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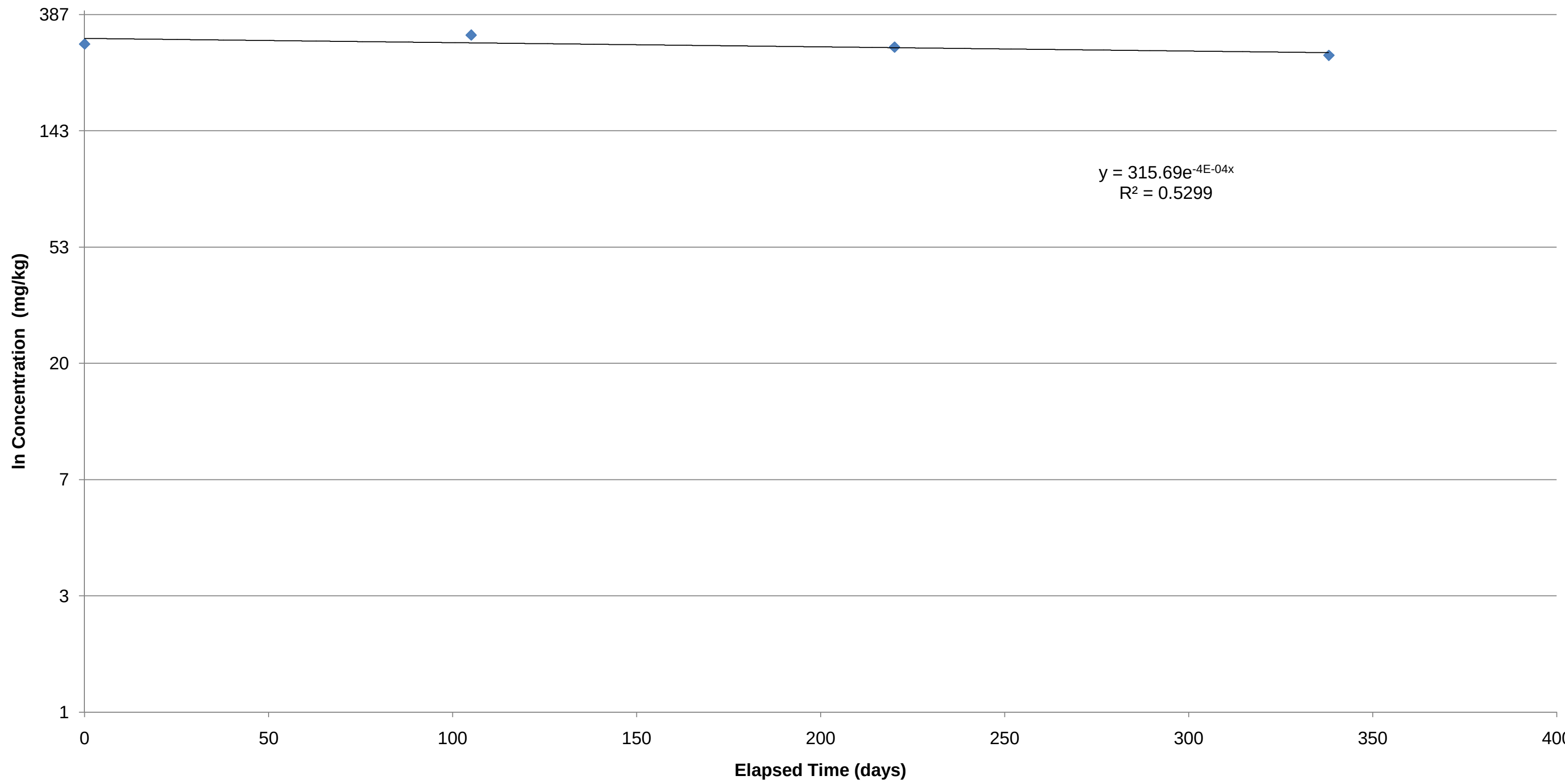
Appendix K

First Order Degradation Rate Constants for cPAH



LEGEND:
ln = natural log
Data from: Rothermich, M., L. Hayes and D. Lovley. 2002. Anaerobic, Sulfate-Dependant Degradation of Polycyclic Aromatic Hydrocarbons in Petroleum-Contaminated Harbor Sediments. *Environmental Science and Technology* 36: 4811-4817.

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BENZO(A)ANTHRACENE FIRST-ORDER RATE CONSTANT PLOT

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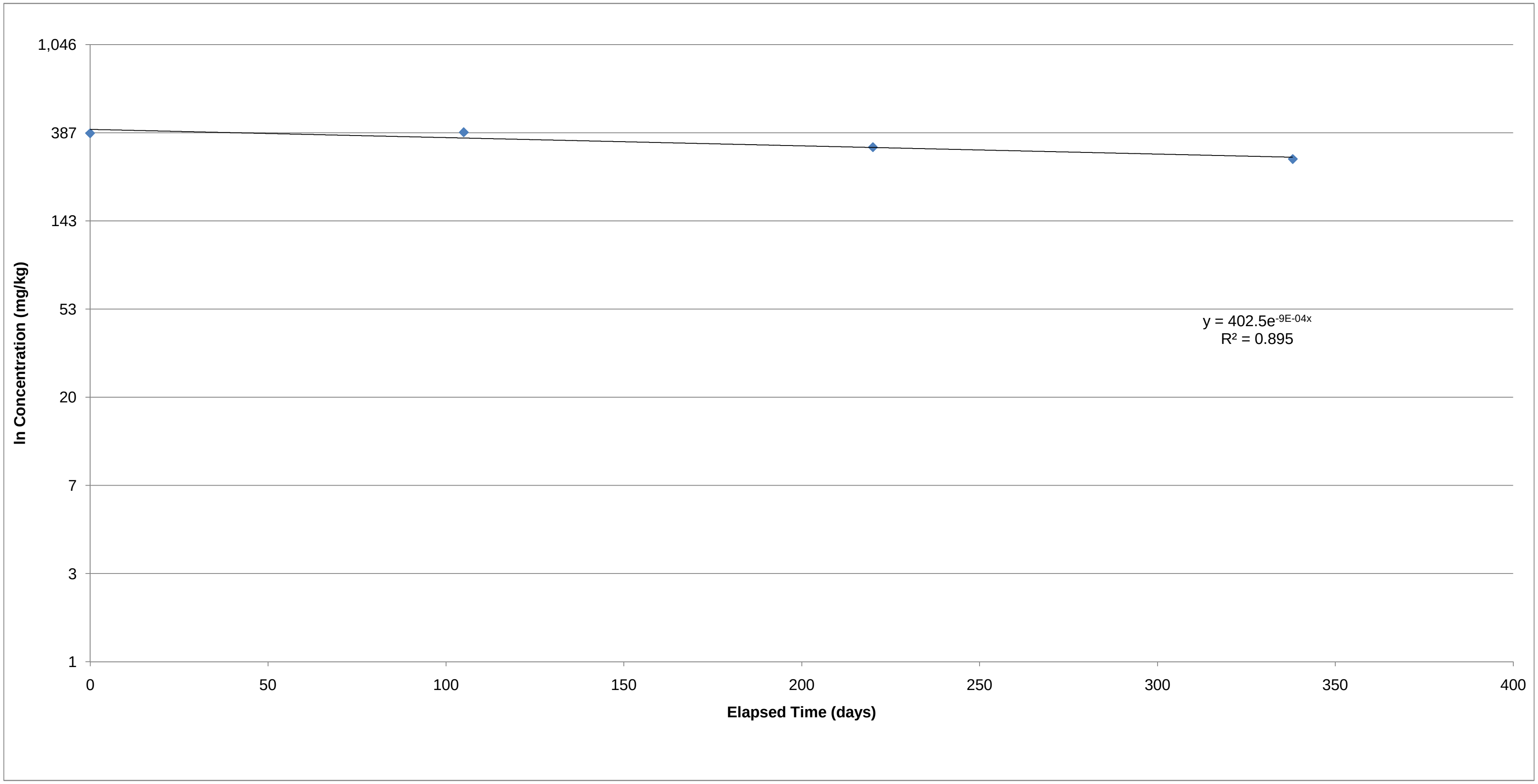
FIGURE



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ln = natural log
Data from: Rothermich, M., L. Hayes and D. Lovley. 2002. Anaerobic, Sulfate-Dependant Degradation of Polycyclic Aromatic Hydrocarbons in Petroleum-Contaminated Harbor Sediments. *Environmental Science and Technology* 36: 4811-4817.

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CHRYSENE FIRST-ORDER RATE CONSTANT PLOT

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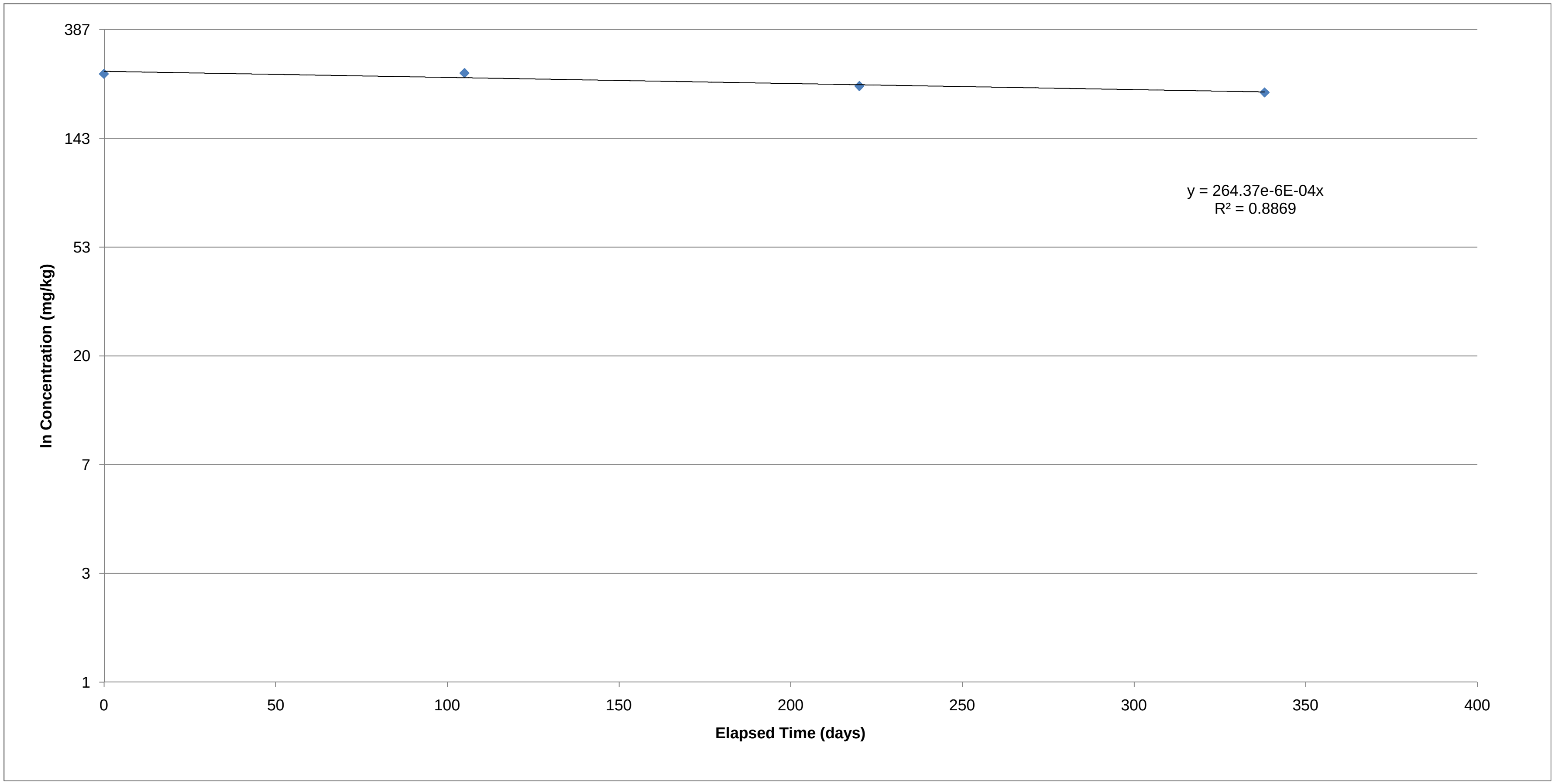
FIGURE



LEGEND:
ln = natural log
Data from: Rothermich, M., L. Hayes and D. Lovley. 2002. Anaerobic, Sulfate-Dependant Degradation of Polycyclic Aromatic Hydrocarbons in Petroleum-Contaminated Harbor Sediments. *Environmental Science and Technology* 36: 4811-4817.

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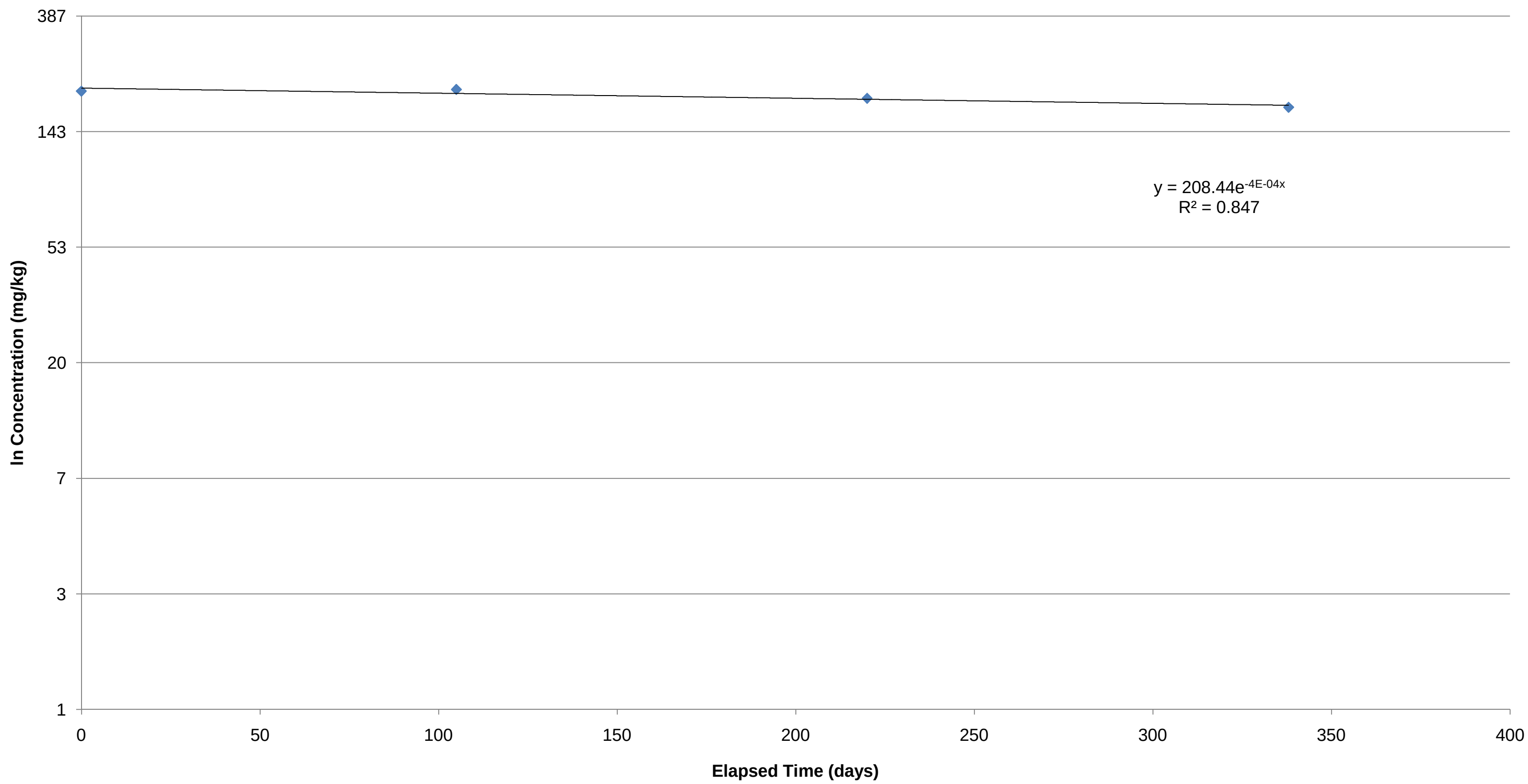
FIGURE



LEGEND:
ln = natural log
Data from: Rothermich, M., L. Hayes and D. Lovley. 2002. Anaerobic, Sulfate-Dependant Degradation of Polycyclic Aromatic Hydrocarbons in Petroleum-Contaminated Harbor Sediments. *Environmental Science and Technology* 36: 4811-4817.

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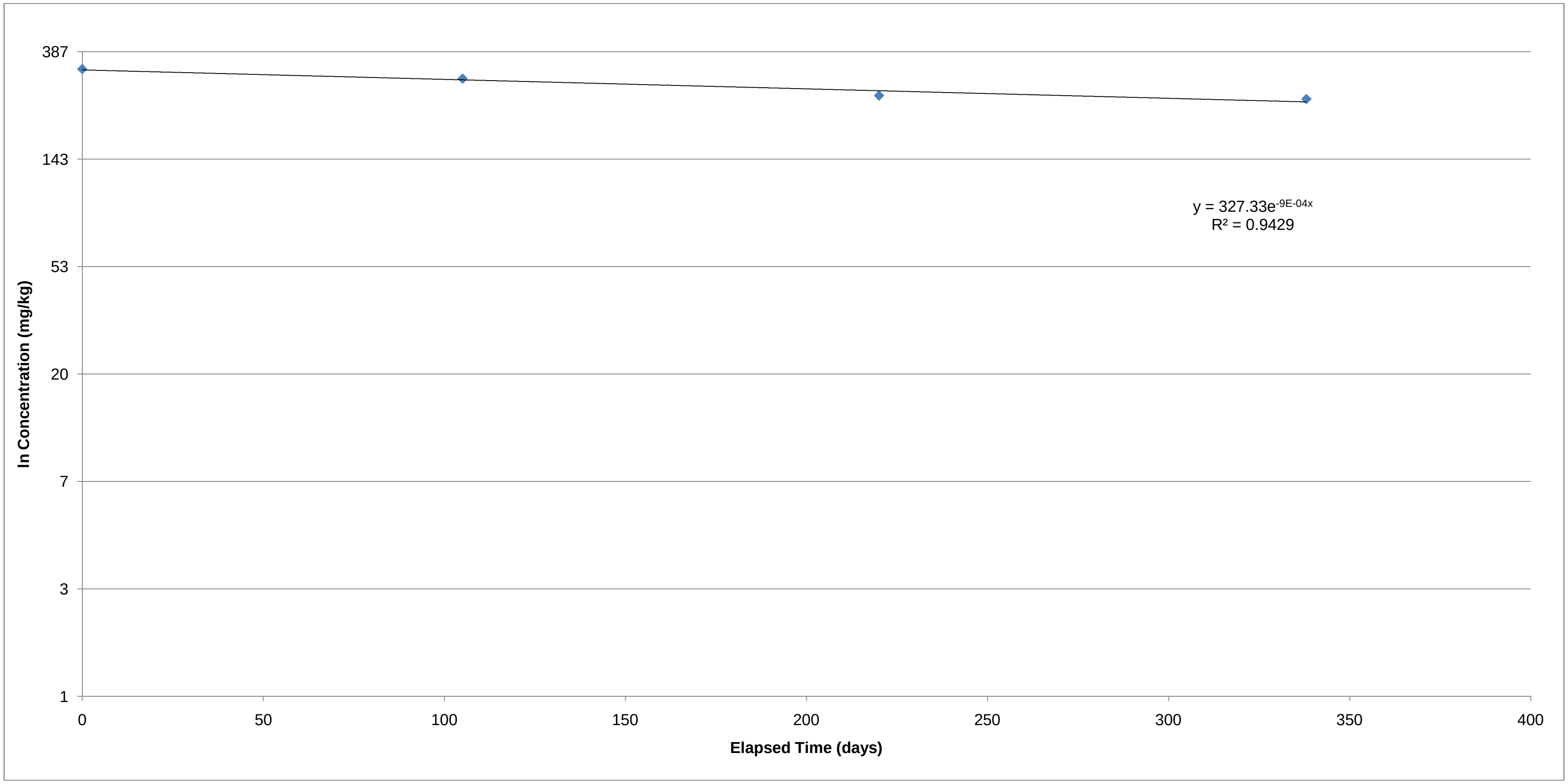
FIGURE



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ln = natural log
Data from: Rothermich, M., L. Hayes and D. Lovley. 2002. Anaerobic, Sulfate-Dependant Degradation of Polycyclic Aromatic Hydrocarbons in Petroleum-Contaminated Harbor Sediments. *Environmental Science and Technology* 36: 4811-4817.

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FIGURE

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Appendix L

LNAPL Mobility and Migration Assessment

Tables

Figures

1. LNAPL Mobility and Migration Assessment

ARCADIS completed a light non-aqueous phase liquid (LNAPL) mobility study to assess the potential for future movement of LNAPL observed in wells MW-30, MW-61A-R, RW-3 and RW-21. The assessment is based on the following:

- historical site information
- analysis of soil cores collected during installation of boring PZ-61A-R (located adjacent to well MW-61A-R)
- the physical properties of LNAPL from well MW-61A-R as determined by an analytical laboratory
- representative physical properties of LNAPL observed in wells MW-30, RW-3 and RW-21 selected from literature values

1.1 Terminology

The Interstate Technology & Regulatory Council (ITRC) defines three conditions that characterize the potential for LNAPL movement:

Immobile: LNAPL is present at or below residual saturation and cannot move. Residual saturation is defined below in Section 1.2.2.

Mobile: LNAPL is present above the residual saturation. LNAPL can potentially move within the existing LNAPL plume at a nominal rate, but the LNAPL plume footprint cannot expand.

Migrating: LNAPL is present above the residual saturation and the LNAPL plume footprint is expanding over time.

1.2 Assessment Approach

A comprehensive LNAPL mobility assessment uses multiple lines of evidence to determine LNAPL mobility. The following lines of evidence were employed to assess LNAPL mobility at the site:

- LNAPL observations in monitoring wells

- LNAPL field and residual saturations

- LNAPL pore velocity calculations

- LNAPL pore entry pressure calculations

These complementary lines of evidence have an inherent logic used to determine if LNAPL is immobile, mobile or migrating. Sections 1.1.2 through 1.1.5 describe each of the lines of evidence used in this assessment.

1.2.1 LNAPL Observations in Monitoring Wells

Temporal fluid level gauging data were inspected for the following indicators of migrating LNAPL:

- If there is a clear trend of increasing LNAPL thickness in monitoring wells through time that is not attributable to seasonal water-table fluctuations.
- If measurement of LNAPL in a portion of the monitoring well network previously lacking measureable LNAPL, suggesting that the LNAPL plume is expanding in that area.

1.2.2 LNAPL Field and Residual Saturations

The degree of fluid saturation within porous media fundamentally controls the mobility of fluids within that media. In a typical groundwater aquifer system, soil pores beneath the water table are completely filled with groundwater, which facilitates lateral groundwater flow in response to small groundwater gradients. Above the water table and within the capillary fringe, the water saturation decreases in relation to the elevation above the groundwater table and the capillary properties of the soil. As the water saturation within the soil pores diminishes, connections between water-filled pores decrease to the point where the groundwater can no longer move laterally.

At a site with LNAPL impacts, the relative saturations of three fluids (air, LNAPL and groundwater) must be considered when evaluating fluid mobility. Of primary interest is the mobility of LNAPL and the related fluid saturations where LNAPL is mobile or immobile. LNAPL is mobile where there is continuity between LNAPL-filled soil pores that allow for lateral LNAPL movement. The LNAPL saturation at which LNAPL is discontinuous to the extent that it cannot flow is termed “residual saturation.”

Residual LNAPL saturation is not a unique value for a given soil type. The residual LNAPL saturation of a soil is directly related to the maximum historical LNAPL saturation, which is spatially variable at an environmental site. Residual saturation is also related to the physical properties of the LNAPL and can vary based on different LNAPL types or weathering of the LNAPL. For this reason, LNAPL residual saturation values are typically determined at several site locations through collection and analysis of undisturbed soil cores.

Laboratory analysis of pore fluid saturations in site soil cores provides data on the field (initial) and residual LNAPL saturations. The fluid saturations are reported as the percentage of soil porosity that is filled by the fluid. The field LNAPL saturation value represents the LNAPL saturation at static in-situ conditions.

1.2.3 LNAPL Pore Velocity Calculations

A theoretical LNAPL pore velocity potential can be calculated using an adaptation of Darcy's law. The calculated LNAPL pore velocities are considered a velocity potential as often a calculated pore velocity is inconsistent with site observations of no LNAPL plume movement. However, consideration of velocity potential can be useful when evaluating whether LNAPL movement is possible. ASTM suggests that a calculated LNAPL pore velocity potential less than 1×10^{-6} centimeters per second (cm/sec) provides confidence that the LNAPL plume is stable and further site characterization may be unnecessary.

Pore velocity of any fluid type is a function of the fluid-specific conductivity, gradient and porosity. The basic equation of pore velocity is altered to account for the presence of LNAPL and flow in a multiphase system, as shown in Equation 1-1. Relative permeability is a modification to the velocity calculation as a whole to account for reduced permeability due to the presence of water and LNAPL. The presence of residual LNAPL effectively reduces the formation porosity; therefore, LNAPL saturation modifies the porosity parameter.

$$V_n = K_n \frac{J_n}{n} \left(\frac{k_{rn}}{S_n} \right) \qquad \text{Equation 1-1}$$

Where:

V_n = LNAPL pore velocity, cm/sec

K_n = LNAPL hydraulic conductivity, cm/sec

J_n = LNAPL hydraulic gradient, dimensionless

n = porosity, dimensionless

k_{rn} = LNAPL relative permeability, dimensionless

S_n = LNAPL saturation, dimensionless

The LNAPL relative permeability is determined from the relative fluid saturations within the impact zone and measurements of soil capillary properties. A full derivation of LNAPL relative permeability calculations can be found in API 4760. LNAPL conductivity is determined from the hydraulic conductivity, by considering modifications for the fluid property differences between water and LNAPL. The relationship between conductivities, density and viscosity is given in Equation 1-2.

$$K_n = K_w \frac{\rho_n \mu_w}{\rho_w \mu_n} \qquad \text{Equation 1-2}$$

Where:

K_n = LNAPL hydraulic conductivity, cm/sec

K_w = water hydraulic conductivity, cm/sec

ρ_n = LNAPL density, grams per cubic centimeter (g/cm^3)

ρ_w = water density, g/cm^3

μ_n = LNAPL viscosity, centipoise

μ_w = water viscosity, centipoise

An LNAPL gradient is preferentially calculated by spatial analysis of LNAPL fluid elevation data. However, LNAPL at this site is only observed in isolated wells suggesting that there is no contiguous LNAPL plume. Therefore, an assumed LNAPL gradient was calculated from the hydraulic gradient, with corrections for fluid density. Equation 1-3 presents this relationship between LNAPL and water gradients and densities.

$$J_n = J_w \frac{\rho_n}{\rho_w} \qquad \text{Equation 1-3}$$

Where:

J_w = water hydraulic gradient, dimensionless

ARCADIS created a mobility calculation spreadsheet based on equations provided in API technical documents, predominantly API 4760 LNAPL Distribution and Recovery Model – Volume 1: Distribution and Recovery of Petroleum Hydrocarbon Liquids in Porous Media (API 2007). The spreadsheet model uses step integration functions to calculate the expected LNAPL saturation and corresponding LNAPL relative permeability and LNAPL pore velocity. The spreadsheet requires the following inputs:

- Site characteristics: hydraulic gradient, hydraulic conductivity
- Fluid characteristics: LNAPL and water density, air-water-LNAPL interfacial tensions
- Aquifer characteristics: porosity, soil capillarity curve fitting parameters (van Genuchten N and alpha), irreducible water saturation and residual LNAPL saturation

1.2.4 LNAPL Pore-Entry Pressure Calculations

Lateral LNAPL migration into an unimpacted aquifer matrix that is saturated with groundwater requires displacement of either air or groundwater. In most aquifer systems, water is the wetting fluid (preferentially coating soil particles) and LNAPL is the non-wetting fluid. A positive capillary pressure (force) is required for LNAPL to displace water from the pores. When LNAPL displaces air as the wetting fluid, the resulting capillary pressure gradient pulls LNAPL into the air-filled pores, which results in capillary rise of LNAPL above the water table. This resistance to LNAPL movement into unimpacted soils at the periphery of the LNAPL plume explains why a calculated LNAPL pore velocity potential does not uniformly translate into actual movement of LNAPL.

The Brooks-Corey capillary pressure model is used to calculate the LNAPL pore-entry pressure into water-filled and air-filled soil pores. The Brooks-Corey model assumes that some minimum force is required for non-wetting fluid migration into water-saturated soil where no non-wetting fluid is present. This phenomenon is commonly observed for entry of air (a non-wetting fluid) into water-wet media.

The critical pressure (or LNAPL head) that must be exerted to force LNAPL into saturated soil can be calculated from physical properties of fluids in the system and laboratory-air-displacing-water pressure (capillarity) data. The laboratory capillarity data are fitted using the Brooks-Corey equation in RETC, a retention curve program for quantifying the hydraulic properties of unsaturated soils developed jointly by staff of

University of California-Riverside, PC-Progress, s.r.o. and Federal University of Rio de Janeiro. The Brooks-Corey model displacement-head fitting parameter is modified using the interfacial tensions of the fluids in the system to adapt the air/water displacement head to the equivalent LNAPL/water displacement head. The critical LNAPL thickness in a well is related to the displacement head (pressure data in centimeters [cm] of water) through a density correction. This mathematical relationship is shown in Equation 1-4.

$$b_{o(crit)} = \left(\frac{\sigma_{ow}}{(1-\rho_r)\sigma_{aw}} - \frac{\sigma_{ao}}{\rho_r \sigma_{aw}} \right) \cdot h_d \qquad \text{Equation 1-4}$$

Where:

$b_{o(crit)}$ = critical LNAPL thickness in well, cm

σ_{aw} = surface tension, dyne/centimeter (dyne/cm)

σ_{ao} = air-oil interfacial tension, dyne/cm

σ_{ow} = oil-water interfacial tension, dyne/cm

h_d = air displacing water pressure head, cm

1.3 Data

Sections 1.2.1, 1.2.2 and 1.2.3 describe data collected from site activities to support the analyses conducted as part of this LNAPL mobility assessment.

1.3.1 Hydraulic Gradient and Conductivity

Hydraulic gradient was derived from a simple calculation defined by Darcy's Slope and is presented in Equation 1-5.

$$i = \frac{dh}{dl} \qquad \text{Equation 1-5}$$

Where:

i = hydraulic gradient, dimensionless

dh = difference between two hydraulic heads, feet

dl = distance between the two wells where said hydraulic heads are measured, feet

Local hydraulic gradients were estimated in the areas of wells MW-30, MW-61A-R, RW-3 and RW-21 using water level data collected on April 13, 2010. Hydraulic gradients were calculated for the area immediately downgradient of the LNAPL impacted well. The hydraulic gradients used for LNAPL mobility calculations are summarized in the following table:

Well	Estimated Local Hydraulic Gradient (unitless)
MW-30	0.012
MW-61A-R	0.015
RW-3	0.014
RW-21	0.025

Due to tidal fluctuations in the Offsite Area and subsurface heterogeneity, hydraulic gradient calculations include the following assumptions:

- The prevailing groundwater flow direction is west toward Puget Sound.
- While Figure 15 of the 2010 Summary Report and Risk Evaluation (summary report) shows an overall trend toward Puget Sound, near RW-3, this is likely an incomplete description of actual site conditions. The potentiometric surface maps from the 2009 tidal study shows groundwater mounding near well MW-203 and there is likely limited groundwater flow from MW-203 toward RW-3 in the smear zone due to the abandoned shoring wall (ARCADIS 2010a). The hydraulic gradient of 0.014 ft/ft represents a maximum value calculated for that area of the site.
- Groundwater gradients could not be calculated upgradient of wells MW-30 or MW-61A-R. The downgradient hydraulic gradient was calculated and used for this study.
- The hydraulic gradient in well RW-21 is best represented by the gradient between RW-21 and RW-1.

Hydraulic conductivity was calculated based on data collected during the short-term aquifer pumping tests completed in August and September 2010 and described in Section 8.4 of the summary report. Hydraulic conductivity values used are summarized in Table 12 of the summary report.

1.3.2 LNAPL Physical Properties

Two primary LNAPL types are present in the subsurface at the site: diesel #2 and California crude oil. Diesel fuel is present near MW-61A-R; California crude oil is present near wells RW-3, RW-21 and MW-30. On March 19, 2009, LNAPL samples collected from MW-61A-R were sent to PTS Laboratories for analysis of density, viscosity and three interfacial tension pairs (ARCADIS 2010b). The LNAPL collected from MW-61A-R is assumed to be representative of LNAPL properties in the area of well MW-61A-R. Repeated attempts were made to collect an LNAPL sample from wells RW -3, RW-21 and MW-30 (California Crude sample) for physical properties analysis. However, due to the small volumes of LNAPL accumulation measured in wells RW-3, RW-21 and MW-30, insufficient LNAPL could be recovered. Therefore, literature values were used to represent the physical properties of California crude oil LNAPL in the area of wells MW-30, RW-3 and RW-21. The fluid physical properties used for this analysis are presented in Table L-1.

1.3.3 Soil Petrophysical Properties

During the installation of piezometer PZ-61A-R, soil cores were collected in 6-inch intervals from 10 to 19 feet bgs and submitted to Core Laboratories of Bakersfield, California for ultraviolet (UV) and natural light photography. The location of PZ-61A-R is shown on Figure 11.

After reviewing soil core photographs, petrophysical tests were designated for specific intervals from each of the soil cores to characterize aquifer-matrix parameters and fluid saturations. The laboratory tests performed are described below:

- *RSWD, Method API RP40*. This method forces water through the subsample to displace free LNAPL. This test provides porosity, field LNAPL saturation and residual LNAPL saturation under saturated conditions, which is expected to be greater than residual saturation under unsaturated conditions. The test is conducted at hydraulic gradients that far exceed typical site conditions; hence, values for residual LNAPL saturation measured using this method will be conservative as compared to field residual saturation.

- *FPM, Methods API RP 40 and ASTM D425M, Dean-Stark centrifugal method*. Centrifugal force at 1,000 times gravity is used to displace free LNAPL in a soil subsample with air. This test provides a conservative residual saturation that is lower than expected in the subsurface. This test provides several LNAPL mobility modeling input parameters, including field LNAPL saturation, residual LNAPL saturation and porosity.

- *Air-Water Capillary Pressure Drainage (AWCD), Method ASTM D6836, centrifugal method*. This method generates a Soil Water Characteristic Curve by measuring the amount of water displaced from a water-saturated sample by air under increasing amounts of centrifugal force.
- *Pore Fluid Saturation (PFS), Method API RP40*. This method gives additional data on field water and LNAPL saturations of core subsamples, which provides information on the variability of LNAPL saturation throughout the core.
- *Grain Size Analysis, Methods ASTM D422 and ASTM D446M*. This test provides a standard grain size distribution of the LNAPL-impacted soil. It is used to confirm field descriptions of the site geology and to determine how results of the above-mentioned tests will translate to other portions of the site.

Subsamples for each test were designated to target the most LNAPL-impacted portions of the cores, by targeting areas showing the highest UV fluorescence. Soil core photographs under white and UV light are included in Appendix M of the summary report. Laboratory analytical results are included in Appendix N of the summary report.

The van Genuchten soil capillarity fitting parameters (alpha and N) were determined for the soil cores using RETC, the Retention Curve Program for Unsaturated Soils. A soil moisture retention model (either Burdine or Mualem) must be selected to estimate the van Genuchten soil capillarity fitting parameters for use in the LNAPL pore velocity calculations. By comparing both the van Genuchten-Burdine (vG-B) and van Genuchten-Mualem (vG-M) models to laboratory AWCD test results using RETC, it is clear that both the vG-B and vG-M models match the laboratory data to a satisfactory degree (see Figure L-1). Based on the soil types in which LNAPL was encountered at the site (medium-grained sands), the vG-B relative permeability model was selected to represent the capillary characteristics of the sandier soils encountered at the site.

Table L-2 presents the aquifer characteristics of the site-specific soil cores determined from laboratory petrophysical testing. These data are used as inputs for the van Genuchten LNAPL mobility calculations.

1.4 LNAPL Mobility and Migration Assessment Results and Discussion

1.4.1 LNAPL Observations in Monitoring Wells

Groundwater and LNAPL gauging is currently conducted quarterly in wells RW-3, RW-21, MW-30 and MW-61A-R. Gauging data prior to 2002 are unavailable for well MW-30, gauging data prior to 2007 are unavailable for wells RW-3 and RW-21, and well MW-61A-R was installed in 2006. Since 2006, measureable thicknesses of LNAPL have rarely been observed in these wells, with the exception of well MW-61A-R. The LNAPL measured in well MW-61A-R has ranged in thickness from nondetectable to 0.52 foot since July 2008. When measurable, the thicknesses of LNAPL in wells RW-3, RW-21 and MW-30 do not appear to change with fluctuations of groundwater levels. LNAPL thicknesses in MW-61A-R have been relatively consistent since LNAPL was first observed and generally increase with a decrease in groundwater elevation (ARCADIS 2010b).

LNAPL has not been observed in any new wells under normal site conditions and observed well accumulation thicknesses are stable, therefore the LNAPL is not migrating. While LNAPL accumulations in site wells indicates that the LNAPL is mobile per the ITRC definition this is only indicative of the LNAPL being able to move within the existing LNAPL plume footprint and not outside of it.

1.4.2 LNAPL Field and Residual Saturations

LNAPL saturation was assessed on soil cores collected during installation of piezometer PZ-61A-R. Six soil core subsamples were tested for field (initial) saturations, which ranged between 0 and 10.7 percent. Two of the six soil core subsamples were additionally tested to determine residual saturation. Both subsample results demonstrated that field LNAPL saturations were at residual values (2.8 and 4.3 percent). Two of the six measured initial saturation values exceeded the reported residual saturation values. However, as previously mentioned, residual LNAPL saturation for a given soil is directly related to the maximum historical LNAPL saturation as well as LNAPL physical properties and inherent soil capillary characteristics. Field and LNAPL saturation values measured by laboratory analyses are summarized in Table L-3.

The data indicate that due to vertical heterogenetity the LNAPL is immobile in some vertical intervals (four of six intervals tested) as evidenced by the residual saturation measurements and may be mobile (two of six intervals tested), but not migratory in others.

1.4.3 LNAPL Pore Velocity Calculations

Figure L-2 presents LNAPL pore velocity potential for each location at the range of possible LNAPL saturation values (from an assumed residual LNAPL saturation of 4.3 percent at the left side of the graph to the irreducible water saturation at the right side). The maximum laboratory-measured LNAPL saturation values from the PZ-61A-R soil core are plotted on Figure L-2 for reference (maximum well saturation values are indicated by the solid markers along each curve). The calculated LNAPL pore velocities at MW-61A-R ranged from 5.6×10^{-6} to 6.2×10^{-6} cm/sec (Table L-4).

The points plotted on Figure L-2 for wells RW-3, RW-21 and MW-30 represent LNAPL velocities that correspond to LNAPL saturations likely to be present under recently observed LNAPL thicknesses. The maximum LNAPL thickness recently observed in each of these wells (0.01 to 0.02 foot) was used to calculate a maximum equilibrium LNAPL saturation in the formation. LNAPL pore velocity results are summarized in Table L-4; Appendix O of the summary report contains the input parameters and results for the LNAPL pore velocity calculations in detailed spreadsheet format for wells RW-3, RW-21 and MW-30. The theoretical LNAPL pore velocity at RW-3, RW-21 and MW-30 ranged between 7.6×10^{-13} and 1.8×10^{-12} cm/sec (Table L-4).

The pore velocity analysis was done under a presumption that the LNAPL is mobile, however the results indicate a de minimus LNAPL pore velocity potential for RW-3, RW-21, and MW-30 that is orders of magnitude below the 1x10-6 cm/sec ASTM velocity potential criterion. Therefore, LNAPL at these locations is considered immobile. Although the pore velocity potential at MW-61A-R slightly exceeds the ASTM standard and is considered mobile, this does not indicate that the LNAPL is migrating as is explained in Section 1.4.1.

1.4.4 LNAPL Pore Entry Pressure Calculations

LNAPL migration into pristine soils occurs when there is sufficient LNAPL head pressure present in the subsurface at the fringe of the LNAPL plume to displace groundwater from the soil pores. The calculated critical LNAPL head pressures that are required for lateral LNAPL migration into saturated soils are shown in Table L-5. These head pressures are converted into critical LNAPL thicknesses, which is a more easily measured indicator than head pressure. The head pressure required for plume expansion within the sandier materials at the site, expressed in LNAPL thickness units, is approximately 1.04 feet for the diesel #2 LNAPL and approximately 1.15 feet for the California crude oil LNAPL. The maximum LNAPL thickness observed since 2008 at the site is 0.52 foot, measured at well MW-61A-R. LNAPL critical thickness estimates compared to recently measured LNAPL thicknesses in monitoring wells are summarized in Table L-5. LNAPL critical thickness estimates compared to recently measured LNAPL thicknesses in monitoring wells are summarized in Table 4 of the summary report.

These results demonstrate that there is insufficient LNAPL head pressure in the subsurface for future migration of LNAPL into soils not previously impacted by LNAPL.

1.5 LNAPL Mobility and Migration Summary and Conclusions

The findings of this LNAPL mobility assessment are:

- LNAPL at RW-3, RW-21 and MW-30 is immobile and by definition not migrating
- LNAPL at MW-61A-R was alternately found to be immobile (residual saturation data) and mobile (pore velocity potential) but cannot migrate further.

A mobile but not migrating finding is common at sites where LNAPL accumulations are observed in wells. The pore velocity potential calculated for MW-61A-R does not imply that LNAPL is moving or will move at this velocity, only that LNAPL at this location is capable of low-velocity redistribution within the footprint of the existing LNAPL impacted soil. This is consistent with the empirical fluid-level data that demonstrates that LNAPL present at the site is stable. The lack of a contiguous LNAPL plume suggests that footprint of the mobile LNAPL plume is minimal.

2. References

American Petroleum Institute. 2007. LNAPL Distribution and Recovery Model Volume 1: Distribution and Recovery of Petroleum Hydrocarbon Liquids in Porous Media. Regulatory and Scientific Affairs Department, Technical Publication 4760. January 2007.

ARCADIS U.S., Inc. 2010a. Tidal Study Summary Report. March 25, 2010.

ARCADIS U.S., Inc. 2010b. Revised Work Plan for LNAPL Mobility Assessment, Natural Attenuation Monitoring and Surfactant Application Pilot Testing. January 19, 2010.

Interstate Technology & Regulatory Council. 2009. Evaluating LNAPL Remedial Technologies for Achieving Project Goals. LNAPL-2. Washington, D.C.: Interstate Technology & Regulatory Council, LNAPLs Team. www.itrcweb.org.

Table L-1
Laboratory Fluid Physical Properties

Former Unocal Seattle Marketing Terminal
3001 Elliott Avenue
Seattle, Washington

Parameter	Units	Value	Value
LNAPL Type Description		California Crude[1]	Diesel #2[2]
LNAPL Density	g/cm^3	0.85	0.8517
LNAPL Viscosity	g/cm-s	340	0.0363
Groundwater Density[1]	g/cm^3	0.9989	0.9989
Groundwater Viscosity[1]	g/cm-s	0.013	0.013
Air-Groundwater Interfacial (Surface) Tension[1]	Dyne/cm	61.8	61.8
Air-LNAPL Interfacial Tension[1]	Dyne/cm	37	27.5
LNAPL-Water Interfacial Tension[1]	Dyne/cm	25[3]	21.4

Notes:
1: California Crude Oil property obtained from API database. LNAPL properties obtained at 15 degrees Celsius.
2: Utilized site sample collected at RW-61A-R on June 4th, 2010.
3: LNAPL surface tension unavailable for California Crude, general crude oil property of API database used.

LNAPL = Light nonaqueous phase liquid
g/cm3 = grams per cubic centimeter
g/cm-s = grams per centimeter per second
Dyne/cm = Dynes per centimeter

Table L-2
Laboratory Aquifer Data for LNAPL Mobility Calculations

Former Unocal Seattle Marketing Terminal
3001 Elliott Avenue
Seattle, Washington

Parameter	Units	Soil Lithology
Soil Type Description	NA	Medium-grained Sand
Sample Depth	feet bgs	17.30-17.50
Relative Permeability Model	NA	Burdine
Porosity[1]	dimensionless	0.31
van Genuchten "N" [1]	dimensionless	2.59337
van Genuchten "α" [1]	1/cm	3.306×10^{-2}
Irreducible water saturation [1]	dimensionless	0.204
Residual LNAPL saturation [1]	dimensionless	0.043

Notes:
1: Utilized site sample collected at PZ-61A-R on June 4th, 2010.

feet bgs = feet below ground surface
NA = Not applicable
1/cm = per centimeter

Table L-3
Laboratory Results for Field and Residual LNAPL Saturation

Former Unocal Seattle Marketing Terminal
3001 Elliott Avenue
Seattle, Washington

Sample ID	Depth	Test	Field LNAPL Saturation	Residual LNAPL Saturation
	(ft bgs)	Method	(% Pore Volume)	(% Pore Volume)
PZ-61A-R	12.25-.45	FPM	4.3	4.3
PZ-61A-R	14.25-.45	PFS	4.1	NA
PZ-61A-R	15.15-.35	RSWD	2.8	2.8
PZ-61A-R	15.15-.35	PFS	10.7	NA
PZ-61A-R	15.55-.75	PFS	9.9	NA
PZ-61A-R	16.55-.75	PFS	ND	NA

Notes:
ft bgs = feet below ground surface
FPM = Free product mobility
PFS = Pore fluid saturation
RSWD = Residual saturation by water drive

Table L-4
LNAPL Velocity Under Site-Specific LNAPL Accumulation

Former Unocal Seattle Marketing Terminal
3001 Elliott Avenue
Seattle, Washington

Well	Soil type	Gradient	LNAPL Saturation (%Pv)	Hydraulic Conductivity (ft/day)	LNAPL Type	LNAPL Velocity (cm/s)
RW-3	Medium grained sand	0.014	4.3001 [1]	0.5	CA Crude	7.65×10^{-13}
RW-21	Medium grained sand	0.025	4.3001 [1]	0.3	CA Crude	8.43×10^{-13}
MW-30	Medium grained sand	0.012	4.3001 [1]	1.4	CA Crude	1.40×10^{-12}
PZ-61A-R (15.65)	Medium grained sand	0.015	9.9 [2]	12.5	Diesel #2	5.60×10^{-6}
PZ-61A-R (15.25)	Medium grained sand	0.015	10.7 [2]	12.5	Diesel #2	6.21×10^{-6}

Notes:
1: LNAPL Saturation Estimated Based on Maximum Recent LNAPL Thickness in Wells
2: Laboratory Determined LNAPL Saturation Results (Pore Fluid Saturation Test)

CA = California
%Pv = Percent pore volume
ft/day = feet per day
LNAPL = Light nonaqueous phase liquid
cm/s = centimeters per second

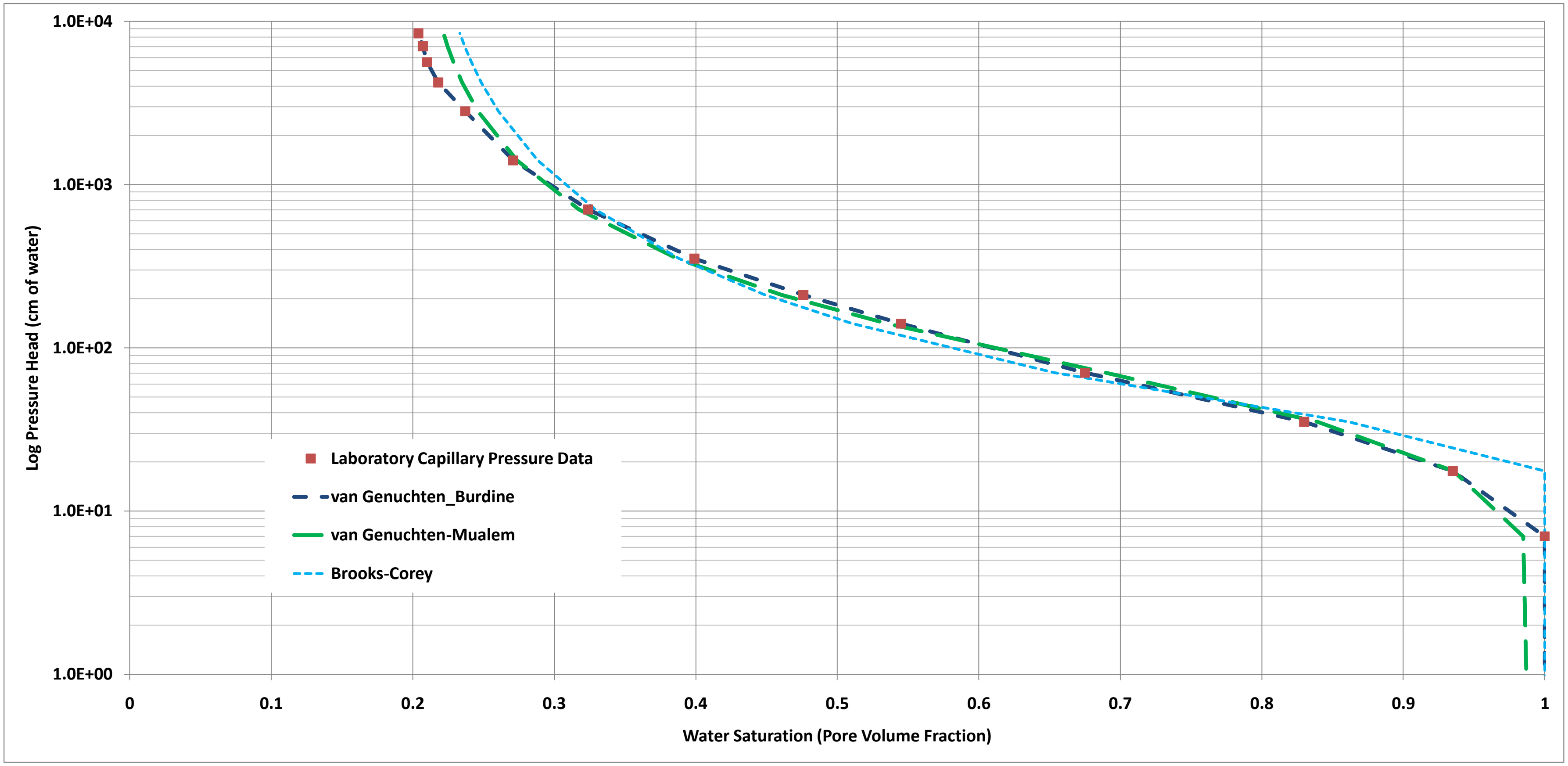
Table L-5
Summarized Results of Critical LNAPL Thickness Calculations Based on Brooks-Corey Capillary Model

Former Unocal Seattle Marketing Terminal
3001 Elliott Avenue
Seattle, Washington

Sample/Well ID	Displacement Head Pressure	Critical LNAPL Thickness	Recently Observed LNAPL Thickness
	h_d (cm H_2O)	$b_{o(crit)}$ (ft)	(ft)
PZ-61A-R (17.3-17.5)	17.6 [1]	1.04 [2]	0.52
RW-3	17.6 [1]	1.15 [3]	0.01
RW-21	17.6 [1]	1.15 [3]	0.02
MW-30	17.6 [1]	1.15 [3]	0.02

Notes:
1. Based on soil properties and the Brooks-Corey Fit to Air Water Capillary Drainage data from PZ-61A-R (17.3-17.5 ft bgs).
2. Critical LNAPL Thickness Based on Displacement Head Pressure and LNAPL Properties from MW-61A-R (Diesel #2).
3. Critical LNAPL Thickness Based on Displacement Head Pressure and Literature LNAPL Properties for California Crude

%Pv = Percent pore volume
ft = feet
LNAPL = Light nonaqueous phase liquid
cm H_2O = centimeters of water



LEGEND:

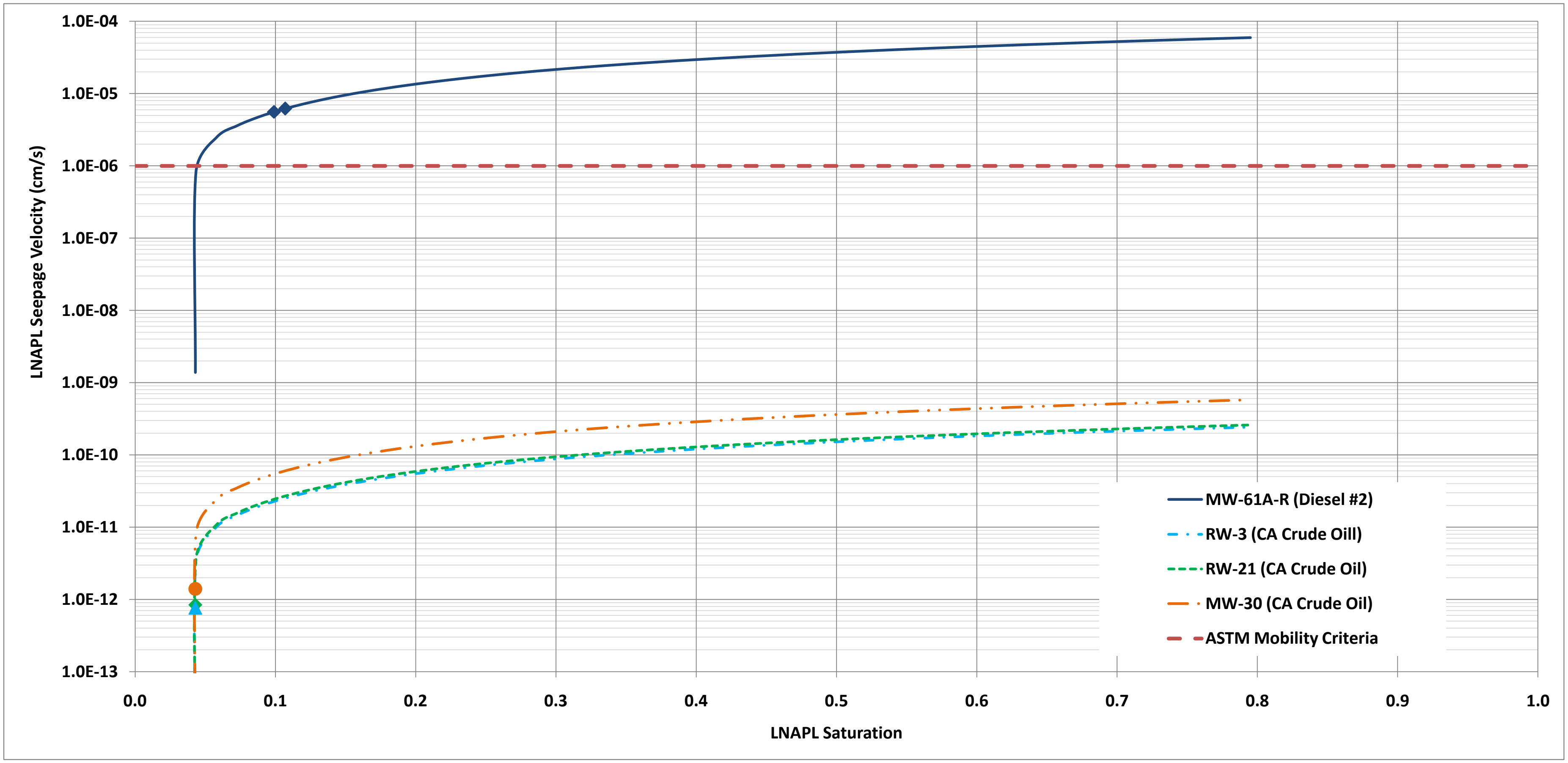
LNAPL = Light nonaqueous phase liquid
cm = centimeters

FORMER UNOCAL SEATTLE MARKETING TERMINAL
3001 ELLIOTT AVENUE. SEATTLE. WASHINGTON
2010 SUMMARY REPORT AND RISK EVALUATION

PZ-61A-R RETC MODEL OUTPUT FOR RELATIVE PERMABILITY MODELS

ARCADIS
Infrastructure, environment, facilities

FIGURE
L-1



LEGEND:
LNAPL = Light non-aqueous phase liquid
cm/s = centimeters per second
CA = California

FORMER UNOCAL SEATTLE MARKETING TERMINAL
3001 ELLIOTT AVENUE. SEATTLE. WASHINGTON
2010 SUMMARY REPORT AND CONCEPTUAL SITE MODEL

LNAPL SEEPAGE VELOCITY VERSUS LNAPL SATURATION

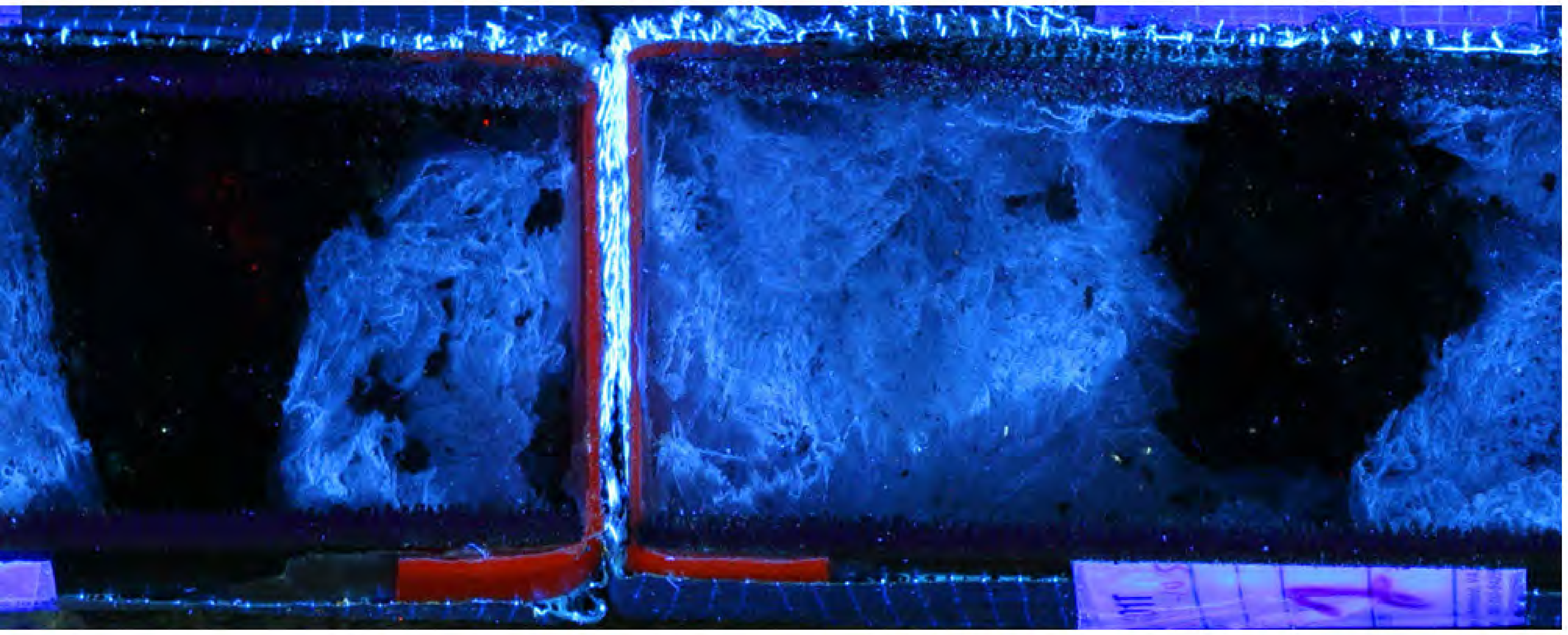
ARCADIS
Infrastructure, environment, facilities

FIGURE
L-2

ARCADIS

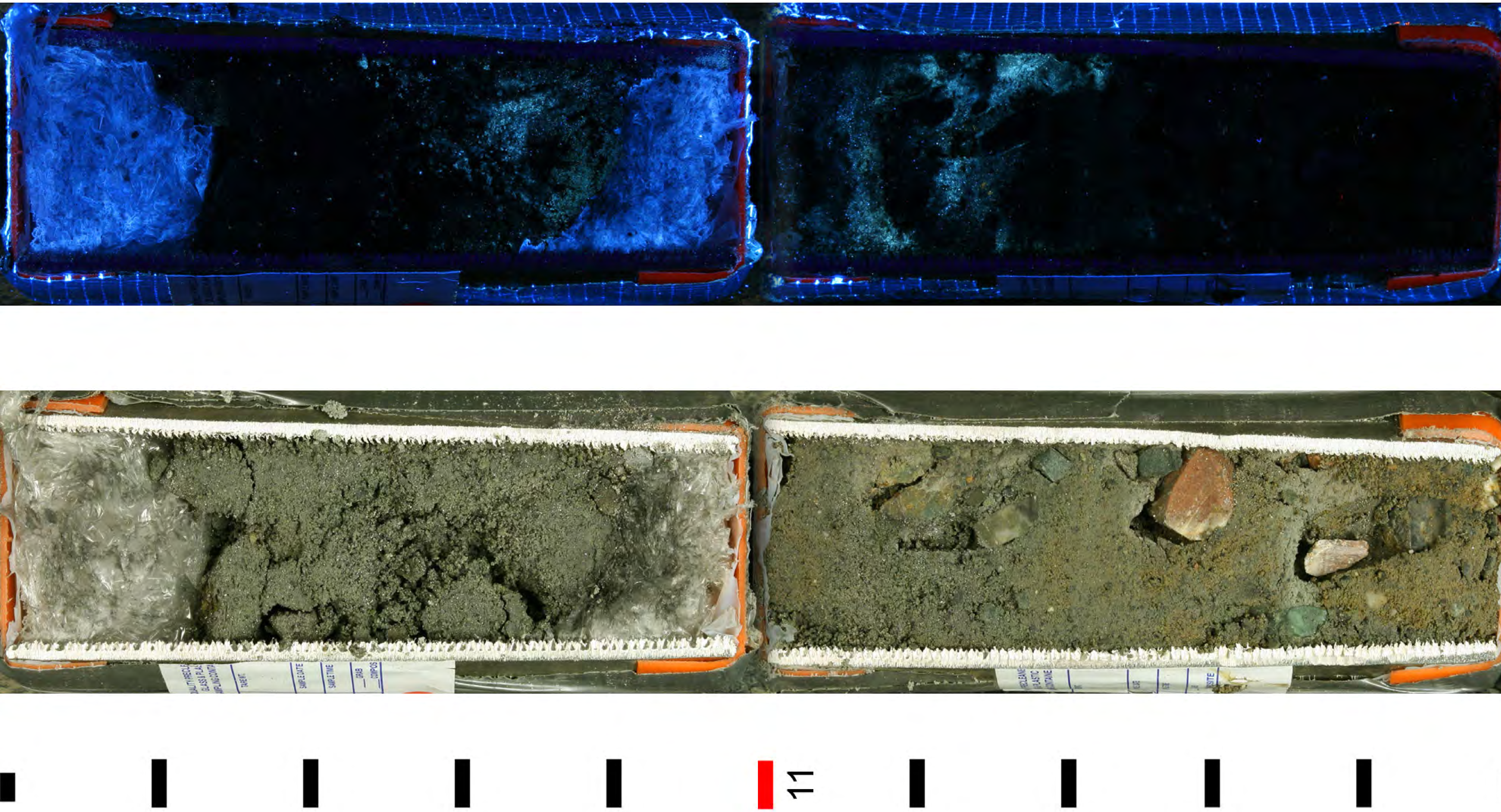
Appendix M

Soil Core
Photographs

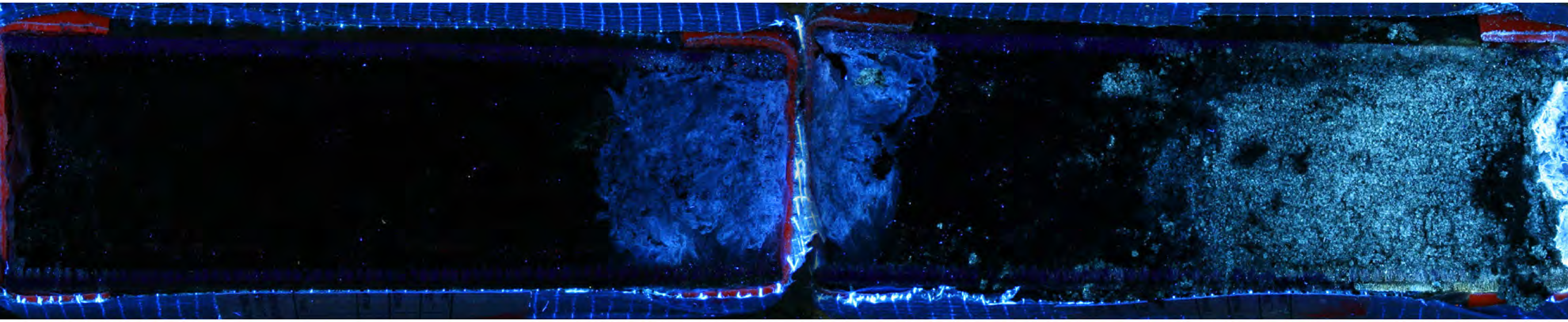


10

Company: Arcadis
Project: Former Unocal Seattle Terminal
Sample ID: PZ-61A-R



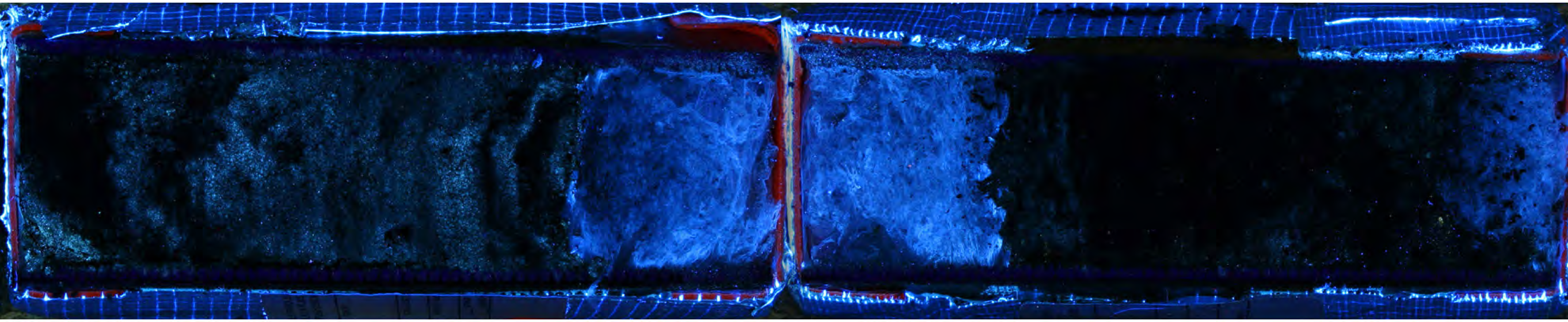
Company: Arcadis
Project: Former Unocal Seattle Terminal
Sample ID: PX-61A-R



12

Company: Arcadis
Project: Former Unocal Seattle Terminal
Sample ID: PX-61A-R

Core Lab
RESERVOIR OPTIMIZATION



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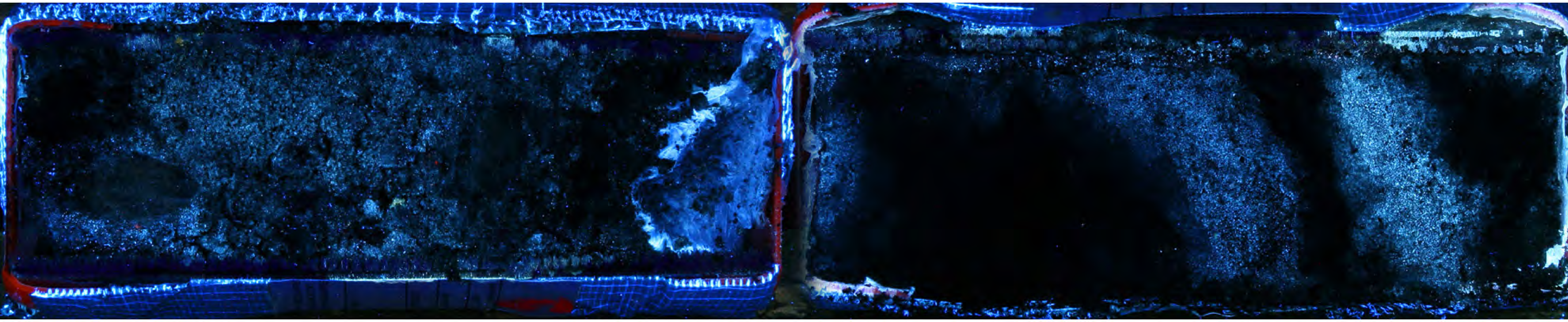
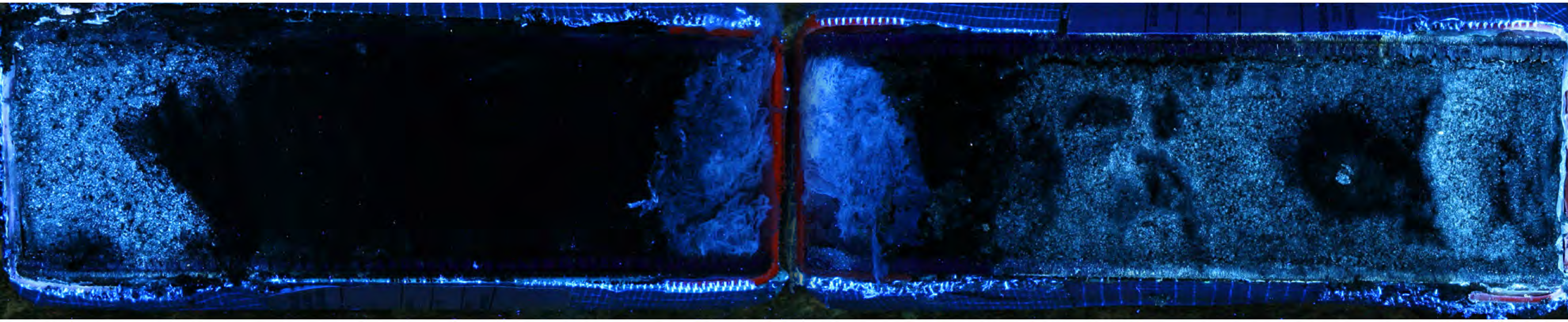
Company: Arcadis
Project: Former Unocal Seattle Terminal
Sample ID: PX-61A-R



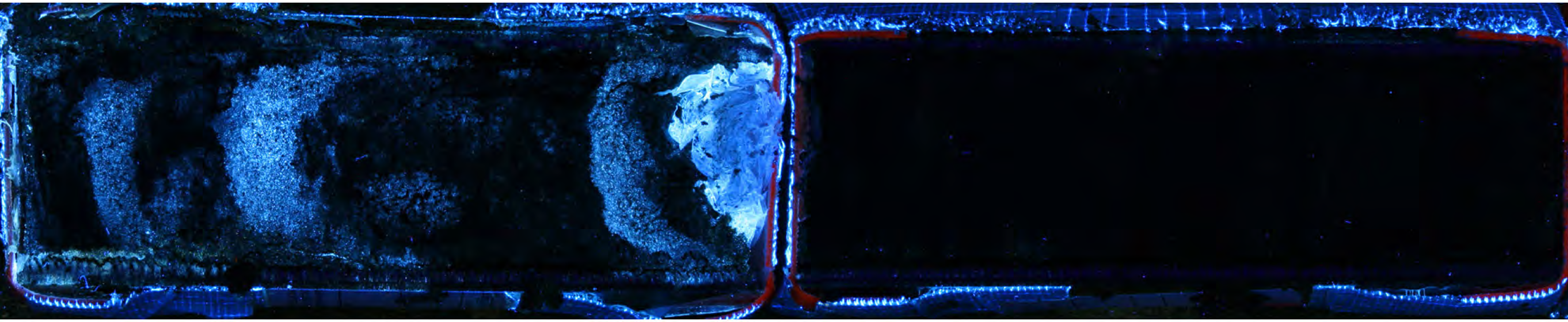
14

Company: Arcadis
Project: Former Unocal Seattle Terminal
Sample ID: PX-61A-R



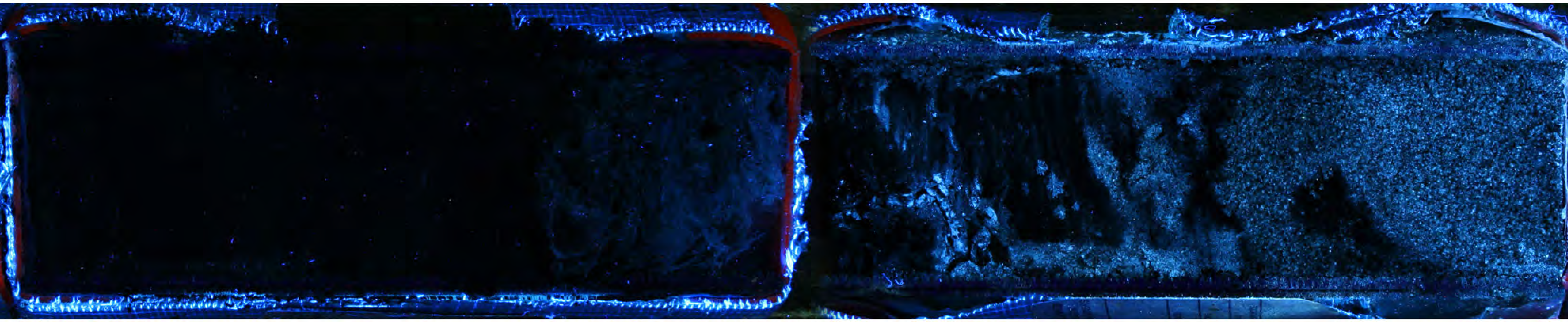
15

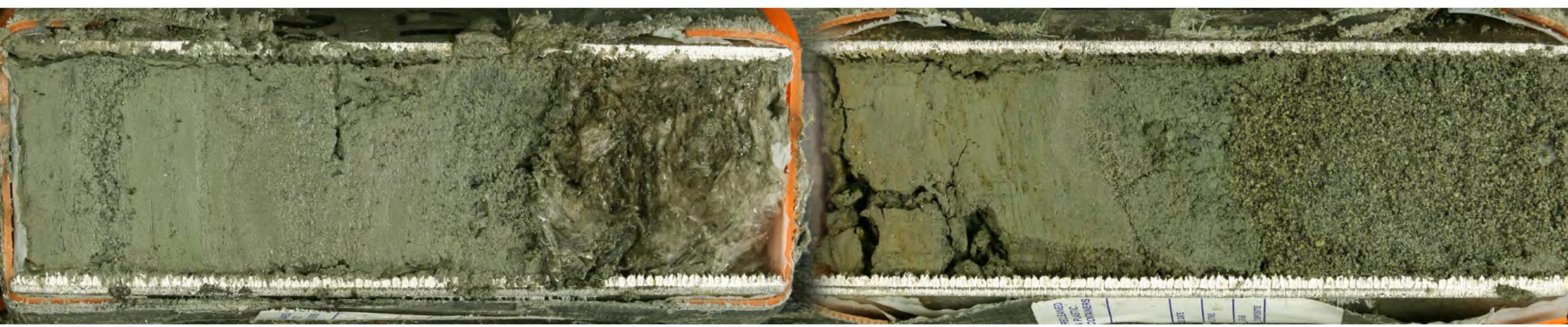
Company: Arcadis
Project: Former Unocal Seattle Terminal
Sample ID: PX-61A-R



16

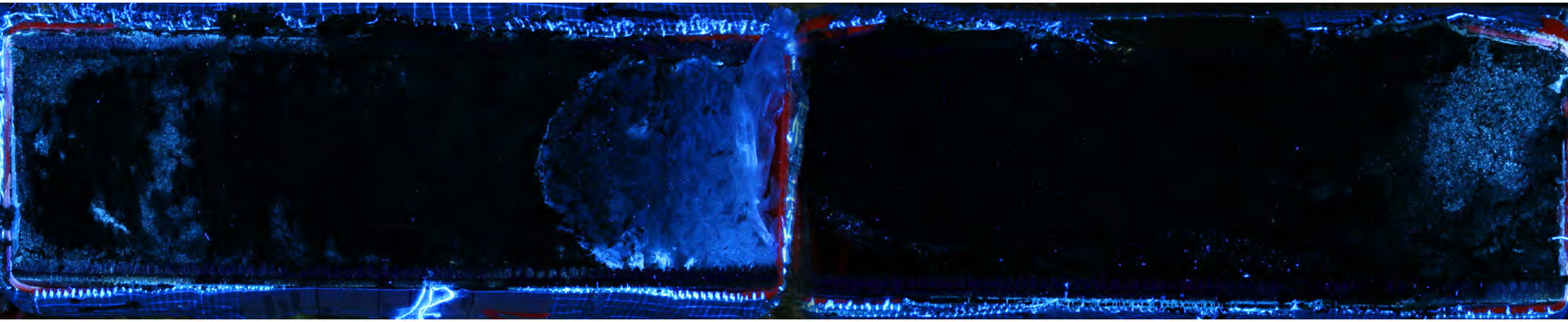
Company: Arcadis
Project: Former Unocal Seattle Terminal
Sample ID: PX-61A-R





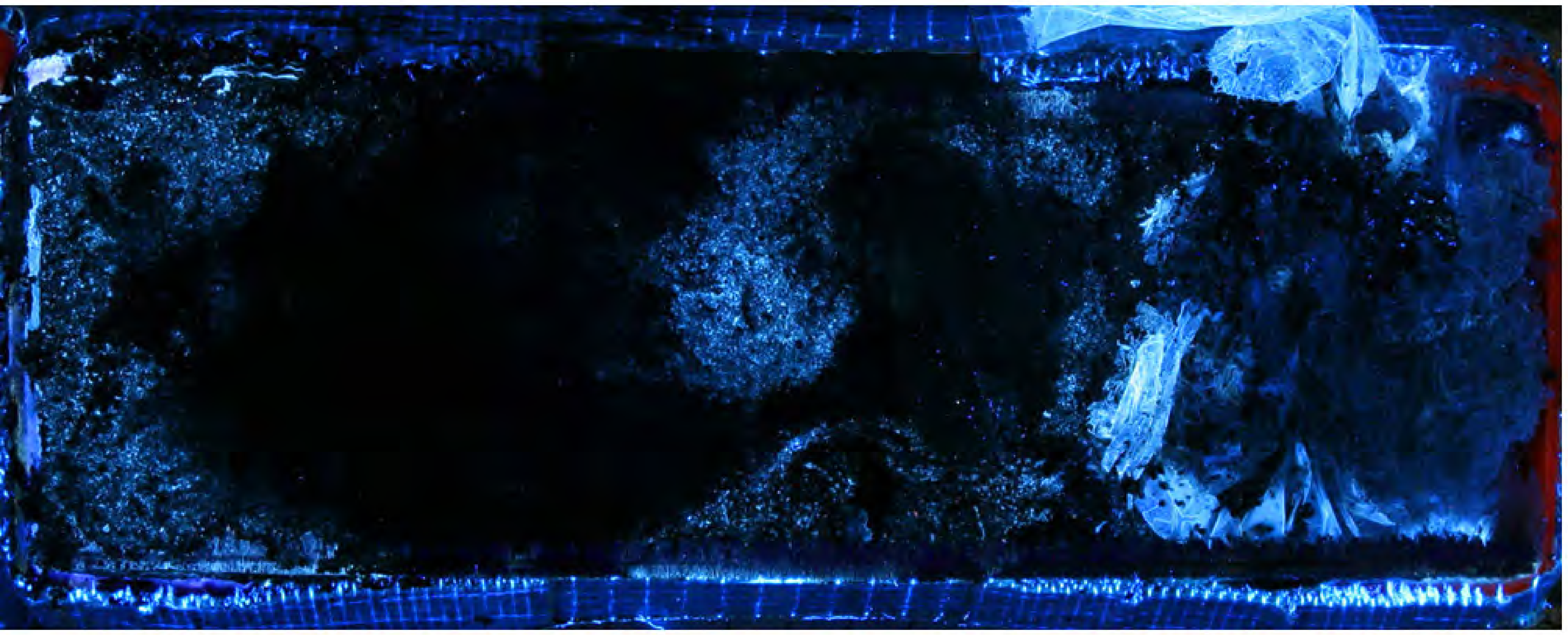
17

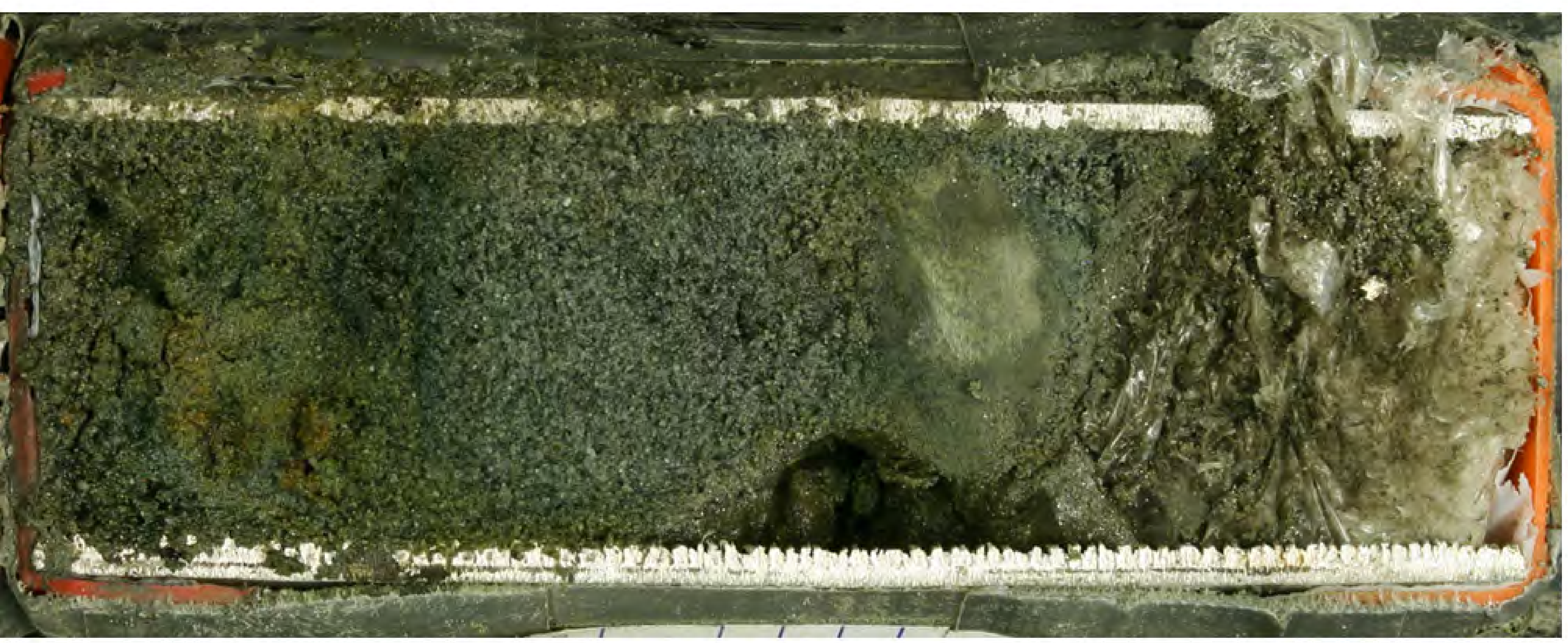
Company: Arcadis
Project: Former Unocal Seattle Terminal
Sample ID: PX-61A-R



18

Company: Arcadis
Project: Former Unocal Seattle Terminal
Sample ID: PX-61A-R





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Company: Arcadis
Project: Former Unocal Seattle Terminal
Sample ID: PX-61A-R

ARCADIS

Appendix N

Soil Core Laboratory Analytical Reports

Sieve and Laser Particle Size Analysis Summary

(METHODOLOGY: ASTM D422/D4464M)

Petroleum Services

Arcadis
Proj. Name : Former Unocal Seattle Terminal
Proj. No. :B0045363.0003.00006

Core Lab File No : 57111-410054EN
Date : 8/18/2010

Depth, ft.	Grain Size Description (Mean from Folk)	Median Grain Size, mm	Component Percentages								Silt & Clay
				Sand Size							
			Gravel	VCoarse	Coarse	Medium	Fine	VFine	Silt	Clay	
16.05-16.15	silt	0.02	0.00	0.00	1.01	4.85	6.52	10.04	61.01	16.58	77.6
17.30-17.50	mgr	0.44	0.27	15.26	27.84	30.00	8.83	3.26	10.94	3.60	14.5

Sieve and Laser Particle Size Analysis (Metric)

Petroleum Services

Comp. : Arcadis
Proj. Name : Former Unocal Seattle Terminal
Proj. No. : B0045363.0003.00006

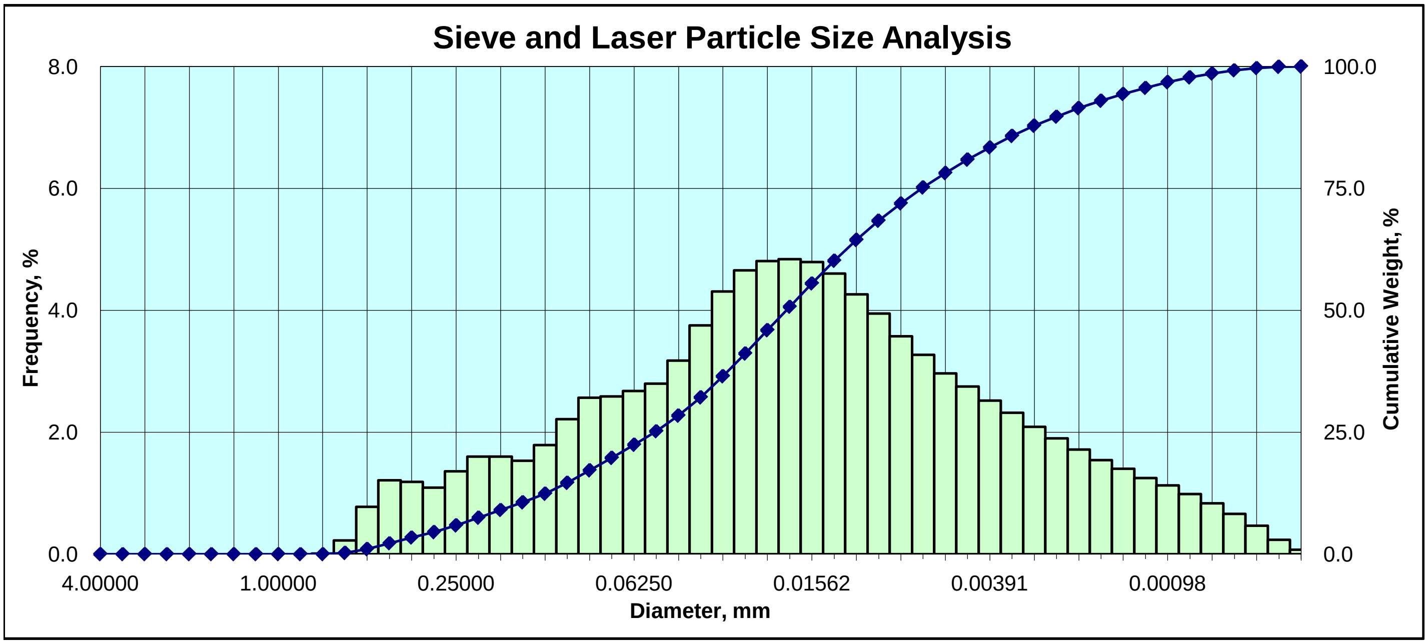
C.L. File No. : 57111-410054EN
Date : 8/18/2010

Sample Depth, ft.	Component Percentages								Percentiles										Sorting Statistics (Folk)				
	Gravel	Sand					Fines		Particle Diameter (mm)										Median	Mean	Sorting	Skew.	Kurt.
		vcgr	cgr	mgr	fgr	vfgr	silt	clay	5	10	16	25	40	50	75	84	90	95	mm	mm	ϕ		
16.05-16.15	0.00	0.00	1.01	4.85	6.52	10.04	61.01	16.58	0.2765	0.1585	0.0949	0.0529	0.0273	0.0190	0.0066	0.0037	0.0023	0.0013	0.019	0.019	2.343	0.006	1.062
									mgr	fgr	vfgr	silt	silt	silt	silt	clay	clay	clay	silt	silt	v. Poor	near sym	mesokurtic
17.30-17.50	0.27	15.26	27.84	30.00	8.83	3.26	10.94	3.60	1.5163	1.2154	0.9831	0.7532	0.5330	0.4387	0.2344	0.0897	0.0205	0.0060	0.439	0.338	2.074	0.439	1.944
									vcgr	vcgr	cgr	cgr	cgr	mgr	fgr	vfgr	silt	silt	mgr	mgr	v. Poor	str. fine	v. lepto.

** Particle-size distribution pattern precludes calculation of these statistical parameters

Comp. : Arcadis
Proj. Name : Former Unocal Seattle Terminal
Proj. No. : B0045363.0003.00006

CL File No. : 57111-410054EN
Depth : 16.05-16.15



Particle Size Distribution

	Diameter [US Mesh]	Diameter [in.]	Diameter [mm]	Diameter [ϕ]	Weight % [Incl.]	Weight % [Cum.]
Granule	5	0.157480	4.00000	-2.00	0.000	0.00
	6	0.132425	3.36359	-1.75	0.000	0.00
	7	0.111355	2.82843	-1.50	0.000	0.00
	8	0.093638	2.37841	-1.25	0.000	0.00
	10	0.078740	2.00000	-1.00	0.000	0.00
V Crse Sand	12	0.066212	1.68179	-0.75	0.000	0.00
	14	0.055678	1.41421	-0.50	0.000	0.00
	16	0.046819	1.18921	-0.25	0.000	0.00
	18	0.039370	1.00000	0.00	0.000	0.00
Coarse Sand	20	0.033106	0.84090	0.25	0.000	0.00
	25	0.027839	0.70711	0.50	0.006	0.01
	30	0.023410	0.59460	0.75	0.226	0.23
	35	0.019685	0.50000	1.00	0.776	1.01
Medium Sand	40	0.016553	0.42045	1.25	1.210	2.22
	45	0.013919	0.35355	1.50	1.187	3.41
	50	0.011705	0.29730	1.75	1.090	4.50
	60	0.009843	0.25000	2.00	1.358	5.85
Fine Sand	70	0.008277	0.21022	2.25	1.601	7.45
	80	0.006960	0.17678	2.50	1.597	9.05
	100	0.005852	0.14865	2.75	1.531	10.58
	120	0.004921	0.12500	3.00	1.787	12.37
V. Fine Sand	140	0.004138	0.10511	3.25	2.211	14.58
	170	0.003480	0.08839	3.50	2.564	17.14
	200	0.002926	0.07433	3.75	2.587	19.73
Silt	230	0.002461	0.06250	4.00	2.675	22.41
	270	0.002069	0.05256	4.25	2.794	25.20
	325	0.001740	0.04419	4.50	3.174	28.37
	400	0.001463	0.03716	4.75	3.754	32.13
	450	0.001230	0.03125	5.00	4.307	36.44
	500	0.001035	0.02628	5.25	4.657	41.09
	635	0.000870	0.02210	5.50	4.806	45.90
		0.000732	0.01858	5.75	4.839	50.74
		0.000615	0.01562	6.00	4.793	55.53
		0.000517	0.01314	6.25	4.605	60.13
		0.000435	0.01105	6.50	4.262	64.40
		0.000366	0.00929	6.75	3.944	68.34
		0.000308	0.00781	7.00	3.574	71.92
		0.000259	0.00657	7.25	3.270	75.19
		0.000217	0.00552	7.50	2.962	78.15
		0.000183	0.00465	7.75	2.749	80.90
		0.000154	0.00391	8.00	2.519	83.42
Clay		0.000129	0.00328	8.25	2.316	85.73
		0.000109	0.00276	8.50	2.089	87.82
		0.000091	0.00232	8.75	1.901	89.72
		0.000077	0.00195	9.00	1.714	91.44
		0.000065	0.00164	9.25	1.542	92.98
		0.000054	0.00138	9.50	1.399	94.38
		0.000046	0.00116	9.75	1.249	95.63
		0.000038	0.00098	10.00	1.127	96.75
		0.000032	0.00082	10.25	0.986	97.74
		0.000027	0.00069	10.50	0.832	98.57
		0.000023	0.00058	10.75	0.657	99.23
		0.000019	0.00049	11.00	0.463	99.69
		0.000016	0.00041	11.25	0.235	99.93
		0.000015	0.00038	11.50	0.073	100.00

Sorting Statistics (Folk)

Parameter	Trask	Inman	Folk
Median	Silt sized		
(in)	0.0007	0.0007	0.0007
(mm)	0.0190	0.0190	0.0190
Mean	Silt sized		
(in)	0.0012	0.0007	0.0007
(mm)	0.0298	0.0189	0.0189
Sorting	V. Poor		
	2.825	0.199	2.343
Skewness	Near symmetrical		
	0.984	0.010	0.006
Kurtosis	Mesokurtic		
	0.148	0.666	1.062

Component Percentages

Gravel	Sand	Silt	Clay	Silt + Clay
0.00	22.41	61.01	16.58	77.59

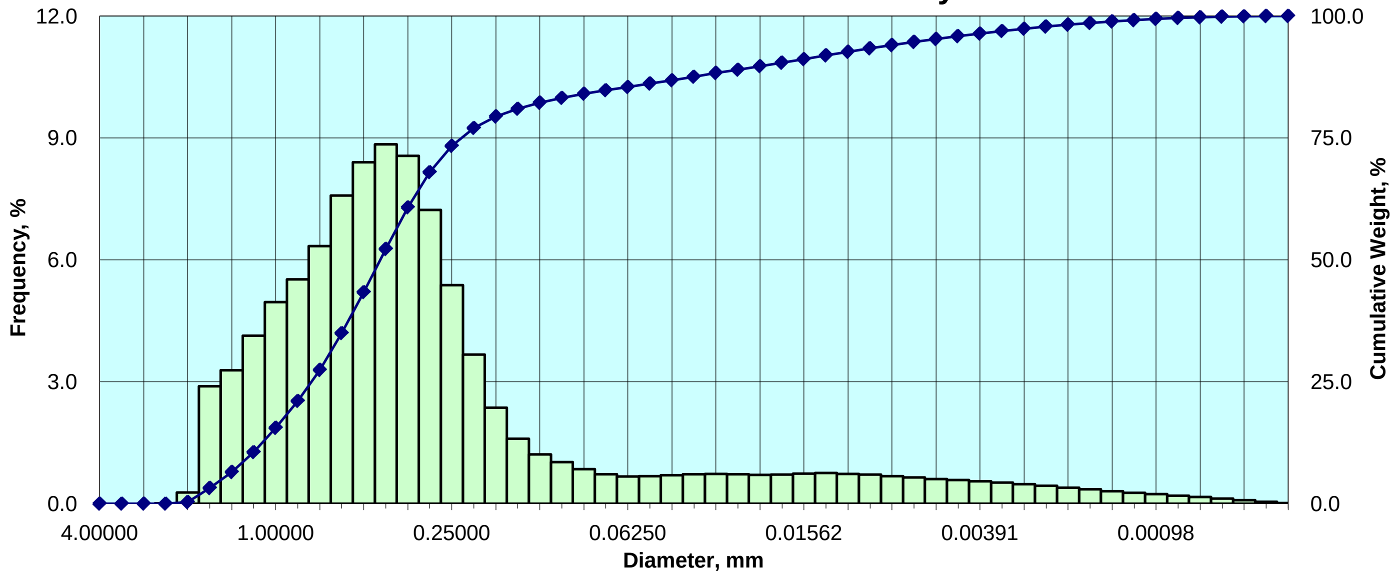
Percentile [Weight, %]	Particle Diameter [in.]	Particle Diameter [mm]	Particle Diameter [phi]
5	0.0109	0.2765	1.8545
10	0.0062	0.1585	2.6570
16	0.0037	0.0949	3.3976
25	0.0021	0.0529	4.2394
40	0.0011	0.0273	5.1955
50	0.0007	0.0190	5.7152
75	0.0003	0.0066	7.2364
84	0.0001	0.0037	8.0610
90	0.0001	0.0023	8.7890
95	0.0000	0.0013	9.6223

** Distribution pattern precludes calculation of these statistical parameters.

Comp. : Arcadis
Proj. Name : Former Unocal Seattle Terminal
Proj. No. : B0045363.0003.00006

CL File No. : 57111-410054EN
Depth : 17.30-17.50

Sieve and Laser Particle Size Analysis



Particle Size Distribution

	Diameter				Weight %	
	[US Mesh]	[in.]	[mm]	[φ]	[Incl.]	[Cum.]
Granule	5	0.157480	4.00000	-2.00	0.000	0.00
	6	0.132425	3.36359	-1.75	0.000	0.00
	7	0.111355	2.82843	-1.50	0.000	0.00
	8	0.093638	2.37841	-1.25	0.001	0.00
	10	0.078740	2.00000	-1.00	0.271	0.27
V Crse Sand	12	0.066212	1.68179	-0.75	2.886	3.16
	14	0.055678	1.41421	-0.50	3.281	6.44
	16	0.046819	1.18921	-0.25	4.130	10.57
	18	0.039370	1.00000	0.00	4.962	15.53
Coarse Sand	20	0.033106	0.84090	0.25	5.521	21.05
	25	0.027839	0.70711	0.50	6.334	27.39
	30	0.023410	0.59460	0.75	7.579	34.97
	35	0.019685	0.50000	1.00	8.404	43.37
Medium Sand	40	0.016553	0.42045	1.25	8.840	52.21
	45	0.013919	0.35355	1.50	8.558	60.77
	50	0.011705	0.29730	1.75	7.223	67.99
	60	0.009843	0.25000	2.00	5.379	73.37
Fine Sand	70	0.008277	0.21022	2.25	3.666	77.04
	80	0.006960	0.17678	2.50	2.358	79.39
	100	0.005852	0.14865	2.75	1.593	80.99
	120	0.004921	0.12500	3.00	1.212	82.20
V. Fine Sand	140	0.004138	0.10511	3.25	1.019	83.22
	170	0.003480	0.08839	3.50	0.849	84.07
	200	0.002926	0.07433	3.75	0.720	84.79
Silt	230	0.002461	0.06250	4.00	0.669	85.46
	270	0.002069	0.05256	4.25	0.673	86.13
	325	0.001740	0.04419	4.50	0.698	86.83
	400	0.001463	0.03716	4.75	0.722	87.55
	450	0.001230	0.03125	5.00	0.731	88.28
	500	0.001035	0.02628	5.25	0.720	89.00
	635	0.000870	0.02210	5.50	0.706	89.71
		0.000732	0.01858	5.75	0.713	90.42
		0.000615	0.01562	6.00	0.737	91.16
		0.000517	0.01314	6.25	0.749	91.91
		0.000435	0.01105	6.50	0.729	92.64
		0.000366	0.00929	6.75	0.713	93.35
		0.000308	0.00781	7.00	0.672	94.02
		0.000259	0.00657	7.25	0.642	94.66
		0.000217	0.00552	7.50	0.602	95.26
		0.000183	0.00465	7.75	0.583	95.85
		0.000154	0.00391	8.00	0.552	96.40
Clay		0.000129	0.00328	8.25	0.520	96.92
		0.000109	0.00276	8.50	0.476	97.40
		0.000091	0.00232	8.75	0.436	97.83
		0.000077	0.00195	9.00	0.392	98.22
		0.000065	0.00164	9.25	0.348	98.57
		0.000054	0.00138	9.50	0.307	98.88
		0.000046	0.00116	9.75	0.267	99.14
		0.000038	0.00098	10.00	0.231	99.38
		0.000032	0.00082	10.25	0.196	99.57
		0.000027	0.00069	10.50	0.161	99.73
		0.000023	0.00058	10.75	0.124	99.86
		0.000019	0.00049	11.00	0.086	99.94
		0.000016	0.00041	11.25	0.043	99.99
		0.000015	0.00038	11.50	0.014	100.00

Sorting Statistics (Folk)

Parameter	Trask	Inman	Folk
Median	Medium sand sized		
(in)	0.0173	0.0173	0.0173
(mm)	0.4387	0.4387	0.4387
Mean	Medium sand sized		
(in)	0.0194	0.0117	0.0133
(mm)	0.4938	0.2970	0.3382
Sorting	V. Poor		
	1.792	0.302	2.074
Skewness	Strongly fine skewed		
	0.958	1.277	0.439
Kurtosis	Very leptokurtic		
	0.217	1.313	1.944

Component Percentages

Gravel	Sand	Silt	Clay	Silt + Clay
0.27	85.18	10.94	3.60	14.54

Percentile [Weight, %]	Particle Diameter [in.]	[mm]	[phi]
5	0.0597	1.5163	-0.6006
10	0.0478	1.2154	-0.2814
16	0.0387	0.9831	0.0246
25	0.0297	0.7532	0.4089
40	0.0210	0.5330	0.9078
50	0.0173	0.4387	1.1887
75	0.0092	0.2344	2.0927
84	0.0035	0.0897	3.4785
90	0.0008	0.0205	5.6073
95	0.0002	0.0060	7.3882

** Distribution pattern precludes calculation of these statistical parameters.

1/1

CHAIN OF CUSTODY RECORD

Company: ARCADIS

Address: 2300 Eastlake Avenue East, Suite 200
Seattle, WA 98102

Project Manager: Rebecca Andresen — Phone: 206-726-4717

Project Name: Former Unocal Seattle Terminal — Fax: 206-325-8218

Project No. B0045363.0003.00006 — Email: Rebecca.Andresen@arcadis-us.com

Site Location: 3001 Elliott Avenue, Seattle, WA

Sampler Signature: [signature]

PO#: B0045363.0003.00006

Turnaround Time: 24 HR [ ] 48 HR [ ] 72 HR [ ] 5 Day [ ] Normal [X]

CL Bid No.: Q10-036EN

CL File No.: 41005HEN

ANALYSIS REQUEST

SOIL: Vadose Zone Suite; Saturated Zone Suite; Pore Fluid Saturation Suite; Moisture Content: ASTM D2216; Porosity: Total, API RP40; Porosity: Effective, ASTM D425M; Bulk Density: API RP40 / ASTM D2937; Hydraulic Conductivity: API RP40; Grain Size Distribution: ASTM D422/D4464M; Atterberg Limits: ASTM D4318; TOC: Walkley-Black

FLUID: Fluid Properties Suite; Viscosity: ASTM D445; Density/Gravity: ASTM D1481; Pryo-Chromatography (Fingerprinting); Interfacial Tension - ASTM D971

Sample ID	Date	Time	Depth, ft.	Number of Samples	Comments
PZ-61A-R-10.0-10.25	6/4/10		10-10.25	✓	HOLD PRESERVED FOR ANALYSIS
PZ-61A-R-10.25-10.5			10.25-10.5	✓	
PZ-61A-R-10.5-11.0			10.5-11.0	✓	
PZ-61A-R-11.0-11.5			11.0-11.5	✓	
PZ-61A-R-11.5-12.0			11.5-12.0	✓	
PZ-61A-R-12.0-12.5			12.0-12.5	✓	
PZ-61A-R-12.5-13.0			12.5-13.0	✓	
PZ-61A-R-13.0-13.5			13.0-13.5	✓	
PZ-61A-R-13.5-14.0			13.5-14.0	✓	
PZ-61A-R-14.5-15.0			14.5-15.0	✓	
PZ-61AR-15.0-15.5			15.0-15.5	✓	
PZ-61AR-15.5-16.0			15.5-16.0	✓	
PZ-61A-R-16.0-16.5			16.0-16.5	✓	
PZ-61A-R-16.5-17.0			16.5-17.0	✓	
PZ-61A-R-17.0-17.5			17.0-17.5	✓	
PZ-61A-R-17.5-18.0			17.5-18.0	✓	
PZ-61A-R-18.0-18.5			18.0-18.5	✓	
PZ-61A-R-18.5-19.0			18.5-19.0	✓	
* PZ-61A-R-14.0-14.5			14.0-14.5	✓ [illegible] total	

1. Relinquished By:	2. Received By:	2. Relinquished By:	2. Received By:
[signature]	FedEx / Tamee Hyh		
Company: ARCADIS	Company: Corelab	Company:	Company:
Date: 6/4/10 Time: 1538	Date: 6/4/10 Time: 1530	Date: Time:	Date: Time:

06.05.10 1530

CORE LABORATORIES - 3437 Landco Dr. - Bakersfield, CA 93308 • Phone 661-325-5657 • Fax 661-325-5808

* out of sequence. I put it in sequence - #10 vs #19

PORE FLUID SATURATION DATA

PETROLEUM SERVICES

Arcadis U.S., Inc.

Core Lab File No: 410054EN

Project Name Former Unocal Seattle Terminal
Project No: B0045363.0003.00006

	METHODS:		API RP 40 / ASTM D2216	API RP 40		API RP 40		API RP 40	
Sample ID.	Depth ft.	Sample Orientation (1)	Moisture Content percent	Density g/cc		Porosity %Vb (2)		Pore Fluid Saturations, % Pv (3)	
				Dry Bulk	Grain	Total	Air Filled	Water	NAPL
PZ-61A-R	14.25-45	V	15.8	1.82	2.57	29.3	0.3	94.9	4.1
PZ-61A-R	15.15-.35	V	13.5	1.83	2.57	28.8	3.5	77.0	10.7
PZ-61A-R	15.55-.75	V	14.4	1.86	2.57	27.6	0.2	89.5	9.9
PZ-61A-R	16.55-.75	V	16.6	1.80	2.74	34.2	4.1	87.8	ND

(1) Sample Orientation: H = horizontal; V = vertical
(2) Total Porosity = no pore fluids in place; all interconnected pore channels; Air Filled = pore channels not occupied by pore fluids
(3) Water = 0.9996 g/cc, Hydrocarbon = 0.80 g/cc;
Vb = Bulk Volume, cc; Pv = Pore Volume, cc; ND = Not Detected

AIR/WATER CAPILLARY PRESSURE SUMMARY

(ASTM D6836; Centrifugal Method: air displacing water)

Core Lab
RESERVOIR OPTIMIZATION

PETROLEUM SERVICES

ARCADIS

Core Lab File No: 410054EN

Project Name: Former Unocal Seattle Terminal
Project No: B0045363.0003.00006

Sample Depth Interval, feet	Boring	Total Porosity, fraction	Bulk Density, gm/cc	Specific Permeability, md		Water Saturation, percent pore volume															
						Capillary Pressure															
				Air	Water	psi	0.0	0.10	0.25	0.50	1.0	2.0	3.0	5.0	10.0	20.0	40.0	60.0	80.0	100.0	120.0
						cm	0.0	7	18	35	70	141	211	352	703	1406	2812	4219	5625	7031	8437
16.05 - 16.15	PZ-61A-R	0.315	1.87	9.33	0.351		1.00	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.973	0.908	0.788	0.696	0.637	0.588	0.555
17.3 - 17.5	PZ-61A-R	0.310	1.88	2719	125		1.00	1.000	0.935	0.830	0.675	0.545	0.476	0.399	0.324	0.271	0.237	0.218	0.210	0.207	0.204

AIR/WATER CAPILLARY PRESSURE

(ASTM D6836; Centrifugal Method: air displacing water)

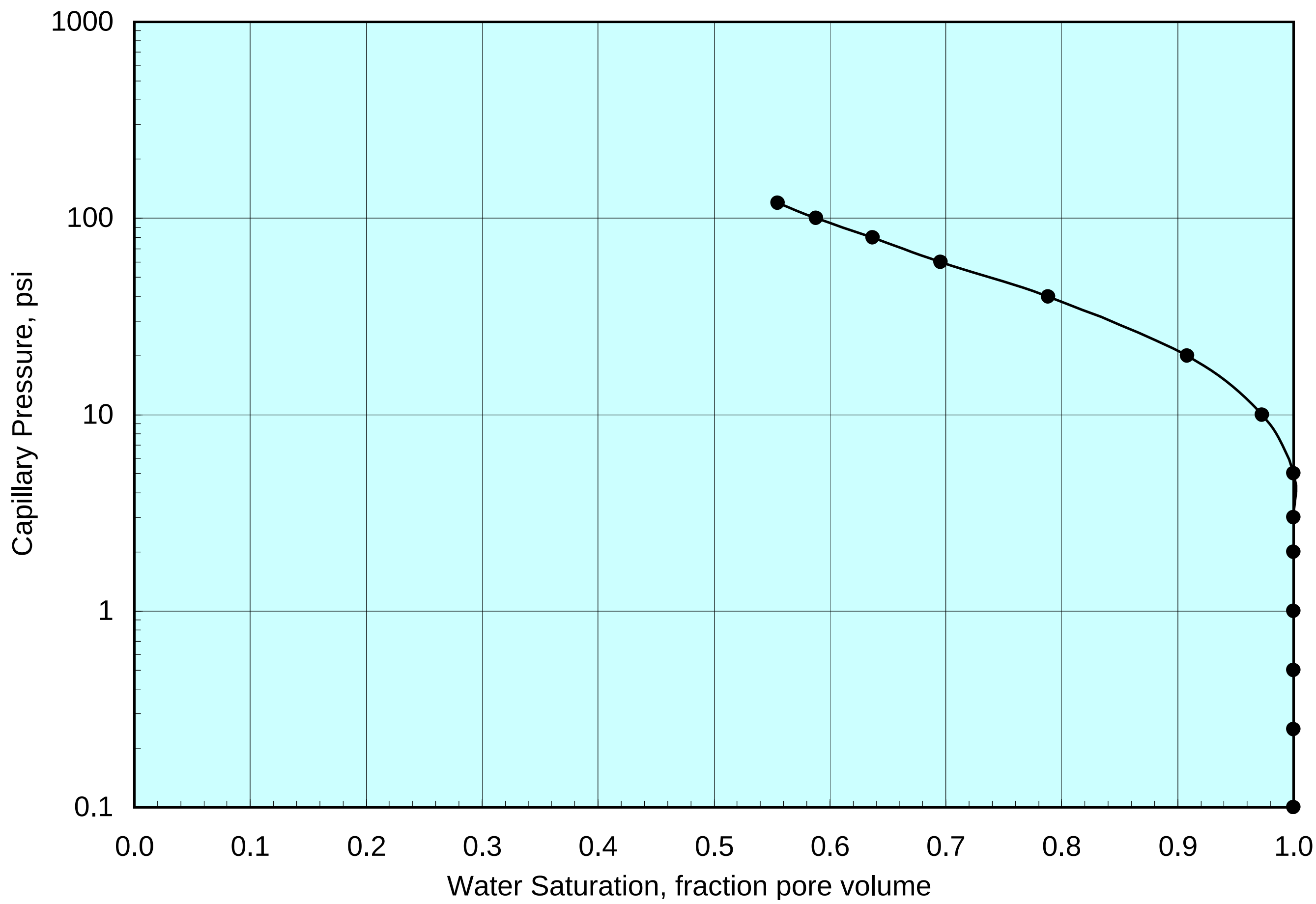
PETROLEUM SERVICES

ARCADIS

Core Lab File No: 410054EN

Project Name: Former Unocal Seattle Terminal
Project No: B0045363.0003.00006

Sample Number	Sample Depth Interval, feet	Boring	Total Porosity, fraction	Bulk Density, gm/cc	Specific Air Permeability mD	Capillary Pressure psi	Capillary Pressure cm water	Height Above Water Table, ft	Water Saturation, frac PV
3	16.05 - 16.15	PZ-61A-R	0.315	1.87	9.33	0.0	0.0	0.00	1.000
						0.10	7.0	0.23	1.000
						0.25	17.6	0.58	1.000
						0.50	35.2	1.16	1.000
						1.0	70.3	2.31	1.000
						2.0	140.6	4.63	1.000
						3.0	210.9	6.94	1.000
						5.0	351.6	11.57	1.000
						10.0	703.1	23.14	0.973
						20.0	1406.2	46.29	0.908
						40.0	2812.4	92.57	0.788
						60.0	4218.6	138.86	0.696
						80.0	5624.8	185.14	0.637
						100.0	7031.0	231.43	0.588
						120.0	8437.2	277.71	0.555



AIR/WATER CAPILLARY PRESSURE

(ASTM D6836; Centrifugal Method: air displacing water)

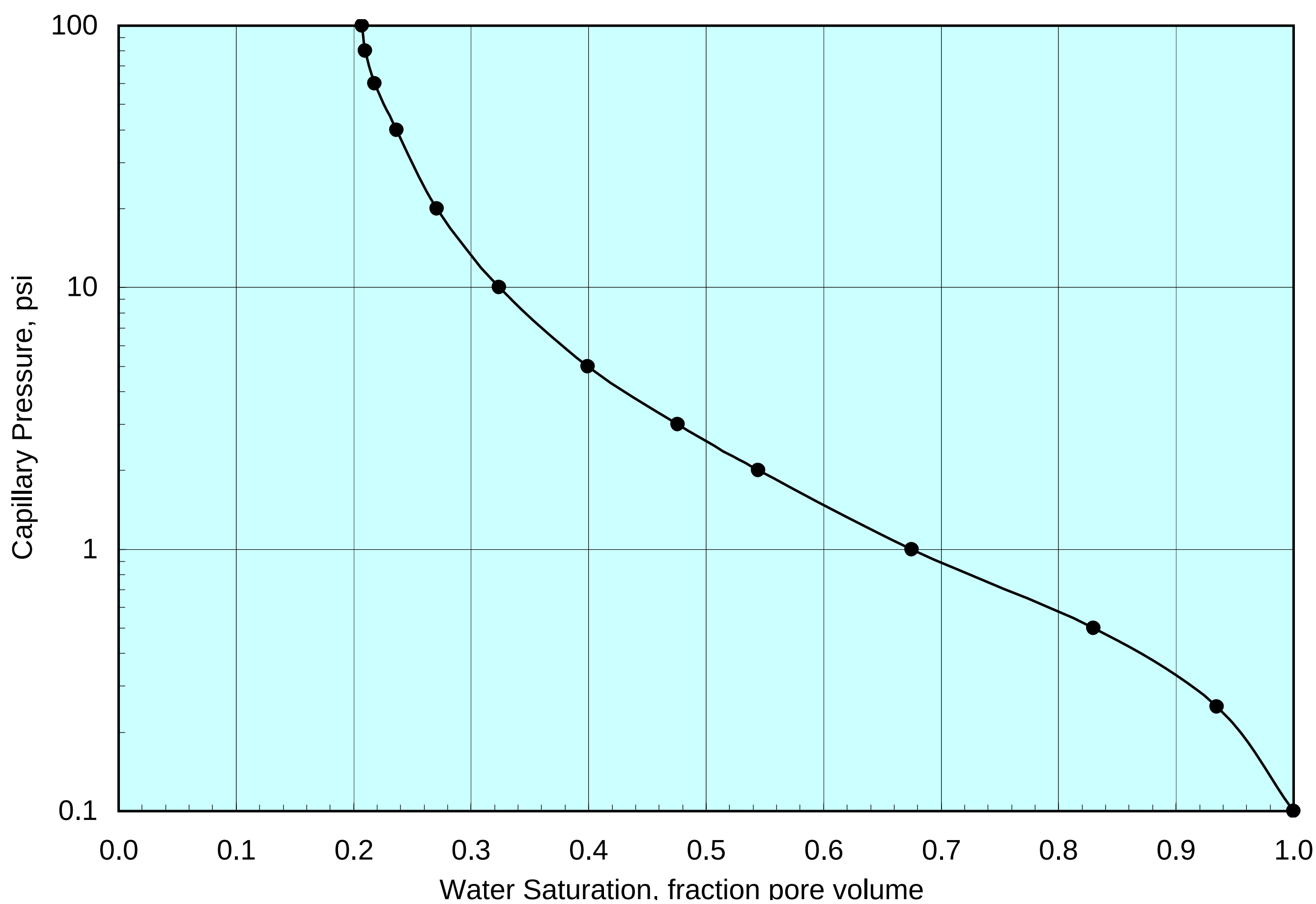
PETROLEUM SERVICES

ARCADIS

Core Lab File No: 410054EN

Project Name: Former Unocal Seattle Terminal
Project No: B0045363.0003.00006

Sample Number	Sample Depth Interval, feet	Boring	Total Porosity, fraction	Bulk Density, gm/cc	Specific Air Permeability mD	Capillary Pressure psi	Capillary Pressure cm water	Height Above Water Table, ft	Water Saturation, frac PV
4	17.3 - 17.5	PZ-61A-R	0.310	1.88	2719	0.00	0.0	0.00	1.000
						0.10	7.0	0.23	1.000
						0.25	17.6	0.58	0.935
						0.50	35.2	1.16	0.830
						1.0	70.3	2.31	0.675
						2.0	140.6	4.63	0.545
						3.0	210.9	6.94	0.476
						5.0	351.6	11.57	0.399
						10.0	703.1	23.14	0.324
						20.0	1406.2	46.29	0.271
						40.0	2812.4	92.57	0.237
						60.0	4218.6	138.86	0.218
						80.0	5624.8	185.14	0.210
						100.0	7031.0	231.43	0.207
						120.0	8437.2	277.71	0.204



FREE PRODUCT MOBILITY EVALUATION

Water Drive Method

Petroleum Services

Arcadis

Core Lab File No: 410054EN

Project Name: Former Unocal Seattle Terminal
Project No: B0045363.0002.00007

METHODS:			API RP 40		API RP 40	Core Lab, API RP40					
						Pore Fluid Saturations, % Pv					
		Sample	Density		Total	Initial Fluid Saturations		Water	Water	Final Fluid Saturations	
Sample ID.	Depth, ft.	Orientation (1)	Bulk (Dry), g/cc	Grain, g/cc	Porosity, %Vb	Water	NAPL	Injected, pore volume	Cut, percent	Water	NAPL
PZ-61A-R	14.5-.7	V	1.85	2.70	31.6	97.0	2.8	15.0	99.9	97.2	2.8

(1) H = horizontal, V = vertical

FREE PRODUCT MOBILITY EVALUATION

Centrifugal Method

Petroleum Services

Arcadis

Core Lab File No: 410054EN

Project Name: Former Unocal Seattle Terminal
Project No: B0045363.0002.00007

		METHODS:	API RP 40		API RP 40	ASTM D425M, DEAN-STARK			
						Pore Fluid Saturations, % Pv			
						Initial Fluid Saturations		Final - After Centrifuge at 1000xG	
		Sample	Density		Total				
Sample ID.	Depth, ft.	Orientation (1)	Bulk (Dry), g/cc	Grain, g/cc	Porosity, %Vb	Water	NAPL	Water	NAPL
PZ-61A-R	12.25-.45	V	1.91	2.70	29.3	95.6	4.3	51.6	4.3

(1) H = horizontal, V = vertical

ARCADIS

Appendix O

LNAPL Mobility Input Parameters and Results

ARCADIS
Infrastructure, environment, buildings

SITE/PROJECT INFORMATION

Date:	9/10/2010
Site Name:	Former Unocal Seattle Marketing Terminal
Site Location (City, ST):	Seattle WA

CASE STUDY ASSUMPTIONS

Case Name:	MW-30
LNAPL Type:	Literature assumptions based on California Crude
Geology Type:	Medium grained sand - based on grain size analysis

CALCULATION INPUTS

Parameter	*Symbol*	*Value*	*Units*	*Source*
Site Data				
Monitoring Well LNAPL Thickness	b_o	0.02	ft	field/site data
Water Hydraulic Conductivity	K_w	0.00049	cm/s	field/site data
Water Hydraulic Gradient	J_w	0.010	dimensionless	field/site data
Fluids Properties Data				
LNAPL Density	ρ_o	0.85	g/cm3	literature (API)
LNAPL Viscosity	μ_o	340	g/cm-s	literature (API)
Water Density	ρ_w	0.9989	g/cm3	field/site data
Water Viscosity	μ_w	0.013	g/cm-s	field/site data
Surface Tension	σ_{aw}	61.8	dyne/cm	field/site data
Air-LNAPL Interfacial Tension	σ_{ao}	37	dyne/cm	literature (API)
LNAPL-Water Interfacial Tension	σ_{ow}	25	dyne/cm	literature (API)
Aquifer Properties Data				
van Genuchten (vG) Alpha	α	3.31E-02	1/cm	Model results from RETC
van Genuchten (vG) Beta	N	2.593	dimensionless	Model results from RETC
Porosity	n	0.31	dimensionless	field/site data
Irreducible Water Saturation	S_{wr}	0.204	dimensionless	field/site data
Residual LNAPL Saturation	S_{or}	0.043	dimensionless	field/site data

INTERIM CALCULATIONS

Parameter	*Symbol*	*Value*	*Units*	*API 4760 Equation*
Air-Water Interface in Subsurface	z_{aw}	0	ft	datum
Density Ratio	ρ_r	0.851	dimensionless	
Air-LNAPL Interface in Well	z_{ao}	0.003	ft	2.19
LNAPL-Water Interface in Well	z_{ow}	-0.017	ft	2.20
Maximum Free LNAPL in Subsurface	z_{max}	0.010	ft	2.38
LNAPL vertical extent in subsurface		0.027	ft	
vG Alpha scaled to oil-water interactions	α_{ow}	0.371	1/ft	2.25
vG Alpha scaled to oil-air interactions	α_{ao}	1.432	1/ft	2.31
M (Burdine)	M	0.229	dimensionless	2.6
Viscosity Ratio	μ_r	26153.846	dimensionless	
Oil Hydraulic Conductivity	K_o	0.00000	cm/s	3.2
Oil Hydraulic Gradient	J_o	0.012	dimensionless	
Intrinsic Permeability	k	6.55E-09	cm2	

	A	B	C	D	E	F	G	H	I	J	K	L	M
29			**SITE/PROJECT INFORMATION**						**CASE STUDY ASSUMPTIONS**				
30			Date:	9/10/2010					Case Name:	MW-30			
31			Site Name:	Former Unocal Seattle Marketing Terminal					LNAPL Type:	Literature assumptions based on California Crude			
32			Site Location (City, ST):		Seattle WA				Geology Type:	Medium grained sand - based on grain size analysis			

PROFILE CALCULATIONS

	Scale	z	$S_{e[w]}$ (z)	S_w (z)	$S_{e[t]}$ (z)	S_o (z)	S_{or}	k_{ro} (Sw, So)	LNAPL velocity (cm/s)	delta z (cm)	Step Calc for T_o (b_o) (cm²/s)	Step Calc for D_o (b_o) (cm³/cm²)	Step Calc for R_o (cm³/cm²)
36	Equation:		2.24	2.27	2.30	2.33		3.14			3.31	2.40	2.41
37	0	0.010	0.999998502	0.956998872	0.999998502	0.043	0.043	0.00E+00	0.00E+00		0.00E+00	0.000	0.00E+00
38	1	0.009	0.999998652	0.956998985	0.99999903	0.043000284	0.043	8.52E-06	1.21E-13	0.03	4.51E-15	0.000	2.90E-09
39	2	0.008	0.999998793	0.956999091	0.999999425	0.043000475	0.043	1.79E-05	2.53E-13	0.03	9.45E-15	0.000	4.85E-09
40	3	0.007	0.999998925	0.95699919	0.999999701	0.043000585	0.043	2.84E-05	4.02E-13	0.03	1.50E-14	0.000	5.97E-09
41	4	0.006	0.999999047	0.956999282	0.999999876	0.043000624	0.043	4.05E-05	5.73E-13	0.03	2.14E-14	0.000	6.37E-09
42	5	0.005	0.99999916	0.956999368	0.999999967	0.043000608	0.043	5.53E-05	7.84E-13	0.03	2.93E-14	0.000	6.20E-09
43	6	0.004	0.999999265	0.956999446	0.999999998	0.043000552	0.043	7.66E-05	1.09E-12	0.03	4.05E-14	0.000	5.64E-09
44	7	0.002	0.999999361	0.956999519	1	0.043000481	0.043	9.91E-05	1.40E-12	0.03	5.24E-14	0.000	4.91E-09
45	8	0.001	0.999999449	0.956999585	1	0.043000415	0.043	9.58E-05	1.36E-12	0.03	5.07E-14	0.000	4.23E-09
46	9	0.000	0.999999529	0.956999645	1	0.043000355	0.043	9.24E-05	1.31E-12	0.03	4.89E-14	0.000	3.62E-09
47	10	-0.001	0.999999602	0.9569997	1	0.0430003	0.043	8.90E-05	1.26E-12	0.03	4.71E-14	0.000	3.06E-09
48	11	-0.002	0.999999667	0.956999749	1	0.043000251	0.043	8.54E-05	1.21E-12	0.03	4.52E-14	0.000	2.56E-09
49	12	-0.003	0.999999725	0.956999793	1	0.043000207	0.043	8.17E-05	1.16E-12	0.03	4.32E-14	0.000	2.11E-09
50	13	-0.004	0.999999777	0.956999832	1	0.043000168	0.043	7.79E-05	1.10E-12	0.03	4.12E-14	0.000	1.72E-09
51	14	-0.005	0.999999822	0.956999866	1	0.043000134	0.043	7.40E-05	1.05E-12	0.03	3.91E-14	0.000	1.37E-09
52	15	-0.006	0.999999861	0.956999895	1	0.043000105	0.043	6.99E-05	9.91E-13	0.03	3.70E-14	0.000	1.07E-09
53	16	-0.007	0.999999894	0.95699992	1	0.04300008	0.043	6.57E-05	9.31E-13	0.03	3.48E-14	0.000	8.14E-10
54	17	-0.008	0.999999922	0.956999941	1	0.043000059	0.043	6.13E-05	8.68E-13	0.03	3.24E-14	0.000	6.00E-10
55	18	-0.009	0.999999945	0.956999958	1	0.043000042	0.043	5.66E-05	8.02E-13	0.03	2.99E-14	0.000	4.24E-10
56	19	-0.011	0.999999963	0.956999972	1	0.043000028	0.043	5.17E-05	7.32E-13	0.03	2.73E-14	0.000	2.84E-10
57	20	-0.012	0.999999977	0.956999983	1	0.043000017	0.043	4.64E-05	6.57E-13	0.03	2.45E-14	0.000	1.77E-10
58	21	-0.013	0.999999987	0.95699999	1	0.04300001	0.043	4.06E-05	5.75E-13	0.03	2.15E-14	0.000	9.94E-11
59	22	-0.014	0.999999994	0.956999995	1	0.043000005	0.043	3.42E-05	4.85E-13	0.03	1.81E-14	0.000	4.71E-11
60	23	-0.015	0.999999998	0.956999998	1	0.043000002	0.043	2.69E-05	3.81E-13	0.03	1.42E-14	0.000	1.65E-11
61	24	-0.016	1	0.957	1	0.043	0.043	1.78E-05	2.53E-13	0.03	9.44E-15	0.000	2.73E-12
62	25	-0.017	1	0.957	1	0.043	0.043	0.00E+00	0.00E+00	0.03	0.00E+00	0.000	0.00E+00

SUMMARY CALCULATIONS (common units)

	G	Average S_o	Maximum LNAPL velocity (cm/s)	T_o (b_o) (ft²/day)	U_{nx} (ft²/yr)	D_o (b_o) (gal/ft²)	R_o (gal/ft²)
66	Equation:			3.31	3.32	2.40	2.41
67		0.043000223	1.40E-12	6.86E-11	2.94E-10	0.003	1.45E-08

ARCADIS
Infrastructure, environment, buildings

SITE/PROJECT INFORMATION

Date:	9/10/2010
Site Name:	Former Unocal Seattle Marketing Terminal
Site Location (City, ST):	Seattle WA

CASE STUDY ASSUMPTIONS

Case Name:	RW-3
LNAPL Type:	Literature assumptions based on California Crude
Geology Type:	Medium grained sand - based on grain size analysis

CALCULATION INPUTS

Parameter	*Symbol*	*Value*	*Units*	*Source*
Site Data				
Monitoring Well LNAPL Thickness	b_o	0.01	ft	field/site data
Water Hydraulic Conductivity	K_w	0.00018	cm/s	field/site data
Water Hydraulic Gradient	J_w	0.023	dimensionless	field/site data
Fluids Properties Data				
LNAPL Density	ρ_o	0.85	g/cm3	literature (API)
LNAPL Viscosity	μ_o	340	g/cm-s	literature (API)
Water Density	ρ_w	0.9989	g/cm3	field/site data
Water Viscosity	μ_w	0.013	g/cm-s	field/site data
Surface Tension	σ_{aw}	61.8	dyne/cm	field/site data
Air-LNAPL Interfacial Tension	σ_{ao}	37	dyne/cm	literature (API)
LNAPL-Water Interfacial Tension	σ_{ow}	25	dyne/cm	literature (API)
Aquifer Properties Data				
van Genuchten (vG) Alpha	α	3.31E-02	1/cm	Model results from RETC
van Genuchten (vG) Beta	N	2.593	dimensionless	Model results from RETC
Porosity	n	0.31	dimensionless	field/site data
Irreducible Water Saturation	S_{wr}	0.204	dimensionless	field/site data
Residual LNAPL Saturation	S_{or}	0.043	dimensionless	field/site data

INTERIM CALCULATIONS

Parameter	*Symbol*	*Value*	*Units*	*API 4760 Equation*
Air-Water Interface in Subsurface	z_{aw}	0	ft	datum
Density Ratio	ρ_r	0.851	dimensionless	
Air-LNAPL Interface in Well	z_{ao}	0.001	ft	2.19
LNAPL-Water Interface in Well	z_{ow}	-0.009	ft	2.20
Maximum Free LNAPL in Subsurface	z_{max}	0.005	ft	2.38
LNAPL vertical extent in subsurface		0.014	ft	
vG Alpha scaled to oil-water interactions	α_{ow}	0.371	1/ft	2.25
vG Alpha scaled to oil-air interactions	α_{ao}	1.432	1/ft	2.31
M (Burdine)	M	0.229	dimensionless	2.6
Viscosity Ratio	μ_r	26153.846	dimensionless	
Oil Hydraulic Conductivity	K_o	0.00000	cm/s	3.2
Oil Hydraulic Gradient	J_o	0.027	dimensionless	
Intrinsic Permeability	k	2.34E-09	cm2	

ARCADIS
Infrastructure, environment, buildings

SITE/PROJECT INFORMATION

Date:	9/10/2010
Site Name:	Former Unocal Seattle Marketing Terminal
Site Location (City, ST):	Seattle WA

CASE STUDY ASSUMPTIONS

Case Name:	RW-3
LNAPL Type:	Literature assumptions based on California Crude
Geology Type:	Medium grained sand - based on grain size analysis

PROFILE CALCULATIONS

Scale	z	$S_{e[w]}$ (z)	S_w (z)	$S_{e[t]}$ (z)	S_o (z)	S_{or}	k_{ro} (Sw, So)	LNAPL velocity (cm/s)	delta z (cm)	Step Calc for T_o (b_o) (cm²/s)	Step Calc for D_o (b_o) (cm³/cm²)	Step Calc for R_o (cm³/cm²)
Equation:		2.24	2.27	2.30	2.33		3.14			3.31	2.40	2.41
0	0.005	0.999999752	0.956999813	0.999999752	0.043	0.043	0.00E+00	0.00E+00		0.00E+00	0.000	0.00E+00
1	0.004	0.999999777	0.956999832	0.999999839	0.043000047	0.043	5.65E-06	6.57E-14	0.02	5.33E-16	0.000	2.40E-10
2	0.004	0.9999998	0.956999849	0.999999905	0.043000079	0.043	1.18E-05	1.38E-13	0.02	1.12E-15	0.000	4.02E-10
3	0.003	0.999999822	0.956999866	0.99999995	0.043000097	0.043	1.88E-05	2.19E-13	0.02	1.78E-15	0.000	4.94E-10
4	0.003	0.999999842	0.956999881	0.999999979	0.043000103	0.043	2.68E-05	3.12E-13	0.02	2.53E-15	0.000	5.28E-10
5	0.002	0.999999861	0.956999895	0.999999995	0.043000101	0.043	3.67E-05	4.27E-13	0.02	3.46E-15	0.000	5.14E-10
6	0.002	0.999999878	0.956999908	1	0.043000092	0.043	5.08E-05	5.91E-13	0.02	4.80E-15	0.000	4.67E-10
7	0.001	0.999999894	0.95699992	1	0.04300008	0.043	6.57E-05	7.65E-13	0.02	6.21E-15	0.000	4.07E-10
8	0.001	0.999999909	0.956999931	1	0.043000069	0.043	6.35E-05	7.39E-13	0.02	6.00E-15	0.000	3.51E-10
9	0.000	0.999999922	0.956999941	1	0.043000059	0.043	6.13E-05	7.13E-13	0.02	5.79E-15	0.000	3.00E-10
10	0.000	0.999999934	0.95699995	1	0.04300005	0.043	5.90E-05	6.86E-13	0.02	5.57E-15	0.000	2.54E-10
11	-0.001	0.999999945	0.956999958	1	0.043000042	0.043	5.66E-05	6.59E-13	0.02	5.35E-15	0.000	2.12E-10
12	-0.001	0.999999954	0.956999966	1	0.043000034	0.043	5.42E-05	6.30E-13	0.02	5.12E-15	0.000	1.75E-10
13	-0.002	0.999999963	0.956999972	1	0.043000028	0.043	5.17E-05	6.01E-13	0.02	4.88E-15	0.000	1.42E-10
14	-0.003	0.99999997	0.956999978	1	0.043000022	0.043	4.91E-05	5.71E-13	0.02	4.63E-15	0.000	1.13E-10
15	-0.003	0.999999977	0.956999983	1	0.043000017	0.043	4.64E-05	5.39E-13	0.02	4.38E-15	0.000	8.86E-11
16	-0.004	0.999999982	0.956999987	1	0.043000013	0.043	4.35E-05	5.07E-13	0.02	4.11E-15	0.000	6.74E-11
17	-0.004	0.999999987	0.95699999	1	0.04300001	0.043	4.06E-05	4.73E-13	0.02	3.84E-15	0.000	4.97E-11
18	-0.005	0.999999991	0.956999993	1	0.043000007	0.043	3.75E-05	4.37E-13	0.02	3.54E-15	0.000	3.51E-11
19	-0.005	0.999999994	0.956999995	1	0.043000005	0.043	3.42E-05	3.98E-13	0.02	3.23E-15	0.000	2.36E-11
20	-0.006	0.999999996	0.956999997	1	0.043000003	0.043	3.07E-05	3.58E-13	0.02	2.90E-15	0.000	1.47E-11
21	-0.006	0.999999998	0.956999998	1	0.043000002	0.043	2.69E-05	3.13E-13	0.02	2.54E-15	0.000	8.23E-12
22	-0.007	0.999999999	0.956999999	1	0.043000001	0.043	2.27E-05	2.64E-13	0.02	2.14E-15	0.000	3.90E-12
23	-0.007	1	0.957	1	0.043	0.043	1.78E-05	2.08E-13	0.02	1.68E-15	0.000	1.36E-12
24	-0.008	1	0.957	1	0.043	0.043	1.18E-05	1.38E-13	0.02	1.12E-15	0.000	2.26E-13
25	-0.009	1	0.957	1	0.043	0.043	0.00E+00	0.00E+00	0.02	0.00E+00	0.000	0.00E+00

SUMMARY CALCULATIONS (common units)

	Average S_o	Maximum LNAPL velocity (cm/s)	T_o (b_o) (ft²/day)	U_{nx} (ft²/yr)	D_o (b_o) (gal/ft²)	R_o (gal/ft²)
Equation:			3.31	3.32	2.40	2.41
	0.043000037	7.65E-13	8.11E-12	8.01E-11	0.001	1.20E-09

ARCADIS
Infrastructure, environment, buildings

SITE/PROJECT INFORMATION

Date:	9/10/2010
Site Name:	Former Unocal Seattle Marketing Terminal
Site Location (City, ST):	Seattle WA

CASE STUDY ASSUMPTIONS

Case Name:	RW-21
LNAPL Type:	Literature assumptions based on California Crude
Geology Type:	Medium grained sand - based on grain size analysis

CALCULATION INPUTS

Parameter	*Symbol*	*Value*	*Units*	*Source*
Site Data				
Monitoring Well LNAPL Thickness	b_o	0.02	ft	field/site data
Water Hydraulic Conductivity	K_w	0.00011	cm/s	field/site data
Water Hydraulic Gradient	J_w	0.028	dimensionless	field/site data
Fluids Properties Data				
LNAPL Density	ρ_o	0.85	g/cm3	literature (API)
LNAPL Viscosity	μ_o	340	g/cm-s	literature (API)
Water Density	ρ_w	0.9989	g/cm3	field/site data
Water Viscosity	μ_w	0.013	g/cm-s	field/site data
Surface Tension	σ_{aw}	61.8	dyne/cm	field/site data
Air-LNAPL Interfacial Tension	σ_{ao}	37	dyne/cm	literature (API)
LNAPL-Water Interfacial Tension	σ_{ow}	25	dyne/cm	literature (API)
Aquifer Properties Data				
van Genuchten (vG) Alpha	α	3.31E-02	1/cm	Model results from RETC
van Genuchten (vG) Beta	N	2.593	dimensionless	Model results from RETC
Porosity	n	0.31	dimensionless	field/site data
Irreducible Water Saturation	S_{wr}	0.204	dimensionless	field/site data
Residual LNAPL Saturation	S_{or}	0.043	dimensionless	field/site data

INTERIM CALCULATIONS

Parameter	*Symbol*	*Value*	*Units*	*API 4760 Equation*
Air-Water Interface in Subsurface	z_{aw}	0	ft	datum
Density Ratio	ρ_r	0.851	dimensionless	
Air-LNAPL Interface in Well	z_{ao}	0.003	ft	2.19
LNAPL-Water Interface in Well	z_{ow}	-0.017	ft	2.20
Maximum Free LNAPL in Subsurface	z_{max}	0.010	ft	2.38
LNAPL vertical extent in subsurface		0.027	ft	
vG Alpha scaled to oil-water interactions	α_{ow}	0.371	1/ft	2.25
vG Alpha scaled to oil-air interactions	α_{ao}	1.432	1/ft	2.31
M (Burdine)	M	0.229	dimensionless	2.6
Viscosity Ratio	μ_r	26153.846	dimensionless	
Oil Hydraulic Conductivity	K_o	0.00000	cm/s	3.2
Oil Hydraulic Gradient	J_o	0.033	dimensionless	
Intrinsic Permeability	k	1.40E-09	cm2	

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SITE/PROJECT INFORMATION

Date:	9/10/2010
Site Name:	Former Unocal Seattle Marketing Terminal
Site Location (City, ST):	Seattle WA

CASE STUDY ASSUMPTIONS

Case Name:	RW-21
LNAPL Type:	Literature assumptions based on California Crude
Geology Type:	Medium grained sand - based on grain size analysis

PROFILE CALCULATIONS

Row	Scale (A)	z (B)	$S_{e[w]}$ (z) (C)	S_w (z) (D)	$S_{e[t]}$ (z) (E)	S_o (z) (F)	S_{or} (G)	k_{ro} (Sw, So) (H)	LNAPL velocity (cm/s) (I)	delta z (cm) (J)	Step Calc for T_o (b_o) (cm²/s) (K)	Step Calc for D_o (b_o) (cm³/cm²) (L)	Step Calc for R_o (cm³/cm²) (M)
36	Equation:		2.24	2.27	2.30	2.33		3.14			3.31	2.40	2.41
37	0	0.010	0.999998502	0.956998872	0.999998502	0.043	0.043	0.00E+00	0.00E+00		0.00E+00	0.000	0.00E+00
38	1	0.009	0.999998652	0.956998985	0.99999903	0.043000284	0.043	8.52E-06	7.24E-14	0.03	9.66E-16	0.000	2.90E-09
39	2	0.008	0.999998793	0.956999091	0.999999425	0.043000475	0.043	1.79E-05	1.52E-13	0.03	2.03E-15	0.000	4.85E-09
40	3	0.007	0.999998925	0.95699919	0.999999701	0.043000585	0.043	2.84E-05	2.41E-13	0.03	3.21E-15	0.000	5.97E-09
41	4	0.006	0.999999047	0.956999282	0.999999876	0.043000624	0.043	4.05E-05	3.44E-13	0.03	4.59E-15	0.000	6.37E-09
42	5	0.005	0.99999916	0.956999368	0.999999967	0.043000608	0.043	5.53E-05	4.70E-13	0.03	6.27E-15	0.000	6.20E-09
43	6	0.004	0.999999265	0.956999446	0.999999998	0.043000552	0.043	7.66E-05	6.51E-13	0.03	8.68E-15	0.000	5.64E-09
44	7	0.002	0.999999361	0.956999519	1	0.043000481	0.043	9.91E-05	8.43E-13	0.03	1.12E-14	0.000	4.91E-09
45	8	0.001	0.999999449	0.956999585	1	0.043000415	0.043	9.58E-05	8.14E-13	0.03	1.09E-14	0.000	4.23E-09
46	9	0.000	0.999999529	0.956999645	1	0.043000355	0.043	9.24E-05	7.86E-13	0.03	1.05E-14	0.000	3.62E-09
47	10	-0.001	0.999999602	0.9569997	1	0.0430003	0.043	8.90E-05	7.56E-13	0.03	1.01E-14	0.000	3.06E-09
48	11	-0.002	0.999999667	0.956999749	1	0.043000251	0.043	8.54E-05	7.26E-13	0.03	9.68E-15	0.000	2.56E-09
49	12	-0.003	0.999999725	0.956999793	1	0.043000207	0.043	8.17E-05	6.95E-13	0.03	9.26E-15	0.000	2.11E-09
50	13	-0.004	0.999999777	0.956999832	1	0.043000168	0.043	7.79E-05	6.62E-13	0.03	8.83E-15	0.000	1.72E-09
51	14	-0.005	0.999999822	0.956999866	1	0.043000134	0.043	7.40E-05	6.29E-13	0.03	8.39E-15	0.000	1.37E-09
52	15	-0.006	0.999999861	0.956999895	1	0.043000105	0.043	6.99E-05	5.94E-13	0.03	7.93E-15	0.000	1.07E-09
53	16	-0.007	0.999999894	0.95699992	1	0.04300008	0.043	6.57E-05	5.58E-13	0.03	7.45E-15	0.000	8.14E-10
54	17	-0.008	0.999999922	0.956999941	1	0.043000059	0.043	6.13E-05	5.21E-13	0.03	6.94E-15	0.000	6.00E-10
55	18	-0.009	0.999999945	0.956999958	1	0.043000042	0.043	5.66E-05	4.81E-13	0.03	6.42E-15	0.000	4.24E-10
56	19	-0.011	0.999999963	0.956999972	1	0.043000028	0.043	5.17E-05	4.39E-13	0.03	5.85E-15	0.000	2.84E-10
57	20	-0.012	0.999999977	0.956999983	1	0.043000017	0.043	4.64E-05	3.94E-13	0.03	5.25E-15	0.000	1.77E-10
58	21	-0.013	0.999999987	0.95699999	1	0.04300001	0.043	4.06E-05	3.45E-13	0.03	4.60E-15	0.000	9.94E-11
59	22	-0.014	0.999999994	0.956999995	1	0.043000005	0.043	3.42E-05	2.91E-13	0.03	3.88E-15	0.000	4.71E-11
60	23	-0.015	0.999999998	0.956999998	1	0.043000002	0.043	2.69E-05	2.29E-13	0.03	3.05E-15	0.000	1.65E-11
61	24	-0.016	1	0.957	1	0.043	0.043	1.78E-05	1.52E-13	0.03	2.02E-15	0.000	2.73E-12
62	25	-0.017	1	0.957	1	0.043	0.043	0.00E+00	0.00E+00	0.03	0.00E+00	0.000	0.00E+00

SUMMARY CALCULATIONS (common units)

Row	G	Average S_o (H)	Maximum LNAPL velocity (cm/s) (I)	T_o (b_o) (ft²/day) (J)	U_{nx} (ft²/yr) (K)	D_o (b_o) (gal/ft²) (L)	R_o (gal/ft²) (M)
66	Equation:			3.31	3.32	2.40	2.41
67		0.043000223	8.43E-13	1.47E-11	1.76E-10	0.003	1.45E-08