PORT OF OAKLAND

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By Alameda County Environmental Health at 2:41 pm, Jul 16, 2014

July 15, 2014

Mr. Keith E. Nowell, P.G., C.H.G.
Hazardous Materials Specialist
Alameda County Environmental Health Department
Environmental Protection
1131 Harbor Bay Parkway, Suite 250
Alameda, California 94502-6507

Subject:
Alameda County Environmental Health Department ("ACEH") Fuel Leak Case Numbers RO0000010/RO0000187

Dear Mr. Nowell:

Please find enclosed our work plan document entitled "Work Plan for Natural Source Zone Depletion Study and LNAPL[1] Assessment", Port of Oakland, 651 Maritime Street, Oakland, California, dated July 16, 2014. This document is being submitted in accordance with ACEH requirements as specified in your e-mail dated July 9, 2014, that summarizes our conference call on the same day, and associated documents ACEH has required for submittal for the above referenced site[2].

The Port of Oakland ("Port") has retained ARCADIS, U.S., Inc. ("ARCADIS") to prepare this document on behalf of the Port. If you have any questions or comments regarding the content of this document, please do not hesitate to contact Jeff Rubin at (510) 627-1134.

I declare, under penalty of perjury, that the information and/or recommendations contained in the attached document prepared by ARCADIS are true and correct to the best of my knowledge. Please note that the report is stamped by a Professional Geologist in the State of California.

Sincerely,

Jeffrey R. Jones
Supervisor
Environmental Programs and Planning

Jeffrey L. Rubin, CPSS, REPA
Port Associate Environmental Scientist
Environmental Programs and Planning

Enclosure: ARCADIS document dated June 15, 2014 entitled: "Work Plan for Natural Source Zone Depletion Study and LNAPL Assessment", Port of Oakland, 651 Maritime Street, Oakland, California

Cc: Dilan Roe, P.E. (ACEH)
Katherine Brandt, P.G. (ARCADIS)

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[1] "LNAPL" - Light Non-Aqueous Phase Liquid

[2] The Site has been referred to historically as the "Shippers" and "Ringsby" sites, based on the Port tenants that occupied the site at the time of release discoveries. Prior to site redevelopment in 2004, the site was also referred to as 2277 and 2225 Seventh Street. After redevelopment, the Site address became 651 and 555 Maritime Street, although referenced hereafter as only 651Maritime Street.

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Mr. Keith Nowell
Alameda County Environmental Health
1131 Harbor Bay Parkway
Alameda, CA 94502

ENVIRONMENT

Subject:
Work Plan for Natural Source Zone Depletion Study and LNAPL Assessment
Port of Oakland, 651 Maritime Street, Oakland, California

Date:
July 16, 2014

Contact:
Katherine Brandt, PG

Phone:
510.596.9675

Email:
Katherine.Brandt@arcadis-us.com

Our ref:
04656020.HFC1

Dear Mr. Nowell:

On behalf of the Port of Oakland (Port), ARCADIS U.S., Inc. (ARCADIS) is submitting this work plan for a Natural Source Zone Depletion (NSZD) Study of the light non-aqueous phase liquid (LNAPL) at the Port of Oakland Site located at 651 Maritime Street, Oakland, California (Site; Figure 1). This work plan presents a site background, geology and hydrology, and activities to evaluate LNAPL mobility, recoverability, and natural depletion.

Site Background

The Site is approximately 13 acres located between the former Oakland Naval Supply Center and the former Oakland Army Base (Figure 1). Groundwater impacts beneath the Site are related to petroleum releases from two former underground storage tank (UST) sites located at 2277 Seventh Street and 2225 Seventh Street. A brief history of the two sites is provided below.

Former 2277 Seventh Street Site

In 1993, Uribe and Associates (Uribe) removed four Port-owned USTs from 2277 Seventh Street. Uribe collected soil samples from beneath the tanks at the time of the removal and submitted them for laboratory analyses. The laboratory reported that soil contained total petroleum hydrocarbons as diesel fuel (TPHd) and as gasoline (TPHg), as well as benzene, toluene, ethylbenzene, and total xylenes (BTEX) compounds. Uribe also observed LNAPL on the groundwater within the excavation. In 1994, Uribe installed three groundwater monitoring wells (MW-1 through MW-3), and in 1995, Alisto Engineering Group installed five additional wells (MW-4 through MW-8). Quarterly groundwater monitoring was initiated in 1996 in accordance with an Alameda County Environmental Health (ACEH) approved work plan dated April 18, 1995.

Former 2225 Seventh Street Site

Former Port tenant Ringsby Terminals (formerly Dongary Investments) and/or its tenant owned and operated nine USTs at 2225 Seventh Street. One of the tanks in the cluster failed a tank integrity test in 1989. National Environmental Service Company (NESCO) removed the UST in March 1990. During the UST removal, NESCO collected soil and groundwater samples from the excavation. Analytical results indicated the presence of TPHd and BTEX. RAMCON Engineering and Environmental Contracting (RAMCON) removed seven of the USTs (six diesel and one fuel oil) in 1992. RAMCON observed a hole in the fuel oil tank and a thin layer of an unspecified petroleum product floating on the groundwater in the excavation. During a separate event in 1992, RAMCON removed the remaining UST (a waste oil tank). Soil samples collected from that excavation indicated the presence of TPHd, TPH as motor oil (TPHmo), benzene, xylenes, and polycyclic aromatic hydrocarbons (PAHs). A water sample collected from the excavation also contained TPHd. In 1993, RAMCON installed three groundwater monitoring wells (MW-1 through MW-3) at the 2225 Seventh Street site, and quarterly groundwater monitoring began in 1994, as required by the ACEH.

651 Maritime Site

In 2004, the Port completed the development of the easternmost 8 acres of the Site into the Harbor Facilities Complex with an address of 651 Maritime Street (Figure 2). In 2006, the remaining 5 acres of the Site were developed by the Port into the Maritime Support Center with an address of 555 Maritime Street. The Maritime Support Center is currently leased to Shippers Transport Express.

Historical site investigations indicate that groundwater and soil beneath the Site contain dissolved and free-phase petroleum hydrocarbons, primarily in the diesel fuel range. In addition, well MW-4 (the westernmost well) has historically contained dissolved petroleum hydrocarbons in the gasoline range.

In 1996, the Port installed a remediation system to recover free-phase product from beneath the Site. The free product recovery system was operated until 2003 when it was removed with approval from the ACEH. The ACEH approved removal of the system with the stipulation that a new free product recovery system be installed. A new system was installed in 2004.

In 1998, Harding Lawson Associates abandoned MW-8 to facilitate the expansion of the railroad tracks to the north of the Site. Replacement well MW-8A was installed in 2001. In 2002, monitoring wells MW-1, MW-2, and MW-3 at the former 2225 Seventh Street site and MW-6 and MW-7 at the former 2277 Seventh Street site were abandoned to facilitate construction of the new Harbor Facilities Complex.

In 2006, the ACEH approved a modification of the groundwater monitoring frequency from quarterly to semiannually at the Site. The first semiannual monitoring event occurred on July 28, 2006. The ACEH also approved the use of Oxygen Release Compound™ (ORC) in well MW-4 to increase the dissolved oxygen (DO) concentration in groundwater and stimulate aerobic biodegradation of the petroleum hydrocarbons present in the groundwater at that location.

In 2007, the product recovery system was enhanced by adding a low vacuum to the recovery well heads to increase product recovery rates. Air drawn from the recovery wells was treated with granular activated carbon (GAC) and discharged to the atmosphere under a permit from the Bay Area Air Quality Management District.

On September 30, 2008, the ACEH approved a plan to install four additional groundwater monitoring wells, MW-9 through MW-12, to enhance the existing monitoring well network and to replace wells removed during Site redevelopment. The wells were installed by MSE Group (MSE) and sampled in December 2008, along with the remaining Site wells. Well installation activities and sample results were reported by MSE in February 2009.

Geology and Hydrology

Subsurface soil underlying the asphalt and baserock at the Site consists of various types of hydraulically placed dredge spoils over Bay Mud. Bay Mud is generally encountered in Site borings at depths ranging from approximately 8.5 to 11 feet below ground surface (bgs). Additionally, fill consisting of a heterogeneous inter-layered mix of gravel, sand and silt containing brick, wood fragments, and glass was encountered on top of the hydraulically placed dredge spoils in a few borings advanced at the Site. Figure 3-1 illustrates the locations of generalized geologic cross-sections prepared for the Site by Innovative Technical Solutions, Inc. (ITSI 2002). Cross-sections are included as Figures 3-2 through 3-4. Figure 3-5, also prepared by ITSI (2002), is a plan view illustrating the lithology between 6 and 8 feet bgs, which is the approximate depth of the shallow groundwater. The lateral extent of the free product plume is also illustrated on the figure. The figure shows lower permeability soils to the north of the area where free product has been identified on the Site. This change in lithology likely influenced the geometry of the plume and limited the lateral extent of the free product to the north.

Groundwater has typically been encountered between 5 feet bgs and 13 feet bgs in soil borings advanced at the Site. Seepage of groundwater into open soil borings has been reported to be slow. The shallow groundwater surface in the wells has been measured at depths ranging from approximately 5.5 feet bgs to 12 feet bgs. Since 2011, the groundwater levels have been steadily decreasing.

The nearest surface water body, the Oakland Outer Harbor (part of the San Francisco Bay), is approximately 0.4 miles west-northwest of the Site (Figure 1). Groundwater beneath the Site generally flows to the north and northwest (Figure 3-6) toward the Oakland Outer Harbor. Groundwater gradients beneath the Site vary, on average, from approximately 0.001 to 0.025 feet per foot.

NSZD Study Work Plan

Due to the proximity of the Oakland Outer Harbor, further evaluation of the LNAPL plume stability is necessary to verify that the harbor is not at risk. Additional site investigation activities will be performed to provide data to evaluate LNAPL mobility, recoverability, and natural depletion. LNAPL investigation activities planned for the Site are described below.

Baildown Testing

Baildown testing will be conducted to quantify LNAPL transmissivity and recoverability in the vicinity of the tested wells. LNAPL baildown testing consists of LNAPL removal from the test well and observation of LNAPL accumulation into the test well over time. The rate of LNAPL flow into the well during the recovery period of a baildown test is a function of LNAPL saturation, permeability of the surrounding formation to LNAPL, LNAPL physical properties, and the magnitude of the initial hydraulic gradient toward the well created during LNAPL removal. The following methods/practices will be employed for performing high-quality LNAPL baildown tests:

- Baildown testing will only be performed in wells where LNAPL is present across the screened interval and has a thickness of 0.5 feet or greater.

- The initial depth to product (LNAPL), depth to groundwater, and depth to bottom will be recorded.

- LNAPL will be removed from the well using a bailer or pump while recovering as little groundwater as possible. The volume of LNAPL recovered will be documented.

- Fluid levels (depth to groundwater and depth to LNAPL) will be frequently measured and recorded at the beginning of the recovery period. The frequency of recordings will be adjusted throughout the test based on the rate of fluid level change.

- The test will continue until 95 percent of the initial LNAPL thickness has been recovered into the test well or it is determined that fluid levels are static within the well. Wells containing large initial volumes of LNAPL may require daily or weekly follow-on gauging until LNAPL thicknesses have recovered.

- Baildown testing will be conducted twice sequentially on each test well if LNAPL recovers within 24 hours.

- LNAPL removed to initiate the first LNAPL baildown test will be collected for LNAPL physical property testing. If a second test is conducted, the LNAPL removed during this test will be used as a representative sample of in-situ LNAPL. Excess LNAPL will be properly disposed.

Baildown tests that have sufficient LNAPL recovery will be quantitatively analyzed to determine LNAPL transmissivity under the test conditions. Baildown tests for which analysis is feasible will be analyzed in the Draft API LNAPL Transmissivity Workbook (API Workbook) using a modified slug test method by Bouwer and Rice (1976) or a modified pump test method by Cooper and Jacob/Jacob and Lohman (Cooper and Jacob 1946; Jacob and Lohman 1952). Additional details on testing methods and field procedures are provided in the attached ARCADIS Standard Operating Procedures (SOPs) for LNAPL Baildown Test and Water-Level and NAPL Thickness Measurement Procedures. The monitoring wells that will be used for LNAPL baildown testing, if conditions are appropriate for testing, are indicated in Table 1.

Slug Tests

An instantaneous change in head (slug) test is conducted to determine the hydraulic conductivity/transmissivity of a water-bearing zone in a quick and inexpensive manner. An estimate of local hydraulic conductivity of the material surrounding a well is calculated by measuring the time/rate of return to static water levels after an instantaneous change in head. Homogeneity and constant aquifer thickness are general assumptions for the test analysis; these are generally met due to the small radius of influence of the test. Approximately four slug tests (MW-8A, MW-9, MW-10, and MW-11) will be performed to determine the hydraulic conductivity across the Site and the length of the plume. The ARCADIS Slug Test SOP provides details on performing the test. The monitoring wells that will be used for slug testing are indicated in Table 1.

LNAPL Characterization

LNAPL and groundwater samples will be collected and analyzed to provide site-specific fluid physical properties for incorporation into the LNAPL assessment of mobility and recoverability.

LNAPL samples will be collected from a subset of existing Site monitoring wells that exhibit measurable LNAPL and contain sufficient sample volumes for laboratory analytical testing of density, viscosity, and interfacial tensions (air/water, air/LNAPL, water/LNAPL). Laboratory testing will be performed at the average annual groundwater temperature of 26 degrees Celsius for results to be representative of in-situ fluid properties.

LNAPL collected for testing of physical properties must be representative of in-situ LNAPL, and any aged, accumulated LNAPL should be purged from the well prior to collecting a sample. The LNAPL removed to initiate the first LNAPL baildown test will purge the accumulated LNAPL, and therefore, the LNAPL removed to initiate the second LNAPL baildown test may be used as a sample for physical property testing. A sufficient volume of groundwater will be collected from the Site and submitted to the analytical laboratory to facilitate water-LNAPL interfacial tension testing, as well as to provide site-specific groundwater density and viscosity data.

Additional details on field procedures and sample handling and shipping are provided in the attached ARCADIS SOPs for LNAPL Sample Collection and Shipping and Water-Level and NAPL Thickness Measurement Procedures. The groundwater samples can be collected from any well with representative groundwater at the Site. LNAPL samples will be collected from the wells indicated in Table 1.

NSZD Evaluation

NSZD is a combination of processes that reduce the mass of LNAPL in the subsurface. NSZD occurs when processes act to physically redistribute LNAPL components to the aqueous phase via dissolution or to the gaseous phase via volatilization. In turn, dissolved or volatilized LNAPL constituents can be biologically degraded by microbial and/or enzymatic activity. Biodegradation rates of LNAPL constituents in groundwater and soil gas depend on the type and availability of electron acceptors (e.g., oxygen, nitrate, sulfate, ferrous iron [Fe^{3+}], and carbon dioxide [CO_2]) in the subsurface soil and groundwater.

The purpose of this NSZD evaluation is to identify and quantify LNAPL depletion processes occurring within the saturated and unsaturated zones that are decreasing LNAPL mass at the Site.

Evaluation of NSZD Rates in the Saturated Zone

In the saturated zone, NSZD by groundwater dissolution and biodegradation processes is controlled primarily by the solubility and effective solubility of individual compounds in the LNAPL, by the availability of electron acceptors in groundwater or within the aquifer matrix, and groundwater flow under, around, and through the LNAPL zone. Effective solubility represents the maximum dissolved-phase equilibrium concentration of a constituent from a multi-component LNAPL mixture in groundwater (Interstate Technology & Regulatory Council [ITRC] 2009a). LNAPL components that dissolve into groundwater are then subject to transport via advective groundwater flow. Increases in dissolved-phase petroleum hydrocarbon constituent concentrations between upgradient and downgradient groundwater monitoring locations provide evidence that LNAPL dissolution is occurring. Groundwater data will be used to assess changes in dissolved-phase petroleum hydrocarbon concentrations between upgradient and downgradient monitoring locations to demonstrate that dissolution of LNAPL is occurring.

Biodegradation of dissolved petroleum hydrocarbons is well documented (ITRC 2009a), and spatial changes in concentrations of dissolved electron acceptors (e.g., oxygen and sulfate) and dissolved biodegradation products (reduced iron [Fe^{2+}], CO_2, and methane) reflect biodegradation of the dissolved-phase petroleum hydrocarbons and NSZD of LNAPL. Biodegradation of dissolved-phase petroleum hydrocarbons in groundwater at the Site will be evaluated by assessing changes in electron acceptors and electron donors from upgradient to downgradient of the LNAPL footprint. Biological degradation rates will be estimated following protocol provided in the ITRC guidance document (ITRC 2009a). Estimated biological degradation rates of dissolved-phase petroleum hydrocarbons will be used to estimate the NSZD via dissolution in the saturated zone.

The potential efficacy of NSZD in the saturated zone will be evaluated following protocols outlined in the ITRC guidance document (ITRC 2009a). NSZD rates are calculated using a mass balance approach. LNAPL attenuation through dissolution and biodegradation is quantified by assessing groundwater quality upgradient and within or downgradient of the LNAPL plume. A summation of the mass flux of electron acceptors into and out of the plume combined with mass flux of dissolved-phase petroleum constituents out of the plume will be used to quantify dissolved-phase NSZD rates (ITRC 2009a).

Additional data collected during the routine groundwater monitoring program will be used to assess the saturated zone LNAPL depletion processes. The electron acceptor compounds and reaction end products that will be evaluated as part of the NSZD evaluation are presented in the table below. This data will be used to assess the NSZD processes occurring at the Site.

Electron Acceptor	Directly Observed	Reaction End Product Observed	Reaction End Product
Oxygen	X	--	--
Nitrate	X	--	--
Manganese (IV)	--	X	Manganese (II)
Ferric Iron	--	X	Ferrous Iron
Sulfate	X	--	--
Carbon Dioxide		X	Methane

Monitoring wells will be sampled for the above parameters to evaluate the NSZD rate. Sample locations will include wells located in the plume and outside the plume considered representative of background conditions. Monitoring wells containing LNAPL will be sampled following routine LNAPL removal, and collected at least 2 feet beneath the piezometric surface so that LNAPL will not be present in the groundwater sample. Monitoring wells to be sampled are presented in Table 1.

Evaluation of NSZD Rates in the Vadose Zone

In the vadose zone, LNAPL components may volatilize and redistribute into soil gas. Microbial degradation of LNAPL constituents under the strongly reducing conditions typically observed in LNAPL source zones results in the production of methane (CH_4). Volatilized petroleum hydrocarbon compounds may then migrate through vadose zone soil from areas of higher concentrations to lower concentrations via advective and diffusive transport processes. Diffusion is typically the dominant vapor-phase transport mechanism under most natural conditions. Advection is driven by pressure gradients, and advective transport of volatilized petroleum hydrocarbon constituents can be enhanced by natural barometric pressure. Under typical conditions, where rates of atmospheric oxygen ingress are sufficiently high to oxidize CH_4 into carbon dioxide (CO_2) as it migrates upward through the soil column, carbon loss across the ground surface is dominated by CO_2 flux.

Current quantification methods include measuring the concentration gradient of volatile organic compounds (VOCs), CH_4, and oxygen (O_2) in the subsurface or measuring the flux of CO_2 across the ground surface to determine biodegradation rates. At the Port of Oakland, the LNAPL plume is below an asphalt parking lot, creating an impermeable surface, which limits the use of these quantification methods. These conditions generally create preferential pathways that dominate soil gas transport or may limit oxygen ingress and result in methane and CO_2 buildup below the surface. ARCADIS proposes to collect soil gas samples at existing well heads to evaluate NSZD. Evidence of NSZD will be indicated by the presence of VOCs, CH_4, and/or CO_2 above atmospheric conditions, and/or O_2 below atmospheric conditions. Concentrations of CH_4, O_2, CO_2, and VOCs will be measured at five locations (Table 1).

Concentrations of CH_4, CO_2, and O_2 will be monitored at each sampling location in the field using a gas meter, and VOCs will be monitored using a photoionization detector (PID). Prior to collection of soil gas readings, vapor-tight fittings with a ¼-inch-diameter valve and sample port will be installed temporarily at each monitoring well where gas sampling is to be completed. Due to potential gas buildup (as a result of the asphalt surface), a peristaltic pump will be used to vent the well prior to filling a 1-liter Tedlar® bag for sampling. The gas in the Tedlar bag will be screened using the field gas meter, and concentrations of CH_4, CO_2, and O_2 will be recorded. Additional soil vapor samples will be collected in Tedlar bags and sent to a laboratory for analysis of VOCs, nitrogen, CH_4, CO_2, and O_2.

Groundwater Temperature Profiling

In the vadose zone, VOCs and CH_4 are aerobically degraded into CO_2 through an exothermic reaction. The heat released during the reaction may generate measurable thermal variation in the monitoring well. Temperature profiles will be recorded within the LNAPL plume and compared to a background location to evaluate whether thermal differences, indicative of NSZD, are evident.

During soil vapor sample collection, groundwater temperature profiles will be recorded at four wells (Table 1). Temperature measurements will be recorded in 1-foot depth increments from the water table to the total depth of each well using a YSI-556 groundwater monitoring instrument equipped with a 10-meter-long, down-well cable. Measurements will be recorded using the following general procedures at each location:

- Measure and record the depth to product (LNAPL) (if present), depth to water, and total depth of the well using an electronic oil-water interface probe.

- Make sure the YSI cable is marked in 1-foot increments to allow accurate depth profiling. This can be achieved by fastening the YSI cable to the interface probe tape using zip ties or other fastener, or by directly marking 1-foot increments on the cable (using zip ties or electrical tape, for instance).

- Measure groundwater temperature, dissolved oxygen (DO), oxidation-reduction potential (ORP), and pH in 1-foot increments from the water table to the total depth of the well. Each reading should be recorded after groundwater temperature readings have stabilized, where stability will be defined by four consecutive temperature readings within 5 percent of each other with no consistently increasing or decreasing temperature trend.

A data collection form template is attached.

LNAPL Assessment

An LNAPL management plan will be developed based on the technical analysis of LNAPL mobility, recoverability, and natural depletion. Demonstrating LNAPL stability and identifying recoverable portions of LNAPL, if any, can be used to optimize LNAPL recovery efforts. An understanding of the natural conditions present for degradation can serve as a basis for passive, long-term LNAPL depletion quantification. These technical assessments will be aligned with several well-recognized resources in the industry, notably, ITRC's technical documents on LNAPL (ITRC 2009b).

Reporting

Data will be summarized and LNAPL assessment methods will be presented in a NSZD study report. The report will summarize the data collected in appropriate tables and figures to facilitate an understanding of Site conditions. The report will also provide an updated Conceptual Site Model (CSM).

The LNAPL assessment will include the following elements:

- Definition of assessment methodology
- Description of assessment methods
- Determination of:
  - LNAPL plume stability based on historical data
  - Recoverability of LNAPL based on transmissivity results from LNAPL baildown tests
  - Rates of LNAPL mass loss due to natural processes (NSZD)
  - Discussion of the %-saturation of soils when evaluating the LNAPL plume
  - Discussion of dissolved-phase equilibrium concentration of constituent from multi-component LNAPL mixture.

Schedule

Baildown tests, slug tests, product samples, soil vapor samples, and temperature profiling will be scheduled for summer 2014. NSZD samples will be collected during the next routine groundwater monitoring event scheduled for June 2014. The report described above will be submitted to the ACEH within 90 days of the receipt of all field data and laboratory analytical data.

If you have any questions regarding the information presented in this work plan, please contact me at 510.596.9675.

Sincerely,

ARCADIS U.S., Inc.

Katherine Brandt, PG
Principal Geologist
California Professional Geologist No. 9132

Enclosure

References

Bouwer, H., and R.C. Rice. 1976. A slug test method for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells, Water Resources Research, vol. 12, no. 3, pp. 423-428.

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Interstate Technology & Regulatory Council (ITRC). 2009a. Technology Overview for Evaluating Natural Source Zone Depletion at Sites with LNAPL. Washington, D.C.: Interstate Technology & Regulatory Council, LNAPLs Team. April. www.itrcweb.org.

ITRC. 2009b. Evaluating LNAPL Remedial Technologies for Achieving Project Goals. Washington, D.C.: Interstate Technology & Regulatory Council, LNAPLs Team. www.itrcweb.org.

Jacob, C.E. and S.W. Lohman. 1952. Nonsteady flow to a well of constant drawdown in an extensive aquifer, Trans. Am. Geophys. Union, vol. 33, pp. 559-569.

Figures

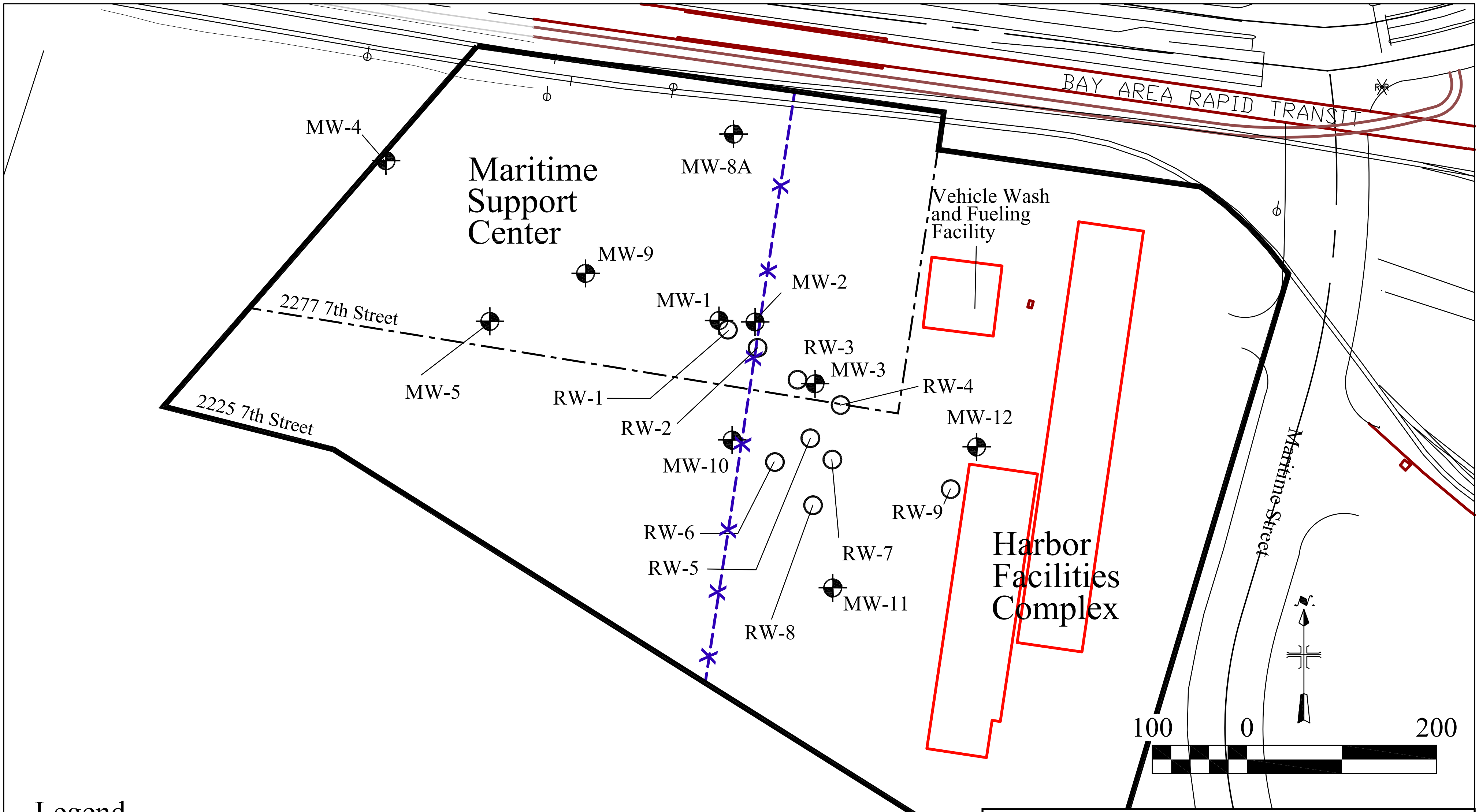
HARBOR FACILITIES COMPLEX, PORT OF OAKLAND
651 MARITIME STREET, OAKLAND, CALIFORNIA

SITE LOCATION MAP

ARCADIS

FIGURE
1

User:Orsi Spec:PIRNIE STANDARD File:G:\Projects\Projects\4656\016\acad\2nd Semi 2013\FIGURES-ARCADIS.DWG



Legend

MW-4	⊕	Groundwater monitoring well
RW-1	○	Recovery well
	—x—x—	Fence
	▬▬	Site boundary

Notes: North American Vertical Datum of 1988.

HARBOR FACILITIES COMPLEX, PORT OF OAKLAND
651 MARITIME STREET, OAKLAND, CALIFORNIA

SITE PLAN

ARCADIS

FIGURE
2

LEGEND

C-407	BUILDING
	PROPERTY BOUNDARY
CPT-13	CPT LOCATIONS WITH UVIF PROFILING (ITSI, 2002)
PZ-F	PIEZOMETER LOCATIONS (ITSI, 2002)
MW-2	EXISTING GROUNDWATER MONITORING WELL LOCATIONS
	FORMER LOCATION OF USTs
MFC-20	SOIL AND GRAB GROUNDWATER BORING (BY OTHERS, 2002)
MFC-43	SOIL BORING (BY OTHERS, 2002)

NOTE:

SURVEYED DATA FOR CPTs, PEIZOMETERS, GROUNDWATER MONITORING WELLS, AND BUILDINGS C-401 AND C-407 PROVIDED BY PLS SURVEYS INC., DRAWING 02-100, 2/27/02

Source: Additional Site Characterization and Remedial Action Plan for 2225 and 2277 Seventh Street, Oakland, California, Innovative Technical Solutions, Inc., May 2002.

0 100 200

SCALE IN FEET

HARBOR FACILITIES COMPLEX, PORT OF OAKLAND
651 MARITIME STREET, OAKLAND, CALIFORNIA

GEOLOGIC CROSS-SECTION LOCATIONS

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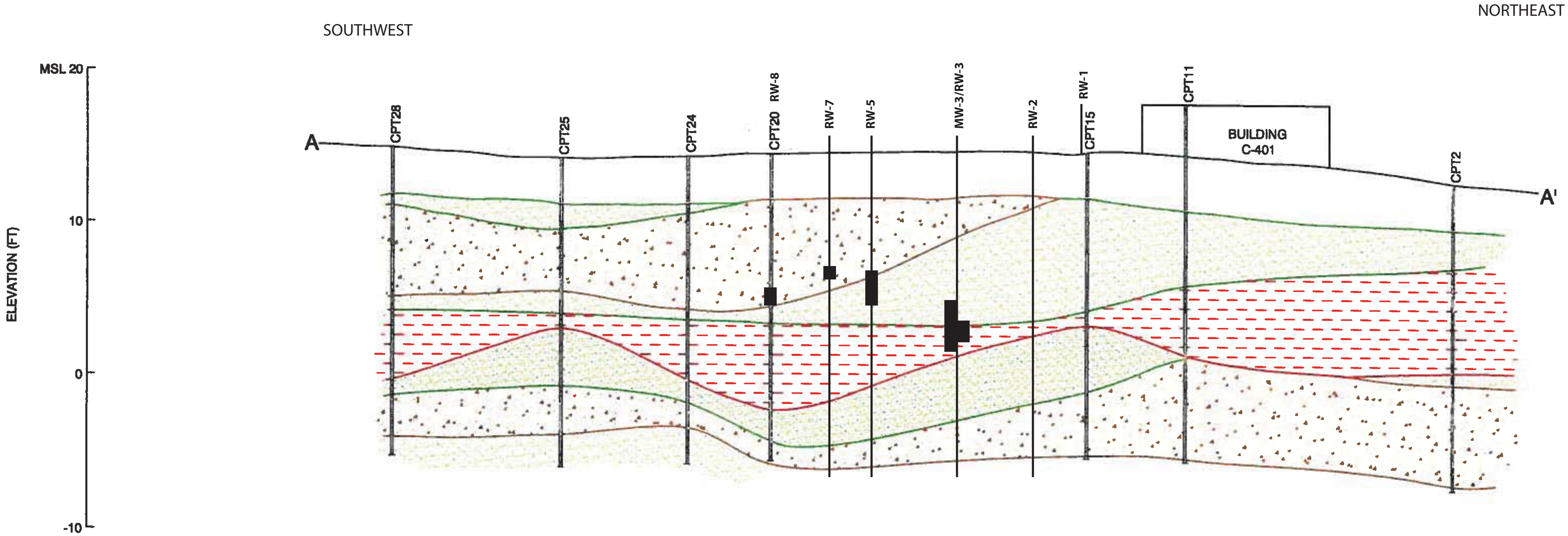
FIGURE
3-1



Source: Additional Site Characterization and Remedial Action Plan for 2225 and 2277 Seventh Street, Oakland, California, Innovative Technical Solutions, Inc., May 2002.

HARBOR FACILITIES COMPLEX, PORT OF OAKLAND
651 MARITIME STREET, OAKLAND, CALIFORNIA

GEOLOGIC CROSS-SECTION A-A'

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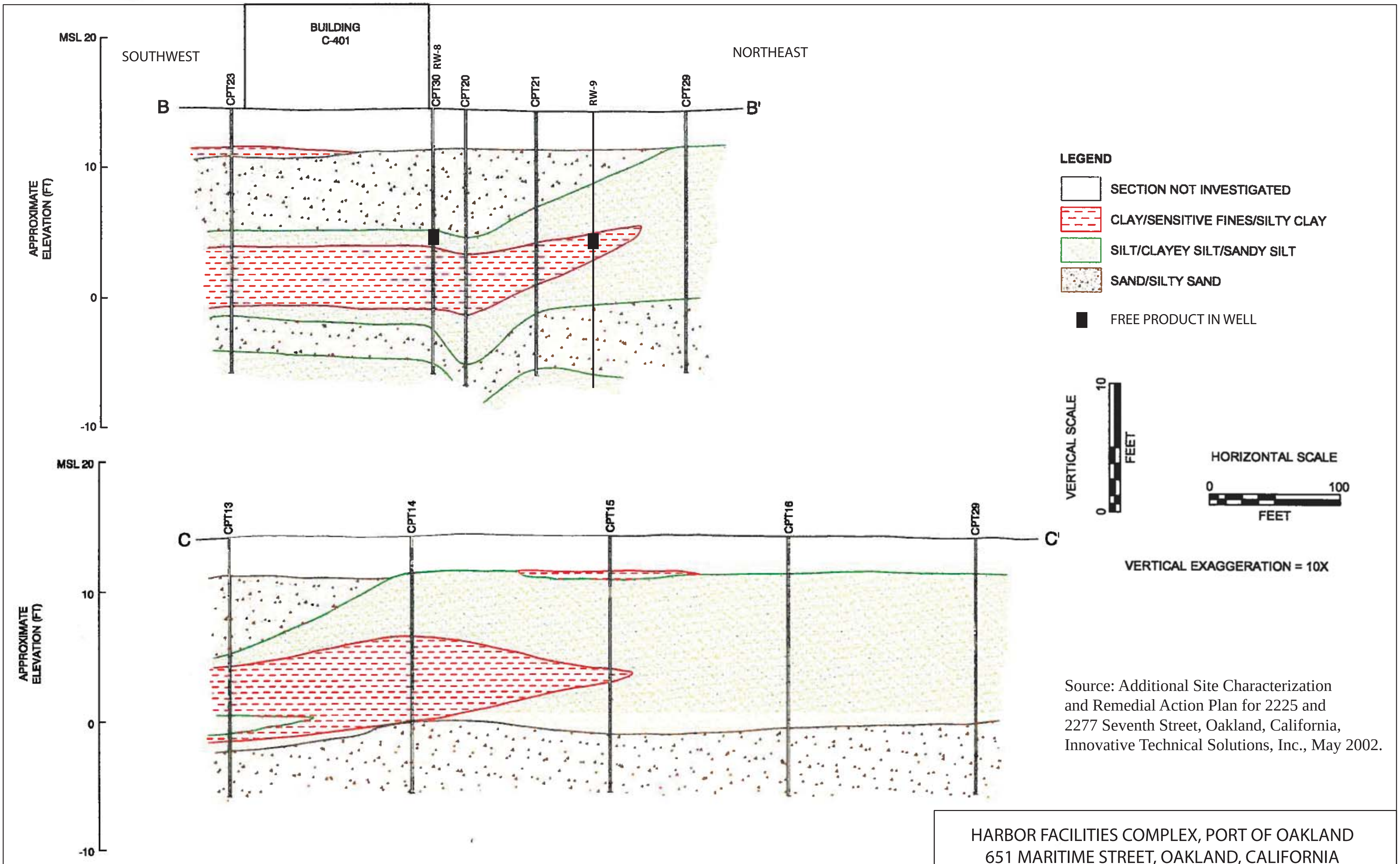
FIGURE 3-2



Source: Additional Site Characterization and Remedial Action Plan for 2225 and 2277 Seventh Street, Oakland, California, Innovative Technical Solutions, Inc., May 2002.

HARBOR FACILITIES COMPLEX, PORT OF OAKLAND
651 MARITIME STREET, OAKLAND, CALIFORNIA

GEOLOGIC CROSS-SECTIONS
B-B' AND C-C'

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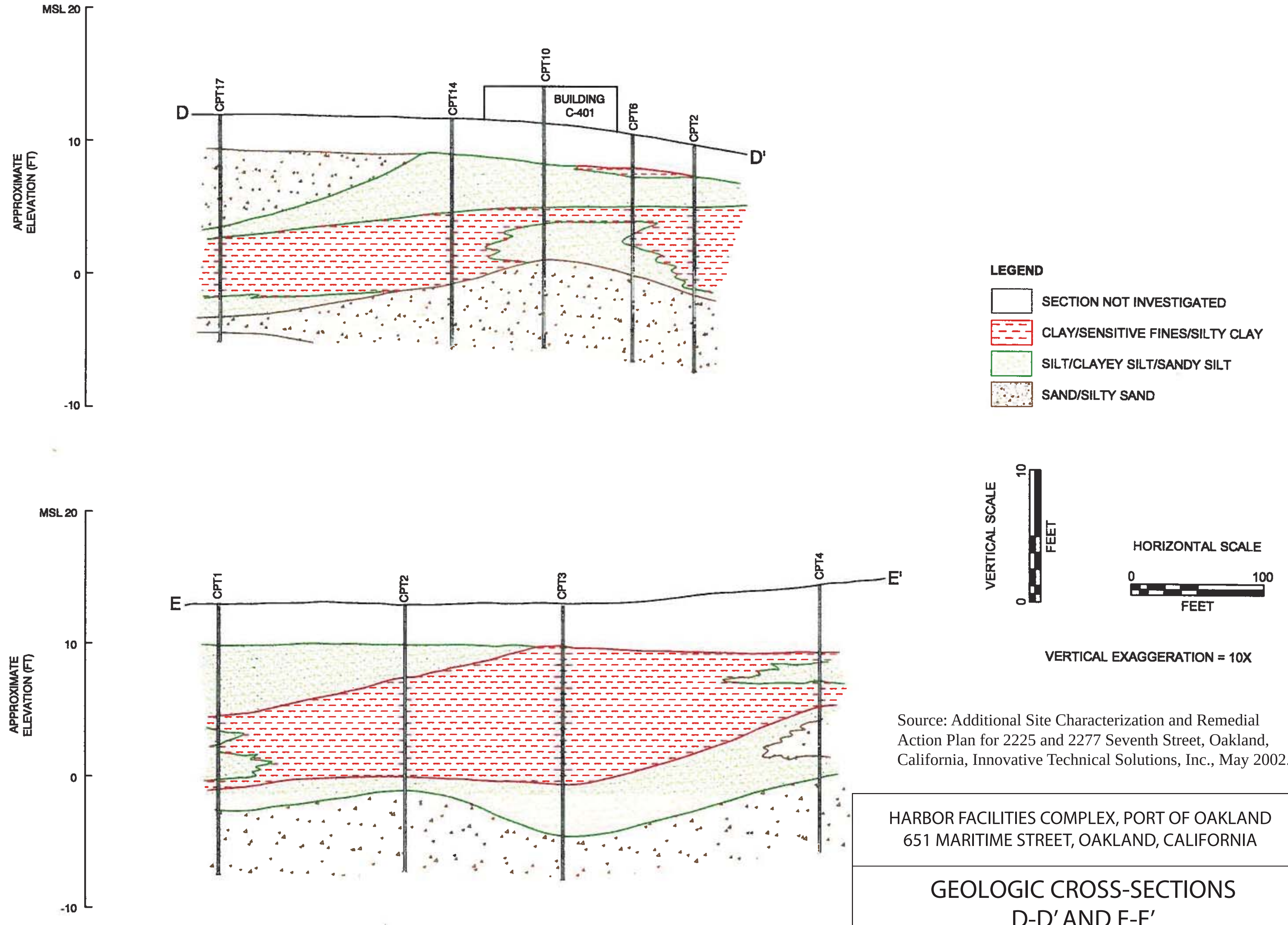
FIGURE
3-3



Source: Additional Site Characterization and Remedial Action Plan for 2225 and 2277 Seventh Street, Oakland, California, Innovative Technical Solutions, Inc., May 2002.

HARBOR FACILITIES COMPLEX, PORT OF OAKLAND
651 MARITIME STREET, OAKLAND, CALIFORNIA

GEOLOGIC CROSS-SECTIONS
D-D' AND E-E'

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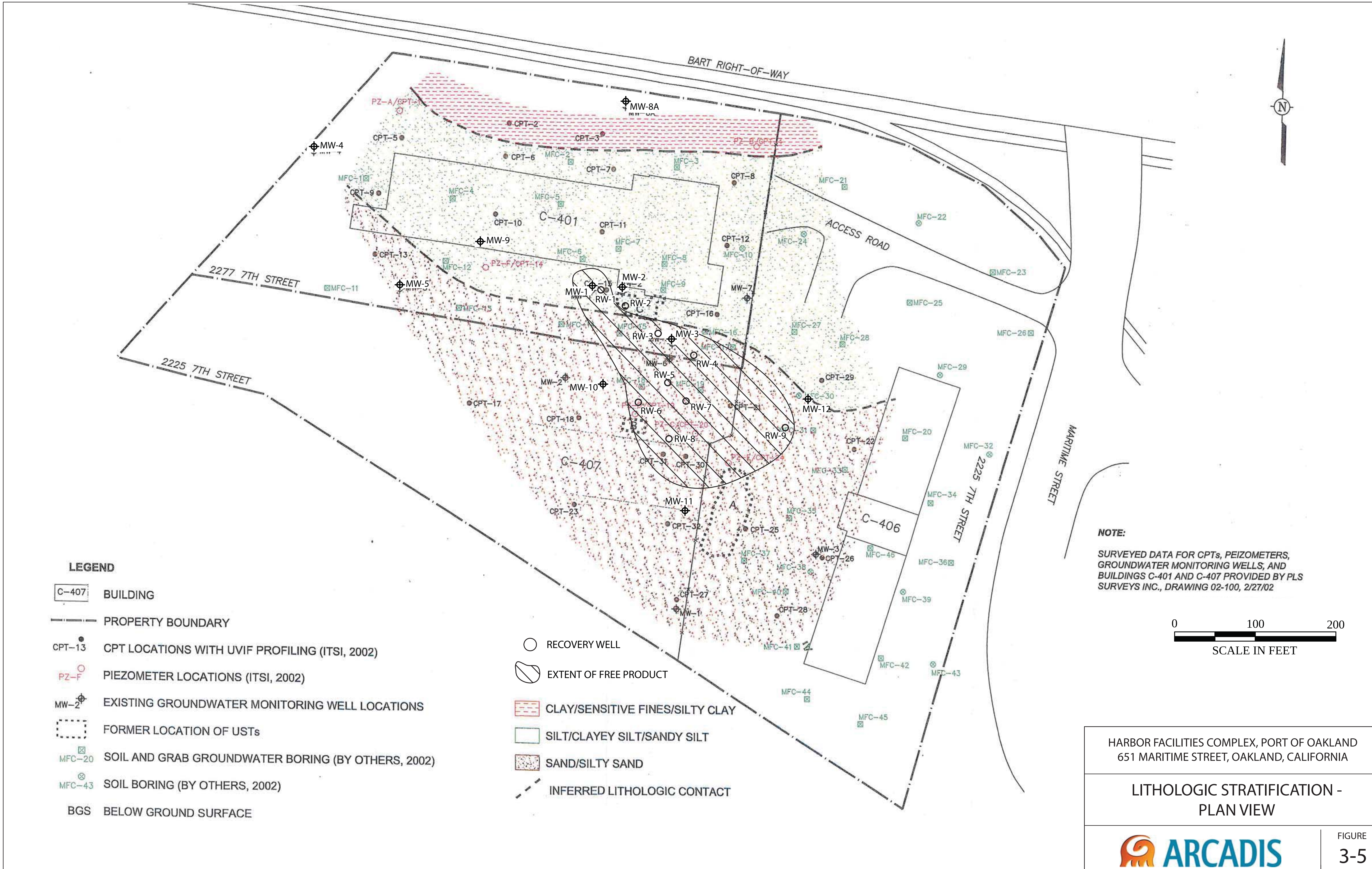
FIGURE
3-4



HARBOR FACILITIES COMPLEX, PORT OF OAKLAND
651 MARITIME STREET, OAKLAND, CALIFORNIA

LITHOLOGIC STRATIFICATION - PLAN VIEW

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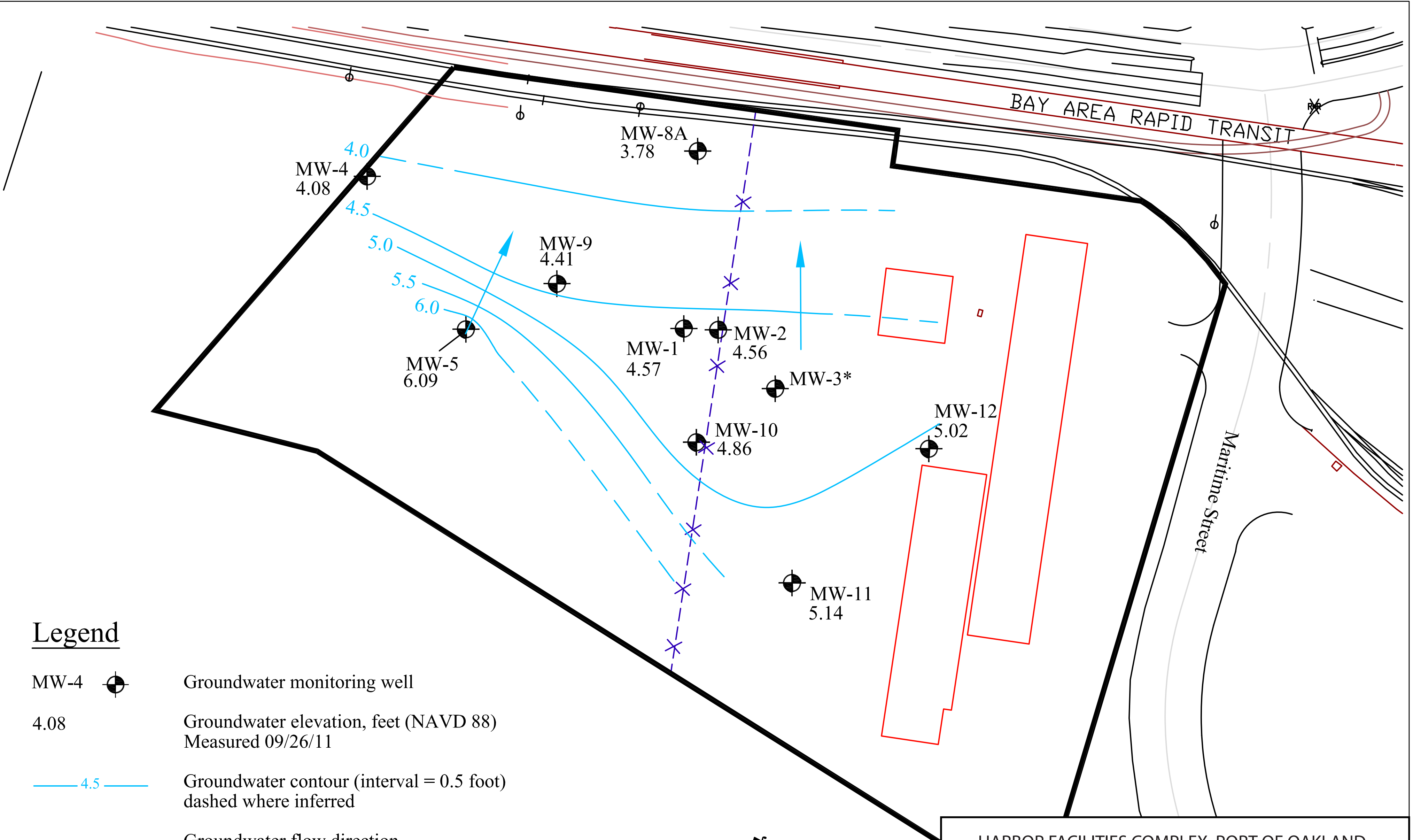
FIGURE 3-5



Legend

MW-4	Groundwater monitoring well
4.08	Groundwater elevation, feet (NAVD 88) Measured 09/26/11
4.5	Groundwater contour (interval = 0.5 foot) dashed where inferred
	Groundwater flow direction
	Fence
	Site boundary

* Well contains measurable free product; not used for contouring

Notes: North American Vertical Datum of 1988.

HARBOR FACILITIES COMPLEX, PORT OF OAKLAND
651 MARITIME STREET, OAKLAND, CALIFORNIA

GROUNDWATER ELEVATION ISOCONTOUR MAP - SEPTEMBER 2011

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FIGURE
3-6

Table 1

Table 1 LNAPL Assessment
Port of Oakland
651 Maritime Street
Oakland, California

Well ID	Baildown Test	Slug Test	LNAPL Sample	GW Sample (for LNAPL properties testing)	Soil Vapor (from wells)	Temperature Profile	NSZD (MNA) in Groundwater
MW-1				X	X		X
MW-3					X	X	
MW-5					X	X	X
MW-8A		X					X
MW-9		X					X
MW-10		X					X
MW-11		X					X
RW-3	X		X		X	X	
RW-4	X		X				X
RW-6	X		X				
RW-7	X						
RW-8							X
RW-9					X	X	

Notes
GW - Groundwater
MNA - Monitor Natural Attenuation
LNAPL - light non-aqueous phase liquid
NSZD - Natural Source Zone Depletion

Added based on Comments from Alameda County Environmental Health or changes based on decisions after initial draft Work Plan submittal

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ARCADIS Standard Operating Procedures

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Water-Level and NAPL Thickness Measurement Procedures

Rev. #: 0

Rev Date: February 27, 2009

Approval Signatures

Prepared by: _______________ Date: 2/27/09
Andrew Korik

Reviewed by: _______________ Date: 2/27/09
Michael Gefell (Technical Expert)

I. Scope and Application

Monitoring well water levels and thickness of non-aqueous phase liquids (NAPLs) will be determined, as appropriate, to develop groundwater elevation contour maps and to assess the presence or absence of NAPL in wells. This SOP applies to light and/or dense NAPLs (LNAPLs and DNAPLs, respectively). In addition, because this SOP describes water-level measurement from surveyed measurement points, this SOP can be followed, to obtain surface water level measurements from surveyed measurement points.

Fluid levels will be measured using an electric water-level probe and/or NAPL-water interface probe from established reference points. Reference points are surveyed, and are established at the highest point at the top of well riser, and will be based on mean sea level, or local/onsite datum. The Operating and Maintenance (O&M) Instruction Manual for the electric water level probe and/or and interface probe should be reviewed prior to commencing work for safe and accurate operation.

II. Personnel Qualifications

Individuals conducting fluid level measurements will have been trained in the proper use of the instruments, including their use for measuring fluid levels and the bottom depth of wells. In addition, ARCADIS field sampling personnel will have current health and safety training including 40-hour HAZWOPER training, site supervisor training, site-specific training, first aid, and CPR, as needed. In addition, ARCADIS field sampling personnel will be versed in the relevant SOPs and posses the required skills and experience necessary to successfully complete the desired field work. ARCADIS field personnel will also be compliant with client-specific training requirements, such as (but not limited to) LPS or other behavior-based training, and short-service employee restrictions.

III. Equipment List

The following materials, as required, shall be available during fluid level measurements.

- photoionization detector (PID)
- appropriate health and safety equipment, as specified in the site Health and Safety Plan (HASP)

- laboratory-type soap (Alconox or equivalent), methanol/hexane rinse, potable water, distilled water, and/or other equipment that may be needed for decontamination purposes
- electronic NAPL-water interface probe
- electronic water-level meter
- 6-foot engineer's rule
- portable containers
- plastic sheeting
- field logbook and/or personal digital assistant (PDA)
- indelible ink pen
- digital camera (optional, if allowed by site policy)

IV. Cautions

Electronic water-level probes and NAPL-water interface probes can sometimes produce false-positive readings. For example, if the inside surface of the well has condensation above the water level, then an electronic water-level probe may produce a signal by contacting the side of the well rather than the true water level in the well. In addition, NAPL-water interface probes can sometimes indicate false positive signals when contacting a sediment layer on the bottom of a well. In contrast, a NAPL-water interface probe may produce a false-negative (no signal) if a floating layer of non-aqueous phase liquid (NAPL) is too thin, such as a film or sheen. To produce reliable data, the electronic water level probe and/or interface probe should be raised and lowered several times at the approximate depth where the instrument produces a tone indicating a fluid interface to verify consistent, repeatable results. In addition, a bottom-loading bailer should periodically be used to check for the presence of NAPLs rather than relying solely on the NAPL-water interface probe.

The graduated tape or cable with depth markings is designed to indicate the depth of the electronic sensor that detects the fluid interface, but not the depth of the bottom of the instrument. When using these devices to measure the total well depth, the additional length of the instrument below the electronic sensor must be added to the apparent well depth reading, as observed on the tape or cable of the instrument, to obtain the true total depth of the well. If the depth markings on the tape or cable are worn or otherwise difficult to read, extra care must be taken in obtaining the depth readings.

V. Health and Safety Considerations

The HASP will be followed, as appropriate, to ensure the safety of field personnel. Access to wells may expose field personnel to hazardous materials such as contaminated groundwater or NAPL. Other potential hazards include stinging insects that may inhabit well heads, other biologic hazards, and potentially the use of sharp cutting tools (scissors, knife). Appropriate personal protective equipment (PPE) will be worn during these activities. Field personnel will thoroughly review client-specific health and safety requirements, which may preclude the use of fixed/folding-blade knives.

VI. Procedure

Calibration Procedures

If there is any uncertainty regarding the accuracy of the tape or cable associated with the electronic water-level probe or NAPL-water interface probe, it should be checked versus a standard length prior to use to assess if the tape or cable above the meter has been correctly calibrated by the manufacturer, and to identify evidence of tape or cable stretching, etc.

1. Measure the lengths between markers on the cable with a 6-foot engineer’s rule or a fiberglass engineer’s tape. The tape or cable associated with the electronic water-level probe or NAPL-water interface probe should be checked for the length corresponding to the deepest total well depth to be monitored during the data collection event.

2. If the length designations on the tape or cable associated with the electronic water-level probe or NAPL-water interface probe are found to be incorrect, the probe will not be used until it is repaired by the manufacturer.

3. Record verification of this calibration process in field logbook or PDA.

Measurement Procedures

The detailed procedure for obtaining fluid level depth measurements is as follows. Field notes on logs will be treated as secured documentation and indelible ink will be used. As a general rule, the order of measuring should proceed from the least to most contaminated monitoring wells, based on available data.

1. Identify site and well number in field logbook using indelible ink, along with date, time, personnel, and weather conditions.

2. Field personnel will avoid activities that may introduce contamination into monitoring wells. Activities such as dispensing gasoline into vehicles or generators should be accomplished well in advance of obtaining field measurements.

3. Don PPE as required by the HASP..

4. Clean the NAPL/water interface probe and cable in accordance with the appropriate cleaning procedures. Down-hole instrumentation should be cleaned prior to obtaining readings at the first monitoring well and upon completion of readings at each well.

5. Clean the NAPL/water level interface probe and cable with a soapy (Alconox) water rinse followed by a solvent rinse (if appropriate based on site-specific constituents of concern) an analyte-free water rinse Contain rinse water in a portable container that will be transferred to an on-site container.

6. Put clean plastic sheeting on the ground next to the well.

7. Unlock and open the well cover while standing upwind from the well. Place the well cap on the plastic sheeting.

8. Locate a measuring reference point on the well casing. If one is not found, initiate a reference point at the highest discernable point on the inner casing (or outer if an inner casing is not present) by notching with a hacksaw, or using an indelible marker. All down-hole measurements will be taken from the reference point established at each well on the inner casing (on the outer only if an inner casing is not present).

9. Measure to the nearest hundredth of a foot and record the height of the inner and outer casings (from reference point, as appropriate) to ground level.

10. Record the inside diameter of the well casing in the field log.

11. If an electronic water level probe is used to measure the water level, lower the probe until it emits a signal (tone and or light) indicating the top of the water surface. Gently raise and lower the instrument through this interface to confirm its depth. Measure and record the depth of the water surface, and the total well depth, to the nearest hundredth of a foot from the reference point at the top of

the well. Lower the probe to the bottom of the well to obtain a total depth measurement.

12. If a NAPL/water interface probe is being used to measure the depth and thickness of NAPL, lower the instrument until it emits a signal (tone and or light) indicating whether LNAPL is present. Continue to lower the NAPL/water level interface probe until it indicates the top of water. Lower the probe to the bottom of the well to obtain a total depth measurement. Note also of the depth indicating the bottom of water and top of DNAPL layer, if any, based on the signal emitted by the interface probe. At each fluid interface, gently raise and lower the instrument through each the interface to confirm its depth. Measure to the nearest hundredth of a foot and record the depth of each fluid interface, and the total well depth, from the reference point.

13. Clean the NAPL/water interface probe and cable in accordance with the appropriate cleaning procedures.

14. If using a bailer to confirm the presence/absence of NAPL, the bailer should either have been previously dedicated to the well, or be a new previously unused bailer.

15. Compare the depth of the well to previous records, and note any discrepancy.

16. Lock the well when all activities are completed.

VII. Waste Management

Decontamination fluids, PPE, and other disposable equipment will be properly stored on site in labeled containers and disposed of properly. Be certain that waste containers are properly labeled and documented in the field log book. Review appropriate waste management SOPs, which may be state- or client-specific.

VIII. Data Recording and Management

Fluid level measurement data will be recorded legibly on “write-in-the-rain” field notebook in indelible pen and/or a PDA. Field situations such as apparent well damage or suspected tampering, or other observations of conditions that may result in compromised data collection will be photographically documented where practicable.

IX. Quality Assurance

As described in the detailed procedure, the electronic water-level meter and/or NAPL-water interface probe will be calibrated prior to use versus an engineer's rule to ensure accurate length demarcations on the tape or cable. Fluid interface measurements will be verified by gently raising and lowering the instrument through each interface to confirm repeatable results.

X. References

No literature references are required for this SOP.

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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

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Standard Operating Procedure for LNAPL Sample Collection and Shipping

Rev. #: 1.0

Rev Date: March 26, 2009

Approval Signatures

Prepared by: ______________________ Date: 3/26/09
(Trika Nelson-Kalmes)

Reviewed by: ______________________ Date: 3/26/09
(Brad Koons)

I. Scope and Application

Subsurface fluid sample collection is often required to characterize Light Nonaqueous Phase Liquid (LNAPL) properties at petroleum-impacted sites. The subsurface fluids (groundwater and separate-phase petroleum product) are submitted to an analytical laboratory(s) for specialized physical testing (e.g., density, viscosity, interfacial tension) and/or chemical speciation testing. It is important to note that the physical parameters are temperature sensitive. Therefore, the laboratory should be directed to analyze the samples at representative subsurface fluid temperatures. The fluid data are used to support site-specific LNAPL mobility calculations and development of the LNAPL site conceptual model.

This SOP does not address details of drilling method selection; soil description; or laboratory analysis. Refer to other ARCADIS SOPs and the project work plan, as appropriate.

II. Personnel Qualifications

ARCADIS personnel overseeing, directing, or supervising LNAPL fluid collection shall have previous related experience (minimum of 2 years) collecting fluid samples from wells and shall be trained in shipping of hazardous materials.

III. Equipment List

- personal protective equipment (PPE), items specified by the site Health and Safety Plan (HASP), and first aid kit;
- measuring tape;
- scissors;
- indelible ink pens;
- site map;
- contact names and numbers;
- well lock keys;
- logbook;
- interface probe;
- cleaning equipment/supplies, including deionized (DI) water and LiquiNox or equivalent;
- plastic sheeting;
- sampling containers;
- bailers, rope, and bailer retrieval device;
- buckets;
- bubble wrap and Styrofoam peanuts;
- duct tape and clear packaging tape;
- shippable cooler or sturdy box;
- shipping labels;
- chain of custody forms;
- garbage bags; and
- drum bung wrench.

IV. Cautions

Please refer to the Site specific HASP and JSAs for the Site.

V. Health and Safety Considerations

Field activities associated with collection of nonaqueous phase liquids and water will be performed in accordance with a site specific HASP, a copy of which will be present on site during such activities. The field staff must be made aware of hazardous substances that may be present in the groundwater and nonaqueous phase liquids and understand the associated health hazards.

VI. Fluid Sample Collection Procedure

1. Measuring the static water level: Proper PPE must be worn (i.e. gloves, safety glasses, steel-toed boots, etc.). Remove cap from well and deploy the oil/LNAPL and water interface probe into the well. Measure the static LNAPL and water levels in each well before sampling. Decontaminate the interface probe using LiquiNox (or equivalent) and DI water between well measurements. Read fluid level measurements to the nearest 0.01 foot on the north side, top of casing. Use the same electronic oil and water interface probe for all wells. Make sure to record all depths to product (DTP) and depths to water (DTW) in the field book. Depending on the probe, it will make different sounds for water and oil/LNAPL.

2. Collecting LNAPL and groundwater samples: Dedicated bailer and rope must be used for each well. Make sure to sample in the same order that water and LNAPL levels were collected to avoid any cross contamination. Collect the LNAPL sample by slowly lowering the bailer into the LNAPL, but not into the water. Pull the bailer out of the well. If both water and LNAPL are present, allow the liquids to separate. Collect the groundwater sample by lowering the bailer below the groundwater/LNAPL interface and slowly removing the bailer. Use a bottom emptying device to decant (drain) the appropriate amount of LNAPL or water into the appropriate container(s), as described below. Drain off remaining, unneeded liquids into a 5 gallon "waste" bucket. Record the amount of LNAPL bailed from each well in the logbook. The required sample volumes and containers, indicated below, are dependent upon the laboratory analyses to be performed.

   a. Fluid Properties Analysis: Requires 250 mL (minimum) of site groundwater and 250 mL (minimum) of LNAPL. The groundwater and LNAPL must be separated and placed into separate 1-liter glass containers.

b. Water/LNAPL Relative Permeability: Requires 1 to 2 liters (minimum) of field water and 1 liter (minimum) of LNAPL, placed in up to three 1-liter glass containers. It is preferable that LNAPL and field water are separated into separate sample containers.

3. Use waterproof labels for the containers and permanent waterproof marking devices for labeling. Labels are to include unique sample IDs, collection date and time, sampler initials, and lab analyses to be performed. These samples **DO NOT** need to be chemically preserved or shipped on ice.

4. Once sampling is complete, put the cap back on the well, close, and secure it as necessary. Personal protective equipment (such as gloves and disposable clothing) and other disposable equipment resulting from cleaning procedures and LNAPL and water sampling/handling activities (such as paper towels, rope, and bailers) will be placed in plastic garbage bags. Disposable PPE and equipment should not be re-used. Dispose of any excess water/LNAPL from the well into a 55-gallon drum or on site poly tank for proper disposal at a later date. Follow the procedures outlined in the Waste Management section below for further waste handling.

VII. Sample Shipping Procedure

The United States Department of Transportation (DOT) hazardous shipping guidelines must be followed when shipping LNAPL. Hazardous samples being shipped by ARCADIS staff must have completed current training through ARCADIS for DOT training for hazardous material shipping. A shipping determination form must be completed for all samples being shipped along with following all ARCADIS and DOT shipping guidelines. All forms and guidelines can be found online at http://team/sites/hazmat/default.aspx. If there are additional questions contact Sam Moyers (ARCADIS H&S).

VIII. Waste Management

The plastic garbage bags containing disposable PPE and equipment will be transferred into appropriately labeled 55-gallon drums or disposed of in a designated debris box for disposal. All decontamination and well water will be placed in separate sealed 55-gallon steel drums and stored in a secured area. Once full, the material will be analyzed to determine the appropriate disposal method.

IX. Data Recording and Management

The supervising geologist/engineer will be responsible for documenting sampling events using a logbook to record all relevant information in a clear and concise format. The sampling event record shall include:

- name and location of project;
- project number, client, and site location;
- names of Contractor, Contractor personnel, inspectors, and other people onsite;
- weather conditions;
- depth to groundwater and depth to LNAPL;
- type of sampling method;
- start and finish dates and times of sampling;
- volume of groundwater bailed and sampled;
- LNAPL as measured in a graduated cylinder and sampled; and
- photo document the LNAPL and cooler packaging.

X. Quality Assurance

Equipment will be cleaned prior to use onsite, between each sampling location, and prior to leaving the site.

Review bottle labels and the COC prior to shipping to ensure everything is labeled and documented correctly.

XI. References

PTS Laboratories, 2009. www.ptslabs.com

Imagine the result

SLUG TEST STANDARD OPERATING PROCEDURES

ARCADIS

PUMPING TEST PROCEDURES

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A. TEST DESIGN

1. Understand What You Are Testing

An instantaneous change in head (slug) test is conducted in order to determine the hydraulic conductivity/transmissivity of a water-bearing zone in a quick and inexpensive manner. It can be conducted in materials of lower hydraulic conductivity than generally considered suitable for pumping tests. A slug test also does not require disposal of large quantities of water.

However, recognize that a slug test's shorter time frame and limited stress on the system provides a measurement of hydraulic conductivity on a smaller scale than a pumping test. Because a slug test affects only the aquifer near the well, its results are more strongly influenced by near-well conditions such as the filter pack, poor well development, and skin effects. Therefore, make sure that the stress on the well (i.e., the amount of change in head) is sufficient to test more than the hydraulic conductivity of the filter pack. Although the results of a slug test are not necessarily representative of the average hydraulic conductivity of the area, this limitation does present an opportunity to test discrete layers within an aquifer. Also understand that the storage coefficient (S) usually cannot be determined from a slug test.

2. Slug Test Theory

An estimate of local hydraulic conductivity of the material surrounding a well is calculated by measuring the time/rate of return to static water levels after an instantaneous change in head. Homogeneity and constant aquifer thickness are general assumptions for the test analysis; these are generally met due to the small radius of influence of the test.

Two classes of solutions are generally used: one that assumes water and soil are incompressible (storage is zero; i.e., Bouwer and Rice, and Hvorslev methods), which is a straight-line solution method similar to Thiem; and one that assumes a non-zero storage coefficient (i.e., Cooper et.al, and Hyder et. al methods), which is a type-curve matching solution method similar to Theis.

3. Determine Well Conditions

Unless installed specifically for the test, sound all wells that are to be tested to verify well depth. (Do not use water level meters for this purpose, because some meters have probes that leak and trap water when subjected to excessive pressure.) Verify that the well has been adequately developed, and is not silted in. If the water-level response in the slug test appears to be too sluggish or no response is apparent, the well may need to be redeveloped.

Measure depth to water, or check historic depths to water, to determine if the screen is below the top of water or straddles the piezometric surface. This will determine the types of slug tests (slug-in, slug-out) and mechanisms (water, mechanical, pneumatic) that are applicable for the particular well to be tested. Note that a fully submerged screen is highly preferable for best test results, otherwise a “double-straight line” effect resulting from filter-pack drainage into the well (initial drainage followed by actual aquifer response) will likely be seen in the test response curve (Bower, 1989).

4. Select the Appropriate Slug-Inducing Equipment

A variety of methods are available for inducing a change in water level. The basic requirements are the change needs to take place rapidly (“instantaneous”), and the change needs to be of sufficient magnitude: at least one foot, preferably two to four feet. (Similar results can be achieved with a wide range of induced head change, so a change greater than four feet is not necessary.) The slug can either be introduced (slug in) or withdrawn (slug out). However, if the well screen is open above the water table, slug out is the only method acceptable.

Methods of introducing a slug are as follows:

a) adding clean (DI or potable) water to the well, preferably from a holding vessel with a ball valve that allows the water to drain into the well quickly;
b) dropping a “blank” (typically capped PVC pipe filled with clean sand) into the well; or
c) after raising the water level within a well by applying a vacuum, releasing the vacuum and observing the drop in water level.

Methods of removing a slug are as follows:

a) pulling a slug of water out of the well quickly with a bailer;
b) pulling a “blank” out of the well; or
c) after pressurizing a well and pushing down the water level, releasing pressure from the well and observing the rise in water level.

5. Select the Appropriate Water-Level Measurement Device

Pressure/head changes are rapid (i.e., “instantaneous”), therefore, the measuring device needs to be able to collect measurements quickly and accurately, especially for fast-responding wells. Pressure transducers with dataloggers are best equipped for slug tests. Pressure transducers are also necessary for closed wells in which water level changes are induced by pressure or vacuum.

(a) Pressure Transducers and Data Logger Combination

Transducers connected to electronic data loggers provide rapid water-level measurements with accuracy and ease. Some electronic data loggers (i.e., Hermit) collect and store data from a number of input channels (downhole pressure transducers plus atmospheric pressure) to provide water-level measurements in multiple within several hundred feet radius of the data logger, while others consist of a single logging transducer (i.e., Troll™, Levelogger™). Typical loggers take readings at preprogrammed linear or logarithmic intervals. If desired, data can be transferred to a personal computer for processing.

Small-diameter transducers (typically 0.5 to 0.75 in) are available that cover a range of pressures. Because they yield readings accurate to a percentage of their pressure range (usually about ±0.1 percent of the range in the center of that range, and ±0.2 percent near the limits) transducers that span a wide pressure range have lower absolute accuracies than those that span a narrow range. For example, a typical transducer with a 5 psi range detects water-level changes over a 11.6 ft with an accuracy of ±0.01 ft, whereas, a transducer with a 15 psi range detects changes over a 34.7 ft with an accuracy of ±0.03 ft. Thus, to ensure the greatest accuracy, select the transducer with the pressure range that most closely encompasses the anticipated drawdown or water-level change. Install the transducer at a depth at least 2 feet from the bottom of the well, but below the targeted drawdown estimated for the well.

Caution: To prevent transducer malfunction, do not submerge transducers in excess of their operating range.

(b) Water Level Meters, Interface Probes

These devices provide quick and easy water-level measurements with reasonable accuracy. They employ a sensor that is lowered into a well on the end of a marked cable (typically imprinted in feet and hundredths of a foot). When the sensor contacts water, a circuit is completed, activating a light, audio signal, ammeter, or digital display in the cable reel or housing. However, because the measurements are manual, the speed of readings cannot match those of a pressure transducer with a data logger. Thus, a water level meter is most useful with slow-responding wells, typically installed in low-permeability formations.

6. Verify Measuring Device Accuracy

Test pressure transducers and data logger readings using a bucket or barrel filled with water. Submerge each transducer, accurately measure the water head above the transducer, and compare the measurement to the data-logger reading. Check transducer response to changing heads by raising the transducer a certain distance, observing the change in the datalogger reading, and then measuring the distance with a standard steel tape. Water level meters should be in good working condition and calibrated, ensuring there are no breaks or splices in the cable.

7. Plan for Test Well Water Disposal

If the water quality is such that direct discharge to the ground is not permitted, arrange for collection and disposal for standard slug-out testing. Discharge water must be disposed according to all applicable laws and regu1ations. Contact the governing agencies to determine which restrictions apply. ARCADIS should not be responsible for signing manifests and should not "take possession" of discharged water.

B. PRETEST ACTIVITIES

1. Establish a Reference Point for Measuring Water Levels

At each test well, establish and clearly mark the position of the selected reference point (often the north side, top of the casing). Determine the elevation of this point, record it, and state how this elevation was determined. This elevation point is important to establish the position of the piezometric surface, so it must be determined accurately.

2. Record Background Water Levels

Measure the groundwater level in the test well before beginning the test for a period of time equal to the length of the slug test response. This will help detect any background water level fluctuations and establish a reference static water level. Be sure to allow time for equilibration with atmospheric pressure for wells with unvented caps. If possible, arrange to have nearby active wells shut down or pumped at a constant rate to ease data interpretation.

3. Set-up: Decontamination

Make sure all equipment that enters the test well (slug, water-level meter, transducer) is decontaminated before use. If testing multiple wells, start with the least contaminated progressing to the most contaminated.

4. Set-up: Remaining Equipment Required for Test

Keep sensitive electronic equipment away from devices that generate significant magnetic fields. For example, do not place data loggers near electric power generators or electric pump motors. Likewise, radio signals may cause dataloggers or computers to malfunction. Secure data logger and transducer cables at the well head to prevent movement that would affect measurements. Mark a reference point on transducer cables and check regularly to detect slippage.

5. Perform a Job Safety Analysis

To ensure that everyone is aware of the hazards associated with the work, and that each person knows his/her responsibilities during the preliminary and full-scale test, run through a JSA of the test before the start of pumping.

C. CONDUCTING THE TEST

1. Record Information

(a) Use appropriate data forms
(b) Record all required background information, including well geometry, on logs before beginning the test
(c) Record time as military (24-hour) time
(d) Record the initial depth to water with a water-level meter. (This can be entered into the datalogger if one is being used.)

2. Start the Test

(a) Introduce or remove the slug quickly, causing a measurable change in water level.
(b) Measure water-level response to the initial change at closely spaced intervals (preferably 0.5 second or less to catch fast response) in order to define the water-level response curve.
(c) Continue measuring and recording depth-time measurements until the

water level has equilibrated or a clear trend on a semi-log plot of time versus depth has been established. Measurements taken manually should continue until the water level has recovered about 80%.

3. Reverse Test

If desired, after a slug-in test has been finished and equilibrium reached, a slug-out test can be performed as a check.

4. Post-test Procedure

Make a preliminary analysis of the data before leaving the test area. Compare volume of slug to actual water displacement in the well. Evaluate the quality of the data, and the method of analysis applicable for the results. If a clear trend was not established, the test may need to be re-run. Ensure that equilibrium has been reached before re-running a test in the same well.

D. ASSESSING TEST RESULTS

1. Have Pertinent Well Construction Details

To evaluate data from the test, it will be necessary to have well construction information, such as the following:

- Lithologic logs
- Well depths
- Screen lengths
- Filter pack thickness and length
- Test well casing radius
- Borehole radius
- Sand pack grain size (affects the size of the practical borehole radius)
- Thickness of saturated zone
- Initial water depth
- Initial head change from slug

2. Determine the Type of Response to the Test

The type of response to the test is as important as the type of permeable zone (confined, unconfined) for picking the type of analysis. As with pumping tests, do not assume that all standard analyses (Bower and Rice; Hvorslev; Cooper, Bredehoeft, Papadopulos) are suitable; pick the type of analysis based on the goodness-of-fit of the response (Herzog and Morse, 1990) to the theoretical curve. Do not force the data; if a clear straight line does not exist then the standard straight-line analytical methods may not be appropriate.

Wells testing confined aquifers with a high transmissivity or long water column (large water mass within the casing) can show an oscillatory recovery (underdamped or critically damped; see ASTM D5785 and ASTM D5881) to initial water level; common response is an exponential decay (overdamped response, frictional forces within the aquifer are dominant over inertial; see ASTM D4104 and ASTM D5912). These oscillatory test results require calculation of the angular frequency and damping factor (Kipp, 1985; van der Kamp, 1976) to account for the inertial effects before solving for transmissivity. The underdamped solution technique is available in the standard aquifer test program, AQTESOLV, and in public domain spreadsheet programs available from the USGS (http://pubs.usgs.gov/of/2002/ofr02197/) and from the Kansas Geological Survey (http:www.kgs.ku.edu/Hydro/Publications/OFR00_40/High_K.zip).

Note: the critically damped well response is a transitional response (showing oscillations) between overdamped and underdamped; its analysis requires the type-curve matching method by Kipp (1985). It is determined by a dimensionless "damping factor":

$$\zeta = \frac{\alpha\left(\sigma + \frac{1}{4} 1n\beta\right)}{2\beta^{\frac{1}{2}}}$$

where $\zeta > 1$ is overdamped; $\zeta = 1$ is critically damped; and $\zeta < 1$ is underdamped.

3. Decontaminate All Equipment Contacting Site Groundwater and Soil

Use appropriate decontamination procedures before proceeding to the next well and/or leaving the site.

E. SPECIAL CONSIDERATIONS

1. Wells Containing Floating Nonaqueous Phase Liquids

It is best to use pressure transducers to measure water levels in wells containing floating product such as gasoline. Contact with floating product, however, may make transducers and cable unsuitable for future use. Thus, protect each transducer and cable assembly by encasing it in plastic tubing or pipe. Be sure that each protected transducer still can respond accurately to any pressure changes.

As an alternative to pressure transducers, make manual measurements (using an interface probe) of both the fuel level and water level individually. Then correct the observed thickness of floating product by its density to arrive at the effective water level. This manual procedure will work, but takes time and is only suitable for slow-responding wells.

2. Karst and Cavernous Aquifers

Recognize that the response of the slug tests within a Karst regime will be as diverse as the stratigraphy. Document the well stratigraphy to understand the range in responses measured within a single groundwater zone.

3. Fractured Aquifers

The upper boundary condition for the Bower-Rice and Hvorslev methods, based on the Thiem analysis, is a no-flow boundary. Often, the residuum above fractured aquifers are at least partially saturated and serve as a leaky upper boundary; this condition cannot generally be confirmed by slug tests.

Fractured-zone aquifers typically meet the assumptions of the analysis by Cooper-Bredehoeft-Papadopulos, although care should be taken in the interpretation in case the screened zone may cross a single fracture or discrete zone

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Data Collection Form

Project No. ____________ Well ID ____________ Date/Time ____________

Project Name ____________ Well Location ____________

Weather ____________

DTW ____________

DTP ____________

Time	Depth (ft bgs)	Temp (ºC)	pH	Cond (mS/cm)	Turbidity (NTU)	DO (mg/L)	ORP (mV)