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LNAPL Pilot Scale Study and Recovery Report

Former Union Oil/PacifiCorp Astoria Site
DEQ ECSI #1646

October 24, 2014

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Acronyms and Abbreviations

API	American Petroleum Institute
ARCADIS	ARCADIS U.S., Inc.
ASTM	ASTM International
bgs	below ground surface
btoc	below top of casing
capillarity	air displacing water pressure
cm/sec	centimeters per second
cP	centipoise
CSM	conceptual site model
cSt	centistokes
DEQ	Oregon Department of Environmental Quality
dynes/cm	dynes per centimeter
ECSI	Environmental Cleanup Site Information
FS	feasibility study
ft^2/day	square foot per day
g/cm^3	gram per cubic centimeter
g/mL	gram per milliliter
gpd	gallon per day
gph	gallon per hour
gpy	gallon per year
IFT	interfacial tension
ITRC	Interstate Technology & Regulatory Council
LNAPL	light nonaqueous phase liquid
MFA	Maul Foster & Alongi, Inc.
MGP	manufactured gas plant
O&M	operation and maintenance

Parties	Union Oil Company of California and PacifiCorp
RAO	remedial action objective
RDWP	Remedial Design Work Plan
RI	remedial investigation
ROD	Record of Decision
Site	former Petroleum Terminal No. 0022 and manufactured gas plant, located at 256 Marine Drive, Astoria Oregon
Union Oil	Union Oil Company of California
°C	degrees Centigrade
°F	degrees Fahrenheit

1. Introduction

On behalf of Union Oil Company of California (Union Oil) and PacifiCorp, collectively referred to as the Parties, ARCADIS U.S., Inc. (ARCADIS) prepared this Light Nonaqueous Phase Liquid Pilot Scale Study and Recovery Report (report) for the Former Petroleum Terminal No. 0022 and manufactured gas plant (MGP), located at 256 Marine Drive, Astoria Oregon (Site; Figure 1) (Oregon Department of Environmental Quality [DEQ] Environmental Cleanup Site Information [ECSI] No. 1646).

This report summarizes light nonaqueous phase liquid (LNAPL) recovery pre-design pilot test activities, pilot test results, evaluation of LNAPL removal data, and recommended LNAPL recovery approach.

1.1 Pilot Study Location

This report focuses on an area of the Site referred to as the "MW-12 LNAPL hot spot" or "upland LNAPL hot spot." Other areas of the Site are being addressed separately in accordance with an email communication from ARCADIS to the DEQ (pers. comm., May 6, 2014). The DEQ (2012) defined the MW-12 LNAPL hot spot as follows:

> *"…if the site presents an unacceptable risk and if the contamination is highly concentrated, highly mobile, or cannot be readily contained...Based on this definition…the upland hot spot includes areas of the site where LNAPL accumulates and has the potential to migrate toward surface water and discharge as seeps in shoreline sediments. This has the significant adverse effect on beneficial uses of water (recharge of surface water by groundwater). LNAPL thickness is greatest at MW-12. Treatment is likely to restore or protect the beneficial use within a reasonable time (less than 30 years)."*

Site investigation activities have delineated the extent of the upland LNAPL hot spot to be localized near MW-12. This area is referred to as the MW-12 hot spot throughout the remedial investigation (RI) and feasibility study (FS), and is the focus of this report.

1.2 Regulatory Background

In 1995, the Site was placed on the Confirmed List and Inventory by the DEQ. The Parties entered the DEQ Voluntary Cleanup Program as co-contributors by signing a letter agreement in May 1996. PacifiCorp and Union Oil entered into a joint remediation agreement for the project to act as co-responsible parties. PacifiCorp signed a voluntary cleanup agreement (WMCVC-NWR-97-06) with the DEQ on October 1, 1997, as the performing party solely for project logistics. The Parties conducted an RI/FS at the Site, pursuant to the 1997 agreement (CH2M Hill 2001). An off-site upland and in-water RI/FS (Maul Foster & Alongi, Inc. [MFA] 2008, 2010) was conducted pursuant to a Voluntary Agreement (DEQ Number LQVC-NWR-02-12, effective October 9, 2002) among the DEQ, Union Oil, and PacifiCorp.

In December 2011, the DEQ issued a Remedial Action Record of Decision (ROD) for the Locality of Facility, which is defined as the on-site upland area (256 Marine Drive property), off-site upland area (upland areas north and northeast of the 256 Marine Drive property), and the off-site in-water area (intertidal zone of the Columbia River north and northeast 256 Marine Drive property) (DEQ 2011) (Figure 2).

The DEQ amended the ROD in May 2012 to incorporate responses to two sets of comments (DEQ 2012). The ROD (DEQ 2012) selected Upland Alternative 2: Capping, Institutional Controls, and Enhanced LNAPL Recovery as the upland remedy, also referred to in this report as the LNAPL remedy.

1.3 Description of the Record of Decision LNAPL Remedy

The ROD LNAPL remedy (Alternative 2) includes the following elements (DEQ 2012):

- 6,000-square-yard cap in upland areas to prevent exposure pathways.
- Enhanced LNAPL recovery, based on an adaptive management strategy.
- Implementation of institutional controls (e.g., deed restrictions, future development to require a vapor barrier, Soil Management Plan (SMP), monitoring and maintenance program).

According to the ROD (DEQ 2012), enhanced LNAPL recovery also includes installation of one recovery well with a skimmer, oil/water separator, and tank system. Results from the recovery well would be used to determine whether LNAPL recovery can be improved with additional recovery wells. A monitoring and maintenance program would be developed in accordance with the SMP and in consultation with DEQ. The ROD (DEQ 2012) LNAPL remedy would also include deed notifications and deed restrictions for on- and off-site capped areas requiring implementation of a SMP during subsurface maintenance activities, and placement of a vapor barrier for any future development that includes buildings. It is assumed that LNAPL recovery will continue for 10 years (DEQ 2012).

One question regarding the ROD LNAPL remedy involves the use of an LNAPL skimmer at the MW-12 location. Monitoring well MW-12 is located in a road, which makes the mechanical use of an automated skimmer infeasible. The ROD (DEQ 2012) anticipated this in its evaluation of feasibility criteria (Section 5), where it cautioned that the trolley line right-of-way may hamper implementability and present an implementation risk.

Because mechanical use of an LNAPL skimmer at MW-12 is infeasible, the enhanced LNAPL remedy at MW-12 will be conducted manually. Enhanced LNAPL recovery will be attempted at a new location designated as MW-12R (Figure 3). Proposed well MW-12R is located between existing monitoring well MW-12 and the Columbia River, and is therefore an ideal location for LNAPL recovery if present, or LNAPL monitoring if LNAPL is not present. Section 6 describes the proposed LNAPL recovery approach.

1.4 Remedial Action Objectives

The ROD (DEQ 2012) establishes the following remedial action objectives (RAOs), which are relevant to remediation of the MW-12 LNAPL hot spot:

- *RAO #4*. Minimize the release of LNAPL from site soil and groundwater to the Columbia River sediment and surface water.
- *RAO #5*. Remediate LNAPL hot spots of contamination to the extent feasible.

The LNAPL remedy is being designed in conjunction with an in-water remedy (ARCADIS 2014), and both the upland and in-water remedies will be implemented in parallel. Therefore, the upland and in-water remedies will function together to achieve the RAOs established in the ROD (DEQ 2012).

1.5 Purpose and Objectives of LNAPL Recovery Pilot Tests

The 2014 pre-design pilot tests were conducted to collect data necessary to evaluate LNAPL recovery strategies and complete an LNAPL remedial design for the Site. LNAPL recovery methods tested included:

- Manual LNAPL removal by pumping and/or bailing.
- In-well heating of the LNAPL for viscosity reduction, followed by manual removal by pumping and/or bailing.
- Manual LNAPL removal using sorbent socks.

The 2014 LNAPL pre-design pilot tests were performed to generate data needed to evaluate LNAPL removal methods and frequency options in the design for enhanced LNAPL removal, as required by the ROD (DEQ 2012). Specific objectives of the 2014 LNAPL recovery pilot tests were to:

- Verify the LNAPL density, viscosity, and interfacial tension (IFT) with groundwater in MW-12 LNAPL samples for a range of temperatures, from ambient groundwater temperature (i.e., 45 degrees Fahrenheit [°F]) to the anticipated temperature of heated LNAPL using in-well heating techniques (i.e., 90°F) to be used during a thermally enhanced LNAPL recovery pilot test.

- Before, during, and after the pilot tests, collect in-well LNAPL thickness data of sufficient quantity and quality to support engineering design of the final upland LNAPL remedy.

- Provide a basis for comparing the relative effectiveness of the three LNAPL removal strategies tested and selecting the most feasible strategy.

- Provide data to allow comparison of use of an automated skimmer system to the three directly evaluated LNAPL recovery methods.

- Provide a basis for evaluating LNAPL mobility in the subsurface at the MW-12 LNAPL hot spot.

2. Conceptual Site Model – MW-12 LNAPL Hot Spot

This conceptual site model (CSM) focuses on the MW-12 LNAPL hot spot based on historical Site data and new data collected during the LNAPL pre-design pilot tests. Updates to the CSM incorporating the LNAPL pre-design pilot test results are discussed in Section 5.7.

2.1 LNAPL Definitions

The following LNAPL-related definitions are used in this CSM and throughout the remainder of this report:

- *Soil porosity* is the volumetric ratio of pore space to total volume of soil. Soil porosity typically varies between approximately 0.30 and 0.45 for most soil. A soil porosity of 40% was assumed for soil near the MW-12 LNAPL hot spot in the RI and FS based on soil descriptions in Site geologic logs, and is used throughout this evaluation.

- *Capillary pressure* is a fluid property that represents the difference between LNAPL pressure and groundwater pressure in soil pores. Capillary pressure is the driving force, or head, within the LNAPL phase.

- *Entry pressure* is a soil property that provides a resisting force to LNAPL migration. Entry pressure is a critical value in terms of LNAPL migration: if the LNAPL capillary pressure exceeds the soil entry pressure, then LNAPL can potentially migrate in the soil pores. If the LNAPL capillary pressure is less than the soil entry pressure then, by definition, the LNAPL is immobile.

- *LNAPL saturation* is the volumetric ratio of LNAPL to total volume of pores in soil. LNAPL saturation theoretically varies between 0% (no LNAPL present) and 100% (all of the pore space is filled with LNAPL). However, at many sites the maximum saturation rarely exceeds 25%. LNAPL saturation is important because it controls LNAPL mobility and recoverability.

- *Residual LNAPL saturation* is the critical LNAPL saturation at and below which LNAPL exists in pore spaces as disconnected, discontinuous blobs or ganglia and is, by definition, immobile and unrecoverable by hydraulic LNAPL recovery technologies (e.g., pumping, bailing, sorbent socks, and/or skimmers). Residual LNAPL is occluded by groundwater. When LNAPL is present above the residual saturation value, it may be potentially mobile and recoverable. Residual LNAPL is typically encountered above the LNAPL within the capillary fringe and forms a "smear zone."

- *Mobile LNAPL* is LNAPL currently migrating through soil pores. Two preconditions must be met for LNAPL to be mobile:

  – LNAPL saturation must be above the residual saturation value.
  – LNAPL capillary pressure must exceed the entry pressure of the soil.

  If either of these conditions is not met, the LNAPL by definition is not currently mobile, but it may be potentially mobile (see below). Mobile LNAPL can cause the extent of the LNAPL body (i.e., the LNAPL footprint) to expand through time. Mobile LNAPL can also occur within the footprint of a stabilized LNAPL body, such as during recovery efforts. Mobile LNAPL can theoretically be removed from the subsurface using hydraulic LNAPL recovery technologies.

- *Potentially mobile LNAPL* is LNAPL present in soil pores above the residual saturation value but the LNAPL capillary pressure does not currently exceed the soil entry pressure. Potentially mobile LNAPL can exist as a stable, nonexpanding LNAPL body whose movement is restricted by resisting forces of the soil entry pressure around the edges of an LNAPL footprint. Potentially mobile LNAPL can theoretically be removed from the subsurface using hydraulic LNAPL recovery technologies.

2.2 LNAPL Volume

Possible sources of LNAPL at the Site include releases from historical MGP operations and wastes, petroleum terminal aboveground storage tanks and piping, and railroad tanker loading and unloading. The volume of LNAPL historically released is unknown. However, the total volume of LNAPL present at the MW-12 LNAPL hot spot can be estimated using Site data and standard environmental engineering calculations.

One of the key parameters needed to estimate LNAPL volume in the subsurface is LNAPL saturation. Site-specific LNAPL saturation values were measured in Site soil samples during the FS (MFA 2010). Results showed that only three of 31 on-site soil samples had LNAPL saturations greater than 20% (identified as the threshold representative of residual saturation in the FS; MFA 2010), and among 51 off-site soil samples, the maximum estimated LNAPL saturation was 10.7%. Given that LNAPL saturation is 0% outside the MW-12 LNAPL hot spot footprint, it can be reasonably assumed that the average LNAPL saturation throughout the upland LNAPL hot spot footprint is 10%.

The estimate of LNAPL volume in the MW-12 LNAPL hot spot is also based on the assumption that the LNAPL footprint occupies an approximately circular zone with a 25-foot radius centered on MW-12 (Figure 3), and that the LNAPL has an average thickness of 2 feet. Using these assumptions and information discussed above, the total LNAPL volume in the subsurface near the MW-12 LNAPL hot spot is approximately 1,175 gallons. Note that not all LNAPL in the MW-12 LNAPL hot spot footprint is potentially mobile or recoverable. In fact, most of the LNAPL at the MW-12 LNAPL hot spot is at or below residual saturation and, therefore, only a minor fraction is recoverable using the enhanced LNAPL recovery techniques established in the ROD selected remedy (i.e., hydraulic LNAPL recovery techniques).

During completion of the RI measurable thicknesses of LNAPL were observed at monitoring wells MW-7, MW-11, MW-12, and MW-13 and the LNAPL was removed (Table 1). As a result, LNAPL recovery continued at these monitoring wells during completion of the FS, and is ongoing. A total LNAPL recovery volume of approximately 40 gallons was produced during 12 years of recovery efforts between November 2002 and September 2014. This results in an LNAPL recovery rate of roughly 3.5 gallons per year (gpy) or 0.009 gallon per day (gpd). This limited amount of LNAPL recovery during the RI and FS reflects the fact that most of the LNAPL at the MW-12 LNAPL hot spot is at or below residual saturation and only a minor fraction is recoverable using hydraulic recovery technologies.

However, as a result of the RI/FS LNAPL recovery efforts, the low LNAPL recovery rates have declined to negligible volumes in monitoring wells MW-7, MW-11, and MW-13, which indicates that LNAPL in the subsurface at those locations has been de-saturated to the point of residual saturation and is no longer mobile or potentially mobile under current conditions. Because measurable thicknesses of LNAPL have persisted at monitoring well MW-12 and the LNAPL recharge rate at MW-12 is consistently approximately 0.006 gpd, the MW-12 LNAPL hot spot is the focus of the pilot study and proposed remedial action in this report.

2.3 LNAPL Mobility

All of the RI/FS and pilot study data collected at the Site demonstrate that LNAPL in the subsurface at the MW-12 LNAPL hot spot is not currently mobile and that the LNAPL footprint at the MW-12 LNAPL hot spot is stable and not expanding. This conclusion is based on observed absences and presence of LNAPL in soil borings and monitoring wells through time and standard environmental engineering calculations documented in Section 5. This information indicates that LNAPL capillary pressures at the perimeter of the MW-12 LNAPL hot spot are less than the entry pressure of Site soil, which provides a natural control on LNAPL mobility and has immobilized and stabilized the MW-12 LNAPL hot spot in this area.

Within the LNAPL footprint at the MW-12 LNAPL hot spot; however, the data show that some amount of LNAPL is present above residual saturation and may drain into a recovery well, albeit at slow rates limited by the naturally high viscosity of the LNAPL, which has been measured at greater than 3,000 centipoise (cP). The rate at which this LNAPL can be recovered with hydraulic recovery technologies is controlled by the LNAPL physical characteristics (namely, viscosity), LNAPL saturation distribution, and entry pressure of Site soil. Therefore, pilot testing was performed at monitoring well MW-12 to determine the best LNAPL recovery method to achieve the RAOs established in the ROD (DEQ 2012).

Regarding other portions of the Site, visibly impacted unsaturated soil and residual LNAPL have been observed in the capillary fringe above the water table in excavations, borings, and monitoring wells in the northern half of the Site and north of the Site along the railroad right of way. Based on field and laboratory data collected during the RI and FS, LNAPL observed in soil and groundwater in the northern portion of the Site is considered residual and immobile, and therefore no further action was selected for these areas in the ROD (DEQ 2012).

2.4 LNAPL Physical Characteristics

Site LNAPL properties were characterized in the RI and FS, and verified with pre-design data collected during LNAPL pre-design pilot testing in 2014. The Site LNAPL physical properties are summarized in Table 2 and below:

- *Viscosity.* Laboratory analysis of Site LNAPL samples collected during the RI showed that LNAPL in the MW-12 LNAPL hot spot had a kinematic viscosity of 2,940 centistokes (cSt) and a dynamic viscosity of 2,896 cP at 16 degrees Centigrade (°C) (Specialty Analytical lab report 0901155). Additional testing of MW-12 LNAPL samples collected during 2014 pre-design pilot testing verified the LNAPL viscosity at MW-12 was 3,526 cP at 16°C, 1,315 cP at 24°C, and 632 cP at 32°C. In comparison, the MW-12 LNAPL is more viscous than all other petroleum fuel types except Fuel Oil No. 6

(45,030 cP) and Crude-California (34,000 cP) (American Petroleum Institute [API] 2004).

- *Specific gravity.* Laboratory analysis of Site LNAPL samples collected during the RI showed LNAPL in the MW-12 LNAPL hot spot with a density 0.985 gram per milliliter (g/mL) at 16°C (Specialty Analytical lab report 0901155). Additional testing of MW-12 LNAPL samples collected during 2014 pre-design pilot testing verified the LNAPL specific gravity at MW-12 was 0.9699 gram per cubic centimeter (g/cm^3) at 13°C, 0.9690 g/cm^3 at 16°C, 0.9651 g/cm^3 at 24°C, and 0.9619 g/cm^3 at 32°C.

- *IFT/surface tension.* Laboratory analysis of Site LNAPL samples collected during the 2014 pre-design pilot testing indicated the IFT/surface tension of MW-12 LNAPL samples was 32.6 dynes per centimeter (dynes/cm) with air and 16 dynes/cm with Site groundwater at 13°C.

- *Flash point.* The flash point of the MW-12 LNAPL was measured at more than 212°F.

2.5 Site Hydrogeology

Gravelly alluvial deposits make up a shallow unconfined water-bearing zone at the Site. The hydrologic properties of the shallow water-bearing zone were characterized during RI and are summarized in Table 3 of this report. Historical investigations at the Site show that bulk density of the shallow water-bearing zone is approximately 135 pounds per cubic feet (based on upper range of bulk density for well-graded, clean gravel) and gravel-sand mixtures (Lindeburg 2006). Porosity was estimated during the RI to be 40%, based on the type of subsurface materials observed under and north of the Site in the uppermost water-bearing zone (i.e., sand and gravel). As reported in the Feasibility Study Report (MFA 2010), hydraulic conductivity of saturated Site soil was measured to be 74.9 feet per day northeast of the Site and 22.1 feet per day north of the Site. These values are typical of sand and gravel. Hydraulic conductivity was estimated to be 4.1 feet per day in the fine-grained alluvium underlying the upper water-bearing zone (CH2M Hill 2001) based on a slug test performed in former well MW-2 in the northern portion of the Site.

The shallow water-bearing zone is primarily recharged by precipitation, which infiltrates through the unpaved portions of the Site. The water table is located between approximately 6 and 12 feet below ground surface (bgs) near the Columbia River and 2 and 14 feet bgs in the southern portion of the Site, depending on season. Shallow groundwater at the Site flows to the north-northeast toward the Columbia River with a gradient ranging from approximately 0.022 to 0.085 foot per foot and is somewhat steeper between the upland and in-water areas at low tide.

Groundwater within the shallow water-bearing zone is affected by river stage fluctuations in the Columbia River. A tidal variation study was conducted at the Site in March 2009, and showed a 0.5 to 1 foot fluctuation in the water table at monitoring wells MW-11, MW-12, and MW-13 in response to Columbia River tidal fluctuations. A tidal variation response test using water levels measured in the Columbia River and in monitoring wells MW-7, MW-11, MW-12, and MW-13 estimated the hydraulic conductivity of the shallow water-bearing zone in the sand and gravel to be between 22 and 75 feet per day (MFA 2009).

The tidal variation data show that daily tidal changes in the Columbia River cause corresponding daily 0.5- to 1-foot groundwater fluctuations in the MW-12 LNAPL hot spot, which over the course of decades has driven most of the LNAPL to residual saturation. Therefore, daily tidal changes in the river are the main reason that most of the LNAPL is at or below residual saturation. Daily groundwater fluctuations vertically smear the LNAPL in the soil column above the water table and create LNAPL and groundwater gradient fluctuations that limit mobility and restrict the distance of LNAPL migration.

Groundwater velocities were estimated to range between 2 and 8 feet per day based on hydrologic information collected during February and March 2009 (MFA 2009).

2.6 History of LNAPL Removal Efforts

LNAPL removal has been performed at the Site since November 2002 from wells MW-7, MW-11, MW-12, and MW-13, which have historically accumulated up to 0.15 foot, 0.50 foot, 4.12 feet, and 0.05 foot of LNAPL, respectively (Table 3). LNAPL removal has been documented in quarterly reports submitted to the DEQ since 2003. From November 2002 through December 2005, LNAPL removal efforts included the use of bailers and peristaltic pumps. In some cases, LNAPL present inside the MW-12 well casing was heated prior to removal to reduce the viscosity and thereby improve the ability to pump the LNAPL out of the well. Since January 2006, LNAPL has been removed using sorbent sock materials. The total volume of LNAPL removed from MW-7, MW-11, MW-12, and MW-13 is summarized in the table below.

Well ID	Total LNAPL Removed (November 2002 to September 2014)
MW-7	1.34 gallons
MW-11	5.33 gallons
MW-12	32.05 gallons
MW-13	2.47 gallons

LNAPL thickness was gauged at Site monitoring wells from November 2002 to December 2005 in conjunction with LNAPL removal activities completed during the RI. Since February 2013, LNAPL removal by inspection and change out of sorbent socks has been conducted bimonthly (every other month) at monitoring wells MW-7, MW-11, MW-12, and MW-13. Sock inspection frequency was increased to monthly starting first quarter 2014 to provide additional information to support pilot testing of LNAPL recovery methods. Sock inspection frequency will revert to bimonthly in fourth quarter 2014, following the end of the pre-design pilot tests.

The high viscosity of the Site LNAPL caused the LNAPL to coat the fluid-level measurement device (i.e., interface probe) used during the RI and FS, and interfered with the ability to obtain accurate LNAPL thickness measurements during that time. Furthermore, since 2005, the use of down-hole sorbent materials (i.e., socks) to remove LNAPL from MW-12 prevented LNAPL thickness measurements in the well. Because of this, LNAPL thickness measurements reported in the RI and FS are considered to be uncertain. To reduce uncertainty in LNAPL thickness measurements during the 2014 pilot tests, ARCADIS developed an improved method to measure the downhole fluid-level thickness of the high-viscosity LNAPL; the resulting 2014 LNAPL pilot test datasets have a higher degree of certainty.

From 2002 to 2005, approximately 0.25 to 1 gallon of LNAPL was removed monthly from MW-12. From 2005 to 2007, approximately 0.1 to 0.5 gallon of LNAPL was removed monthly from MW-12. Since 2007, approximately 0.2 gallon of LNAPL has been removed monthly from MW-12. These results suggest that either: the LNAPL recovery rate at MW-12 is declining through time, or the LNAPL-sorbent socks could have been replaced more frequently.

At the beginning of the 2014 pre-design pilot testing activities, approximately 4.12 feet of LNAPL had accumulated in monitoring well MW-12 when it was first gauged in March 2014. This represents the maximum LNAPL thickness ever recorded at monitoring well MW-12.

The methodologies used to gauge and remove LNAPL from Site monitoring wells during the RI and FS were of sufficient quality to identify which wells have historically accumulated or continue to accumulate LNAPL. These efforts have removed the small volumes of LNAPL that have migrated into MW-7, MW-11, MW-12, and MW-13 since the LNAPL monitoring and removal program began. In contrast, one of the main goals of the 2014 pre-design pilot tests was to collect data, including LNAPL physical properties and LNAPL recharge rate at MW-12, necessary to evaluate the relative effectiveness of the hydraulic LNAPL recovery technologies that will be used for remediation of the MW-12 LNAPL hot spot.

3. Pilot Test Methods

This section summarizes the methods used to conduct the 2014 pre-design pilot tests and to collect data for use in the LNAPL removal design. Pilot testing was conducted in accordance with the Remedial Design Work Plan (RDWP; ARCADIS 2013), with some deviations as described below.

Gauging and removal of LNAPL from MW-7, MW-11, MW-12, and MW-13 increased from bimonthly (previously approved by the DEQ) to monthly beginning in April 2014. As of September 24, 2014, the pilot test phase was complete and the gauging and LNAPL removal schedule for these wells reverted to the approved bimonthly schedule.

The field methods, data collected, and deviations from the RDWP (ARCADIS 2013) are described below.

3.1 LNAPL Gauging Technique

As described in Section 2.4, the viscosity of LNAPL in MW-12 is more than 3,000 cP at ambient groundwater temperatures and is approximately 3,000 times greater than the viscosity of groundwater. One implication of the high-viscosity LNAPL is that it makes measuring the LNAPL-groundwater interface difficult because the LNAPL can coat the oil-water interface probe sensor and prevent the sensor from accurately detecting the level of the LNAPL-groundwater interface. To overcome this, ARCADIS developed an improved technique during pilot test field activities that was found to generate reasonable, reproducible, and reliable LNAPL thickness measurements. The new technique for gauging LNAPL thicknesses at MW-12 used two interface probes and the following procedure:

1. Used one interface probe (any model) to measure the depth to the air-LNAPL interface. After the depth to the air-LNAPL interface was recorded, the probe was removed and decontaminated. This was repeated for each measurement of the air-LNAPL interface.

2. Sprayed the second oil-water interface probe (in this case, a Solinst® with P1 sensor tip)[1] with a solution of laboratory-grade, phosphate-free detergent (Alconox)[2] to reduce

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[1]Solinst® recently changed the design of their oil-water interface probes. ARCADIS found that the older model, Model 122 with the P1 sensor, worked for this method, while the new Model 122 with the P8 sensor did not. Any model of oil-water interface probe is suitable for gauging the air-LNAPL interface.

the surface tension with the LNAPL. The second probe (Solinst® with P1 sensor tip) was lowered to a depth anticipated to be at least 2 feet below the LNAPL-water interface (i.e., based on previous measurements). The probe was left in place for approximately 5 minutes or until the solid "product" tone on the probe changed to the intermittent "water" tone. This allowed any disruption to the LNAPL column, or any mixing between LNAPL and water that may have occurred during insertion of the probe, to settle.

3. Slowly raised the second probe (Solinst® with P1 sensor tip) until the probe read "product." This defined the LNAPL-water interface, the depth to which was recorded from the top of the well casing.

4. Calculated the difference between the depth to the LNAPL-water interface and the air-LNAPL interface; the difference corresponds to the LNAPL thickness in the well.

5. When additional LNAPL-water interface measurements were needed, as in the case of monitoring LNAPL recharge during bail-down testing, repeated Step 3 by re-lowering the second probe (Solinst® with P1 sensor tip) approximately 2 feet into the water column and waiting approximately 5 minutes or until the solid "product" tone changed to the intermittent "water" tone.

6. When the LNAPL-water interface gauging was complete, removed the second probe (Solinst® with P1 sensor tip) from the well and decontaminated the probe.

3.2 Phase 1 – Manual Removal Using Peristaltic Pump

Manual removal of LNAPL from MW-12 using a peristaltic pump was performed to evaluate the effectiveness of pumping LNAPL. Recharge of the LNAPL column within MW-12 was subsequently gauged.

On March 17, 2014, ARCADIS initiated Phase 1 of pilot testing, in accordance with the RDWP (ARCADIS 2013). The sorbent sock deployed as part of the ongoing operation and maintenance (O&M) requirement at MW-12 was removed on March 14, 2014, to allow LNAPL inside MW-12 to equilibrate with LNAPL outside the well in the adjacent formation. After the LNAPL equilibration period and prior to beginning LNAPL removal from MW-12, an initial LNAPL thickness of 4.12 feet was measured. Pumping and bailing were performed for

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[2] ARCADIS attempted this method without using a detergent, but found that measurements made without the detergent were less precise.

2 days, and were completed on March 18, 2014. Deviations from the RDWP (ARCADIS 2013) are explained below.

After completion of LNAPL removal for Phase 1, LNAPL recharge monitoring was conducted on March 18 and 21, April 3 and 18, and May 8. On May 8, 2014, the LNAPL thickness in MW-12 had recovered to approximately 1.37 feet. Although this was less than 50% of the initial LNAPL thickness, the project team determined that this was sufficient recharge to continue with subsequent phases of the pilot tests, as described below.

LNAPL and groundwater gauging results and river stage records from the Phase 1 test are summarized in Appendix A and on Figure 4.

*Deviations from the Remedial Design Work Plan (ARCADIS 2013)*The removal method was modified to use manual bailing, in addition to the initial use of the peristaltic pump, to bail down the LNAPL column present in the well. A peristaltic pump was used to pump LNAPL for approximately 5 hours on March 17, 2014, resulting in drawdown of the LNAPL column by approximately 2 feet. Pumping was stopped due to insufficient daylight to complete the LNAPL removal using the peristaltic pump. ARCADIS returned to the Site on March 18, 2014 to remove the remainder of the LNAPL. Based on initial pumping activities, which demonstrated that LNAPL could be drawn down in MW-12 at a rate of approximately 0.4 foot per hour, the field team altered the removal method and used a bailer to remove the remainder of the LNAPL column present in MW-12. Removal using the bailer was substantially faster and equally as effective as pumping for LNAPL removal from MW-12, but may bias high the estimated volume of LNAPL removed as a result of emulsification of LNAPL with water during bailing.

Frequency of gauging during LNAPL recharge was modified based on a significantly slower recharge rate than anticipated in the RDWP. LNAPL recharge was gauged approximately every 30 minutes for the first 5.5 hours following removal. Follow-up visits to gauge LNAPL recharge were conducted approximately 3 days, 2 weeks, 4 weeks, and 7 weeks following LNAPL removal.

The LNAPL recharge period for Phase 1 was terminated on May 8, 2014, when the LNAPL thickness was approximately 50% of the initial LNAPL thickness. Based on the LNAPL recharge rate observed during the approximately 7-week Phase 1 recharge period, ARCADIS estimated that full recharge to the starting LNAPL thickness of approximately 4 feet would require an additional 6 to 8 weeks. To move forward with remediation, it was determined that representative pilot test data could be collected with the partial LNAPL column recharge achieved as of May 8, 2014.

3.3 Phase 2 – Manual Removal Using Peristaltic Pump in Conjunction with In-Well Heating

Heating LNAPL present within the MW-12 well casing and subsequent manual removal of LNAPL using a peristaltic pump was performed to evaluate the effectiveness of this approach. On May 8, 2014, ARCADIS initiated Phase 2 of pilot testing in accordance with the RDWP (ARCADIS 2013).

An initial Phase 2 LNAPL thickness of 1.37 feet was measured prior to initiating Phase 2 pilot test activities. A 75-watt finger heater designed for in-well applications, manufactured by Xitech, Inc. of Placitas, New Mexico, was placed below the LNAPL layer and within the water column inside the casing of monitoring well MW-12. The finger heater was approximately 1 foot long and centered approximately 2 feet below the LNAPL-water interface, in accordance with the manufacturer's instructions (Dwight Patterson, pers. com., March 3, 2014). The temperatures of the groundwater and LNAPL columns were monitored using a thermocouple thermometer during heating. After approximately 3 hours of heating, the LNAPL temperature was raised to 88°F (31°C), which lowered the viscosity of LNAPL within the MW-12 well casing to approximately 660 cSt (604.5 cP) based on viscosity-temperature measurements performed on Site LNAPL samples (see Table 2).

After heating the LNAPL to 88°F (31°C), a peristaltic pump was used to remove heated LNAPL from MW-12. Approximately 0.24 gallon of heated LNAPL was removed from MW-12, the LNAPL thickness was less than the detectable limit of the interface probe, and the LNAPL was no longer measureable or removable. The LNAPL removal period during Phase 2 was 2 hours. Pumping and heating were stopped when no further LNAPL was measurable or removable. After completion of LNAPL removal during Phase 2, gauging was conducted on May 9, 16, and 30; June 27; and July 31, 2014, to monitor recharge of LNAPL. On July 31, 2014, 84 days after the initiation of the Phase 2 tests, the LNAPL column within MW-12 was approximately 1.95 feet thick, representing full recharge to the initial LNAPL column at the beginning of Phase 2 of the pilot tests. LNAPL and groundwater gauging results and river stage records from the Phase 2 test are summarized in Appendix B and on Figure 5.

Deviations from the Remedial Design Work Plan (ARCADIS 2013)

The heater was placed in the water column below the LNAPL layer, per manufacturer instructions, rather than at the approximate center of the floating LNAPL, as described in the RDWP (ARCADIS 2013).

Although the RDWP (ARCADIS 2013) indicated that the heater would be turned off and removed from the well prior to removing LNAPL, heating of the LNAPL was continued during pumping activities to further enhance LNAPL pumpability. The heater was turned off and removed from the well at the completion of LNAPL removal activities, at the beginning of the recharge monitoring period.

Similar to the Phase 1 pilot test, recharge monitoring was conducted for 7 weeks due to the slow rate of LNAPL recharge.

3.4 Phase 3 – Manual Removal Using Hydrophobic Sorbent Product

On July 31, 2014, ARCADIS initiated Phase 3 of LNAPL pilot testing. As described below, this phase was modified from the RDWP (ARCADIS 2013) by starting the test from a condition of minimal LNAPL in MW-12 and adding a Site-specific LNAPL absorption test.

For the Phase 3 pilot tests, ARCADIS used SoakEase™ 39-inch-long, 1.7-inch-diameter hydrophobic sorbent socks with a rated LNAPL capacity of 0.25 gallon per sock. In the well, the sock is housed in a 36-inch-long, perforated, stainless steel canister that is hung on a rope from the well plug. On July 31, 2014, ARCADIS adjusted the length of the rope to set the bottom of the canister at 12 feet below top of casing (btoc), based on a depth to water measurement of 11.3 feet btoc at approximate low tide. This was done to allow the tidal range of LNAPL to be entirely within the canister’s length and allow for maximum LNAPL sorption.

Prior to the in-well component of Phase 3, ARCADIS conducted an LNAPL absorption test. ARCADIS manually bailed 1.95 feet of LNAPL from MW-12 and into a metal bucket. A mixture of an estimated 0.25 gallon of LNAPL and 1 gallon of groundwater were contained in the bucket (a portion of LNAPL from the well was lost to sorbent pads used for cleanup and secondary containment). A new SoakEase™ sock was weighed, placed in the bucket, removed, and weighed periodically until the sock’s weight stabilized. Results of the absorption test are presented on Figure 6 and discussed in Section 4.3.

After completion of the LNAPL absorption test, ARCADIS initiated the in-well test on July 31, 2014. A bailer and new sorbent sock were used to remove as much of the residual LNAPL as possible from MW-12. A new sock was weighed and deployed in the well in the stainless steel canister at a pre-established depth. The sock was retrieved and weighed after 1 hour and the well was gauged. ARCADIS returned to the Site on August 13, 2014 to weigh the sock and gauge the well. At that time, ARCADIS deployed a new sock in MW-12. ARCADIS returned to the Site on August 28, 2014 to weigh the sock and gauge the well, and again deployed a new sock in MW-12. ARCADIS returned to the Site on September 10, 2014 to weigh the sock. During this visit, ARCADIS left the sock in the well until a return visit on September 24, 2014 to assess the 4-week performance of the monitoring well sock. At that time, ARCADIS deployed a new sock in MW-12 for O&M purposes. During the Phase 3 recharge monitoring period, the sorbent socks were found to effectively absorb all

LNAPL that flowed into MW-12 and no measurable LNAPL thickness was present during the Site visits on August 13 and 28, and September 10 and 24.

LNAPL and groundwater gauging results, sock weights, and river stage records from the Phase 3 test are summarized in Appendix C and on Figure 7.

Deviations from the Remedial Design Work Plan (ARCADIS 2013)

The sorbent sock absorption test was not described in the RDWP (ARCADIS 2013), but was conducted to determine the Site-specific LNAPL absorption rate and capacity of the sorbent socks used for pilot testing.

The Phase 3 pilot test approach was modified from the approach outlined in the RDWP (ARCADIS 2013) after Phases 1 and 2 identified that under recent conditions, the volume of LNAPL in MW-12 exceeded the sorbent capacity of a sock. Instead of placing a sock in MW-12 under recent LNAPL conditions, the LNAPL was removed using a bailer prior to initiating Phase 3 pilot testing to avoid immediately saturating the sock. Due to the slow LNAPL recovery rates observed during the first two phases of pilot testing, this method allowed ARCADIS to assess how well the sock could maintain a minimal LNAPL thickness in the well. The Phase 3 test was conducted using three sorbent socks in series, with the first two socks in place for 2 weeks each and the third sock in place for 4 weeks.

3.5 LNAPL Sampling and Analysis

Two LNAPL samples were collected from MW-12 for analysis of physical properties. In preparation for pilot testing, the first LNAPL sample was collected on November 18, 2013, in conjunction with a routine O&M Site visit, and submitted to a certified laboratory for the following analyses:

- Viscosity by ASTM International (ASTM) Method D445 at 60, 75, and 90°F at PTS Laboratories of Santa Fe Springs, California

- Flashpoint by United States Environmental Protection Agency Method 1020A at TestAmerica of Seattle, Washington

The second LNAPL sample was collected from MW-12 on May 8, 2014, in conjunction with initiation of Phase 2 of the pre-design pilot test, and submitted to a certified laboratory for the following analyses:

- IFT (air-LNAPL, LNAPL-groundwater, and air-groundwater) by ASTM Methods D445 and D1481 at 55°F at PTS Laboratories of Santa Fe Springs, California

4. Pilot Test Results

4.1 Phase 1 Results – Manual Removal with Peristaltic Pump

On March 17, 2014, prior to conducting Phase 1 of the LNAPL removal pilot test, ARCADIS measured 4.12 feet of LNAPL in MW-12. Approximately 0.71 gallon of LNAPL was removed from the well during Phase 1 (Table 1). Data from Phase 1 are provided in Appendix A.

LNAPL removal using a peristaltic pump was slow due to the high LNAPL viscosity. The LNAPL removal rate using the peristaltic pump was 0.08 gallon per hour (gph). LNAPL removal by manual bailing was effective at removing LNAPL from MW-12 and was significantly more efficient than pumping due to viscosity limitations. The LNAPL removal rate by manual bailing was 0.24 gph.

LNAPL recharge in MW-12 was monitored for 7 weeks from March 18 to May 8, 2014. On May 8, 2014, at the end of the Phase 1 LNAPL recharge period, the LNAPL thickness was 1.37 feet.

4.2 Phase 2 Results – Manual Removal Using Peristaltic Pump in Conjunction with In-Well Heating

On May 8, 2014, prior to collecting LNAPL samples for analysis and conducting the Phase 2 LNAPL removal pilot test, ARCADIS measured approximately 1.37 feet of LNAPL in MW-12. ARCADIS collected an LNAPL sample (approximately 0.04 gallon) for analysis with a bailer prior to starting the heating for the Phase 2 pilot test. LNAPL present within MW-12 was heated from 55 to 88°F over approximately 3.5 hours. Approximately 0.20 gallon of heated LNAPL was removed using a peristaltic pump during Phase 2 (Table 1, Figure 5). Data from Phase 2 are provided in Appendix B.

Heated LNAPL removal using a peristaltic pump was slightly faster than removal of LNAPL at ambient temperature by equivalent pumping methods, achieving a removal rate of approximately 0.1 gph. This marginal increase in the LNAPL removal rate was offset by the additional 3 hours required for in-well heating prior to pumping.

LNAPL recharge in MW-12 was monitored for 12 weeks from May 8 to July 31, 2014. On July 31, 2014, at the end of the Phase 2 LNAPL recharge period, the LNAPL thickness was 1.95 feet.

4.3 Phase 3 Results – Manual Removal Using Hydrophobic Sorbent Product

On July 31, 2014, prior to conducting the Phase 3 LNAPL removal pilot test, ARCADIS measured approximately 1.95 feet of LNAPL in MW-12. This LNAPL was removed with a bailer and used for the absorption test. During the LNAPL absorption test, the sorbent sock absorbed nearly all of the LNAPL in the test bucket after 18 minutes. By 30 minutes, the sock weight had stabilized (Figure 6). Calculations based on the density of the LNAPL (approximately 0.96 g/mL at 60°F, Appendix D) indicate that the sock had sorbed approximately 75% of its rated capacity. The maximum weight of the sock may have been limited by the amount of LNAPL in the bucket; however, results indicate that the rate of LNAPL sorption into the sock (approximately 0.35 gph) far exceeds the rate of LNAPL recharge into the well (discussed in Section 4.5).

The in-well sorbent sock test results indicate that sorbent socks are able to maintain a minimal LNAPL thickness in the well for up to 4 weeks before becoming effectively saturated.

When ARCADIS returned to the Site on August 13, 2014, the sock weight was nearly the maximum weight observed during the absorption test. The top and bottom of the sock contained significant unstained portions, indicating that placement of the canister spanned the tidal range of the potentiometric surface in the well during this time period. Due to the near-saturation of the sock, ARCADIS deployed a new sock in MW-12. Only a trace amount of LNAPL thickness was measured at this time. Similar results were obtained when ARCADIS conducted a Site visit on August 28, 2014, when again ARCADIS replaced the sock in MW-12. This sock was left in place for 4 weeks, with an intermediate weight measurement after 2 weeks (September 10, 2014) and a final weight measurement on September 24, 2014. At the conclusion of Phase 3 pilot testing, a trace (no measureable thickness) amount of LNAPL was present in MW-12.

4.4 LNAPL Physical Properties

LNAPL samples collected from MW-12 were analyzed for select physical properties to support evaluation of LNAPL removal options. Analytical data reports are included in Appendix D and summarized in Table 2.

4.4.1 Flash Point

Flash point data indicated that the LNAPL's flash point was more than 212°F and could therefore be safely heated to approximately 90°F without creating a fire or explosion hazard.

4.4.2 Viscosity

Temperature-dependent viscosity data indicated that heating the LNAPL to realistic in-well temperatures of up to 90°F (32°C) would provide an approximate six-fold decrease in the

LNAPL viscosity compared to ambient in-well temperatures, from 3,643 to 660 cSt (3,588.3 cP).

4.4.3 Interfacial Tension

IFT was measured for the LNAPL-water interface, LNAPL-air interface, and water-air interface. These values were 16, 32.6, and 70.3 dynes/cm, respectively. IFT data were used to evaluate LNAPL critical head thicknesses that would cause mobility of LNAPL from the well and are discussed in Section 5.1.

4.5 LNAPL Recovery Evaluation

LNAPL removal pilot test results show that the LNAPL recharge rate in MW-12 was fairly consistent regardless of which LNAPL removal method was attempted. LNAPL recharge to a recovery well is controlled by a combination of the soil properties of the formation immediately adjacent to the well and the physical properties of the LNAPL. For LNAPL at MW-12, the high viscosity of the LNAPL provides the primary control on LNAPL recovery rates.

The average LNAPL recharge rate was calculated by performing a linear regression of the LNAPL thicknesses measured during the Phase 1 and 2 recharge monitoring periods. LNAPL recharge during the Phase 1 and 2 recharge periods was approximately linear and ranged from 0.0036 to 0.0045 gpd, which is roughly equivalent to 1.3 to 1.6 gpy (Table 4 and Figure 8).

The recharge rate of LNAPL in MW-12 following manual removal was approximately 0.0045 gpd. The recharge rate of LNAPL in MW-12 following heating and manual removal was 0.0036 gpd. During Phase 3, the sorbent sock continuously absorbed LNAPL such that there was no accumulated LNAPL thickness and 0.71 gallon of LNAPL was collected by the sorbent socks. The recharge rate of LNAPL in MW-12 during Phase 3 pilot testing was 0.0100 gpd. The Phase 3 recovery rates are likely biased high because sorbent socks absorb a small amount of water. The volume of LNAPL recovered, calculated from the mass of the soiled sock, may overestimate the recovered LNAPL and correspondingly the LNAPL recharge rate due to the small additional weight of water within the sorbent sock. This results in a faster LNAPL recharge rate calculated for Phase 3 relative to Phases 1 and 2.

5. LNAPL Predesign Analysis

This section presents an analysis of Site data, including historical data (as appropriate) and data collected during predesign pilot tests, to determine the recommended LNAPL removal approach that will be carried forward into the remedial design.

5.1 LNAPL Mobility Evaluation

5.1.1 Critical LNAPL Mobility Thickness Calculation

This section calculates the critical LNAPL mobility thickness above which LNAPL migration is possible, and below which LNAPL is no longer mobile. As discussed above, almost all soils provide a natural resisting force to LNAPL migration (soil entry pressure), with finer-grained soil having higher entry pressures and coarser-grained soil having lower entry pressures. The critical LNAPL mobility thickness depends on the physical properties of the LNAPL, specifically the LNAPL-groundwater IFT. The critical LNAPL mobility thickness also depends on the radius of soil pores. The critical LNAPL mobility thickness is therefore a Site-specific value that depends on Site-specific LNAPL and soil physical properties. The critical LNAPL mobility thickness can serve as the basis for a remediation goal for LNAPL removal.

The critical LNAPL mobility thickness was calculated using the Brooks and Corey method (1964) based on Site-specific LNAPL properties measured in samples collected at MW-12 and soil properties determined during the RI and FS. Calculations are provided in Appendix F and results are summarized in Table 6. As shown, the critical LNAPL mobility thickness for the Site varies between approximately 1.4 and 1.7 feet. This result indicates that the MW-12 LNAPL hot spot will be stable and no longer capable of expanding when LNAPL thicknesses in monitoring and recovery wells are consistently below 1.4 feet. These findings should be considered when evaluating remedial effectiveness.

5.1.2 LNAPL Transmissivity

The mobility and recoverability of LNAPL in the subsurface can be evaluated by measuring LNAPL transmissivity at wells (API 2012, Interstate Technology & Regulatory Council [ITRC] 2009). LNAPL transmissivity represents the volumetric rate of LNAPL flow through a unit width of porous media per unit time under a unit capillary pressure. A direct mathematical relationship exists between LNAPL transmissivity and the rate of LNAPL flow into a well, and therefore LNAPL transmissivity may be estimated during LNAPL removal activities.

LNAPL transmissivity was historically estimated at the Site during completion of the RI and FS using bail-down test data and was determined to be approximately 0.014 square foot per day (ft^2/day) (MFA 2010). However, LNAPL thickness measurements made during the RI and FS were uncertain due to complexities of measuring levels of highly viscous fluids with conventional electronic fluid-measurement devices. Therefore, additional LNAPL transmissivity estimates were made using the 2014 pilot test data to verify results of the RI and FS.

To estimate LNAPL transmissivity at MW-12 based on 2014 pilot test data, the data were analyzed using a modified version of the Bouwer and Rice (1976) groundwater slug test solution for unconfined aquifers, in accordance with technical guidance documents provided by API (2007) and ITRC (2009). Curve fitting of the pilot test data was achieved by manually and visually matching the modified Bouwer and Rice (1976) slug test model to the MW-12 LNAPL field data. Appendix F presents the relevant calculations. Assumptions for the modified Bouwer and Rice (1976) method include quasi-steady-state recharge to the well, with drawdown dependent on rate and no storage effects.

The LNAPL transmissivity at MW-12 was determined to vary between approximately 0.03 and 0.04 ft^2/day based on the 2014 pilot test data (Appendix F and Table 7). These results are consistent with and verify historical LNAPL transmissivity estimates made during the RI and FS.

It is notable that these Site-specific LNAPL transmissivity measurements are significantly below the LNAPL transmissivity criterion of 0.1 to 0.8 ft^2/day established by the ITRC (2009) for screening LNAPL recovery technologies. According to the ITRC (2009), because the Site LNAPL transmissivity is below this criterion, LNAPL recovery at MW-12 using skimming technologies will not recover LNAPL in sufficient quantities to reduce the overall LNAPL mass. Nonetheless, LNAPL recovery at MW-12 could potentially de-saturate the LNAPL to the point that it is no longer mobile. LNAPL de-saturation and immobilization at the Site will be demonstrated by long-term gauging of LNAPL thicknesses in Site monitoring wells following cessation of LNAPL recovery. Assuming that LNAPL transmissivity at the new MW-12R location is similar to that at MW-12, skimming technology will likely have similar limitations and LNAPL recovery could be similarly performed using other LNAPL removal methods, as discussed below.

5.2 Evaluation of LNAPL Recovery Well Options

This section evaluates alternative LNAPL recovery well options for use in enhancing the LNAPL recovery rate during remediation. Options include the use of a larger diameter recovery well or multiple recovery wells, with the goal of recovering LNAPL at a rate significantly faster than was recovered at well MW-12 during pilot testing.

To accomplish this, a modified version of the unconfined equilibrium well equation (Thiem 1906, Driscoll 1986) was used to estimate and compare relative LNAPL recovery rates under the selected LNAPL recovery well alternatives:

$$Q_L = \frac{K_L({H_L}^2 - {h_L}^2)}{1{,}055 \log R/r}$$

Where:

$b_{n(crit)}$	=	critical LNAPL thickness in well (centimeters)
Q_L	=	estimated LNAPL recovery rate
H_L	=	static LNAPL thickness outside the recovery well
h_L	=	LNAPL thickness inside the recovery well
R	=	radius of the LNAPL zone contributing flow to the recovery well
r	=	radius of the recovery well.

In this equation, K_L is the LNAPL conductivity, which is equivalent to hydraulic conductivity of groundwater (K_W) modified to account for the density and viscosity of the LNAPL using the standard hydrogeologic equation (Freeze and Cherry 1979):

$$K = \frac{k\rho g}{\mu}$$

Where:

K, ρ, and μ	=	conductivity, density, and viscosity of the fluid, respectively
k	=	permeability of the porous medium
g	=	gravitational constant.

This equation can be rearranged to estimate the LNAPL conductivity as follows:

$$K_L = K_W \left(\frac{\rho_L}{\rho_W}\right)\left(\frac{\mu_W}{\mu_L}\right)$$

In this equation, all of the symbols are as defined above and the subscripts *L* and *W* stand for LNAPL and groundwater, respectively. Using this equation, a geometric mean hydraulic conductivity for the Site of 7×10^{-3} centimeters per second (cm/sec), an LNAPL density of 0.98 gram per centimeter, and an LNAPL viscosity of 3,211 cP, it can be estimated that the Site-specific LNAPL conductivity is approximately 2×10^{-6} cm/sec.

To perform this remedial evaluation, the LNAPL-modified version of the unconfined equilibrium well equation was first used to estimate uncertain parameters, including static LNAPL thickness outside the recovery well (H_L) and radius of the LNAPL zone (R). This was accomplished by adjusting these parameters within reasonable ranges until the predicted LNAPL recovery rate (Q_L) was consistent with the measured recovery rate of

0.005 gpd. The final values were 0.5 foot of LNAPL thickness outside the recovery well and 25 feet for the LNAPL zone radius. It is important to note that these values are estimates because the physics of LNAPL migration and distribution in the subsurface is complex, highly nonlinear, and involves multiphase fluid-flow concepts. The parameter estimates were held constant for the predictive analysis and provide a reasonable basis for evaluating relative LNAPL recovery rates that may be associated with alternative recovery well designs.

After uncertain parameters were estimated, the LNAPL-modified version of the unconfined equilibrium well equation was used to predict LNAPL recovery rates under the alternative LNAPL recovery well options. Results are shown in the table below.

Scenario	Number of Recovery Wells	Well Diameter (inches)	Predicted LNAPL Recovery Rate (gpd)
Base Case	1	2	0.005
Increase Well Diameter	1	6	0.006
Increase # of Wells	2	6	0.012

As shown in the table above, neither increasing the LNAPL recovery well diameter nor doubling the number of LNAPL recovery wells appreciably increases the anticipated LNAPL recovery rates. This is because LNAPL at the Site is approximately 3,000 times more viscous than groundwater and this viscosity limitation governs the rate of LNAPL migration, rate of LNAPL recovery, and overall LNAPL remediability. In other words, no amount of additional recovery wells or alternative recovery well designs can overcome the viscosity limitation. Therefore, the use of alternative recovery well designs provides negligible benefit compared to the cost.

Although it is unlikely that installation of a new well will significantly improve the volume of LNAPL recovered or the rate of LNAPL recovery from the MW-12 LNAPL hot spot, installation of a new well designated as MW-12R is nonetheless proposed as part of the LNAPL remedy in accordance with the ROD (DEQ 2012). As discussed below, if LNAPL conditions at proposed well MW-12R are similar to LNAPL conditions at existing monitoring well MW-12 (i.e., LNAPL physical properties and transmissivity), then LNAPL recovery at MW-12R will be conducted using the LNAPL recovery approach outlined in this report. If LNAPL conditions at proposed well MW-12R are not similar to conditions at MW-12, then conditions will be assessed and the LNAPL recovery approach will be developed based on conditions at that location. If no LNAPL is present at proposed well MW-12R, then the new well will be rolled into the long-term monitoring program. Note that the location of proposed well MW-12R is between existing monitoring well MW-12 and the Columbia River, which indicates that it is in an ideal location in terms of LNAPL recovery, if present, or LNAPL stability monitoring if LNAPL is not present.

5.3 Evaluation of LNAPL Removal Options

During 2014, ARCADIS conducted LNAPL removal pilot tests using manual LNAPL removal methods that could be used to evaluate various hydraulic LNAPL recovery approaches, including use of an automated skimmer. Based on the pilot tests, LNAPL removal options are evaluated below:

- *Option 1: LNAPL removal by pumping with a peristaltic pump or by manual bailing*. A peristaltic pump was used to pump LNAPL for approximately 5 hours, pumping was stopped at the end of the day, and ARCADIS returned to the Site the following morning to remove the remainder of the LNAPL via manual bailing, due to the slow removal rate achieved by the pump. Additionally, LNAPL recovery was slow into MW-12. Over 52 days, only 33% of the LNAPL original thickness recovered in the well (Figure 3).

- *Option 2: LNAPL removal by heating LNAPL within the well to reduce its viscosity and removal by pumping with a peristaltic pump*. LNAPL removal using an in-well heater and peristaltic pump was slow. While the LNAPL removal rate (approximately 0.1 gph) was faster than pumping unheated LNAPL during Phase 1, the additional time required for heating resulted in an overall slower removal rate (approximately 0.04 gph). Furthermore, the LNAPL recharge rate into MW-12 after the LNAPL was heated was consistent with the recharge rate obtained when the LNAPL was removed only by manual bailing. Although an increase in the LNAPL removal rate from MW-12 was observed using Option 2 compared to Option 1 (Figures 3 and 4), Option 2 does not provide any benefit because the in-well heating technique only marginally improved the pumpability of the LNAPL and had no effect on the volume of LNAPL removed versus removal of LNAPL at ambient temperatures.

- *Option 3: LNAPL removal using sorbent socks*. The in-well sorbent sock test results indicate that during three separate sock change out events, a total of 0.71 gallon of LNAPL was removed (Table 3). Approximate LNAPL removal volumes recovered in each sorbent sock used during Phase 3 were consistent and ranged from 0.15 to 0.19 gallon. These results show that socks could effectively absorb LNAPL recharging into MW-12 and maintain LNAPL thickness at or near 0 foot with a regular changeout frequency between 2 and 4 weeks given a current recharge rate of approximately 0.006 gpd (Appendix C). Furthermore, because the socks were deployed across the tidal range in the well, the socks maintain a minimum LNAPL thickness in the well which maximizes the LNAPL gradient toward the well.

- *Option 4: Automated skimming*. As discussed above, LNAPL recovery at MW-12 using skimming technologies could be used for LNAPL recovery, although the effectiveness would be limited by the LNAPL physical properties and transmissivity. Similar to the other three methods, the overall recovery rate using an automated skimmer system is expected to be limited by the rate of recharge rate of LNAPL into the well. Skimming technology requires LNAPL to accumulate and intermittent operation of the skimmer to remove accumulated LNAPL from the well and therefore does not maintain a near-zero thickness of LNAPL in the well during skimmer operation. Operation of automated skimmer systems also requires frequent routine O&M and includes the potential for malfunction, unplanned system shutdowns, and accidental releases.

5.4 Recommended LNAPL Removal Method

As discussed in Sections 5.1, 5.2, and 5.3, the LNAPL removal and recharge rates at the Site are controlled by the LNAPL's high viscosity. The LNAPL removal method has been shown to have an insignificant effect on the rate of LNAPL recharge and the volume of LNAPL removed from MW-12. If LNAPL is encountered at the location of new well MW-12R, the LNAPL physical conditions are likely to be similar to those encountered at MW-12, and therefore the removal method selected for MW-12 is likely to be effective at MW-12R, if needed.

Implementation of LNAPL removal from the MW-12 LNAPL hot spot using any of the above-listed manual removal options is likely to have equivalent results because the LNAPL recovery rate is controlled by its viscosity (not by differences in remedial technologies), and can therefore be considered to be equivalent in terms of effectiveness. Therefore, implementability and cost are the most significant considerations affecting the selection of the LNAPL removal method for the Site. All of the manual LNAPL removal methods are implementable. Option 2 does not offer any benefits over other manual removal alternatives, and therefore is not recommended. Automated LNAPL removal using a skimmer offers no advantage because the LNAPL recovery rate is controlled by the LNAPL physical properties and transmissivity.

Based on the pilot test results, Option 3 is the best remedial option for MW-12. Option 3 allows for continuous LNAPL removal because LNAPL transmissivity is low. Also, Option 3 offers the easiest way to remove the highly viscous LNAPL without having to heat LNAPL in the well. Compared to Option 4, Option 3 has the advantage that LNAPL removal is continuous rather than intermittent. Option 3 provides for continuous LNAPL removal with few technical challenges.

As discussed above, the use of automated skimmers does not offer a technical advantage for LNAPL removal based on the LNAPL physical properties and transmissivity. Furthermore, as discussed below, the location of MW-12 in an active roadway makes use of a skimmer system at that location technically impracticable. Although it may be possible to install a skimmer at the new MW-12R location, it is unlikely that LNAPL conditions at that location would be suitable for use of an automated skimmer, and recovery using Option 3 (sorbent socks) would likely be the most suitable if LNAPL physical properties and transmissivity are similar to MW-12 at the new MW-12R location.

5.5 Evaluation of LNAPL Removal Frequency

The recharge rate of LNAPL at MW-12 was calculated to range from approximately 0.004 to 0.009 gpd. Assuming that the LNAPL recharge rate is constant during the initial phase of LNAPL recovery and based on the results of Phase 3 of the pre-design pilot test, LNAPL removal should be conducted with sorbent socks with a changeout frequency of every 4 weeks to maintain an LNAPL thickness at or near 0.00 foot at MW-12.

Through time, as LNAPL within the MW-12 LNAPL hot spot is depleted, the recharge rate is likely to decrease and the sock changeout frequency necessary to maintain a 0.00-foot LNAPL thickness at MW-12 is likely to decrease as well. The LNAPL removal frequency would be continuously evaluated and updated as the LNAPL recharge rate changes, in accordance with the adaptive management approach.

5.6 LNAPL Removal Locations

Historically, measurable thicknesses of LNAPL have been observed at monitoring wells MW-7, MW-11, MW-12, and MW-13. Sorbent socks are currently maintained in these wells to collect and remove any LNAPL that accumulates in these wells. While socks are deployed in these wells, the objective is to maintain LNAPL thicknesses at or near 0.00 foot.

Historically, MW-12 has had the thickest LNAPL column measured at the Site and the largest volume of LNAPL removed. MW-12 is considered to be the center of the MW-12 LNAPL hot spot at the Site; therefore, LNAPL removal at MW-12 is an important element of the planned LNAPL recovery remedy. MW-12 is a flush-mount well located within an active roadway and within the railroad right of way used by the City of Astoria tourist trolley (Figure 3). The roadway serves traffic accessing the condominium complex as well as the businesses and facilities in the neighborhood. MW-12 can be accessed for limited durations by establishing a work zone around the well, including traffic control signs and delineators. The short-term effect on traffic does not cause a hardship on the community and can be timed to avoid the most congested or heavily used times of day.

Manual LNAPL removal is the only implementable LNAPL removal approach at MW-12. It is technically impracticable and therefore infeasible to install a skimmer and the associated piping, oil/water separator, collection tank, and power supply that would be necessary to operate such an LNAPL recovery system. These permanent or semipermanent structures would interfere with the use of the river walk and railroad right of way for both vehicular and trolley traffic. Furthermore, as described in Section 5.3, LNAPL removal using a skimmer is not likely to be beneficial at any well within the MW-12 LNAPL hot spot due to viscosity limitations.

5.7 Updated LNAPL Conceptual Site Model

The LNAPL CSM should be updated based on the following findings as a result of the recent pilot testing and subsequent remedial evaluations:

- Recoverable quantities of LNAPL are present in well MW-12.
- The recovery rate of LNAPL at MW-12 is limited by the high viscosity of the LNAPL, which has been measured, verified, and is approximately 3,000 times more viscous than water.
- A maximum LNAPL recovery rate of approximately 0.005 gpd can be achieved using the remedial technologies tested.
- The radius of the LNAPL zone is estimated to be 25 feet.
- The LNAPL conditions at the proposed location for MW-12R are unknown. However, MW-12R is located within approximately 12 feet of MW-12 and within the area assumed to lie within the downgradient portion of the MW-12 LNAPL hot spot.
- A conservative estimate of the total LNAPL volume near the MW-12 LNAPL hot spot can be made assuming that the LNAPL occupies an approximately circular zone with radius of 25 feet, LNAPL layer/smear zone thickness of 2 feet, formation porosity of 0.4, and 10% LNAPL saturation. These values give a total LNAPL volume of approximately 1,175 gallons.

LNAPL mobility in the subsurface is limited due to the high LNAPL viscosity, and is restricted due to the IFT properties of the LNAPL and natural entry pressure of Site soil, which provides a resisting force. Based on standard multiphase fluid flow concepts, the critical LNAPL height required for LNAPL to enter previously unimpacted soil is approximately 1.4 to 1.7 feet.

6. Proposed LNAPL Recovery Approach

Based on the pre-design data collected during the 2014 pilot tests and subsequent data analysis, and in accordance with the ROD-selected remedy (DEQ 2012) for the MW-12 LNAPL hot spot, the proposed LNAPL removal approach consists of the following elements:

- Implementation of a long-term monitoring program consisting of monthly water-level and LNAPL gauging at existing monitoring wells MW-7, MW-11, MW-12, and MW-13, and at proposed well MW-12R.

- Implementation of enhanced LNAPL recovery at existing monitoring well MW-12 using a manual LNAPL removal program of sorbent socks.

- Further enhancement of LNAPL recovery through the installation of a new monitoring well, designated as MW-12R. If LNAPL conditions at proposed well MW-12R are similar to conditions at existing monitoring well MW-12, then LNAPL recovery at MW-12R will begin using sorbent socks. If LNAPL conditions at proposed well MW-12R are different than at MW-12, then conditions will be assessed as per this report to determine the best method to remove LNAPL from MW-12R. If no LNAPL occurs at proposed well MW-12R, then it will be rolled into the long-term monitoring program.

- If LNAPL enters any Site monitoring wells at a measurable thickness, then LNAPL removal will be performed using sorbent socks.

This approach complies with the selected remedy established in the ROD (DEQ 2012) and maximizes the potential for long-term effectiveness for protecting the beneficial uses of surface water in the Columbia River.

Because the ROD (DEQ 2012) specifies that LNAPL removal will be performed through an adaptive management approach, this proposed LNAPL recovery approach will be implemented as a phased remedy in which subsequent phases depend on data and results obtained during earlier phases. Specifically, the proposed LNAPL removal approach will rely on ongoing evaluation of LNAPL absence/presence, LNAPL removal quantities, LNAPL physical properties, and LNAPL thickness data collected at the Site monitoring network to support remedial decision-making. The proposed LNAPL removal approach is shown on Figure 9 and described below.

The initial phase of the LNAPL remedy will include immediate implementation of a manual LNAPL removal program at MW-12 using sorbent socks. Sorbent socks, if replaced at regular intervals, will maintain a near-zero LNAPL thickness in the recovery well and therefore maximize the LNAPL flow rate into the well. LNAPL removal using sorbent socks requires appropriately timed O&M to ensure that sock saturation does not allow LNAPL to accumulate in the well casing. Data collected during the 2014 pilot tests show that the initial sorbent sock replacement frequency at MW-12 should be every 4 weeks. However, the O&M frequency may be adjusted through the adaptive management approach and will depend on, among other things, the rate of LNAPL removal and LNAPL thickness data for MW-12.

The manual LNAPL removal program at MW-12 will continue until LNAPL recovery is no longer technically practicable, as demonstrated, for example, by an asymptotically declining LNAPL recovery rate. Note that the ROD (DEQ 2012) assumed an operational period of 10 years. Therefore, if LNAPL is still present in Site monitoring and recovery wells after 10 years of active recovery, assumptions in the ROD (DEQ 2012) will be revisited during the second 5-year review.

Additionally, the proposed approach involves installation of one new 6-inch-diameter monitoring well at the proposed MW-12R location in accordance with the ROD (DEQ 2012) where LNAPL recovery will be attempted (Figure 3). As shown, monitoring well MW-12R is located approximately 12 feet northwest of MW-12, between MW-12 and the Columbia River. This location is within 25 feet of MW-12 and therefore likely to encounter LNAPL, if present, and is also protective of the river.

After MW-12R is installed and developed, it will be monitored to determine if LNAPL is present and accumulates within the well casing. If LNAPL accumulates in MW-12R, the LNAPL will be sampled and analyzed for density, viscosity, and IFT with groundwater at a range of temperatures bracketing ambient groundwater temperatures, and an LNAPL bail-down test will be performed. If present, LNAPL conditions at MW-12R will be compared with conditions at MW-12 on the basis of LNAPL physical properties and transmissivity.

If LNAPL conditions at MW-12R are similar to those at MW-12, then LNAPL recovery will be initiated at MW-12R using sorbent socks. The initial sorbent sock replacement frequency at MW-12R will be monthly, but may be adjusted using the adaptive management approach based on monitoring data (e.g., removal rates, LNAPL thicknesses).

If LNAPL conditions at MW-12R are different than at MW-12, then conditions will be assessed and the LNAPL recovery approach will be developed based on conditions at that location, as described in Section 5. If no LNAPL accumulates in MW-12R, then MW-12R will be rolled into the long-term monitoring program.

Furthermore, if LNAPL enters any other Site monitoring wells during implementation of the ROD (DEQ 2012) and long-term monitoring program, then LNAPL removal will occur at those monitoring wells using sorbent socks.

After LNAPL recovery is no longer technically practicable in Site monitoring and recovery wells as demonstrated by monitoring data (e.g., declining recovery rates), LNAPL recovery will cease and effectiveness monitoring at the Site monitoring network will be performed for 6 months. Effectiveness monitoring will include monthly fluid-level measurements without removal of LNAPL.

If residual LNAPL thicknesses (if present) are declining or stable after 6 months of effectiveness monitoring without recovery, then remediation of the MW-12 LNAPL hot spot will be considered complete. At this point, the LNAPL will be considered immobile and not able to migrate and impact the beneficial use of surface water in the Columbia River. LNAPL removal will therefore no longer be necessary, remediation of the MW-12 LNAPL hot spot will cease, and the Parties will request a No Further Action determination from the DEQ. Please note that remedy effectiveness will continue to be evaluated through the 5-year review process. If at any time during the 6-month effectiveness monitoring period LNAPL thicknesses increase significantly, LNAPL removal can be performed as described above.

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Tables

Table 1
Historical LNAPL Gauging and Removal Results
Former Union Oil/PacifiCorp Astoria Site
256 Marine Drive, Astoria Oregon

Location	Date	Tidal Stage[1] (ft)	Tidal Status	Depth To Water (ft)	LNAPL Thickness (ft)	LNAPL Removed (gallons)	Removal Method	Cumulative LNAPL Removed (gallons)
MW-7	2/7/1995	-	-	-	0.00	0	-	0.00
MW-7	2/14/1995	-	-	-	0.00	0	-	0.00
MW-7	3/13/1995	-	-	-	0.00	0	-	0.00
MW-7	8/14/1997	-	-	-	0.00	0	-	0.00
MW-7	11/18/1997	-	-	-	0.15	0	-	0.00
MW-7	2/11/1998	-	-	-	0.00	0	-	0.00
MW-7	5/19/1998	-	-	-	0.00	0	-	0.00
MW-7	12/27/2001	-	-	-	0.06	0	-	0.00
MW-7	1/24/2002	-	-	-	0.00	0	-	0.00
MW-7	2/28/2002	-	-	-	0.00	0	-	0.00
MW-7	1/28/2003	-	-	-	0.00	T	-	0.00
MW-7	2/27/2003	-	-	-	0.01	0.002	-	0.00
MW-7	4/18/2003	-	-	-	0.00	T	-	0.00
MW-7	5/19/2003	-	-	-	0.01	0.002	-	0.00
MW-7	6/23/2003	-	-	-	0.00	0	-	0.00
MW-7	6/24/2003	-	-	-	0.00	0	-	0.00
MW-7	7/15/2003	-	-	-	0.00	T	-	0.00
MW-7	8/14/2003	-	-	-	0.15	0.02	-	0.02
MW-7	9/22/2003	-	-	-	0.10	0.02	-	0.04
MW-7	10/23/2003	-	-	-	0.00	0	-	0.04
MW-7	11/17/2003	-	-	-	0.00	0	-	0.04
MW-7	12/23/2003	-	-	-	0.00	0	-	0.04
MW-7	1/15/2004	-	-	-	0.00	0	-	0.04
MW-7	2/26/2004	-	-	-	0.01	0.002	-	0.05
MW-7	3/22/2004	-	-	-	0.00	T	-	0.05
MW-7	4/22/2004	-	-	-	0.00	T	-	0.05
MW-7	5/24/2004	-	-	-	0.00	T	-	0.05
MW-7	6/22/2004	-	-	-	0.01	0.002	-	0.05
MW-7	7/22/2004	-	-	-	0.00	T	-	0.05
MW-7	8/19/2004	-	-	-	0.04	0.007	-	0.06
MW-7	9/15/2004	-	-	-	0.00	T	-	0.06
MW-7	10/14/2004	-	-	-	0.00	0	-	0.06
MW-7	11/9/2004	-	-	-	0.00	T	-	0.06
MW-7	12/8/2004	-	-	-	0.00	0	-	0.06
MW-7	1/20/2005	-	-	-	0.00	T	-	0.06
MW-7	2/14/2005	-	-	-	0.00	T	-	0.06
MW-7	3/30/2005	-	-	-	0.00	0.01	-	0.07
MW-7	5/3/2005	-	-	-	0.00	0	-	0.07
MW-7	5/26/2005	-	-	-	0.00	0	-	0.07
MW-7	5/31/2005	-	-	-	-	T	-	0.07
MW-7	6/27/2005	-	-	-	0.00	0	-	0.07
MW-7	7/25/2005	-	-	-	0.00	0	-	0.07
MW-7	8/23/2005	-	-	-	0.00	0	-	0.07

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MW-7	9/19/2005	-	-	-	0.00	T	-	0.07
MW-7	10/19/2005	-	-	-	0.00	T	-	0.07
MW-7	11/10/2005	-	-	-	0.10	T	-	0.07
MW-7	12/8/2005	-	-	-	0.00	T	-	0.07
MW-7	04/18/2006	-	-	-	-	0.05	Sock	0.11
MW-7	06/15/2006	-	-	-	-	0.06	Sock	0.17
MW-7	11/13/2006	-	-	-	-	0.11	Sock	0.28
MW-7	09/13/2007	-	-	-	-	0.14	Sock	0.42
MW-7	10/24/2007	-	-	-	-	0.08	Sock	0.50
MW-7	12/19/2007	-	-	-	-	0.06	Sock	0.56
MW-7	02/15/2008	-	-	-	-	0.10	Sock	0.66
MW-7	04/24/2008	-	-	-	-	0.08	Sock	0.74
MW-7	07/22/2008	-	-	-	-	0.06	Sock	0.80
MW-7	10/16/2008	-	-	-	-	0.11	Sock	0.91
MW-7	01/16/2009	-	-	-	-	0.16	Sock	1.07
MW-7	07/24/2009	-	-	-	-	0.02	Sock	1.09
MW-7	06/30/2010	-	-	-	-	0.10	Sock	1.19
MW-7	01/26/2011	-	-	-	-	0.04	Sock	1.23
MW-7	06/27/2014	-	-	-	-	0.09	Sock	1.32
MW-7	09/10/2014	-	-	-	-	0.02	Sock	1.34
MW-7			Maximum Thickness:		0.15		Total:	1.34

Table 1

Historical LNAPL Gauging and Removal Results

Former Union Oil/PacifiCorp Astoria Site

256 Marine Drive, Astoria Oregon

Location	Date	Tidal Stage[1] (ft)	Tidal Status	Depth To Water (ft)	LNAPL Thickness (ft)	LNAPL Removed (gallons)	Removal Method	Cumulative LNAPL Removed (gallons)
MW-11	10/23/1998	-	-	-	0.00	0.00	-	0.00
MW-11	1/29/1999	-	-	-	0.10	0.00	-	0.00
MW-11	4/15/1999	-	-	-	0.50	0.00	-	0.00
MW-11	7/14/1999	-	-	-	0.06	0.00	-	0.00
MW-11	9/1/2000	-	-	-	0.05	0.00	-	0.00
MW-11	11/6/2001	-	-	-	0.06	0.00	-	0.00
MW-11	12/27/2001	-	-	-	0.05	0.00	-	0.00
MW-11	2/28/2002	-	-	-	0.06	0.00	-	0.00
MW-11	12/30/2002	-	-	-	0.10	0.00	-	0.00
MW-11	1/28/2003	-	-	-	0.03	0.00	-	0.00
MW-11	2/27/2003	-	-	-	0.02	0.00	-	0.00
MW-11	3/26/2003	-	-	-	0.06	0.00	-	0.00
MW-11	4/18/2003	-	-	-	0.04	0.00	-	0.00
MW-11	5/19/2003	-	-	-	0.04	0.00	-	0.00
MW-11	6/24/2003	-	-	-	0.02	0.00	-	0.00
MW-11	7/15/2003	-	-	-	0.10	0.00	-	0.00
MW-11	8/14/2003	-	-	-	0.02	0.00	-	0.00
MW-11	9/22/2003	-	-	-	0.11	0.00	-	0.00
MW-11	10/23/2003	-	-	-	0.28	0.00	-	0.00
MW-11	11/17/2003	-	-	-	0.04	0.00	-	0.00
MW-11	12/23/2003	-	-	-	0.17	0.00	-	0.00
MW-11	1/15/2004	-	-	-	0.00	0.00	-	0.00
MW-11	2/26/2004	-	-	-	0.00	0.00	-	0.00
MW-11	3/22/2004	-	-	-	0.00	0.00	-	0.00
MW-11	4/22/2004	-	-	-	0.00	0.00	-	0.00
MW-11	5/24/2004	-	-	-	0.00	0.00	-	0.00
MW-11	6/22/2004	-	-	-	0.05	0.00	-	0.00
MW-11	7/22/2004	-	-	-	0.00	0.00	-	0.00
MW-11	8/19/2004	-	-	-	0.00	0.00	-	0.00
MW-11	9/15/2004	-	-	-	0.00	0.00	-	0.00
MW-11	10/14/2004	-	-	-	0.02	0.00	-	0.00
MW-11	11/9/2004	-	-	-	0.00	0.00	-	0.00
MW-11	12/8/2004	-	-	-	0.00	0.00	-	0.00
MW-11	1/20/2005	-	-	-	0.00	0.00	-	0.00
MW-11	2/15/2005	-	-	-	0.00	0.00	-	0.00
MW-11	3/30/2005	-	-	-	0.00	0.00	-	0.00
MW-11	5/3/2005	-	-	-	0.00	0.00	-	0.00
MW-11	5/26/2005	-	-	-	0.00	0.00	-	0.00
MW-11	6/27/2005	-	-	-	0.01	0.00	-	0.00
MW-11	7/25/2005	-	-	-	0.26	0.00	-	0.00
MW-11	8/23/2005	-	-	-	0.04	0.00	-	0.00
MW-11	9/19/2005	-	-	-	0.00	0.00	-	0.00

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Location	Date	Tidal Stage[1] (ft)	Tidal Status	Depth To Water (ft)	LNAPL Thickness (ft)	LNAPL Removed (gallons)	Removal Method	Cumulative LNAPL Removed (gallons)
MW-11	10/19/2005	-	-	-	0.02	0.00	-	0.00
MW-11	11/10/2005	-	-	-	0.08	0.00	-	0.00
MW-11	12/8/2005	-	-	-	0.07	0.00	-	0.00
MW-11	03/21/2006	-	-	-	-	0.05	Sock	0.05
MW-11	04/18/2006	-	-	-	-	0.08	Sock	0.13
MW-11	06/15/2006	-	-	-	-	0.14	Sock	0.27
MW-11	08/11/2006	-	-	-	-	0.12	Sock	0.39
MW-11	10/09/2006	-	-	-	-	0.11	Sock	0.50
MW-11	11/13/2006	-	-	-	-	0.13	Sock	0.62
MW-11	12/11/2006	-	-	-	-	0.11	Sock	0.73
MW-11	02/19/2007	-	-	-	-	0.14	Sock	0.87
MW-11	06/18/2007	-	-	-	-	0.07	Sock	0.94
MW-11	08/17/2007	-	-	-	-	0.07	Sock	1.01
MW-11	10/24/2007	-	-	-	-	0.13	Sock	1.14
MW-11	11/20/2007	-	-	-	-	0.08	Sock	1.22
MW-11	12/19/2007	-	-	-	-	0.08	Sock	1.30
MW-11	02/15/2008	-	-	-	-	0.11	Sock	1.41
MW-11	05/22/2008	-	-	-	-	0.11	Sock	1.52
MW-11	07/22/2008	-	-	-	-	0.05	Sock	1.57
MW-11	08/21/2008	-	-	-	-	0.12	Sock	1.69
MW-11	10/16/2008	-	-	-	-	0.10	Sock	1.79
MW-11	11/21/2008	-	-	-	-	0.10	Sock	1.89
MW-11	01/16/2009	-	-	-	-	0.12	Sock	2.01
MW-11	07/24/2009	-	-	-	-	0.09	Sock	2.09
MW-11	10/19/2009	-	-	-	-	0.12	Sock	2.21
MW-11	11/12/2009	-	-	-	-	0.10	Sock	2.31
MW-11	01/08/2010	-	-	-	-	0.09	Sock	2.41
MW-11	03/05/2010	-	-	-	-	0.07	Sock	2.48
MW-11	04/29/2010	-	-	-	-	0.06	Sock	2.54
MW-11	06/30/2010	-	-	-	-	0.03	Sock	2.57
MW-11	09/23/2010	-	-	-	-	0.07	Sock	2.64
MW-11	10/22/2010	-	-	-	-	0.04	Sock	2.68
MW-11	11/30/2010	-	-	-	-	0.05	Sock	2.74
MW-11	01/26/2011	-	-	-	-	0.10	Sock	2.84
MW-11	03/16/2011	-	-	-	-	0.09	Sock	2.93
MW-11	04/22/2011	-	-	-	-	0.10	Sock	3.03
MW-11	06/14/2011	-	-	-	-	0.03	Sock	3.06
MW-11	07/15/2011	-	-	-	-	0.04	Sock	3.10
MW-11	09/19/2011	-	-	-	-	0.04	Sock	3.14
MW-11	10/25/2011	-	-	-	-	0.03	Sock	3.17
MW-11	11/22/2011	-	-	-	-	0.16	Sock	3.34
MW-11	01/19/2012	-	-	-	-	0.11	Sock	3.45

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MW-11	02/15/2012	-	-	-	-	0.09	Sock	3.53
MW-11	03/12/2012	-	-	-	-	0.07	Sock	3.60
MW-11	04/13/2012	-	-	-	-	0.05	Sock	3.66
MW-11	05/11/2012	-	-	-	-	0.09	Sock	3.74
MW-11	06/15/2012	-	-	-	-	0.08	Sock	3.82
MW-11	07/11/2012	-	-	-	-	0.06	Sock	3.88
MW-11	08/15/2012	-	-	-	-	0.03	Sock	3.91
MW-11	09/11/2012	-	-	-	-	0.05	Sock	3.97
MW-11	10/04/2012	-	-	-	-	0.05	Sock	4.02
MW-11	11/27/2012	-	-	-	-	0.03	Sock	4.05
MW-11	12/27/2012	-	-	-	-	0.05	Sock	4.09
MW-11	02/14/2013	-	-	-	-	0.06	Sock	4.16
MW-11	04/19/2013	-	-	-	-	0.04	Sock	4.20
MW-11	06/19/2013	-	-	-	-	0.03	Sock	4.23
MW-11	09/19/2013	-	-	-	-	0.13	Sock	4.36
MW-11	11/18/2013	-	-	-	-	0.16	Sock	4.51
MW-11	01/27/2014	-	-	-	-	0.07	Sock	4.58
MW-11	03/14/2014	-	-	-	-	0.12	Sock	4.70
MW-11	04/18/2014	-	-	-	-	0.13	Sock	4.83
MW-11	05/16/2014	-	-	-	-	0.11	Sock	4.94
MW-11	06/27/2014	-	-	-	-	0.12	Sock	5.06
MW-11	07/31/2014	-	-	-	-	0.08	Sock	5.14
MW-11	08/13/2014	-	-	-	-	0.09	Sock	5.23
MW-11	09/10/2014	-	-	-	-	0.10	Sock	5.33
MW-11			Maximum Thickness:		0.50		Total:	5.33

Table 1

Historical LNAPL Gauging and Removal Results

Former Union Oil/PacifiCorp Astoria Site

256 Marine Drive, Astoria Oregon

Location	Date	Tidal Stage[1] (ft)	Tidal Status	Depth To Water (ft)	LNAPL Thickness (ft)	LNAPL Removed (gallons)	Removal Method	Cumulative LNAPL Removed (gallons)
MW-12	10/23/1998	-	-	-	0.00	0.00	-	0.00
MW-12	1/29/1999	-	-	-	0.30	0.00	-	0.00
MW-12	4/15/1999	-	-	-	0.13	0.00	-	0.00
MW-12	7/13/1999	-	-	-	2.18	0.00	-	0.00
MW-12	12/31/2002	-	-	-	-	0.13	Pump	0.13
MW-12	1/31/2003	-	-	-	-	0.35	Pump	0.48
MW-12	2/28/2003	-	-	-	-	0.5	Pump	0.98
MW-12	3/31/2003	-	-	-	-	0.75	Pump	1.73
MW-12	4/18/2003	-	-	-	0.10	1	Pump	2.73
MW-12	4/30/2003	-	-	-	-	0	-	2.73
MW-12	5/31/2003	-	-	-	-	1	Pump	3.73
MW-12	6/30/2003	-	-	-	-	1	Pump	4.73
MW-12	7/31/2003	-	-	-	-	1	Pump	5.73
MW-12	8/31/2003	-	-	-	-	0.5	Pump	6.23
MW-12	9/23/2003	-	-	-	0.05	0.75	Pump	6.98
MW-12	10/31/2003	-	-	-	-	0.75	Pump	7.73
MW-12	11/30/2003	-	-	-	-	0.75	Pump	8.48
MW-12	12/31/2003	-	-	-	-	0.75	Pump	9.23
MW-12	1/15/2004	-	-	-	0.58	0.25	Pump	9.48
MW-12	2/28/2004	-	-	-	-	0.5	Pump	9.98
MW-12	3/22/2004	-	-	-	0.64	0.25	Pump	10.23
MW-12	4/30/2004	-	-	-	-	0.25	Pump	10.48
MW-12	5/24/2004	-	-	-	0.99	0.25	Pump	10.73
MW-12	6/30/2004	-	-	-	-	0.5	Pump	11.23
MW-12	7/22/2004	-	-	-	1.30	0.25	Pump	11.48
MW-12	8/19/2004	-	-	-	0.53	0.33	Pump	11.81
MW-12	9/16/2004	-	-	-	0.99	0.16	Pump	11.97
MW-12	10/14/2004	-	-	-	1.30	0.25	Pump	12.22
MW-12	11/9/2004	-	-	-	1.30	0.25	Pump	12.47
MW-12	12/8/2004	-	-	-	1.56	0.3	Pump	12.77
MW-12	1/20/2005	-	-	-	1.62	0.00	Pump	12.77
MW-12	2/28/2005	-	-	-	-	0.5	Pump	13.27
MW-12	3/30/2005	-	-	-	1.78	0.3	Pump	13.57
MW-12	4/30/2005	-	-	-	-	0.2	Pump	13.77
MW-12	5/31/2005	-	-	-	-	0.3	Pump	14.07
MW-12	6/27/2005	-	-	-	1.03	0.5	Pump	14.57
MW-12	7/25/2005	-	-	-	0.75	0.25	Pump	14.82
MW-12	8/23/2005	-	-	-	0.64	0.1	Pump	14.92
MW-12	9/19/2005	-	-	-	0.58	0.1	Pump	15.02
MW-12	11/10/2005	-	-	-	2.42	0.5	Pump	15.52
MW-12	12/8/2005	-	-	-	1.53	0.25	Pump	15.77
MW-12	03/21/2006	-	-	-	-	0.15	Sock	15.92

Table 1
Historical LNAPL Gauging and Removal Results
Former Union Oil/PacifiCorp Astoria Site
256 Marine Drive, Astoria Oregon

Location	Date	Tidal Stage[1] (ft)	Tidal Status	Depth To Water (ft)	LNAPL Thickness (ft)	LNAPL Removed (gallons)	Removal Method	Cumulative LNAPL Removed (gallons)
MW-12	04/18/2006	-	-	-	-	0.16	Sock	16.08
MW-12	06/15/2006	-	-	-	-	0.18	Sock	16.26
MW-12	07/13/2006	-	-	-	-	0.18	Sock	16.44
MW-12	08/11/2006	-	-	-	-	0.18	Sock	16.62
MW-12	09/11/2006	-	-	-	-	0.17	Sock	16.79
MW-12	10/09/2006	-	-	-	-	0.16	Sock	16.96
MW-12	11/13/2006	-	-	-	-	0.28	Sock	17.24
MW-12	12/11/2006	-	-	-	-	0.19	Sock	17.42
MW-12	01/25/2007	-	-	-	-	0.25	Sock	17.67
MW-12	02/19/2007	-	-	-	-	0.23	Sock	17.90
MW-12	03/19/2007	-	-	-	-	0.20	Sock	18.10
MW-12	04/19/2007	-	-	-	-	0.11	Sock	18.21
MW-12	05/16/2007	-	-	-	-	0.20	Sock	18.41
MW-12	06/18/2007	-	-	-	-	0.18	Sock	18.59
MW-12	07/18/2007	-	-	-	-	0.19	Sock	18.78
MW-12	08/17/2007	-	-	-	-	0.21	Sock	18.99
MW-12	09/13/2007	-	-	-	-	0.13	Sock	19.11
MW-12	10/24/2007	-	-	-	-	0.20	Sock	19.31
MW-12	11/20/2007	-	-	-	-	0.15	Sock	19.46
MW-12	12/19/2007	-	-	-	-	0.24	Sock	19.69
MW-12	01/17/2008	-	-	-	-	0.23	Sock	19.92
MW-12	02/15/2008	-	-	-	-	0.17	Sock	20.08
MW-12	03/14/2008	-	-	-	-	0.20	Sock	20.28
MW-12	04/24/2008	-	-	-	-	0.20	Sock	20.48
MW-12	05/22/2008	-	-	-	-	0.16	Sock	20.65
MW-12	06/19/2008	-	-	-	-	0.16	Sock	20.81
MW-12	07/22/2008	-	-	-	-	0.19	Sock	21.00
MW-12	08/21/2008	-	-	-	-	0.33	Sock	21.33
MW-12	09/17/2008	-	-	-	-	0.16	Sock	21.48
MW-12	10/16/2008	-	-	-	-	0.20	Sock	21.68
MW-12	11/21/2008	-	-	-	-	0.15	Sock	21.83
MW-12	01/16/2009	-	-	-	-	0.19	Sock	22.01
MW-12	02/04/2009	-	-	-	-	0.18	Sock	22.19
MW-12	05/26/2009	-	-	-	-	0.16	Sock	22.35
MW-12	06/25/2009	-	-	-	-	0.14	Sock	22.49
MW-12	08/21/2009	-	-	-	-	0.17	Sock	22.66
MW-12	09/18/2009	-	-	-	-	0.21	Sock	22.87
MW-12	11/12/2009	-	-	-	-	0.20	Sock	23.08
MW-12	12/11/2009	-	-	-	-	0.18	Sock	23.26
MW-12	01/08/2010	-	-	-	-	0.19	Sock	23.44
MW-12	02/05/2010	-	-	-	-	0.18	Sock	23.62
MW-12	03/05/2010	-	-	-	-	0.16	Sock	23.78

Table 1
Historical LNAPL Gauging and Removal Results
Former Union Oil/PacifiCorp Astoria Site
256 Marine Drive, Astoria Oregon

Location	Date	Tidal Stage[1] (ft)	Tidal Status	Depth To Water (ft)	LNAPL Thickness (ft)	LNAPL Removed (gallons)	Removal Method	Cumulative LNAPL Removed (gallons)
MW-12	04/29/2010	-	-	-	-	0.19	Sock	23.97
MW-12	05/20/2010	-	-	-	-	0.14	Sock	24.11
MW-12	06/30/2010	-	-	-	-	0.16	Sock	24.27
MW-12	07/30/2010	-	-	-	-	0.13	Sock	24.40
MW-12	08/27/2010	-	-	-	-	0.13	Sock	24.53
MW-12	09/23/2010	-	-	-	-	0.17	Sock	24.70
MW-12	10/22/2010	-	-	-	-	0.20	Sock	24.91
MW-12	11/30/2010	-	-	-	-	0.27	Sock	25.17
MW-12	12/17/2010	-	-	-	-	0.16	Sock	25.34
MW-12	01/26/2011	-	-	-	-	0.16	Sock	25.49
MW-12	02/23/2011	-	-	-	-	0.09	Sock	25.59
MW-12	03/16/2011	-	-	-	-	0.17	Sock	25.76
MW-12	04/22/2011	-	-	-	-	0.16	Sock	25.91
MW-12	05/19/2011	-	-	-	-	0.15	Sock	26.06
MW-12	06/14/2011	-	-	-	-	0.13	Sock	26.19
MW-12	07/15/2011	-	-	-	-	0.16	Sock	26.36
MW-12	08/16/2011	-	-	-	-	0.14	Sock	26.50
MW-12	09/19/2011	-	-	-	-	0.13	Sock	26.62
MW-12	10/25/2011	-	-	-	-	0.14	Sock	26.77
MW-12	11/22/2011	-	-	-	-	0.23	Sock	26.99
MW-12	12/19/2011	-	-	-	-	0.14	Sock	27.13
MW-12	01/19/2012	-	-	-	-	0.19	Sock	27.32
MW-12	02/15/2012	-	-	-	-	0.16	Sock	27.48
MW-12	03/12/2012	-	-	-	-	0.16	Sock	27.64
MW-12	04/13/2012	-	-	-	-	0.15	Sock	27.79
MW-12	05/11/2012	-	-	-	-	0.13	Sock	27.92
MW-12	06/15/2012	-	-	-	-	0.17	Sock	28.09
MW-12	07/11/2012	-	-	-	-	0.14	Sock	28.23
MW-12	08/15/2012	-	-	-	-	0.13	Sock	28.37
MW-12	09/11/2012	-	-	-	-	0.16	Sock	28.52
MW-12	10/04/2012	-	-	-	-	0.13	Sock	28.66
MW-12	11/27/2012	-	-	-	-	0.12	Sock	28.77
MW-12	12/27/2012	-	-	-	-	0.16	Sock	28.94
MW-12	02/14/2013	-	-	-	-	0.22	Sock	29.16
MW-12	04/19/2013	-	-	-	-	0.20	Sock	29.36
MW-12	06/19/2013	-	-	-	-	0.21	Sock	29.57
MW-12	09/19/2013	-	-	-	-	0.16	Sock	29.73
MW-12	11/18/2013	-	-	-	-	0.25	Sock	29.97
MW-12	01/27/2014	-	-	-	-	0.20	Sock	30.17
MW-12	03/14/2014	-	-	-	-	0.21	Sock	30.38
MW-12	03/17/2014	5.56	Falling	14.40	4.12	0.39	Pump	30.77
MW-12	03/18/2014	7.33	Rising	11.84	2.17	0.32	Pump	31.09

Table 1
Historical LNAPL Gauging and Removal Results
Former Union Oil/PacifiCorp Astoria Site
256 Marine Drive, Astoria Oregon

Location	Date	Tidal Stage[1] (ft)	Tidal Status	Depth To Water (ft)	LNAPL Thickness (ft)	LNAPL Removed (gallons)	Removal Method	Cumulative LNAPL Removed (gallons)
MW-12	03/21/2014	7.60	Rising	10.85	0.21	0.01	Pump	31.10
MW-12	04/03/2014	5.58	Falling	11.01	0.54	0.00	-	31.10
MW-12	04/18/2014	8.57	Falling	11.65	0.74	0.00	-	31.10
MW-12	05/08/2014	3.40	Low	11.28	1.37	0.24	Pump	31.34
MW-12	05/09/2014	3.60	Falling	9.76	0.01	0.00	-	31.34
MW-12	05/16/2014	10.14	High	10.82	0.03	0.00	-	31.34
MW-12	05/30/2014	6.91	Falling	11.58	0.53	0.00	-	31.34
MW-12	06/27/2014	7.10	Falling	12.21	1.23	0.00	-	31.34
MW-12	07/31/2014	7.28	High	13.30	1.95	0.21	Pump	31.55
MW-12	08/13/2014	9.08	High	11.33	0.00	0.17	Sock	31.72
MW-12	08/28/2014	7.86	High	11.65	0.00	0.15	Sock	31.86
MW-12	09/10/2014	5.61	Falling	11.19	0.00	0.00	-	31.86
MW-12	09/24/2014	1.76	Low	9.51	0.00	0.19	Sock	32.05
MW-12			Maximum Thickness:		4.12		Total:	32.05

Table 1

Historical LNAPL Gauging and Removal Results

Former Union Oil/PacifiCorp Astoria Site

256 Marine Drive, Astoria Oregon

Location	Date	Tidal Stage[1] (ft)	Tidal Status	Depth To Water (ft)	LNAPL Thickness (ft)	LNAPL Removed (gallons)	Removal Method	Cumulative LNAPL Removed (gallons)
MW-13	5/19/2003	-	-	-	0.00	0.00	-	0.00
MW-13	5/19/2003	-	-	-	0.00	0.00	-	0.00
MW-13	6/23/2003	-	-	-	0.00	0.00	-	0.00
MW-13	6/23/2003	-	-	-	0.00	0.00	-	0.00
MW-13	6/24/2003	-	-	-	0.00	0.00	-	0.00
MW-13	6/24/2003	-	-	-	0.00	0.00	-	0.00
MW-13	7/15/2003	-	-	-	0.00	0.00	-	0.00
MW-13	7/15/2003	-	-	-	0.00	0.00	-	0.00
MW-13	8/14/2003	-	-	-	0.00	0.00	-	0.00
MW-13	8/14/2003	-	-	-	0.00	0.00	-	0.00
MW-13	9/22/2003	-	-	-	0.00	0.00	-	0.00
MW-13	10/23/2003	-	-	-	0.00	0.00	-	0.00
MW-13	10/23/2003	-	-	-	0.00	0.00	-	0.00
MW-13	11/17/2003	-	-	-	0.00	0.00	-	0.00
MW-13	12/23/2003	-	-	-	0.00	0.00	-	0.00
MW-13	1/15/2004	-	-	-	0.00	0.00	-	0.00
MW-13	2/26/2004	-	-	-	0.00	0.00	-	0.00
MW-13	3/22/2004	-	-	-	0.00	0.00	-	0.00
MW-13	4/22/2004	-	-	-	0.00	0.00	-	0.00
MW-13	5/24/2004	-	-	-	0.00	0.00	-	0.00
MW-13	6/22/2004	-	-	-	0.00	0.00	-	0.00
MW-13	7/22/2004	-	-	-	0.00	0.00	-	0.00
MW-13	8/19/2004	-	-	-	0.02	0.00	-	0.00
MW-13	9/15/2004	-	-	-	0.00	0.00	-	0.00
MW-13	10/14/2004	-	-	-	0.02	0.00	-	0.00
MW-13	11/9/2004	-	-	-	0.00	0.00	-	0.00
MW-13	12/8/2004	-	-	-	0.00	0.00	-	0.00
MW-13	1/20/2005	-	-	-	0.00	0.00	-	0.00
MW-13	2/15/2005	-	-	-	0.00	0.00	-	0.00
MW-13	3/30/2005	-	-	-	0.00	0.00	-	0.00
MW-13	5/3/2005	-	-	-	0.00	0.00	-	0.00
MW-13	5/26/2005	-	-	-	0.00	0.00	-	0.00
MW-13	6/27/2005	-	-	-	0.00	0.00	-	0.00
MW-13	7/25/2005	-	-	-	0.05	0.00	-	0.00
MW-13	8/23/2005	-	-	-	0.04	0.00	-	0.00
MW-13	9/19/2005	-	-	-	0.00	0.00	-	0.00
MW-13	10/19/2005	-	-	-	0.02	0.00	-	0.00
MW-13	11/10/2005	-	-	-	0.00	0.00	-	0.00
MW-13	12/8/2005	-	-	-	0.00	0.00	-	0.00
MW-13	4/18/2006	-	-	-	-	0.02	Sock	0.02
MW-13	6/15/2006	-	-	-	-	0.14	Sock	0.16
MW-13	11/13/2006	-	-	-	-	0.1	Sock	0.26

Table 1
Historical LNAPL Gauging and Removal Results
Former Union Oil/PacifiCorp Astoria Site
256 Marine Drive, Astoria Oregon

Location	Date	Tidal Stage[1] (ft)	Tidal Status	Depth To Water (ft)	LNAPL Thickness (ft)	LNAPL Removed (gallons)	Removal Method	Cumulative LNAPL Removed (gallons)
MW-13	1/25/2007	-	-	-	-	0.14	Sock	0.40
MW-13	4/19/2007	-	-	-	-	0.19	Sock	0.59
MW-13	5/16/2007	-	-	-	-	0.12	Sock	0.71
MW-13	8/17/2007	-	-	-	-	0.15	Sock	0.86
MW-13	9/13/2007	-	-	-	-	0.11	Sock	0.97
MW-13	10/24/2007	-	-	-	-	0.09	Sock	1.06
MW-13	12/19/2007	-	-	-	-	0.05	Sock	1.11
MW-13	2/15/2008	-	-	-	-	0.1	Sock	1.21
MW-13	5/22/2008	-	-	-	-	0.06	Sock	1.27
MW-13	6/19/2008	-	-	-	-	0.08	Sock	1.35
MW-13	10/16/2008	-	-	-	-	0.13	Sock	1.48
MW-13	1/16/2009	-	-	-	-	0.11	Sock	1.59
MW-13	7/24/2009	-	-	-	-	0.08	Sock	1.67
MW-13	9/18/2009	-	-	-	-	0.11	Sock	1.78
MW-13	10/19/2009	-	-	-	-	0.06	Sock	1.84
MW-13	11/12/2009	-	-	-	-	0.11	Sock	1.94
MW-13	02/05/2010	-	-	-	-	0.13	Sock	2.07
MW-13	04/29/2010	-	-	-	-	0.09	Sock	2.15
MW-13	06/30/2010	-	-	-	-	0.02	Sock	2.18
MW-13	10/22/2010	-	-	-	-	0.02	Sock	2.19
MW-13	01/26/2011	-	-	-	-	0.02	Sock	2.22
MW-13	02/14/2013	-	-	-	-	0.03	Sock	2.25
MW-13	01/27/2014	-	-	-	-	0.13	Sock	2.37
MW-13	06/27/2014	-	-	-	-	0.10	Sock	2.47
MW-13			Maximum Thickness:		0.05		Total:	2.47

Notes:
-- = measurement not collected at this time
ft = feet
lbs = pounds
min = minutes
LNAPL = Light Non-Aqueous Phase Liquid
[1]Tidal stage recorded at National Oceanographic and Atmospheric Administration Station ID: 9439040 in Astoria, Oregon. September 2014 data are preliminary.

Table 2
Summary of LNAPL Physical Properties
Former Union Oil/PacifiCorp Astoria Site
256 Marine Drive, Astoria Oregon

Sample Location	Sample Date	Analysis Temperature (°F)	Kinematic Viscosity (centiStokes)	Dynamic Viscosity[1] (centipoise)	LNAPL Specfic Gravity	LNAPL Density (g/cm^3)	Interfacial Tension (Dynes/centimeter)			Flashpoint (°F)
							LNAPL/Water	LNAPL/Air	Water/Air	
MW-12	10/16/2008[2]	70	1,400	1,330	0.95	--	--	--	--	--
		90	562	534	0.951	--	--	--	--	--
		110	269	254	0.944	--	--	--	--	--
		130	122	115	0.945	--	--	--	--	--
		150	97.5	--	--	--	--	--	--	--
	11/18/2013[3]	--	--	--	--	--	--	--	--	>212
		60	3,643	3,526	0.9690	0.9680	--	--	--	--
		75	1,366	1,315	0.9651	0.9625	--	--	--	--
		90	660	632	0.9619	0.9571	--	--	--	--
	5/7/2014[3]	55	--		0.9699	0.9694	16.0	32.6	70.3	--

Notes
-- = no data available
°F = degrees Fahrenheit
cm = centimeter
[1]Dynamic viscosity for sample collected in 2008 was calculated by multiplying the kinematic viscosity by the LNAPL specific gravity.
[2]Reported in Specialty Analytical report prepared for MFA in 2008.
[3]Pre-design Pilot Study. Laboratory reports presented in Appendix D.

Table 3
Summary of Site Hydrogeologic Parameters
Former Union Oil/PacifiCorp Astoria Site
256 Marine Drive, Astoria Oregon

Soil Type	Location	Water Table Depth (ft bgs)	Average Soil Bulk Density (lbs/ft^3)	Estimated Average Porosity	Hydraulic Gradient (ft/ft)	Transmissivity (ft^2/min)	Hydraulic Conductivity (ft/day)	Hydraulic Conductivity Method	Permeability (cm/s)	Groundwater velocity (ft/day)	Reference
Gravelly alluvium	MW-7	3-17	135	0.4 - 0.45	0.022 - 0.085	0.18 - 1.51	22.1 - 74.9	Ferris method	-	-	MFA 2009
	MW-11				-					-	MFA 2009
	MW-13				0.053 - 0.109					2.6 - 5.4	MFA 2009
	MW-12				0.022 - 0.060	-	-	-		3.8 - 10	MFA 2009
	average	-	-	-	-	-	48.5	-		-	MFA 2009
Fine-grained alluvium	MW-2	-	-	-	-	-	4.1	slug test	-	2 - 8	CH2M Hill 1998
	MW-1, MW-2, MW-5						45	tidal response test		-	CH2M Hill 1998
	MW-1						-	-		0.4 - 6.4	CH2M Hill 2002
	B-21, B-28						-	-	$5.1x10^{-8}$ - $8.9x10^{-9}$	-	CH2M Hill 1998

Notes:

CH2M Hill 1998 Remedial investigation field work data summary for the former petroleum terminal and manufactured gas plant, Astoria, Oregon. Prepared for PacifiCorp and Unocal. December.

CH2M Hill 2002 Draft hydrogeologc conceptual model. Technical memorandum. Prepared for PacifiCorp and Unocal. January 18

MFA 2009 Pre-Remedial-Design Tasks: March 2009 Tidal Variation Study, Former Petroleum Terminal No. 0022 and Manufactured Gas Plant, Astoria, Oregon (DEQ ECSI Number 1646). July 6.

bgs - below ground surface
ft - feet
lbs - pounds
min - minute

Table 4
Summary of Calculated LNAPL Recharge Rates
Former Union Oil/PacifiCorp Astoria Site
256 Marine Drive, Astoria Oregon

Pilot Test	Corrected Total Elapsed Time (minutes)*	Corrected Total Elapsed Time (days)*	Total Volume Recharged (gallons)	Average Recharge Rate (Gallons Per Minute)	Recharge Rate - Average (Gallons Per Day)	Recharge Rate - From Linear Regression (Gallons per Day)	Calculated Time to Sock Saturation - From Average (Days)**	Calculated Time to Sock Saturation - From Regression (Days)**
Phase 1	67725.00	47.03	0.22	3.3E-06	0.0047	0.0045	53.01	55.56
Phase 2	71580.00	49.71	0.19	2.6E-06	0.0038	0.0036	65.61	69.44
Phase 3	79361.00	55.11	0.50	6.3E-06	0.0091	0.0100	27.42	25.00
Average	69652.50	48.37	0.30	4.4E-06	0.0063	0.0060	39.70	41.44

Notes

* Correction factor used the end of bailing or pumping LNAPL or the first sock installation as zero elapsed time

**Calculation based on sock manufacturer's specified absorption capacity of 0.25 gallons per 2-inch diameter, 39-inch long SoakEase™ sock

Table 5
LNAPL Pore Velocity Calculations
Former Union Oil/PacifiCorp Astoria Site
256 Marine Drive, Astoria Oregon

Pre-Design Pilot Test Well	LNAPL Gradient[1]	Porosity[2]	LNAPL Saturation[3]	LNAPL Hydraulic Conductivity[4]	LNAPL Hydraulic Conductivity	LNAPL Velocity
				feet/day	cm/sec	cm/sec
MW-12	0.0878	0.4	0.15	0.19	0.00007	**9.81E-05**
MW-12	0.0878	0.4	0.15	0.02	0.00001	**1.03E-05**

Notes:

[1] Values for LNAPL gradient were derived from 2010 Remedial Report.
[2] Porosity is value for fine sand sample at Site 107 from the LNAPL Parameter Database included in the API Interactive LNAPL Guide (API 2003) dataset.
[3] Value of residual LNAPL saturation for diesel and light fuel oil (Mercer and Cohen 1990).
[4] Values determined using LNAPL transmissivity results from LNAPL baildown tests.

Acronyms and Abbreviations:

Bold = Pore velocity exceeds functionally immobile criteria of 1.00 x 10^{-6} cm/s (ASTM 2006).
cm/sec = centimeters per second
LNAPL = light nonaqueous phase liquid

Table 6

LNAPL Pore Entry Pressure Calculations

Former Union Oil/PacifiCorp Astoria Site

256 Marine Drive, Astoria Oregon

Location	Air-Water Displacement Pressure Head (centimeters)	Critical LNAPL Thickness (feet)	Current LNAPL Thickness Observed[1] (feet)
MW-12	6.37	1.38	0.00
MW-12	7.96	1.73	0.00

General Notes:

[1]LNAPL gauged on 9/24/2014. Clean sorbent sock placed in the well on that date. Routine bi-monthly LNAPL gauging and removal have resumed as of the end of Phase 3 of the pre-design pilot tests on 9/24/2014.

Acronyms and Abbreviations:

LNAPL = light nonaqueous phase liquid

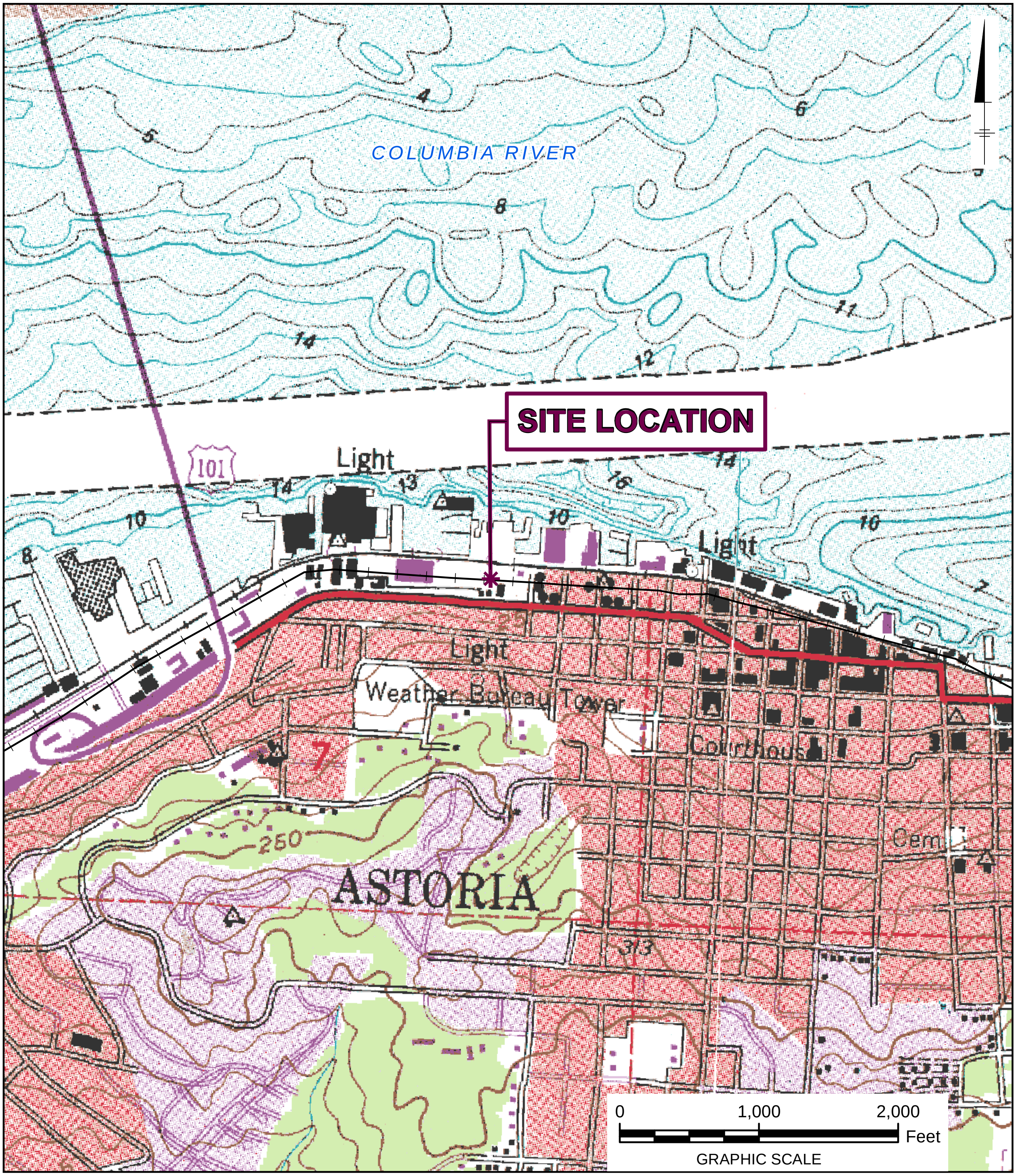
Table 7
LNAPL Baildown Test Analysis Results
Former Union Oil/PacifiCorp Astoria Site
256 Marine Drive, Astoria Oregon

Well ID	Date	Initial LNAPL Thickness (feet)	Test Duration (hours)	Final LNAPL Thickness (feet)	Percent Recovery (%)	LNAPL Transmissivity ($feet^2$/day)	LNAPL Hydraulic Conductivity (feet/day)	Geomean of LNAPL Hydraulic Conductivity (feet/day)
						Bouwer & Rice		
MW-12	3/18/2014	4.12	71.8	0.21	5.1	0.039	0.19	0.07
MW-12	5/8/2014	1.37	1195.7	1.23	89.8	0.029	0.02	

General Notes:
Bold Exceeds upper limit of ITRC criterion range of 0.1 to 0.8 $foot^2$/day for beneficial LNAPL recoverability (ITRC 2009a).

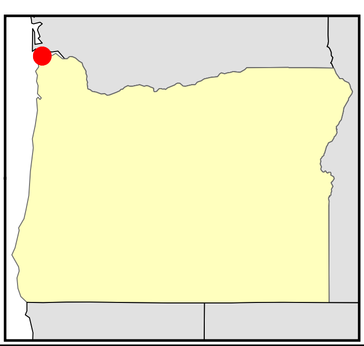
Acronyms and Abbreviations:
Bouwer & Rice = Bouwer & Rice modified slug test analysis method for LNAPL baildown test analysis
LNAPL = light nonaqueous phase liquid

Figures



NOTE:

1. 1949 USGS QUADRANGLE FOR ASTORIA OREGON DOWNLOADED AT: http://store.usgs.gov/

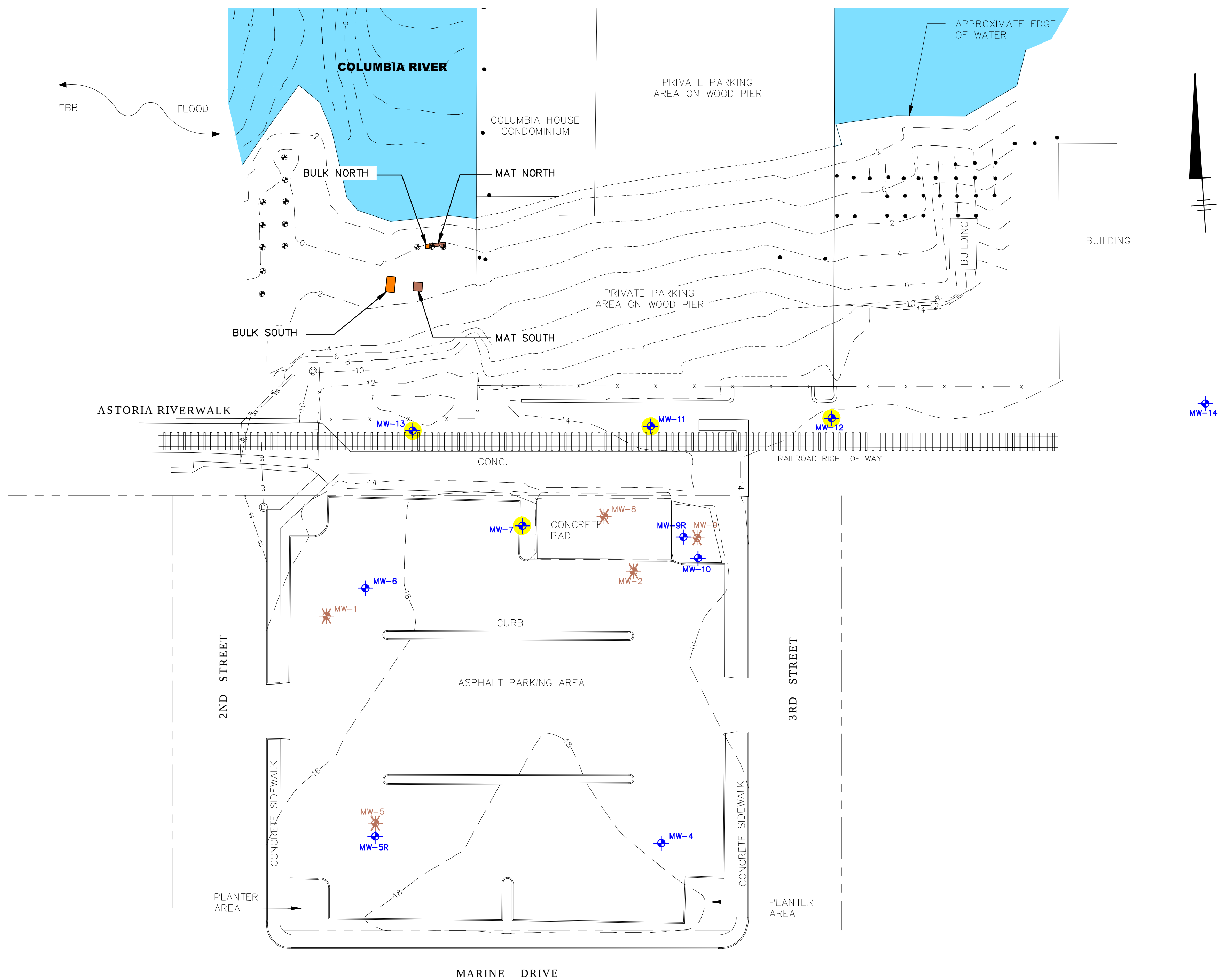


PACIFICORP - FORMER UNOCAL TERMINAL 0022
256 MARINE DRIVE, ASTORIA, OREGON
LNAPL PILOT SCALE STUDY AND RECOVERY REPORT

SITE LOCATION MAP

ARCADIS

FIGURE
1



LEGEND:

- CONTOUR
- CONTOUR (BENEATH PIER)
- CHAIN LINK FENCE
- STRUCTURAL BENT
- PILE
- RAILROAD TRACKS
- ORGANOCLAY CONTAINED IN GEOTEXTILE FABRIC
- REACTIVE CORE MAT
- MONITORING WELL
- DECOMMISSIONED MONITORING WELL
- MONITORING WELLS WITH LNAPL

ABBREVIATIONS:

LNAPL = LIGHT NON-AQUEOUS PHASE LIQUID

NOTES:

1. BASE MAP INFORMATION FROM OTAK, INC. DATED 4/24/2014, AT A SCALE OF 1" = 30'.
2. APPARENT HORIZONTAL COORDINATE SYSTEM IS NORTH AMERICAN DATUM OF 1983 (NAD83). APPARENT VERTICAL COORDINATE SYSTEM IS NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88).

0 30' 60'
GRAPHIC SCALE

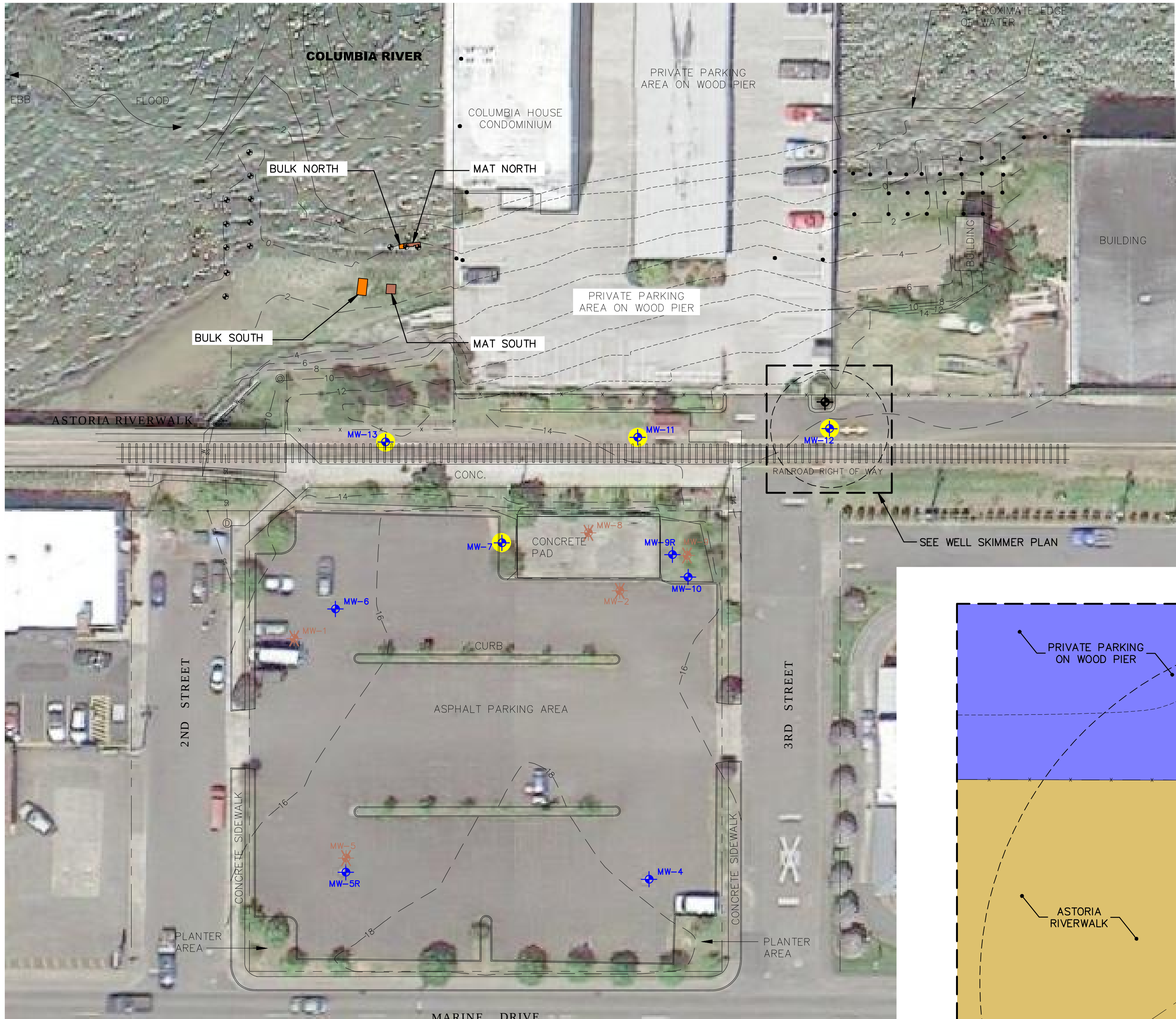
PACIFICORP - FORMER UNOCAL TERMINAL 0022
256 MARINE DRIVE, ASTORIA, OREGON
LNAPL PILOT SCALE STUDY AND RECOVERY REPORT

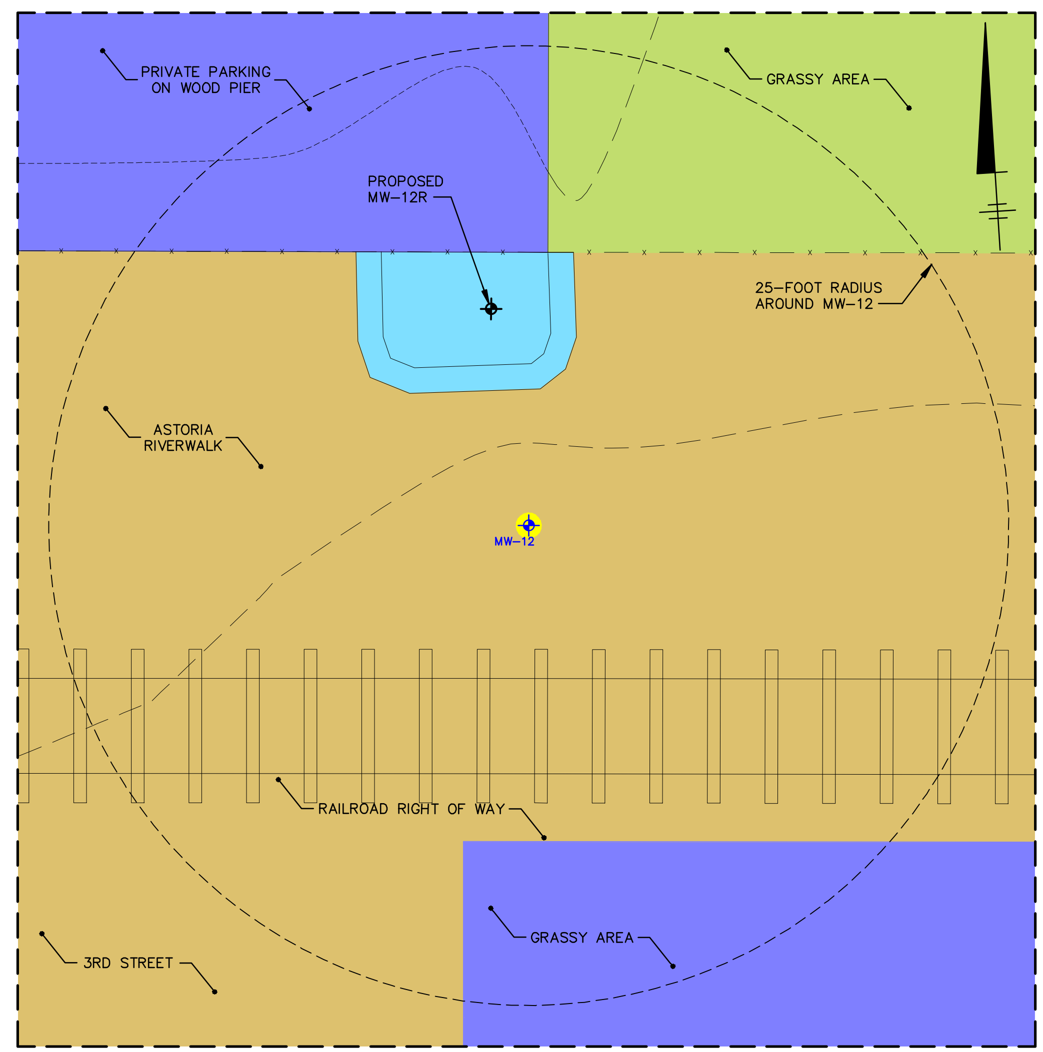
SITE PLAN

ARCADIS

FIGURE **2**

CITY:SYRACUSE-NY DIV/GROUP:ENVCAD DB:G.STEINBERGER LD:(Opt) PIC: PM:J.STARR TM:G.GUMMADI LYR:(Opt)ON=*;OFF=*REF*
G:\ENVCAD\SYRACUSE\ACT\PO100006\0000\00022\DWG\LNAPL\PO100006G02.dwg LAYOUT: 2 SAVED: 10/7/2014 9:40 AM ACADVER: 18.1S (LMS TECH) PAGESETUP: ---- PLOTSTYLETABLE: PLTFULL.CTB PLOTTED: 10/7/2014 9:41 AM BY: GETTS, BRIAN
XREFS: IMAGES:
PO100006X00
PO100006X01





WELL SKIMMER PLAN

SCALE: 1"=5'

LEGEND:

- CONTOUR
- CONTOUR (BENEATH PIER)
- CHAIN LINK FENCE
- STRUCTURAL BENT
- PILE
- RAILROAD TRACKS
- ORGANOCLAY CONTAINED IN GEOTEXTILE FABRIC
- REACTIVE CORE MAT
- MONITORING WELL
- DECOMMISSIONED MONITORING WELL
- MONITORING WELLS WITH LNAPL
- CURRENT PLANTER
- ACTIVE ROADWAY/DRIVEWAY/TROLLEY LINE
- VACANT CHEVRON OWNED PROPERTY
- ACTIVE THIRD PARTY OWNED PROPERTY

ABBREVIATIONS:

LNAPL = LIGHT NON-AQUEOUS PHASE LIQUID

NOTES:

1. BASE MAP INFORMATION FROM OTAK, INC. DATED 4/24/2014, AT A SCALE OF 1" = 30'.
2. APPARENT HORIZONTAL COORDINATE SYSTEM IS NORTH AMERICAN DATUM OF 1983 (NAD83). APPARENT VERTICAL COORDINATE SYSTEM IS NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88).

0 30' 60'
GRAPHIC SCALE

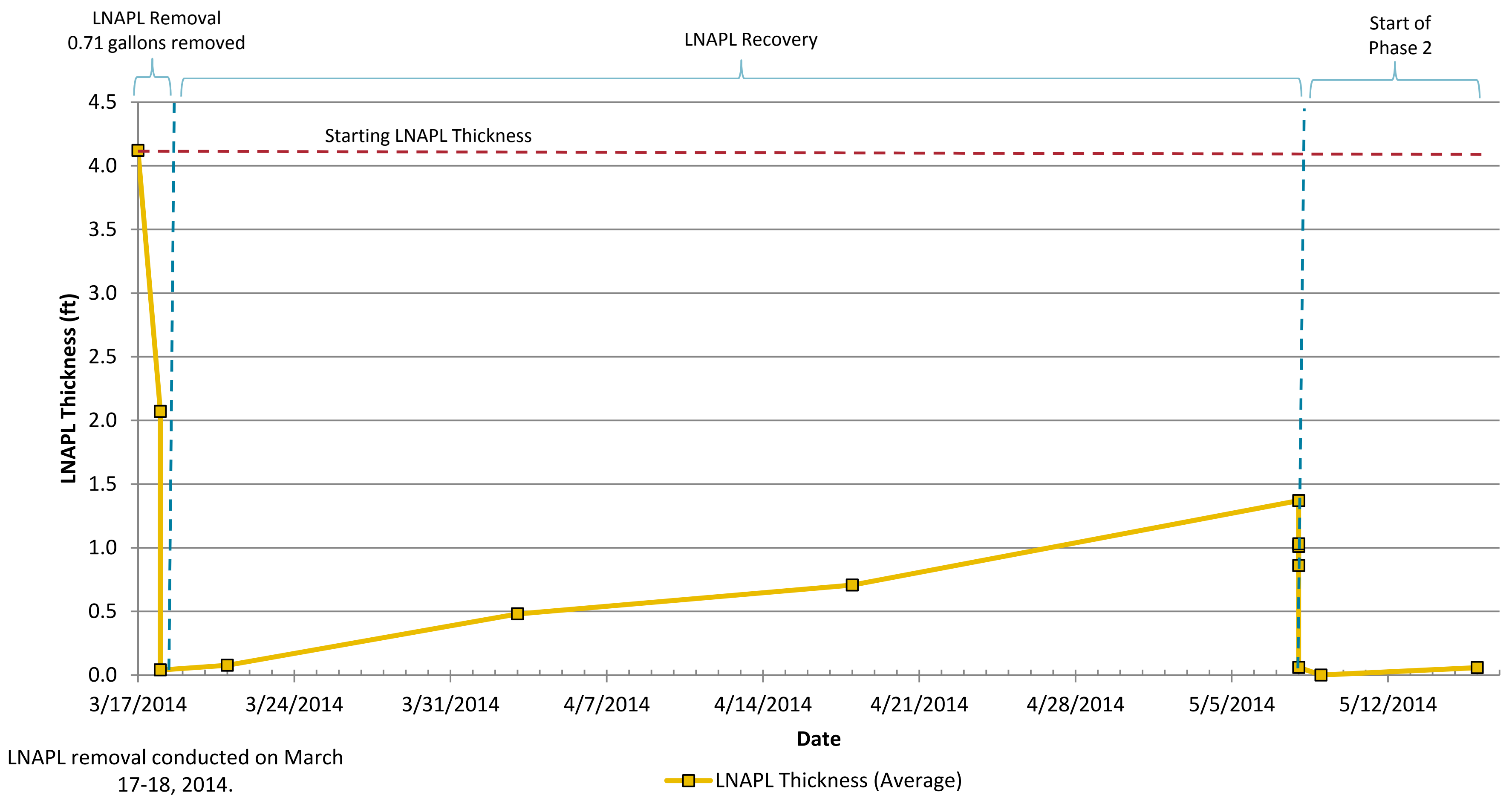
PACIFICORP - FORMER UNOCAL TERMINAL 0022
256 MARINE DRIVE, ASTORIA, OREGON
LNAPL PILOT SCALE STUDY AND RECOVERY REPORT

PROPOSED LNAPL RECOVERY APPROACH

ARCADIS

FIGURE
3

CITY:SYRACUSE-NY DIV/GROUP:ENVCAD DB:G.STEINBERGER LD:(Opt) PIC: PM:J.STARR TM:G.GUMMADI LYR:(Opt)ON=*;OFF=*REF*
G:\ENVCAD\SYRACUSE\ACT\PO100006\0000\00022\DWG\LNAPL\PO100006G03.dwg LAYOUT: 3 SAVED: 10/17/2014 12:42 PM ACADVER: 18.1S (LMS TECH) PAGESETUP: ---- PLOTSTYLETABLE: PLTFULL.CTB PLOTTED: 10/17/2014 12:42 PM BY: GETTS, BRIAN
XREFS: IMAGES:
PO100006X01 PO100006X01.JPG



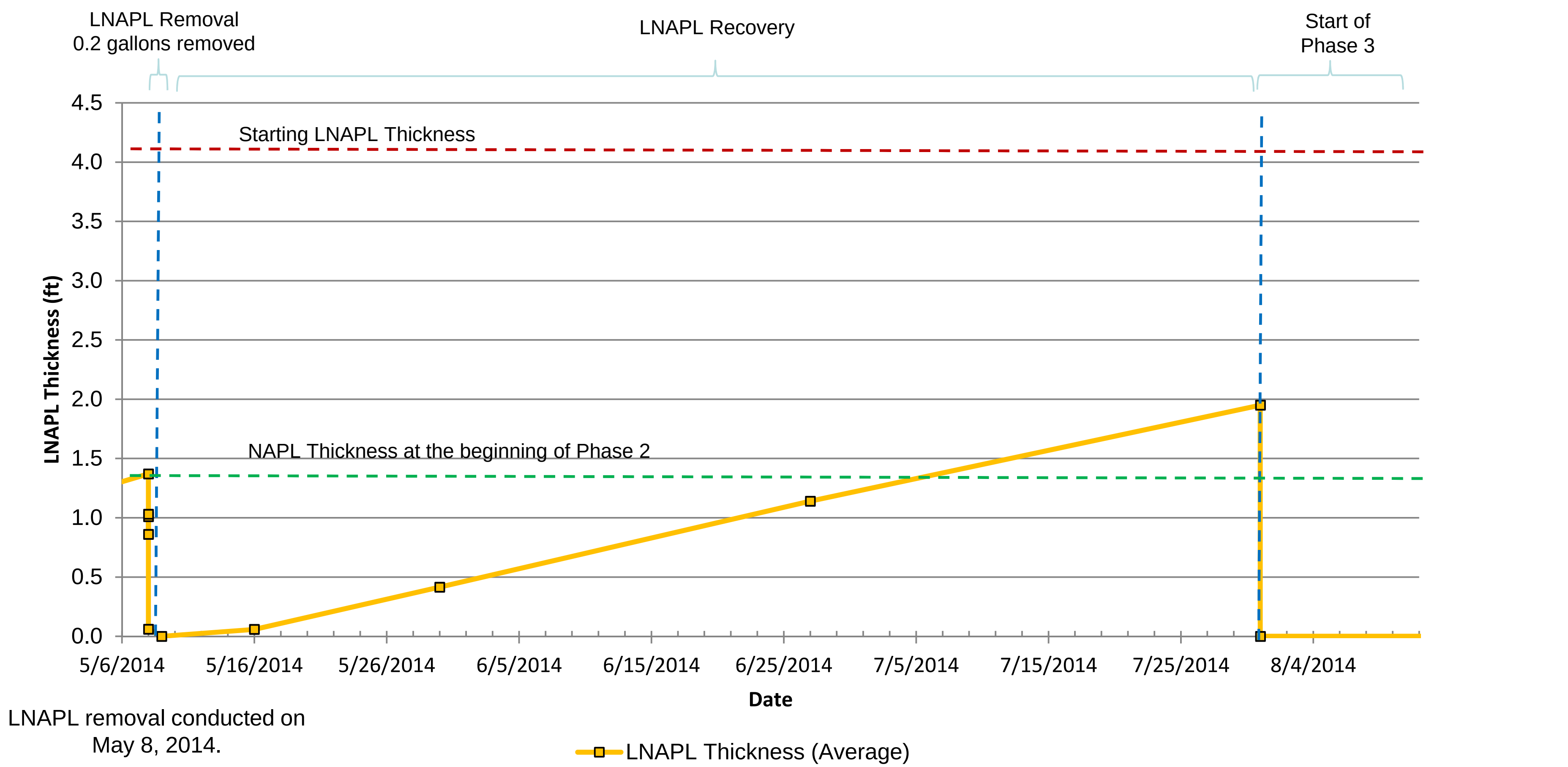
PACIFICORP - FORMER UNOCAL TERMINAL 0022
256 MARINE DRIVE, ASTORIA, OREGON

LNAPL PILOT SCALE STUDY AND RECOVERY REPORT

Phase 1 - Manual Removal Using Peristaltic Pump

ARCADIS

FIGURE
4



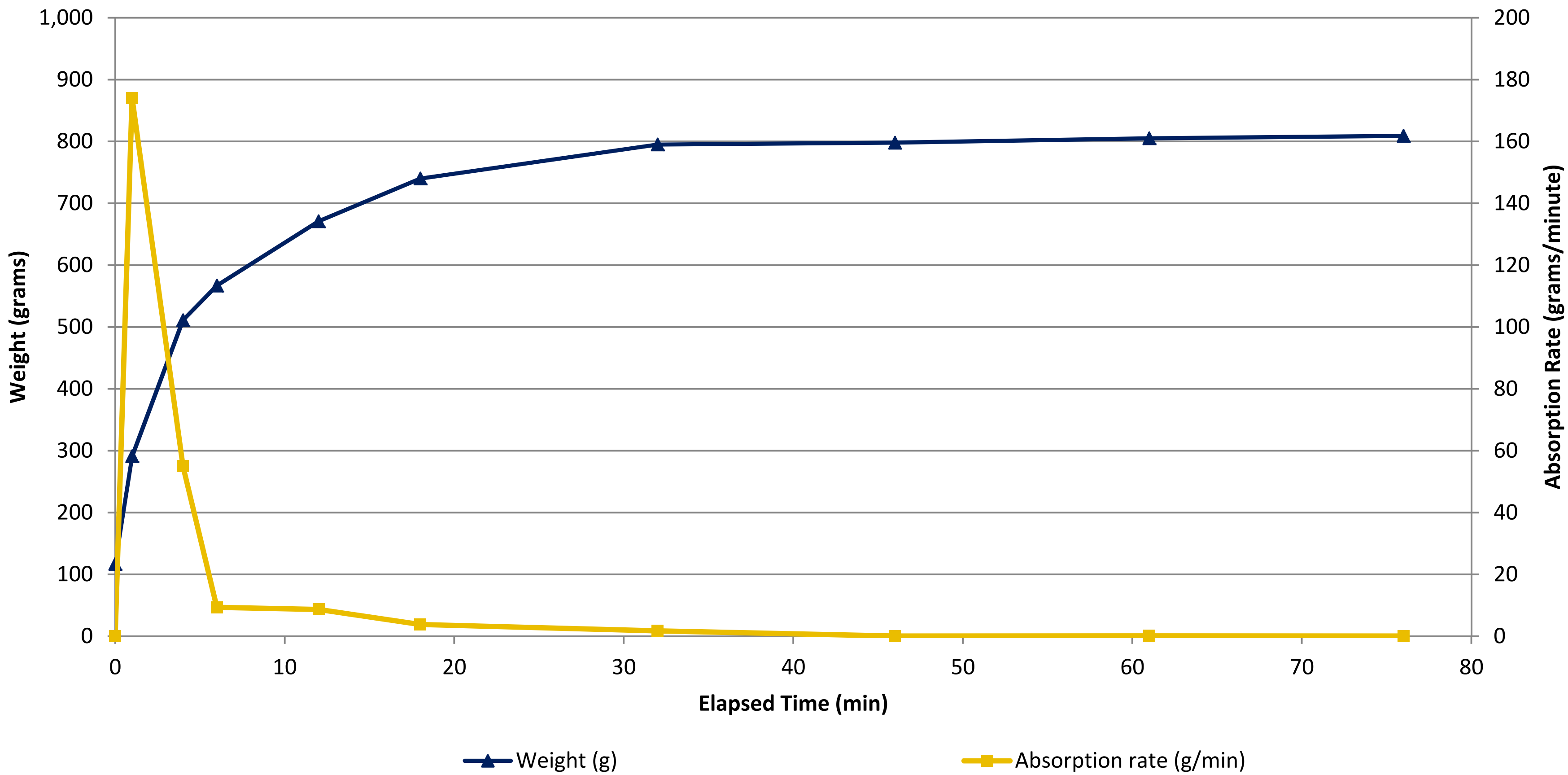
PACIFICORP - FORMER UNOCAL TERMINAL 0022
256 MARINE DRIVE, ASTORIA, OREGON

LNAPL PILOT SCALE STUDY AND RECOVERY REPORT

Phase 2 - Manual Removal Using Peristaltic Pump in Conjunction with In-Well Heating

ARCADIS

FIGURE
5



Absorption Test conducted on July 31, 2014. A new SoakEase sock was placed in a bucket containing LNAPL and water that had been removed from MW-12. The sock was weighed periodically.

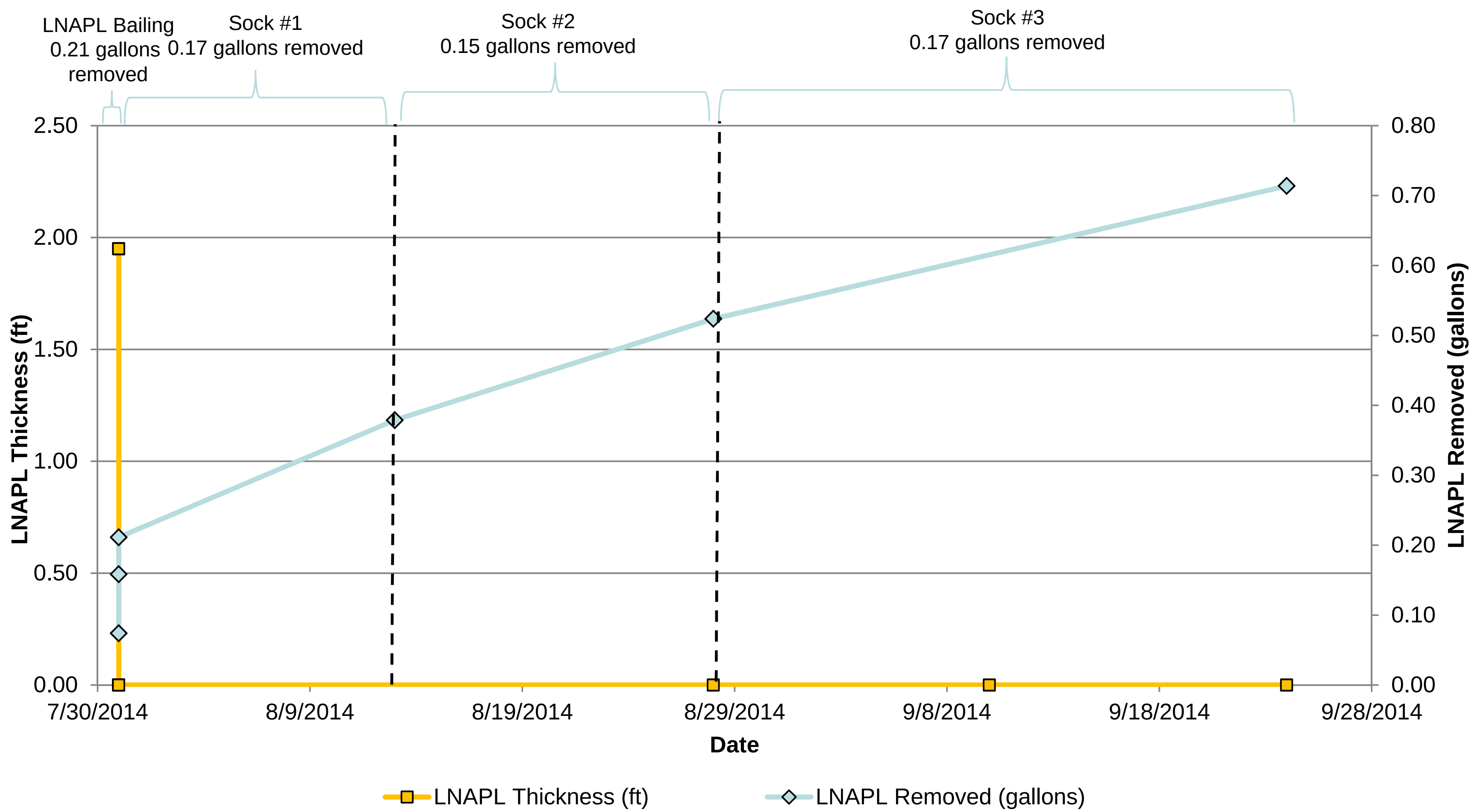
PACIFICORP - FORMER UNOCAL TERMINAL 0022
256 MARINE DRIVE, ASTORIA, OREGON

LNAPL PILOT SCALE STUDY AND RECOVERY REPORT

Phase 3 – Manual Removal Using Hydrophobic Sorbent Product – Absorption Test

ARCADIS

FIGURE
6



LNAPL was removed with a bailer until no measureable thickness remained. A new SoakEase sock was placed in the well and replaced as indicated above. No measureable thickness of LNAPL recovered during the Phase 3 pilot test.

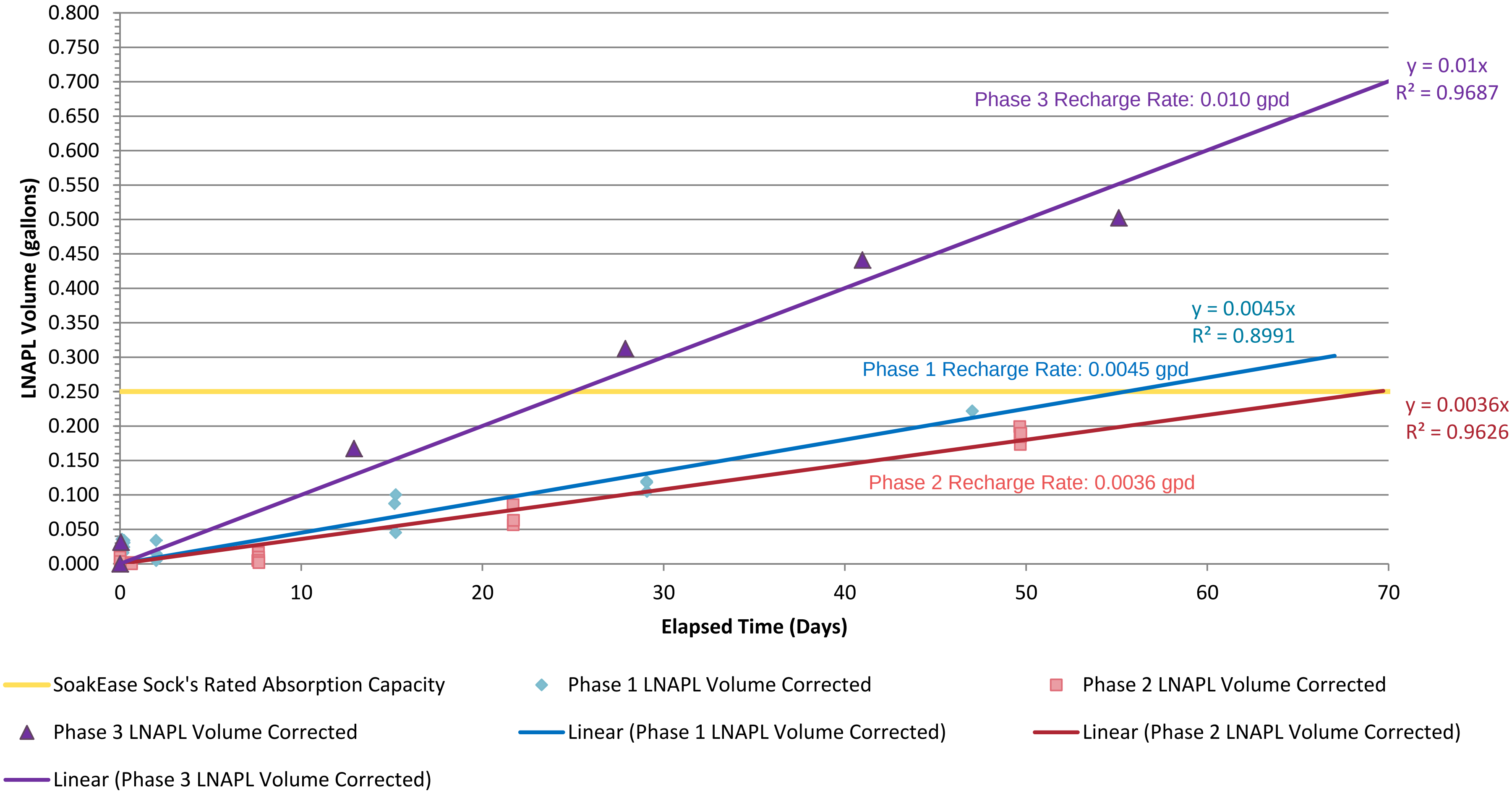
PACIFICORP - FORMER UNOCAL TERMINAL 0022
256 MARINE DRIVE, ASTORIA, OREGON

LNAPL PILOT SCALE STUDY AND RECOVERY REPORT

Phase 3 – Manual Removal Using Hydrophobic Sorbent Product – In-Well Test

ARCADIS

FIGURE 7



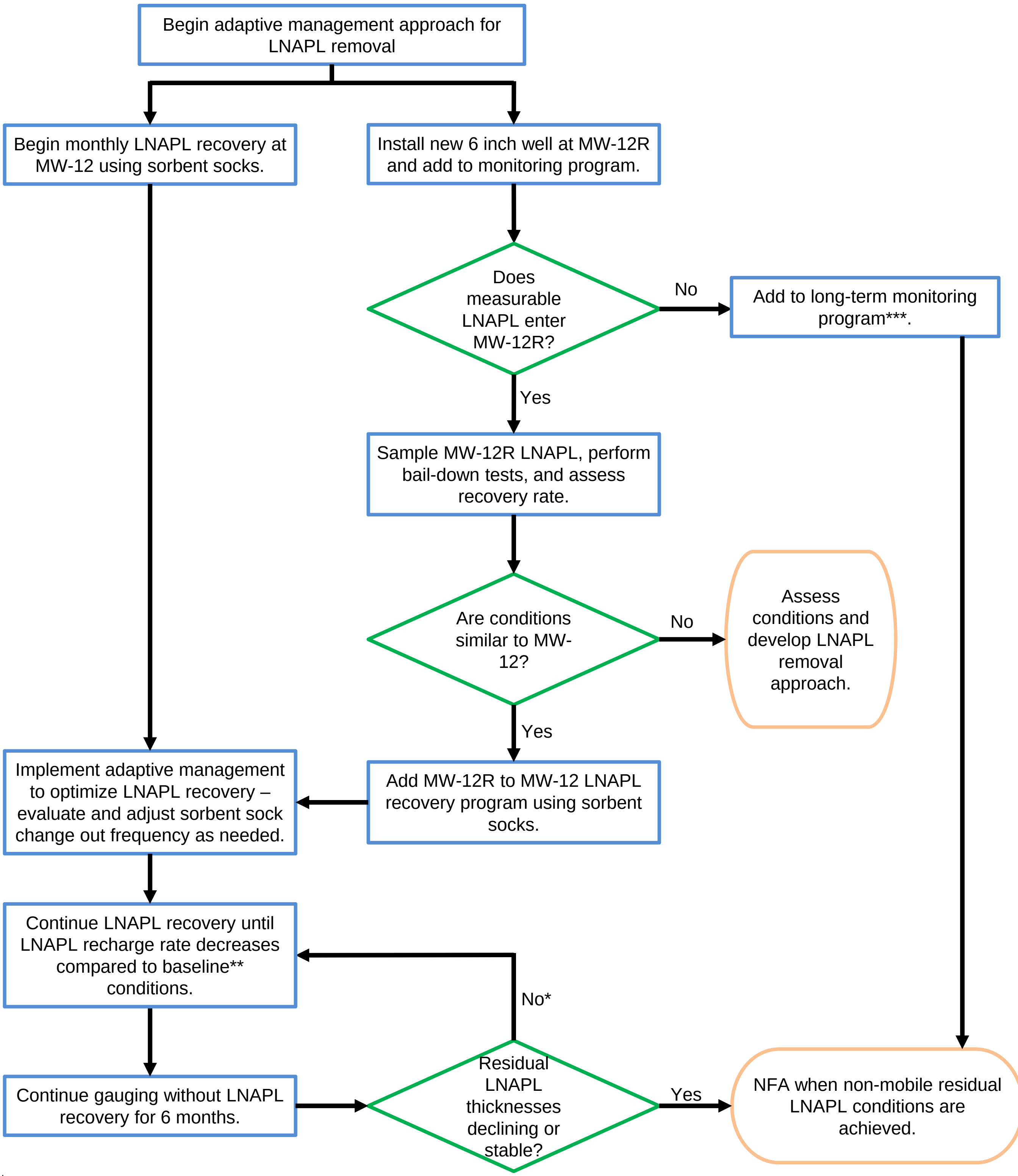
Notes:
gpd = gallons per day
1) Average data utilizes average measurements collected each day of monitoring
2) Correction factor utilized the end of bailing/pumping LNAPL as zero elapsed time
3) Linear Regressions are set at an intercept of 0,0 and projected ahead 20 days
4) Specifications given for 2-inch diameter and 3-feet 3-inch length SoakEase absorbent socks
5) Phase 3 recovery data are likely skewed high due to some water sorption contributing to net weight change of socks

PACIFICORP - FORMER UNOCAL TERMINAL 0022
256 MARINE DRIVE, ASTORIA, OREGON
LNAPL PILOT SCALE STUDY AND RECOVERY REPORT

LNAPL Recovery Rates

ARCADIS

FIGURE
8



Notes:

*The ROD assumes an operational period of 10 years. If recoverable LNAPL persists at the site after 10 years of active recovery, then the ROD assumptions will need to be revisited during the second 5-year review.

**"Baseline" is defined as recovery rates determined by bail-down testing during pre-design pilot tests or new baseline established through the adaptive management approach.

***Long-term monitoring program includes gauging of wells MW-7, MW-11, MW-12, MW-12R, and MW-13. LNAPL removal will proceed until technically impracticable.

LNAPL – Light nonaqueous phase liquid
MW – Monitoring Well
NFA – No Further Action determination
ROD – Record of Decision

PACIFICORP – FORMER UNOCAL TERMINAL 022
256 MARINE DRIVE, ASTORIA, OREGON
LNAPL RECOVERY DESIGN ANALYSIS REPORT

ADAPTIVE MANAGEMENT APPROACH
UPLAND REMEDY – LNAPL REMOVAL

ARCADIS

FIGURE
9

7/21/2010 5:34 PM

ARCADIS

Appendix A

Phase 1 Data – Manual Removal of LNAPL Using Peristaltic Pump

Site traffic control and secondary containment at MW-12

Manual removal of NAPL using peristaltic pump.

LNAPL removed measured in graduated cylinder.

Appendix A
Phase 1 Data – Manual Removal of LNAPL Using a Peristaltic Pump
Former Union Oil/PacifiCorp Astoria Site
256 Marine Drive, Astoria Oregon

	Date	Time	Elapsed time (hh:mm)	Elapsed time (min)	Depth to LNAPL (ft)	Depth to Water (ft)	LNAPL Thickness (ft)	Incremental LNAPL removed (gallons)	Cumulative LNAPL removed (gallons)	Tidal Stage[1] (ft)	Tidal Status
Peristaltic Pumping	3/17/2014	12:20	0:00:00	0	10.28	14.40	4.12	0.00	0.00	5.56	Falling
	3/17/2014	13:00	0:40:00	40	--	--	--	0.04	0.04	4.23	Falling
	3/17/2014	14:00	1:40:00	100	--	--	--	0.08	0.12	2.64	Falling
	3/17/2014	14:30	2:10:00	130	--	--	--	0.04	0.16	2.00	Falling
	3/17/2014	14:45	2:25:00	145	9.48	12.83	3.35	0.03	0.18	1.68	Falling
	3/17/2014	15:00	2:40:00	160	9.43	12.50	3.07	0.06	0.24	1.48	Low
	3/17/2014	15:20	3:00:00	180	9.43	12.35	2.92	0.02	0.26	1.24	Low
	3/17/2014	15:30	3:10:00	190	9.36	12.23	2.87	0.01	0.28	1.14	Low
	3/17/2014	15:45	3:25:00	205	9.38	12.18	2.80	0.01	0.29	1.10	Low
	3/17/2014	16:00	3:40:00	220	9.36	12.12	2.76	0.01	0.30	1.03	Low
	3/17/2014	16:15	3:55:00	235	9.38	12.18	2.80	0.01	0.31	1.02	Low
	3/17/2014	16:30	4:10:00	250	9.42	11.95	2.53	0.01	0.32	1.12	Low
	3/17/2014	16:45	4:25:00	265	9.46	11.80	2.34	0.02	0.34	1.27	Low
	3/17/2014	17:00	4:40:00	280	9.49	11.85	2.36	0.01	0.35	1.49	Low
	3/17/2014	17:15	4:55:00	295	9.56	11.83	2.27	0.02	0.37	1.75	Rising
	3/17/2014	17:30	5:10:00	310	9.62	11.83	2.21	0.01	0.39	2.16	Rising
No Removal	3/17/2014	17:40	5:20:00	320	9.67	11.84	2.17	0.00	0.39	2.45	Rising
	3/17/2014	17:50	5:30:00	330	9.71	11.99	2.28	0.00	0.39	2.61	Rising
	3/17/2014	18:05	5:45:00	345	9.79	11.90	2.11	0.00	0.39	3.14	Rising
	3/17/2014	18:20	6:00:00	360	9.85	12.05	2.20	0.00	0.39	3.49	Rising
	3/17/2014	18:35	6:15:00	375	9.93	12.17	2.24	0.00	0.39	4.05	Rising
	3/18/2014	8:25	20:05:00	1205	10.39	12.46	2.07	0.00	0.39	7.33	Rising
	3/18/2014	9:15	20:55:00	1255	10.39	12.46	2.07	0.00	0.39	8.29	Rising
Manual Bailing	3/18/2014	9:25	21:05:00	1265	--	--	--	0.11	0.49	8.46	Rising
	3/18/2014	9:32	21:12:00	1272	--	--	--	0.10	0.60	8.54	High
	3/18/2014	9:50	21:30:00	1290	--	--	--	0.09	0.69	8.70	High
	3/18/2014	10:00	21:40:00	1300	10.83	11.15	0.32	0.00	0.69	8.73	High
	3/18/2014	10:12	21:52:00	1312	--	--	--	0.01	0.70	8.72	High
	3/18/2014	10:20	22:00:00	1320	10.89	11.00	0.11	0.01	0.71	8.69	High

Appendix A
Phase 1 Data – Manual Removal of LNAPL Using a Peristaltic Pump
Former Union Oil/PacifiCorp Astoria Site
256 Marine Drive, Astoria Oregon

	Date	Time	Elapsed time (hh:mm)	Elapsed time (min)	Depth to LNAPL (ft)	Depth to Water (ft)	LNAPL Thickness (ft)	Incremental LNAPL removed (gallons)	Cumulative LNAPL removed (gallons)	Tidal Stage[1] (ft)	Tidal Status
Recovery	3/18/2014	10:35	22:15:00	1335	10.85	10.89	0.04	0.00	0.71	8.56	High
	3/18/2014	11:00	22:40:00	1360	10.84	10.88	0.04	0.00	0.71	8.21	Falling
	3/18/2014	11:30	23:10:00	1390	10.76	10.80	0.04	0.00	0.71	7.58	Falling
	3/18/2014	12:00	23:40:00	1420	10.69	10.80	0.11*	0.00	0.71	6.73	Falling
	3/18/2014	12:30	24:10:00	1450	10.59	10.61	0.02	0.00	0.71	5.76	Falling
	3/18/2014	13:00	24:40:00	1480	10.45	10.67	0.22*	0.00	0.71	4.78	Falling
	3/18/2014	13:30	25:10:00	1510	10.32	10.44	0.12	0.00	0.71	3.81	Falling
	3/18/2014	14:00	25:40:00	1540	10.13	10.29	0.16	0.00	0.71	2.97	Falling
	3/18/2014	14:30	26:10:00	1570	9.95	10.05	0.1	0.00	0.71	2.20	Falling
	3/18/2014	15:00	26:40:00	1600	9.79	9.82	0.03*	0.00	0.71	1.56	Falling
	3/18/2014	15:15	26:55:00	1615	9.74	9.93	0.19	0.00	0.71	1.32	Falling
	3/18/2014	15:30	27:10:00	1630	9.66	9.81	0.15	0.00	0.71	1.04	Falling
	3/18/2014	15:45	27:25:00	1645	9.63	9.84	0.21	0.00	0.71	0.87	Low
	3/18/2014	16:00	27:40:00	1660	9.60	9.79	0.19	0.00	0.71	0.71	Low
	3/21/2014	10:20	70:00:00	4200	10.64	10.85	0.21**	0.00	0.71	7.60	Rising
	3/21/2014	10:30	70:10:00	4210	10.68	10.71	0.03**	0.00	0.71	7.84	Rising
	3/21/2014	10:40	70:20:00	4220	10.72	10.81	0.09**	0.00	0.71	8.04	Rising
	3/21/2014	10:50	70:30:00	4230	10.79	10.83	0.04**	0.00	0.71	8.14	Rising
	3/21/2014	11:00	70:40:00	4240	10.81	10.85	0.04**	0.00	0.71	8.29	Rising
	3/21/2014	11:15	70:55:00	4255	10.95	11.00	0.05**	0.00	0.71	8.43	High
	4/3/2014	14:10	385:50:00	23150	10.47	11.01	0.54	0.00	0.71	5.58	Falling
	4/3/2014	15:30	387:10:00	23230	10.04	10.32	0.28*	0.00	0.71	3.08	Falling
	4/3/2014	15:45	387:25:00	23245	9.96	10.58	0.62	0.00	0.71	2.75	Falling
	4/18/2014	11:55	719:35:00	43175	10.91	11.65	0.74	0.00	0.71	8.57	Falling
	4/18/2014	12:10	719:50:00	43190	10.90	11.63	0.73	0.00	0.71	8.10	Falling
	4/18/2014	12:25	720:05:00	43205	10.89	11.54	0.65	0.00	0.71	7.76	Falling
	5/8/2014	11:05	718:45:00	43125	9.91	11.28	1.37	0.00	0.71	3.40	Low
	5/8/2014	11:20	719:00:00	43140	9.91	11.28	1.37	0.00	0.71	3.48	Low

Notes:

-- = measurement not collected at this time

ft = feet

min = Minutes

LNAPL = Light Non-Aqueous Phase Liquid

* LNAPL thickness discrepancy likely associated with difficulty of measurement due to consistency of LNAPL

** Gauging completed with newer model probe; difference in probe shape resulted in greater difficulty clearing LNAPL from probe tip to obtain bottom of LNAPL layer measurements.

Appendix B

Phase 2 Data – Manual Removal of LNAPL Using a Peristaltic Pump In Conjunction with In-Well Heating

In-well heater prior to insertion into MW-12.

Bailer used to collect LNAPL sample from MW-12.

Heater, thermometer, and oil/water interface probe in MW-12

Appendix B

Phase 2 Data – Manual Removal of LNAPL Using a Peristaltic Pump In Conjunction with In-Well Heating

Former Union Oil/PacifiCorp Astoria Site

256 Marine Drive, Astoria Oregon

	Date	Time	Elapsed time (min)	Depth to LNAPL (ft)	Depth to Water (ft)	LNAPL Temp (°F)	Water Temp (°F)	LNAPL Thickness (ft)	Incremental LNAPL removed (gallons)	Cumulative LNAPL removed (gallons)	Tidal Stage[1] (ft)	Tidal Status
Initial Gauging and Sample Collection	5/8/2014	11:05	0	9.91	11.28	--	--	1.37	0.00	0.00	3.40	Low
	5/8/2014	11:20	15	9.91	11.28	--	--	1.37	--	--	3.48	Low
	5/8/2014	11:45	40	9.99	11.11	--	--	1.12	0.04	0.04	3.74	Rising
	5/8/2014	13:00	115	10.20	11.06	--	--	0.86*	--	--	4.83	Rising
	5/8/2014	13:05	120	10.20	11.35	55	55	1.15*	--	--	4.93	Rising
Heating	5/8/2014	13:20	135	10.24	11.25	55	55	1.01*	--	--	5.09	Rising
	5/8/2014	13:30	145	10.25	11.26	56	61	1.01	--	--	5.28	Rising
	5/8/2014	13:42	157	10.28	11.22	59	67	0.94	--	--	5.46	Rising
	5/8/2014	13:55	170	10.29	11.32	60	70	1.03	--	--	5.63	Rising
	5/8/2014	14:10	185	10.32	11.18	66	75	0.86	--	--	5.84	Rising
	5/8/2014	14:40	215	10.37	11.47	73	80	1.10	--	--	6.20	Rising
	5/8/2014	15:00	235	10.39	11.42	70	82	1.03	--	--	6.38	Rising
	5/8/2014	15:20	255	10.42	11.51	75	84	1.09	--	--	6.48	High
	5/8/2014	15:42	277	10.46	11.49	80	87	1.03	--	--	6.55	High
	5/8/2014	16:00	295	10.45	11.44	82	90	0.99	--	--	6.58	High
	5/8/2014	16:15	310	10.45	11.48	84	91	1.03	--	--	6.57	High
Heating and Peristaltic Pumping	5/8/2014	16:30	325	10.46	11.65	86	--	1.19	--	--	6.51	High
	5/8/2014	16:40	335	10.46	11.35	88	--	0.89	--	--	6.44	Falling
	5/8/2014	16:47	342	10.50	11.22	84	--	0.72	--	--	6.40	Falling
	5/8/2014	17:00	355	10.49	11.11	83	--	0.62	0.11	0.14	6.29	Falling
	5/8/2014	17:25	380	10.45	11.00	81	--	0.55	--	--	5.92	Falling
	5/8/2014	17:30	385	10.52	10.91	81	--	0.39	--	--	5.89	Falling
	5/8/2014	17:50	405	10.46	10.66	80	--	0.20	0.05	0.20	5.63	Falling
	5/8/2014	18:05	420	10.59	10.71	80	--	0.12	0.01	0.21	5.32	Falling
	5/8/2014	18:20	435	10.54	10.57	76	--	0.03	0.03	0.24	5.10	Falling
Recovery	5/8/2014	19:00	475	10.17	10.23	66	--	0.06*	--	--	4.33	Falling
	5/8/2014	19:20	495	10.09	10.11	63	--	0.02**	--	--	4.04	Falling
	5/9/2014	9:35	1,350	9.75	9.76	--	--	0.01**	--	--	3.60	Falling
	5/9/2014	9:50	1,365	9.74	9.75	--	--	0.01**	--	--	3.42	Falling
	5/9/2014	10:05	1,380	9.71	9.72	--	--	0.01**	--	--	3.25	Falling
	5/9/2014	10:20	1,395	9.70	9.70	--	--	0**	--	--	3.08	Low
	5/16/2014	9:25	11,420	10.74	--	--	--	--	--	--	10.12	High
	5/16/2014	9:31	11,426	10.79	10.82	--	--	0.03	--	--	10.14	High
	5/16/2014	9:51	11,446	10.85	--	--	--	--	--	--	10.09	High
	5/16/2014	10:01	11,456	10.88	11.00	--	--	0.12*	--	--	10.01	High
	5/16/2014	10:15	11,470	10.92	10.95	--	--	0.03	--	--	9.87	Falling
	5/16/2014	10:25	11,480	10.95	11.05	--	--	0.10*	--	--	9.70	Falling
	5/16/2014	10:35	11,490	10.90	10.96	--	--	0.06	--	--	9.47	Falling
	5/16/2014	10:45	11,500	10.97	11.00	--	--	0.03	--	--	9.33	Falling
	5/16/2014	10:55	11,510	10.98	10.99	--	--	0.01	--	--	9.04	Falling
	5/30/2014	11:35	31,710	11.05	11.58	--	--	0.53	--	--	6.91	Falling
	5/30/2014	11:45	31,720	11.03	11.38	--	--	0.35	--	--	6.73	Falling
	5/30/2014	11:55	31,730	11.02	11.41	--	--	0.39	--	--	6.33	Falling
	5/30/2014	12:05	31,740	11.01	11.40	--	--	0.39	--	--	5.92	Falling
	6/27/2014	10:35	31,650	10.99	--	--	--	--	--	--	7.29	Falling
	6/27/2014	10:40	71,975	10.98	12.21	--	--	1.23*	--	--	7.10	Falling
	6/27/2014	11:00	71,995	10.95	12.11	--	--	1.16	--	--	6.52	Falling
	6/27/2014	11:20	72,015	10.92	11.99	--	--	1.07*	--	--	5.86	Falling
	6/27/2014	11:40	72,035	10.87	12.01	--	--	1.14	--	--	5.06	Falling
	6/27/2014	12:00	72,055	10.81	11.98	--	--	1.17	--	--	4.47	Falling

Notes:

-- = measurement not collected at this time

ft = feet

min = Minutes

LNAPL = Light Non-Aqueous Phase Liquid

* LNAPL thickness discrepancy likely associated with difficulty of measurement due to consistency of LNAPL

** LNAPL thickness discrepancy likely associated with difference in tidal phase

LNAPL removal volumes are very approximate estimates due to difficulty measuring the proportion of LNAPL to water in total amount of fluid removed from well.

[1]Tidal stage recorded at National Oceanographic and Atmospheric Administration Station ID: 9439040 in Astoria, Oregon. September data are preliminary.

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Appendix C

Phase 3 Data – Manual Removal of LNAPL Using Hydrophobic Sorbent Products

Site specific LNAPL absorption test.

Absorbent sock from MW-12 after two weeks.

Trace NAPL in well at two weeks

Appendix C

Phase 3 Data – Manual Removal of LNAPL Using Hydrophobic Sorbent Products

Absorption Test

Former Union Oil/PacifiCorp Astoria Site

256 Marine Drive, Astoria Oregon

Date	Time	Elapsed time (min)	Weight (g)	Weight Change (g)	Rate Absorbed (g/min)	Notes
7/31/2014	12:59	0	117	0	--	
7/31/2014	13:00	1	291	174	174	
7/31/2014	13:03	4	511	220	55	
7/31/2014	13:05	6	567	56	9	
7/31/2014	13:11	12	671	104	9	
7/31/2014	13:17	18	740	69	4	Only floating blobs of LNAPL on water remaining in bucket
7/31/2014	13:31	32	795	55	2	
7/31/2014	13:45	46	798	3	0	
7/31/2014	14:00	61	805	7	0	Bucket almost completely LNAPL free, only water remaining
7/31/2014	14:15	76	809	4	0	

Notes:

-- = measurement not collected at this time

g = grams

min = Minutes

LNAPL = Light Non-Aqueous Phase Liquid

Appendix C
Phase 3 Data – Manual Removal of LNAPL Using Hydrophobic Sorbent Products
In-Well Test
Former Union Oil/PacifiCorp Astoria Site
256 Marine Drive, Astoria Oregon

Date	Time	Elasped time (min)	Elapsed time (days)	Depth to LNAPL (ft)	Depth to Water (ft)	LNAPL Thickness (ft)	Sock Initial Weight (lbs)	Sock Weight (lbs)	LNAPL Weight Removed (lbs)	LNAPL Removed (gallons)	Cumulative LNAPL Removed (gallons)	Tidal Stage[1] (ft)	Tidal Status	Notes
7/31/2014	11:45	0	0	11.41	--	--	--	--	--	--	0.00	7.30	High	Initial gauging measurements
7/31/2014	11:47	2	0	11.35	13.3	1.95	--	--	--	--	0.00	7.28	High	Initial gauging measurements
7/31/2014	11:55	10	0	11.36	13.31	1.95	--	--	--	--	0.00	7.24	High	Initial gauging measurements
7/31/2014	12:11	26	0	--	--	--	--	--	--	0.07	0.07	7.06	High	Manual bailing of LNAPL
7/31/2014	12:15	30	0	--	--	--	--	--	--	0.08	0.16	7.06	High	Manual bailing of LNAPL
7/31/2014	12:18	33	0	--	--	--	--	--	--	0.05	0.21	6.98	High	Manual bailing of LNAPL
7/31/2014	12:30	45	0	--	--	--	--	--	--	--	0.21	6.78	Falling	Removed remaining LNAPL from well with new socks.
7/31/2014	12:50	65	0	11.56	11.56	0.00	--	--	--	--	0.21	6.39	Falling	No measureable LNAPL.
7/31/2014	13:12	87	0	--	--	--	--	--	--	--	0.21	5.83	Falling	In well sock test start - sock placed at 9 - 12 ft
7/31/2014	13:24	99	0	--	--	--	0.30	--	--	--	0.21	5.50	Falling	Deployed sock in well
7/31/2014	14:27	162	0	11.2	11.2	0.00	0.30	0.55	--	--	0.21	3.78	Falling	1 hour sock weight
8/13/2014	11:15	18,690	13	11.33	11.33	0.00	0.30	1.64	1.34	0.17	0.38	9.08	High	Sock #1 removed, sock #2 installed
8/28/2014	10:35	40,250	28	11.65	11.65	0.00	0.31	1.47	1.16	0.15	0.52	7.86	High	Sock #2 removed, sock #3 installed
9/10/2014	12:05	59,060	41	11.19	11.19	0.00	0.31	1.34	--	--	0.52	5.61	Falling	Sock #3 weighed and replaced in well.
9/24/2014	16:05	79,460	55	9.51	9.51	0.00	0.31	1.83	1.52	0.19	0.71	1.76	Low	Sock #3 removed.

Notes:

-- = measurement not collected at this time

ft = feet

lbs = pounds

min = minutes

LNAPL = Light Non-Aqueous Phase Liquid

[1]Tidal stage recorded at National Oceanographic and Atmospheric Administration Station ID: 9439040 in Astoria, Oregon. September data are preliminary.

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Appendix D

Laboratory Reports

PTS
Laboratories, Inc.

8100 Secura Way • Santa Fe Springs, CA 90670
Telephone (562) 347-2500 • Fax (562) 907-3610

December 5, 2013

Jesse Hemmen
ARCADIS
111 Southwest Columbia Street, Suite 670
Portland, OR 97201

Re: PTS File No: 43774
Physical Properties Data
PacifiCorp Astoria; PO10006.0001.00001

Dear Ms. Hemmen:

Please find enclosed report for Physical Properties analyses conducted upon the sample received from your PacifiCorp Astoria; PO10006.0001.00001 project. All analyses were performed by applicable ASTM, EPA, or API methodologies. An electronic version of the report has previously been sent to your attention via the internet. The sample is currently in storage and will be retained for thirty days past completion of testing at no charge. Please note that the sample will be disposed of at that time. You may contact me regarding storage, disposal, or return of the sample.

PTS Laboratories, Inc. appreciates the opportunity to be of service. If you have any questions or require additional information, please contact Rachel Spitz at (562) 347-2504.

Sincerely,
PTS Laboratories, Inc.

Michael Mark Brady, P.G.
District Manager

Encl.

PTS Laboratories

Project Name: **PacifiCorp Astoria** **PTS File No:** **43774**
Project Number: **PO10006.0001.00001** **Client:** **ARCADIS**

TEST PROGRAM - 20131120

FLUID ID	Date	Time	Fluid Type	3-Point Viscosity	Fluid Cleaning			
Method:				ASTM D445, D1481	Proprietary			
Date Received: 20131120								
MW-12-NAPL	20131118	1230	NAPL	X	X			
TOTALS:				1	1			1

Laboratory Test Program Notes

Standard TAT for basic analysis is 10 business days.

Viscosity at three temperatures (60, 75, and 90°F).

PTS File No: 43774
Client: ARCADIS
Report Date: 12/05/13

PTS Laboratories

VISCOSITY, DENSITY, and SPECIFIC GRAVITY DATA

(METHODOLOGY: ASTM D445, ASTM D1481, API RP40)

Project Name: PacifiCorp Astoria
Project No: PO10006.0001.00001

SAMPLE ID	MATRIX	TEMPERATURE, °F	SPECIFIC GRAVITY	DENSITY, g/cc	VISCOSITY	
					centistokes	centipoise
MW-12-NAPL	NAPL	60	0.9690	0.9680	3643	3526
		75	0.9651	0.9625	1366	1315
		90	0.9619	0.9571	660	632

QUALITY CONTROL DATA

Date:	12/02/13	12/04/13	12/05/13	12/05/13
FLUID TYPE:	Cannon® CVS S3	Cannon® CVS S3	Cannon® CVS S3	DI Water
TEMPERATURE, °F:	70	70	70	70
DENSITY, MEASURED:			0.8651	0.9980
DENSITY, PUBLISHED:			0.8641	0.9980
RPD:			0.12	0.00
VISCOSITY, MEASURED:	4.4968	4.5766	4.6145	0.9935
VISCOSITY, PUBLISHED:	4.4950	4.4950	4.4950	0.9773
RPD:	0.04	1.80	2.62	1.65
CVS Lot #:	13101	CVS = Certified Viscosity Standard		

PTS Laboratories, Inc.

CHAIN OF CUSTODY RECORD

COMPANY: ARCADIS U.S. Inc.

ADDRESS: 111 SW Columbia St., Ste. 670, CITY: Portland, OR ZIP CODE: 97201

PROJECT MANAGER: Jesse Hemmen

PROJECT NAME: PacifiCorp Astoria — PHONE NUMBER: 503.220.8201 x1106

PROJECT NUMBER: PO10006.0001.00001 — FAX NUMBER: 503.220.8209

SITE LOCATION: 256 Marine Drive, Astoria, Oregon

SAMPLER SIGNATURE: [signature]

PO#:

TURNAROUND TIME: 24 HOURS ☐ 48 HOURS ☐ 72 HOURS ☐ 5 DAYS ☐ NORMAL ☒ OTHER: ______

SAMPLE INTEGRITY (CHECK): INTACT X ON ICE X

PTS QUOTE NO. 13-157

PTS FILE: 43774

ANALYSIS REQUEST

SAMPLE ID NUMBER	DATE	TIME	DEPTH, FT	NUMBER OF SAMPLES	SOIL PROPERTIES PACKAGE	HYDRAULIC CONDUCTIVITY PACKAGE	PORE FLUID SATURATIONS PACKAGE	TCEQ/TNRCC PROPERTIES PACKAGE	CAPILLARITY PACKAGE	FLUID PROPERTIES PACKAGE	PHOTOLOG: CORE PHOTOGRAPHY	MOISTURE CONTENT, ASTM D2216	POROSITY: TOTAL, API RP40	POROSITY: EFFECTIVE, ASTM D425M	SPECIFIC GRAVITY, ASTM D854	BULK DENSITY (DRY), API RP40 or ASTM D2937	AIR PERMEABILITY, API RP40	HYDRAULIC CONDUCTIVITY, EPA9100, API RP40, D5084	GRAIN SIZE DISTRIBUTION, ASTM D422/4464M	TOC: WALKLEY-BLACK	ATTERBERG LIMITS, ASTM D4318	Viscosity, ASTM D445: 60°F, 75°F, 90°F				COMMENTS
MW-12-NAPL	11/18/13	1230	—	1																		X				

1. RELINQUISHED BY	2. RECEIVED BY	3. RELINQUISHED BY	4. RECEIVED BY
[signature]			[signature] 46 °F
COMPANY: ARCADIS	COMPANY: Fed Ex	COMPANY:	COMPANY: PTS LABS
DATE: 11/19/13 TIME: 1200	DATE: 11/19/13 TIME: 1200	DATE: TIME:	DATE: 11/20/13 TIME: 10:34

TestAmerica

THE LEADER IN ENVIRONMENTAL TESTING

ANALYTICAL REPORT

TestAmerica Laboratories, Inc.
TestAmerica Portland
9405 SW Nimbus Ave.
Beaverton, OR 97008
Tel: (503)906-9200

TestAmerica Job ID: 250-15569-1
Client Project/Site: Pacificorp Astoria

For:
ARCADIS U.S. Inc
111 SW Columbia Street
Suite 670
Portland, Oregon 97201

Attn: Timothy Bellis

Erica Fot

Authorized for release by:
11/26/2013 3:23:47 PM
Erica Fot, Project Management Assistant II
erica.fot@testamericainc.com

Designee for

Vanessa Berry, Project Manager I
(503)906-9233
vanessa.berry@testamericainc.com

The test results in this report meet all 2003 NELAC and 2009 TNI requirements for accredited parameters, exceptions are noted in this report. This report may not be reproduced except in full, and with written approval from the laboratory. For questions please contact the Project Manager at the e-mail address or telephone number listed on this page.

This report has been electronically signed and authorized by the signatory. Electronic signature is intended to be the legally binding equivalent of a traditionally handwritten signature.

Results relate only to the items tested and the sample(s) as received by the laboratory.

Table of Contents

Sample Summary

Client: ARCADIS U.S. Inc
Project/Site: Pacificorp Astoria

TestAmerica Job ID: 250-15569-1

Lab Sample ID	Client Sample ID	Matrix	Collected	Received
250-15569-1	MW-12-NAPL	Waste	11/18/13 12:30	11/19/13 17:54

Job ID: 250-15569-1

Laboratory: TestAmerica Portland

Narrative

Job Narrative
250-15569-1

Comments

No additional comments.

Receipt

The sample was received on 11/19/2013 5:54 PM; the sample arrived in good condition, properly preserved and, where required, on ice.
The temperature of the cooler at receipt was 5.5º C.

General Chemistry

No analytical or quality issues were noted.

Client: ARCADIS U.S. Inc
Project/Site: Pacificorp Astoria

TestAmerica Job ID: 250-15569-1

Glossary

Abbreviation	These commonly used abbreviations may or may not be present in this report.
¤	Listed under the "D" column to designate that the result is reported on a dry weight basis
%R	Percent Recovery
CNF	Contains no Free Liquid
DER	Duplicate error ratio (normalized absolute difference)
Dil Fac	Dilution Factor
DL, RA, RE, IN	Indicates a Dilution, Re-analysis, Re-extraction, or additional Initial metals/anion analysis of the sample
DLC	Decision level concentration
MDA	Minimum detectable activity
EDL	Estimated Detection Limit
MDC	Minimum detectable concentration
MDL	Method Detection Limit
ML	Minimum Level (Dioxin)
NC	Not Calculated
ND	Not detected at the reporting limit (or MDL or EDL if shown)
PQL	Practical Quantitation Limit
QC	Quality Control
RER	Relative error ratio
RL	Reporting Limit or Requested Limit (Radiochemistry)
RPD	Relative Percent Difference, a measure of the relative difference between two points
TEF	Toxicity Equivalent Factor (Dioxin)
TEQ	Toxicity Equivalent Quotient (Dioxin)

General Chemistry

Client Sample ID: MW-12-NAPL
Date Collected: 11/18/13 12:30
Date Received: 11/19/13 17:54

Lab Sample ID: 250-15569-1
Matrix: Waste

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Flashpoint	>212				Degrees F			11/26/13 10:41	1

Client: ARCADIS U.S. Inc
Project/Site: Pacificorp Astoria

TestAmerica Job ID: 250-15569-1

Method: 1020A - Ignitability, Setaflash Closed-Cup Method

Lab Sample ID: 580-41378-A-1 DU
Matrix: Waste
Analysis Batch: 149900

Client Sample ID: Duplicate
Prep Type: Total/NA

Analyte	Sample Result	Sample Qualifier	DU Result	DU Qualifier	Unit	D	RPD	RPD Limit
Flashpoint	134.6		135		Degrees F		NC	20

Certification Summary

Client: ARCADIS U.S. Inc
Project/Site: Pacificorp Astoria

TestAmerica Job ID: 250-15569-1

Laboratory: TestAmerica Portland

All certifications held by this laboratory are listed. Not all certifications are applicable to this report.

Authority	Program	EPA Region	Certification ID	Expiration Date
Alaska (UST)	State Program	10	UST-012	12-26-13
California	State Program	9	2597	09-30-15
Oregon	NELAP	10	OR100021	01-09-14
USDA	Federal		P330-11-00092	02-17-14
Washington	State Program	10	C586	06-23-14

Laboratory: TestAmerica Seattle

All certifications held by this laboratory are listed. Not all certifications are applicable to this report.

Authority	Program	EPA Region	Certification ID	Expiration Date
Alaska (UST)	State Program	10	UST-022	03-04-14
California	NELAP	9	01115CA	01-31-14
L-A-B	DoD ELAP		L2236	01-19-16
L-A-B	ISO/IEC 17025		L2236	01-19-16
Montana (UST)	State Program	8	N/A	04-30-20
Oregon	NELAP	10	WA100007	11-06-14
USDA	Federal		P330-11-00222	05-20-14
Washington	State Program	10	C553	02-17-14

Method Summary

Method	Method Description	Protocol	Laboratory
1020A	Ignitability, Setaflash Closed-Cup Method	SW846	TAL SEA

Protocol References:

SW846 = "Test Methods For Evaluating Solid Waste, Physical/Chemical Methods", Third Edition, November 1986 And Its Updates.

Laboratory References:

TAL SEA = TestAmerica Seattle, 5755 8th Street East, Tacoma, WA 98424, TEL (253)922-2310

TestAmerica Portland
9405 SW Nimbus Avenue
Beaverton, OR 97008
phone 503.906.9200 fax 503.906.9210

Chain of Custody Record

250-15569 Chain of Custody

Regulatory Program: ☐ DW ☐ NPDES ☐ RCRA ☐ Other:

Client Contact	Project Manager: JESSIE HEMMEN	Site Contact: TIM BELLES	Date: 11/18/13	COC No:
Your Company Name here ARCADIS	Tel/Fax: 503-220-8201	Lab Contact: VANESSA	Carrier:	1 of 1 COCs
Address 111 SW COLUMBIA ST STE 670	**Analysis Turnaround Time**			**For Lab Use Only:**
City/State/Zip PORTLAND OR 97201	☐ CALENDAR DAYS ☐ WORKING DAYS			Walk-in Client:
(xxx) xxx-xxxx 503 220 8201 Phone	TAT if different from Below			Lab Sampling:
(xxx) xxx-xxxx 503 220 8209 FAX	☒ 2 weeks			
Project Name: PACIFICORP ASTORIA	☐ 1 week			Job / SDG No.:
Site:	☐ 2 days			
P O # P01D0006.0000	☐ 1 day			Sampler:

Sample Identification	Sample Date	Sample Time	Sample Type (C=Comp, G=Grab)	Matrix	# of Cont.	Filtered Sample (Y / N)	Perform MS / MSD (Y / N)	FLASH POINT	Sample Specific Notes:
MW-12-NAPL	11/18/13	12:30	G		1			X	

Preservation Used: 1=Ice, 2=HCl; 3=H2SO4; 4=HNO3; 5=NaOH; 6= Other

Possible Hazard Identification:
Are any samples from a listed EPA Hazardous Waste? Please List any EPA Waste Codes for the sample in the Comments Section if the lab is to dispose of the sample.

☐ Non-Hazard ☐ Flammable ☐ Skin Irritant ☐ Poison B ☐ Unknown

Sample Disposal (A fee may be assessed if samples are retained longer than 1 month)

☐ Return to Client ☒ Disposal by Lab ☐ Archive for______ Months

Special Instructions/QC Requirements & Comments:

Custody Seals Intact: ☐ Yes ☐ No | Custody Seal No.: | Cooler Temp. (°C): Obs'd: 5.5 Corr'd: ____ | Therm ID No.: I.R

Relinquished by:	Company:	Date/Time:	Received by:	Company:	Date/Time:
[signature]	ARCADIS	11/18/13 1754	[signature]	TAP	11/18/13 1754
Relinquished by:	Company:	Date/Time:	Received by:	Company:	Date/Time:
Relinquished by:	Company:	Date/Time:	Received in Laboratory by:	Company:	Date/Time:

TAL-1003 (0413) Form No: CA-C-WI-002, Rev. 4.1, dated 02/20/2013

1 2 3 4 5 6 7 8 9 10 11

Login Sample Receipt Checklist

Client: ARCADIS U.S. Inc

Job Number: 250-15569-1

Login Number: 15569

List Source: TestAmerica Portland

List Number: 1

Creator: Krause, Thomas A

Question	Answer	Comment
Radioactivity wasn't checked or is </= background as measured by a survey meter.	N/A	
The cooler's custody seal, if present, is intact.	N/A	
Sample custody seals, if present, are intact.	N/A	
The cooler or samples do not appear to have been compromised or tampered with.	True	
Samples were received on ice.	True	
Cooler Temperature is acceptable.	True	
Cooler Temperature is recorded.	True	
COC is present.	True	
COC is filled out in ink and legible.	True	
COC is filled out with all pertinent information.	True	
Is the Field Sampler's name present on COC?	False	No sampler name on COC.
There are no discrepancies between the containers received and the COC.	True	
Samples are received within Holding Time.	True	
Sample containers have legible labels.	True	
Containers are not broken or leaking.	True	
Sample collection date/times are provided.	True	
Appropriate sample containers are used.	True	
Sample bottles are completely filled.	True	
Sample Preservation Verified.	N/A	
There is sufficient vol. for all requested analyses, incl. any requested MS/MSDs	True	
Containers requiring zero headspace have no headspace or bubble is <6mm (1/4").	N/A	
Multiphasic samples are not present.	N/A	
Samples do not require splitting or compositing.	N/A	
Residual Chlorine Checked.	N/A	

Login Sample Receipt Checklist

Client: ARCADIS U.S. Inc | Job Number: 250-15569-1

Login Number: 15569
List Number: 1
Creator: McDaniel, Ronald T

List Source: TestAmerica Seattle
List Creation: 11/20/13 11:43 AM

Question	Answer	Comment
Radioactivity wasn't checked or is </= background as measured by a survey meter.	True	
The cooler's custody seal, if present, is intact.	True	
Sample custody seals, if present, are intact.	True	
The cooler or samples do not appear to have been compromised or tampered with.	True	
Samples were received on ice.	True	
Cooler Temperature is acceptable.	True	
Cooler Temperature is recorded.	True	IR=2.2/2.3
COC is present.	True	
COC is filled out in ink and legible.	True	
COC is filled out with all pertinent information.	True	
Is the Field Sampler's name present on COC?	True	
There are no discrepancies between the containers received and the COC.	True	
Samples are received within Holding Time.	True	
Sample containers have legible labels.	True	
Containers are not broken or leaking.	True	
Sample collection date/times are provided.	True	
Appropriate sample containers are used.	True	
Sample bottles are completely filled.	True	
Sample Preservation Verified.	True	
There is sufficient vol. for all requested analyses, incl. any requested MS/MSDs	True	
Containers requiring zero headspace have no headspace or bubble is <6mm (1/4").	N/A	
Multiphasic samples are not present.	True	
Samples do not require splitting or compositing.	True	
Residual Chlorine Checked.	N/A	

8100 Secura Way • Santa Fe Springs, CA 90670
Telephone (562) 347-2500 • Fax (562) 907-3610

May 27, 2014

Brooke Bonkoski
ARCADIS - US
111 SW Columbia St., Suite 670
Portland, OR 97201

Re: PTS File No: 44281
Fluid Properties Data
PacifiCorp Astoria; PO10006.0002.00001

Dear Ms. Bonkoski:

Please find enclosed report for Fluid Properties analyses conducted upon samples received from your PacifiCorp Astoria; PO10006.0002.00001 project. All analyses were performed by applicable ASTM, EPA, or API methodologies. An electronic version of the report has previously been sent to your attention via the internet. The samples are currently in storage and will be retained for thirty days past completion of testing at no charge. Please note that the samples will be disposed of at that time. You may contact me regarding storage, disposal, or return of the samples.

PTS Laboratories appreciates the opportunity to be of service. If you have any questions or require additional information, please give me a call at (562) 347-2502.

Sincerely,
PTS Laboratories, Inc.

Michael Mark Brady, P.G.
District Manager

Encl.

PTS Laboratories

Project Name:	**PacifiCorp Astoria**	**PTS File No:**	**44281**
Project Number:	**PO10006.0002.00001**	**Client:**	**ARCADIS**

TEST PROGRAM - 20140512

FLUID ID	Date	Time	Fluid Type	Interfacial Tension Oil/Water at 55ºF	Interfacial Tension Oil/Air at 55°F	Interfacial Tension Water/Air at 55ºF	IFT at Chilled Temperature	Comments
			Method:	ASTM D971	ASTM D971	ASTM D971		
Date Received: 20140512								
MW-12-NAPL	**20140507**	**N/A**	**NAPL**	**X**	**X**		**X**	
MW-12-W	**20140507**	**N/A**	**Water**			**X**		
TOTALS:				**1**	**1**	**1**	**1**	**5 jars**

Laboratory Test Program Notes

Standard TAT for basic analysis is 10 business days.

Run IFT pairs at 55 degrees F - per COC

CLIENT CONFIDENTIAL

PTS File No: 44281
Client: ARCADIS
Report Date: 05/27/14

PTS Laboratories

VISCOSITY, DENSITY, and SPECIFIC GRAVITY DATA

(METHODOLOGY: ASTM D445, ASTM D1481, API RP40)

Project Name: PacifiCorp Astoria
Project No: PO10006.0002.00001

SAMPLE ID	MATRIX	TEMPERATURE, °F	SPECIFIC GRAVITY	DENSITY, g/cc	VISCOSITY	
					centistokes	centipoise
MW-12-W	Water	55	1.000	0.9996		
MW-12-NAPL	NAPL	55	0.9699	0.9694		

QUALITY CONTROL DATA

Date:	05/15/14	05/15/14
FLUID TYPE:	Cannon® CVS S3	DI Water
TEMPERATURE, °F:	70	70
DENSITY, MEASURED:	0.8652	0.9981
DENSITY, PUBLISHED:	0.8649	0.9980
RPD:	0.03	0.01
VISCOSITY, MEASURED:		1.00
VISCOSITY, PUBLISHED:		0.977
RPD:		2.76
CVS Lot #: 13401		CVS = Certified Viscosity Standard

PTS File No: 44281
Client: ARCADIS
Report Date: 05/27/14

PTS Laboratories

INTERFACIAL / SURFACE TENSION DATA

(METHODOLOGY: DuNuoy Method - ASTM D971)

Project Name: PacifiCorp Astoria
Project No: PO10006.0002.00001

PHASE PAIR		TEMPERATURE,	INTERFACIAL TENSION,
SAMPLE ID / PHASE	SAMPLE ID / PHASE	°F	Dynes/centimeter
MW-12-W / Water	Air	55	70.3
MW-12-NAPL / NAPL	Air	55	32.6
MW-12-W / Water	MW-12-NAPL / NAPL	55	16.0

QUALITY CONTROL DATA

Date: 05/23/14
PHASE PAIR: DIWATER / AIR
TEMPERATURE, °F: 74
IFT, MEASURED: 69.9
IFT, PUBLISHED: 72.2
RPD: -3.21

PTS Laboratories, Inc.

CHAIN OF CUSTODY RECORD

PAGE 1 OF 1

COMPANY: ARCADIS U.S. Inc.

ADDRESS / CITY / ZIP CODE: 111 SW Columbia St., Ste. 670, Portland, OR 97201

PROJECT MANAGER Brooke Bonkoski

PROJECT NAME: PacifiCorp Astoria — PHONE NUMBER: 503.220.8201 x1105

PROJECT NUMBER: PO10006.0001.00001 — FAX NUMBER: 503.220.8209

SITE LOCATION: 256 Marine Drive, Astoria, Oregon

SAMPLER SIGNATURE

ANALYSIS REQUEST

SAMPLE ID NUMBER	DATE	TIME	DEPTH, FT	NUMBER OF SAMPLES	SOIL PROPERTIES PACKAGE	HYDRAULIC CONDUCTIVITY PACKAGE	PORE FLUID SATURATIONS PACKAGE	TCEQ/TNRCC PROPERTIES PACKAGE	CAPILLARITY PACKAGE	FLUID PROPERTIES PACKAGE	PHOTOLOG: CORE PHOTOGRAPHY	MOISTURE CONTENT, ASTM D2216	POROSITY: TOTAL, API RP40	POROSITY: EFFECTIVE, ASTM D425M	SPECIFIC GRAVITY, ASTM D854	BULK DENSITY (DRY), API RP40 or ASTM D2937	AIR PERMEABILITY, API RP40	HYDRAULIC CONDUCTIVITY, EPA9100, API RP40, D5084	GRAIN SIZE DISTRIBUTION, ASTM D422/4464M	TOC: WALKLEY-BLACK	ATTERBERG LIMITS, ASTM D4318	Interfacial Tension Oil-water, air-water, oil-air			COMMENTS
MW-12-NAPL	5/7/14		—	1																		X			Run IFT pairs at 55 degrees F
MW-12-W	5/7/14		—	1																		X			Run IFT pairs at 55 degrees F

PO#

TURNAROUND TIME: 24 HOURS ☐ 48 HOURS ☐ 72 HOURS ☐ 5 DAYS ☐ NORMAL ☒

OTHER: ______

SAMPLE INTEGRITY (CHECK): INTACT X ON ICE 71 °F

PTS QUOTE NO.

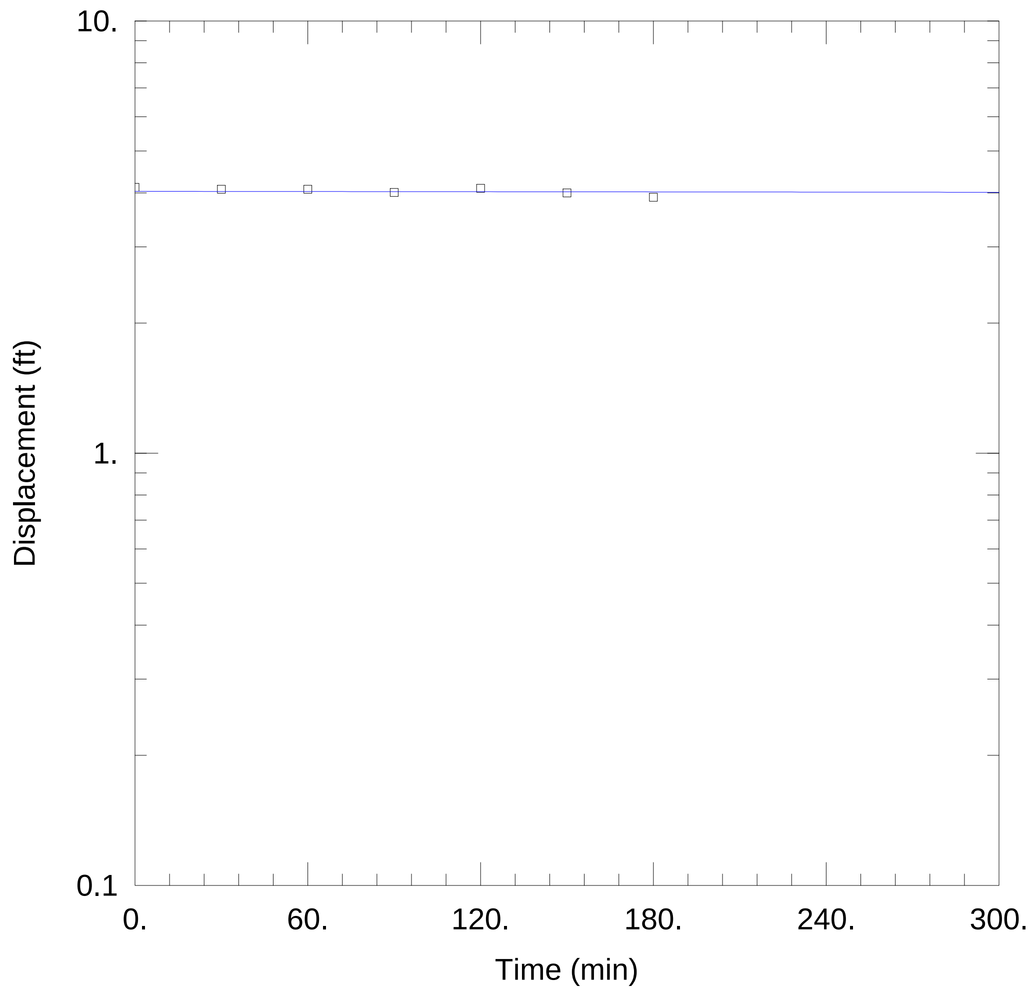
PTS FILE: 44281

1. RELINQUISHED BY	2. RECEIVED BY	3. RELINQUISHED BY	4. RECEIVED BY
[signature]	FedEx		[signature]
COMPANY ARCADIS	COMPANY ↓	COMPANY	COMPANY PTS LABS
DATE 5/9/14 TIME 1200	DATE 5/9/14 TIME 1200	DATE TIME	DATE 5/12/14 TIME 14:04

ARCADIS

Appendix E

AQTESOLV™ Solutions for MW-12
Pilot Test Results



MW-12 BAIL-DOWN TEST PHASE I

Data Set: C:\Users\tnelson\Desktop\Dashbaords\MW-12LZ (BR).aqt
Date: 08/11/14 Time: 19:19:39

PROJECT INFORMATION

Company: ARCADIS
Location: Astoria, Oregon
Test Well: MW-12
Test Date: 3-18-14

AQUIFER DATA

Saturated Thickness: 4.12 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (MW-12)

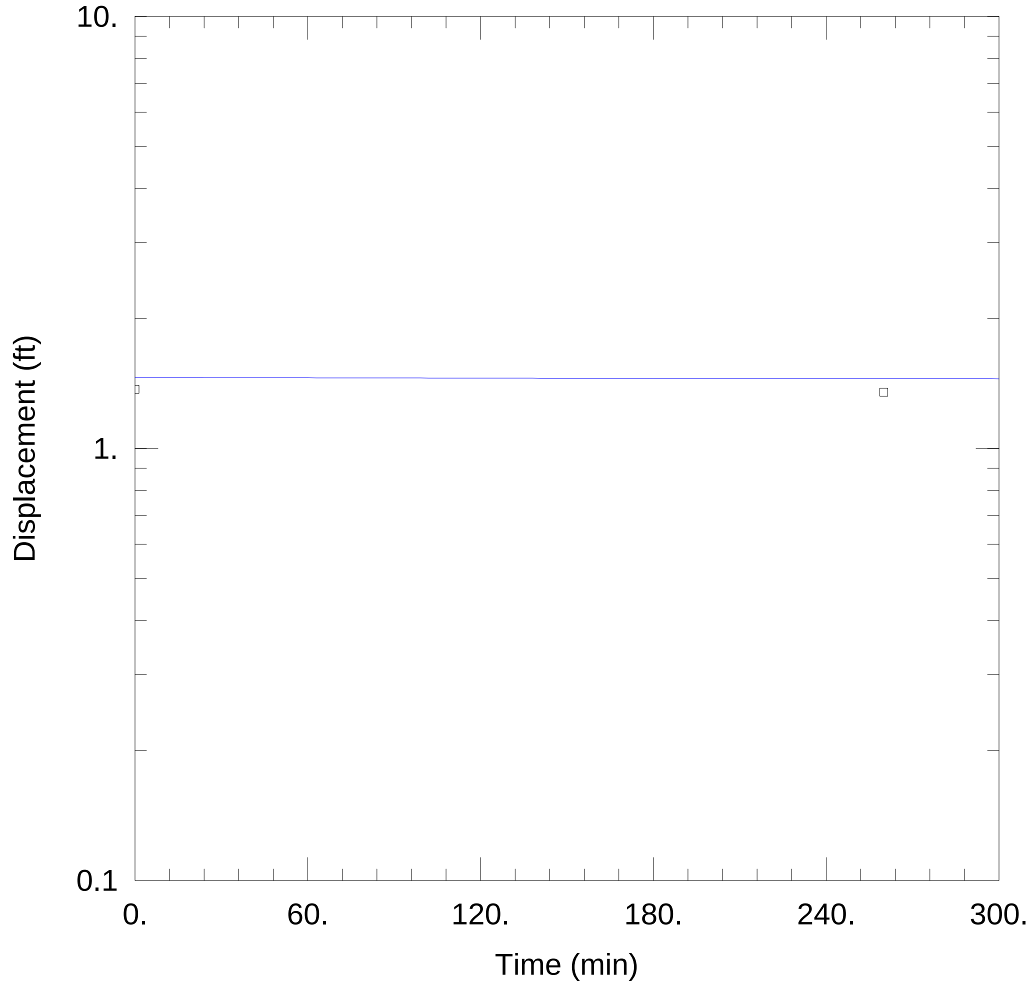
Initial Displacement: 4.12 ft
Total Well Penetration Depth: 4.12 ft
Casing Radius: 0.167 ft

Static Water Column Height: 4.12 ft
Screen Length: 4.12 ft
Well Radius: 0.375 ft
Gravel Pack Porosity: 0.3

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 0.0003047 ft/day y0 = 4.034 ft



MW-12 BAIL-DOWN TEST PHASE 2

Data Set: C:\Users\tnelson\Desktop\Dashbaords\MW-12LZ (BR)P2.aqt
Date: 08/11/14 Time: 19:20:08

PROJECT INFORMATION

Company: ARCADIS
Location: Astoria, Oregon
Test Well: MW-12
Test Date: 5-8-14

AQUIFER DATA

Saturated Thickness: 1.37 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (MW-12)

Initial Displacement: 1.37 ft
Total Well Penetration Depth: 1.37 ft
Casing Radius: 0.167 ft
Static Water Column Height: 1.37 ft
Screen Length: 1.37 ft
Well Radius: 0.375 ft
Gravel Pack Porosity: 0.3

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

K = 0.0006726 ft/day
y0 = 1.459 ft

Appendix F

Brooks and Corey Critical Thickness Calculations

MW-12				INPUT/SOURCE
Surface Tension	σ_{aw}	70.3	dyne/cm	MW-12 Fluid Properties
Air-LNAPL Interfacial Tension	σ_{ao}	32.6	dyne/cm	MW-12 Fluid Properties
LNAPL-Water Interfacial Tension	σ_{ow}	16	dyne/cm	MW-12 Fluid Properties
Density Ratio (LNAPL/Water)	ρ_r	0.968	dimensionless	MW-12 Fluid Properties

MW-12				INPUT/SOURCE
Surface Tension	σ_{aw}	70.3	dyne/cm	MW-12 Fluid Properties
Air-LNAPL Interfacial Tension	σ_{ao}	32.6	dyne/cm	MW-12 Fluid Properties
LNAPL-Water Interfacial Tension	σ_{ow}	16	dyne/cm	MW-12 Fluid Properties
Density Ratio (LNAPL/Water)	ρ_r	0.968	dimensionless	MW-12 Fluid Properties

Brooks and Corey Pore-Entry Pressure Calculation

$$b_{n[crit]} = \left(\frac{\sigma_{nw}}{(1-\rho_r)\sigma_{aw}} - \frac{\sigma_{an}}{\rho_r \sigma_{aw}} \right) h_d$$

API 4760 Equation: 3.25
Report Equation: 4

MW-26A				**INPUT/SOURCE**
Surface Tension	σ_{aw}	70.3	dyne/cm	MW-12 Fluid Properties
Air-LNAPL Interfacial Tension	σ_{ao}	32.6	dyne/cm	MW-12 Fluid Properties
LNAPL-Water Interfacial Tension	σ_{ow}	16	dyne/cm	MW-12 Fluid Properties
Density Ratio (LNAPL/Water)	ρ_r	0.968	dimensionless	MW-12 Fluid Properties
Displacement Pressure Head	h_d	6.37	(cm H_2O)	Site 107
Critical LNAPL Thickness	b_o	42.25	(cm LNAPL)	Uses equation and data above.
Critical LNAPL Thickness	b_o	**1.386**	(ft LNAPL)	Unit conversion

Abbreviations:
API = American Petroleum Institute
$b_{n(crit)}$ = critical LNAPL thickness
cm = centimeters
ft = feet
h_d = displacement pressure head
LNAPL = light non-aqueous phase liquid
RETC = Retention Curve Program
σ_{aw} = surface tension
σ_{an} = air-LNAPL interfacial tension
σ_{nw} = LNAPL-water interfacial tension
ρ_r = LNAPL-water density ratio

Brooks and Corey Pore-Entry Pressure Calculation

$$b_{n[crit]} = \left(\frac{\sigma_{nw}}{(1-\rho_r)\sigma_{aw}} - \frac{\sigma_{an}}{\rho_r \sigma_{aw}} \right) h_d$$

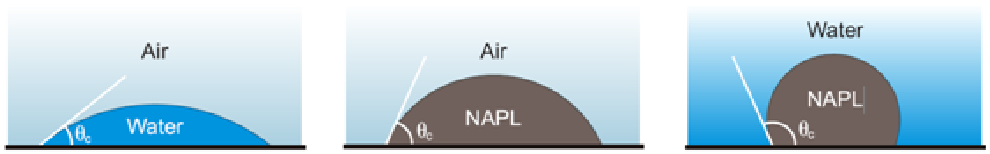
API 4760 Equation: 3.25
Report Equation: 4

MW-26A				INPUT/SOURCE
Surface Tension	σ_{aw}	70.3	dyne/cm	MW-12 Fluid Properties
Air-LNAPL Interfacial Tension	σ_{ao}	32.6	dyne/cm	MW-12 Fluid Properties
LNAPL-Water Interfacial Tension	σ_{ow}	16	dyne/cm	MW-12 Fluid Properties
Density Ratio (LNAPL/Water)	ρ_r	0.968	dimensionless	MW-12 Fluid Properties
Displacement Pressure Head	h_d	7.96	(cm H_2O)	Site 107
Critical LNAPL Thickness	b_o	52.80	(cm LNAPL)	Uses equation and data above.
Critical LNAPL Thickness	b_o	**1.732**	(ft LNAPL)	Unit conversion

Abbreviations:
API = American Petroleum Institute
$b_{n(crit)}$ = critical LNAPL thickness
cm = centimeters
ft = feet
h_d = displacement pressure head
LNAPL = light non-aqueous phase liquid
RETC = Retention Curve Program
σ_{aw} = surface tension
σ_{an} = air-LNAPL interfacial tension
σ_{nw} = LNAPL-water interfacial tension
ρ_r = LNAPL-water density ratio

For immiscible liquids such as LNAPLs, the molecular forces at interfaces between fluids are of critical importance. Since forces are unbalanced, there is a tendency for molecules to move away from the surface and the surface [GWL1]to curve. The tension that arises between two phases when a fluid is in contact with its own vapour is called *surface tension*, while when a liquid is in contact with a different fluid, ~~be it~~ gas or liquid, the resulting tension is called *interfacial tension*.

Wettability between different phases is ~~characterised~~ characterized by the contact angle, θ_c, at the interface between the solid phase and fluids. The phase with the smaller contact angle preferentially covers the surface, and is called the wetting phase. Different conditions of wettability are shown below. The typical wettability sequence observed for LNAPL within soils is water, followed by NAPL and then air, with water being the most wetting phase and air being the least wetting phase.



Wettability and Contact Angle

The pressure difference between two phases is called the *capillary pressure*, which depends on the interfacial energy or tension between the LNAPL and water (σ)[GWL2], ~~contact angle (θ_c)~~, and mean radius of curvature (r), approximated by the radius of the pores. For the LNAPL-water interface, the capillary pressure (P_{cow}) that must be overcome for a non-wetting NAPL to enter water-saturated media is called the *displacement entry pressure* (Mercer and Cohen, 1990) and may be calculated using the Young-Laplace equation, as follows (API, 2007):

$$P_{cow} = P_o - P_w = 2\,\sigma_{ow} \cos\theta_c / r$$

where P_o is the non-wetting (LNAPL) phase and P_w is the wetting (water) phase. The subscript "o" is used to denote oil (*i.e.*, LNAPL). If atmospheric pressure is taken as the reference level, then the capillary pressure head required to balance the upward buoyant force of LNAPL may be calculated, as follows:

$$h_{cow} = P_{cow} / (\rho_w - \rho_o)\, g$$

where ρ_w and ρ_o are the density of water and LNAPL, and "g" is the gravitational constant. The capillary pressure decreases as the radius of the pores increases and/or as the interfacial tension decreases. The interfacial tension is primarily a function of the fluid, temperature and the presence of surface-active agents (*e.g.*, surfactants in LNAPL lower the interfacial tension). These theoretical concepts have significant practical implications for LNAPL mobility, as subsequently described in this guidance.

3.3. Displacement Pressure Model

A LNAPL plume present near the water table (*i.e.*, where LNAPL is the non-wetting fluid with respect to water) will only migrate laterally into saturated soil pores if the capillary displacement pore entry pressure is exceeded. The Brooks-Corey air-water displacement head model ("bubbling pressure") may, through the application of appropriate scaling parameters, be converted to an LNAPL displacement head. If the thickness of LNAPL in the well is greater than the LNAPL displacement head, the free-phase LNAPL is potentially mobile (Lefebvre and Boutin, 2000; API, 2007). In wells near the periphery of the plume, where the LNAPL is not as thick as the displacement head, LNAPL cannot move laterally into pristine areas.

The displacement head ($\Delta\Psi$) is estimated based on theory developed by Parker and Lenhard (1989) and Charbeneau and Chiang (1995), as follows:

$$\Delta\Psi = \Psi_{bow} - \Psi_{boa} \qquad [5.1]$$

$$\Psi_{boa} = \frac{\Psi_{baw}\,\sigma_{ao}}{\rho_r\,\sigma_{aw}} \qquad [5.2]$$

$$\Psi_{bow} = \frac{\Psi_{baw}\,\sigma_{ow}}{(1-\rho_r)\,\sigma_{aw}} \qquad [5.3]$$

where: Ψ_{boa} is the LNAPL-air displacement head (m)
Ψ_{bow} is the LNAPL-water displacement head (m)
Ψ_{baw} is the air-water displacement head (bubbling pressure) (m)

The inputs are the Brooks-Corey air-water displacement head (bubbling pressure) and physical properties of the LNAPL and water. The Brooks-Corey air-water displacement head may be obtained through:

(i) "Look-up" or "default" value based on soil textural class.

(ii) "Data mining" through comparison of the measured grain size (or other relevant soil property such as hydraulic conductivity) to a database with soil property and water retention data (*e.g.*, API Parameter Database, SoilVision database).

(iii) Estimated from the measured grain size or the proportions of sand, silt and clay.

(iv) Estimated from water retention tests through a fitting procedure.

An alternate, but less desirable method is estimation of the van Genuchten alpha from the air-water displacement head. For large capillary heads, Ψ_{baw} is approximately equal to $1/\alpha$. However, a model developed by Dr. Randall Charbeneau, API (1999) indicates that the Lenhard equation is a more accurate method of estimating air-water displacement head for a broader range of water contents (see details in Appendix IV).

The Brooks-Corey displacement pressure model is a reasonable conceptual construct for potential mobility. However, it is a finite approximation that, by virtue of its definition, will tend to over-estimate the actual displacement head needed for mobility. It is also important to recognize that it is a model for LNAPL displacement of saturated, or nearly saturated, soil pores. Above the capillary fringe, the water content decreases and LNAPL is much more readily able to enter air-filled pores. While potentially a non-conservative model for mobility, it is nevertheless considered a useful assessment tool when interpreted in the context of other model results using a multiple lines-of-evidence approach. This method may also be used to provide insight on the approximate relative thickness of LNAPL that would indicate potential mobility for different soil types.