URS

20-239

December 7, 2004

Mr. Robert Schultz
Alameda County Environmental Health
1131 Harbor Bay Parkway, Suite 250
Alameda, CA 94502

Re: Work Plan For Additional Site Investigation at Former BP Service Station #11124, 3315 High Street, Oakland, California, For Atlantic Richfield Company

Dear Mr. Schultz:

At the request of Atlantic Richfield Company, Remediation Management (RM- a BP affiliated company), URS Corporation (URS) is pleased to submit this *Work Plan For Additional Site Investigation* at Former BP service station #11124, at 3315 High Street, Oakland (the Site, Figure 1). Alameda County Environmental Health (ACEH) requested a work plan for the Site, in a letter to RM dated October 22, 2003 which URS received on September 15, 2004 requesting confirmation soil and groundwater sampling in the vicinity of the former underground storage tanks (USTs), product dispensers, and oil/water separators. A copy of the ACEH directive is included in Attachment A.

1.0 BACKGROUND

The Site currently is a non-operating service station awaiting divestment by the current property owner, ConocoPhillips. Site facilities consist of a station building, one-10,000-gallon underground storage tank (UST), one-12,000 gallon UST, two dispenser islands and one waste-oil tank (Figure 2). The station is located in a mixed residential/commercial area of Oakland, California. The Site was operated as a Mobil service station prior to 1989, when it was transferred to BP. BP operated the Site as a service station until it was transferred to TOSCO (currently ConocoPhillips) in 1994, and was then operated as a 76-branded service station until 2004. The USTs were removed in November or early December 2004. Analytical results for the tank removal were not available to URS at this time.

1.1 SITE ASSESSMENT

On July 1, 1986, Kaprealian Engineering installed three groundwater monitoring wells (MW-1 through MW-3) to a maximum depth of 35 feet below ground surface (bgs) to assess the impact of petroleum hydrocarbons in groundwater following replacement of USTs. Petroleum hydrocarbons were not detected in soil samples.

On May 13, 1991 RESNA abandoned MW-3 due to an obstruction in the well preventing sampling. Three soil borings B1, B2(a and b) and B-3 were to depths between 17.5 and 30.5 feet bgs near the waste-oil tank. Boring B-1 was converted to MW-4 to replace well MW-3, Figure 2. Historical soil

URS Corporation
1333 Broadway, Suite 800
Oakland, CA 94612-1924
Tel: 510.893.3600
Fax: 510.874.3268

data is included in Attachment B. No total petroleum hydrocarbons as gasoline (TPH-g), benzene, ethyl benzene or xylenes were detected in soil samples from these borings. Toluene was detected at a maximum concentration of 0.011 parts per million (ppm) in B2 from a depth of 10 feet bgs. Oil and grease was detected in boring B2 at a depth of 10 feet bgs and a concentration of 120 ppm.

On December 12, 1996, Pacific Environmental Group (PEG) investigated soil conditions beneath the oil/water separator. Confirmatory samples collected from the excavation from 0.5 feet bgs contained maximum concentrations of 970 ppm TPH-g, 0.8 ppm toluene, 20 ppm ethylbenzene and 90 ppm xylenes. No benzene was detected.

Groundwater monitoring was conducted at the Site from 1986 to 1993. During the last previous monitoring events on March 15, and April 21, 1993, TPH-g and BTEX were not detected in groundwater samples, with the exception of 2.1 micrograms per liter (μg/L) total xylenes in MW-1. Historical groundwater analytical results are included in Attachment B. On October 19, 2004, URS conducted a groundwater monitoring event in response to the ACEH directive. Only wells MW-1 and MW-4 contained sufficient water to sample. Methyl tertiary butyl ether (MTBE) was detected in MW-1 at 14 μg/L. Gasoline range organics (GRO) and benzene, toluene, ethylbenzene and xylenes (BTEX) were not detected in either well.

1.2 GEOLOGY AND HYDROGEOLOGY

Sediments encountered beneath the Site consist primarily of clays and silts with traces of sand and gravel, extending from the ground surface to the total depth investigated, approximately 30 feet below ground surface (ft bgs). Boring logs are included as Attachment C. The historical groundwater gradient direction at the Site is to the south-southwest (1991-1993). The calculated groundwater gradient during this period fluctuated between 0.01 and 0.018 feet per foot. Although a sample could not be collected from well MW-2 during October 2004, the calculated hydraulic gradient of 0.022 and gradient direction to the south/southwest is consistent with previous events.

2.0 PROPOSED SITE INVESTIGATION

The purpose of the proposed additional Site investigation is to evaluate soil and groundwater for petroleum hydrocarbons in the vicinity and downgradient of the USTs, product dispensers, and oil/water separator.

URS proposes advancing five direct push technology (DPT) soil borings to evaluate potential petroleum hydrocarbon impacted soil and groundwater. Three borings will be placed downgradient of the UST complex and dispenser islands. One boring will be placed adjacent to MW-2 to assess groundwater conditions near that well since no sample was obtained from that well during the fourth quarter monitoring event. One soil boring will be advanced downgradient of the oil-water separator to assess soil and groundwater conditions. The proposed soil boring locations are shown on Figure 2.

2.1 SUBSURFACE INVESTIGATION

The subsurface investigation will include advancing five DPT soil borings (SB-1 through SB-5) to a total approximate depth of 35 feet bgs or approximately five feet into groundwater. The borings will be advanced under the supervision of a URS field geologist using a GeoProbe® DPT rig. Soil and groundwater samples will be collected for laboratory analysis.

2.2 PRELIMINARY FIELD ACTIVITIES

Prior to initiating field activities, URS will obtain the necessary ACEH permit, prepare a site health and safety plan (HASP) for the proposed work; clear the Site for subsurface utilities; and complete the URS borehole checklist. The utility clearance will include notifying Underground Service Alert (USA) of the pending work a minimum of 48 hours prior to initiating the field investigation, and securing the services of a private utility locating company to confirm the absence of underground utilities at each boring location. In accordance with RM and URS underground utility safety protocols, borings will not be located within 10 feet of any UST, product line system or within five feet of any other underground utility. Boreholes will be physically cleared to five feet bgs using air-knife methods.

The Site-specific HASP will be prepared for use by personnel implementing the work plan. The HASP will address the proposed soil boring. A copy of the HASP will be available on-Site at all times. The subcontractor(s) performing field activities will be provided with a copy of the HASP prior to initiating work. A safety tailgate meeting will also be conducted daily to review the Site hazards and drilling work scope.

2.3 SOIL BORING ADVANCEMENT AND SAMPLING

A URS field geologist will observe a California-licensed driller advance the soil borings using a direct-push drilling rig. Soils will be classified according to the Unified Soil Classification System (USCS), and will be examined using visual and manual methods for parameters including odor, staining, color, grain size, and moisture content. Soil samples will be collected continuously in acrylic tubes, and preserved at five-foot intervals, at changes in lithology, and at areas of obvious chemical impact. For every soil sample collected for analysis, an extra soil sample will be collected and placed in a Ziploc® bag for field screening. The soil samples collected for field screening will be allowed to volatilize and later analyzed using a photoionization detector (PID) for the presence of volatile petroleum compounds. Based on field screening results and observations, soil samples will be submitted to the laboratory for analysis.

Groundwater samples will be collected from each of the borings using a temporary well screen and a bailer, and will be placed in appropriate preserved containers. Drilling and sampling methods will be conducted in general accordance with U.S. Environmental Protection Agency Expedited Site Assessment Guidance Protocols (EPA, 1997). Applicable sections are included as Attachment D.

Selected soil and groundwater samples collected will be submitted to the laboratory for chemical analysis. Following sample collection, each boring will be grouted to the surface using neat cement, and the surface refinished to match the surrounding area.

2.4 SAMPLE HANDLING AND ANALYSIS

Soil samples collected for possible chemical analysis will be retained in sampling tubes, covered at each end with Teflon™ sheeting, capped with plastic end caps, labeled, and placed in an ice-filled cooler for preservation. Groundwater samples collected will be placed in appropriate preserved containers, labeled, and placed in an ice-filled cooler for preservation.

The samples will be submitted under chain-of-custody protocol to Sequoia Analytical a California State-certified analytical laboratory

Soil and groundwater samples will be analyzed for the following:

- Gasoline Range Organics (GRO), benzene, toluene, ethylbenzene, and xylenes (BTEX), methyl tertiary butyl ether (MTBE), di-isopropyl ether (DIPE), tertiary amyl methyl ether (TAME), ethyl tertiary butyl ether (ETBE), tertiary butyl alcohol (TBA), ethanol, ethylene dibromide (EDB) and 1,2 Dichloroethane (1,2-DCA) using EPA Method 8260B.

In addition to the above constituents, samples collected from the boring near the waste-oil tank will be analyzed for:

- Diesel range organics (DRO) by EPA Method 8015 and total oil and grease by EPA Method 413.2 (Silica gel/IR).

2.5 WASTE DISPOSAL

Investigation-derived residuals will be temporarily stored on-Site in 55-gallon, DOT-approved 17H drums, pending characterization and disposal. URS will coordinate the soil transportation and disposal at a California regulated facility.

2.6 ADDITIONAL SITE INVESTIGATION REPORT

Upon completion of field activities and receipt of all laboratory analytical data, URS will provide ACEH with a Soil and Water Investigation (SWI) Report. The report will document the results of

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the investigation, field operations, findings, conclusions and recommendations. Any deviations from the work plan or data inconsistencies will be discussed in the report.

3.0 PROPOSED SCHEDULE

Upon receiving written approval of this work plan from ACEH, URS will proceed with the proposed work. URS will obtain all necessary permits to complete the proposed work. URS anticipates submitting the SWI report to ACEH within 60 days of drilling activities.

We appreciate the opportunity to submit this work plan to ACEH and trust that it meets with your approval. Please notify us of your approval as soon as practical. If you have any questions or concerns, please contact Leonard Niles at (510) 874-1720.

CERTIFIED HYDROGEOLOGIST
LEONARD P. NILES
NO.HG357
EXP.3/31/06
STATE OF CALIFORNIA

Sincerely,

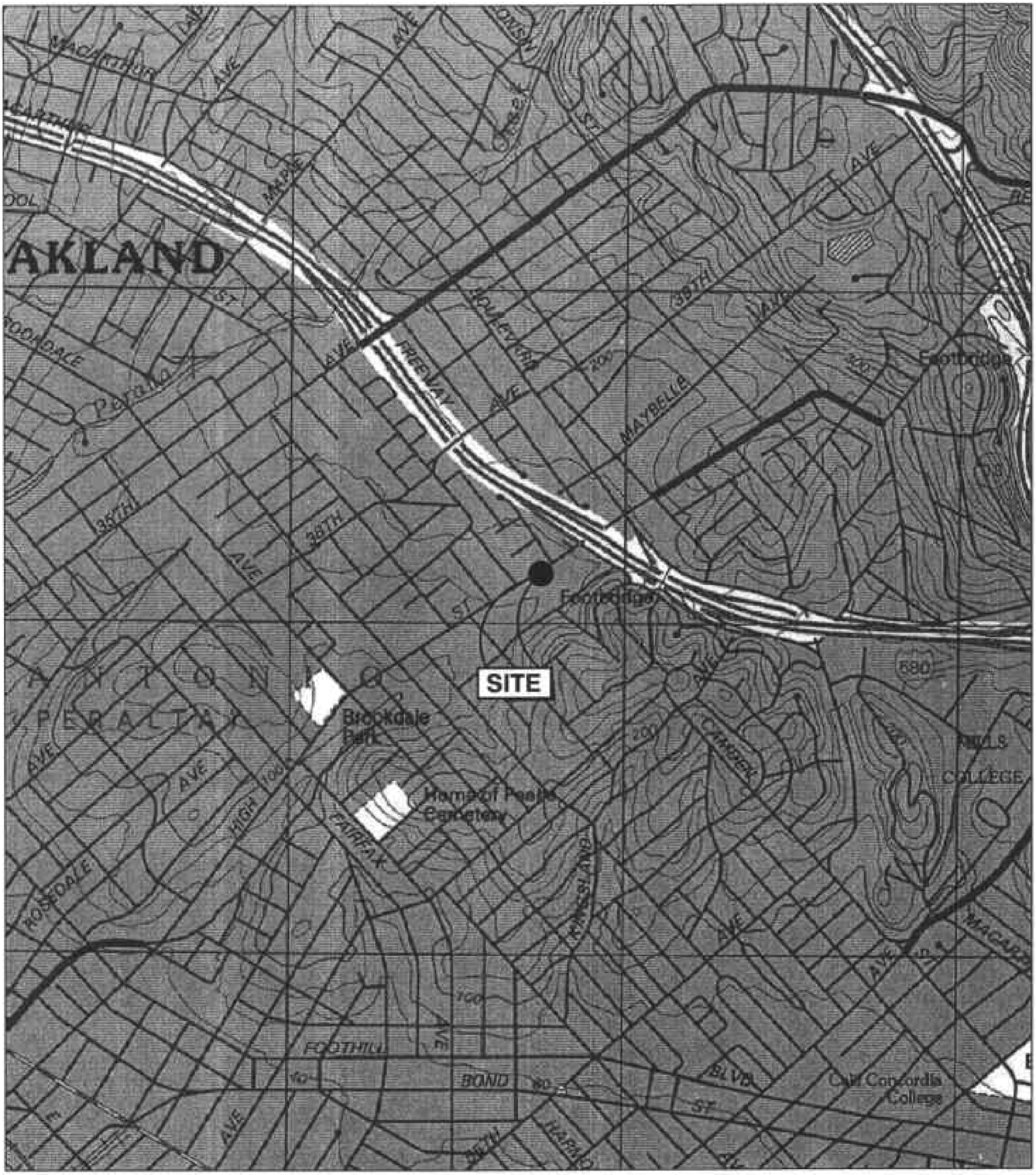
URS CORPORATION

Jacob Henry
Geologist

Leonard P. Niles, R.G./C.H.G
Senior Geologist/Project Manger

Attachments:	Figure 1	-	Site Vicinity Map
	Figure 2	-	Proposed Soil Boring Locations Map
	Attachment A		ACEH October 22, 2003 Letter
	Attachment B		Historical Soil and Groundwater Sampling Results
	Attachment C		Soil Boring and Well Logs
	Attachment D		EPA Expedited Site Assessment Guidance (1997), Chapter V - Direct Push Technologies

cc: Mr. Kyle Christie, RM (electronic copy uploaded to Enfos)



REFERENCE:

BASE MAP FROM USGS TOPO!
NORTH REGION 7

7.5 MINUTE TOPOGRAPHIC
PHOTOREVISED 1998

QUADRANGLE LOCATION

NORTH

0 1400 2800

APPROXIMATE SCALE 1"= 1400'

URS	Project No. 38486985	SITE LOCATION MAP	FIGURE
	Former BP Service Station #11124 3315 High Street Oakland, California		1

Dec 02, 2004 - 10:23am
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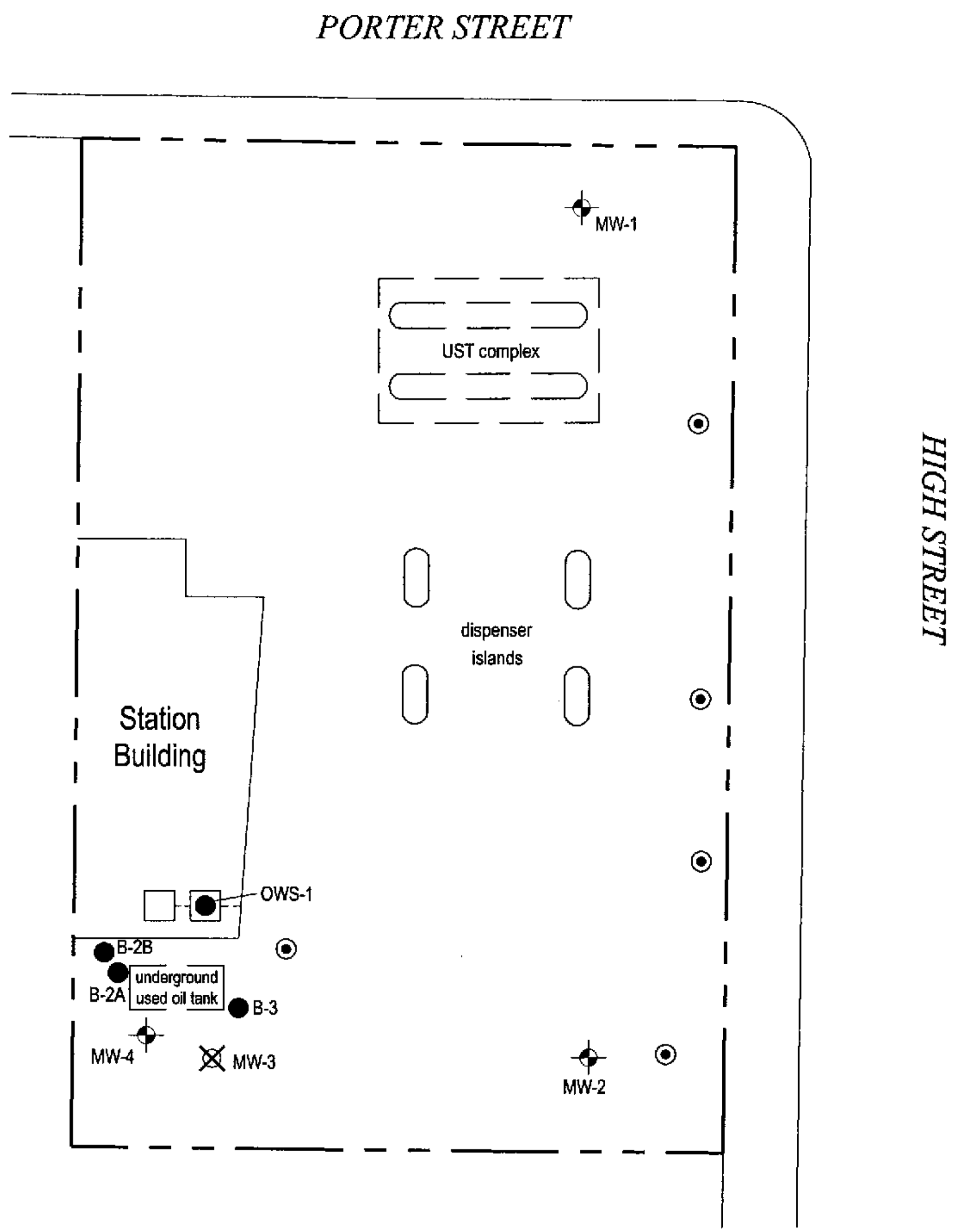
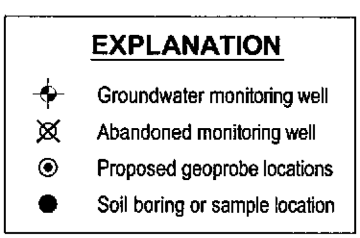
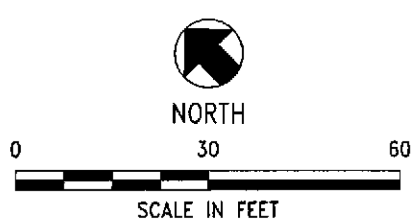




NOTE: SITE MAP ADAPTED FROM ALISTO ENGINEERING FIGURES.
SITE DIMENSIONS AND FIGURES FACILITY LOCATIONS NOT VERIFIED.



URS	Project No. 38486985 Former BP Service Station #11124 3315 High Street Oakland, California	SITE PLAN	FIGURE 2

Dec 06, 2004 - 11:10am
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Attachment A

ACEH October 22, 2003 Letter

ALAMEDA COUNTY
HEALTH CARE SERVICES
AGENCY
DAVID J. KEARS, Agency Director

ENVIRONMENTAL HEALTH SERVICES
ENVIRONMENTAL PROTECTION
1131 Harbor Bay Parkway, Suite 250
Alameda, CA 94502-6577
(510) 567-6700
FAX (510) 337-9335

October 22, 2003

Bob Schultz
Digitally signed by Bob Schultz
DN: cn=Bob Schultz, o=ACOEH, c=US
Date: 2004.09.15 13:56:03 -07'00'
Signature Not Verified

Paul Supple
Atlantic Richfield Co.
(a BP affiliated co.)
PO Box 6549
Moraga, CA 94570

Dear Mr. Supple:

Subject: Fuel Leak Case No. RO0000239, BP Station #11124, 3315 High St., Oakland, CA

Alameda County Environmental Health (ACEH) staff has reviewed the Leaking Underground Storage Tank Oversight Program file. We do not believe that the case is ready for closure. We request that you address the following technical comments and send us the technical reports requested below.

TECHNICAL COMMENTS

1. Groundwater Monitoring Well Locations – There are no wells close to and downgradient of the former underground gasoline tanks and dispensers. The dissolved contaminant plume may have been missed by the wells. Please propose a sampling scheme to determine if this is the case and also propose sampling locations close to and downgradient of the former underground gasoline tanks and dispensers in the Work Plan requested below. Also, the analyses of the borings will need to include methyl tertiary-butyl ether (MTBE), the lead scavengers, EDB and EDC, in soil samples.
2. Groundwater Analyses – We request that you include methyl tertiary-butyl ether (MTBE) and the other fuel oxygenates Tertiary Amyl Methyl Ether (TAME), Ethyl Tertiary Butyl Ether (ETBE), Di-Isopropyl Ether (DIPE), and Tertiary Butyl Alcohol (TBA), Ethanol by EPA Method 8260 and the lead scavengers, Ethylene Dibromide (EDB), Ethylene Dichloride (EDC) for analyses of grab and monitoring well groundwater samples. Additionally, 5,200 ug/l Total Oil & Grease (TOG) was detected from MW-4 the last time this well was sampled, on September 30, 1992.
3. Oil/Water Separator – Soil samples detected 970 mg/kg and 750 mg/kg TPH-G at 0.5 feet depth and 2 feet depth, respectively. We request that you propose additional borings to delineate the lateral and vertical extent of soil contamination in the source area. Additionally, groundwater impact must be evaluated. Please propose boring locations in the Work Plan requested below.

TECHINCAL REPORT REQUEST

Please submit technical reports to the Alameda County Environmental Health (Attention: Don Hwang), according to the following schedule:

December 30, 2003 – Workplan
60 days after Work Plan approval - Soil and Water Investigation Report

These reports are being requested pursuant to the Regional Water Quality Control Board's (Regional Board) authority under Section 13267 of the California Water Code. If you have any questions, please call me at (510) 567-6746.

Sincerely,

Don Hwang
Hazardous Materials Specialist
Local Oversight Program

C: Donna Drogos
File

Attachment B

Historical Soil and Groundwater Analytical Data

SEQUOIA Analytical Laboratory
2549 Middlefield Road
Redwood City, CA 94063 • (415) 364-9222

Kaprealian Engineering, Inc.
535 Main Street, Suite 309
Martinez, CA 94553
Attn: Mardo Kaprealian, P.E.
President

Date Sampled: ~~8/4/86~~ 7/[illegible]/86
Date Received: 8/4/86
Date Reported: 8/26/86

Sample Number	Sample Description Mobil-3315 High St. in Oakland, soil	Detection Limit ppm	Total Hydrocarbons ppm
6080106	MW-1, 15½-16 feet	1	< 1
6080107	MW-2, 15½-16 feet	1	< 1
6080108	MW-3, 15½-16 feet	1	< 1

NOTE: Analysis was performed using EPA methods 5020 and 8015.

SEQUOIA ANALYTICAL LABORATORY

Arthur G. Burton
Laboratory Director

sls

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TABLE 3
CUMULATIVE RESULTS OF ANALYSES OF SOIL SAMPLES
BP Facility No. 11124
3315 High Street
Oakland, California
(page 1 of 3)

Sample ID	Sample Date	TPHg	TPHd	Benzene	Toluene	Ethyl-benzene	Total Xylenes
S-5-B1	05/13/91	<1	<10	<0.005	<0.005	<0.005	<0.005
S-15-B1	05/13/91	<1	<10	<0.005	<0.005	<0.005	<0.005
S-10-B2	05/14/91	<1	<10	<0.005	0.011*	<0.005	<0.005
S-18-B2	05/14/91	<1	<10	<0.005	0.006*	<0.005	<0.005
S-10-B3	05/14/91	<1	<10	<0.005	0.010*	<0.005	<0.005
S-17-B3	05/14/91	<1	<10	<0.005	0.007*	<0.005	<0.005
S-0514-1ABCD	05/14/91	<1	<10	<0.005	0.040*	0.030*	0.140*

See notes on page 3 of 3

RESNA

TABLE 3
CUMULATIVE RESULTS OF ANALYSES OF SOIL SAMPLES
BP Facility No. 11124
3315 High Street
Oakland, California
(page 2 of 3)

Sample ID	Sample Date	Cadmium	Chromium	Lead	Nickel	Zinc
S-5-B1	05/13/91	NR	NR	NR	NR	NR
S-15-B1	05/13/91	NR	NR	NR	NR	NR
S-10-B2	05/14/91	16	23	16	65	55
S-18-B2	05/14/91	15	27	16	57	51
S-10-B3	05/14/91	11	24	10	41	48
S-17-B3	05/14/91	11	22	11	52	43
S-0514-1ABCD	05/14/91	11	27	14	42	53

See notes on page 3 of 3

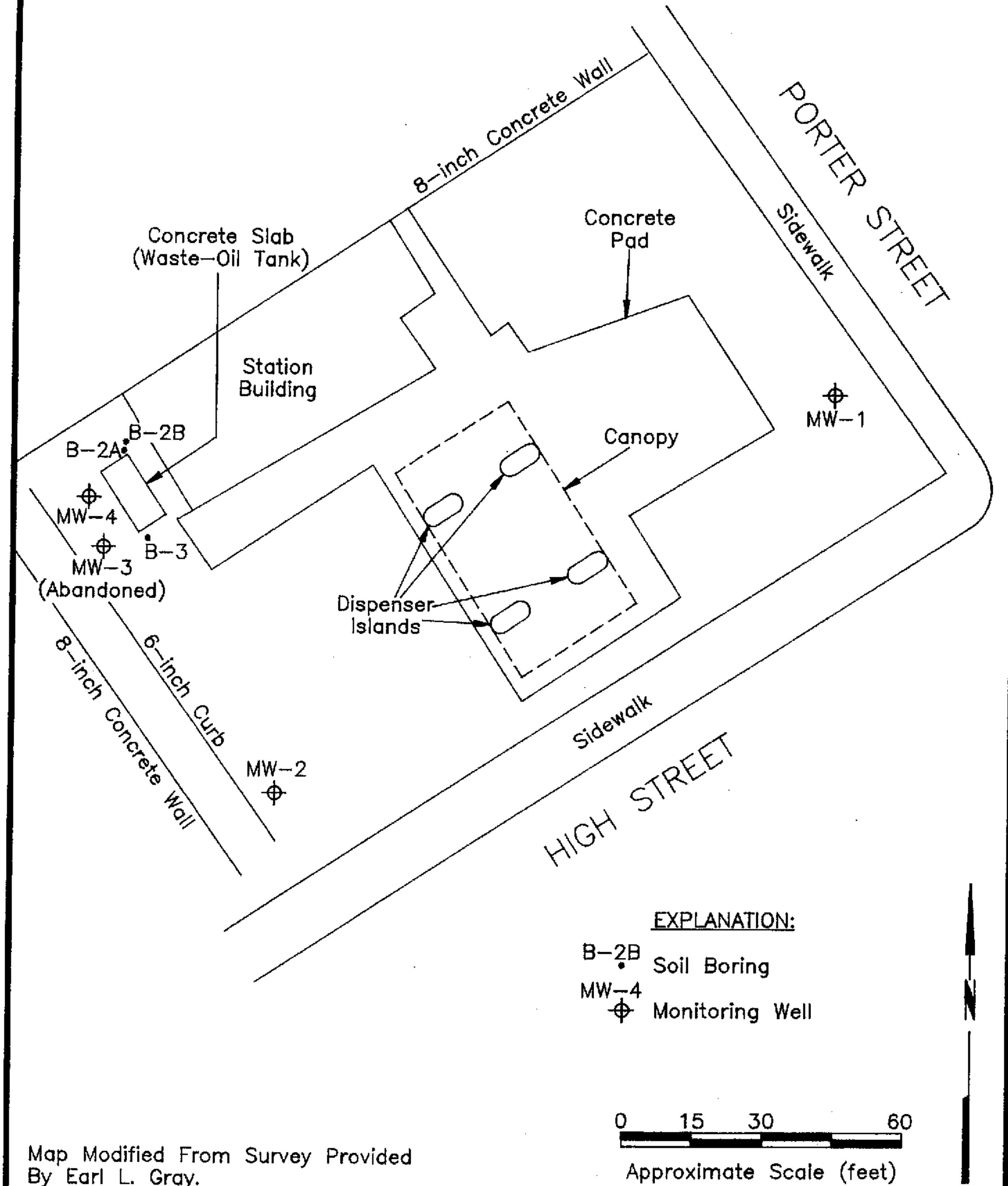
RESNA

TABLE 3
CUMULATIVE RESULTS OF ANALYSES OF SOIL SAMPLES
BP Facility No. 11124
3315 High Street
Oakland, California
(page 3 of 3)

Sample ID	Sample Date	O&G	Purgeable Organic Compounds	PCB's	Semi-VOC	Phenan.
S-5-B1	05/13/91	<50	ND	ND	ND	ND
S-15-B1	05/13/91	<50	ND	ND	ND	ND
S-10-B2	05/14/91	120	ND	ND	ND	ND
S-18-B2	05/14/91	<50	ND	ND	ND	ND
S-10-B3	05/14/91	<50	ND	ND	ND	ND
S-17-B3	05/14/91	<50	ND	ND	ND	ND
S-0514-1ABCD	05/14/91	120	ND	ND	ND	2

Results in parts per million (ppm)
TPHg = Total petroleum hydrocarbons as gasoline
TPHd = Total petroleum hydrocarbons as diesel
PCB's = Polychlorobiphenyls
O&G = Oil and Grease
Semi-VOC = Semi-volatile organic compounds
Phenan. = Phenanthrene
NR = Not Requested
ND = No compounds detected above the laboratory detection limits
< = Below detection limit of method of analysis used
* = Sample results reported from purgeable organic analyses

Sample designation:
S-18-B3
- B3 — Boring number
- 18 — Sample depth in feet below ground surface
- S — Soil sample



Map Modified From Survey Provided By Earl L. Gray.

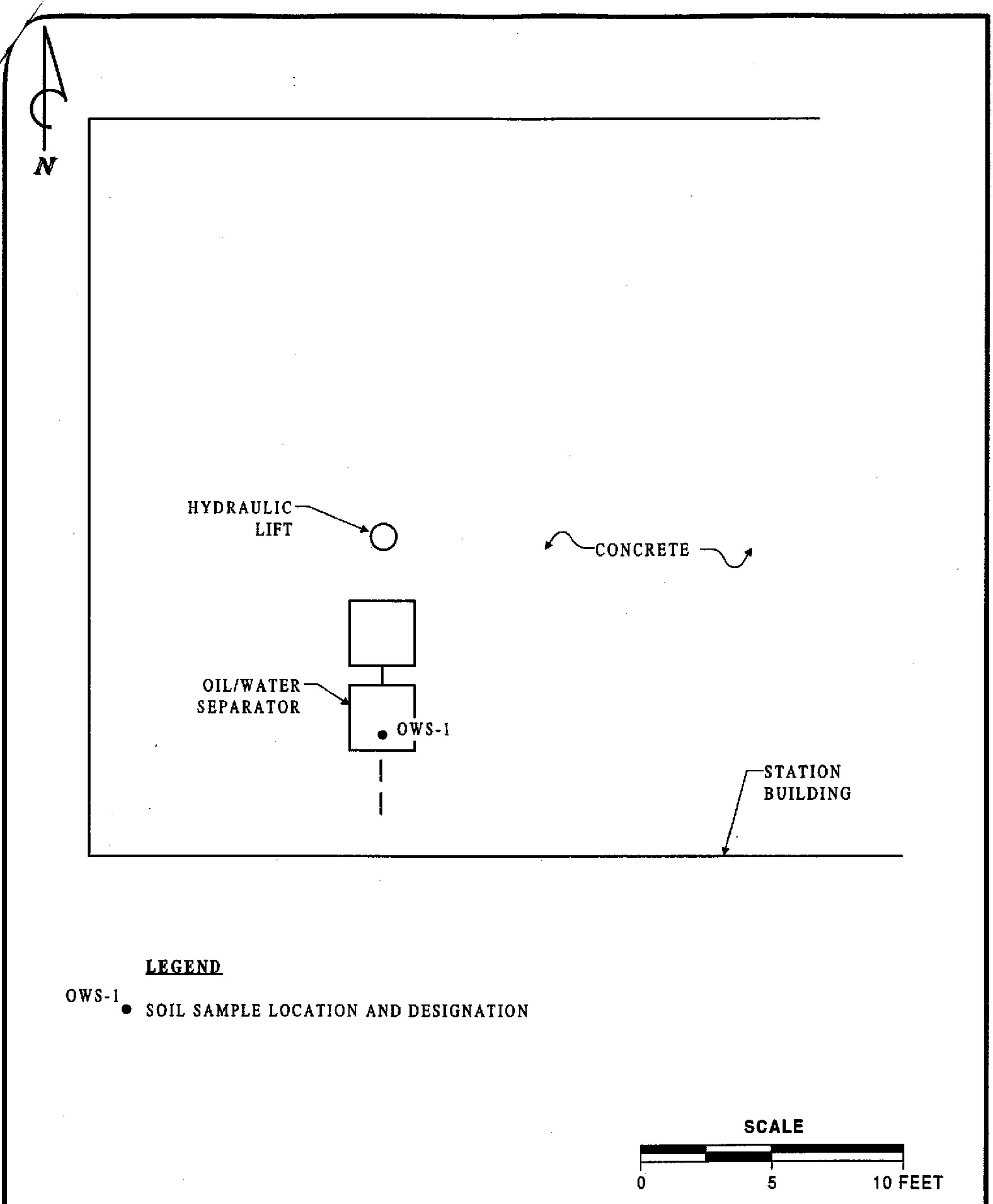
RESNA	GENERALIZED SITE PLAN BP Facility No. 11124 3315 High Street Oakland, California	PLATE 2
PROJECT NO. 30061-2 — FILE NO. 0061B2A		

Table 1
Soil Analytical Data
Oil/Water Separator
Total Petroleum Hydrocarbons
(TPH as Gasoline, BTEX Compounds, TPH as Diesel, TRPH, and HVOCs)

Tosco Service Station 11124
3315 High Street
Oakland, California

Sample ID	Sample Depth (feet)	Date Sampled	TPH as Gasoline (ppm)	Benzene (ppm)	Toluene (ppm)	Ethyl-benzene (ppm)	Total Xylenes (ppm)	TPH as Diesel (ppm)	TRPH (ppm)	Tetrachloro-methane (PCE) (ppm)	Methylene Chloride (ppm)	1,1-Dichloro-ethane (ppm)	Chloro-benzene (ppm)	1,2-Dichloro benzene (ppm)
OWS-1, 0.5'	0.5	12/12/96	970 a	ND b	0.8	20	90	45 c	220	1	8.3	ND	0.77	9.2
OWS-1, 2'	2	12/12/96	750 a	ND b	0.6	16	73	150 d	120	0	2.6	0.05	0.13	1.7

TRPH = Total recoverable petroleum hydrocarbons
HVOCs = Halogenated volatile organic compounds
ppm = Parts per million
ND = Not detected at a concentration above the laboratory method reporting limit.
a. The sample contains components eluting in the gasoline range that were quantified as gasoline. The chromatogram does not match the typical gasoline fingerprint.
b. The method reporting limit (MRL) is elevated due to high analyte concentration requiring sample dilution.
c. Quantified as diesel. The sample contained components that elute in the diesel range, but the chromatogram did not match the typical fingerprints. The patterns were similar to mineral spirits. the sample also contained a heavy oil at 61 ppm.
d. Quantified as diesel. The sample contained components that elute in the diesel range, but the chromatogram did not match the typical fingerprints. The patterns were similar to mineral spirits. The sample also contained a heavy oil at 1,400 ppm.



PACIFIC ENVIRONMENTAL GROUP, INC.	**TOSCO SERVICE STATION 11124** 3315 High Street Oakland, California	FIGURE: **1**
	SITE MAP	PROJECT: 304-015.1A

304/015/Sitemap5.vsd

TABLE 1 - SUMMARY OF RESULTS OF GROUNDWATER SAMPLING
BP OIL COMPANY SERVICE STATION NO. 11124
3315 HIGH STREET, OAKLAND, CALIFORNIA

ALISTO PROJECT NO. 10-020

WELL ID	DATE OF SAMPLING/ MONITORING	CASING ELEVATION (a) (Feet)	DEPTH TO WATER (b) (Feet)	GROUNDWATER ELEVATION (Feet)	TPH-G (ppb)	B (ppb)	T (ppb)	E (ppb)	X (ppb)	TOG (ppb)	LAB
MW-1	08/18/86	154.99	10.10	144.89	ND<50	ND<1.0	ND<1.0	ND<1.0	ND<1.0	—	—
MW-1	11/12/90	154.99	11.42	143.57	ND<50	ND<0.5	ND<0.5	ND<0.5	ND<0.5	—	—
MW-1	07/15/91	154.99	10.66	144.33	ND<50	ND<0.5	ND<0.5	ND<0.5	ND<0.5	—	—
MW-1	10/15/91	154.99	11.67	143.32	ND<50	ND<0.5	0.8	0.6	0.8	ND<5000	—
MW-1	01/15/92	154.99	10.03	144.96	ND<50	ND<0.5	ND<0.5	ND<0.5	ND<0.5	ND<5000	—
MW-1	04/17/92	154.99	10.31	144.68	ND<50	ND<0.5	ND<0.5	ND<0.5	ND<0.5	ND<5000	—
MW-1	09/30/92	154.99	11.64	143.35	ND<50	ND<0.5	ND<0.5	ND<0.5	ND<0.5	ND<5000	ANA
MW-1	12/17/92	154.99	9.92	145.07	ND<50	ND<0.5	ND<0.5	ND<0.5	ND<0.5	ND<5000	ANA
QC-1 (c)	12/17/92	—	—	—	ND<50	ND<0.5	ND<0.5	ND<0.5	ND<0.5	—	ANA
MW-1	03/15/93	154.99	10.22	144.77	ND<50	ND<0.5	ND<0.5	ND<0.5	2.1	ND<5000	PACE
MW-1	04/21/93	154.99	10.20	144.79	—	—	—	—	—	—	—
MW-2	08/18/86	152.02	10.00	142.02	ND<50	ND<1.0	ND<1.0	ND<1.0	ND<1.0	—	—
MW-2	11/12/90	152.02	10.94	141.08	ND<50	ND<0.5	ND<0.5	ND<0.5	ND<0.5	—	—
MW-2	07/15/91	152.02	9.87	142.15	ND<50	ND<0.5	ND<0.5	ND<0.5	ND<0.5	—	—
MW-2	10/15/91	152.02	11.16	140.86	ND<50	ND<0.5	0.7	ND<0.5	1.5	ND<5000	—
MW-2	01/15/92	152.02	8.81	143.21	ND<50	ND<0.5	ND<0.5	ND<0.5	ND<0.5	ND<5000	—
MW-2	04/17/92	152.02	8.41	143.61	ND<50	ND<0.5	ND<0.5	ND<0.5	ND<0.5	ND<5000	—
MW-2	09/30/92	152.02	11.13	140.89	ND<50	ND<0.5	ND<0.5	ND<0.5	ND<0.5	ND<5000	ANA
MW-2	12/17/92	152.02	8.16	143.86	ND<50	ND<0.5	ND<0.5	ND<0.5	ND<0.5	ND<5000	ANA
MW-2	03/15/93	152.02	7.70	144.32	180	ND<0.5	ND<0.5	ND<0.5	ND<0.5	ND<5000	PACE
MW-2	04/21/93	152.02	7.75	144.27	ND<50	ND<0.5	ND<0.5	ND<0.5	ND<0.5	—	PACE
QC-2 (c)	04/21/93	—	—	—	ND<50	ND<0.5	ND<0.5	ND<0.5	ND<0.5	—	PACE
MW-3	08/18/86	—	9.60	—	ND<50	ND<1.0	ND<1.0	ND<1.0	ND<1.0	—	—
MW-3 (d)	11/12/90	—	—	—	—	—	—	—	—	—	—

TABLE 1 - SUMMARY OF RESULTS OF GROUNDWATER SAMPLING
BP OIL COMPANY SERVICE STATION NO. 11124
3315 HIGH STREET, OAKLAND, CALIFORNIA

ALISTO PROJECT NO. 10-020

WELL ID	DATE OF SAMPLING/ MONITORING	CASING ELEVATION (a) (Feet)	DEPTH TO WATER (b) (Feet)	GROUNDWATER ELEVATION (Feet)	TPH-G (ppb)	B (ppb)	T (ppb)	E (ppb)	X (ppb)	TOG (ppb)	LAB
MW-4	07/15/91	152.77	9.62	143.15	ND<50	ND<0.5	ND<0.5	ND<0.5	0.8	---	---
MW-4	10/15/91	152.77	11.30	141.47	ND<50	ND<0.5	0.7	0.6	1.1	ND<5000	---
MW-4	01/15/92	152.77	8.81	143.96	ND<50	ND<0.5	2.7	ND<0.5	ND<0.5	ND<5000	---
MW-4	04/17/92	152.77	8.20	144.57	ND<50	ND<0.5	ND<0.5	ND<0.5	ND<0.5	ND<5000	---
MW-4	09/30/92	152.77	11.33	141.44	ND<50	ND<0.5	ND<0.5	ND<0.5	ND<0.5	5200	ANA
QC-1 (c)	09/30/92	152.77	11.33	141.44	ND<50	ND<0.5	ND<0.5	ND<0.5	ND<0.5	---	ANA
MW-4	12/17/92	152.77	8.15	144.62	ND<50	ND<0.5	ND<0.5	ND<0.5	ND<0.5	ND<5000	ANA
MW-4	03/15/93	152.77	7.88	144.89	ND<50	ND<0.5	ND<0.5	ND<0.5	ND<0.5	ND<5000	PACE
QC-1 (c)	03/15/93	---	---	---	ND<50	ND<0.5	ND<0.5	ND<0.5	ND<0.5	---	PACE
MW-4	04/21/93	152.77	7.61	145.16	---	---	---	---	---	---	---
QC-2 (e)	09/30/92	---	---	---	ND<50	ND<0.5	ND<0.5	ND<0.5	ND<0.5	---	ANA
QC-2 (e)	12/17/92	---	---	---	ND<50	ND<0.5	ND<0.5	ND<0.5	ND<0.5	---	ANA
QC-2 (e)	03/15/93	---	---	---	ND<50	ND<0.5	ND<0.5	ND<0.5	ND<0.5	---	PACE

ABBREVIATIONS:

TPH-G	Total petroleum hydrocarbons as gasoline
B	Benzene
T	Toluene
E	Ethylbenzene
X	Total xylenes
TOG	Total oil and grease
ppb	Parts per billion
ND	Not detected above reported detection limits
---	Not analyzed/measured
ANA	Anametrix, Inc.
PACE	Pace, Inc.

NOTES:

(a) Casing elevations surveyed to the nearest 0.01 foot relative to mean sea level.

(b) Groundwater elevations in feet above mean sea level.

(c) Blind duplicate.

(d) Monitoring well destroyed.

(e) Travel blank.

Attachment C

Soil Boring and Well Logs

MOBIL OIL CORPORATION

OAKLAND, CALIFORNIA

MW-1

Well completed to 35.0 feet in depth with 2-inch Class 160 PVC casing, flush-threaded joints. Screen (.020-inch slot) set from 7.0 to 35.0 feet. 6 X 12 Monterey sand placed from 5.5 to 35.0 feet, bentonite pellets placed from 5.0 to 5.5 feet, and concrete seal placed from 0 to 5.0 feet.

DRILL RIG Hollow Stem	SURFACE ELEVATION -----	LOGGED BY JCW
DEPTH TO GROUNDWATER As noted	BORING DIAMETER 8"	DATE DRILLED 7/29/86

DESCRIPTION AND CLASSIFICATION									
DESCRIPTION AND REMARKS	COLOR	CONSIST.	SOIL TYPE	DEPTH (FEET)	SAMPLER	UNCONFINED COMPRESSIVE STRENGTH (KSF)	WATER CONTENT (%)	DRY DENSITY (PCF)	PENETRATION RESISTANCE (BLOWS/FT.)
ASPHALT, BASE ROCK AND FILL									
SILTY CLAY with rock fragments; dry	tan	stiff	CL						
Cobbles; damp									
				5					
Grading to clayey gravel; damp	tan to brown		CL-GC				▽		
				10					
GRAVELLY CLAY, with some fine sand; damp to moist No product odor	tan to light brown	stiff	CL						
				15	⊢ ⊣				
Increasing clay at 17 feet, moist; no product odor									
				20					

EXPLORATORY BORING LOG

MOBIL OIL CORPORATION
HIGH STREET, OAKLAND

PROJECT NO.	DATE	BORING NO.
H182-21	8/86	MW-1

DRILL RIG Hollow Stem	SURFACE ELEVATION ----	LOGGED BY JCW
DEPTH TO GROUNDWATER As Noted	BORING DIAMETER 8"	DATE DRILLED 7/29/86

DESCRIPTION AND REMARKS	COLOR	CONSIST.	SOIL TYPE	DEPTH (FEET)	SAMPLER	UNCONFINED COMPRESSIVE STRENGTH (KSF)	WATER CONTENT (%)	DRY DENSITY (PCF)	PENETRATION RESISTANCE (BLOWS/FT.)
GRAVELLY CLAY (CONTD)	light brown	stiff to very stiff	CL				▽		
CLAYEY GRAVEL; wet, no product odor	light brown	dense	GC	25					
				30					
CLAYEY SAND; grading to sandy clay	light brown	medium dense	SC						
				35					
TOTAL DEPTH = 35.0 feet									

EXPLORATORY BORING LOG

MOBIL OIL CORPORATION
HIGH STREET, OAKLAND

PROJECT NO.	DATE	BORING NO.
H182-21	8/86	MW-1

MOBIL OIL CORPORATION

OAKLAND, CALIFORNIA

MW-2

Well completed to 30.0 feet in depth with 2-inch Class 160 PVC casing, flush-threaded joints. Screen (.020-inch slot) set from 7.0 to 30.0 feet. 6 X 12 Monterey sand placed from 5.0 to 30.0 feet, bentonite pellets placed from 4.5 to 5.0 feet, and concrete seal placed from 0 to 4.5 feet.

[illegible]ILL RIG Hollow Stem	SURFACE ELEVATION ---	LOGGED BY JCW
DEPTH TO GROUNDWATER As Noted	BORING DIAMETER 8"	DATE DRILLED 7/30/86

DESCRIPTION AND REMARKS	COLOR	CONSIST.	SOIL TYPE	DEPTH (FEET)	SAMPLER	UNCONFINED COMPRESSIVE STRENGTH (KSF)	WATER CONTENT (%)	DRY DENSITY (PCF)	PENETRATION RESISTANCE (BLOWS/FT.)
ASPHALT AND BASE ROCK									
SILTY CLAY with rock fragments; dry	tan	stiff	CL						
Large rock fragments				5					
Damp; no product odor	motld tan to gray to brown								
Decreasing rock fragments				10					
Slightly sandy No product odor			CL-SC	15	▯				
							▽		
CLAYEY GRAVEL	light brown	dense	GC	20					

EXPLORATORY BORING LOG

MOBIL OIL CORPORATION
HIGH STREET, OAKLAND

PROJECT NO.	DATE	BORING NO.
H182-21	8/86	MW-2

DRILL RIG Hollow Stem	SURFACE ELEVATION ----	LOGGED BY JCW
DEPTH TO GROUNDWATER As Noted	BORING DIAMETER 8"	DATE DRILLED 7/30/86

DESCRIPTION AND CLASSIFICATION				DEPTH (FEET)	SAMPLER	UNCONFINED COMPRESSIVE STRENGTH (KSF)	WATER CONTENT (%)	DRY DENSITY (PCF)	PENETRATION RESISTANCE (BLOWS/FT.)
DESCRIPTION AND REMARKS	COLOR	CONSIST.	SOIL TYPE						
CLAYEY GRAVEL (CONTD)	light brown to tan	dense	GC						
				25					
Large gravel		dense to very dense							
				30					
TOTAL DEPTH = 30.0 feet									

EXPLORATORY BORING LOG

MOBIL OIL CORPORATION
HIGH STREET, OAKLAND

PROJECT NO.	DATE	BORING NO.
H182-21	8/86	MW-2

MOBIL OIL CORPORATION

OAKLAND, CALIFORNIA

MW-3

Well completed to 30.0 feet in depth with 2-inch Class 160 PVC casing, flush-threaded joints. Screen (.020-inch slot) set from 7.0 to 30.0 feet. 6 X 12 Monterey sand placed from 5.0 to 30.0 feet, bentonite pellets placed from 4.5 to 5.0 feet, and concrete seal placed from 0 to 4.5 feet.

DRILL RIG Hollow Stem	SURFACE ELEVATION ----	LOGGED BY JCW
DEPTH TO GROUNDWATER As Noted	BORING DIAMETER 8"	DATE DRILLED 7/30/86

DESCRIPTION AND REMARKS	COLOR	CONSIST.	SOIL TYPE	DEPTH (FEET)	SAMPLER	UNCONFINED COMPRESSIVE STRENGTH (KSF)	WATER CONTENT (%)	DRY DENSITY (PCF)	PENETRATION RESISTANCE (BLOWS/FT.)
ASPHALT AND BASE ROCK									
SILTY CLAY with rock fragments; dry	tan to brown	stiff	CL-						
Large rock fragments			CL-GC	5					
Decreasing rock fragments									
SILTY CLAY, damp No product odor	tan to gray	stiff	CL						
				10					
		very stiff		15	▯				
Wet; no product odor				20			▽		

EXPLORATORY BORING LOG

MOBIL OIL CORPORATION
HIGH STREET, OAKLAND

PROJECT NO.	DATE	BORING NO.
H182-21	8/86	MW-3

DRILL RIG Hollow Stem	SURFACE ELEVATION -----	LOGGED BY JCW
DEPTH TO GROUNDWATER As Noted	BORING DIAMETER 8"	DATE DRILLED 7/30/86

DESCRIPTION AND CLASSIFICATION				DEPTH (FEET)	SAMPLER	UNCONFINED COMPRESSIVE STRENGTH (KSF)	WATER CONTENT (%)	DRY DENSITY (PCF)	PENETRATION RESISTANCE (BLOWS/FT.)
DESCRIPTION AND REMARKS	COLOR	CONSIST.	SOIL TYPE						
SILTY CLAY (CONTD)	tan to gray	very stiff	CL						
CLAYEY GRAVEL; wet	light brown		GC						
SILTY CLAY	light brown	very stiff to hard	CL	25					
CLAYEY GRAVEL	light brown	dense to very dense	GC						
TOTAL DEPTH = 30.0 feet				30					

EXPLORATORY BORING LOG

MOBIL OIL CORPORATION
HIGH STREET, OAKLAND

PROJECT NO.	DATE	BORING NO.
H182-21	8/86	MW-3

Total depth of boring: 30-1/2 ft. **Diameter of boring:** 8 in. **Date drilled:** 5/13/91

Casing diameter: 2 in. **Length:** 15 ft. **Slot size:** 0.020 in.

Screen diameter: 2 in. **Length:** 15 ft. **Material type:** PVC

Drilling Company: Kvilhaug **Driller:** Mike and Cliff

Method Used: Hollow-stem Auger **Field Geologist:** C. Avila

Signature of Registered Professional: ____________

Registration No.: 4313 **State:** Calif.

DEPTH	SAMPLE NO.	BLOWS	P.I.D.	USCS CODE	DESCRIPTION	WELL CONST.
0					Asphalt.	
2						
4	S-5	40		SM	Silty sand with some gravel, medium- to coarse-grained sand and coarse gravel, light brown, damp, dense.	
6						
8						
10	S-10	23		CL	Clay with some silt, light brown, damp, medium plasticity, very stiff.	
12						
14	S-15	24		ML	Silt with some clay and trace gravel, light brown, damp, slight plasticity, very stiff.	
16						
18						
20	S-20	38		▼	Silt with some fine- to coarse-grained sand and coarse gravel, wet, hard.	

(section continues downward)

RESNA

PROJECT NO. 30061-2

FILE NO. 0061B4A

LOG OF BORING: B-1/MW-4
BP Facility No. 11124
3315 High Street
Oakland, California

PLATE 4

DEPTH	SAMPLE NO.	BLOWS	P.I.D.	USCS CODE	DESCRIPTION	WELL CONST.
20	S-20	38		▼ ML	Silt with some fine- to coarse-grained sand and coarse gravel, wet, hard.	
22						
24	S-25	20			Silt with some fine- to medium-grained sand, trace coarse gravel and clay, light brown, wet, very stiff.	
26						
28	S-28	37				
30	S-30	37				
32					Total depth = 30-1/2 feet. Ground water encountered at 19-1/2 feet. Boring terminated to construct monitoring well.	
34						
36						
38						
40						
42						
44						
46						
48						
50						

RESNA

PROJECT NO. 30061-2

FILE NO. 0061B4B

LOG OF BORING: B-1/MW-4
BP Facility No. 11124
3315 High Street
Oakland, California

PLATE 5

Total depth of boring: 18-1/2 ft **Diameter of boring:** 8 in. **Date drilled:** 5/14/91
Casing diameter: N/A **Length:** N/A **Slot size:** N/A
Screen diameter: N/A **Length:** N/A **Material type:** N/A
Drilling Company: Kvilhaug **Driller:** Mike & Cliff
Method Used: Hollow-stem Auger **Field Geologist:** Claudio
Signature of Registered Professional: ____________
Registration No.: 4313 **State:** Calif.

DEPTH	SAMPLE NO.	BLOWS	P.I.D.	USCS CODE	DESCRIPTION	WELL CONST.
0					Asphalt	
4–6	S-5	33	0 ppmv	SM	Sandy silt with some gravel, medium-to coarse-grained sand and coarse gravel, light brown, damp, hard.	
10	S-10	26	0 ppmv		Clayey silt with trace of sand, fine-to medium-grained sand, light brown, damp, slight plasticity, very stiff.	
15	S-15	30	0 ppmv	ML	Silt with some clay and a trace of fine-grained sand, light brown, damp, slight plasticity, very stiff.	
18	S-18	24	0 ppmv		Silt with some gravel and a trace of clay, coarse gravel, light brown, very moist, very stiff.	
20					Total depth = 18-1/2 feet. Boring backfilled with cement/bentonite slurry.	

RESNA

PROJECT NO. 30061-2 FILE NO. 0061B5A

LOG OF BORING: B-2B
BP Facility No. 11124
3315 High Street
Oakland, California

PLATE 6

Total depth of boring: 17-1/2 ft **Diameter of boring:** 8 in. **Date drilled:** 5/14/91
Casing diameter: N/A **Length:** N/A **Slot size:** N/A
Screen diameter: N/A **Length:** N/A **Material type:** N/A
Drilling Company: Kvilhaug **Driller:** Mike & Cliff
Method Used: Hollow-stem Auger **Field Geologist:** Claudio
Signature of Registered Professional:
Registration No.: 4313 **State:** Calif.

DEPTH	SAMPLE NO.	BLOWS	P.I.D.	USCS CODE	DESCRIPTION	WELL CONST.
0					Asphalt	
4–6	S-5	28	0 ppmv	ML	Silt with trace sand and gravel, medium-to coarse-grained sand and coarse gravel, light brown, damp, very stiff.	
10	S-10	26	0 ppmv		(trace of clay)	
14–16	S-15	43	0 ppmv	SW	Sand with some gravel and trace silt, medium-to coarse-grained sand and coarse gravel, light brown, damp, dense.	
16–17.5	S-20	26	0 ppmv	ML	Silt with some sand and trace fine-grained sand and coarse gravel, light brown, damp, very stiff.	
18					Total depth = 17-1/2 feet. Boring backfilled with cement/bentonite slurry.	

Depth scale: 0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20

RESNA

PROJECT NO. 30061-2

FILE NO. 0061B6A

LOG OF BORING: B-3
BP Facility No. 11124
3315 High Street
Oakland, California

PLATE 7

Attachment D

EPA Expedited Site Assessment Guidance (1997), Chapter V – Direct Push Technologies

Chapter V
Direct Push Technologies

Direct push (DP) technology (also known as "direct drive," "drive point," or "push" technology) refers to a growing family of tools used for performing subsurface investigations by driving, pushing, and/or vibrating small-diameter hollow steel rods into the ground. By attaching sampling tools to the end of the steel rods they can be used to collect soil, soil-gas, and groundwater samples. DP rods can also be equipped with probes that provide continuous *in situ* measurements of subsurface properties (*e.g.*, stratigraphy, contaminant distribution). DP equipment can be advanced with various methods ranging from 30 pound manual hammers to trucks weighing 60 tons.

DP technology has developed in response to a growing need to assess contaminated sites more completely and more quickly than is possible with conventional methods. As explained in Chapter II, The Expedited Site Assessment Process, conventional assessments have relied heavily on traditional drilling methods, primarily hollow stem augers (HSA), to collect soil and groundwater samples and install permanent monitoring wells. Because installing permanent monitoring wells with HSA is a relatively slow process that provides a limited number of samples for analysis, the most economical use for the equipment is to perform site assessments in phases with rigid work plans and off-site analysis of samples.

With the development of DP technologies, large, permanent monitoring wells are no longer the only method for collecting groundwater samples or characterizing a site. Multiple soil, soil-gas, and groundwater samples can now be collected rapidly, allowing high data quality analytical methods to be used on-site, economically. As a result, DP technologies have played a major role in the development of expedited site assessments (ESAs).

DP technologies are most applicable in unconsolidated sediments, typically to depths less than 100 feet. In addition to being used to collect samples from various media, they can also be used to install small-diameter (*i.e.*, less than 2 inches) temporary or permanent monitoring wells and small-diameter piezometers (used for measuring groundwater gradients). They have also been used in the installation of remediation equipment such as soil vapor extraction wells and air sparging injection points. Penetration is limited in semiconsolidated sediments and is generally not possible in consolidated formations, although highly weathered bedrock (*i.e.*, saprolite) is an exception for some equipment. DP equipment may also be limited in unconsolidated sediments with high percentages of gravels and cobbles. As a result, other drilling methods are necessary in site assessment and remediation activities where geological conditions are unfavorable for DP technologies or where larger diameter (*i.e.*, greater than 2 inches) wells are needed.

An additional benefit of DP technologies is that they produce a minimal amount of waste material because very little soil is removed as the probe rods advance and retract. Although this feature may result in some soil compaction that could reduce the hydraulic conductivity of silts and clays, methods exist for minimizing resulting problems.

In contrast, although most other drilling methods remove soil from the hole, resulting in less compaction, conventional drilling methods create a significant amount of contaminated cuttings and they also smear clay and silt across more permeable formations which can obscure their true nature. Moreover, these other drilling methods have the potential of causing a redistribution of contamination as residual and free product are brought to the surface.

Choosing a DP method (or combination of DP methods) appropriate for a specific site requires a clear understanding of data collection goals because many tools are designed for only one specific purpose (*e.g.*, collection of groundwater samples). This chapter contains descriptions of the operation of specific DP systems and tools, highlighting their main advantages and limitations; its purpose is to assist regulators in evaluating the appropriateness of these systems and tools.

This chapter does not contain discussions of specific tools manufactured by specific companies because equipment is evolving rapidly. Not only are unique tools being invented, but existing equipment is being used in creative ways to meet the needs of specific site conditions. As a result, the distinctions between types of DP equipment is becoming blurred and it is necessary to focus on component groups rather than entire DP systems. The four component groups discussed in this chapter include:

- Rod systems;
- Sampling tools;
- *In situ* measurements using specialized probes; and
- Equipment for advancing DP rods.

The chapter also includes a discussion of methods for sealing DP holes because of their importance in preventing the spread of contaminants and, therefore, in the selection of DP equipment. The cost of various DP equipment is not discussed in this chapter because cost estimates become quickly outdated due to rapid changes in the industry. An overview of the advantages and limitations of DP equipment and systems discussed in this chapter are presented in Exhibit V-1.

Exhibit V-1
Overview Of Direct Push Technologies

Direct Push Component	Example	Advantages	Limitations
Probing systems	Single-rod or cased	Minimizes the need for waste disposal or treatment	Compaction of sediments may decrease hydraulic conductivity
Soil, soil-gas, and groundwater sampling	Piston samplers, expendable tip samplers	Relatively rapid	Permanent monitoring wells are limited to 2 inch diameter or less
In situ measurement of subsurface conditions	Conductivity probes, laser induced fluorescence	Can be used to rapidly log site	Correlation with boring logs is necessary
Methods for advancing probe rods	Percussion hammers, hydraulic presses	Some methods are extremely portable	Very dense, consolidated formations are generally impenetrable
Sealing methods	Re-entry grouting, retraction grouting	Holes can be sealed so that contaminants cannot preferentially migrate through them	Appropriate sealing methods may limit sampling equipment options

Direct Push Rod Systems

DP systems use hollow steel rods to advance a probe or sampling tool. The rods are typically 3-feet long and have male threads on one end and female threads on the other. As the DP rods are pushed, hammered, and/or vibrated into the ground, new sections are added until the target depth has been reached, or until the equipment is unable to advance (*i.e.*, refusal). There are two types of rod systems, single-rod and cased. Both systems allow for the collection of soil, soil-gas, and groundwater samples. Exhibit V-2 presents a schematic drawing of single-rod and cased DP rod systems.

Single-Rod Systems

Single-rod systems are the most common types of rods used in DP equipment. They use only a single string (*i.e.*, sequence) of rods to connect the probe or sampling tool to the rig. Once a sample has been collected, the entire string of rods must usually be removed from the probe hole. Collection of samples at greater depths may require re-entering the probe hole with an empty sampler and repeating the process. The diameter of the rods is typically around 1 inch, but it can range from 0.5 to 2.125 inches.

Cased Systems

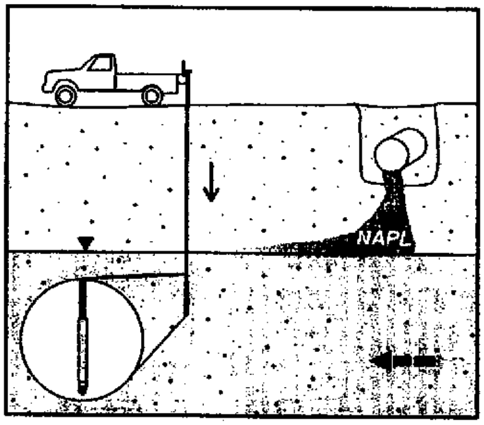
Cased systems, which are also called dual-tube systems, advance two sections--an outer tube, or casing, and a separate inner sampling rod. The outer casing can be advanced simultaneously with, or immediately after, the inner rods. Samples can, therefore, be collected without removing the entire string of rods from the ground. Because two tubes are advanced, outer tube diameters are relatively large, typically 2.4 inches, but they can range between 1.25 and 4.2 inches.

Discussion And Recommendations

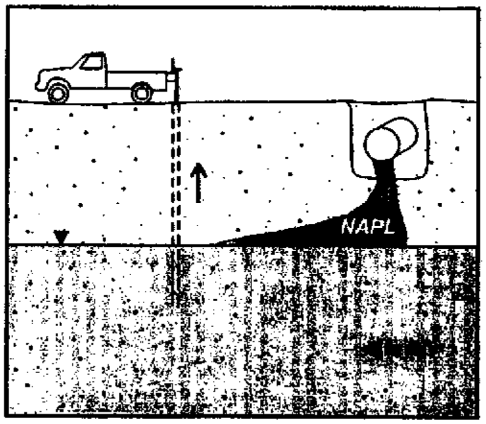
Single-rod and cased systems have overlapping applications; they can be used in many of the same environments. However, when compared with cased systems, single-rod systems are easier to use and are capable of collecting soil, soil-gas, or groundwater samples more rapidly when only one sample is retrieved. They are particularly useful at sites where the stratigraphy is either relatively homogeneous or well delineated.

Exhibit V-2
Schematic Drawing Of Single And Cased Direct Push Rod Systems

Single-Rod Direct Push System

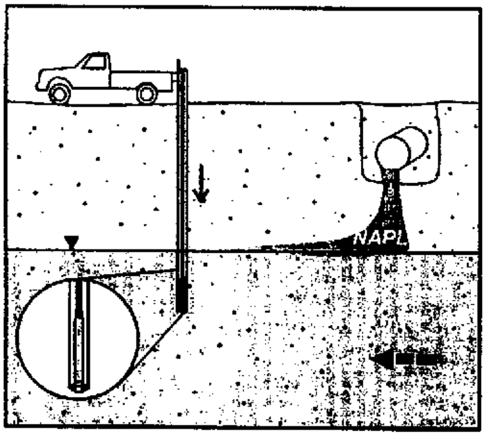


1) DP sampling tool is advanced on the end of a single sequence of rods.

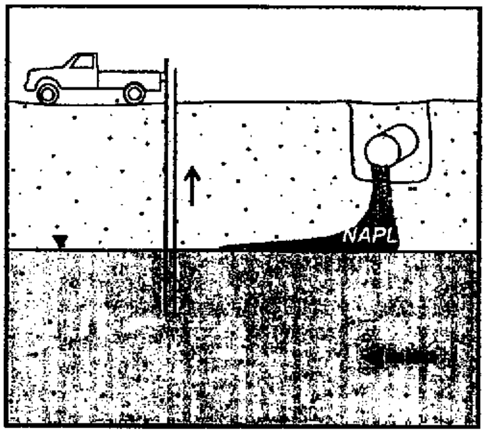


2) Once the sampling tool is full, tool and rods are withdrawn from the ground. To collect another sample, the tool must be re-inserted and pushed to the next sampling depth.

Cased Direct Push System



1) DP sampling tool is attached to inner rods. Sampling tool, inner rods, and outer drive casing are advanced simultaneously.



2) To collect the sample, only the sampling tool and inner rods are removed. The outer drive casing remains in the ground to prevent sloughing or hole collapse. To collect a deeper sample, the tool and inner rods are re-inserted to the bottom of probe hole and advanced along with the outer drive casing. The outer casing is removed only after the last sample has been collected.

The primary advantage of cased DP systems is that the outer casing prevents the probe hole from collapsing and sloughing during sampling. This feature allows for the collection of continuous soil samples that do not contain any slough, thereby preventing sample contamination. Because only the inner sample barrel is removed, and not the entire rod string, cased systems are faster than single-rod systems for continuous sampling at depths below 10 feet. The collection of continuous samples is especially important at geologically heterogeneous sites where direct visual observation of lithology is necessary to ensure that small-scale features such as sand stringers in aquitards or thin zones of non-aqueous-phase liquids (NAPLs) are not missed.

Another advantage of cased systems is that they allow sampling of groundwater after the zone of saturation has been identified. This feature allows investigators to identify soils with relatively high hydraulic conductivities from which to take groundwater samples. If only soils with low hydraulic conductivity are present, investigators may choose to take a soil sample and/or install a monitoring well. With most single-rod systems, groundwater samples must be taken without prior knowledge of the type of soil present. (Some exposed-screen samplers used with single-rod systems as described in the *Groundwater Sampling Tools* section are an exception.)

A major drawback of single-rod systems is that they can be slow when multiple entries into the probe hole are necessary, such as when collecting continuous soil samples. In addition, in non-cohesive formations (*i.e.*, loose sands), sections of the probe hole may collapse, particularly in the zone of saturation, enabling contaminated soil present to reach depths that may be otherwise uncontaminated. Sloughing soils may, therefore, contaminate the sample. This contamination can be minimized through the use of sealed soil sampling tools (*i.e.*, piston samplers, which are discussed in more detail in the *Soil Sampling Tools* section that follows).

Multiple entries made with single-rod systems into the same hole should be avoided when NAPLs are present because contaminants could flow through the open hole after the probe rods have been removed; particularly if dense-non-aqueous phase liquids (DNAPLs) are present. In addition, multiple entries into the probe hole may result in the ineffective sealing of holes. (These issues are discussed in more detail in *Methods For Sealing Direct Push Holes* at the end of the chapter.) If samples need to be taken at different depths in zones of significant NAPL contamination, single-rod systems can be used, but new entries into soil should be made next to previous holes.

The major drawback of cased systems is that they are more complex and difficult to use than single-rod systems. In addition, because they require larger-diameter probe rods, cased systems require heavier DP rigs, larger percussion hammers, and/or vibratory systems for advancing the probe rod. Furthermore, even with the additional equipment, penetration depths are often not as great as are possible with single-rod systems and sampling rates are slower when single, discrete samples are collected. Exhibit V-3 summarizes the comparison of single and cased systems.

Exhibit V-3
Comparison Of Single-Rod And Cased Systems

	Single-Rod	Cased
Allows collection of a single soil, soil-gas, or groundwater sample	□ (faster)	□
Allows collection of continuous soil samples	□ [1]	□ [2] (faster)
Allows collection of groundwater sampling after determining ideal sampling zone[3]		□
Lighter carrier vehicles can be used to advance rods	□	
Greater penetration depths	□	
Multiple soil samples can be collected when NAPLs are present		□

[1] Sloughed soil may also be collected.
[2] Faster at depths below approximately 10 feet.
[3] Some exposed-screen samplers, discussed in the groundwater sampling section, also have this ability.

A large number of DP tools have been developed for sampling soil, soil-gas, and groundwater. Each of these tools was designed to meet a specific purpose; however, many of these tools also have overlapping capabilities. This section describes the commonly used tools currently available and clarifies their applications. All of the tools described in this section can be advanced by rigs designed specifically for DP. In addition, many of these tools can also be used with conventional drilling rigs.

Soil Sampling Tools

There are two types of soil samplers: Nonsealed and sealed. Nonsealed soil sampling tools remain open as they are pushed to the target depth; sealed soil samplers remain closed until they reach the sampling depth.

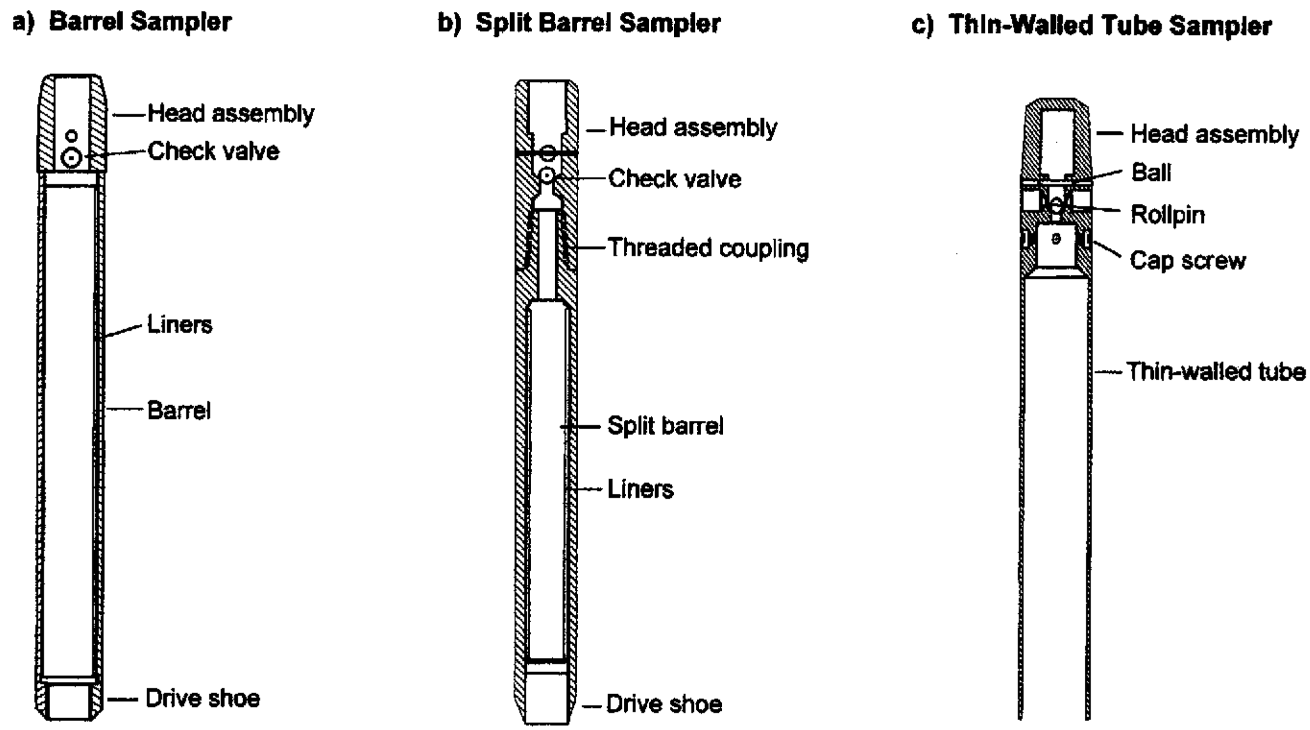
Nonsealed Soil Samplers

The three most commonly used nonsealed soil samplers are barrel, split-barrel, and thin-walled tube samplers. All three are modified from soil samplers used with conventional drilling rigs (*e.g.*, HSA). The primary difference is that DP soil samplers have smaller diameters. Nonsealed soil samplers should only be used in combination with single-rod systems when sampling in uncontaminated fine-grained, cohesive formations because multiple entries into the probe hole are required. When sloughing soils and cross-contamination are a significant concern, nonsealed soil samplers may be used with cased DP systems or more conventional sampling methods (*e.g.*, HSA). In addition, nonsealed samplers necessitate continuous soil coring because there is no other way to remove soil from the hole. All three types of nonsealed soil sampling tools are presented in Exhibit V-4.

Barrel Samplers

Barrel samplers, also referred to as solid-barrel or open-barrel samplers, consist of a head assembly, a barrel, and a drive shoe (Exhibit V-4a). The sampler is attached to the DP rods at the head assembly. A check valve, which allows air or water to escape as the barrel fills with soil, is located within the head assembly. The check valve improves the amount of soil recovered in each sample by allowing air to escape. With the use of liners, samples can be easily removed for volatile organic compound (VOC) analysis or for observation of soil structure.

Exhibit V-4
Types Of Nonsealed Direct Push Soil Sampling Tools



Source: Christensen/Acker

Without the use of liners, soil cores must be physically extruded using a hydraulic ram which may damage fragile structures (*e.g.*, root holes, desiccation cracks).

Split-Barrel Samplers

Split-barrel samplers, also referred to as "split-spoon" samplers, are similar to barrel samplers except that the barrels are split longitudinally (Exhibit V-4b) so that the sampler can be easily opened. The primary advantage of split-barrel samplers is that they allow direct observation of soil cores without the use of liners and without physically extruding the soil core. As a result, split-barrel samplers are often used for geologic logging. Split-barrel samplers, however, may cause more soil compaction than barrel samplers because the tool wall thickness is often greater. In addition, although liners are not compatible with all split-barrel samplers, liners are necessary if samples are used for analysis of VOCs.

Thin-Wall Tube Samplers

Thin-wall tube samplers (larger diameter samplers are known as Shelby Tubes) are DP sampling tools used primarily for collecting undisturbed soil samples (Exhibit V-4c). The sampling tube is typically attached to the sampler head using recessed cap screws or rubber expanding bushings. The walls of the samplers are made of thin steel (*e.g.*, 1/16-inch thick). The thin walls of the sampler cause the least compaction of the soil, making it the DP tool of choice for geotechnical sample analysis (*e.g.*, laboratory measurement of hydraulic conductivity, moisture content, density, bearing strength).

Samples are typically preserved, inside the tube, for off-site geotechnical analysis. If the samples are intended for on-site chemical analysis, they can be extruded from the sampler using a hydraulic ram, or the tubes can be cut with a hacksaw or tubing cutter. Because of their fragile construction, thin-wall tube samplers can be used only in soft, fine-grained sediments. In addition, the sampler is usually pushed at a constant rate rather than driven with impact hammers. If samples are needed for off-site VOC analysis, the tube is used as the sample container which can be capped and preserved.

Sealed Soil (Piston) Samplers

Piston samplers are the only type of sealed soil sampler currently available. They are similar to barrel samplers, except that the opening of the sampler is sealed with a piston. Thus, while the sampler is re-inserted into an open probe hole, contaminated soil and water can be prevented from entering the sampler. The probe displaces the soil as it is advanced. When the sampler has been pushed to the desired sampling depth, the piston is unlocked by releasing a retaining device, and subsequent pushing or driving forces soil into the sampler (Exhibit V-5).

Several types of piston samplers are currently available. Most use a rigid, pointed piston that displaces soil as it is advanced. Piston samplers are typically air- and water-tight; however, if o-ring seals are not maintained, leakage may occur. Piston samplers also have the advantage of increasing the recovery of unconsolidated sediments as a result of the relative vacuum that is created by the movement of the piston.

Discussion And Recommendations

Issues affecting the selection of soil samplers include the ability of the sampler to provide samples for lithological description, geotechnical characterization, or chemical analysis. In addition, the potential of a sample contamination with a specific sampler must be considered.

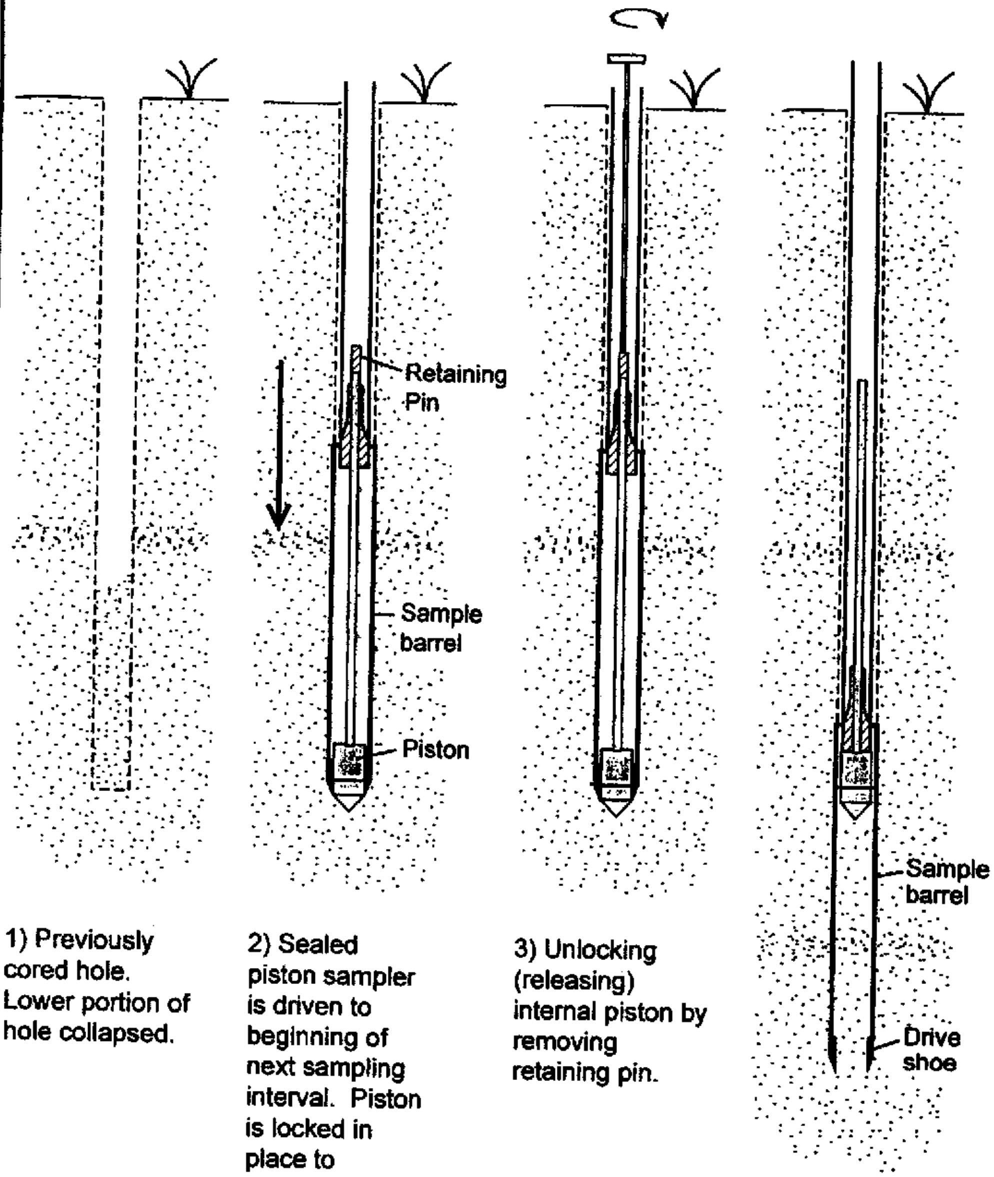
Lithologic Description/Geotechnical Characterization

All soil samplers can be used to some extent for lithologic description and geotechnical characterization but because the disturbance to the sample varies between tools, the preferred tool will vary depending on the application. Split-barrel samplers or barrel samplers used with split-liners are the best DP sampling methods for lithological description because they allow the investigator to directly inspect the soil without further disturbing the sample. Thin-walled tube samplers are best for collecting undisturbed samples needed for geotechnical analysis; barrel and piston samplers are the next best option. With single-rod systems, piston samplers are the only tools that can reliably be used for these same objectives because they produce discrete soil samples.

Chemical Analysis

All sealed or nonsealed soil samplers can be used for the collection of samples for VOC analysis. If samples are analyzed on-site, liners of various materials (*e.g.*, brass, stainless steel, clear acrylic, polyvinylchloride [PVC]) can be used as long as the soil is immediately subsampled and preserved. Soil samples intended for off-site analysis should be collected directly into brass or stainless steel liners within the DP soil sampling tool. Once the tool has been retrieved, the liners can be immediately capped, minimizing the loss of VOCs. Unfortunately, without extruding the soil core from the metal liners, detailed

Exhibit V-5
Using The Sealed Direct Push Soil Sampler (Piston Sampler)



1) Previously cored hole. Lower portion of hole collapsed.

2) Sealed piston sampler is driven to beginning of next sampling interval. Piston is locked in place to prevent soil and water from entering sample barrel.

3) Unlocking (releasing) internal piston by removing retaining pin.

4) Sampler driven to collect next soil core. Piston remains stationary while sample barrel is advanced. Soil core is retrieved by removing entire assembly from hole.

Source: Geoprobe® Systems

logging of the soil core is not possible. Short liners (4 to 6 inches long) may be useful for providing a minimal amount of lithological information. The soil lithology can be roughly discerned by inspecting the ends of the soil-filled liners; specific liners can then be sealed and submitted for chemical analysis. Extruding soil cores directly into glass jars for chemical analysis should be avoided since up to 90 percent of the VOCs may be lost from the sample (Siegrist, 1990).

Sample Contamination

The potential for sample contamination will depend on both the type of soil sampler and the type of DP rod system. The major concern with nonsealed samplers is that the open bottom may, when used with single-rod systems, allow them to collect soil that has sloughed from an upper section of the probe hole; they, therefore, may collect samples that are not representative of the sampling zone. If the sloughed soil contains contaminants, an incorrect conclusion could be made regarding the presence of contaminants at the target interval. Alternatively, if the overlying soil is less contaminated than the soil in the targeted interval, erroneously low concentrations could be indicated. As a result, nonsealed samplers should not be used with single-rod DP systems where contaminated soils are present. In such cases, piston samplers are the only appropriate soil samplers.

Nonsealed samplers can be safely used with cased DP systems above the water table. When sampling below the water table, particularly through geological formations with a high hydraulic conductivity, nonsealed samplers should not be used because contaminated water can enter the drive casing. In this situation, water-tight piston samplers must be used in combination with cased DP systems. In many low permeability formations, water does not immediately enter the outer drive casing of cased DP systems, even when the casing is driven to depths well below the water table. In these settings the potential for sample contamination is greatly reduced, and nonsealed soil samplers can be lowered through the outer casing. A summary of sealed and nonsealed soil samplers is presented in Exhibit V-6.

Active Soil-Gas Sampling Tools

Chapter IV, Soil-Gas Surveys, discusses the methods, capabilities, and applicabilities of both active and passive soil-gas surveys. Because active soil-gas sampling is performed with DP equipment, the various DP tools used in the collection of active soil-gas samples are covered in this section.

Exhibit V-6
Summary Of Sealed And Nonsealed Soil Sampler Applications

		Single-Rod System		Cased System	
		Nonsealed	Sealed	Nonsealed	Sealed
Sampling Above Watertable	NAPLs Not Present	□ [1]	□	□	□
	NAPLs Present		□	□	□
Sampling Below Watertable	NAPLs Not Present	□ [1]	□	□	□
	NAPLs Present		□	□ [2]	□

[1] Fine-grained (cohesive) formations where probe hole does not collapse.
[2] In low permeability soil where groundwater does not enter drive casing.

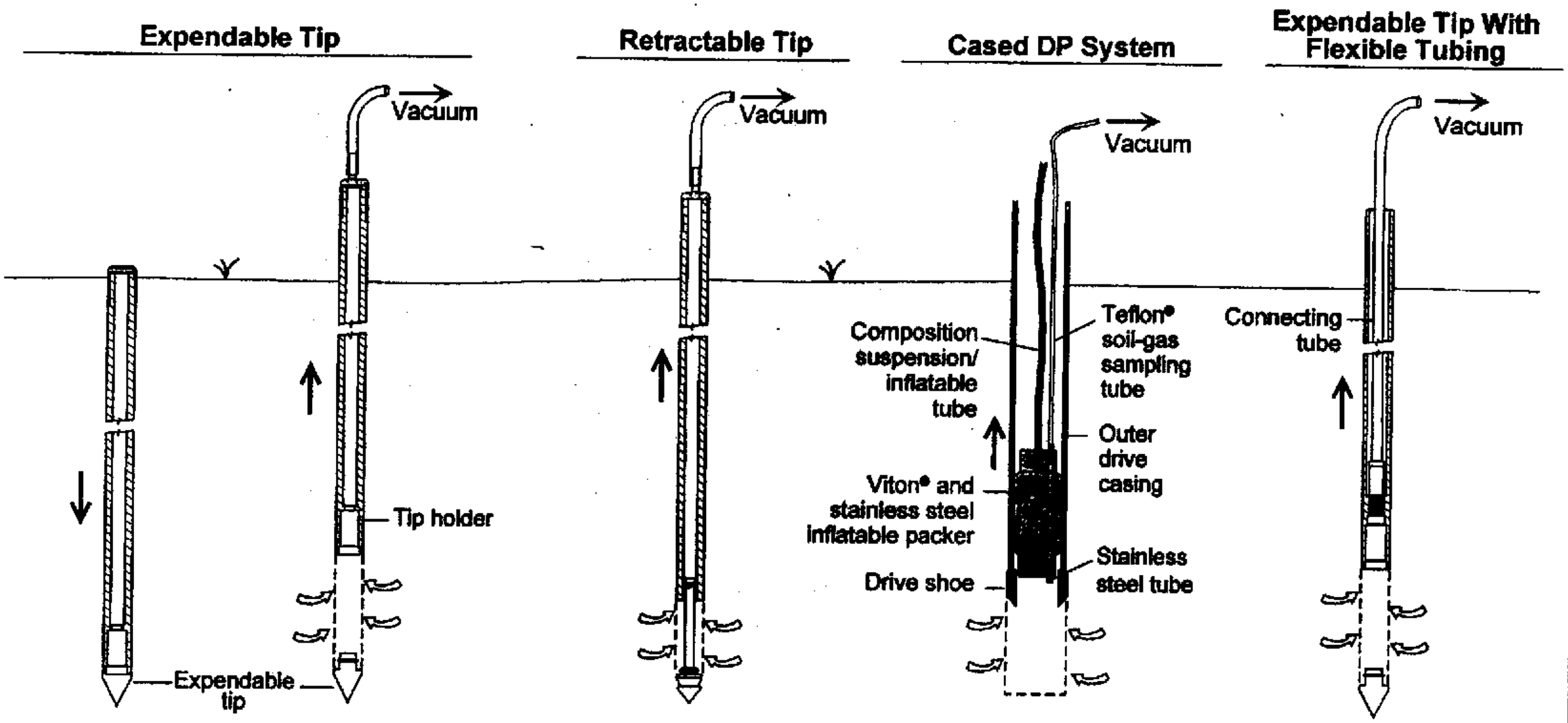
In active soil-gas sampling, a probe rod is pushed (either manually or mechanically) to a specified depth below the ground surface (bgs) into the vadose zone. A vacuum is applied to the rods (or tubing within the rods), and the sample is collected. The use of probe tips with larger diameters than the probe rods is a practice that should be discouraged when soil-gas sampling. Some DP practitioners use these large tips in order to reduce friction on advancing probe rods and therefore increase depth of penetration. This practice, however, will increase the likelihood of sampling atmospheric gases and diluting constituent concentrations.

There are four variations of soil-gas sampling tools and procedures: expendable tip samplers, retractable tip samplers, exposed samplers, and cased system sampling. Exhibit V-7 presents several soil-gas sampling tools.

Expendable Tip Samplers

Expendable cone-shaped tips, made of either steel or aluminum, are held in a tip holder as the DP rod advances (Exhibit V-7a_1). Once the desired depth has been reached, the DP rods are pulled back a few inches (Exhibit V-7a_2) and the tip can be separated from the tip holder, exposing the soil. Deeper samples can be collected in the same hole by withdrawing the probe and attaching another expendable tip. The previous tip can usually be pushed out of the way in most soils; however, some soils (*e.g.*, dense clays) may prevent the tip from moving and, therefore, prevent re-entry into the same hole.

Exhibit V-7
Types Of Direct Push Soil Gas Sampling Tools



a₁) DP rods equipped with expendable tip pushed to target depth.

a₂) DP rods withdrawn to expose target interval. Soil-gas sample collected through probe rods.

b) Soil-gas samples are collected through probe rods. Tip is removed with probe rods.

c) Soil-gas samples are collected through small-diameter tubing.

d) Soil-gas samples are collected through inner tubing.

Source: Geoprobe Systems and Precision Sampling, Inc.

The advantage of this method is that it allows retraction grouting (discussed in detail on page V-47). The major disadvantage of this method is that collection of deeper soil-gas samples in the same probe hole can be very time consuming because of the need to retract and re-insert the entire probe rod.

Retractable Tip Samplers

Retractable tips are similar to the expendable tips described above, except that the tip is physically attached to the tip holder by a small steel connecting tube (Exhibit V-7b). The connecting tube contains small holes, slots, or screens, and is held within the probe rod until the sampling depth is reached. As with the expendable tip sampler, the probe rod is withdrawn a few inches so that the tip can be dislodged, exposing the connecting tube.

Retractable tip samplers can be used to sample a single probe hole at multiple levels if the formation will not allow an expendable tip to be moved out of the way of the advancing probe rod. Generally, the probe rod should be withdrawn entirely from the probe hole in order to properly secure the tip. The probe rod should not be pushed back over the tip while in the hole because if the tip does not seat properly the assembly will be damaged. A disadvantage of this method is that it does not allow retraction grouting.

Exposed-Screen Samplers

Exposed screen samplers are probe rods that are fitted with slotted or screened terminal ends. They are similar to the exposed-screen samplers described in the groundwater sampling section which follows and which is depicted in Exhibit V-10a (page V-22). They may be made of steel or PVC and are exposed to the subsurface as they are driven to the sampling depth.

The major advantage of this tool is that it allows rapid sampling of multiple intervals within the same probe hole because the probe rod does not need to be retrieved before advancing to the next depth. The primary drawback is that if the slots are exposed to contaminants as the probe is pushed into the subsurface, sample contamination can result. In addition, the slots or screen may become clogged as the probe is pushed through fine grained soils, and retraction grouting can not be used with this method.

Sampling With Cased Systems

Soil-gas sampling can also be accomplished with cased DP systems. Once the sampling depth is reached, samples can be collected either directly through the outer casing or through disposable tubing (Exhibit V-7c). The major advantages of this method are that it creates less compaction of soils and it enables multiple level sampling. The major disadvantage is that it can be slower than single-rod methods.

Methods For Retrieving Active Soil-Gas Samples

Active soil-gas samples can be retrieved by two methods: soil gas can be drawn directly through the probe rods, or soil gas can be drawn through tubing inside the probe rods. Both methods are available with all the above-mentioned sampling tools.

Sampling Through Probe Rods

Soil gas can be pumped to the surface directly through probe rods, whether single-rod or cased systems. The advantage of this method is that it is relatively simple and less equipment is needed than for sampling through tubing. The drawbacks, however, are significant. First, because the volume of air within the probe rods is large (compared with sampling through tubing), the amount of time needed to purge the rods and collect a representative sample of soil-gas is relatively long. The increased volume of soil gas also increases the chances that short circuiting will occur, resulting in the sampling of atmospheric gases. This issue is particularly a problem with cased systems because the inside diameter of the casing can be much larger than single-rod systems. Second, the joints of most DP rods are not air-tight, so when the rod string is placed under vacuum, soil gas may be drawn from intervals other than the targeted zone.

Sampling Through Tubing

Sampling through tubing (Exhibit V-7d) is a method used to overcome many of the problems associated with sampling directly through the probe rods. The tubing is commonly made of polyethylene (PE) or Teflon® (polytetrafluoroethylene [PTFE]). The advantages of this method are that air is not withdrawn from the joints between rod sections, and purge volumes and sampling times are reduced. The disadvantage is that the tubing makes the sampling equipment more complicated and adds an additional expense.

Discussion And Recommendations

In general, sampling soil-gas through PE or PTFE tubing is the preferred method. Sampling directly through the probe rods can be successfully

Exhibit V-8
Summary Of Soil-Gas Sampling Tool Applications

	Sampling Through Probe Rods				Sampling Through Tubing			
	Expendable Tip	Retractable Tip	Exposed Sampler	Cased DP System	Expendable Tip	Retractable Tip	Exposed Sampler	Cased DP System
VOCs less likely to be lost					□	□	□	□
Sample contamination is less likely	□	□		□	□	□		□
Multi-level sampling	□	□	□[1]	□[1]	□	□	□[1]	□[1]
Minimizes purge volume/sampling time					□	□	□	□
Allows retraction grouting[2]	□			□	□			□
Macropores may be re-opened in silts and clays	□			□	□			□

[1] Allows multi-level sampling without removing the tool each time.
[2] Refer to "Methods For Sealing Direct Push Holes" at the end of the chapter.

accomplished, but it requires longer sampling times and investigators must ensure that probe rod joints are completely sealed.

If a soil-gas survey requires multi-level sampling, retraction tip samplers are applicable; however, these samplers require multiple entries into the same probe hole. Exposed screen samplers and cased systems allow for rapid sampling without the problems associated with multiple entry (discussed previously in the *Direct Push Rod System* section). However, exposed samplers may also result in sample contamination if NAPLs are dragged down in the slots or screen.

If soil gas is to be sampled in fine-grained sediments, sampling through tubing should be used to minimize sample volumes and the rod string should be withdrawn a greater distance than normal in order to expose a larger sampling interval. Alternatively, expendable tip samplers and cased systems may be useful if macropores (*e.g.*, root holes, desiccation cracks) exist. These features may be sealed by the advancing probe rod. Expendable tip and cased systems may allow brushes to be inserted into the sampling zone to scour away compacted soil, thus restoring the original permeability. Exhibit V-8 provides a summary of the applicability of the soil-gas sampling tools discussed in this section.

Groundwater Sampling Tools

DP technologies can be used in various ways to collect groundwater samples. Groundwater can be collected during a one-time sampling event in which the sampling tool is withdrawn and the probe hole grouted after a single sample is collected; groundwater sampling tools can be left in the ground for extended periods of time (*e.g.*, days, weeks) to collect multiple samples; or, DP technologies can be used to construct monitoring wells that can be used to collect samples over months or even years.

In general, when the hydraulic conductivity of a formation reaches 10^{-4} cm/second (typical for silts), collection of groundwater samples through one-time sampling events is rarely economical. Instead, collection of groundwater samples requires the installation of monitoring devices that can be left in the ground for days, weeks, or months. In general, however, it is difficult to get an accurate groundwater sample in low permeability formations with any method (whether DP or rotary drilling) because the slow infiltration of groundwater into the sampling zone may cause a significant loss of VOCs. As a result, DP groundwater sampling is most appropriate for sampling in fine sands or coarser sediments.

As with soil-gas sampling, probe tips for one-time groundwater sampling events should not be larger than DP rods because they can create an open annulus that could allow for contaminant migration. When installing long-term monitoring points, large tips can be used in conjunction with sealing methods that do not allow contaminant migration (*e.g.*, grouting to the surface).

Although most DP groundwater sampling equipment can also be used for determining groundwater gradients, using piezometers (*i.e.*, non-pumping, narrow, short-screened wells used to measure potentiometric pressures, such as the water table elevation) early in a site assessment is typically the best method. Piezometers are quick to install; they are inexpensive to purchase, and, because of their narrow diameter, they are quick to reach equilibrium. DP-installed monitoring wells may also be used for this purpose; however, they are more appropriate for determining groundwater contaminant concentrations once groundwater gradients and site geology have been characterized. Undertaking these activities first greatly simplifies the task of determining contaminant location, depth, and flow direction.

Methods now exist for installing permanent monitoring wells with both single-rod and cased DP systems (Exhibit V-9). These methods allow for the installation of annular seals that isolate the sampling zone. In addition, some methods allow for the installation of fine-grained sand filter packs that can provide samples with low turbidity (although the need for filter packs is an issue of debate among researchers). When samples are turbid, they should not be filtered prior to the constituent extraction process because organic constituents can sorb onto sediment particles. As a result, filtering samples prior to extraction may result in an analytical negative bias. For further information on the need for sediment filtration, refer to Nielsen, 1991.

The following text focuses on the tools used for single-event sampling. These tools can be divided into two groups--exposed-screen samplers and sealed-screen samplers. Exhibit V-10 presents examples of these two groups of groundwater samplers. Exhibit V-10a is a simple exposed-screen sampler; Exhibit V-10b is a common sealed-screen sampler; and Exhibit V-10c is a sealed-screen sampling method used with cased systems. Because new tools are continually being invented, and because of the great variety of equipment currently available, this *Guide* can not provide a detailed description and analysis of all available groundwater sampling tools. Instead, the advantages and limitations of general categories of samplers is discussed.

Exposed-Screen Samplers

Exposed-screen samplers are water sampling tools that have a short (*e.g.*, 6 inches to 3 feet) interval of exposed fine mesh screens, narrow slots, or small holes at the terminal end of the tool. The advantage of the exposed screen is

Exhibit V-9
Permanent Monitoring Well Installed
With Pre-packed Well Screens

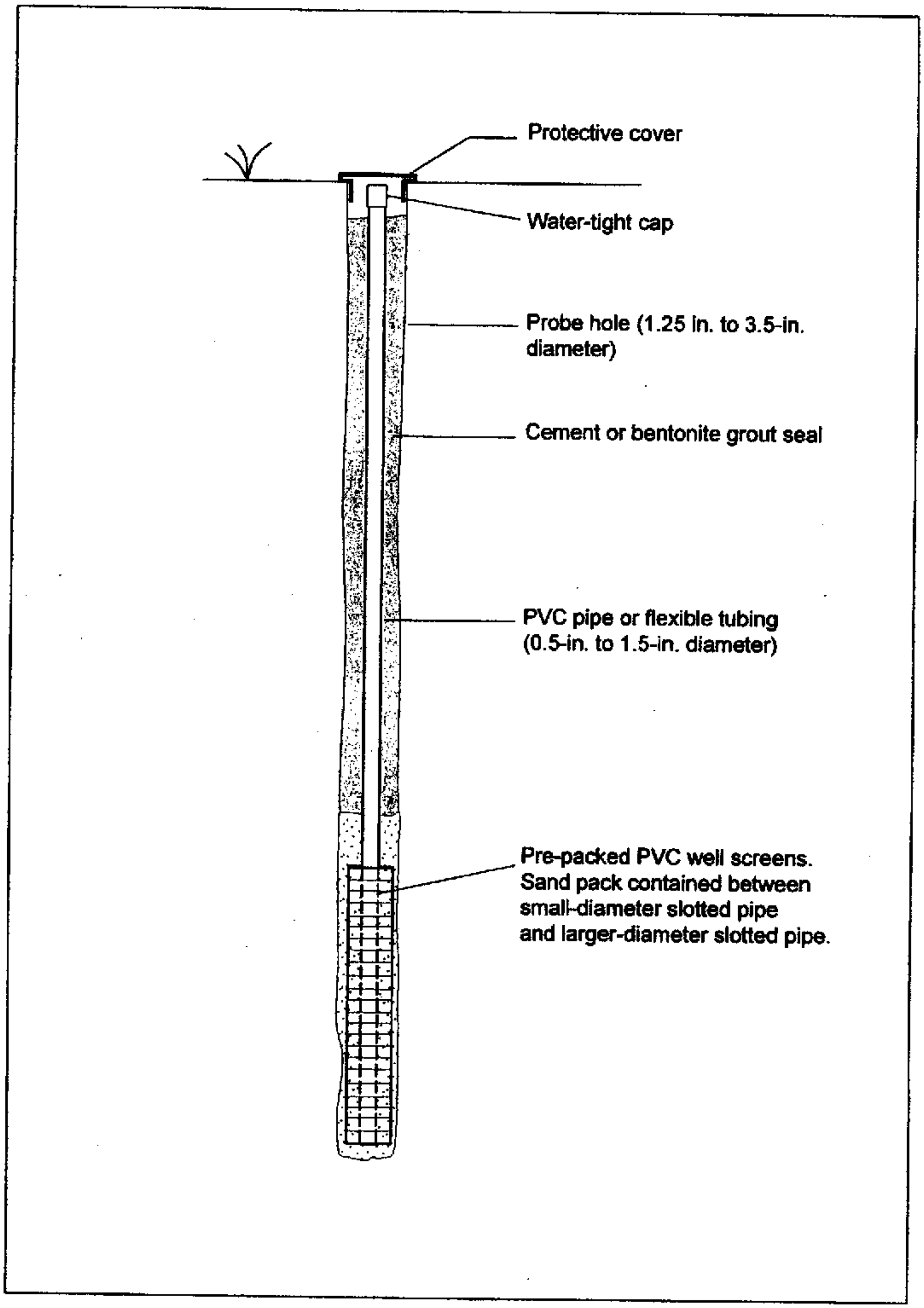
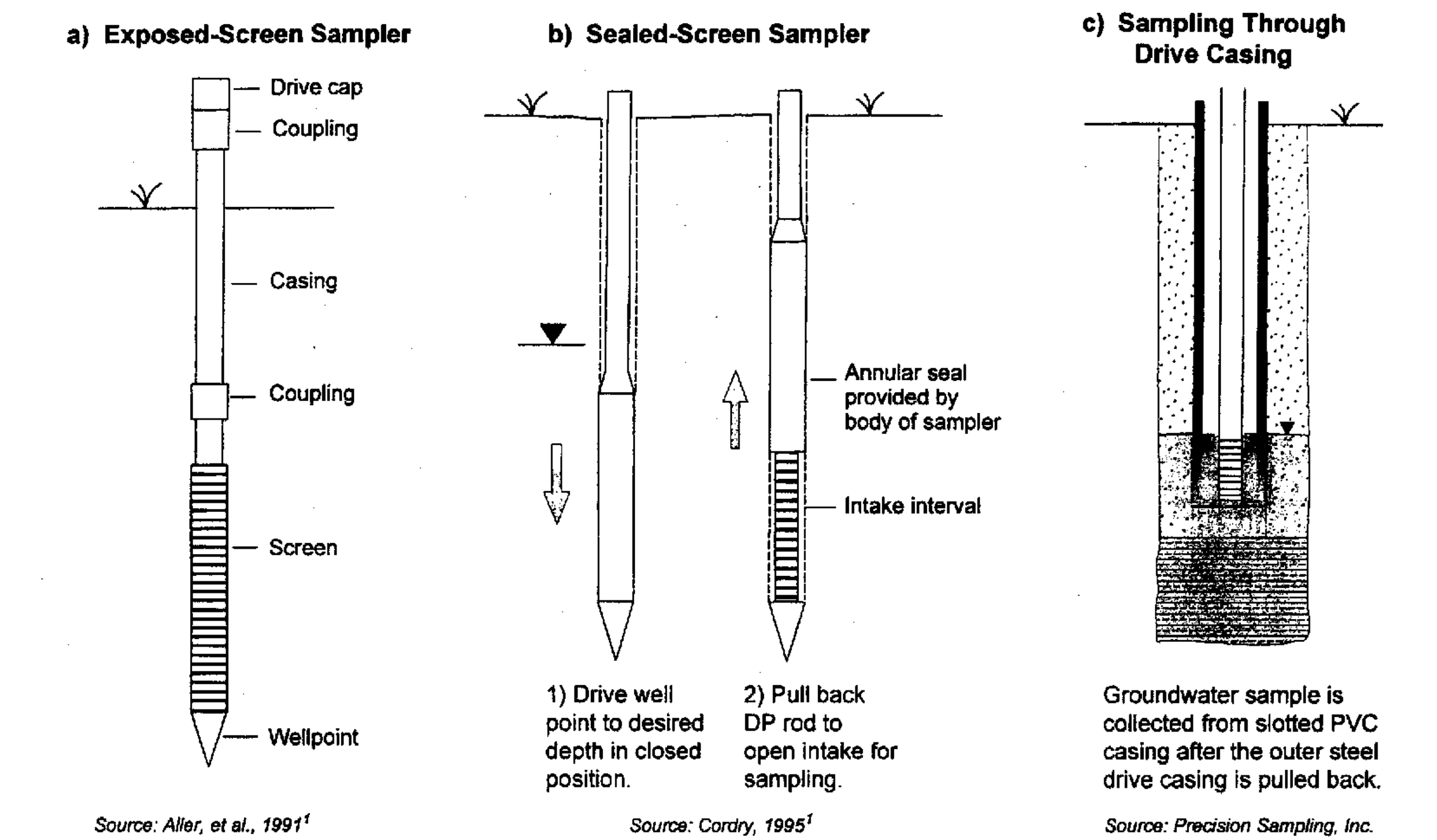


Exhibit V-10
Types Of Direct Push Groundwater Sampling Tools



[1]Reprinted by permission of the National Ground Water Association, Westerville, Ohio. Copyright 1991 and 1995. All rights reserved.

that it allows multi-level sampling in a single DP hole, without withdrawing the DP rods. The exposed screen, however, also causes some problems that should be recognized and resolved when sampling contaminants. These problems may include:

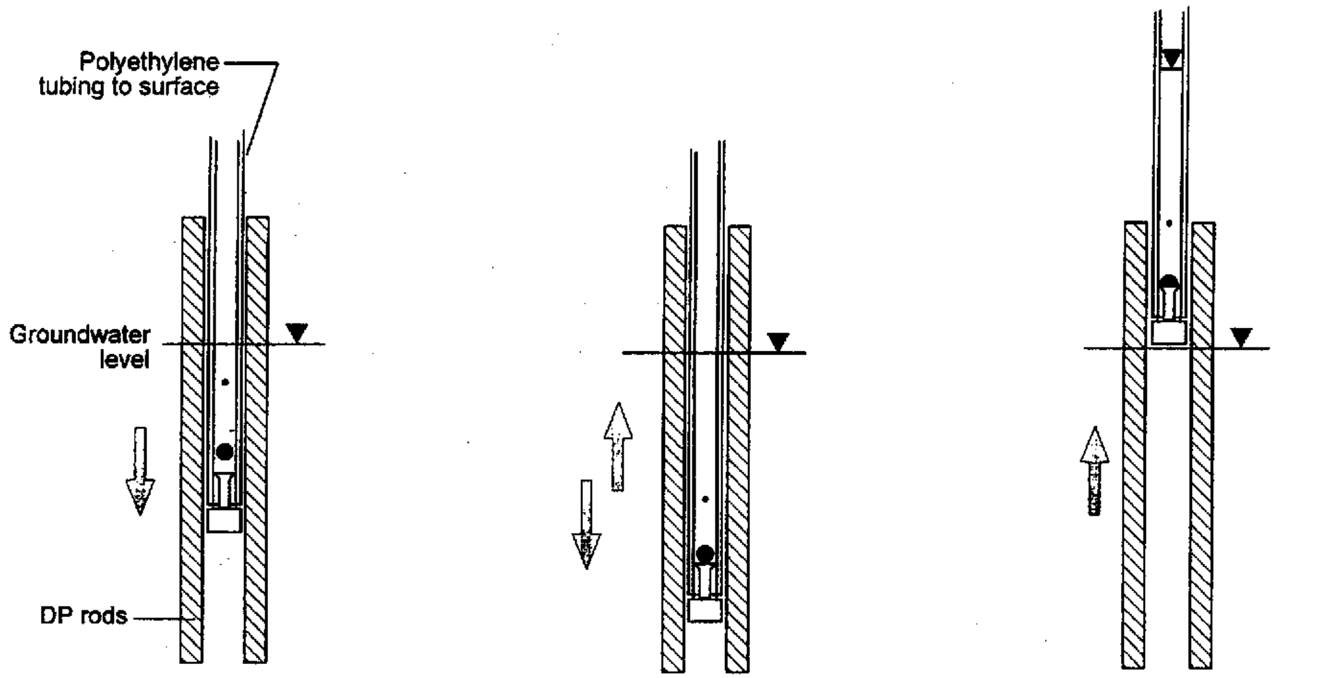
- Dragging down of NAPLs, contaminated soil, and/or contaminated groundwater in the screen;
- Clogging of exposed screen (by silts and clays) as it passes through sediments;
- The need for significant purging of sampler and/or the sampling zone because of drag down and clogging concerns; and
- Frigility of sampler because of the perforated open area.

There are several varieties of exposed-screen samplers. The simplest exposed-screen sampler is often referred to as a well point (Exhibit V-10a). As groundwater seeps into the well point, samples can be collected with bailers, check-valve pumps (Exhibit V-11), or peristaltic pumps. (Narrow-diameter bladder pumps may also soon be available for use with DP equipment.) Because well points are the simplest exposed-screen sampler, they are affected by all of the above mentioned limitations. As a result, they are more commonly used for water supply systems than groundwater sampling. They should not be used below NAPL or significant soil contamination.

The drive-point profiler is an innovative type of exposed-screen sampler that resolves many of the limitations of well points by pumping deionized water through exposed ports as the probe advances. This feature minimizes clogging of the sampling ports and drag down of contaminants and allows for collection of multiple level, depth-discrete groundwater samples. Once the desired sampling depth is reached, the flow of the pump is reversed, and groundwater samples are extracted. Purging of the system prior to sample collection is important because a small quantity of water is added to the formation. Purging is complete when the electrical conductivity of the extracted groundwater has stabilized. The data provided by these samples can then be used to form a vertical profile of contaminant distributions. Exhibit V-12 provides a schematic drawing of a drive-point profiler. Additional information about a drive-point profiling system is presented in Pitkin, 1994.

Another innovative exposed-screen sampler can be use in conjunction with cone penetrometer testing (CPT). This sampler allows for multi-level sampling by providing a mechanism for *in situ* clearing of clogged screens through the use of a pressurized gas and *in situ* decontamination of the sampling equipment with an inert gas and/or deionized water. Various CPT cones, which allow investigators to determine the soil conditions of the sampling zone, can be used simultaneously with this tool.

Exhibit V-11
Using The Check Valve Tubing Pump



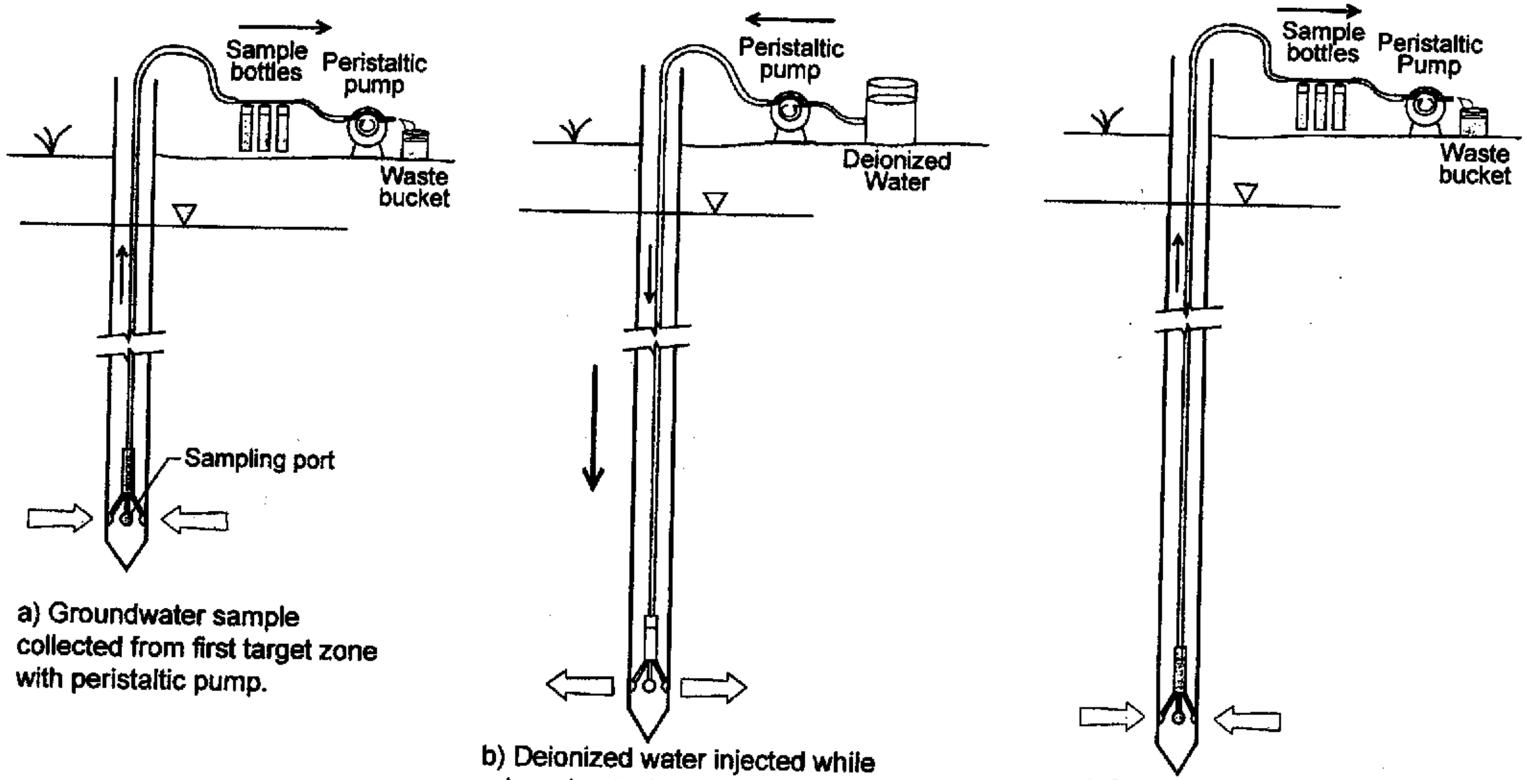
1) Insert tubing and check valve.

2) Oscillate tubing (pump).

3) Sample is recovered as water discharges at the surface.

Source: Geoprobe® Systems

Exhibit V-12
Using A Drive-Point Profiler



a) Groundwater sample collected from first target zone with peristaltic pump.

b) Deionized water injected while advancing tool to prevent sampling ports from becoming plugged.

c) Groundwater sample collected from second target zone with peristaltic pump.

Source: Precision Sampling, Inc.

Sealed-Screen Samplers

Sealed-screened samplers are groundwater samplers that contain a well screen nested inside a water-tight sealed body. The screen is exposed by retracting the probe rods once the desired sampling depth has been reached. They can be used for collecting accurate, depth-discrete samples. A very common type of sealed-screen sampler is presented in Exhibit V-10b.

The design of sealed-screen samplers is extremely variable. Many are similar to expendable or retractable tip samplers used for soil gas sampling. Some samplers are designed only for a single sampling event; others are designed to be left in the ground for an extended period of time (many weeks or even beyond one year) so that changes in concentrations can be monitored.

The main advantage of this type of sampler is that the well screen is not exposed to soil while the tool is being pushed to the target depth. Thus, the screen cannot become plugged or damaged, and the potential for sample contamination is greatly reduced. O-rings are used to make the sampler water-tight while it is being pushed to the sampling depth. (In order to ensure a water-tight seal, o-rings should be replaced frequently; water tightness can be checked by placing the sealed sampler in a bucket of water.) Sealed-screen samplers are appropriate for the collection of depth-discrete groundwater samples beneath areas with soil contamination in the vadose zone. Because there is no drag-down of contaminants or clogging of the sampling screens, sealed-screen samplers do not require purging.

Some sealed-screen samplers allow sample collection with bailers, check-valve pumps, or peristaltic pumps. (Bladder pumps can also be used with wide diameter cased DP systems.) The quantity of groundwater provided by these samplers is limited only by the hydraulic conductivity of the formation. Other samplers collect groundwater in sealed chambers, *in situ*, which are then are raised to the surface. Depending on their design, these samplers may be extremely limited in the quantity of groundwater that they can collect (*e.g.*, 250 ml per sampling event), and they may not collect free product above the water table. If the storage chamber is located above the screen intake, groundwater samples must be collected sufficiently below the water table to create enough hydrostatic pressure to fill the chamber. Only sampling chambers located below the screen intake are, therefore, useful for collecting groundwater or LNAPL samples at or above the water table.

Cased DP systems can also be used as sealed-screen groundwater samplers. After the target zone has been penetrated and the inner rods have been removed, well screen can be lowered through the outer casing to the bottom of the probe hole. The drive casing is then retracted (a few inches to a few feet) exposing the well screen (Exhibit V-10c). This method allows for the collection of deeper samples by attaching a sealed-screen sampling tool that is pushed into the formation ahead of the tip of the drive casing.

Discussion And Recommendations

Exposed-screen samplers are most appropriate for multi-level sampling in coarse-grained formations (*i.e.*, sediments of fine-grained sands and coarser material). They are typically used in a single sampling event. The major concern with using exposed-screen samplers is that they can cause cross contamination if precautions are not taken (*e.g.*, pumping deionized water through sample collection ports). As a result of these concerns, significant purging of the sampling zone is required.

Sealed-screen samplers are most appropriate for single-depth samples. When they are used in a single sampling event, they are appropriate in formations of fine-grained sands or coarser material because these soils typically allow rapid collection of groundwater. When they are used as either temporary or long-term monitoring wells, they can also be used in formations composed of silts. In addition, because sealed-screen groundwater samplers do not require purging of groundwater, they allow more rapid sampling from a single depth than exposed-screen samplers. Multi-level sampling with sealed-screened samplers is possible with cased and single-rod systems; however, with single-rod systems, the entire rod string must be withdrawn after samples are collected from a given depth. This practice with single-rod systems may create some cross contamination concerns in permeable, contaminated aquifers because the hole remains open between sampling events, allowing migration.

In addition, DP groundwater sampling tools have several advantages over traditional monitoring wells. DP tools allow groundwater samples to be collected more rapidly, at a lower cost, and at depth-discrete intervals. As a result, many more samples can be collected in a short period of time, providing a detailed 3-dimensional characterization of a site. Exhibit V-13 provides a summary of DP sampling tool applications.

General Issues Concerning Groundwater Sampling

There are several issues concerning the collection, analysis and interpretation of groundwater samples that affect both DP equipment and more conventional monitoring wells. Two major issues are the loss of VOCs and the stratification of contaminants.

Exhibit V-13
Summary Of Groundwater Sampling Tool Applications

	Exposed-Screen	Sealed-Screen
Multi-level sampling	□ [1]	□ [2]
Samples can be collected immediately, little or no purging required		□ [3]
Used to install long-term monitoring point	□ [4]	□
Can be used in formations composed of silts		□ [5]
Appropriate below contaminated soil		□

[1] Cross contamination may be an issue of concern, and purging is required.
[2] Multi-level sampling without withdrawing all DP rods is only possible with cased DP systems.
[3] Collection of a single sample is more rapid with this method.
[4] One type of exposed-screen sampler (*i.e.*, well points) has been used to install monitoring points, but this method is generally not recommended in zones of NAPL contamination. It may be appropriate at the leading edge of a contaminant groundwater plume.
[5] Sampling in silts is generally only appropriate when temporary monitoring wells are installed. Significant VOC loss may occur if water flows into sampling point over days, weeks, or months.

Loss Of VOCs

The ability of DP groundwater sampling methods to collect samples equivalent to traditional monitoring wells is a topic of continued debate and research. Loss of VOCs is the most significant groundwater sampling issue. All groundwater sampling methods--including methods used with traditional monitoring wells--can affect VOC concentrations to some degree. The key to preventing the loss of VOCs is to minimize the disturbance of samples and exposure to the atmosphere. Several studies that have compared VOC concentrations of samples collected with DP methods with samples collected by traditional monitoring wells have shown that DP methods compare favorably (Smolley *et al.*, 1991; Zemo, *et al.*, 1994).

Stratification Of Contaminants

Being able to take multiple, depth-discrete groundwater samples with DP equipment is both an advantage and a necessity. At least one recent study has shown that the concentration of organic compounds dissolved in groundwater can vary by several orders of magnitude over vertical distances of just a few centimeters (Cherry, 1994). Because DP sampling tools collect samples from very small intervals (*e.g.*, 6 inches to 3 feet), they may sometimes fail to detect dissolved contamination if the tool is advanced to the wrong depth. Therefore, multiple depths should be sampled to minimize the chances of missing contaminants. At sites with heterogeneous geology, contamination may be particularly stratified. Because the distribution of the contaminants is controlled by the site geology and groundwater flow system, the hydrogeology of the site must be adequately defined before collecting groundwater samples for chemical analysis.

The stratification of contaminants may also result in artificially low analytical results from traditional monitoring wells. These wells are typically screened over many feet (*e.g.*, 5 to 15 feet), while high concentrations of contaminants may be limited to only a few inches (in the case of LNAPLs, typically the top of the aquifer). The process of sampling groundwater, however, may cause the water in the well to be mixed, resulting in a sample that represents an average for the entire screen length (*i.e.*, very high concentrations from a specific zone may be diluted). DP methods avoid this problem by collecting depth-discrete samples.

Conclusion

The practice of collecting groundwater samples both with DP systems and with traditional monitoring wells is a subject of continued research and debate. Both methods can provide high quality groundwater samples for regulatory decisions. Both methods may also provide misleading information if appropriate procedures are not followed and/or if the hydrogeology of a site is not well characterized. Investigators and regulators must be aware of the issues that affect groundwater sample quality and interpretation in order to make appropriate site assessment and corrective action decisions.