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January 23, 2006

**Denis L. Brown**

Jerry Wickham  
Alameda County Health Care Services Agency  
1131 Harbor Bay Parkway, Suite 250  
Alameda, CA 94502-6577

**Shell Oil Products US**  
HSE – Environmental Services  
20945 S. Wilmington Ave.  
Carson, CA 90810-1039  
Tel (707) 865 0251  
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Email [denis.l.brown@shell.com](mailto:denis.l.brown@shell.com)

Re: Remedial Action and Additional Site Investigation Work Plan  
Shell-branded Service Station  
2120 Montana Street  
Oakland, California  
SAP Code 135675  
Incident No. 98995740

Dear Mr. Wickham:

Attached for your review and comment is a copy of the *Remedial Action and Additional Site Investigation Work Plan* for the above referenced site. Upon information and belief, I declare, under penalty of perjury, that the information contained in the attached document is true and correct.

If you have any questions or concerns, please call me at (707) 865-0251.

Sincerely,

Denis L. Brown  
Project Manager

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C A M B R I A

January 23, 2006

Mr. Jerry Wickham  
Alameda County Health Care Services Agency  
1131 Harbor Bay Parkway, Suite 250  
Alameda, California 94502-6577

Re: **Remedial Action and Additional Site Investigation Work Plan**  
Shell-branded Service Station  
2120 Montana Street  
Oakland, California  
Incident # 98995740  
Cambria Project #248-0733-008  
ACHCSA Case # RO-0173



Dear Mr. Wickham:

Cambria Environmental Technology, Inc. (Cambria) prepared this work plan on behalf of Equilon Enterprises LLC dba Shell Oil Products US (Shell). Shell recommended groundwater extraction (GWE) system expansion and additional soil vapor investigation in Cambria's October 24, 2005 *Subsurface Investigation and Vapor Sampling Report*. Alameda County Health Care Services Agency (ACHCSA) concurred with these recommendations in their November 10, 2005 letter to Shell. The scope of work presented in this work plan complies with ACHCSA and San Francisco Regional Water Quality Control Board (SFRWQCB) guidelines.

## **SITE LOCATION AND DESCRIPTION**

**Site Location:** This operating Shell-branded service station is located at the Montana Street and Fruitvale Avenue intersection in Oakland, California (Figures 1 and 2). Commercial properties lie to the north and east of the site, and residential properties lie to the west. Montana Street, a freeway on-ramp, and Highway 580 are located south of the site.

**Site Lithology:** The site is located within the East Bay Plain groundwater basin of Alameda County, west of the Hayward Fault. The East Bay Plain area is characterized by Quaternary age Bay Mud composed of unconsolidated plastic clay and silty clay, rich in organic material with some lenses of silt and sand. Beneath the Bay Mud deposits lay unconsolidated younger and older alluvial deposits (Hickenbottom and Muir, 1988).

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The site is underlain by interbedded sandy silt, silty sand, clayey sand, clay, and sand to the total explored depth of 28 feet below grade (fbg). In boring logs from wells MW-1, MW-2, and SB-3, a small sand lens is observed below 15 fbg (~underground storage tank [UST] complex bottom). The log for MW-4 shows this lens, but at a shallower depth. The logs for SB-4, SB-5, and SB-8 show similar lenses located deeper than 15 fbg. This sand lens or series of sand lenses may serve as primary groundwater transport pathways.

**Hydrogeology:** The Older Alluvium is the dominant aquifer in the East Bay Plain area west of the Hayward Fault. Regional groundwater flow is to the west-southwest toward San Francisco Bay.




The site elevation is approximately 150 feet above mean sea level. Historically, groundwater depth has ranged from approximately 10.1 to 14.3 fbg. Groundwater flow direction is predominantly to the south-southwest, but has varied to the northwest. A rose diagram of groundwater flow direction is included on Figure 3.

## PREVIOUS INVESTIGATIONS

**1997 Dispenser and Turbine Sump Upgrades:** In November 1997, Paradiso Mechanical (Paradiso) of San Leandro, California upgraded fuel-related equipment at the service station. Secondary containment was added to the three existing dispensers and to the turbine sumps above the USTs. Soil samples D-1, D-2, and D-3 were collected from beneath the dispensers at a depth of approximately 5 fbg (Figure 2). Soil samples were not collected from beneath the associated piping because it was not exposed during upgrade activities. The maximum total petroleum hydrocarbons as gasoline (TPHg), benzene, and methyl tertiary butyl ether (MTBE) (analyzed by EPA Method 8020) concentrations were reported in sample D-3 at 59 parts per million (ppm), 0.76 ppm, and 1.1 ppm, respectively. Cambria's February 3, 1998 *Dispenser Soil Sampling Report* summarizes these activities.

**1999 Subsurface Investigation:** In October 1999, Cambria advanced soil borings SB-1 through SB-3 (Figure 2). SB-1 was advanced to 16 fbg, and SB-2 and SB-3 were advanced to 20 fbg. The maximum detected hydrocarbon concentrations in soil were 54 ppm TPHg in boring SB-1 at 5 fbg, 0.019 ppm benzene in boring SB-2 at 15 fbg, and 0.24 ppm MTBE (by EPA Method 8260) in boring SB-2 at 10 fbg. The maximum reported hydrocarbon concentrations in groundwater were 2,380 parts per billion (ppb) TPHg in boring SB-3, 10.6 ppb benzene in SB-2, and 3,210 ppb MTBE (by EPA Method 8020) in SB-3. Cambria's June 7, 2000 *Subsurface Investigation Report and Work Plan for Installation of Groundwater Monitoring Wells* summarizes these activities.

**2001 Monitoring Well Installation:** In February 2001, Cambria installed groundwater monitoring wells MW-1, MW-2, and MW-3. The maximum TPHg and MTBE concentrations were found in soil samples collected from monitoring well MW-2, located in Montana Street across from the site. TPHg was detected at 21 fbg at a concentration of 10 ppm, and MTBE was detected at 15.5 fbg at a concentration of 5.2 ppm. The maximum detected benzene concentration of 0.066 ppm was detected in the soil sample collected from monitoring well MW-1 at 10 fbg. Cambria's May 22, 2001 *Groundwater Monitoring Well Installation Report* summarizes these activities.



**2001 Sensitive Receptor Survey, Well Survey, and Conduit Study:** In August 2001, Cambria conducted a sensitive receptor survey, well survey, and conduit study. ACHCSA requested this work in a July 23, 2001 letter to Shell. The sensitive receptor survey indicated that no known water-producing wells are located within ½-mile radius of the site. The nearest surface water body is Sausal Creek, located approximately 240 feet west-northwest of the site. Sausal Creek is diverted into a 10-foot by 10-foot culvert, located approximately 420 feet west-northwest of the site, with a flow line depth shallower than the typical water table at the site. Sausal Creek resurfaces approximately 730 feet southwest of the site. The utility study indicated that utility conduits in the area do not typically encounter groundwater, and likely do not act as preferential pathways for contaminant migration. Based on this information, no known receptors are likely to be impacted by chemicals at the site. However, at the time of this survey, the potential for hydrocarbon vapor migration to the neighboring residences had not been investigated. Cambria's September 24, 2001 *Sensitive Receptor Survey, Well Survey, and Conduit Study Report* summarizes these activities.

**2001-2003 Mobile GWE:** In August 2001, mobile GWE from wells MW-1 and TBW-N, using a vacuum truck, began at the site. Mobile GWE was conducted on a weekly basis through November 2001, on a bi-weekly basis through December 2001, on a monthly basis through March 2003, and then again on a weekly basis between August 19, 2003 and January 6, 2004. The cumulative estimated mass of TPHg and MTBE GWE removed at the site is 25.27 pounds and 8.13 pounds, respectively. Additionally, approximately 2.68 pounds of separate-phase hydrocarbons (SPH) were removed from wells MW-1 and TBW-N through manual bailing and mobile GWE.

**2002 Soil Vapor Extraction (SVE) Test:** In June 2002, Cambria performed a 5-day SVE test from tank backfill well TBW-E to remove petroleum hydrocarbon mass and to determine whether extracted vapor concentrations would be sustained over a long period of time. High initial vapor concentrations indicated the presence of source material available for recovery within the UST facility. Operation of the internal combustion engine over the 5-day test period resulted in an order of magnitude decrease in TPHg and MTBE vapor concentrations. Based on operating parameters and vapor sample analytical results collected throughout the test period, the TPHg, benzene, and MTBE vapor-phase mass removal over the test period is estimated at 176, 0.998,

and 1.92 pounds, respectively. Cambria's September 4, 2002 *Subsurface Investigation, Soil Vapor Extraction Pilot Test Report, and Interim Remediation Work Plan* summarizes these activities.

**2002 Monitoring Well Installation:** In June 2002, Cambria installed groundwater monitoring wells MW-4 and MW-5 (Figure 2). TPHg and benzene, toluene, ethylbenzene, and xylenes (BTEX) were not detected in soil samples collected from MW-4. TPHg was detected in samples collected from MW-5 from 9 fbg and 19 fbg at concentrations of 1.3 ppm and 18 ppm, respectively. Benzene was detected in samples collected from MW-5 from 9 fbg and 19 fbg at concentrations of 0.0083 ppm and 0.0071 ppm, respectively. MTBE was not detected in any soil samples collected during this investigation. Cambria's September 4, 2002 *Subsurface Investigation, Soil Vapor Extraction Pilot Test Report, and Interim Remediation Work Plan* summarizes these activities.

**2003 GWE System:** Cambria's September 4, 2002 *Subsurface Investigation, Soil Vapor Extraction Pilot Test Report, and Interim Remediation Work Plan* proposed GWE as interim remediation. Construction of a GWE system began in early February 2003, and start-up occurred on April 2, 2003. The GWE system is designed to extract groundwater from monitoring well MW-1 and tank backfill well TBW-N. Due to the presence of SPH, Cambria did not operate the GWE system between July 18, 2003 and April 21, 2004. Cambria re-designed the GWE system to include an oil-water separator. Modifications to the GWE system were completed on March 31, 2004. An oil-water separator, two particle filters in parallel, and a series of three 1,000-pound aqueous-phase carbon vessels treat the groundwater stream. Treated groundwater is discharged to the sanitary sewer under the authorization of an East Bay Municipal Utilities District (EBMUD) wastewater discharge permit. As of December 30, 2005, a total of approximately 432,139 gallons of groundwater has been extracted. A total of approximately 16.8 pounds of TPHg, 0.657 pounds of benzene, and 4.25 pounds of MTBE has been recovered.

**2003 Tank Repair:** In November 2003, Able Maintenance of Santa Rosa, California exposed the regular grade UST for inspection by the tank manufacturer (Xerxes Company). Xerxes Company found a small crack on the bottom of the tank. The crack was investigated, repaired with fiberglass resin, and air tested for the City of Oakland Fire department by the Xerxes Company. After the Xerxes Company completed their air test, Able Maintenance called in a third-party tank tester to precision test the tank. Afford-a-Test completed that test, and the tank was certified as tight. Able Maintenance monitored the tank through Shell's Veeder-Root monitoring system since the repair, and it passed the associated pressure tests.


**2004 Fuel System Upgrades:** In May 2004, Paradiso upgraded the station's fuel dispensers and UST sumps. Cambria collected soil samples D-1-4.0, D-2-4.0, and D-3-4.0 from underneath the dispensers (Figure 2). TPHg was detected in D-2-4.0 and D-3-4.0 at concentrations of 1,900 and 110 ppm, respectively. Benzene was detected in D-2-4.0 at a concentration of 1.7 ppm.

Ethylbenzene was detected in D-2-4.0 and D-3-4.0 at concentrations of 21 and 3.1 ppm, respectively. Xylenes were detected in D-1-4.0 and D-2-4.0 at concentrations of 0.17 and 57 ppm, respectively. MTBE was detected in all three samples at concentrations ranging from 0.65 ppm in D-3-4.0 to 5.8 ppm in D-2-4.0. Lead was detected in all three samples at concentrations ranging from 7.3 ppm in D-2-4.0 to 8.7 ppm in D-3-4.0. Cambria's November 1, 2004 *Dispenser Upgrade Sampling Report* summarizes these activities.

**2004 SVE Test:** In July 2004, Cambria performed a 5-day SVE test from monitoring well MW-1 to evaluate enhanced removal of petroleum hydrocarbons and MTBE from the source area. Cambria initially used the GWE system's submersible pneumatic pump in MW-1 to dewater the soils, but switched to an electric pump to achieve greater drawdown. Data from MW-1 suggests that SVE was effective as interim remediation. An average flow rate of 30.3 standard cubic feet per minute was obtained with a measured wellhead vacuum ranging from 249.8 to 382.9 inches water column. High TPHg, BTEX and MTBE vapor concentrations (up to 10,240 parts per million by volume total volatile organic compounds [VOCs]) were sustained over the duration of SVE. Cambria measured up to 0.8 feet (9.6 inches) of SPH in off-site monitoring well MW-2 during dewatering and SVE from on-site well MW-1. Based on operating parameters and vapor sample analytical results collected throughout the test period, the TPHg, benzene, and MTBE vapor-phase mass removal over the test period is estimated at 257, 0.822, and 1.22 pounds, respectively. Cambria's January 18, 2005 *Interim Remediation Report* summarizes these activities.

**2005 Cone Penetrometer Test (CPT) Borings and Soil Vapor Investigation:** On June 14 through June 16, 2005, Cambria oversaw the advancement of four CPT borings (SB-4, SB-5, SB-6, and SB-8) and installation of two soil vapor probe pairs (SV-D and SV-E). Five CPT borings and five soil vapor probes were originally proposed in our January 18, 2005 *Interim Remediation Report*. However, subsurface utilities and refusal prevented SB-7 from being advanced, and the presence of subsurface debris prevented field staff from hand clearing the SV-A through SV-C boring locations. Due to utility conflicts in the planter, the soil vapor probe pairs that were completed are located farther from the western property boundary than originally proposed. Figure 2 shows all attempted and completed soil boring and vapor probe locations.

At each CPT location, an ultraviolet induced fluorescence (UVIF) module was used to identify SPH in the subsurface. However, no evidence of an SPH plume was found during this investigation. The maximum TPHg concentration of 23 ppm in soil was detected in SB-4 at 20 fbg. Benzene was detected only in soil collected from SB-4 at 5 fbg, at a concentration of 0.0072 ppm. The maximum MTBE concentration in soil was 0.23 ppm, detected in SB-8 at 15 fbg. The maximum concentration of tertiary butyl alcohol (TBA) in soil was 9.3 ppm, detected in SB-6 at 15 fbg. Grab groundwater samples collected from the CPT borings contained maximum concentrations of 28,000 ppb TPHg (SB-5-W), 100 ppb benzene (SB-5-W), 1,100 ppb MTBE (SB-6-W), and 15,000 ppb TBA (SB-6-W).



Cambria collected soil vapor samples from each probe pair (SV-D and SV-E), at both 5 and 10 fbg, on August 24, 2005. Sample SV-D-5.0 contained 22,000 micrograms per cubic meter ( $\mu\text{g}/\text{m}^3$ ) TPHg, and sample SV-E-5.0 contained 25,000  $\mu\text{g}/\text{m}^3$  TPHg. Sample SV-D-10.0 contained 16,000,000  $\mu\text{g}/\text{m}^3$  TPHg and 480  $\mu\text{g}/\text{m}^3$  benzene. Sample SV-E-10.0 contained 78,000,000  $\mu\text{g}/\text{m}^3$  TPHg and 46,000  $\mu\text{g}/\text{m}^3$  benzene. Soil vapor concentrations for samples collected at 5 fbg from SV-D and SV-E are below the SFRWQCB Environmental Screening Level (ESL) for TPHg (26,000  $\mu\text{g}/\text{m}^3$ ) for shallow soil gas in a residential setting. TPHg concentrations in 10 fbg samples from both soil vapor probes exceeded the applicable ESL. Benzene was not detected in samples collected from the soil vapor probes at 5 fbg, although the reporting limit for SV-D-5.0 was greater than the SFRWQCB ESL of 85  $\mu\text{g}/\text{m}^3$ . Benzene concentrations in samples collected from both soil vapor probes at 10 fbg exceeded the applicable ESL. The results indicate that higher concentrations of hydrocarbons, carbon dioxide, and methane in vapor are present at 10 fbg than 5 fbg. Higher concentrations of oxygen are present in the 5 fbg samples. These results suggest that biological attenuation of hydrocarbons is occurring.

Since the soil vapor data was originally reported to ACHCSA on October 24, 2005, Cambria requested and received MTBE and TBA data for the existing vapor samples. MTBE and TBA were not detected in any soil vapor samples, though the detection limits for some samples were elevated. A revised soil vapor analytical data table, including MTBE and TBA results, is presented as Table 1.

On August 10, 2005, Cambria staff conducted a survey of businesses and residences within approximately 200 feet of the subject site to determine the building foundation type and the presence of any wells (existing or abandoned), sump pumps, basements or crawl spaces on the surrounding properties. Cambria received responses for four of the nine properties within the survey area. No wells (existing or abandoned) or sump pumps were identified in any of the responses. Facilities at 3401, 3407, 3409 and 3411 Fruitvale Avenue are all located in the same building. So, it can be assumed that the responses for 3401 and 3407 Fruitvale Avenue apply to the other properties within that building. These responses indicated that the building was of slab-on-grade foundation construction with no basement or crawl spaces. Based on external building features, 3400 Fruitvale Avenue, located across Fruitvale Avenue from the site, appears to be of slab-on-grade construction with no basements or crawl spaces. As reported by the tenant and/or owner, the property west of and adjacent to the subject site, 2110 Montana Street, contains a concrete basement approximately one-fourth the size of the total structure, and an earthen crawl space. The property four doors down in the west direction, 2026 Montana Street, contains an earthen crawl space but no basement, as reported by the property owner. Although we did not receive a response regarding the two other properties on this street (2106 and 2102 Montana Street), the buildings appear to be similarly constructed, and may contain basements and/or crawl spaces.

Cambria's October 24, 2005 *Subsurface Investigation and Vapor Sampling Report* presents detailed result of the CPT borings, vapor probe installation and sampling, and the door-to-door survey.

**Groundwater Monitoring:** Quarterly groundwater monitoring has been conducted at the site since well installation in 2001. Tank backfill well TBW-N, one of four tank backfill wells at the site and the only tank backfill well which encounters groundwater, was added to the quarterly monitoring program in September 2001. Since June 2001, SPH have been detected intermittently in monitoring well MW-1 as well as in tank backfill well TBW-N. SPH were observed in well MW-2 near the end of SVE testing in July 2004. Figure 2 presents data from the third quarter 2005 groundwater monitoring event.



During the third quarter 2005, TPHg was detected in groundwater from wells MW-2, MW-4, MW-5 and TBW-N at concentrations ranging from 1,900 ppb (MW-5) to 140,000 ppb (MW-2). Benzene was detected in groundwater from wells MW-1, MW-2 and MW-5 at concentrations ranging from 5.3 ppb (MW-5) to 490 ppb (MW-2). MTBE was detected in all monitoring wells except MW-5 at concentrations ranging from 0.54 ppb (MW-3) to 2,400 ppb (MW-1). TBA was detected in groundwater samples from wells MW-1, MW-2, and TBW-N at concentrations ranging from 1,700 ppb (TBW-N) to 13,000 ppb (MW-1). Analytical results for additional oxygenates di-isopropyl ether (DIPE), ethyl tert-butyl ether (ETBE), and tert-amyl methyl ether (TAME) were below laboratory reporting limits.

## PROPOSED GWE SYSTEM EXPANSION

In order to enhance hydraulic control of MTBE in groundwater, Shell recommends installing two 4-inch-diameter GWE wells near the southern boundary of the site and connecting them to the existing GWE system. Proposed well EW-1 will replace 2-inch-diameter monitoring well MW-1 as a GWE point. Proposed well EW-2 will extend the hydraulic influence of the GWE system to the south-southwest. The existing monitoring well network is considered sufficient to monitor groundwater concentration trends and to determine GWE system effectiveness. Figure 3 shows the locations of the existing remediation compound, and the proposed wells and expanded trench layout.

Groundwater will be extracted from proposed wells EW-1 and EW-2 using new submersible pneumatic pumps. The existing air compressor will provide compressed air to drive the pneumatic pumps. Extracted groundwater will be pumped from the wells into the existing baffled oil-water separator located in the remediation compound. To prevent overflow of the separator, a liquid-level switch in the separator will shut off the pumps when any of the separator chambers become full. Extracted groundwater will be pumped from the separator, using a transfer pump,



through two silt filters and then through three 1,000-pound aqueous-phase carbon vessels (in series) prior to discharge to the local sanitary sewer system under the existing EBMUD permit. Flow meters, pressure gauges, and sample ports will be used to control and monitor system operation. SPH is contained in a holding chamber within the oil-water separator. Accumulated SPH is off-hauled for disposal as needed.

### Work Tasks

**Permits:** Cambria will notify EBMUD of the anticipated increase in groundwater discharge flow rate. Cambria will obtain a drilling permit for installing the GWE wells from the Alameda County Public Works Agency.

**Health and Safety Plan:** Cambria will prepare a site-specific health and safety plan for well installation activities. Cambria and the installation contractor will prepare site-specific health and safety plans for construction activities.

**Request for Bid:** Cambria will prepare a request-for-bid for construction services to expand the GWE system. A contractor will be selected based on quality of bid, availability, and quality of service.

**Utility Clearance:** The proposed drilling and trenching locations will be marked and the locations cleared through Underground Service Alert prior to drilling and construction activities, respectively.

**Extraction Well Installation:** Two borings (EW-1 and EW-2) will be drilled at the locations shown on Figure 3 to approximately 30 fbg. The borings will be drilled using hollow-stem auger drilling equipment and converted to GWE wells.

A Cambria geologist will supervise the drilling and describe encountered soils using the Unified Soil Classification System. Soil samples from the borings will be collected continuously for soil description. Soil samples will be collected at 5-foot intervals for possible chemical analyses and organic vapor screening with a photo-ionization detector (PID). Cambria will prepare an exploratory boring log for each boring, and PID measurements will be recorded on the boring logs.

Soil samples designated for chemical analyses will be retained in brass sample tubes. The tubes will be covered on both ends with Teflon® sheets and plastic end caps. Soil samples will be labeled, entered onto a chain-of-custody record, and placed into a cooler with ice for transport to a State-of-California-certified laboratory for analyses. Cambria will request a standard 2-week turn around time for laboratory results. Cambria's Standard Field Procedures for Remediation Well Installation are included as Attachment A. The proposed scope of work will be performed under the supervision of a professional geologist or engineer.

The wells will be completed using 4-inch diameter ASTM F480 casing. The screened sections will be composed of 0.020-inch slotted ASTM F480 CircumSlot™ casing. The screen intervals, based on existing site data, will be from approximately 13 fbg to 28 fbg. The sand pack will consist of Lonestar # 2/12 sand (or equivalent) and will be placed along the entire length of the screen interval to 2-feet above the top of the well screen followed by a 2-foot thick bentonite seal and cement grout to grade. Actual well construction details will be based on field conditions at the time of drilling.

The wells will be secured with a locking cap under a traffic-rated well box. After the GWE system is installed, a licensed surveyor will survey wellhead elevations of the wells relative to mean sea level and the horizontal locations of the wells.



**Well Development and Sampling:** Blaine Tech Services, Inc. (Blaine) will develop the wells prior to sampling. After well development, Blaine will sample the wells and submit the samples to a State-certified laboratory for chemical analyses.

**Chemical Analyses:** Groundwater samples will be analyzed for TPHg, BTEX, MTBE, TBA, DIPE, ETBE, and TAME by EPA Method 8260.

**Construction:** Cambria will provide oversight of construction activities included in the contractor's scope of work. Cambria and/or the contractor will arrange all required inspections.

**System Restart:** Once system expansion activities are completed, Cambria will notify EBMUD prior to restarting the GWE system. Cambria will continue to submit semi-annual self-monitoring reports in accordance with the wastewater discharge permit.

**Operation and Maintenance Schedule:** Cambria will continue to perform routine GWE system operation and maintenance twice per month. Influent, midpoint, and effluent samples will be collected on a monthly basis and in accordance with discharge permit requirements. Waste water discharge self-monitoring reports will be submitted to EBMUD as required by the waste water discharge permit. GWE system operation and maintenance data, sampling results, and performance information will be submitted to ACHCSA on a quarterly basis as part of the site's groundwater monitoring reports.

## PROPOSED SOIL VAPOR INVESTIGATION

Since the full scope of proposed on-site soil vapor investigation could not be completed, Shell recommends installing four off-site soil vapor sampling probes (SV-F through SV-I) to further assess potential soil vapor impacts west of the site (Figure 3). Shell also recommends additional sampling of the existing soil vapor probes (SV-D and SV-E) concurrent with sampling the off-site

vapor probes. With the additional data, Shell may recommend re-evaluating the health risks from soil, groundwater, and soil vapor to potential on-site commercial and off-site residential receptors.

### Work Tasks

**Access:** Cambria will request an access agreement with the owner of the adjacent property at 2110 Montana Street to perform the proposed work. Completion of the remaining work tasks listed below is contingent upon obtaining the required property access.

**Permits:** Appropriate permits for drilling will be obtained from Alameda County Public Works Agency.

**Health and Safety Plan:** Cambria will prepare a site-specific health and safety plans for soil vapor probe installation and sampling activities.

**Utility Clearance:** Proposed hand auger locations will be marked and their locations cleared through Underground Service Alert prior to auguring.

**Soil-Vapor Investigation:** Based on the document *Guidance on Use of Soil-Gas Surveys to Assess Vapor Transport to Indoor Air* prepared by Shell (Attachment B), Cambria proposes to perform active sampling from fixed soil-gas probe locations. As shown on Figure 3, four soil-vapor probes (SV-F through SV-I) are proposed to be installed off site along the western property boundary of the subject site.

**Soil-Gas Probe Installation:** The soil-vapor probe nests will be installed using hand-auger equipment. Two intervals will be screened at each location, one at approximately 5 fbg and one at approximately 10 fbg. Adjustments to the screen depths will be made based on the observed lithology. Zones of higher permeability will be targeted for screening.

Each probe will consist of 0.25-inch inside diameter Teflon tubing, with no greater than 3-inch lengths of screen (perforated in the field using a drill and very small bit). The bottom of the tubing and the screened interval will be wrapped with stainless steel screen to avoid potential clogging with soil. Teflon tape will be used to secure the screen on the tubing. A clean, fine-grained silica sand filter pack will be installed approximately 3 to 6 inches below and above the screened interval. The annulus between probe intervals will be sealed using a bentonite slurry, set atop a 2-inch base of bentonite pellets. Each nest of soil-probes will be sealed by grout from the surface. The wellhead will be protected by a traffic-rated well box.

**Chemical Analyses:** Selected soil samples will be analyzed for TPHg, BTEX, and fuel oxygenates by EPA Method 8260.

**Physical Parameter Testing:** Select soil samples will be submitted for additional analyses to determine physical characteristics. Cambria proposes submitting samples from the 5- and 10-foot intervals for analysis of moisture content, total porosity, soil bulk density, specific gravity, grain size, and organic carbon content. Soil physical parameter data may be used to perform a site-specific risk assessment.

**Soil-Vapor Sampling:** To allow adequate time for soil-vapor equilibration within the disturbed soils, the initial vapor sampling event will occur no earlier than 3 weeks following probe installation. Furthermore, soil-gas sampling will occur no sooner than 3 days following a precipitation event. Cambria will discuss the sampling schedule with the property owners and request that they do not perform any irrigation within 3 days prior to the proposed sampling date. Sample collection procedures are detailed in Attachment C.



A schematic of the aboveground soil-vapor sampling apparatus is shown on Figure 4. A flow meter-controller will regulate the flow of air extracted from the tubing by the purge pump. Isopropanol (rubbing alcohol) will be used as a “tracer” compound to help evaluate potential dilution of soil vapor samples by ambient air. All joints and fittings upstream of the sampling canister will be covered with a cloth or other porous material soaked in isopropanol. Subsequent analytical results will indicate whether ambient air entered sample via any leaks in the sampling apparatus. Approximately three tubing volumes will be purged from each vapor point over a period of approximately 10 minutes prior to sample collection. Immediately after purging, soil-vapor samples will be collected over an approximate 30-minute period using 1-liter Summa canisters provided by the laboratory.

**Chemical Analyses:** The vapor samples will be kept at ambient temperature and submitted under chain-of-custody to a State-of-California-certified laboratory for analysis. The samples will be analyzed for TPHg using EPA Method TO-3, VOCs (including isopropanol) using TO-14A GC/MS full scan, and for oxygen, carbon dioxide, and methane by ASTM D1940. Concentrations of oxygen, carbon dioxide, and methane at different depths and relative to ambient air will be used to evaluate whether biodegradation of petroleum hydrocarbons is occurring in the subsurface.

**Report Preparation:** Following the receipt of analytical and physical parameter results from the laboratory, Cambria will prepare a written report which will include field procedures, laboratory results, boring logs, conclusions, and recommendations for further activities.

**CLOSING**

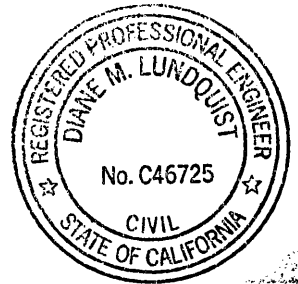
Cambria is prepared to begin permitting activities for the proposed GWE expansion upon ACHCSA approval of this work plan. The soil vapor investigation activities are contingent upon obtaining an access agreement with the adjacent property owner. If you have any questions regarding the contents of this document, please call Cynthia Vasko at (510)420-3344.

Sincerely,  
**Cambria Environmental Technology, Inc.**



Cynthia Vasko  
Project Engineer

Diane Lundquist, P.E.  
Principal Engineer



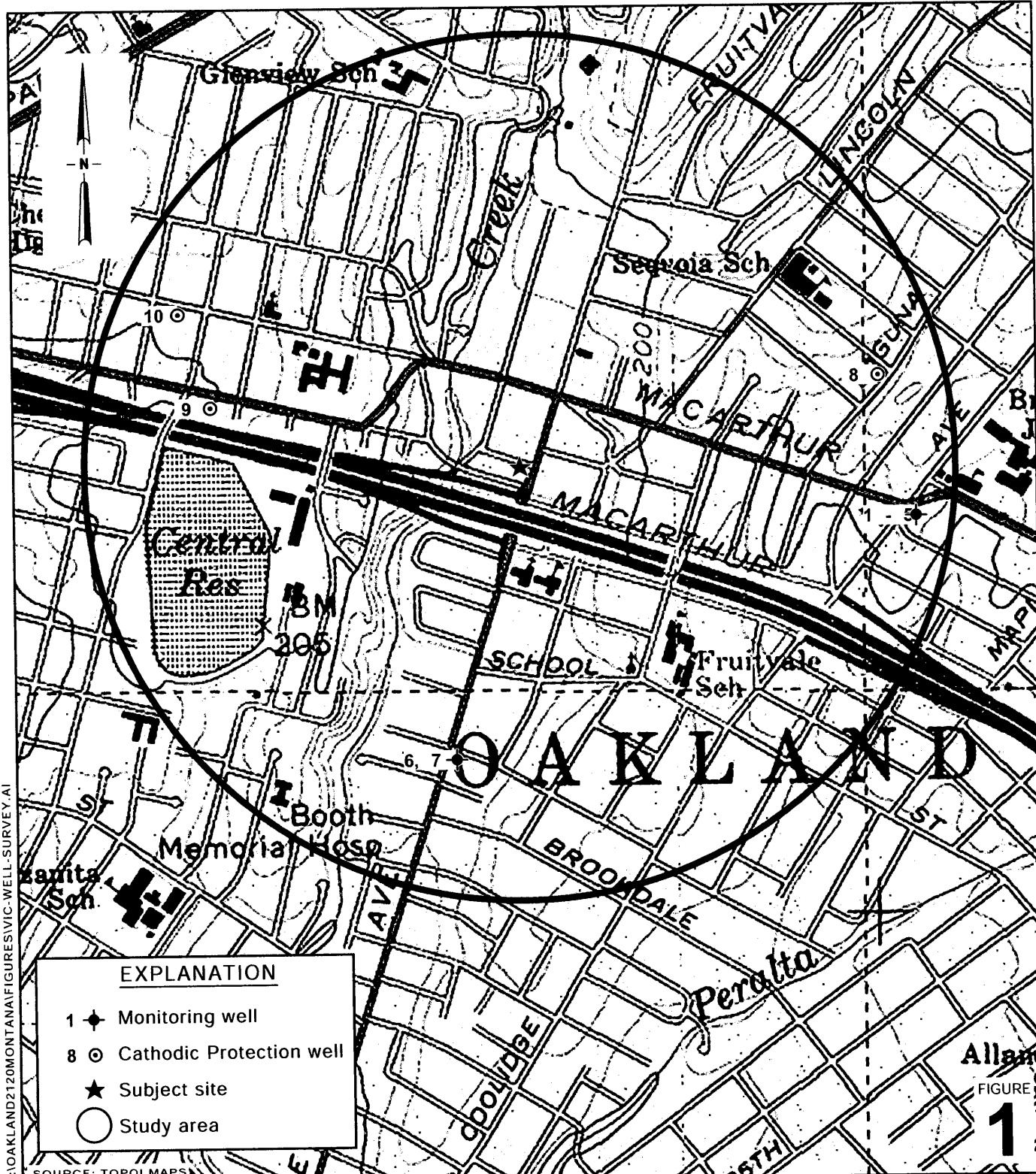
- Figures:
- 1 - Vicinity/Area Well Survey Map
  - 2 - Groundwater Elevation Contour Map
  - 3 - Proposed Extraction Well and Soil Vapor Probe Location Map
  - 4 - Soil Vapor Sampling Apparatus Diagram

- Tables:
- 1 - Soil Vapor Analytical Data

- Attachments:
- A - Standard Field Procedures for Remediation Well Installation
  - B - Guidance on Use of Soil-Gas Surveys to Assess Vapor Transport to Indoor Air
  - C - Standard Field Procedures for Soil Vapor Sampling

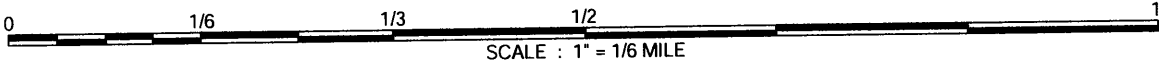
cc: Denis Brown, Shell Oil Products US, 20945 S. Wilmington Ave., Carson, CA 90810

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SOURCE: TOPOI MAPS



**Shell-branded Service Station**  
 2120 Montana Street  
 Oakland, California  
 Incident #98995740



C A M B R I A

**Vicinity / Area Well  
 Survey Map**  
 (1/2-Mile Radius)

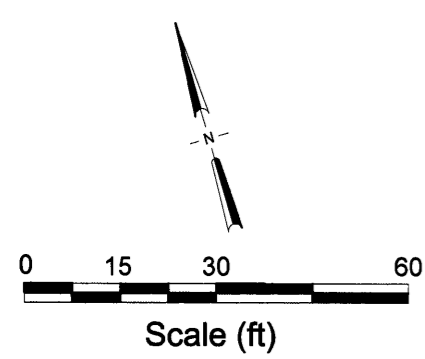
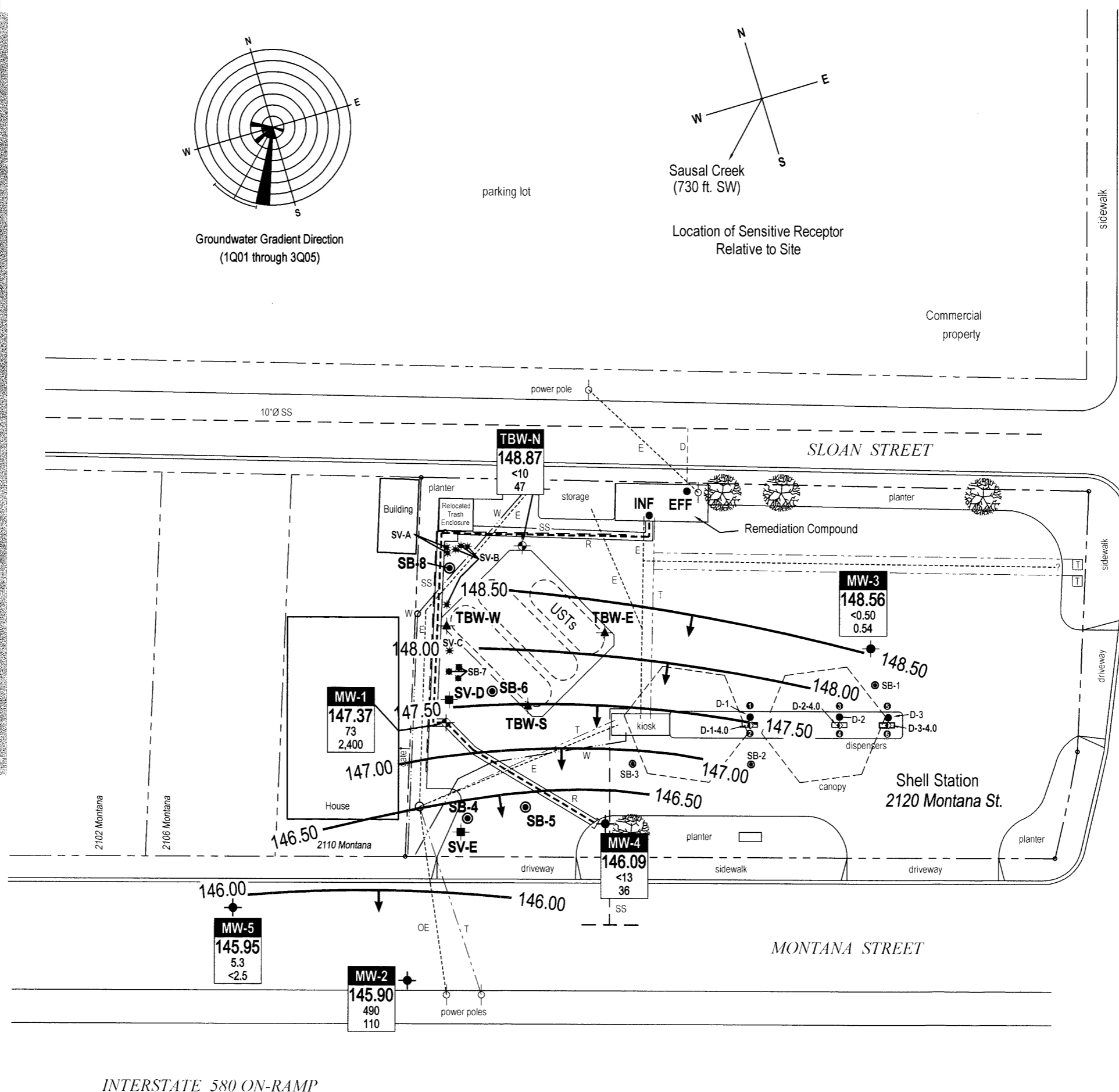
FIGURE 2

**EXPLANATION**

- SB-4 ● Soil boring location (6/14-16/05)
- SV-D ■ Soil vapor sampling location (6/14-16/05)
- SB-7 ■ Attempted soil boring location (6/15/05)
- SV-A \* Attempted soil vapor sampling location (6/14/05)
- MW-1 ⊕ Well used for groundwater extraction
- MW-2 ● Monitoring well location
- TBW-N ⊕ Tank backfill well location
- D-1-4.0 ⊕ Cambria soil sampling location (5/04)
- SB-1 ● Cambria soil boring location (10/99)
- D-1 ● Cambria soil sampling location (11/97)
- INF ● GWE system sampling location
- Groundwater flow direction
- XX.XX Groundwater elevation contour, in feet above mean sea level (msl), dashed where inferred

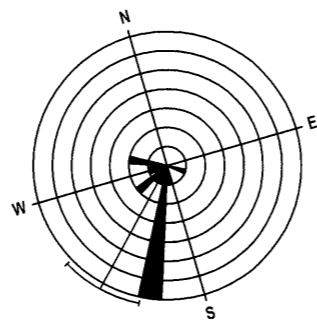
Well	ELEV	Benzene	MTBE
MW-1	147.37	73	2,400
MW-2	145.90	490	110
MW-3	148.56	<0.50	0.54
MW-4	146.09	<13	36
MW-5	145.95	5.3	<2.5
TBW-N	148.87	<10	47

- Electrical and overhead electric line (E, OE)
- - - Sanitary sewer (SS)
- Water line (W)
- - - Telecommunications line (T)
- - - Remediation piping (R)
- - - Discharge line (D)
- Product dispenser number

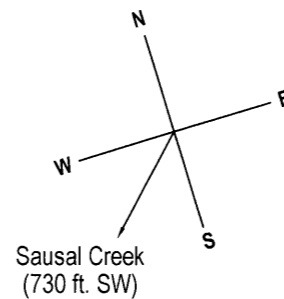


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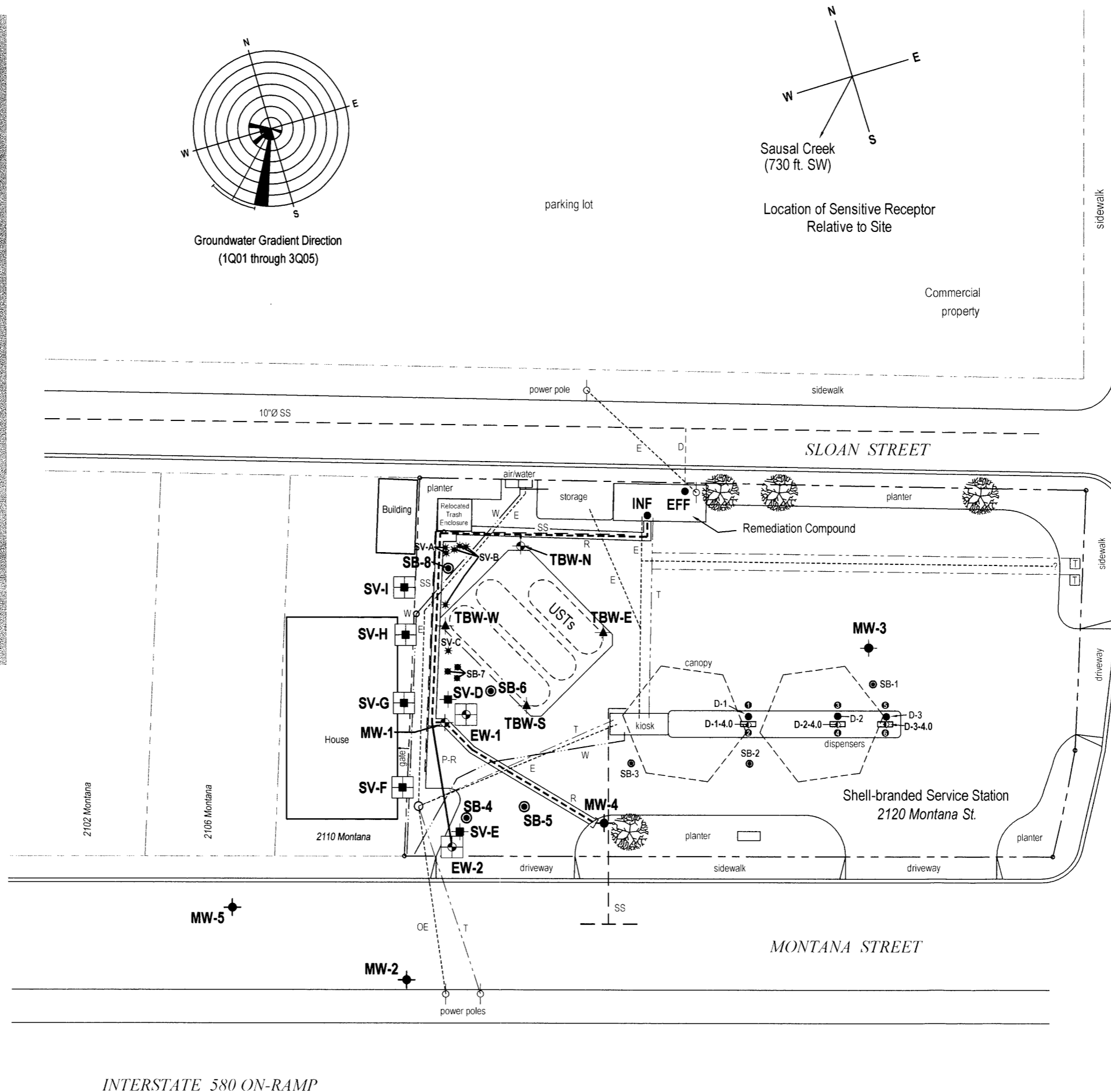
EXPLANATION	
SV-F	Proposed soil vapor probe location
EW-1	Proposed extraction well location
SB-4	Soil boring location (06/14-16/05)
SV-D	Soil vapor sampling location (06/14-16/05)
SB-7	Attempted soil boring location (6/15/05)
SV-A	Attempted soil vapor sampling location (6/14/05)
D-1-4.0	Soil sample location (Cambria, 5/04)
MW-1	Well used for groundwater extraction
MW-2	Monitoring well location
TBW-N	Tank backfill well location
SB-1	Cambria soil boring location (10/99)
D-1	Cambria soil sampling location (11/97)
INF	GWE system sampling location
-----	Electrical and overhead electric line (E, OE)
- - - - -	Sanitary sewer (SS)
-----	Water line (W)
- - - - -	Telecommunications line (T)
- - - - -	Remediation piping (R)
-----	Proposed remediation piping (P-R)
- - - - -	Discharge line (D)
●	Product dispenser number



Groundwater Gradient Direction  
(1Q01 through 3Q05)



Location of Sensitive Receptor  
Relative to Site



**Proposed Extraction Well and  
Soil Vapor Probe Location Map**



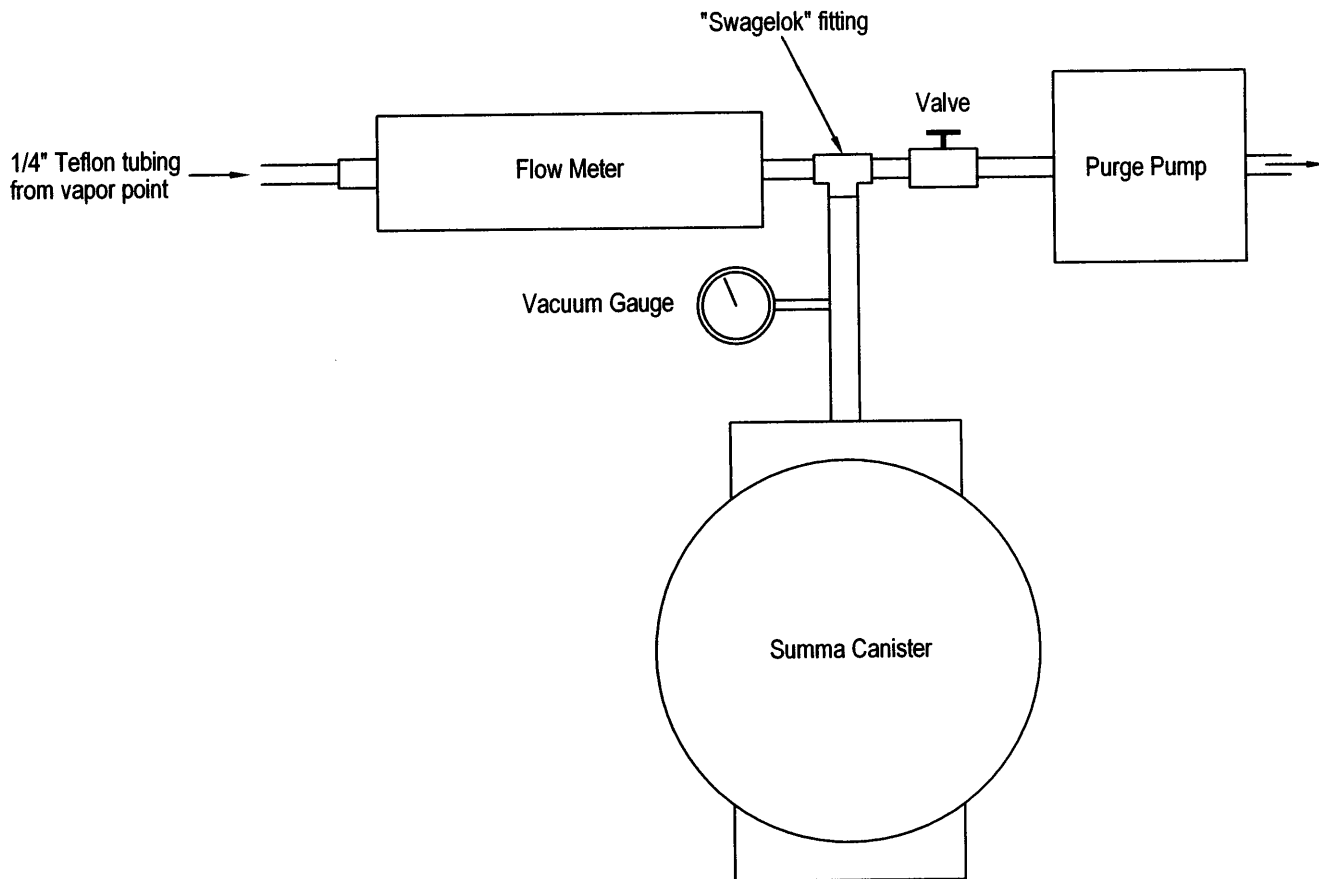
C A M B R I A

**Shell-branded Service Station**

2120 Montana Street  
Oakland, California  
Incident No. 98995740

FIGURE  
**3**





G:\OAKLAND 2120 MONTANA\FIGURES\VAPOR DIA.DWG

Schematic Not to Scale

FIGURE

4

**Shell-branded Service Station**

2120 Montana Street  
Oakland, California  
Incident No.98995740



C A M B R I A

**Soil Vapor Sampling  
Apparatus Diagram**

**Table 1: Soil Vapor Analytical Data - Shell-branded Service Station, Incident #98995740, 2120 Montana Street, Oakland, California**

Sample ID	Date	Depth (fbg)	TPHg ( $\mu\text{g}/\text{m}^3$ )	Benzene ( $\mu\text{g}/\text{m}^3$ )	Toluene ( $\mu\text{g}/\text{m}^3$ )	Ethylbenzene ( $\mu\text{g}/\text{m}^3$ )	Total Xylenes ( $\mu\text{g}/\text{m}^3$ )	MTBE ( $\mu\text{g}/\text{m}^3$ )	TBA ( $\mu\text{g}/\text{m}^3$ )	Acetone ( $\mu\text{g}/\text{m}^3$ )	Isopropanol ( $\mu\text{g}/\text{m}^3$ )	Propane ( $\mu\text{g}/\text{m}^3$ )	Carbon dioxide ( $\mu\text{g}/\text{m}^3$ )	Methane ( $\mu\text{g}/\text{m}^3$ )	Oxygen ( $\mu\text{g}/\text{m}^3$ )
SV-D-5.0	8/24/05	5	<b>22,000</b>	<130	<150	<170	<170	<140	<600	<480	<b>52,000</b>	<180	<b>160,000,000</b>	<2,700	<b>130,000,000</b>
SV-D-10.0	8/24/05	10	<b>16,000,000</b>	<b>480</b>	<510	<590	<590	<490	<2,000	<1,600	<b>3,700</b>	<b>770</b>	<b>260,000,000</b>	<b>7,800,000</b>	<b>41,000,000</b>
SV-E-5.0	8/24/05	5	<b>25,000</b>	<6.4	<b>25</b>	<8.7	<8.7	<7.2	<30	<24	<b>140</b>	<b>20</b>	<b>130,000,000</b>	<b>10,000</b>	<b>140,000,000</b>
SV-E-5.0 DUP	8/24/05	5	<b>10,000</b>	<6.4	<7.5	<8.7	<8.7	<7.2	<30	<b>26</b>	<b>130</b>	<b>21</b>	<b>130,000,000</b>	<b>7,300</b>	<b>140,000,000</b>
SV-E-10.0	8/24/05	10	<b>78,000,000</b>	<b>46,000</b>	<7,800	<9,000	<9,000	<7,500	<31,000	<25,000	<25,000	<9,300	<b>250,000,000</b>	<b>40,000,000</b>	<b>36,000,000</b>
TRIP BLANK	8/24/05	N/A	<4.1	<6.4	<7.5	<8.7	<8.7	<7.2	<30	<24	<24	<9.0	<180,000	<1,300	<2,600,000

**Abbreviations and Notes:**

fbg = Feet below grade

$\mu\text{g}/\text{m}^3$  = Micrograms per cubic meter

<x = Not detected at detection limit x

N/A = Not applicable

TPHg = Total petroleum hydrocarbons as gasoline

MTBE = Methyl tertiary butyl ether

TBA = Tert-butyl alcohol

TPHg analyzed by method EPA-19 TO-3.

Carbon dioxide, methane, and oxygen analyzed by method ASTM D1946.

Benzene, toluene, ethylbenzene, total xylenes, MTBE, TBA, acetone, isopropanol, and propane analyzed by method EPA-19 TO-14A.

**ATTACHMENT A**

**Standard Field Procedures for  
Remediation Well Installation**

## **STANDARD FIELD PROCEDURES FOR REMEDIATION WELL INSTALLATION**

This document presents standard field methods for drilling and sampling soil borings and installing remediation wells. These procedures are designed to comply with Federal, State and local regulatory guidelines. Specific field procedures are summarized below.

### **SOIL BORING AND SAMPLING**

#### **Objectives**

Soil samples are collected to characterize subsurface lithology, assess whether the soils exhibit obvious hydrocarbon or other compound vapor or staining, and to collect samples for analysis at a State-certified laboratory. All borings are logged using the Unified Soil Classification System by a trained geologist working under the supervision of a California Registered Geologist (RG) or a Certified Engineering Geologist (CEG).

#### **Soil Boring and Sampling**

Soil borings are typically drilled using hollow-stem augers or push technologies such as the Geoprobe. Prior to drilling, the first 8 ft of the boring are cleared using an air or water knife and vacuum extraction. This minimizes the potential for impacting utilities.

Soil samples are collected at least every five ft to characterize the subsurface sediments and for possible chemical analysis. Additional soil samples are collected near the water table and at lithologic changes. Samples are collected using lined split-barrel or equivalent samplers driven into undisturbed sediments at the bottom of the borehole.

Drilling and sampling equipment is steam-cleaned prior to drilling and between borings to prevent cross-contamination. Sampling equipment is washed between samples with trisodium phosphate or an equivalent EPA-approved detergent.

#### **Sample Analysis**

Sampling tubes chosen for analysis are trimmed of excess soil and capped with Teflon tape and plastic end caps. Soil samples are labeled and stored at or below 40C on either crushed or dry ice, depending upon local regulations. Samples are transported under chain-of-custody to a State-certified analytic laboratory.

## **Field Screening**

One of the remaining tubes is partially emptied leaving about one-third of the soil in the tube. The tube is capped with plastic end caps and set aside to allow hydrocarbons to volatilize from the soil. After ten to fifteen minutes, a portable photoionization detector (PID) measures volatile hydrocarbon vapor concentrations in the tube headspace, extracting the vapor through a slit in the cap. PID measurements are used along with the field observations, odors, stratigraphy and groundwater depth to select soil samples for analysis.

## **Grouting**

If the borings are not completed as wells, the borings are filled to the ground surface with cement grout poured or pumped through a tremie pipe.

## **REMEDATION WELL INSTALLATION**

### **Well Construction**

Remediation wells are commonly installed for dual phase extraction (DPE), soil vapor extraction (SVE), groundwater extraction (GWE), oxygenation, air sparging (AS), and vapor monitoring (VM). Well depths and screen lengths will vary depending upon several factors including the intended use of the well, groundwater depth, occurrence of hydrocarbons or other compounds in the borehole, stratigraphy and State and local regulatory guidelines.

Well casing and screen are typically one to four inch diameter flush-threaded Schedule 40 PVC. Screen slot size varies according to the sediments screened, but slots are generally 0.010 or 0.020 inches wide. A rinsed and graded sand occupies the annular space between the boring and the well screen to about one to two ft above the well screen. A two ft thick hydrated bentonite seal separates the sand from the overlying sanitary surface seal composed of Portland type I,II cement. Well-heads are typically connected with remediation piping set in traffic-rated vaults finished flush with the ground surface. Typical well screen intervals for each type of well are described below.

***DPE Wells:*** DPE wells are screened in the vadose zone targeting horizons with the highest hydrocarbon concentrations and a few feet into the saturated zone, targeting SPH on or submerged by the water table. A vacuum is applied to the well casing and/or a 'stinger' (a one-inch diameter tube) placed in the well about 1 to 2 feet below the static fluid level. Vacuums can be adjusted to fine tune the performance of the well/system and to optimize the removal of SPH without excessive production of ground water.

***SVE Wells:*** SVE wells are screened in the vadose zone targeting horizons with the highest hydrocarbon concentrations. SVE wells are also occasionally screened as concurrent soil vapor and groundwater extraction wells with screen interval above and below the water table.

**GWE Wells:** Groundwater extraction wells are typically screened ten to fifteen ft below the first water-bearing zone encountered. The well screen may or may not be screened above the water table depending upon whether the water bearing zone is unconfined or confined.

**Oxygenation Wells:** Oxygenation wells are installed above or below the water table to supply oxygen and enhance naturally occurring hydrocarbon biodegradation. Oxygenation wells installed in the vadose zone typically have well screens that are two to ten feet long and target horizons with the highest hydrocarbon concentrations. Oxygenation wells installed below the water table typically have a two foot screen interval set ten to fifteen ft below the water table.

**AS Wells:** Air sparging wells are installed below the water table and typically have a two foot screen interval set ten to fifteen ft below the water table.

**VM Wells:** Vapor monitoring wells are installed in the vadose zone to check for hydrocarbon vapor migration during air injection. The wells are typically constructed with short screens to target horizons through which hydrocarbon vapor migration could occur. These wells can also be constructed in borings drilled using push technologies such as the Geoprobe by using non-collapsible Teflon tubing set in small sand packed regions overlain by grout.

## **Well Development**

Groundwater extraction wells are generally developed using a combination of groundwater surging and extraction. Surging agitates the groundwater and dislodges fine sediments from the sand pack. After about ten minutes of surging, groundwater is extracted from the well using bailing, pumping and/or reverse air-lifting through an eductor pipe to remove the sediments from the well. Surging and extraction continue until at least ten well-casing volumes of groundwater are extracted and the sediment volume in the groundwater is negligible. This process usually occurs prior to installing the sanitary surface seal to ensure sand pack stabilization. If development occurs after surface seal installation, then development occurs 24 to 72 hours after seal installation to ensure that the Portland cement has set up correctly.

All equipment is steam-cleaned prior to use and air used for air-lifting is filtered to prevent oil entrained in the compressed air from entering the well. Wells that are developed using air-lift evacuation are not sampled until at least 24 hours after they are developed.

**ATTACHMENT B**

**Guidance on Use of Soil-Gas Surveys to Assess  
Vapor Transport to Indoor Air**



**Shell Global Solutions**

GUIDANCE ON USE OF SOIL-GAS SURVEYS  
TO ASSESS VAPOR TRANSPORT TO  
INDOOR AIR





**GUIDANCE ON USE OF SOIL-GAS SURVEYS TO  
ASSESS VAPOR TRANSPORT TO INDOOR AIR**

Report Prepared by:

**Shell Global Solutions (US) Inc.  
Matthew A. Lahvis**

07 October 2002

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# INTRODUCTION

Risk-Based Corrective Action (RBCA) has become commonplace in evaluating remediation at leaking underground storage tank (LUST) sites. At many LUST sites, migration of volatile organic compounds (VOCs) from ground water or soil into buildings or other enclosed spaces is a potential exposure pathway (see Figure 1). Soil-gas surveys can provide fundamental data needed to evaluate this pathway and should be included as part of any risk assessment. For example, soil-gas surveys can be used for:

- Tier 1 (screening-level) applications
  - to help identify chemicals of concern and maximum concentrations,
  - to delineate sources and exposure pathways,
  - to detect immediate risks for combustion and human health.

- Tier 2 and Tier 3 (site-specific) evaluations
  - to validate or predict indoor-air concentrations,
  - to quantify rates of vapor intrusion and
  - to establish site-specific target levels (SSTLs)
  - to verify biodegradation hypotheses.

The purpose of this report is to provide technical guidance on conducting soil-gas surveys at sites where long-term or chronic vapor intrusion is a concern. The reader is referred to the American Society of Testing and Materials *Standard Guide for Soil Gas Monitoring in the Vadose Zone (ASTM D 5314)* and the Environmental Protection Agency *Expedited Site Assessment Tools for Underground Storage Tank Sites: A Guide for Regulators – Chapter IV (EPA 510-B-97-*

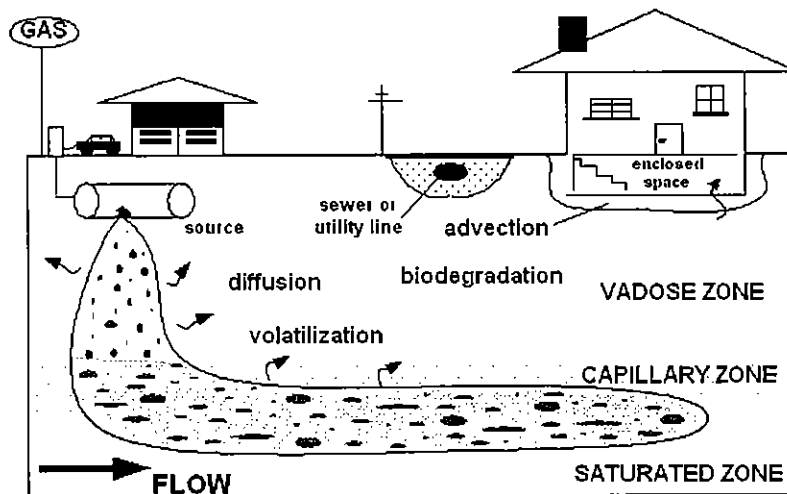


Figure 1. Conceptualization of vapor transport to indoor air at a LUST site.

Table 1. Common ranges of soil-gas concentrations for compounds of environmental interest at 25°C

Compound	Pure Component Water Solubility (mg/L)	Henry's Law Constant (unitless)	Saturated Vapor Concentration (mg/m <sup>3</sup> )	Maximum Concentration in Soil Gas (mg/m <sup>3</sup> )	Maximum Concentration in Soil Gas Based on Target Indoor Air Concentration (mg/m <sup>3</sup> ) <sup>2</sup>
benzene	1.75E+03	2.28E-01	4.0E+05	5.2E+03 <sup>1</sup>	1.3E-01
toluene	5.26E+02	2.72E-01	1.4E+05	2.8E+04 <sup>1</sup>	4.0E+01
ethylbenzene	1.69E+02	3.23E-01	5.5E+04	1.7E+03 <sup>1</sup>	1.0E+02
o-xylene	1.78E+02	2.13E-01	3.8E+04	3.8E+02 <sup>1</sup>	7.0E+02
trichloroethylene	1.10E+03	4.22E-01	4.6E+05	4.6E+05	5.9E-01
1,1 dichloroethylene	2.25E+03	1.07E+00	2.4E+06	2.4E+06	2.0E-02
1,1,1 trichloroethane	1.33E+03	7.05E-01	9.4E+05	9.4E+05	1.0E+02
1,1,2,2 tetrachloroethylene	2.00E+02	7.54E-01	1.5E+05	1.5E+05	1.7E-02

<sup>1</sup>Concentration in equilibrium with gasoline having the following mole fraction composition for gasoline: benzene – 1.3%, toluene -- 20%, ethylbenzene -- 3%, and o-xylene – 1%.

<sup>2</sup>Target concentration calculated by assuming a risk level = 10<sup>-5</sup>, a hazard index = 1, and a soil gas to indoor air attenuation coefficient = 0.01.

001) for more detailed discussions of soil-gas surveys and various methodologies. This report does not evaluate cases where high concentrations of vapors are present in enclosed spaces (e.g., utility, sewer, and dry-well conduits) that pose flammability and/or acute health risks. These cases typically require immediate attention and response.

## THEORETICAL PRINCIPLES

Transport of VOCs to indoor air is a complex phenomenon involving partitioning, migration, and biodegradation (see Figure 1).

- Partitioning:** The potential for vapor migration to indoor air is greatest for compounds that strongly partition to the gaseous phase. Partitioning of a compound to the gaseous-phase is defined by Raoult's Law (gaseous/immiscible phase partitioning) and Henry's Law (gaseous/aqueous phase partitioning), which, in turn, is defined by the vapor pressure and solubility of a compound, which are temperature and pressure dependent. At LUST sites, benzene, trichloroethylene, 1,1 dichloroethylene, 1,1,1 trichloroethane, and tetrachloroethylene are potential chemicals of concern due to their high source concentrations, vapor pressures, Henry's Laws, and human toxicities (see Table 1).
- Migration:** Migration of VOCs to indoor air is governed by gaseous-phase advection and gaseous-phase diffusion. Gaseous-phase advection, caused by pressure gradients near foundation walls, is the more dominant migration mechanism near the receptor. Gaseous-phase diffusion, caused by concentration gradients between the source and the receptor, is the more dominant migration

mechanism away from the receptor. The magnitude of these mechanisms is dependent upon soil type, source concentration, and building characteristics. Seasonal effects, including the presence of a frost layer and variations in soil moisture content, water table elevation, barometric pressure, and biodegradation rate, can also affect rate of vapor intrusion. Vapors will tend to migrate toward areas of lower pressure and concentration and along paths of least resistance (e.g., backfill materials surrounding sewer and utility lines, tree roots, or drains and cracks in basement foundations).

- Biodegradation:** Depending on substrate (VOC), electron acceptor (e.g., oxygen -- O<sub>2</sub>), and nutrient conditions, biodegradation can also play a significant role in limiting transport to indoor air, especially for benzene and other biodegradable petroleum compounds. This mechanism, however, is not considered in most risk assessments.

## APPROACH

The following approach is intended to serve as guidance for conducting soil-gas surveys at LUST sites where vapor transport to indoor air is a potential exposure pathway. The actual approach that is taken will depend on site-specific conditions, project confidence, and available resources.

The approach for conducting a soil-gas survey is divided into four phases:

- Phase I: Method Selection and Sampling Design,
- Phase II: Probe Construction and Installation,
- Phase III: Soil Sampling,

- Phase IV: Soil-Gas Sampling, and
- Phase V: Analysis.

## Phase I: Method Selection and Sampling Design

The two principal methods applied in soil-gas sampling are active and passive. Selection of the appropriate method depends on site-assessment objectives.

- **Active Sampling:** Active sampling is a technique that involves collecting a whole air (grab) sample by induction of air flow either directly into an analytical instrument (detector) or into a gas-tight container for subsequent analysis. Active sampling is performed at fixed or temporary locations and is generally more costly than passive sampling. The active method provides quantitative real-time data and is recommended for risk assessment.
- **Passive Sampling:** Passive sampling is used primarily for qualitative (field screening) purposes. Soil-gas samples are collected in sorbent cartridges or flux chambers without induction of air flow. The sample is retrieved at a later date for analysis. Passive sampling is not recommended for risk assessment because soil-gas concentrations cannot be directly measured.
- **Vertical Sampling:** The design of a soil-gas sampling network requires fundamental knowledge of source location, soil stratigraphy, and potential exposure pathways. These data are often determined through reconnaissance soil and soil-gas sampling using a Geoprobe® and on-site soil-gas analysis (see Table 2). Placing soil-gas probes between the source (soil or ground-water plume) and the receptor (building foundation) provides a means to assess the vapor pathway. A minimum of 2 soil gas probes is needed to define a concentration gradient and the direction of the source. In general, more probes are needed, however, to evaluate perturbations in the soil-gas distribution caused by heterogeneities in the transport properties of unsaturated-zone soils. It is often advantageous to maximize the number of soil-gas probes within a given nest because they can be installed without much additional cost and effort. In general, soil-gas probes should be positioned near areas of concern (source, receptor) to validate pathway assumptions. In addition, it is often beneficial to place soil-gas probes in

regions where sharp soil-gas concentration gradient tend to develop, such as near the water table (for sources in ground water) or just above or below fine-grained soil layers. Soil-gas probes should also be placed in higher-permeability units that may serve as preferential pathways for vapor migration. This approach requires greater effort and expense than fixed-interval installation because the presence, thickness, and depth of target soil horizons, needs to be known *a priori*. Boring logs and site plans should always be evaluated to identify soil strata, perched water and clay lenses, buried structures, and recently disturbed soils or backfills.

Placement of 1 or 2 soil-gas probes below the water table can also be beneficial at sites where a ground-water source is present. These probes can provide more accurate water-table concentration data than can be obtained through conventional monitoring wells that are typically screened over much greater lengths (2 – 20 ft). These probes can also provide additional soil-gas data during periods when the water-table elevation is low.

- **Areal Sampling:** Areal spacing of soil-gas probes depends on the purpose of the soil-gas investigation. For general mapping purposes, probe nests are spaced rather sparsely (e.g., 15 to 30 ft apart), usually along a grid pattern. Probe nests are spaced at closer intervals (e.g., 3 to 10 ft apart) when targeting identified exposure pathways, such as building foundations, storage tanks, and transfer conduits (e.g., sewer lines, trenches, utility vaults, pipelines and other preferential pathways). In addition, installation of two or more probe nests in close proximity can provide confirmatory data, which may be beneficial, even at sites where the vapor pathway is considered well defined.
- **Chronic Sampling:** Temporal effects that occur as a result of changes in barometric pressure, water-table elevation, moisture content, source composition, recharge, biodegradation, can affect the distribution of VOCs in soil-gas over time. Depending on the chemical compound, soil type, distance from the source, and relative age of the release, response and equilibration times can range from hours to years. Chronic sampling at fixed locations provides a means to assess these temporal variabilities. The equilibration time should also be accounted for in determining the

**Table 2.** Comparison of commonly employed analytical methods

Instrument	Compounds Detected	Detection Limits	Data Quality Level	Advantages	Limitations
Detector tubes	Aliphatics and aromatics, alcohols, inorganics	0.1 – 8,000 ppm	1A/1B	Inexpensive Easy to use Provides immediate results Compound specific	Low sensitivity (mainly for screening purposes) Cross-contamination by other compounds Affected by humidity, sample flow rate, temperature extremes, storage conditions and shelf life
Portable Photoionization Detector (PID)	Aromatics (e.g., BTEX), some aliphatics, less methane	1 - < 300 ppm	1A/1B	Inexpensive Easy to use Provides immediate results	No inorganic analyses Low sensitivity (mainly for screening purposes) Inconsistent readings Can not detect methane (CH <sub>4</sub> ) and thus may produce false low readings when CH <sub>4</sub> concentrations exceed 1 % Instrument response can be affected by high relative humidity(> 90%), dust, temperature (< 0°C), and electrical currents (power lines)
Portable Flame Ionization Detector (FID)	Aliphatics (e.g., butane), less sensitive to aromatics (e.g., BTEX)	1 - > 1,000 ppm	1A/1B	Inexpensive Easy to use Provides immediate results	Low sensitivity (mainly for screening purposes) Inconsistent readings High CO <sub>2</sub> , low O <sub>2</sub> (<15 %) Requires a hydrogen source and more training than PID High flow rates (~ 2L/min) needed for analysis Instrument response can be affected by wind and temperature (< 0°C) High CH <sub>4</sub> concentrations may be interpreted as contamination
Portable Explosivity Detector (ED)	Combustible gas mixture (gasoline, O <sub>2</sub> , and CH <sub>4</sub> )	> 100 ppm	1A/1B	Inexpensive Easy to use Provides immediate results Less sensitive to environmental effects than PIDs or FIDs	Low sensitivity (mainly for screening purposes)
Portable Gas Chromatograph (GC)	Aromatics and aliphatics, inorganics, and chlorinated compounds	1 ppb – >1,000 ppm	2	More quantitative than typical PIDs and FIDs More easily transported than transportable GCs (no carrier gas – hydrogen, helium) needed Relatively short analysis time (< 10 minutes)	Requires power supply Relatively long analysis time (10 – 60 minutes) Expensive Higher operator training than other portable detectors
Transportable Gas Chromatograph (GC)	Aromatics and aliphatics, inorganics, and chlorinated compounds	1 ppb – >1,000 ppm	2/3	Provides better quantification and identification of compounds than portable GCs High sensitivity Consistent measurements	Requires power supply Relatively long analysis time (10 – 60 minutes) Expensive Higher concentration samples generally require dilution Higher operator training than portable GC
Gas Chromatograph / Mass Spectrometry (GC/MS)	Aromatics and aliphatics, total organic vapor, and chlorinated compounds	0.05 ppb - > 1,000 ppm	3	High sensitivity Consistent measurements Provides the highest quality of speciation	Requires power supply Relatively long analysis time (10 – 60 minutes) Expensive

1A – Qualitative (used to detect general presence of VOCs).

1B – Semi-quantitative (used to approximate total VOC contamination within an order of magnitude).

2 – Quantitative.

3 – Highly quantitative.

**Table 3.** Capillary rise in soils based on grain-size (from Lohman, 1972)

Soil Type	Grain Size (mm)	Capillary Rise (cm)
Fine gravel	5	1.5
Very coarse sand	2	4
Coarse sand	0.5	15
Medium sand	0.3	25
Fine sand	0.15	50
Very fine sand	0.075	100
Coarse silt	0.025	300
Fine silt	0.008	750

commencement of soil-gas sampling following probe installation. In general, 3 to 4 weeks should be allowed for re-equilibration.

## Phase II: Soil Sampling

Soil sampling is an essential component of any soil-gas survey. Soil sampling can be used to locate potential sources in soil as well as soil units that may serve as potential barriers or conduits for soil-gas migration. Soil samples should be collected from each distinct (mappable) stratigraphic unit using a stainless-steel soil sampler (barrel, split-spoon, or piston type) attached to the auger or direct-push rod. The soil sampler may be driven into the subsurface manually using a sledgehammer, pneumatic hammer, or slam bar or mechanically using a drop hammer attached to a drill rig or Geoprobe®. Method selection will depend on the vadose-zone thickness, soil type, and degree of consolidation. Soil samples should be field screened using a portable PID or FID to locate sources. Remaining sections of the core should be analyzed for the following soil properties:

- bulk density (American Society for Testing and Materials– ASTM D 2937)
- specific gravity (American Society for Testing and Materials– ASTM D 854-92)
- moisture content (American Society for Testing and Materials – ASTM D 2216-90)
- grain size (American Society for Testing and Materials – ASTM D 422-63)
- organic carbon content (American Society for Testing and Materials – ASTM E1195-87(1993))

Bulk density measurements are needed to estimate total porosity, which is used in conjunction with moisture content, to estimate the effective diffusion coefficient, a critical transport parameter (American Petroleum Institute, 1998)<sup>1</sup>. Moisture content measurements and grain size measurements (see

<sup>1</sup>Effective diffusion coefficients can also be determined experimentally either *in situ* (Kreamer et al., 1988; Johnson et al., 1998) or in laboratory column experiments (Fischer et al., 1996; Batterman et al., 1996).

Table 3) are used for estimating the thickness of the capillary zone. An accurate estimate of the capillary-zone thickness is important because of the sensitivity of vapor transport to this parameter. Grain-size measurements can also be used to estimate air-phase permeabilities (U.S. Environmental Protection Agency, 1995). Likewise, *in-situ* techniques, such as Baehr and Hult (1988), can be used to estimate air-phase permeabilities. Organic-carbon content measurements are needed to quantify sorption to vadose-zone soils.

Further discussion of soil boring and sampling techniques is provided in the American Society for Testing and Materials *Standard Guide for Soil Sampling in the Vadose Zone (ASTM D 4700)*.

## Phase III: Probe Construction and Installation

- **Probe Construction:** Soil-gas probes can either be bought commercially (implants) or be constructed by hand using 1/8 – 1/4 in. O.D. stainless-steel (grade 304) or teflon tubing. Stainless steel and teflon are recommended because of their inert chemical properties and low potential for adsorption. A small tubing diameter is recommended to minimize purge requirements, especially when sampling in fine-grained soils where the soil-gas flow rate is limited.
- **Installation:** Soil-gas surveys can be conducted from either temporary or fixed sampling locations. Temporary soil-gas sampling is practical for site reconnaissance and field screening, but is not recommended for risk assessment due to inability to assess temporal variabilities. Temporary probes installed in coarse-grained or hard pan soils may also be susceptible to entrainment (flow) of soil gas or atmospheric air along probe walls provided tight contact between the probe and soil is not achieved. For these reasons, fixed sampling is generally recommended for risk assessment. Soil-gas probes can either be installed manually by using hand augers or slam bars or mechanically by using rotary augers or direct-push rods (U.S. Environmental Protection Agency, 1997). Manual methods are recommended for probe installation in shallow, unconsolidated vadose zones (< 10 ft.). Mechanical methods are preferable for probe installation in deeper, more consolidated vadose zones or below perched or regional ground-water tables. Direct push methods will yield small

diameter boreholes (< 2 in.) that, in general, accommodate only a few (1 – 2) soil-gas probes. Augers typically create larger diameter (>4 in.) boreholes that can accommodate several soil-gas probes. As shown in Figure 2, soil-gas probes should be nested in fine-medium grained (clean) silica sand layers and separated by layers (seals) of bentonite. The bentonite seals should be pressure tested to avoid short-circuiting (air flow) between probes or the atmosphere. The minimum separation distance between probes is generally 6 to 12 inches depending on the length of the screened interval (see Figure 2). Additional boreholes are therefore necessary if finer-scale resolution is desired. If using an auger, pre-casing is required to install probes below the water table requires.

### Phase IV: Soil-Gas Sampling

Active soil-gas sampling is conducted by inducing air flow either manually (by using a gas-tight syringe or hand pump) or mechanically (by using a peristaltic pump or SUMMA® canister). Soil-gas samples are collected directly into a sampling container (see Table 4) or from the effluent air stream induced by the sampling pump. The EPA has issued standard operating procedures for SUMMA® canister (SOP #1704, U.S. Environmental Protection Agency, 1995) and tedlar bag (SOP #2102, U.S. Environmental Protection Agency, 1994) sampling.

- Purge and Sample Volumes:** Prior to sample collection, soil-gas probes and auxiliary tubing should be purged with at least 1 system volume. The purge volume should remain consistent for the entire sampling event and should always be reported in field logs. Manual purging using a hand (suction) pump or syringe is preferred over mechanical purging using a vacuum or peristaltic pump because purge volumes can be more accurately controlled, which is especially important when sampling in low permeability soils.
- Flow Rates:** Flow rates on peristaltic pumps and SUMMA® canisters should always be set at a minimum during sample collection to avoid development of significant vacuum pressures (> 10 in. water) that can affect the soil-gas concentration measurement. If vacuum pressures of this magnitude are encountered, sampling should be abandoned or performed periodically at lower flow rates (time integrated). Vacuum pressures should be continuously

monitored using pressure gauges arranged in-line, especially in highly saturated or fine-grained, low-permeability soils where higher vacuum pressures can be expected. Vacuum pressures observed during sampling may indicate a clogged or water-saturated probe. Inserting a small diameter (1/8 in. O.D.) wire down the inside of the probe can often times unplug a clogged probe. Care should be taken, however, to avoid displacing or piercing the screen attached to the base of the soil-gas probe.

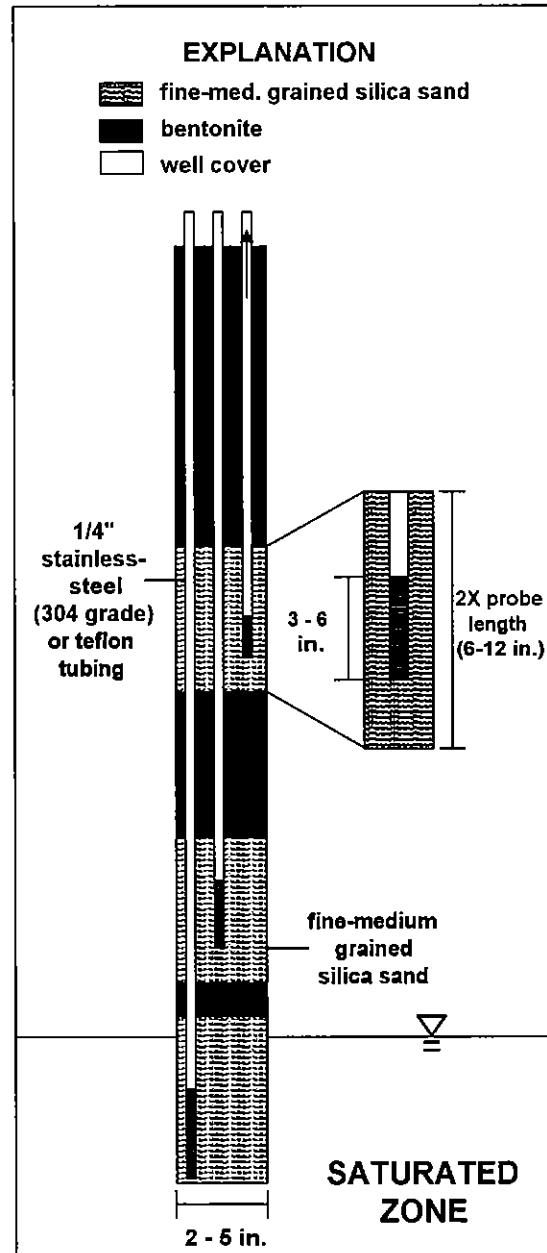


Figure 2. Schematic of vapor-probe nest in augered hole.



- **Sample Containers (see Table 4):** Selection of an appropriate sampling container will depend on the holding time (time between sample collection and analysis) and detection limits. In general, SUMMA<sup>®</sup> canister and syringe sampling provide more accurate quantification of soil gas concentrations than Tedlar bag sampling and should always be used at sites where low detection levels are desired.

## Phase V: Analysis

Various soil-gas analyses are available depending on the survey objectives, budget constraints, and quality assurance/quality control (QA/QC) objectives.

- **Analytes:** At LUST sites, VOCs, nitrogen (N<sub>2</sub>), O<sub>2</sub>, carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), and in some cases, hydrogen sulfide (H<sub>2</sub>S) may all be present in soil gas. Their distribution depends on the soil type, stratigraphy, presence of impermeable surface boundaries (e.g., building foundations, asphalt surfaces), and biodegradation. In most risk assessments, identification of the types of VOCs present and their concentration in soil gas is the primary concern. Total VOC concentration data, however, can also be useful for screening level

applications. Although not required in most risk assessments, O<sub>2</sub>, CO<sub>2</sub>, CH<sub>4</sub> and H<sub>2</sub>S concentration data can also provide fundamental biodegradation data to help assess vapor intrusion. In particular, these data can be used to verify biodegradation hypotheses, and estimate biodegradation rates (Lahvis and Baehr, 1996). O<sub>2</sub> and CO<sub>2</sub> concentration data can also be used to map VOC plumes (Kerfoot et al., 1988).

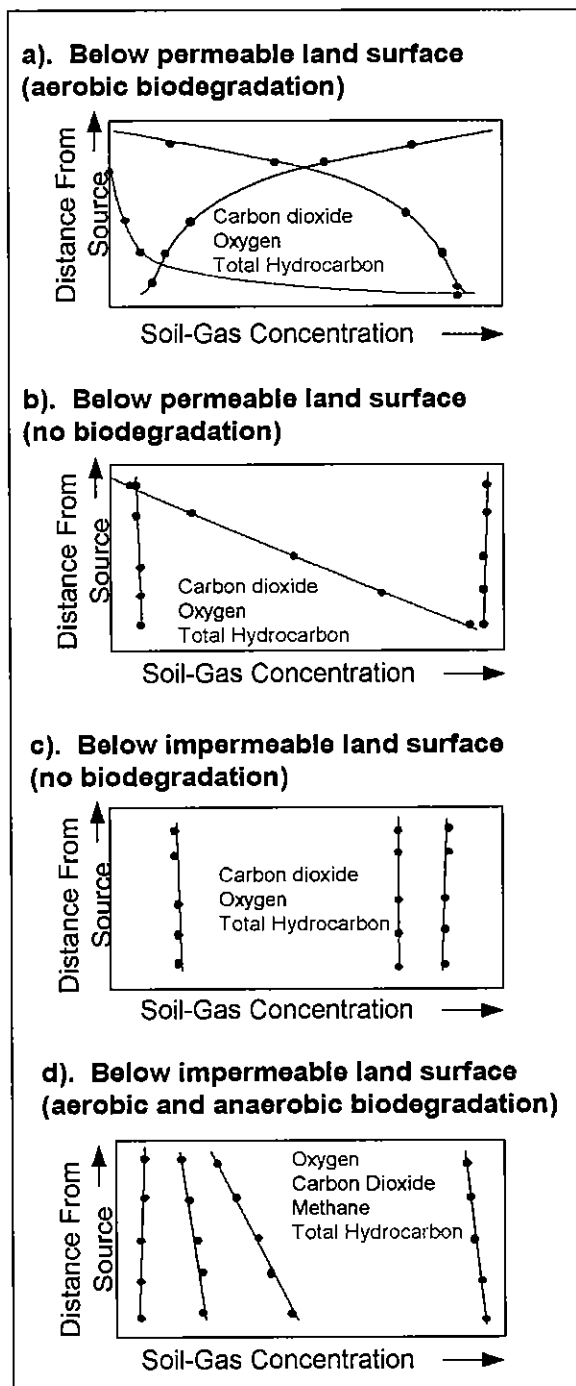
- **Analyses:** A comparison of commonly employed field analyses is provided in Table 2. In general, the cost associated with each analysis is proportional to the degree of quantification.
- **Methods:** Most soil-gas analyses are performed off-site. The following are approved U.S. Environmental Protection Agency methods for laboratory (off-site) soil-gas analyses:

<u>Analytes</u>	<u>Sample Container</u>	<u>Analysis</u>	<u>EPA Method</u>
organics	canister/tedlar bag	GC	TO-3, 12, 14, 14A
organics	canister	GC/MS	TO - 15
organics	sorbent tubes (cartridges)	GC	TO - 1, 2, 17
inorganics*	canister/tedlar bag	GC	Method 3C

\*O<sub>2</sub>, CO<sub>2</sub>, N<sub>2</sub>, CH<sub>4</sub>, and H<sub>2</sub>S

**Table 4.** Comparison of common soil-gas sampling containers (modified from Mayer, 1989)

Type	Application	Sample Volume	Advantages	Limitations
Glass syringe	Collection of samples for on-site GC analysis Suspected concentrations of COC should generally exceed 10 ppb	25-mL	Inert Allows quick, replicate analysis	Holding times are typically short (< 8 hours) Small sample volume Generally unable to detect VOCs at concentrations < 10 ppb
Sorbent trap	Allows for low-concentration measurements (< 10 ppb)	Variable—depends on VOC concentration	Ease of handling Relatively long holding times (days)	Requires precise sample volume (flow) measurements Requires thermal or solvent desorption Soil-gas moisture can affect analysis Provide only qualitative information if used for passive sampling
Tedlar <sup>®</sup> bag	Collection of samples for delayed analysis (see U.S. Environmental Protection Agency, 1994)	1 – 25 liters	Bulk loss of sample is readily apparent Sample volume measurement not required	Some container materials may contaminate sample Potential for adsorption to bag walls and leakage to atmosphere limits application for risk assessment Containers are not easily reused
Glass bulb	Collection of samples for delayed analysis	2 mL – 2 L	Inert Allows replicate samples	Easily breakable Expensive Leakage through stopcocks and septa possible Short holding times (< 4 hours)
Stainless-steel (SUMMA <sup>®</sup> ) canisters	Collection of samples for delayed analysis(see U.S. Environmental Protection Agency, 1995)	2 mL – 6 L	Inert and durable Longer sample retention times	Expensive Containers not easily reused Can be difficult to decontaminate



**Figure 3.** Generalization of soil-gas profiles at a petroleum-release site.

- **QA/QC:** QA/QC procedures are an integral part of any soil-gas survey and should be performed to ensure that soil-gas samples are representative of subsurface conditions. The following is a list of some important QA/QC procedures:

- Sampling should be consistent and completed in a relatively short period of time (hours, days) to reduce effects of temperature, barometric pressure, and recharge on soil-gas transport. Holding times and exposure of sampling containers to direct sunlight should be minimized.
- Sampling and drilling equipment should be decontaminated between boreholes to prevent cross contamination.
- All bentonite seals constructed during vapor sampling or probe installation should be pressure tested.
- Soil-gas samples should be collected outside the zone of contamination to assess background concentrations.
- All connections and fittings in the sampling line should be leak checked.
- Field and trip blanks should be used to ensure proper sampling and decontamination procedures. Approximately 1 out of every 10 soil-gas samples should be duplicated to ensure reproducibility of the data.
- Analytical QA/QC should be routinely performed and include: a multi-point calibration curve generated over the range of anticipated soil-gas concentrations, periodic calibration checks, spike samples to determine percent recovery and aid retention time analysis, and sample blanks.

## INTERPRETATION AND APPLICATION

### Interpretation

The following are important factors to consider in the interpretation of a soil-gas survey:

- Soil gas-concentrations can be relied upon for risk assessment provided the concentration is approximately steady state. The time required to reach steady state increases as the square of the distance from the source. Soil-gas concentrations measured near the source will therefore reach steady state more quickly (hours-days) than concentrations several meters away (weeks to years).
- Regions where soil-gas concentrations increase or decrease sharply should be identified. Steep concentration gradients will exist in fine-grained or wet soils and in areas of significant (aerobic) biodegradation (see Figures 3a and 3d). VOC concentration gradients will be less steep in regions where  $O_2$  is depleted ( $< 5\%$ ), an impermeable barrier exists at land surface, and/or anaerobic biodegradation (as indicated by the presence of  $CH_4$  or  $H_2S$  in soil gas) is occurring (Figures 3b, 3c, and 3d). Anaerobic biodegradation is likely to occur in regions, such as, near the source or beneath impermeable barriers, where  $O_2$  concentrations are low ( $< 2\%$ ) and vapor transport is limited.

**Table 5.** Evaluation of commonly applied models to assess transport in the vadose zone

Model	Type		Processes Considered									
	Analytical	Numerical	Finite Source	NAPL Partitioning	Non-Equilibrium Partitioning	Gaseous-Phase Diffusion	Gaseous-Phase Advection	Ground-water Infiltration	Sorption	Biodegradation	Soil Layering	Variable Moisture
VLEACH (Ravi and Johnson, 1997)		X	X		X	X		X	X		X	X
R-UNSAT (Lahvis and Baehr, 1997)	X	X	X	X		X		X	X	X	X	X
Little et al. (1992)	X					X	X		X			
Farmer et al. (1980)	X					X			X			
Jury et al. (1983)	X		X			X		X	X	X		
Johnson and Ettinger (1991)	X		X			X	X		X		X	
Johnson et al. (1999)	X		X			X	X		X	X	X	

- VOC concentrations in soil gas cannot exceed saturated vapor concentrations for sources present above the water table or the vapor-phase equivalent of the aqueous-phase solubility for sources present in ground water (see Table 1). VOC concentrations in soil gas that approach maximum concentrations likely indicate the presence of a non-aqueous phase liquid (NAPL). Maximum concentrations in soil gas can, however, vary significantly depending on source composition, subsurface temperature and pressure, and other temporal phenomena.
- Placing measured soil-gas concentration data along side vertical cross sections of the subsurface can often facilitate interpretation of the soil-gas concentration data.

#### Application

Although soil gas surveys are beneficial for initial site-assessment (Tier 1) purposes, soil-gas surveys are primarily used in site-specific (Tier 2 and Tier 3) evaluations after risk based screening levels (RBSLs) have been exceeded. For example, soil-gas concentration data can be used to verify indoor-air concentrations, assess long-term vapor intrusion, and establish SSTLs. Transport conditions are assumed to be at or near steady state and biodegradation is typically not considered.

- **Verifying Indoor-Air Concentrations:** According to the American Petroleum Institute (American Petroleum Institute, 1998), indoor-air concentrations are approximately one thousandth of the soil-gas concentration immediately adjacent the building foundation. This relation is consistent with published data from field studies conducted by Nazaroff et al. (1987) on radon-gas intrusion and model results from Johnson and Ettinger (1991). However, there are limitations with this assumption. Near-surface soil-gas concentrations and sub-foundation conditions may differ substantially as a result of varying flow conditions around the building foundation and the potential for short-circuiting (atmospheric contamination) in soil-gas samples collected near land surface.
- **Assessing Long-Term Vapor Intrusion:** Several mathematical models are available for assessing long-term vapor intrusion (see Table 5). Analytical solutions developed by Farmer et al. (1980), Little et al. (1992), Johnson and Ettinger (1991), and Johnson et al. (1999) are most commonly used for this purpose. Transport models developed by Ravi and Johnson (1997), Lahvis and Baehr (1997), Farmer et al. (1980), and Jury et al (1983) can also be used to assess vapor transport, however, these models do not account for gaseous-phase advection, which may be significant at some field sites.

Reliance on near-surface and sub-foundation soil-gas concentrations to assess long-term impacts is not recommended because these concentrations are typically measured several meters away from the source and, consequently, may not have reached steady state. Soil-gas concentrations measured adjacent the source may be more appropriate for assessing long-term impacts, however, this application requires knowledge of the subsurface geology between the source and the receptor.

- **Assessing Site-Specific Target Levels (SSTLs):** Once conditions protective of indoor air (RBSL) have been established, SSTLs can be back-calculated by transport modeling. The SSTL concentration determined by modeling can be directly compared to concentrations in soil gas, or concentrations in soil or groundwater calculated from equilibrium partitioning relations (U.S. Environmental Protection Agency, 1996; American Society for Testing and Materials, 1995).
- **Other Applications:** There are several other applications of soil-gas surveys that are not discussed in this report, which have practical implications for site assessment. These applications include, tracking contaminant plumes in groundwater (Kerfoot, 1988), estimating volatilization rates of hydrocarbon from ground water (Lahvis et al., 1999), predicting mass-loading rates to ground water from sources in the vadose zone (Lahvis and Rehmann, 1999), and quantifying the effectiveness of bioventing applications (Lahvis and Baehr, 1996).

## SUMMARY

For soil-gas surveys to be an effective tool in RBCA decision making, care should be taken in the sampling design, sampling process, and, in particular, interpretation of results. Soil-gas survey data should always be supported with site-specific soil and groundwater data as part of a multimedia approach to risk assessment. Lastly, it is important to realize that soil-gas transport is dynamic by nature and may not always be representative of steady-state, long-term conditions.

-- Matthew A. Lahvis, George E. DeVauil and Robert A. Ettinger, Equilon Enterprises, LLC.

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**ATTACHMENT C**

**Standard Field Procedures for  
Soil Vapor Sampling**

## **STANDARD FIELD PROCEDURES FOR SOIL VAPOR SAMPLING**

This document describes Cambria Environmental Technology's standard field methods for soil vapor sampling. These procedures are designed to comply with Federal, State and local regulatory guidelines. Specific field procedures are summarized below.

### **Objectives**

Soil vapor samples are collected and analyzed to assess whether vapor-phase subsurface contaminants pose a threat to human health or the environment.

### **Soil Vapor Probe Installation**

Soil vapor probes are installed in the vadose zone to check for hydrocarbon vapor migration during air injection. The wells are typically constructed with short screens to target horizons through which hydrocarbon vapor migration could occur. These wells can also be constructed in borings drilled using push technologies such as the Geoprobe by using non-collapsible Teflon tubing set in small sand packed regions overlain by grout.

### **Soil Vapor Sampling**

The required volume of soil vapor is purged through the polyethylene tubing using a standard vacuum pump. The soil vapor can then be sampled by attaching a vacuum sealed summa canister to the tubing. The summa canister should be attached to an air flow regulator which will regulate the rate that air can fill the summa canister. Once the canister is appropriately connected and a pressure test has been performed the canister can be opened and air allowed to flow in under vacuum pressure. Once the pressure valve reads -5 pounds per square inch the vacuum canister can be closed and sampling ended. Once collected, the vapor sample is transported under chain-of-custody to a state-certified laboratory. The ground surface immediately adjacent to the boring is used as a datum to measure sample depth. Drilling and sampling equipment is washed between samples with trisodium phosphate or an equivalent EPA-approved detergent.

### **Sample Storage, Handling and Transport**

Samples are stored out of direct sunlight in coolers and transported under chain-of-custody to a state-certified analytic laboratory.

### **Field Screening**

After collecting a vapor sample for laboratory analysis, Cambria often collects an additional vapor sample for field screening using a portable photo-ionization detector (PID), flame-ionization detector (FID), or GasTech• combustible gas detector to measure volatile hydrocarbon vapor concentrations. These measurements are used along with the field observations, odors, stratigraphy and ground water depth to help select the best location for additional borings to be advanced during the field mobilization.

### **Grouting**

The borings are filled to the ground surface with neat cement.