portion of a site that poses a significant threat to human health and the environment.

Possible solutions to overcome the effects of large variations over short distances include: (1) the use of a sequential sampling design in which the first phase would be to carefully log the soil morphology and obtain estimates of soil property and VOC concentration variances followed by a second phase sampling to more fully characterize the site based on the first phase results; (2) sample compositing, where possible and depending upon the parameter of interest; and (3) the

collection of abundant samples both horizontally and vertically to better delineate the parameter's distribution in the soil. Selection of an appropriate solution will depend on the project's objectives, fiscal constraints, site characteristics, and the soil property or contaminant of interest.

#### **NOTICE**

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Table 1. Variability in Soil Properties of Study Samples.

	moisture	TOC <sup>a</sup>	sand	clay
	(-----%-----)			
<u>Portland</u>				
mean	0.27	0.47	44.6	18.8
median	0.28	0.28	46.9	15.9
range	0.08 - 0.33	0.18 - 2.71	2.6 - 74.7	8.9 - 38.0
<u>Kent</u>				
mean	0.27	0.83	67.6	5.7
median	0.28	0.33	75.8	4.9
range	0.07 - 0.44	0.07 - 4.48	25.2 - 92.2	1.5 - 22.0

<sup>a</sup> TOC = total organic carbon.



**Table 2.** Sand, clay, and TOC contents and VOC concentrations for duplicate and co-located samples, respectively<sup>a</sup>.

Sample <sup>b</sup>	Sand (-----%-----)	Clay	Sample	TOC <sup>b</sup> (-----%-----)	Sample	TCE <sup>b</sup> (-----ng/g-----)	PCE <sup>b</sup>	TCA <sup>b</sup>
K05-U	89.6, 90.9 (1)	2.5, 2.5 (0)	K01-U	1.68, 1.53 (9)	5 g samples			
P11-L	63.6, 58.0 (9)	13.2, 13.9 (5)	K07-L	0.09, 0.10 (10)	K07-L	3685, 3634 (1)	474, 385 (21)	3313, 3223 (3)
P19-U	61.1, 66.6 (9)	9.8, 9.8 (0)	K17-L	0.24, 0.23 (4)	K09-U	663, 632 (5)	359, 210 (52)	221, 173 (24)
			P01-U	0.38, 0.42 (10)	P01-U	0 <sup>c</sup> , 0	50, 55 (10)	n/a <sup>c</sup>
			P09-L	0.29, 0.27 (7)	P07-L	1093, 976 (11)	1713, 1723 (1)	n/a
			P17-U	0.29, 0.28 (4)	P09-U	2148, 3351 (44)	81, 87 (7)	n/a
					P15-U	34, 26 (27)	23, 15 (42)	n/a
					20 g samples			
					K05-U	2309, 2151 (7)	359, 390 (8)	2273, 2017 (12)
					K11-L	691, 717 (4)	277, 302 (9)	126, 136 (8)
					K17-U	194, 238 (20)	2009, 2801 (33)	23, 30 (26)
					K23-L	150, 126 (17)	2019, 1528 (28)	855. 586 (37)
					P11-L	2367, 2311 (2)	0,0	n/a
					P13-L	16, 19 (17)	12, 13 (8)	n/a

<sup>a</sup> RPD values presented in parentheses. <sup>b</sup> K = Kent, Washington; P = Portland, Oregon; U = upper 15 cm; L = lower 15 cm; TCE = trichloroethylene; TCA = 1,1,1-trichloroethane; PCE = perchloroethylene. <sup>c</sup> "0" values = non-detects; n/a = not applicable since TCA was not found at the Portland site.

**Table 3.** Sand, clay, and total organic carbon contents at the Kent and Portland sites.

Sample <sup>a</sup>	Sand	Clay	TOC <sup>b</sup>	Sample	Sand	Clay	TOC	Sample	Sand	Clay	TOC
	(-%-----)				(-%-----)				(-%-----)		
K01-U	49.5	9.4	1.61	P01-U	59.2	13.9	0.40	P15-U	37.5	19.7	0.26
K01-L	i <sup>c</sup>	i	i	P01-L	67.2	8.9	0.19	P15-L	47.9	13.9	0.19
K03-U	39.0	22.0	2.17	P03-U	74.7	8.9	2.71	P17-U	72.0	11.0	0.29
K03-L	56.8	5.8	0.93	P03-L	56.8	11.4	0.29	P17-L	55.1	13.9	0.18
K05-U	89.6	2.5	0.07	P05-U	46.0	17.2	0.69	P19-U	61.1	9.8	0.21
K05-L	76.8	3.5	0.20	P05-L	46.0	17.2	0.25	P19-L	45.0	13.9	0.24
K07-U	82.2	4.7	0.32	P07-U	72.5	8.9	0.84	P21-U	9.4	36.3	0.75
K07-L	83.2	3.5	0.10	P07-L	25.5	26.3	0.39	P21-L	6.9	38.0	0.69
K09-U	77.1	5.0	0.10	P09-U	35.7	22.2	0.28	P23-U	2.6	38.0	0.77
K09-L	30.4	7.9	0.12	P09-L	43.8	23.2	0.28	P23-L	6.1	38.0	0.73
K11-U	87.4	5.7	0.10	P11-U	54.1	16.4	0.19				
K11-L	84.7	4.4	0.15	P11-L	63.6	13.2	0.19				
K23-U	60.7	3.8	0.56	P13-U	56.8	11.4	0.18				
K23-L	81.4	2.8	0.49	P13-L	33.2	17.2	0.21				

<sup>a</sup> K = Kent, Washington; P = Portland, Oregon; U = upper 15 cm; and L = lower 15 cm. <sup>b</sup> TOC = total organic carbon. <sup>c</sup> i = insufficient sample remaining to perform analysis. "0" values = non-detects.

**Table 4.** Relative percent differences in sand, clay, and TOC contents between upper and lower 15-cm soil core sections.

Sample <sup>a</sup>	Sand	Clay	TOC <sup>b</sup>	Sample	Sand	Clay	TOC
K01	i <sup>c</sup>	i	i	P01	13	44	71
K03	37	117	80	P03	27	25	161
K05	15	33	96	P05	0	0	94
K07	1	29	105	P07	96	99	73
K09	87	45	18	P09	20	4	0
K11	3	26	40	P11	16	22	0
K23	29	30	13	P13	52	81	15
				P15	24	35	31
				P17	27	23	47
				P19	30	35	13
				P21	31	5	8
				P23	80	0	5

<sup>a</sup> K = Kent, Washington; P = Portland, Oregon. <sup>b</sup> TOC = total organic carbon. <sup>c</sup> i = insufficient sample in the lower 15-cm core section of K01 to perform analyses.

**Table 5.** VOC concentrations from different sample sizes collected at the Kent and Portland sites.

Sampl e <sup>a</sup>	<u>5 g samples</u>			<u>20 g samples</u>			<u>120 g samples</u>			Sampl e	<u>5 g samples</u>		<u>20 g samples</u>		<u>120 g samples</u>	
	TCE b	PCE b	TCA b	TCE	PCE	TCA	TCE	PCE	TCA		TCE	PCE	TCE	PCE	TCE	PCE
	(-----ng/g-----)										(-----ng/g-----)					
K01-U	527	130	305	159	98	120	257	151	144	P01-U	0 <sup>c</sup>	52	0	40	0	99
K01-L	767	211	239	496	174	168	333	50	111	P01-L	17	68	0	43	0	32
K03-U	126	91	176	174	130	148	285	263	185	P03-U	0	71	27	97	0	122
K03-L	381	160	169	315	144	114	77	44	126	P03-L	0	52	0	53	0	69
K05-U	2231	428	1971	2230	374	2145	2704	480	2509	P05-U	883	1924	731	1471	856	1937
K05-L	5036	858	4439	3793	621	2901	3998	557	3564	P05-L	643	1946	1019	1391	886	1461
K07-U	3967	1771	1966	6750	2252	1275	3711	2000	1496	P07-U	74	295	78	423	179	423
K07-L	3660	429	3267	4853	781	3751	3854	402	3538	P07-L	1035	1718	3371	1042	1288	2030

0

K09-U	648	284	197	707	258	140	552	197	99	P09-U	2747	84	3214	53	2707	0
K09-L	256	144	707	532	166	213	634	94	215	P09-L	2167	42	2187	0	2569	0
K11-U	669	623	243	702	287	132	611	251	93	P11-U	1732	0	1832	0	2257	0
K11-L	600	187	119	704	290	131	531	65	137	P11-L	2978	51	2339	0	2161	0
K23-U	84	322	331	82	317	391	174	1609	753	P13-U	28	23	16	12	19	13
K23-L	186	3130	1266	133	1774	721	160	2440	1186	P13-L	16	12	17	12	20	14
										P15-U	30	20	29	19	39	28
										P15-L	33	19	32	18	33	19
										P17-U	45	103	51	90	55	103
										P17-L	45	46	49	47	77	69
										P19-U	37	53	29	36	43	67
										P19-L	39	61	38	56	39	50
										P21-U	41	18	46	17	45	21
										P21-L	58	17	69	21	53	13
										P23-U	56	20	52	12	65	15
										P23-L	63	14	66	14	64	13

<sup>a</sup> K = Kent, Washington; P = Portland, Oregon; U = upper 15 cm; and L = lower 15 cm. <sup>b</sup> TCE = trichloroethylene; PCE = perchloroethylene; and TCA = 1,1,1-trichloroethane. <sup>c</sup> "0" values = non-detects.

**Table 6.** Relative percent differences between VOC concentrations from upper and lower 15-cm soil core sections.

Sampl e <sup>a</sup>	<u>5 g samples</u>			<u>20 g samples</u>			<u>120 g samples</u>			Sampl e	<u>5 g samples</u>		<u>20 g samples</u>		<u>120 g samples</u>	
	TCE b	PCE b	TC A <sup>b</sup>	TCE	PCE	TC A	TCE	PCE	TC A		TCE	PCE	TCE	PCE	TCE	PCE
K01	37	48	24	103	56	33	26	100	26	P01	nc <sup>c</sup>	27	nc	7	nc	102
K03	101	55	4	58	10	26	115	143	38	P03	nc	31	nc	59	nc	55
K05	77	67	77	52	50	30	39	15	35	P05	31	1	33	6	3	28
K07	8	122	50	33	97	99	4	133	81	P07	173	141	191	184	151	131
K09	87	65	113	28	43	41	14	71	74	P09	24	67	38	nc	5	nc
K11	11	108	69	0	1	1	14	118	38	P11	53	nc	24	nc	4	nc
K23	76	163	117	47	139	59	8	41	45	P13	55	63	6	0	5	7
										P15	10	5	10	5	17	38
										P17	0	77	4	63	33	40
										P19	5	14	27	43	10	29
										P21	34	6	40	21	16	47
										P23	12	35	24	15	2	14

<sup>a</sup> K = Kent, Washington; P = Portland, Oregon. <sup>b</sup> TCE = trichloroethylene; PCE = perchloroethylene; and TCA = 1,1,1-trichloroethane. <sup>c</sup> nc = not calculated due to presence of a non-detect (i.e., "0" ng/g) for one or both VOC concentrations.

## List of Figures

Figure 1. Brass ring configuration used for the collection of upper and lower core sections and individual 5, 20, and 120 g samples. Individual 5, 20, and 120 g samples were collected using truncated syringes. Depth on left axis in cm.

