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ARCADIS
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ARCADIS U.S., Inc.
100 Montgomery Street
Suite 300
San Francisco
California 94104
Tel 415.374.2744
Fax 415.374.2745
www.arcadis-us.com

Mr. Keith Nowell
Hazardous Materials Specialist
Alameda County Environmental Health
1131 Harbor Bay Parkway
Alameda, California 94502

ENVIRONMENT

Subject:
Work Plan – Additional Site Characterization
Former BP Service Station No. 11132
3201 35th Avenue
Oakland, California 94619
Alameda County Local Oversight Program Case # RO0000014

Date:
June 25, 2014

Contact:
Hollis Phillips

Phone:
415.432.6903

Email:
Hollis.Phillips@arcadis-us.com

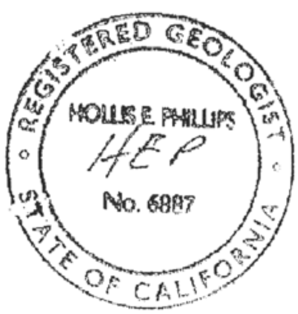
Our ref:
GP09BPNA.C112

Dear Mr. Nowell:

"I declare that to the best of my knowledge at the present time, that the information and/or recommendations contained in the attached document are true and correct."

Submitted by:

ARCADIS U.S., Inc



Hollis E. Phillips, P.G. (No. 6887)
Project Manager/Principal Geologist

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Dear Mr. Nowell:

ARCADIS U.S., Inc. (ARCADIS) on behalf of British Petroleum (BP) has prepared this work plan for additional site investigation activities at the Former BP Service Station No. 11132, located at 3201 35th Avenue in Oakland, California (the Site, Figures 1 and 2). The proposed additional site investigation activities were developed to eliminate data gaps identified in the *ACEH Low Threat Closure Policy Checklist and Site Conceptual Model* (SCM; ARCADIS 2013) and to resolve impediments identified in the path to closure plan.

Proposed Scope of Work

Investigation activities developed within the scope of this work plan are proposed to further characterize downgradient concentrations of site constituents of concern (COCs) in groundwater; characterize soil vapor concentrations adjacent to off-site residences; and recover separate phase hydrocarbons (SPH) to the extent practicable.

This work plan includes the recommendation for replacement of monitoring well MW-10, installation of an additional off-site monitoring well, completion of a soil vapor investigation, and completion of a bail down test and mobile vacuum extraction test at OW-1.

Pre-Field Activities

Prior to initiating the proposed activities, the site-specific Health and Safety Plan (HASP) will be updated in accordance with state and federal requirements to address hazards associated with the updated scope of work for the Site. All necessary soil boring and well construction/destruction permits will be obtained prior to the initiation of intrusive activities. Obstruction permits for the offsite wells will be obtained from the City of Oakland.

Underground utilities and other potential subsurface obstructions in the vicinity of the proposed wells and vapor probes will be located and marked by a private utility locator. In addition, Underground Service Alert (USA) will be notified a minimum of 48 hours prior to the commencement of intrusive activities.

Monitoring Well Replacement

Monitoring well MW-10, on the south side of 35th Avenue, has historically contained elevated concentrations of site COCs and indicated the presence of SPH. As discussed in the SCM, observations reported during SPH baildown activities indicate that residual product is likely stuck to the inside of the well casing; thus occasional sheen observed at the well may be attributed to poor well condition. Additionally the well screen has been submerged during a majority of the time it has been sampled. Prior to the destruction of monitoring well MW-10, the total depth will be measured to confirm the well casing is free of obstructions. Well construction details are included in Table 1.

ARCADIS will destroy MW-10 in accordance with Alameda County Environmental Health (ACEH) well destruction permit requirements. Well destruction activities will be conducted under the direct supervision on an ARCADIS geologist.

Monitoring Well Installation

The installation of two monitoring wells (MW-10R and MW-11; Figure 2) is proposed to further delineate the extent of off-site COCs and to evaluate the presence of SPH in the vicinity of well MW-10. As discussed above, monitoring well MW-10R is proposed to be installed adjacent to well MW-10. Monitoring well MW-11 is proposed to be installed downgradient of the Site to delineate the extent of the plume. Further discussion of the nature and extent of COCs at the site and data gaps is provided in the SCM (ARCADIS 2013).

Installation Procedures

Prior to the initiation of drilling activities, all proposed well locations will be cleared to a minimum depth of 6.5 feet below ground surface (bgs) with a hand auger or air knife as a third line of evidence to identify potential subsurface utilities. Once cleared, the boring will be advanced using a hollow stem auger (HSA) rig to an approximate total depth of 27 feet bgs by a C-57 licensed drilling contractor. Soil samples will be collected every five feet, logged for stratigraphic characteristics, and field screened for the presence of volatile organic carbons (VOCs) using a photoionization detector (PID). If soil samples indicate elevated concentrations of VOCs based on PID readings or visual/olfactory observations they will be submitted for the following laboratory analyses:

- total petroleum hydrocarbons as GRO (C6-C12) using United States Environmental Protection Agency (USEPA) Test Method 8015 Modified;
- benzene, toluene, ethylbenzene, and xylenes (collectively BTEX) and fuel additives methyl tertiary butyl ether (MTBE), tertiary butyl alcohol (TBA), and diisopropyl ether (DIPE) using USEPA Method 8260

Monitoring wells will be constructed with 2-inch-diameter schedule 40 polyvinyl chloride (PVC) casing with 15 feet of 0.010-inch slotted PVC screen. The screen interval will be set from approximately 12 to 27 feet bgs. The final well depth and screen placement interval will be dependent upon field observations to optimize well performance.

A clean sand filter pack consisting of No. 2/12 Monterey Sand will be placed around the well from the bottom of the borehole to approximately 2 feet above the screen interval. Approximately 2 feet of hydrated bentonite will be placed above the filter pack. The remainder of the annular space will be grouted with neat cement to approximately 1 foot bgs. The well will be fitted with a well cap and completed with a locking, traffic-rated flush mounted well box. All well construction activities will be conducted in accordance with specifications outlined in the permit.

The top of casing and ground surface elevation, as well as the northing and easting for the new monitoring wells, will be surveyed by a California-licensed land surveyor after completion of the monitoring well installation.

Well Development

After a minimum of 72 hours after installation, the newly installed monitoring wells (MW-10R and MW-11) will be developed using a combination of surging, bailing, and pumping. A surge block will be moved up and down across the screened interval to remove fine-grained deposits from the formation near the monitoring well and boring wall and from the filter pack material. After surging the monitoring well, a bailer will be used to remove water containing suspended sediments from the casing. Additional purging activities will be conducted with a submersible pump placed near the bottom of the well. The final development task will consist of pumping the well at a steady flow rate while monitoring groundwater parameters (including pH, temperature, conductivity, and turbidity) using a water quality meter with a flow-through cell. Pumping will continue until at least ten casing-volumes of water have been removed, and/or consecutive groundwater parameter readings have stabilized to within 10%.

Monitoring Well Sampling

Following well development, the monitoring wells will be gauged and sampled quarterly for one year and then will be added to the routine groundwater sampling program. The current groundwater sampling program consists of semi-annual groundwater monitoring conducted in the first and third calendar quarters. If SPH is not present in monitoring well MW-10R and MW-11, groundwater samples will be collected and submitted under chain-of-custody protocol to TestAmerica Laboratories, Inc., a California state-certified laboratory located in Pleasanton, California, and analyzed for

- GRO (C6-C12) using USEPA Test Method 8015 Modified;
- BTEX and fuel additives MTBE, TBA, and DIPE using USEPA Method 8260.

Data collected during the sampling events will be incorporated into the SCM and Low-Threat Closure (LTC) checklists previously prepared for ACEH.

Soil Vapor Investigation

To evaluate potential vapor instruction concerns associated with residences adjacent to the Site and eliminate data gaps identified in the SCM (ARCADIS 2013), ARCADIS proposes to install a dual-nested soil vapor probe (SV-1S/SV-1D) at 5 and 10 feet bgs, near the residential property across 35th Avenue (Figure 2). The exact vapor probe location is subject to change by the field team based on the proximity of subsurface utilities and access considerations. The vapor probes will be permanently installed until the Site receives Low-Threat Underground Storage Tank (UST) Case Closure allowing the decommissioning of the probes. The installation and sampling will be completed in accordance with the Standard Operating Procedures (SOPs) included in Attachment A.

Soil Vapor Probe Construction

The soil vapor probe SV-1 will contain two soil vapor screens set at depths of 5 and 10 feet bgs. These depths were selected based on the requirements detailed within Appendix 4 of the LTC Policy. The multiple depth intervals will assist in determining a soil vapor concentration gradient as well as the extent to which biodegradation of volatile constituents of potential concern (COPCs) may be occurring. The soil vapor probe depths may be adjusted in the field based on soil properties.

When the boring has been advanced to its final depth of approximately 10.5 feet bgs, a 6-inch-long, 0.375-inch-outer-diameter stainless steel soil vapor screen will be set in a 1-foot interval of standard sand pack, allowing approximately 3 inches of sand above and below the screen. Teflon tubing (or equivalent) will be connected to the soil vapor screen and capped with a vapor-tight two-way valve or compression cap fitting at the surface to eliminate the potential for barometric pressure fluctuations to induce vapor transport between the subsurface and the atmosphere. The two-way valve will be installed in the closed position to allow equilibration of soil vapor concentrations to commence immediately after installation.

A 1-foot interval of dry granular bentonite will be placed above the sand pack followed by hydrated granular bentonite to the depth of the next sample probe. Sand pack is used around the screened interval of each sample probe to allow soil vapor from the adjacent soil to reach the probes. Dry granular bentonite is used to ensure that the hydrated bentonite does not seal the vapor probe screen and inhibit the collection of soil vapor. This process will be repeated for the 5-foot soil vapor screen. The surface of the multilevel probe cluster location will be fitted with a temporary concrete cap at approximately 0.5 foot bgs. The surface of each soil vapor probe will be fitted with a concrete cap and a flush mounted well box with sufficient room to secure the tubing and fittings. A soil vapor probe schematic diagram detailing the construction is shown on Figure 3**.**

Soil Vapor Sampling

Due to the introduction of atmospheric oxygen into the vadose zone during soil vapor probe installation, an equilibration time is required to allow the sand pack and tubing to equilibrate with the subsurface. The CalEPA *Advisory – Active Soil Gas Investigation* (CalEPA 2012) requires a minimum of 48 hours for equilibration before testing, purging, and sampling of the soil vapor probes. The equilibration time will be increased to 72 hours to minimize the purge volume during testing of the soil vapor probes. Due to this increase in equilibration time, purge volumes will be calculated based on the dimensions of the above-ground gauges, tubing, sampling equipment, below-ground sand pack pore space, tubing, and soil vapor probe. Purge volume calculations, field conditions, flow rate, pump specifics, and other applicable information will be recorded by field personnel on soil vapor sample collection logs.

To confirm sampling train integrity, a shut-in leak detection test will be implemented. One vapor-tight two-way ball valve will be installed closest to the soil vapor port (port valve) and another vapor-tight two-way ball valve will be installed on the opposite end of the sampling train as a purge valve (purge valve). While the port valve is left in the closed position, a laboratory-provided syringe will be used to remove approximately 25 milliliters (ml) from the purge port, inducing a vacuum of approximately 7.5 inches of mercury (approximately 102 inches of water) within the sampling train. The purge valve will be closed and the vacuum within the sampling train will be monitored for a minimum of 2 minutes. If there is any observable loss in the vacuum within the sampling train after 2 minutes, fittings will be adjusted and the test will be repeated until the vacuum in the sampling train does not dissipate.

A purge volume test will be conducted in three steps (one, two, and three volumes) at a flow rate of ≤ 100 ml per minute (ml/min). A Tedlar bag will be collected after each volume step is completed and field measured for VOCs using a parts per billion PID. As soon as the VOC measurements stabilize, assuming ~10 percent (%) variance, soil vapor sample collection will begin. If the VOC concentrations do not stabilize, additional volumes will be purged until concentrations stabilize or until 10 purge volumes are reached, whichever comes first. If VOCs are not detected by PID in any of the step purge tests, a default of three purge volumes will be used. This method will ensure accurate subsurface soil vapor measurements are collected and that subsurface conditions are stable. The ideal purge volumes established are expected to be used in subsequent soil vapor sampling, if necessary.

Leak testing will also be conducted concurrently with the purge volume testing to ensure the integrity of the sampling system. The well head and entire sampling train (valves, tubing, gauges, manifold, and sample canister) will be placed in an enclosure with pliable weather stripping along the base. A tracer check compound (high purity helium) will be permitted into the enclosure. Approximately 10 to 20% helium will be maintained in the enclosure using a portable helium detector. Analysis for the tracer compound in the soil vapor sample will be used to assess if leakage occurred. Purged soil vapor from purge volume testing will also be measured for helium as a pre-sampling leak detection procedure. Leakage will be calculated based on the following equation:

% Leakage = ((helium conc in sample (%) / helium conc in shroud (%) X 100 (%)

According to Section 4.2.2.2 of the CalEPA *Advisory – Active Soil Gas Investigations,* “An ambient air leak up to 5 percent is acceptable if quantitative tracer testing is performed by shrouding.” If leakage is calculated to be above 5% based on fixed gas analytical data, the quality of the soil vapor data will be considered potentially questionable.

The soil vapor samples will then be collected using 1-liter batch certified SUMMA™ canisters (or an acceptable alternative) at a flow rate of ≤ 100 ml/min. A vacuum of <10 inches of mercury (inHg) will be maintained throughout sampling. Soil vapor sampling will be stopped when the canister vacuum has dropped to no less than 5 inHg.

The soil vapor samples will be shipped under appropriate chain-of-custody protocols to Eurofins Air Toxics Ltd. in Folsom, California, for analysis of the following:

- Benzene, ethylbenzene, and naphthalene by Modified USEPA Method TO-15; and
- Oxygen and helium by Modified ASTM International D-1946.

Soil samples may be collected from 0 to 5 feet at or near the locations of the soil vapor probes and analyzed for GRO and DRO if needed in conjunction with the soil vapor sampling to satisfy the criteria established in *Petroleum Vapor Intrusion to Indoor Air* of the LTC Policy.

Bail Down Test

In order to address residual light non-aqueous phase liquid (LNAPL) observed in well OW-1, ARCADIS proposes to conduct a bail down test and monitor recharge to determine LNAPL mobility. Determining the rate of LNAPL recharge will enable ARCADIS to estimate LNAPL mobility and determine the most effective approach for removing LNAPL to the extent practicable. The bail down test will be conducted by removing LNAPL from the well using a disposable polyethylene bailer and subsequently monitoring LNAPL recharge. Based on historical observations, ARCADIS anticipates relatively slow LNAPL recharge. Subsequent to LNAPL removal, LNAPL and groundwater recovery will be monitored approximately every minute for the first 15 minutes, every five minutes for the next 15 minutes, and every ten minutes until approximately two hours after LNAPL removal or until conditions stabilize. ARCADIS will subsequently conduct periodic monitoring until LNAPL has recharged to at least 85 percent of the initial LNAPL thickness, which will include monitoring twice daily for the first two days after bail down activities, twice weekly during the subsequent week, and weekly for approximately three weeks. ARCADIS will re-evaluate this schedule once field data from the first two weeks have been collected in order to accurately monitor recharge until 85 percent recovery has been achieved. The SOP for bail down testing is presented in Attachment A.

Vacuum Truck Extraction

Following the baildown test, vacuum truck extraction (VTE) will be performed on OW-1 to evaluate if additional LNAPL and/or dissolved phase hydrocarbons can be removed from the well. The primary objective of VTE is to dewater the smear zone and volatilize dissolved phase hydrocarbons trapped in the pore space of the soil. The operational metrics of VTE are based on aquifer drawdown and vacuum distribution. In most applications, maximizing water table drawdown and casing vacuum in the extraction wells optimizes both dewatering and volatilization of dissolved phase hydrocarbons.

In order to remove residual LNAPL from vadose zone and smear zone soils, high vacuum and smear zone dewatering will be implemented through VTE. LNAPL and groundwater will be recovered using a down well submersible pump, and VTE will be implemented at OW-1 for approximately four hours.

A gauging round will occur after completion. The location and duration of additional VTE events will be determined by evaluating mass recovery and LNAPL removal data from this initial event. Vacuum radius of influence (ROI), groundwater drawdown, and system operational vacuums will be analyzed to determine if sufficient groundwater drawdown is sustainable to expose smear zone soils.

Decontamination

All equipment conducted within the scope of investigation activities will be decontaminated appropriately using Liquinox ® solution and deionized water rinse prior to demobilization or mobilization between locations to prevent potential cross-contamination. All decontamination procedures will be conducted in accordance with procedures outlined in the HASP.

Investigation-Derived Waste

Investigation derived waste (IDW) generated during investigation activities will likely include soil cuttings, decontamination fluids, purge water, personal protective equipment (PPE), extracted SPH and vapors, and other disposable sampling materials. Soil cuttings derived from drilling as well as wastewater from decontamination procedures and purgewater from well development and the collection of groundwater samples will be placed in 55-gallon drums for temporary storage prior to disposal. PPE, such as nitrile gloves, and disposable supplies or other household-type waste, such as paper and plastic, will be treated as municipal waste. If required, one composite soil sample and one composite water sample will be collected from the IDW drums to characterize the waste for disposal. Pending characterization, the IDW will be stored on-site in a secure and controlled area. The IDW will be disposed of in accordance with the waste hauler, waste handling facility, and state and federal requirements. Water, SPH, and vapors generated during the VTE event will be transported by the subcontractor to the appropriate waste facility for disposal after waste characterization.

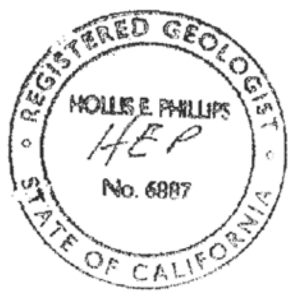
Reporting and Schedule

Upon receipt of ACEH approval for the work plan and procurement of necessary permits, ARCADIS will implement the proposed activities as quickly as possible to expedite elimination of data gaps and further the Site toward closure. Once field activities are complete, ARCADIS will prepare a letter report summarizing the results of the proposed investigation activities with conclusions and recommendations. The results of investigation activities will be incorporated into the previously submitted ACEH LTC checklist and the SCM will be revised and submitted with the results of the investigation report.

If you have any questions please contact Hollis Phillips by telephone at 415.432.6903 or by email at Hollis.Phillips@arcadis-us.com.

Sincerely,

ARCADIS U.S., Inc.



Hollis E. Phillips, P.G. (No. 6887)
Project Manager/Principal Geologist

Enclosures:

Table 1	Well Construction Details
Figure 1	Site Location Map
Figure 2	Site Plan
Figure 3	Vapor Probe Schematic Diagram

Attachment A – Standard Operating Procedures

Copies:
Electronic Copy uploaded to Geotracker

Table

Table 1
Well Construction Details
Former BP Service Station No. 11132
3201 35th Avenue, Oakland, California

Monitoring Well ID	Well Installation Date	Boring Diameter (inches)	Well Diameter (inches)	Total Depth (feet bgs)	Well Depth (feet bgs)	Screen Interval (feet bgs)
MW-1	07/30/86	8	2	45	45	10-45
MW-2	07/31/86	8	2	35	35	10-35
MW-3	07/31/86	8	2	35	35	10-35
MW-4	01/29/90	8	2	40	40	10-40
MW-5	02/01/90	8	2	35	35	10-35
MW-6	02/01/90	8	2	35	35	15-35
MW-7	02/01/90	8	2	35	35	17-35
MW-8	02/25/91	8	2	41.5	40	20-40
MW-9	02/26/91	8	2	36.5	35	15-35
MW-10	02/27/91	8	2	36.5	35	20-35
RW-1	01/29/90	10	6	40.0	40	20-40
AS-1	09/08/10	8	2	47	45	42-45
OW-1	09/08/10	8	2	42	40	20-40
SVE-1	09/08/10	8	2	20	20	10-20
VM-1	09/08/10	8	2	20	20	10-20
VM-2	09/08/10	8	2	22	20	10-20

Notes
bgs = below ground surface

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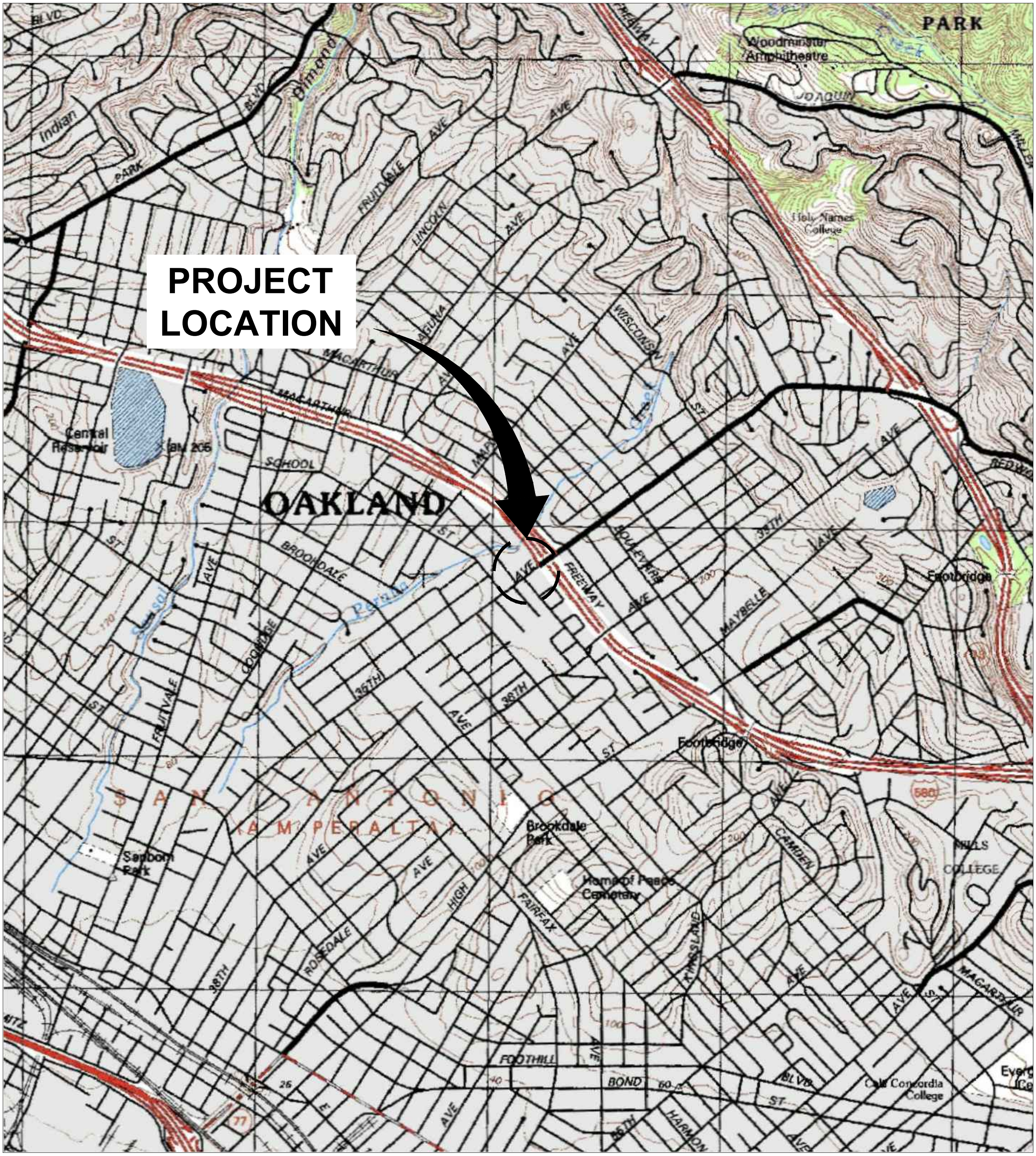
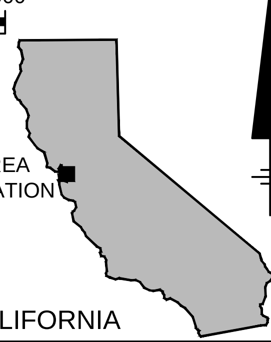
Figures



REFERENCE: BASE MAP USGS 7.5. MIN. TOPO. QUAD., OAKLAND EAST, CALIFORNIA, 1997.

0 2000' 4000'

Approximate Scale: 1 in. = 2000 ft.



FORMER BP STATION No. 11132
3201 35TH AVENUE
OAKLAND, CALIFORNIA

SITE LOCATION MAP

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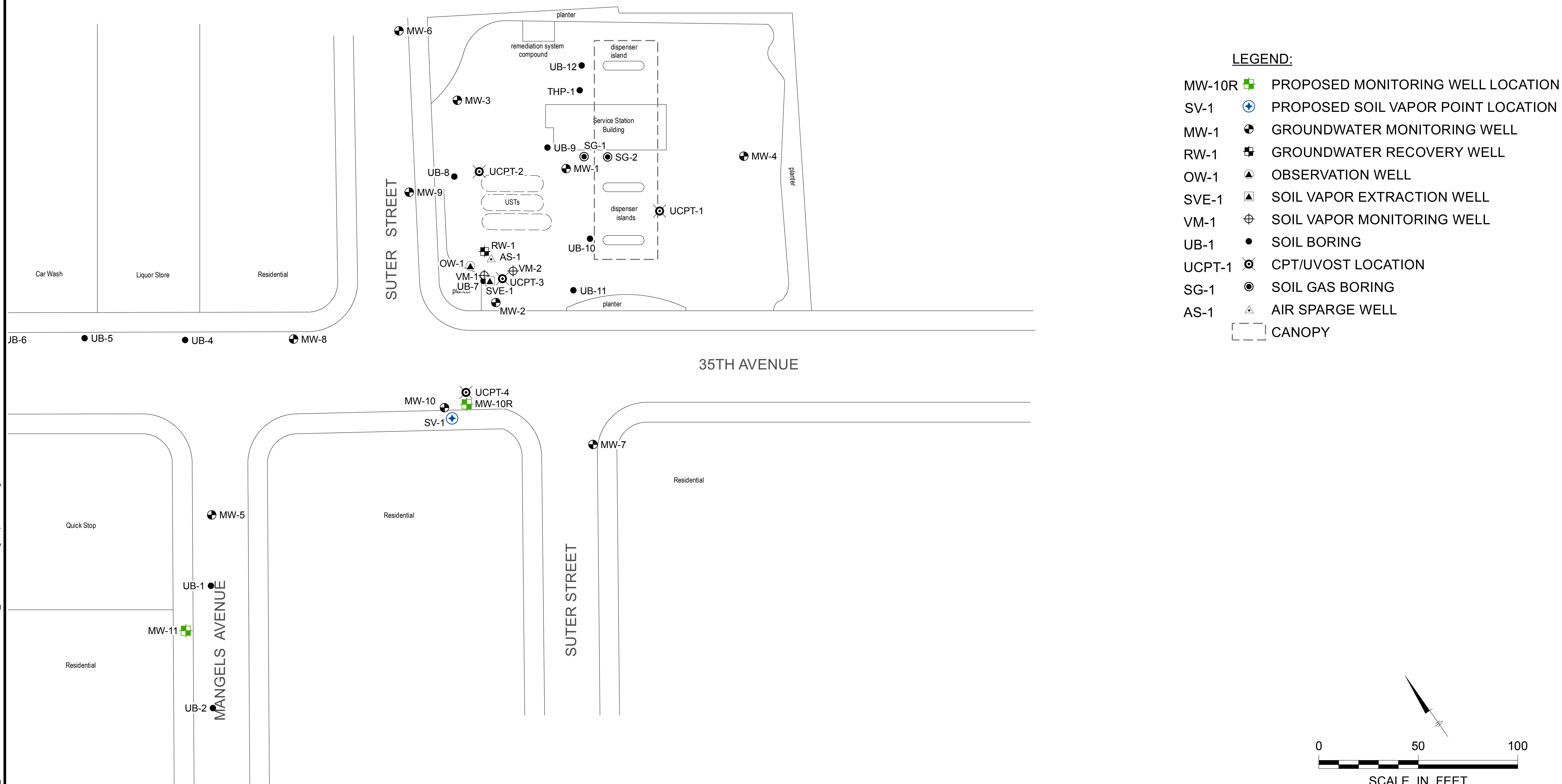
FIGURE
1



NOTES:

1. SITE MAP ADAPTED FROM CAMBRIA ENVIRONMENTAL FIGURES. SITE DIMENSIONS AND FIGURES FACILITY LOCATIONS NOT VERIFIED.

FORMER BP SERVICE STATION #11132
3201 35TH AVENUE
OAKLAND, CALIFORNIA

SITE PLAN

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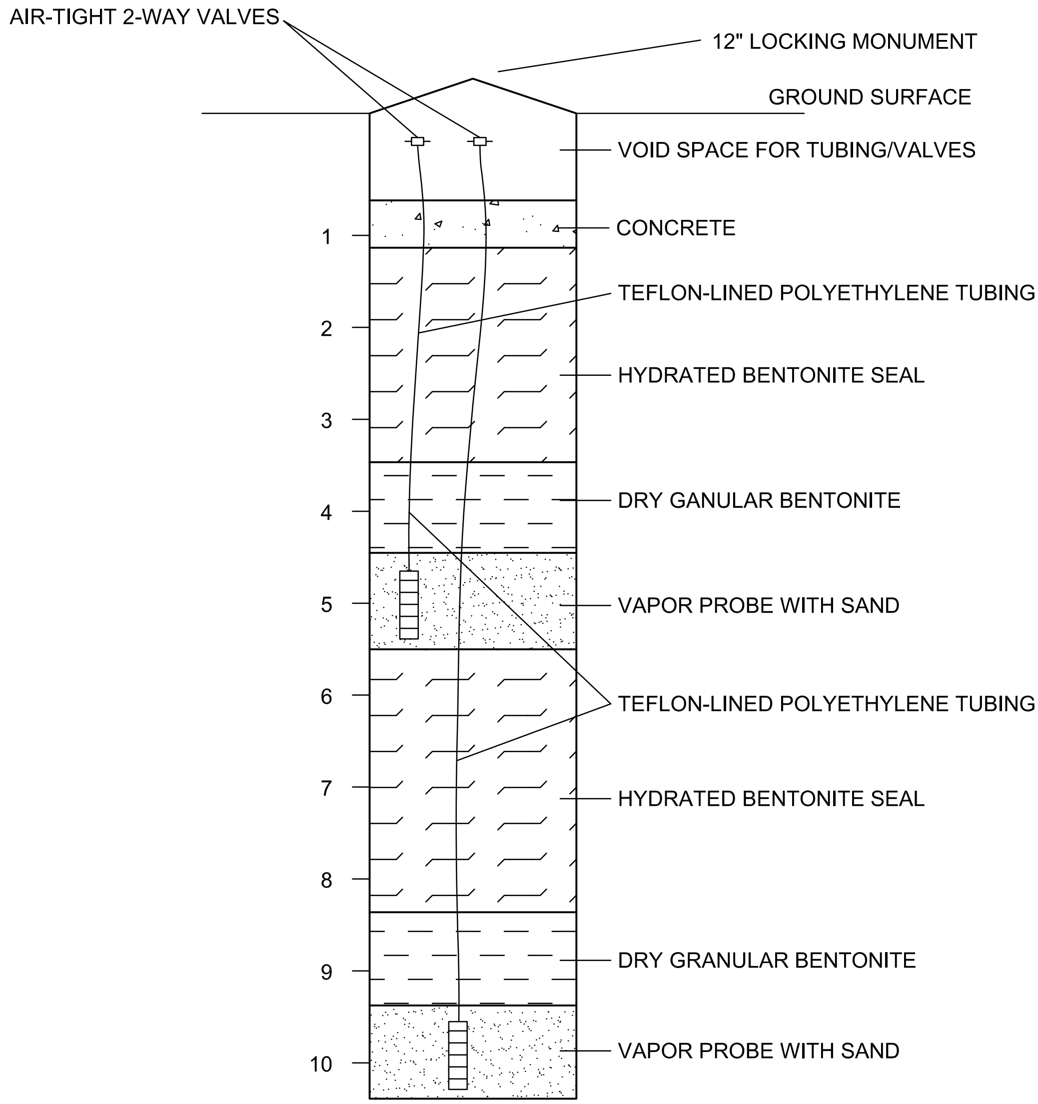
FIGURE
2

CITY: SAN FRANCISCO DIV/GROUP: ENV/IM DB: kgpeters LD: PIC: PM: TM:
PROJECT: PATH: Z:\GISPROJECTS_ENV\BP_FOXGLOVE\CA\CA11132\GIS\MXD\CA11132_SitePlanShowingProposedBoringLocations.mxd DATE: 6/24/2014 3:50:01 PM



NOTE:

VAPOR PROBE IS CONSTRUCTED WITH A 6-INCH, 0.375-INCH OUTER DIAMETER STAINLESS STEEL SOIL VAPOR SCREEN WITH A STAINLESS STEEL INIPLANT ANCHOR

FORMER BP SERVICE STATION #11132
3201 35TH AVENUE
OAKLAND, CALIFORNIA

VAPOR PROBE SCHEMATIC DIAGRAM

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FIGURE
3

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Attachment A

Standard Operating
Procedures

ARCADIS
Infrastructure, environment, facilities

Imagine the result

Soil Gas Sampling Using Single or Nested Ports

SOP # 428199

Rev. #: 4

Rev Date: July 9, 2010

Approval Signatures

Prepared by: _______________ Date: 07/09/2010
Mitch Wacksman and Andrew Gutherz

Approved by: _______________ Date: 07/09/2010
Christopher Lutes and Nadine Weinberg

I. Scope and Application

This document describes the procedures for installing semi-permanent or permanent single or nested soil-gas ports and collecting soil-gas samples. Nested soil-gas ports allow for the generation of discrete data as a function of depth and time. Samples are collected for the analysis of volatile organic compounds (VOCs) by United States Environmental Protection Agency (USEPA) Method TO-15 (TO-15). Method TO-15 uses a 1-liter, 3-liter of 6-liter SUMMA® passivated stainless steel canister. An evacuated SUMMA canister (less than 28 inches of mercury [Hg]) will provide a recoverable whole-gas sample of approximately 5 liters when allowed to fill to a vacuum of 6 inches of Hg. The whole-air sample is then analyzed for VOCs using a quadrupole or ion-trap gas chromatograph/mass spectrometer (GS/MS) system to provide compound detection limits of 0.5 parts per billion volume (ppbv). Optionally, the whole air sample can also be analyzed for permanent gasses such as oxygen and carbon dioxide.

The following sections list the necessary equipment and provide detailed instructions for the installation of semi-permanent or permanent single or nested soil-gas ports (using direct-push technology or a hollow stem auger) and the collection of soil-gas samples for VOC analysis.

II. Personnel Qualifications

ARCADIS field sampling personnel will have current health and safety training, including 40-hour Hazardous Waste Operations and Emergency Response (HAZWOPER) training. Site supervisor training, site-specific training, first-aid, and cardiopulmonary resuscitation (CPR), may be appropriate at some sites. ARCADIS field sampling personnel will be well versed in the relevant standard operating procedures (SOPs) and possess the required skills and experience necessary to successfully complete the desired field work. ARCADIS personnel responsible for leading soil-gas sample collection activities must have previous soil-gas sampling experience.

III. Health and Safety Considerations

All sampling personnel should review the appropriate health and safety plan (HASP) and job loss analysis (JLA) prior to beginning work to be aware of all potential hazards associated with the job site and the specific installation. Field sampling equipment must be carefully handled to minimize the potential for injury and the spread of hazardous substances. For vapor port installation, drilling with a direct-push drilling rig or hollow stem auger rig should be done only by personnel with prior experience using such of equipment.

IV. Equipment List

The equipment required to install single or nested soil vapor ports is presented below:

- Appropriate personal protective equipment (PPE ; as required by the HASP and JLA);

- Appropriate drill rig to reach necessary sample depth (hollow stem auger, direct-push rig, etc)

    - Hollow stem auger rig with interconnecting augers. The inner diameter of typical augers ranges from 2.25-inches to 7.75-inches; the auger size should be chosen should be large enough to accommodate the number of nested ports that will be installed inside the boring.

    - Direct-push rig (e.g., -Geoprobe) equipped with interconnecting 4-foot lengths of steel drive rods (2.25-inch-diameter, or 3.25-inch diameter depending on the number of ports to be installed).

- 1/4-inch outside diameter (OD) x 1/8-inch inside diameter (ID) tubing (Teflon, Teflon lined, or nylon). Note that Nylaflow tubing has a somewhat higher background level of BTEX and much poorer recovery of trichlorobenzene and naphthalene then Teflon, so it should not be used on site where these compounds are a concern (Hayes, 2006)

- Stainless steel sample screens with sacrificial point (one per sample depth to weight sample screen, available from Geoprobe). Typically 6" long for sized for 1/4-inch OD tubing.

- Stainless steel, or Teflon ball valve or needle valve (one per sample depth to match sample tubing) for sample line termination.

- Commercially available clean sand filter pack or glass beads having a grain size larger than 0.0057-inch (pore diameter of screen)

- Granular and powdered bentonite (Benseal®, Volclay® Crumbles, or equivalent)

- Down hole measuring device

- Distilled or Deionized water for hydration of bentonite

- Plastic or aluminum tags for permanently labeling port with sample depth, and port identification number. It is no recommended to write on or affix adhesive tape to tubing as these methods fail over time.

- Well cover for permanent installation, This should be a traffic rated road box for exterior installations or an appropriate clean-out cover for interior installations.

- Photoionization Detector (PID) (with a lamp of 11.7 eV).

The equipment required for soil-gas sample collection from single or nested ports is presented below:

- 1,3, or 6 – liter stainless steel SUMMA® canisters (order at least one extra, if feasible) (batch certified canisters or individual certified canisters as required by the project)

- Flow controllers with in-line particulate filters and vacuum gauges; flow controllers are pre-calibrated to specified sample duration (e.g., 30 minutes, 8 hours, 24 hours) or flow rate (e.g., 200 milliliters per minute [mL/min]); confirm with the laboratory that the flow controller comes with an in-line particulate filter and pressure gauge (order at least one extra, if feasible). Flow rate should be selected based on expected soil type (see below)

- Decontaminated stainless steel1/4-inch Swagelok (or equivalent) fittings (e.g., nuts, ferrules and backers)

- Decontaminated stainless steel Swagelok or comparable “T” fitting and needle valve for isolation of purge pump.

- Stainless steel or brass “T” fitting (if collecting duplicate [i.e., split] samples). Swage-lok or comparable

- Portable vacuum pump capable of producing very low flow rates (e.g., 100 to 200 mL/min) with vacuum gauge. Purging flow rate should also be selected based on expected soil type (see below).
- Rotameter or an electric flow sensor if vacuum pump does not have an accurate flow gauge (Bios DryCal or equivalent).
- Tracer gas testing supplies if applicable (refer to tracer SOP)
- Photoionization Detector (PID) (with a lamp of 11.7 eV)
- Appropriate-sized open-end wrench (typically 9/16-inch, 1/2-inch, and 3/4-inch)
- Down hole measuring device (e.g., water level probe, tape measure)
- Portable weather meter, if appropriate
- Chain-of-custody (COC) forms
- Sample collection logs (attached)
- Field Book

V. Cautions

The following cautions and field tips should be reviewed and considered prior to installing or collecting a single or nested soil-gas sample.

- When drilling to install sampling ports , be mindful of utilities that may be in the area. Follow ARCADIS utility location procedure. If the driller is concerned about a particular location, consult the project manager about moving it to another location. Do not hesitate to use Stop Work Authority; if something doesn't seem right stop and remedy the situation.
- Sampling personnel should not handle hazardous substances (such as gasoline), permanent marking pens (sharpies), wear/apply fragrances, or smoke cigarettes/cigars before and/or during the sampling event.

- Ensure that the flow controller is pre-calibrated to the proper sample collection duration (confirm with laboratory). Sample integrity can be compromised if sample collection is extended to the point that the canister reaches atmospheric pressure. Sample integrity is maintained if sample collection is terminated prior to the target duration and a measurable vacuum (e.g., 3-7–inches Hg) remains in the canister when sample collection is terminated. Do not let sample canister reach atmospheric pressure (e.g., 0-inches Hg).

- Care should be taken to ensure that nested ports are installed at the target sample depths within the sand filer pack.. Sampling personnel should work closely with the driller to accomplish this.

- When introducing granular bentonite to the boring, the material should be introduced slowly and hydrated properly. Consult the bentonite manufacturer's instructions on the bag to determine the proper amount of to be used. When hydrated properly bentonite forms a thick clay mass that remains moist. The hydration step is crucial in the installation process and if not done properly the integrity of the bentonite seal can be compromised.

- Using prehydrated bentonite is best and should be discussed with drilling subcontractor.

- The purge flow rate of 100 ml/min should be suitable for a variety of silt and sand conditions but will not be achievable in some clays without excessive vacuum. Thus lower flow rates may be necessary in clay. A low vacuum (<10" of mercury) should be maintained. Record the measured flow rate and vacuum pressure during sample collection.

  The cutoff value for vacuum differs in the literature from 10" of water column (ITRC 2007) to 136" of water column or 10" of mercury (http://www.dtsc.ca.gov/lawsregspolicies/policies/SiteCleanup/upload/SMBR_ADV_activesoilgasinvst.pdf). A detailed discussion of the achievable flow rates in various permeability materials can be found in Nicholson 2007. Related issues of contaminant partitioning are summarized in ASTM D5314-92. Passive sampling approaches can be considered as an alternative for clay soils although most passive methods for soil gas do not yield a quantitative concentration in soil gas.

- It is important to record the canister pressure, start and stop times and ID on a proper field sampling form. You should observe and record the time/pressure at a mid-point in the sample duration. It is a good practice to lightly tap the pressure gauge with your finger before reading it to make sure it isn't stuck.

- Ensure that there is still measureable vacuum in the SUMMA® after sampling. Sometimes the gauges sent from labs have offset errors, or they stick.

- When sampling carefully consider elevation. If your site is over 2,000' above sea level or the difference in elevation between your site and your lab is more than 2,000' then pressure effects will be significant. If you take your samples at a high elevation they will contain less air for a given ending pressure reading. High elevation samples analyzed at low elevation will result in more dilution at the lab, which could affect reporting limits. Conversely low elevation samples when received at high elevation may appear to not have much vacuum left in them. http://www.uigi.com/Atmos_pressure.html.

- If possible, have equipment shipped a two or three days before the sampling date so that all materials can be checked. Order replacements if needed.

- Requesting extra canisters from the laboratory should also be considered to ensure that you have enough equipment on site in case of an equipment failure.

- Soil-gas sampling should not proceed within 5 days following a significant rain event (1/2-inch of rainfall or more). Exceptions to this requirement may be appropriate depending on site climatic conditions, soil gas point depth and soil drainage characteristics. However since this requirement is frequently contained in regulatory documents, any exception to this requirement must be discussed with client and/or regulatory representatives. ITRC (2007) discussed the conditions when this requirement may not be necessary: "*Infiltration from rainfall can potentially impact soil gas concentrations by displacing the soil gas, dissolving VOCs, and by creating a "cap" above the soil gas. In many settings, infiltration from large storms penetrates into only the uppermost vadose zone. In general, soil gas samples collected at depths greater than about 3–5 feet bgs or under foundations or areas with surface cover are unlikely to be significantly affected. Soil gas samples collected closer to the surface (<3 feet) with no surface cover may be affected. If the moisture has penetrated to the* *sampling zone, it typically can be recognized by difficulty in collecting soil gas samples. "*

VI. Procedure

Single or Nested Soil-Gas Monitoring Point Installation

The procedure used to install semi-permanent or permanent single or nested soil-gas ports will vary based upon the method of boring installation. In most situations a temporary well casing well need to be installed to keep the down hole formation from collapsing during port installation. The following steps will detail installing nested soil-gas ports through a temporary well casing.

If the nested ports will be installed at shallow depths, or the formation is thought to be stable enough to not collapse, a temporary well casing may not be necessary to facilitate the installation of the sample ports. Either way, the steps for installing the sample ports are nearly identical. These following steps should be discussed with the drilling subcontractor and altered based on the methods chosen for a given project.

1. Advance boring to bottom of deepest sampling interval and install a temporary well casing. Care should be taken to ensure that the terminal depth of the boring does not reach groundwater or the capillary fringe. Soil-gas probes should not be installed in groundwater or the capillary fringe. Moisture conditions and/or other observations (such as depth to water in nearby monitoring wells) should be recorded on the soil-gas collection log, as indicated.

2. Cut a length of 1/4-inch tubing slightly longer (e.g., 4 to 5 feet) than the collection depth. Attach a stainless steel sample screen and sacrificial point to the tubing and lower the screen and attached tubing through the boring.

3. Assure that the sample screen has reached the bottom of the boring and record this depth.

4. Begin simultaneously filling in the area around the sample screen with sand filter pack and retracting the temporary well casing. The casing should be lowered back down onto the sand every few inches to compact the sand around the screen. Sand should be introduced 3-inches below the screen, to cover the 6-inch sample screen and extend 3-inches inches above the screen for a total of 12 inches of sand. Closely monitor the amount of sand added to the borehole with a tape measure or water level probe.

5. With the proper sand pack in place begin slowly introducing 6-inches of dry granular bentonite into the boring. This dry Bentonite will prevent water from entering the sand filter pack during hydration.

6. A slurry of hydrated bentonite should be placed above the dry granular bentonite to the next sample depth (for nested ports) or to the ground surface (for single ports).

7. Properly label the sample tubing with a permanent label to designate the sample number and screen depth.

8. Affix a Swagelok fitting and valve to the end of the tubing.

9. Add an inch or two of dry granular Bentonite over the bentonite slurry prior to installing the subsequent sand filter pack and screen.

10. Repeat steps 2-8 until all the sample depths are installed.

11. With all semi-permanent or permanent single or nested ports installed and labeled, a well cover may be installed.

    a. For permanent installations, the well cover should be rated for whatever type of traffic it may encounter in the future. For interior installations a brass clean-out cover available from a plumbing supply store may provide adequate protection. For exterior installations in high traffic areas a heavy duty groundwater well cover may be appropriate.

    b. For a semi-permanent installation, a well cover is generally not necessary as the tubing will be removed within several days.

12. All soil-gas points should be allowed to sit and equilibrate for a minimum of 24-hours before proceeding to soil-gas sample collection.

Soil-Gas Sample Collection

The following steps should be used to collect a soil-gas sample from each of the single or nested probes installed using the above procedure.

1. Record the following information on the sample log, if appropriate (contact the local airport or other suitable information source [e.g., site-specific measurements, weatherunderground.com] to obtain the information):

    a. wind speed and direction;

    b. ambient temperature;

    c. barometric pressure; and

    d. relative humidity.

2. Assemble the sample train by removing the cap from the SUMMA canister and connecting the Swagelok T-fitting to the can using a short length of 1/4-inch OD Teflon tubing. The flow controller with in-line particulate filter and vacuum gauge is then attached to the T-fitting. The Swagelok (or similar) two-way valve is connected to the free end of the T-fitting using a short length of ¼-inch OD Teflon tubing (precleaned stainless steel tubing could also be used)..

3. When collecting duplicate or other quality assurance/quality control (QA/QC) samples as required by applicable regulations and guidance, couple two SUMMA canisters using stainless steel Swagelok duplicate sample T-fitting supplied by the laboratory. Attach flow controller with in-line particulate filter and vacuum gauge to duplicate sample T-fitting provided by the laboratory.

4. Attach Teflon sample tubing to the flow controller using Swagelok fittings.

5. Remove the flush Swagelok cap from the sample port and install a Swagelok nut, ferrules, and sample tubing into the sub-slab port.

6. Connect the two-way valve and the portable purge pump using a length of Teflon sample tubing.

7. Record on the sample log and COC form the flow controller number with the appropriate SUMMA® canister number.

    a. Perform a leak-down-test by replacing the nut which secures sample tubing with the cap from the canister or closing the valve on the sample port. This will create a closed system. Open the canister valve and quickly close it; the vacuum should increase approaching 30" Hg. If there are no leaks in the system this vacuum should be held. If vacuum holds proceed with sample collection; if not attempt to rectify the situation by tightening fittings.

8. The seal around the soil-gas sampling port and the numerous connections comprising the sampling train will be evaluated for leaks using helium as a tracer gas. The helium tracer gas will be administered according to the methods established in the appropriate guidance documents and SOP: Administering Tracer Gas.

9. Open the two-way valve and purge the soil-gas sampling port and tubing with the portable sampling pump. Purge approximately three volumes of air from the soil-gas sampling port and sampling line using a flow rate of 200 mL/min. Purge volume is calculated by the following equation "purge volume = 3 x Pi x inner radius of tubing^2 x length of tubing. Purge air should be vented away from personnel and sampling equipment, a length of tubing or Tedlar bag can be used for this purpose. Measure organic vapor levels and tracer gas within the Tedlar bag, as appropriate.

10. Close the two-way valve to isolate the purge pump.

11. Open the SUMMA® canister valve to initiate sample collection. Record on the sample log (attached) the time sampling began and the canister pressure.

If the initial vacuum pressure registers less than -25 inches of Hg, then the SUMMA® canister is not appropriate for use and another canister should be used.

12. Take a photograph of the SUMMA® canister and surrounding area unless prohibited by the property owner.

13. Check the SUMMA canister pressure approximately half way through the sample duration and note progress on sample logs.

14. Steps 2-10 should be repeated for each of the nested soil-gas ports; samples can be collected concurrently.

Termination of Sample Collection

1. Arrive at the SUMMA® canister location at least 1-2 hours prior to the end of the required sampling interval (e.g., 8, 24-hours)..

2. Record the final vacuum pressure. Stop collecting the sample by closing the SUMMA® canister valves. The canister should have a minimum amount of vacuum (approximately 6 inches of Hg or slightly greater).

3. Record the date and time of valve closing on the sample log and COC form.

4. Close the valve on the nested soil-gas sample tubing or replace Swagelok cap.

5. Once all the nested samples have been collected, be sure the well cover (if applicable) is properly re-installed and secured.

6. Remove the particulate filters and flow controllers from the SUMMA® canisters, re-install the brass plugs on the canister fittings, and tighten with the appropriate wrench.

7. Package the canisters and flow controllers in the shipping container supplied by the laboratory for return shipment to the laboratory. The SUMMA® canisters should not be preserved with ice or refrigeration during shipment.

8. Complete the appropriate forms and sample labels as directed by the laboratory (e.g., affix card with a string).

9. Complete the COC form and place the requisite copies in a shipping container. Close the shipping container and affix a custody seal to the container closure. Ship the container to the laboratory via overnight carrier (e.g., Federal Express) for analysis.

VII. Soil-Gas Monitoring Point Abandonment

If the single or nested soil-gas ports were installed in a semi-permanent manner, and the soil-gas samples have been collected, the soil-gas monitoring points will be abandoned by pulling up the sample tubing. Since the boring is filled with bentonite and sand, no additional abandonment steps are necessary. Ensure that the boring location and surrounding area are returned to as close to their original appearance as possible.

VIII. Waste Management

The waste materials generated by these activities should be minimal. Personal protective equipment, such as gloves and other disposable equipment (i.e., tubing) should be collected by field personnel for proper disposal. Any soils brought up from the borehole should be disposed of in a manner consistent with the project workplan.

IX. Data Recording and Management

Measurements will be recorded on the sample log at the time of measurement with notations of the project name, sample date, sample start and finish time, sample location (e.g., GPS coordinates, distance from permanent structure), canister serial number, flow controller serial number, initial vacuum reading, and final pressure reading. Field sampling logs and COC records will be transmitted to the Project Manager.

X. Quality Assurance

Duplicate samples should be collected in the field as a quality assurance step. Generally, duplicates are taken of 10% of samples, but project specific requirements should take precedence.

Soil-gas sample analysis will generally be performed using USEPA TO-15 methodology or a project specific constituent list. Method TO-15 uses a quadrupole or ion-trap GC/MS with a capillary column to provide optimum detection limits (typically 0.5-ppbv for most VOCs). A trip blank sample will accompany each shipment of soil-gas samples to the laboratory for analysis. Trip blanks assess potential sample contamination resulting from the transportation and storing of samples.

Duplicate soil gas samples should be collected via a split sample train, allowing the primary and duplicate sample to be collected from the soil-gas probe simultaneously.

XI. References

ASTM – “Standard Guide for Soil Gas Monitoring in the Vadose Zone”, D5314-92.

ITRC “Vapor Intrusion Pathway: A Practical Guide”, January 2007, Appendix F: “regulators Checklist for Reviewing Soil Gas Data”

New York State Department of Health (NYSDOH). 2005. DRAFT “Guidance for Evaluating Soil Vapor Intrusion in the State of New York” February 23, 2005.

Nicholson, P, D. Bertrand and T. McAlary. “Soil Gas Sampling in Low-Permeability Materials” Presented at AWMA Specialty Conference on Vapor Intrusion, Providence RI, Sept 200

Hayes, H. C., D. J. Benton and N. Khan “Impact of Sampling Media on Soil Gas Measurements” Presented with short paper at AWMA Vapor Intrusion Conference, January2006, Philadelphia, PA.

Sub-slab Soil Vapor Sample Collection Log

		Sample ID:	
Client:		**Boring Equipment:**	
Project:		**Sealant:**	
Location:		**Tubing Information:**	
Project #:		**Miscellaneous Equipment:**	
Samplers:		**Subcontractor:**	
`		**Equipment:**	
Sampling Depth:		**Moisture Content of Sampling Zone):**	
Time and Date of Installation:		**Approximate Purge Volume:**	

Instrument Readings:

Date	Time	Canister Vacuum (a) (inches of Hg)	Temperature (°F)	Relative Humidity (%)	Air Speed (mph)	Barometric Pressure (inches of Hg)	PID (ppb)

(a) Record canister information at a minimum at the beginning and end of sampling

SUMMA Canister Information:

Size (circle one):	**1 L** **6 L**
Canister ID:	
Flow Controller ID:	
Notes:	

Tracer Test Information (if applicable):

Initial Helium Shroud:		
Final Helium Shroud:		
Tracer Test Passed:	**Yes**	**No**
Notes:		

General Observations/Notes:

Approximating One-Well Volume (for purging):

When using 1¼-inch "Dummy Point" and a 6-inch sampling interval, the sampling space will have a volume of approximately 150 mL. Each foot of ¼-inch tubing will have a volume of approximately 10 mL.

Infrastructure, environment, facilities

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Standard Operating Procedure for LNAPL Baildown Test

Rev. # 2

Rev. Date: January 14, 2010

Approval Signatures

Prepared by: ______________________ Date: January 14, 2010
Jonathon J. Smith

Reviewed by: ______________________ Date: January 14, 2010
Brad W. Koons, P.E.

I. Scope and Application

The objective of this Standard Operating Procedure (SOP) is to establish uniform procedures for conducting rising-head light non-aqueous-phase liquid (LNAPL) baildown tests to evaluate LNAPL conductivity (K_n) in the subsurface at a specific well location. The data generated from the LNAPL baildown test can be used, along with other site data, to evaluate LNAPL mobility and recoverability at a site. This SOP describes the equipment, field procedures, materials and documentation procedures necessary to determine LNAPL conductivity. The details within this SOP should be used in conjunction with project work plans.

This SOP applies to task orders and projects associated with ARCADIS. This SOP may be modified, as required, depending on site-specific conditions, equipment limitations or limitations imposed by the procedure. The ultimate procedure employed will be documented in the appropriate project work plans or reports. If changes to the testing procedures are required due to unanticipated field conditions, the changes will be discussed with the project manager as soon as practicable and documented in the project report.

II. Personnel Qualifications

Only qualified ARCADIS-related personnel will conduct LNAPL baildown tests. ARCADIS field sampling personnel will have sufficient “hands-on” experience necessary to successfully complete the LNAPL baildown test field work. Training requirements for conducting LNAPL baildown tests include reviewing this SOP and other applicable SOPs and/or guidance documents, instrument calibration training, and health and safety training.

ARCADIS field sampling personnel will have completed current company-required health and safety training (e.g., 40-hour Hazardous Waste Operations training, site-specific training, first aid and cardiopulmonary resuscitation (CPR) training), as needed.

III. Equipment List

Equipment and materials used for conducting the LNAPL baildown tests may include, but are not limited to, the following:

- appropriate personal protective equipment (PPE), as specified in the site Health and Safety Plan (HASP)
- equipment decontamination supplies
- photoionization detector (PID) (see ARCADIS SOP: Photoionization Detector Air Monitoring and Field Screening)
- plastic sheeting
- oil absorbent pads
- stopwatch
- polypropylene rope
- clean disposable bailers
- oil-specific skimmer pump
- vacuum truck
- plastic bucket with lid
- plastic beakers or graduated cylinders (appropriately sized for anticipated NAPL/water recovery volume)
- Calculator
- appropriate field logs/forms
- oil-water interface probe (see ARCADIS SOP: Water Level Measurement)
- data logger and transducer
- white masking tape

- measuring tape with gradation in hundredths of a foot
- indelible ink pen
- monitoring well keys
- bolt cutters
- monitoring well locks
- field log book or PDA or field (computer) notebook

IV. Cautions and Procedure Considerations

Wells containing LNAPL for baildown testing should be selected based on project-specific objectives and a review of historical site data. It is good practice to select several baildown test wells to bracket the range of observed historical apparent LNAPL thickness measurements and LNAPL mobility/recoverability conditions across a given area. As a rule of thumb, apparent LNAPL thicknesses in wells used for baildown tests should be greater than or equal to the borehole diameter (Lundy and Parcher, 2007). Additional guidelines for selecting appropriate wells for LNAPL baildown testing include:

- Select wells located near the interior and exterior portions of the LNAPL plume(s)
- Select wells located in a variety of geologic materials, as feasible
- Consider the position of wells relative to groundwater and LNAPL flow direction
- Consider the potential of wells to exhibit different equilibrated apparent LNAPL thicknesses
- Select wells which contain different types of LNAPL, if present

In addition, understanding the areas affected by recent remediation efforts should be considered because these areas may not be representative of static subsurface conditions. Also, ARCADIS field sampling personnel must be aware of historical fluid levels as they compare to the conditions at the time of testing (i.e., the smear zone).

If higher LNAPL recovery rates are expected, larger diameter wells (4- to 6-inch-diameter casings) are generally preferred. The increased area of the wellbore seepage face for larger diameter wells will provide information that is applicable to a larger, more representative volume of aquifer material. However, if the expected recovery rate is low, smaller diameter wells are often preferred because the volume of the borehole is smaller relative to the formation recovery capacity. Further discussion on accounting for the well filter pack is presented in *A Protocol for Performing Field Tasks and Follow-up Analytical Evaluation for LNAPL Transmissivity using Well Baildown Procedures* (Beckett and Lyverse, 2002).

ARCADIS project personnel must confirm that the test wells have been properly developed. This cannot be overemphasized, as incomplete well development results in underestimates of LNAPL transmissivity (T_n) and LNAPL conductivity (K_n). See the ARCADIS SOP titled *Monitoring Well Development* for additional details.

ARCADIS field sampling personnel must verify that the air/LNAPL and LNAPL/groundwater interfaces occur within the screen interval. At a minimum, the piezometric head elevation in the well should occur below the top of the screen.

ARCADIS field sampling personnel will choose the most appropriate technique to evacuate the LNAPL from the well. These techniques include:

- **Manual bailer** — A 1¾-inch-diameter bailer will be used for 2-inch-diameter wells. For 4-inch-diameter wells, a 3-inch-diameter bailer will be used for LNAPL recovery. ARCADIS highly recommends using product recovery cups, which attach to the bottom of the bailer and maximize the surface area for LNAPL recovery (For example, the Superbailer™, manufactured by EON Products, Inc. has this feature built-in). This will allow for more complete LNAPL removal and more accurate recovery measurements.

- **Pumping** — LNAPL removal can be accomplished by using an oil-specific skimmer pump that operates at a pumping rate which exceeds the LNAPL recharge capacity. For shallow wells (< 25 feet below ground surface), a peristaltic pump may also be a useful, effective and appropriate mode of LNAPL removal.

- **Vacuum Truck** — If large LNAPL volumes are to be removed or extremely rapid recovery rates are anticipated, LNAPL removal can be accomplished using a vacuum truck. The vacuum extraction line is to be outfitted with a small-diameter stinger attachment that will be extended down the well and an in-line site glass to observe extracted fluid color for determination of whether LNAPL or groundwater is being extracted. Begin pumping at the LNAPL/air interface and slowly move the stinger tube downward to extract LNAPL. When groundwater recovery is observed indicating that the LNAPL has been evacuated withdraw the stinger tube and begin fluid level measurements.

Follow the sequential steps below for each baildown test well. Data collection is generally manual using an interface probe, although a data logger can also be used as long as it can sense either the fluid interfaces or the head change only with respect to LNAPL. Before performing an LNAPL baildown test, allow monitoring well water and LNAPL levels to equilibrate with atmospheric pressure. Gauge fluid levels periodically for 5 to 10 minutes to monitor changes in head. Monitoring wells without vents (flush mounts) may require more time to equilibrate with atmospheric pressure following well cap removal.

ARCADIS recommends taking LNAPL measurements initially in one-minute intervals and then adjusting the frequency of measurements thereafter, based on site-specific conditions. The rate of LNAPL recovery will usually slow over time unless the zone of interest is highly conductive. Once the rate of recovery is slow enough, a new baildown test can be initiated at another location, returning to take periodic measurements at the initial test well. Continue this process as long as it is viable based on soil characteristics, field logistics, well locations and data collection needs. Real-time examination of the data curves is the best indicator of data sufficiency. A plot of the change in LNAPL thickness over time may exhibit up to three theoretical segments:

1) initial steep segment that could reflect filter pack drainage

2) main production segment where the formation LNAPL gradient to the wells controls recovery

3) third segment where the diminishing formation LNAPL gradient produces a flatter recovery curve

Repeatedly introducing the oil-water interface indicator may alter the fluid-level measurements. Avoid splashing the probe into the water table or lowering the probe too far beyond the LNAPL-water interface depth. To avoid introducing surface soil or other material into the monitoring well, stage downhole equipment on a clean and dry working surface.

Two field personnel are recommended to adequately perform this test, one person to collect the data and one person to record the data.

V. Health and Safety Considerations

Overall, the Loss Prevention System™ (LPS) tools and the site-specific HASP will be used to guide the performance of LNAPL baildown tests in a safe manner without incident. A Job Safety Analysis (JSA) will be prepared for LNAPL baildown tests. The following specific health and safety issues must be considered when conducting LNAPL baildown tests:

- Monitoring for volatile organic compounds (VOCs) in the monitoring well head space must be conducted with a PID and recorded in the field logbook prior to initiating the LNAPL baildown test. PID readings will be compared to action levels established in the site HASP for appropriate action.

- Appropriate PPE must be worn to avoid contact with LNAPL during the baildown test.

- LNAPL removed from the test well must be managed with caution to avoid igniting the LNAPL material. LNAPL characteristics must be reviewed in the JSA, which will be prepared and reviewed by the project team prior to implementing the baildown test.

- LNAPL generated during the baildown test must be properly managed in accordance with facility and applicable regulatory requirements.

- Well covers must be carefully removed to avoid potential contact with insects or animals nesting in the well casings.

VI. Procedure

Specific procedures for conducting LNAPL baildown tests are presented below:

1. Identify site, well number, date and time on the LNAPL Baildown Test Log and field logbook or PDA, along with other appropriate LNAPL baildown testing information. An example LNAPL Baildown Test Log is provided in Attachment 1 to this SOP.

2. Place clean plastic sheeting and several oil absorbent pads on the ground next to the well.

3. Unlock and open the monitoring well cover while standing upwind from the well.

4. Measure the concentration of detectible organics present in the worker breathing zone immediately after opening the well using a PID. If the PID reading(s) exceed the thresholds provided in the HASP, take appropriate actions per the HASP. After monitoring the worker breathing zone, proceed to

monitor the well head space with the PID and record the PID reading in the field logbook.

5. Prepare a test log to record LNAPL recovery data. Initially, data should be collected very frequently. As time progresses and the LNAPL recovery rate slows, less frequent measurements will be required. In most cases, initial measurement increments of 1 minute are sufficient, with subsequent measurements farther apart as appropriate, based on observed rate of recovery during the first few readings. If LNAPL recovery rates are high, data should be collected more frequently. For lower LNAPL recovery rates, time intervals between measurements can be increased.

6. It is important to monitor rapid LNAPL recovery at a higher frequency, again as indicated by the observed recovery data.

7. Secure one end of the rope to the bailer and the other end to the well casing using a bowline knot.

8. Before beginning the baildown testing, measure and record static fluid levels using the oil/ water interface probe (i.e., depth to LNAPL and depth to groundwater) and document the well construction details. Using the conversion chart at the bottom of the test log, the measured LNAPL thickness and the well diameter, calculate and record the initial LNAPL volume in the well. Gauge fluid levels periodically for 5 to 10 minutes to monitor changes in head. Do not begin the test until the well has equilibrated. Ideally, one person will be responsible for lowering the bailer into the well and recording time intervals in the log, and another person will be responsible for lowering the water-level probe into the well and measuring and communicating water-level depths to the person recording information in the log.

9. To begin baildown testing, slowly lower the bailer or equivalent into the well until it is just below the LNAPL-water interface.

10. Set stopwatch. Wait to start the stopwatch until immediately after LNAPL removal is finished.

11. Evacuate LNAPL from the well by gently bailing, pumping, or vacuum recovery as described in Section IV above <u>while minimizing water production. One of the assumptions employed in the analysis of the baildown test data is that the LNAPL is removed from the well instantaneously. Thus, it is important to avoid spending excessive amounts of time (more than 5 minutes) removing LNAPL from the well.</u>

12. Record the time at which LNAPL removal is complete (or removed to the maximum practical extent) as the test start time. Begin measuring the elapsed time, starting with this point. Monitor depth to LNAPL and depth to water at the appropriate intervals, as discussed above (5). Measure fluid levels to the nearest hundredth of a foot with the oil-water interface probe and record, along with the corresponding time reading in minutes and seconds.

13. Transfer the LNAPL and groundwater evacuated from the well into an appropriately sized beaker or graduated cylinder. Record the volumes of LNAPL and groundwater on the Baildown Test Log (Attachment 1). If an LNAPL/water emulsion was formed during fluid recovery, allow time for LNAPL/water separation and make note of the observed emulsification.

14. Two to eight hours of data collection is usually sufficient. However, faster LNAPL recovery need not be monitored for extended periods, and slow recovering wells may benefit from follow-up readings the next day.

15. Place all LNAPL and groundwater collected during the test into an appropriate container for proper waste management.

16. Decontaminate the oil-water level indicator with a non-phosphate detergent and water scrub, a tap water rinse, a reagent grade methanol rinse, a second tap water rinse, a second methanol rinse, a third tap water rinse, and a triple rinse with distilled water (see SOP titled *Field Equipment Decontamination*).

17. Secure the monitoring well prior to leaving by replacing the well cap and/or cover and locking it.

VII. Waste Management

Rinse water, PPE and other waste materials generated during equipment decontamination must be placed in appropriate containers and labeled. Containerized waste will be disposed of in a manner consistent with appropriate waste management procedures for investigation-derived waste.

VIII. Data Recording and Management

ARCADIS field sampling personnel will record data using the LNAPL Baildown Test Log (Attachment 1). All information relevant to the test data beyond the items identified in the Baildown Test Log will be recorded using the field logbook, PDA or field computer. Field equipment decontamination activities and waste management activities will be recorded in the field logbook. Records generated as a result of implementing this SOP will be controlled and maintained in the project record files in accordance with client-specific requirements.

IX. Quality Assurance/Quality Control

ARCADIS project personnel will review the data set collected during the LNAPL baildown test in the field to determine whether or not the data are reasonable given site-specific conditions. For example, if the data indicates that LNAPL recovery is very rapid in a very low-permeability soil type, this may indicate that there are problems with the data set. If the data are questionable, the field equipment must be checked to confirm it is working properly and the test will be repeated, if possible. Depending on data quality objectives, a duplicate LNAPL baildown test may be conducted as a quality control check 48 hours after the initial test, assuming water levels and apparent LNAPL thicknesses have returned to static conditions.

Any issues that may affect the data must be recorded in the field log book so that analysts can consider those issues when processing the data.

X. References

Beckett, G.D. and Lyverse, M.A. 2002. *A Protocol for Performing Field Tasks and Follow-up Analytical Evaluation for LNAPL Transmissivity using Well Baildown Procedures, August 2002.*

Lundy, D. and Parcher, M. 2007. *Assessment of LNAPL Volume, Mobility and Recoverability for Recovery Systems: Design and Risk-Based Corrective Action. National Ground Water Association Short Course, November 2007.*

ARCADIS SOPs Referenced Herein:

Field Equipment Decontamination, Revision No.1, April, 2009.

Monitoring Well Development, Revision No.2, March, 2008.

Photoionization Detector Air Monitoring and Field Screening, Revision No. 0, July, 2003.

Water Level Measurement, Revision No. 1, March, 2004.

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Attachment 1: LNAPL BAILDOWN TEST LOG

LNAPL Baildown Test Standard Operating Procedure

Site Name		Test Well ID	
Date and Time In		Date and Time Out	
Personnel		Weather	

Well Construction Details

Top of Casing Elevation (ft amsl)		Screen Slot Size (in)	
Total Well Depth (ft)		Filter Pack Type	
Depth to Top of Screen (ft)		Depth to Bottom of Screen (ft)	
Well Casing Diameter (in)		Borehole Diameter (in)	

Initial Test Conditions

Static Depth to LNAPL (ft)		Test Date	
Static Depth to Water (ft)		Start Time	
LNAPL Thickness (ft)		Initial LNAPL Volume in Well (gal)	

LNAPL Removal Information

LNAPL Removal Method/Equipment		Time LNAPL Removal Begins	
Volume of LNAPL Removed (gal)		Time LNAPL Removal is Completed	
Volume of Groundwater Removed (gal)			

Baildown Test Data

Elapsed Time (min)	Depth to LNAPL (ft)	Depth to Water (ft)	Observations

(Modified after Beckett and Lyverse, 2002)

Well Casing Volumes	1-¼" = 0.06	2" = 0.16	3" = 0.37	4" = 0.65
(Gal./Ft.)	1-½" = 0.09	2-½" = 0.26	3-½" = 0.50	6" = 1.47