

A Study on the New Method by EMPLUX for Soil-Remediation(1)

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The utility of soil-gas surveys is directly proportional to their accuracy in reflecting and representing changes in the subsurface concentrations of source compounds. Passive soil-gas vapor-phase is merely a fractional trace of the source, so, as a matter of convenience, the units used in reporting detection values from EMFLUX surveys are smaller than those employed for source-compound concentrations. According to the Leaking Underground Storage Tank (LUST) Program Annual Report, approximately 16 U.S. million dollars were spent for environmental site investigations at over 1,600 Underground Storage Tank (UST) sites and approximately over 1,000 acres of land was characterized and remediated in the State of Illinois in the year of 2003 alone. The main purpose of this study is to propose an idea to significantly reduce the site investigation cost by utilizing a passive soil-gas survey and conventional intrusive drilling method and to fully define the three dimensional characteristics of subsurface contamination from two industrial drycleaning facilities.

Key Words : EMPLUX, ASTM, Soil-remediation

1. Introduction

Title 35¹⁾ of the Illinois Administrative Code (IAC) Part 742 Tiered Approach to Corrective Action Objectives (TACO)¹⁾ describes the baseline soil and groundwater remediation objectives (SROs and GROs) for volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), poly-nuclear aromatic compounds (PNAs), and inorganic compounds. The SROs and GROs for common chlorinated solvents are shown in table below. Factors to determine the baseline SROs and GROs for each subject site include: constituents of potential concern (i.e., PCE, TCE, or VC), current and future land use (i.e., residential or industrial/commercial), exposure pathways of constituents of potential concern (i.e., soil ingestion, inhalation, soil component of groundwater ingestion, or groundwater component of groundwater ingestion), and classification of groundwater beneath the subject site (i.e., Class I for potable water source or Class II for non-potable water source)²⁾. The criteria to determine

the Class of groundwater are described in Title 35 IAC Part 620 Groundwater Quality.

TACO¹⁾ also describes how to determine Risk-Based Corrective Action (RBCA)²⁾ objectives for soil and groundwater using site-specific parameters (i.e., total organic carbon contents, source dimensions, geologic formation, hydraulic conductivity, and hydraulic gradient) and institutional controls possible for a No Further Remediation (NFR) determination (i.e., legal closure) without active subsurface remediation. The institutional controls include, but not limited to: a groundwater use restriction, a land use restriction, an Environmental Land Use Control (ELUC), a Highway Authority Agreement (HAA), Engineered Barriers, a Worker Precaution, and any combinations of such institutional controls. Primarily, RBCA is designed to protect human health and the environment while allowing for practical and cost-effective cleanup measures that are site-specific. It standardizes the principles and procedures of site assessment and remedial action, eliminates inflexible clean up limits and allows for expanded use of natural attenuation.

Approximately 40 years after the Pollution Prevention Law in 1963, the first environmental regulation in the Republic of Korea, Korean researchers and scientists

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Tier 1 Soil and groundwater remediation objectives for chlorinated solvents (35 IAC Part 742)

VOCs	Residential		Industrial/Commercial		Construction workers		SCGIER		GCGIER	
	Ingestion (mg/kg)	Inhalation (mg/kg)	Ingestion (mg/kg)	Inhalation (mg/kg)	Ingestion (mg/kg)	Inhalation (mg/kg)	Class I (mg/kg)	Class II (mg/kg)	Class I (mg/L)	Class II (mg/L)
PCE	12	11	110	20	2,400	28	0.06	0.3	0.005	0.025
TCE	58	5	520	8.9	1,200	12	0.06	0.3	0.005	0.025
IDCE	700	1,500	18,000	1,500	1,800	300	0.06	0.3	0.007	0.035
cDCE	780	1,200	20,000	1,200	20,000	1,200	0.4	1.1	0.07	0.2
tDCE	1,600	3,100	41,000	3,100	41,000	3,100	0.7	3.4	0.1	0.5
VC	0.46	0.28	7.9	1.1	170	1.1	0.01	0.07	0.002	0.01

Notes: VOCs = volatile organic compounds

SCGIER = soil component of groundwater ingestion exposure route

GCGIER = groundwater component of groundwater ingestion exposure route

Ingestion = soil ingestion

Class I = Class I groundwater categorized by Title 35 IAC Part 620 Groundwater Quality

PCE = tetrachloroethylene

TCE = tetrachloroethylene

IDCE = 1,1-dichloroethylene

cDCE = cis-1,2-dichloroethylene

tDCE = trans-1,2-dichloroethylene

VC = vinyl chloride

mg/kg = milligrams per kilogram

mg/L = milligrams per liter

developed two-tiered levels (i.e., Concern-Level and Exceedance-Level) for each contaminant to differentiate practical remediation methods for legal closure based upon the current and future uses of land where the contamination was found. However, due to the large number of potential exposure routes and the broad range of movement-related properties for contaminants, a further toxicological study would be recommended to develop pathway-specific soil remediation objectives (i.e., soil ingestion, inhalation, dermal contact, groundwater contamination induced from soil leaching, and direct groundwater ingestion). In addition, site-specific transport and fate models need to be developed to consider the potential hazards of current contamination. The site-specific parameters include, but not limited to, a hydraulic gradient, a hydraulic conductivity, dimensions of the contamination source, distances to the point of compliance, and transport media (i.e., soil, water, or air).

In 2002³⁾ and 2003, environmental soil investigations were performed at two active drycleaning facilities located in the State of Illinois in U.S. The purpose of these investigations was to determine the presence of

subsurface contamination induced from approximately 35 to 50 years of on-site drycleaning operations at the subject sites. The constituents of concern (COC) from drycleaning operations are tetrachloroethylene (i.e., perc or PCE) and its daughter products such as trichloroethylene (TCE), *cis*-1,2-dichloroethylene (cDCE), *trans*-1,2-dichloroethylene (tDCE), 1,1-dichloroethylene (1DCE), and vinyl chloride (VC). Laboratory analytical results of 22 hydrophobic adsorbants coils (i.e., soil-vapor sampling device) exposed to the interior and exterior surface soils of the subject sites and laboratory analytical results of 44 soil samples collected using intrusive soil investigation by direct push technique (GeoProbe®) from the soil-vapor sampling locations were compared to evaluate the performance of the passive soil-vapor survey.

2. Materials and Methods

According to the historical documentation (i.e., the Phase I⁴⁾ Environmental Site Assessment Reports) prepared for the subject sites, the Site A is a 2,500 square feet (sq ft) active drycleaning facility and has operated drycleaning operations since approximately

1972. Silty clay or clay is predominant beneath the Site A and the depths to water are ranged from 13 to 15 feet below the land surface (ft bls). A total of 10 soil-vapor sampling locations were advanced to approximately one to two ft bls followed by 10 soil borings at the same locations down to a maximum depth of 32 ft bls at the Site A.

The Site B is a 4,000 sq ft active drycleaning facility and the drycleaning operation has been performed at the site since 1956. Fine sand with a trace of gravel is predominant beneath the Site B and the depths to water are ranged from 6 to 8 ft bls. At this site, 12 soil-vapor sampling locations were drilled and 12 soil borings at the same locations to a maximum depth of 28 ft bls.

2.1. Passive soil-gas sampling and laboratory analyses

A soil-gas sampling device consists of a glass vial containing hydrophobic adsorbent cartridges with a length of wire attached to the vial for retrieval as seen in Fig. 1. The deployments of soil-gas sampling devices in soils and through the concrete or asphalt are also depicted in Fig. 1 and 2, respectively. Prior to installing the soil-gas sampling device, the overlying concrete slab, asphalt, or topsoil layer was removed. Surface fills were then continuously removed until natural soil was encountered. At least three-inch diameter hole is desirable to install the soil-vapor sampling device. Upon replacing a solid plastic cap from the soil-gas sampling device with a sampling cap (a plastic cap with a hole covered by

DEPLOYMENT THROUGH CONCRETE OR ASPHALT

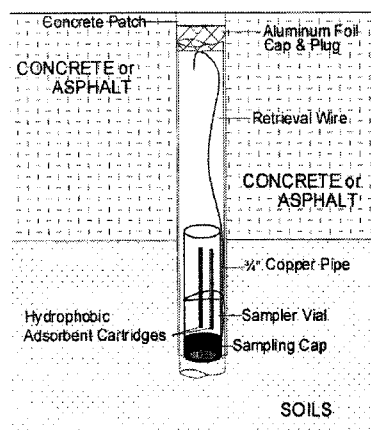


Fig. 2. Soil vapor sampling device and deployment.

screen meshing), the soil-gas sampling device was installed into the hole, with the sampling cap end facing down. The device was then covered with local soils or aluminum foil and a concrete patch. The device's locations, times and dates of emplacement, and other relevant information were recorded.

Approximately⁵⁾ 48 to 72 hours after deployment, the soil-gas sampling devices were retrieved from the boreholes and were decontaminated using gauze cloth. Then the sampling caps were replaced with solid plastic caps. The soil-gas sampling devices (i.e., vials) were labeled and delivered to the analytical laboratory.

The soil-gas sampling devices were analyzed using the United States Environmental Protection Agency (US EPA)^{2,4-24)} Method 8021 as described in the Solid Waste Manual (SW-846) for screening purposes. This method, which is modified to accommodate thermal desorption screening of the adsorbent cartridges, uses a capillary gas chromatograph (GC) with a photoionization detector (PID) in series with a flame ionization detector (FID) and a dry electrolytic conductivity detector.

The laboratory did not target VC with the Method 8021⁹⁾ because the laboratory did not use a focusing trap. Now the laboratory analyzes samples by the Method 8260 and targets VC. The soil-gas vapor adsorbents could be analyzed for petroleum-related compounds, fuel oil, gasoline, stoddard solvent, and jet fuel. More detailed analysis procedures are available upon the request.

DEPLOYMENT IN SOILS

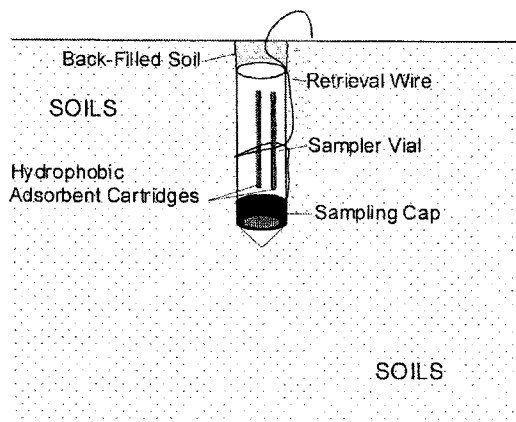


Fig. 1. Deployment of soil-vapor sampling device in soils.

2.2. Intrusive soil sampling and laboratory analyses

Soil borings were advanced using direct-push techniques. Interior soil borings were advanced using a dolly-mounted GeoProbe equipment. Prior to conducting soil sampling, a 4-inch diameter electric core machine was used to remove the overlying concrete. Soils were then continuously sampled using a 1-inch diameter sampling tube with disposable sample liners at 4-foot intervals to depths ranged from 12 to 16 ft bls.

Exterior soil borings were advanced using a truck-mounted rig equipped with hydraulically powered direct-push technology and a hollow stem auger. Prior to conducting soil sampling, the overlying asphalt or topsoil layer was removed. Soils were then continuously sampled at 4-foot intervals to the maximum depths mentioned above.

Soil samples were examined for visual and olfactory evidence of contamination and screened for the presence of organic vapors with a photo-ionization detector (PID). Within less than one or two minutes after opening sample liners, the PID readings were measured over the sample liners. The PID was equipped with a 11.7 electron volt (eV) lamp. Measurements of head space vapors are approximately proportional to the concentration of volatile organic compounds (VOCs) and can be indicative of the presence of VOC impacts. PID screening samples were collected at approximately two foot depth intervals and each soil sample was split into two equal sections. One section was placed using TerraCore into laboratory prepared sample containers consisting of one 40 milliliter (ml)-glass vial with methanol preservative, two 40 ml-glass vials with sodium bisulfate preservative, and two 40 ml-glass vials with deionized water if the soil rigorously reacts with sodium bisulfate, and one four-ounce (oz.) glass jar, labeled, and placed into a cooler with ice. It approximately takes less than five minutes from opening sample liners to completing sample collection during the soil boring installation activities to minimize the evaporation of constituents of potential concern (COPC).

Evidence of contamination was noted based on the PID readings, and a log of soil conditions was prepared. Upon completion of the sampling activities, the soil boring holes were grouted with saturated bentonite and concrete- or asphalt-patched to grade.

Disposable nitrile gloves were worn during sampling activities to prevent cross-contamination between sample intervals.

The soil samples from each boring were submitted to a laboratory for quantitative analysis. Samples were analyzed for VOCs using the US EPA Method 8260B (EPA Target Compound List)²⁵. The use of full-scan VOC analysis ensures the detection of the targeted contaminants, PCE, TCE, cDCE, tDCE, and VC.

3. Results and Discussion

3.1. Passive soil-gas laboratory results

The soil-vapor survey results are the mass collected from the vapor-phase emanating from the source. Since the vapor-phase is merely a fractional trace of the actual source, the units (i.e., nanograms) used in this report are smaller than those employed for intrusive soil sample analytical results (milligrams per kilogram). Also, the quantitative level for each COC provides a reliable basis for comparing the relative strength of any detection of that compound from various sampling locations. All 22 sampling locations at Site A and Site B were covered by asphalt for exterior and concrete slab for interior for the sites.

As presented in Table 1, the maximum detections in soil-vapor samples collected from Site A were 7,400 from E-3, 1,300 from E-2, 1,900 from E-8, and 540 nanograms (ng) from E-8 for PCE, TCE, cDCE, and tDCE, respectively. The soil-vapor PCE detection contour map, Fig. 3, indicated the source of contamination was originated from the vicinity of dry-cleaning machine and is migrating off-site.

For Site B, the maximum detections were 2,100 from E-8 and E-11, 1,000 from E-11, 320 from E-11, and 94 ng from E-11 for PCE, TCE, cDCE, and tDCE, respectively. The laboratory analytical results of the soil-vapor devices and soil samples collected from Site B are summarized in Table 2. The PCE distribution map from the soil-vapor survey is presented in Fig. 4. The soil-gas laboratory results revealed the presence of highest PCE contamination in soil in the drycleaning equipment on-site area.

3.2. Intrusive soil laboratory results

Table 1 and Table 2 also present the laboratory analytical results of 44 soil samples (22 from the intervals showing the highest physical impact such as PID

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Table 1. Comparisons of soil laboratory analytical and soil vapor results - Site A

Sample ID	Depth	Sampled date	PCE	TCE	cDCE	tDCE	VC
E-1	-	1-10-03	5,700	920	850	<25	NA
B-1	3-4.5 ft bls	1-30-03	2.5	<0.029	<0.015	<0.025	<0.022
	13.5-15 ft bls	1-30-03	<0.0013	<0.0011	<0.0027	<0.0025	<0.0019
E-2	-	1-10-03	4,100	1,300	790	<25	NA
B-2	3-4.5 ft bls	1-30-03	47	3.4	2.3	<0.12	<0.11
	13.5-15 ft bls	1-30-03	<0.0012	<0.001	<0.0024	<0.0023	<0.0017
E-3	-	1-10-03	7,400	1,100	1,400	81	NA
B-3	3-4.5 ft bls	1-30-03	660	5.7	9.6	<2.7	<2.4
	13.5-15 ft bls	1-30-03	0.047	<0.001	<0.0024	<0.0023	<0.0017
E-5	-	1-10-03	240	<25	93	<25	NA
B-4	6-8 ft bls	1-29-03	0.057	0.046	0.07	<0.0025	<0.0019
	18-20 ft bls	1-29-03	<0.0013	<0.0011	<0.0026	<0.0024	<0.0018
E-7	-	1-10-03	2,100	600	300	<25	NA
B-5	2-4 ft bls	1-29-03	2	0.39	0.18	<0.025	<0.022
	18-20 ft bls	1-29-03	<0.0013	<0.0011	<0.0026	<0.0025	<0.0019
E-8	-	1-10-03	970	550	1,900	540	NA
B-6	2-4 ft bls	1-29-03	0.14	0.032	0.082	<0.0029	<0.0022
	26-28 ft bls	1-29-03	<0.0014	<0.0011	<0.0027	<0.0026	<0.0019
E-9	-	1-10-03	1,400	690	740	<25	NA
B-7	6-8 ft bls	3-14-03	36	0.42	0.47	<0.13	<0.11
	18-20 ft bls	3-14-03	<0.0014	<0.0011	<0.0028	<0.0026	<0.002
E-10	-	1-10-03	430	<25	<25	<25	NA
B-8	4-6 ft bls	3-14-03	0.014	0.0052	<0.003	<0.0029	<0.0022
	18-20 ft bls	3-14-03	<0.0013	<0.0011	<0.0027	<0.0025	<0.0019
E-11	-	1-10-03	72	<25	<25	<25	NA
B-9	4-6 ft bls	3-14-03	<0.0014	<0.0011	<0.0028	<0.0026	<0.0019
	18-20 ft bls	3-14-03	<0.0014	<0.0012	<0.0029	<0.0027	<0.002
E-12	-	1-10-03	39	<25	<25	<25	NA
B-10	12-14 ft bls	3-14-03	<0.0015	<0.0012	<0.0029	<0.0028	<0.0021
	18-20 ft bls	3-14-03	<0.0015	<0.0012	<0.0029	<0.0028	<0.0021

Notes:

- 1) PCE = Tetrachloroethylene, TCE = Trichloroethylene, cDCE = *cis*-1,2-dichloroethylene, tDCE = *trans*-1,2-dichloroethylene, and VC = vinyl chloride
- 2) Soil samples (i.e., B-1) were analyzed by the US EPA Method 5035/8260B and expressed in mg/kg.
- 3) Soil vapor samples (i.e., E-1) were analyzed by the US EPA Method 8021/8015B and expressed in nanograms (ng).
- 4) E = Soil vapor sampling location. E-4 and E-6 do not have corresponding soil boring locations.
- 5) B = Soil boring location
- 6) <25 = below reported quantitation level
- 7) NA = not analyzed
- 8) VC were not analyzed for vapor samples because Method 8021 did not use a focusing trap to target VC in 2002. Now VC are analyzed by 8260.

readings and 22 from deep soil each boring) collected from Site A and Site B. The intrusive soil sampling locations could be different from the soil-vapor sampling locations by maximum six inches.

The maximum detected concentrations or highest laboratory detection limits of PCE, TCE, cDCE, tDCE, and VC at Site A were 660, 5.7, 9.6, <2.7, and <2.4 mg/kg, respectively, in the sample collected

from 3 to 4.5 ft bls at boring location B-3. The highest PCE concentration was above the soil saturation limit of PCE (i.e., 240 mg/kg pursuant to the *Title 35 Illinois Administrative Code Part 742 Tiered Approach to Corrective Action Objectives*).

At Site B, the maximum detected concentrations were 3,700, 15, 4.8, 2.9, and 0.19 mg/kg for PCE, TCE, cDCE, tDCE, and VC, respectively. The highest

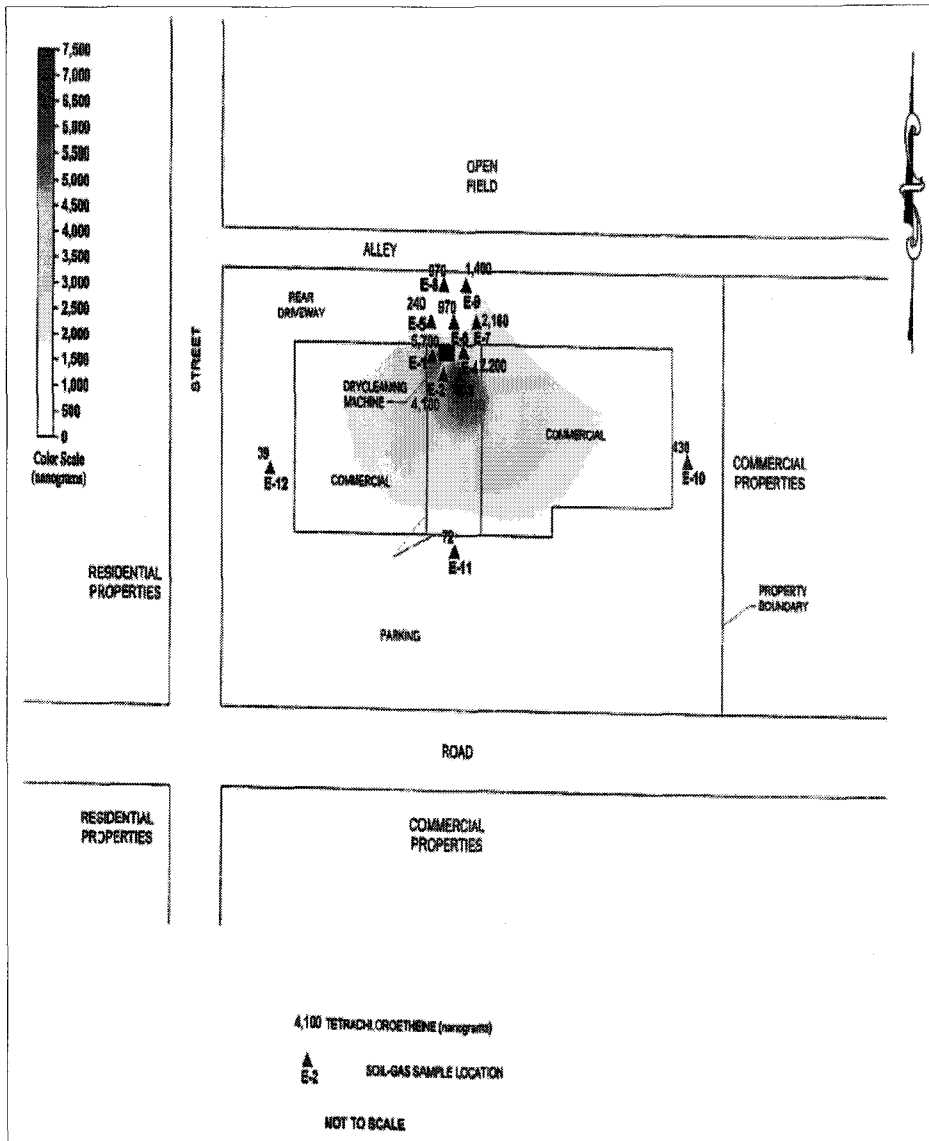


Fig. 3. Soil-vapor analytical contour map-Site A.

PCE and TCE were detected in the soil sample collected from 10 to 12 ft bls at boring location B-12. The highest PCE concentration detected at Site B was also above the soil saturation limit of PCE.

Laboratory analytical results of PCE in the soil samples and the soil-vapor samples collected from Site A and Site B are compared in Fig. 5 and Fig. 6, respectively. The figures show the relative detections of PCE and relative values of PCE concentrations in surface soil, in subsurface (i.e., deeper) soil, and sum of the surface and subsurface soil each sample. Each

detection or concentration was divided by the highest detection or concentration of corresponding compound in either surface soil or subsurface soil to determine the relative value.

For Site A, considering the results for the shallow soil samples, the soil-vapor survey effectively screened the site to identify the location reporting the highest soil concentration of PCE and TCE as presented in Fig. 5. While the second highest soil-vapor detection did not correlate with the second highest soil concentration, it did represent the fourth highest soil concen-

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Table 2. Comparisons of soil laboratory analytical and soil vapor results - Site B

Sample ID	Depth	Sampled date	PCE	TCE	cDCE	tDCE	VC
E-1	-	7-15-02	88	<25	<25	<25	NA
B-1	1-2 ft bls	7-30-02	<0.0059	<0.0059	<0.0059	<0.0059	<0.0059
	8-10 ft bls	7-30-02	<0.0058	<0.0058	<0.0058	<0.0058	<0.0058
E-2	-	7-15-02	522	73	<25	<25	NA
B-2	2-3 ft bls	7-30-02	0.0056	<0.0051	<0.0051	<0.0051	<0.0051
	8-10 ft bls	7-30-02	<0.0056	<0.0056	<0.0056	<0.0056	<0.0056
E-3	-	7-15-02	1,200	240	<25	<25	NA
B-3	4-6 ft bls	7-30-02	0.021	<0.0051	<0.0051	<0.0051	<0.0051
	18-20 ft bls	7-30-02	<0.0045	<0.0045	<0.0045	<0.0045	<0.0045
E-4	-	7-15-02	1,000	32	<25	<25	NA
B-4	1-2 ft bls	7-31-02	0.067	<0.005	<0.005	<0.005	<0.005
	8-10 ft bls	7-31-02	<0.0058	<0.0058	0.0083	<0.0058	<0.0058
E-5	-	7-15-02	880	85	<25	<25	NA
B-5	8-10 ft bls	7-31-02	0.055	0.028	0.019	<0.0044	<0.0044
	18-20 ft bls	7-31-02	<0.0044	<0.0044	<0.0044	<0.0044	<0.0044
E-6	-	7-15-02	1,000	57	<25	<25	NA
B-6	6-8 ft bls	7-30-02	3	0.095	0.039	0.0068	<0.0056
	18-20 ft bls	7-30-02	<0.0048	<0.0048	<0.0048	<0.0048	<0.0048
E-7	-	7-15-02	1,900	780	<25	<25	NA
B-7	6-8 ft bls	7-31-02	19	0.59	0.15	0.02	<0.0055
	18-20 ft bls	7-31-02	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053
E-8	-	7-15-02	2,100	550	<25	<25	NA
B-8	4-6 ft bls	7-31-02	18	0.5	0.041	<0.0053	<0.0053
	18-20 ft bls	7-31-02	<0.0045	<0.0045	<0.0045	<0.0045	<0.0045
E-9	-	7-15-02	1,200	150	<25	<25	NA
B-9	4-6 ft bls	7-30-02	6.2	0.039	<0.0046	<0.0046	<0.0046
	18-20 ft bls	7-30-02	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053
E-10	-	7-15-02	1,200	100	<25	<25	NA
B-10	6-8 ft bls	7-31-02	0.92	1.7	0.077	2.9	0.19
	16-20 ft bls	7-31-02	<0.004	<0.004	<0.004	<0.004	<0.004
E-11	-	7-15-02	2,100	1,000	320	94	NA
B-11	6-8 ft bls	7-30-02	49	9.5	4.8	0.069	0.019
	16-20 ft bls	7-30-02	<0.0043	<0.0043	<0.0043	<0.0043	<0.0043
E-12	-	7-15-02	1,700	430	60	<25	NA
B-12	10-12 ft bls	7-30-02	3,700	15	<2.7	0.024	0.071
	30-32 ft bls	7-30-02	0.018	<0.0049	<0.0049	<0.0049	<0.0049

Notes:

- 1) PCE = Tetrachloroethylene, TCE = Trichloroethylene, cDCE = *cis*-1,2-dichloroethylene, tDCE = *trans*-1,2-dichloroethylene, and VC = vinyl chloride
- 2) Soil samples (i.e., B-1) were analyzed by the US EPA Method 5035/8260B and expressed in mg/kg.
- 3) Soil vapor samples (i.e., E-1) were analyzed by the US EPA Method 8021/8015B and expressed in nanograms (ng).
- 4) E = Soil vapor sampling location.
- 5) B = Soil boring location
- 6) <25 = below reported quantitation level
- 7) NA = not analyzed
- 8) VC were not analyzed for vapor samples because Method 8021 did not use a focusing trap to target VC in 2002. Now VC are analyzed by 8260.

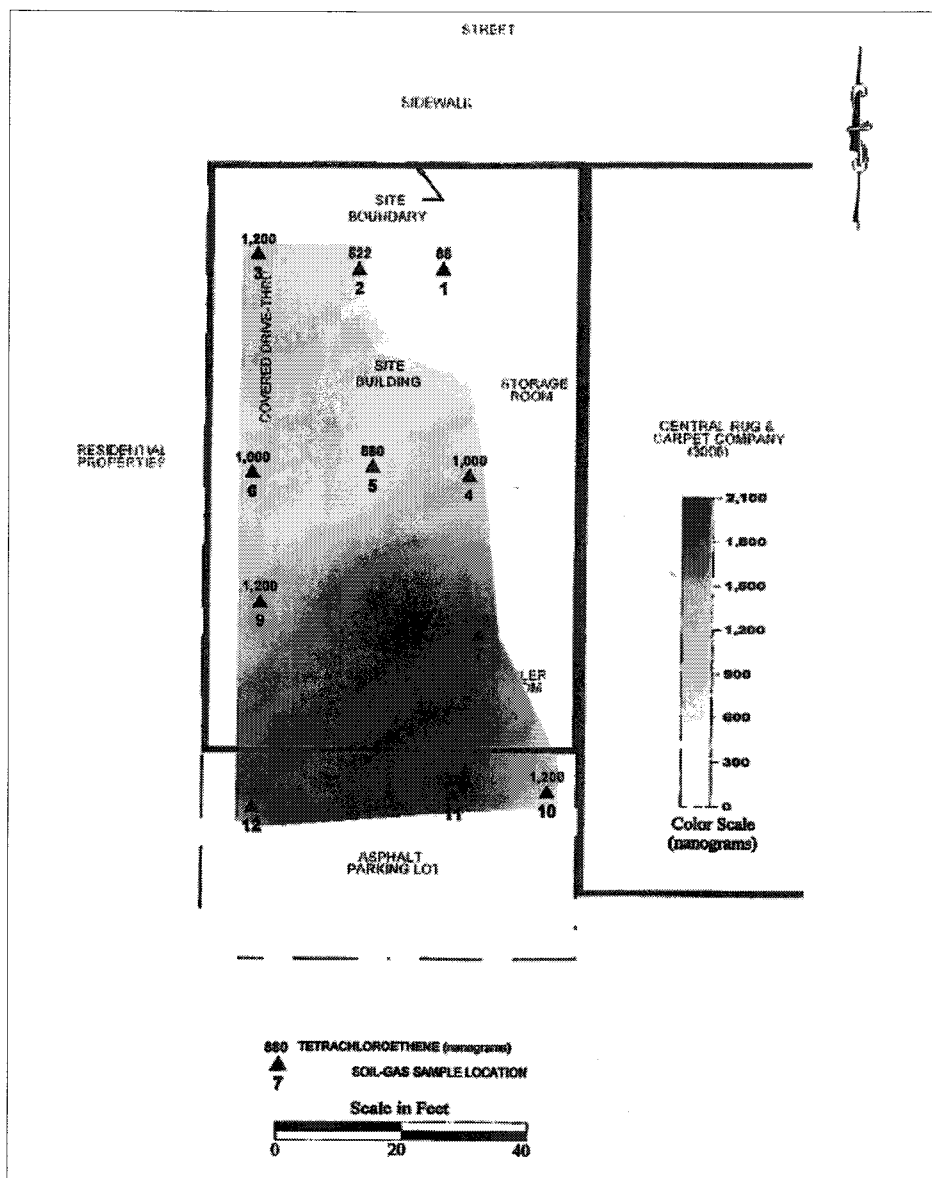


Fig. 4. Soil-vapor analytical contour map-Site B.

tration of PCE identified. In general, the 5 highest soil-vapor detections, which were all greater than 1,000 ng, identified the 5 locations reporting the highest soil concentration of PCE. It is quite possible that at the soil-vapor sampling location E-1, the contaminants may be present at a depth less than 3 ft bls but at a lower concentration, which could provide a higher soil-vapor measurement because the source is closer to the soil-vapor sampling device.

At Site B, the highest PCE soil-gas was measured

at E-8 and E-11. In contrast, the maximum concentration of PCE in soil was detected at B-12 as shown in Table 2. It is difficult to define the correlation between the relative detections of soil-vapor and the relative concentrations of PCE in soil at Site B as presented in Fig. 6. Note that at boring location B-12 the soil sample the maximum PCE was detected was taken at a depth interval from 10 to 12 ft bls, at least ten times of that the soil-vapor sample taken at E-8 and E-11. Since the depth at which the contamination

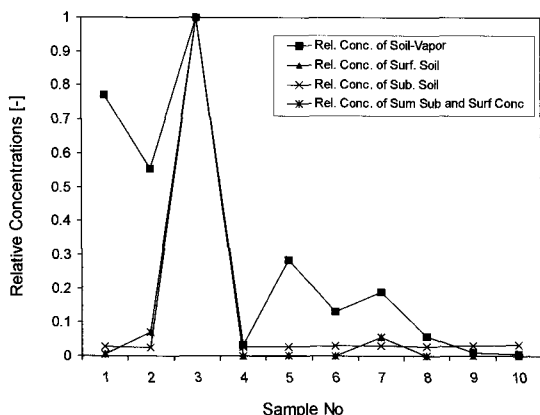


Fig. 5. Comparisons of Laboratory Analytical Results of Soil Samples and Soil-Vapor Samples at Site A.

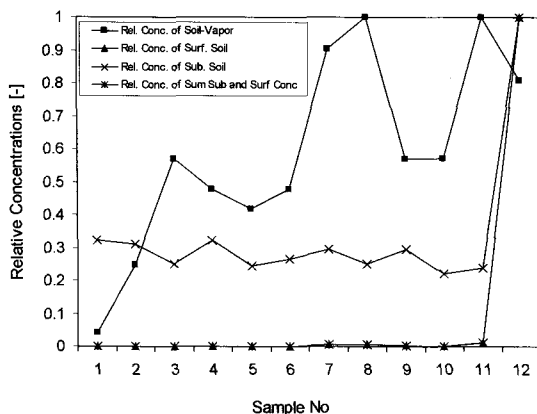


Fig. 6. Comparisons of Laboratory Analytical Results of Soil Samples and Soil-Vapor Samples at Site B.

is from the soil-gas sampling device affects the amount of compounds that will be present in the soil-vapor, it might be acceptable to state that the soil-vapor survey at this site was failed to identify the extent of subsurface contamination due to the relatively long distance between the soil-vapor samplers and the location of actual contamination.

The distance from the samplers to the actual contamination, which is the most valuable factor to determine the effectiveness of soil-vapor survey, mainly depend on the history of contaminant-generating operations and geologic formation at a site. Longer dry-cleaning operation history (i.e., 50 years) and presence of fine sand at the beneath Site B allow the contaminants to migrate farther and deeper over a fixed time compared to Site A (i.e., 35 years of drycleaning operation and the presence of silty clay as a predom-

inant lithology).

It is also important to note that when soil-vapor sample locations are covered with asphalt or concrete, sample measurements are often increased significantly. Such distortion can be attributed to the fact that gas rising from sources beneath impermeable caps tends to reach equilibrium underneath the cap. Thus, a reading taken below or near an impermeable surface is much higher than it would be in the absence of such a cap.

Another critical fact is that, whatever the relative concentrations of source and associated soil gas, best results are achieved when the ratio of soil-gas measurements to actual subsurface concentrations remains as close to constant. It is the reliability and consistency of this ratio, not the particular units of mass (i.e., nanograms in this study) that determine usefulness. Thus, it is necessary to conduct following intrusive sampling at one or two points which show relatively high soil-gas vapor values to obtain corresponding concentrations of soil and ground-water contaminants. These correspondent values furnish the basis for approximating the required ratio. Once that ratio is established, it can be used in conjunction with the soil-gas measurements (regardless of the units adopted) to estimate subsurface contaminant concentrations across the survey field.

Conclusively, it is important to keep in mind that specific conditions at individual sample points, such as soil porosity, permeability, depth to contamination, and presence of perched ground water, can have significant impact on soil-gas measurements at those locations. When soil-gas survey is handled in this way, the data provide information that can yield substantial savings in drilling costs and in time. For example, approximately 25% of the time and budget for conventional investigation activities was sufficient to complete the soil-gas survey at the cases presented in this study. They furnished, among other things, a checklist of compounds expected at each survey location and helped to determine how and where drilling budgets can most effectively be spent.

4. Conclusions

Laboratory analytical results of 22 sets of hydrophobic adsorbent coils containing surface soil-vapor and two soil samples collected by conventional in-

trusive method from each boring location at two active dry cleaning facilities in the State of Illinois, U.S.A, were presented to evaluate the performance of soil-gas survey.

The most critical factor to determine the effectiveness of soil-gas survey is the distance from the soil-vapor sampling device to the actual contamination, which is a function of soil porosity, permeability, primary lithology, and other geological and hydrogeological site-specific parameters. Also this factor can be affected by the history of contaminant-generating operations.

The laboratory analytical results in this study showed longer drycleaning operation history (i.e., 50 years) and presence of fine sand at the beneath Site B allow the contaminants to migrate farther and deeper over a fixed time compared to Site A (i.e., 35 years of drycleaning operation and the presence of silty clay as a predominant lithology) so that the soil-vapor survey is not likely the most effective environmental site investigation method alone for Site B. However, for Site A, the soil-vapor survey successfully screened the site to identify the location reporting the highest soil concentration of chlorinated solvents.

Since the best soil-vapor survey results are achieved when the ratio of soil-vapor measurements to actual subsurface concentrations remains as close to constant a minimum intrusive soil and groundwater investigation should be followed to determine the reliability and consistency of the ratio. When soil-gas survey is handled with this precautionary understanding, the data provide information that can yield substantial savings in drilling costs and in time.

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