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Cleanup Action Plan
January 2012


BP West Coast Products, LLC

Cleanup Action Plan


ARCO Facility No. 01835
4812 196th Street
Lynnwood, Washington 98087

January 2012

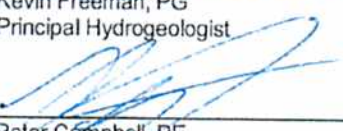
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Cleanup Action Plan

ARCO #01835
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Lynnwood, Washington 98087

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Acronyms and Abbreviations

ARCADIS	ARCADIS U.S., Inc.
AS	air sparge
bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene, and xylenes
cm/s	centimeters per second
CAP	Cleanup Action Plan
CL	Cleanup Level
COC	constituents of concern
Delta	Delta Environmental Consultants, Inc.
ft/ft	feet per foot
gpm	gallons per minute
GRO	gasoline range organics
LNAPL	Light Nonaqueous Phase Liquid
msl	mean sea level
µg/L	micrograms per liter
mg/kg	milligrams per kilogram
MTBE	methyl tertiary-butyl ether
MTCA	Model Toxics Control Act
NWTPH	Northwest Total Petroleum Hydrocarbon
ppm	parts per million
PVC	polyvinyl chloride
lbs	pounds
SVE	soil vapor extraction

1. Introduction

ARCADIS U.S. Inc. (ARCADIS) has prepared this Cleanup Action Plan (CAP) for the former ARCO Facility No. 01835 located at 4812 196th Street in Lynnwood, Washington 98087 (the site). The site and surrounding area are shown on **Figure 1**. This CAP summarizes the remedial strategy and proposed activities for Soil Vapor Extraction, magnesium sulfate (Epsom salt) injection and performance monitoring.

2. Background

The site is an active AM/PM gasoline fueling station and convenience store located on the Southeast corner of 196th St SW and 48th Ave W. An aerial photo of the site is shown on **Figure 2**. Site features include a convenience store building, canopy, nine dispenser islands, three underground storage tanks (USTs), and associated fueling system components. UST's are located in the north-central portion of the property and the dispenser islands are located directly south of the USTs. The surface of the site is asphalt and concrete pavement with landscaped areas around the perimeter. A site plan depicting site features is shown on **Figure 3**.

2.1 Site Vicinity

The site is located at 4812 196th Street in Lynnwood, Washington. The site is bounded by 196th Street SW to the north, retail businesses to the east, 48th Avenue West to the east, and a residential apartment complex to the south and southwest. Local topography slopes slightly to the southwest. The approximate elevation of the site is between 366 and 385 ft above mean sea level (msl).

2.2 Regional and Site-specific Settings

2.2.1 Regional Geology and Hydrogeology

The site is located in the Puget Sound Lowland, bound by the North Cascade Mountains to the east, South Cascade Mountains to the south, and Puget Sound and Olympic Mountains to the west. Continental glaciers advanced into the region several times during the Pleistocene Epoch (between 2 million and 10,000 years ago). This part of the Cordilleran ice sheet is known as the Puget Lobe. The most recent period of glaciation, the Vashon Stade, began about 15,000 years ago. As the climate cooled during the Vashon Stade, the continental ice sheet in Canada expanded, and the Puget Lobe slowly advanced southward into western Snohomish County and beyond.

The ice of this Vashon Glacier blanketed the entire Puget Sound Basin before halting and retreating (Thomas 1997).

As the Vashon Glacier advanced southward, streams and melting ice in front of the glacier deposited sediments throughout the Puget Sound Lowland. As the glacier continued its advance, it overrode these advance outwash deposits and covered them with glacial till. This till, also known as hardpan, consists of reworked older deposits and rocks scoured by the bottom and sides of the advancing glacier. Because of the pressure of thousands of feet of overlying ice, the till is very compact and cemented in some areas, with a texture much like concrete. However, there also are areas where the till was subjected to the influence of sub-glacial water during deposition, resulting in local deposits of fine- and coarse-grained sediments. About 13,500 years ago, the climate began to warm and the Vashon Glacier started to retreat. During this retreat, recessional outwash sediments were deposited, filling in discontinuous depressions and channels in front of the glacier. Subsequent to the deposition of glacial sediments, alluvial sediments of Holocene age (10,000 years ago to the present) were deposited. These are predominantly fluvial deposits of sand and gravel in stream and river valleys. During the same time, bog, marsh, and peat deposits were formed in small low-lying and poorly drained areas (Thomas 1997).

As a result of the glacial and fluvial activity and erosion during the Pleistocene Epoch, the study area is underlain by unconsolidated sediments of both glacial and non-glacial origin. Beneath these deposits are consolidated Tertiary rocks. The thickness of the entire assemblage of unconsolidated deposits varies considerably, but averages about 500 feet thick, with a maximum thickness of more than 1,200 feet. The deposits are thickest in western Snohomish County and are thinner to the east where the Tertiary bedrock is at or near land surface (Thomas 1997).

The site is located within the Puget-Willamette Trough Regional Aquifer System, which is a linear elongated basin stretching from the Canadian border in Washington to central Oregon. Specifically, the site is situated on Pleistocene-age Vashon Formation till deposits (Vashon Till). Vashon Till typically consists of compact, unsorted sand, gravel, and boulders in a matrix of silt and clay with some lenses of sand and gravel. The Vashon Till typically acts as confining unit within the formation, but can yield usable amounts of water from thin lenses of sand and gravel.

2.2.2 Site Geology

Soil types encountered during drilling and excavation consisted of compacted beds of very dense till interbedded with sands, silts and gravels with occasional lacustrine deposits to an explored depth of 30 feet below ground surface (bgs). There is fill at the north end of the site underlain by poorly graded sand in turn underlain by well graded sand and silt with well graded sand at boring depths. Soil borings are presented in **Appendix A**.

2.2.3 Regional Groundwater Depth and Flow

Based on observed surface topography in the vicinity of the site, groundwater would be expected to flow generally south. This is consistent with general trends observed during historical groundwater monitoring events at the site. Groundwater was encountered in previous borings at depths ranging from approximately 1 to 18 feet bgs. A rose diagram is present on **Figure 4**.

2.2.4 Specific Semi-annual Gauging Data

Measured depth to groundwater at the site ranged from approximately 2 to 115 feet bgs during the latest groundwater gauging event on September 27, 2011. The site topography slopes to the southwest where groundwater is measured at the shallowest point (MW-11 and MW-12). Groundwater gradient direction is southwest at an average gradient of 0.039 feet per foot (ft/ ft). Historically, groundwater depths at the site range from 1 to 18 feet bgs. Average gradients were taken from 2001 to present range between 0.01 and 0.05 ft/ ft, with flow directions predominantly south.

2.3 Site Clean-Up Levels

The Washington State Department of Ecology issued or approved site specific clean-up levels under the Model Toxics Control Act (MTCA) Method A clean up regulations. Method A Cleanup Levels (CLs) have been established for groundwater and drinking water beneficial use, soil for unrestricted land use and industrial properties. Residual and dissolved phase constituents of concern (COCs) detected at the site above MTCA Method A CULs are as follows:

- Gasoline Range Organics in soil and groundwater
- Benzene in soil and groundwater
- Toluene in soil and groundwater

- Ethylbenzene in soil and groundwater
- Xylenes in soil and groundwater

Additional guidance used to compare residual and dissolved phase concentrations of COCs with clean up criteria is from the Washington State Department of Ecology Model Toxics Control Act Cleanup Regulation Method A Cleanup Levels (MTCA Chapter 173-340). Hazardous substances cleanup levels are based on the Ecology established Method A Cleanup Levels (Table 720-1, Table 740-1).

Groundwater

Constituent	Clean-up Criteria (µg/L)
GRO	800 / 1,000
Benzene	5
Toluene	1000
Ethylbenzene	700
Total Xylenes	1,000

Soils

Constituent	Clean-up Criteria (mg/kg)
GRO	100 / 30 ¹
Benzene	0.03
Toluene	7
Ethylbenzene	6
Total Xylenes	9

Clean-up Criteria based on Washington State MTCA Method A Clean up Levels for Soils and groundwater (MTCA Cleanup Regulation 173-340).

µg/L = micrograms per liter.

mg/kg = milligrams per kilogram.

¹ Method A Cleanup Levels for GRO are determined based on the presence of benzene.

2.4 Site History

In December 1988, Brown & Caldwell conducted environmental oversight during the removal of three underground storage tanks (USTs) and the associated product piping formerly located south of the existing pump islands. Approximately 1000 cubic yards of petroleum hydrocarbon-impacted soil was removed from the excavation and a total of 20 soil samples were collected from the UST excavation, pipeline trench and stockpile. Brown & Caldwell reported that all petroleum hydrocarbon impacted soil that exceeded the 1988 Washington State Department of Ecology cleanup guidelines was removed with the exception of the southern end of the western pipeline trench located just north of W-1R. The report indicated that petroleum hydrocarbon related impacts in soil were not found below a depth of 18 feet bgs.

In August 1989, Brown & Caldwell directed the installation of three soil borings which were subsequently converted to groundwater monitoring wells (W-1 through W-3) near the former UST system to depths of approximately 23 to 30 feet bgs. One soil sample and one groundwater sample were collected from each boring. Laboratory results indicated that soil sample concentrations did not exceed Method A CLs.

In December 1994, EMCON Northwest, Inc. (EMCON) directed the installation of three soil borings which were converted to groundwater monitoring wells (MW-4 through MW-6) near the southern property boundary to a total depth ranging from 24.5 ft to 26.5 feet bgs. The investigation was initiated based on the analytical results from quarterly groundwater samples collected from August 1992 to May 1994. Groundwater analytical results from the subsurface investigation indicated detectable concentrations of petroleum hydrocarbon-related compounds in MW-1, MW-2, and MW-4. Soil samples were taken but not analyzed for petroleum hydrocarbon-related compounds for an unspecified reason.

In August 2001, 1.5 feet of light non aqueous phase liquids (LNAPL) were measured in monitoring well W-1. The source of the LNAPL was determined to be from a malfunctioning filter on two former fuel dispensers. In September 2001, Delta Environmental Consultants Inc. (Delta) directed the installation of three groundwater monitoring wells (MW-7, MW-8, and MW-9 on-site) to a depth of 25 ft. LNAPL was not detected in these new monitoring wells. The laboratory analytical results associated with the soil samples indicated benzene concentrations in excess of MTCA Method A CULs in MW-8 at 5 and 10 feet bgs and in MW-9 at 5 feet bgs.

In April 2005, Delta completed a subsurface investigation that included advancing three groundwater monitoring wells MW-10, MW-11, and MW-12 to a depth of 30.5 feet bgs. A total of five soil samples were collected and analyzed for GRO, MTBE, and BTEX from MW-10 and MW-11. No GRO, MTBE, and BTEX were detected above laboratory detection limits.

In 2009, Evergreen Environmental Services (EES) of Mill Creek, Washington was contracted to coordinate and complete the demolition, grading and new construction of an AM/PM facility. The former ARCO 6214 station kiosk, canopy and dispenser islands were demolished and all site asphalt, concrete and structural foundations were removed from the site in preparation for site grading and new station construction. A new AM/PM convenience store building was constructed in the southern quarter of the site. A new canopy was constructed in the central portion of the site and nine dispensers were installed along three refueling islands. A large storm water retention vault was also installed along the western and southern property boundaries. The AM/PM facility opened in late December 2009. Monitoring wells MW-4 and MW-5 were abandoned, six groundwater monitoring wells (MW-2, W-3, MW-7, MW-8, MW-9, and MW-10) were damaged or needed to have new monuments set due to re-grading of the site, and monitoring wells W-1 and MW-6 were destroyed during the raze and rebuild activities. A total of 35 samples were collected during the excavation.

Impacted soil was not detected in the southern portion of the site during re-grading of the storm water vault excavation and construction activities. Impacted soil above Method A CLs was identified in the area of the former dispenser islands and beneath the new dispenser canopy area. A total of 380.9 tons of soil were transported off site to Cemex for thermal treatment and disposal. Exact excavation footprints were not reported by Delta.

Replacement of monitoring well W-1 and MW-6 was conducted by Delta on February 26, 2010. The two borings were completed as monitoring wells W-1R and MW-6R at the locations shown on **Figure 3**. Four soil samples were collected and analytical results indicated concentrations were below Method A CLs for GRO, BTEX, and lead.

Quarterly groundwater monitoring began in 1992 and is ongoing. In 2002, 2006, and 2008 monitoring wells were sampled on a semi-annual basis. A summary of historical groundwater analytical results is presented in **Table 1**. Analytical results from the most recent sampling event indicate that monitoring wells MW-7, W-1R, and W-2 contain dissolved phase GRO and BTEX at concentrations above Method A CLs.

3. Site Petroleum Hydrocarbon Impacts

3.1 Soil Impacts

Historical data indicate that petroleum hydrocarbon related impacts to soil remain in-place. COC concentrations in soil were detected above method A CLs from the following soil samples:

- Soil sample MW-8-5 collected from 5 feet bgs contained a benzene concentration of 0.0666 mg/Kg.
- Soil sample MW-8-10 collected from 10 feet bgs contained a benzene concentration of 0.0347 mg/Kg.
- Soil sample MW-9-5 collected from 5 feet bgs contained a benzene concentration of 0.0377 mg/Kg.
- Soil sample FT-1-5 collected from 5 feet bgs contained benzene and total xylenes concentrations of 2.2 mg/Kg and 18 mg/Kg, respectively.

- Soil sample FT-1-8 collected 8 feet bgs contained a benzene concentration of 0.98 mg/Kg.
- Soil sample FT-2-5 collected 5 feet bgs contained GRO, benzene, toluene, and total xylenes concentrations of 360 mg/Kg, 0.61 mg/Kg, 15 mg/Kg, and 29 mg/Kg respectively.
- Soil sample FT-2-8 collected 8 feet bgs contained GRO, benzene, toluene, ethylbenzene, and total xylenes concentrations of 1700 mg/Kg, 0.48 mg/Kg, 11 mg/Kg, 27 mg/Kg, and 120 mg/Kg respectively.
- Soil sample FT-3-5 collected 5 feet bgs contained GRO, benzene, toluene, ethylbenzene, and total xylenes concentrations of 550 mg/Kg, 0.11 mg/Kg, 8.2 mg/Kg, 7.1 mg/Kg, and 58 mg/Kg respectively.
- Soil sample FT-4-5 collected 5 feet bgs contained a benzene concentration of 0.26 mg/Kg.
- Soil sample FT-4-8 collected 8 feet bgs contained a benzene concentration of 0.048 mg/Kg.
- Soil sample FT-7-8 collected 8 feet bgs contained a benzene concentration of 0.35 mg/Kg.
- Soil sample FT-9-8 collected 8 feet bgs contained a benzene concentration of 0.41 mg/Kg.
- Soil sample Line-SE contained a benzene concentration of 1,600 mg/Kg.
- Soil sample MW-6R-10.5 collected 10.5 feet bgs contained a benzene concentration of 3.4 mg/Kg.
- Soil sample MW-6R-16.5 collected 16.5 feet bgs contained a benzene concentration of 2.7 mg/Kg.

Soil sampling analytical data is summarized in **Table 2** and shown on **Figure 5**. Cross-section locations are depicted on **Figure 6**. Cross-section A-A' is shown on **Figure 7**.

3.2 Groundwater Impacts

Groundwater gauging and sampling was initiated in 1992 on a quarterly or semi-annual basis. The most recent round of groundwater sampling was on September 27, 2011. Monitoring wells MW-6R, MW-7, MW-8, MW-9, MW-10, MW-11, MW-12, W-1R, W-2, and W-3 were gauged, sampled and analyzed for GRO, BTEX, MTBE, and total lead. Monitoring wells MW-7, MW-8, MW-9, and W-1R had concentrations of GRO, benzene, toluene, total xylenes and/or MTBE above the Method A CLs. The highest concentrations were found in MW-7 and W-1R. The most recent groundwater data is present on **Figure 8**. Historical groundwater data is summarized in **Table 1**.

4. Evaluation of Remedial Alternatives

This section discusses select cleanup alternatives for groundwater and their associated feasibility for implementation at the site. For this CAP, three remedial alternatives were identified for affected soil and groundwater:

- Monitored natural attenuation (MNA)
- Active remediation using a trailer-mounted air sparge (AS) and soil vapor extraction (SVE) system to address identified soil impacts in the area of the dispenser island
- Enhanced anaerobic bioattenuation using electron acceptor solution injected/gravity fed into the groundwater plume

4.1 Alternative-1 MNA

This alternative does not involve the implementation of intrusive remedial activities to remove, treat or contain COCs at the site. Under this alternative, natural attenuation processes will reduce chemical concentrations through time and routine (semi-annual) groundwater monitoring will be performed to document changes.

Monitored natural attenuation has been defined as the reliance on natural attenuation processes (within the context of a carefully controlled and monitored site cleanup approach) to achieve site specific remediation objectives within a time frame that is reasonable compared to that offered by other, more active methods. The "natural attenuation processes" at work in such a remediation approach include a variety of physical dilution, chemical or biological processes that, under favorable conditions, act

to reduce the mass, toxicity, mobility, volume or concentration of COCs in groundwater. These in-situ processes include dilution, sorption, biodegradation, volatilization, chemical and biological stabilization, transformation or destruction of COCs.

Natural attenuation processes are typically occurring at all sites, but to varying degree of effectiveness depending on the types and concentrations of contaminants present and physical, chemical, and biological characteristics of the soil and groundwater. Natural attenuation processes may reduce the potential risk posed by site impacts in three ways:

- The contaminant may be converted to a less toxic form through destructive processes such as bioremediation or abiotic transformations.
- Potential exposure levels may be reduced by lowering concentration levels through physical processes or by dilution.
- Contaminant mobility and bioavailability may be reduced by sorption to the soil or aquifer matrix.

Monitored natural attenuation is not the preferred remedial alternative at this site due to elevated COC concentrations and a prohibitive timeframe required to achieve dissolved concentrations below Method A CLs. Based on the effectiveness of the selected remedial alternatives, MNA may be implemented following additional COC mass removal.

4.2 Alternative 2 – AS/SVE

An SVE system involves extracting air under vacuum from the vadose zone to increase vadose zone concentrations and thus degrading saturated phase COC concentrations through aerobic degradation. Soil vapor extraction removes potential residual LNAPL and sorbed phase hydrocarbons from vadose zone soil. An SVE system could be installed in the vicinity of the former USTs, and would consist of SVE wells connected to blower via manifold piping. Effluent vapors would be treated aboveground through catalytic oxidation. Components of this alternative potentially include:

- Installing a skid-mounted SVE treatment system at the site.
- Installing new trenching and subsurface piping.

- Performing system startup and operation and maintenance (O&M) activities.
- Conduct air monitoring activities to evaluate the reduction of total volatile organic compound (VOC) concentrations in the influent air to the treatment system.
- Continued air monitoring activities to evaluate the reduction of VOCs concentrations in soil and groundwater

SVE will only address vadose zone and potentially smear zone VOCs. Implementation of SVE will be in conjunction with enhanced anaerobic bio-oxidation to address dissolved phase petroleum hydrocarbon related impacts as discussed in the section below.

4.3 Alternative 3 – Enhanced Anaerobic Biodegradation

Organic carbon in the form of aromatics and ketones (i.e., GRO and BTEX constituents) can stimulate indigenous microorganisms to use available electron acceptors to facilitate microbial growth. As the indigenous ecology evolves, available electron acceptors are depleted in order of thermodynamic favorability, as follows: oxygen, nitrate, manganese, iron, sulfate and eventually carbon dioxide under methanogenic conditions. The electron acceptors are reduced through electron transport as the petroleum hydrocarbon related constituents are oxidized to benign end products (hydrogen, acetic acid and carbon dioxide) as microbes generate energy.

Typical undisturbed GRO and BTEX impacts can generate strong sulfate-reducing conditions and establish strongly reductive environments. If sulfate exists (or is supplied) in sufficient quantity to meet the stoichiometric demand of the available hydrocarbon related impacts, GRO and BTEX constituents will be destroyed naturally. This alternative involves adding electron acceptors in the form of magnesium sulfate (Epsom Salt) to enhance ongoing BTEX oxidation mechanisms induced by metabolic activity of native microorganisms.

Decreasing groundwater COC concentration trends indicate that anaerobic bio-oxidation may be occurring within the site groundwater plume. ARCADIS proposes to inject a potable water and Epsom salt solution under gravity flow to enhance anaerobic bio-oxidation of dissolved - and sorbed-phase, petroleum-related hydrocarbons.

Components of this alternative potentially include:

- Installing an electron acceptor delivery system through a network of three injection wells (IW-1 to IW-3) at and/or hydraulically upgradient from wells W-1R, W-2 and MW-7.
- Performing a baseline sampling event in select site wells to collect COC and biogeochemical data prior to injection of the electron acceptor solution. Biogeochemical parameters may include: alkalinity, nitrate, sulfate, total and dissolved iron, downhole field parameters (pH, conductivity, temperature), and sulfide (collect in the field with a field spectrometer kit).
- Performing an initial pilot study injection of electron acceptor solution and monitoring downgradient wells to confirm arrival of the solution.
- One week, one month and three months following injection, performing sampling events to evaluate the extent of biodegradation processes (i.e., occurring within site groundwater). This includes collecting biogeochemical indicator parameters, such as nitrate, total and dissolved iron, sulfate, and downhole water quality parameters.
- Performing additional electron acceptor solution injections, with volumes and target concentrations adjusted based on pilot test results.
- Initiating a quarterly monitoring program for one year following injection

Enhanced anaerobic bio-oxidation injections may be an effective method for site remediation. This approach will be used to address hydrocarbon-related impacts to groundwater seen in W-1R, W-2 and MW-7.

5. Pilot Testing

Pilot testing will involve the installation of dual purpose wells for testing the feasibility of extracting soil vapor and of injecting an electron acceptor solution of magnesium sulfate (Epsom salt). This section describes the advancement and construction of the newly installed dual purpose wells, the technical application of the selected remedial alternatives, and the scope of work for SVE and Epsom salt injection pilot testing.

5.1 Well installation

Three new dual purpose injection/vapor extraction wells will be installed for SVE and enhanced anaerobic bio-oxidation pilot testing in the following locations

- Pilot test well VE-1 will be installed approximately 5 feet east of Monitoring well W-1R
- Pilot Test well VE-2 will be installed approximately 5 feet northeast of monitoring well MW-7
- Pilot test well VE-3 will be installed approximately five feet north of W-2

5.1.1 Utility Clearance and Permitting

Prior to drilling activities, a private utility locating company will be contracted to survey the site for underground utilities. The area will be surveyed with ground penetrating radar (GPR) and magnetic locating equipment to identify utilities not included under the public locating service. The proposed injection well locations shown on **Figure 9** will be marked prior to utility mark out by Underground Service Alert and a private utility locator.

5.1.2 Well Construction

During drilling, soil samples will be collected by split spoon continuous sampling from 6.5 feet bgs to the total depth of each boring (22 feet bgs). Soil samples will be screened in the field for volatile organic compounds (VOCs) using a photo-ionization detector (PID). PID readings, soil types, and other pertinent geologic data will be recorded on the boring log.

Upon reaching the total depth of the borehole, the injection well will be installed within the annulus of the hollow-stem augers. The injection wells will be constructed of 4-inch diameter, Schedule 40 PVC with a screened interval of 0.0200 slot stainless steel wire wrapped screen. Depth to groundwater at the site is approximately between 12 and 16 feet bgs, thus the injection wells will be advanced to a depth of approximately 22 feet bgs and the screened interval will extend from 7 feet bgs to 22 feet bgs depending on soil sample classification. The sand pack of #2/12 silica sand will be placed around the well screen to a minimum of one foot above the top of screen. One foot of fine grain sugar sand will be placed above the #2/12 silica sand followed by neat cement to completion. The well will be capped with a locking water-tight well plug and a traffic-rated well box installed at grade. A well construction diagram is provided on **Figure 10**.

5.2 SVE Pilot Testing

SVE pilot testing will aid in determining the feasibility of vapor extraction within vadose zone soils to remove petroleum related hydrocarbon mass. The pilot test will determine vapor phase VOC concentrations, determine mass removal rates, aid in the layout of vapor extraction points, estimate the induced vacuum radius of influence and determine the required operational parameters for a full scale SVE system including blower size and vacuum requirements. The pilot test will involve a step test where increased vacuum and flow rates are applied to determine the optimum vacuum/flow operational parameters and a constant rate extraction test to determine remediation time frames and maximize vapor phase mass removal.

A trailer mounted SVE blower will be temporarily placed onsite within the vicinity of the three newly installed wells. The mobile trailer will be connected to a portable generator and include an SVE blower and catalytic oxidizer treatment train. A two-inch diameter flexible polyvinylchloride (PVC) vacuum hose will be connected to a temporary SVE manifold containing differential pressure gauge connected to a pilot tube for air flow measurements, a vapor sampling port, a vacuum gauge and flow control valve. Above ground hose will connect the manifold to the SVE well heads creating an airtight seal. Extracted vapor will run through a moisture separator and then treated through an electrical catalytic oxidizer prior to discharge to the air through the effluent stack.

During the pilot test, system readings including runtime, pre and post treatment flow rates, pre and post treatment VOC concentrations, process temperatures and system vacuum will be measured periodically.

5.2.1 Pilot Test Vacuum Monitoring Points

During pilot testing activities, induced vacuum will be measured on several wells to determine vacuum radius of influence and spatial distribution of vapor extraction wells for a full scale SVE system. Existing monitoring wells W-1R, W-2, W-3, MW-7, MW-9 and MW-10 will be used as vacuum monitoring points. During the step test on individual vapor extraction wells, the remaining two extraction wells will also be monitored for induced vacuum. Magnehelic differential pressure gauges will be attached to well head adaptors at each well and induced vacuum measurement will be recorded periodically throughout the pilot test.

5.2.2 SVE Pilot Test Procedures

Initial SVE testing will involve the incremental increase of extraction flow rates to determine the flow capacity of the extraction well. A target extraction rate of approximately 30 scfm is assumed due to subsurface soil conditions encountered during previous soil boring activities. The target flow rate may change based on geotechnical samples collected from the screen interval during the installation of VE-1. The target extraction rate is calculated based on a pore volume exchange rate of 3 per day as follows:

$$Q = \frac{\pi \times r^2 \times d \times n \times \epsilon}{1440 \text{ min/day}}$$

Where:

Q = flow rate in cubic feet per minute (cfm)

r = target radius of influence of 40 feet

d = is the screen interval of 10 feet

n = assumed soil porosity of 30% based on sandy soils

ε = pore volume exchange rate in volumes per day; assume 3 pore volumes per day.

Flow from the mobile SVE unit should be adjusted to pull an initial flow rate of 15 scfm or 50% of the target estimated flow rate. This flow rate should be sustained until stable readings are observed at vacuum monitoring points. Once stable readings are observed (approximately three data points), flow should be increased until the maximum sustainable flow rate and vacuum from the well is achieved. Steps should increase to 75%, 100% and 150% of the target flow rate.

During each step test, vapor extraction flow rates, influent vapor concentrations and vacuum readings will be monitored and recorded. Readings will be recorded from flow meters, vacuum gauges and sampling ports located at the manifold, the monitoring wells, the pre-treatment air stream and from the post treatment effluent stack every five minutes.

Once the maximum sustainable flow rate is achieved, a constant rate test will be performed on each vapor extraction wells for a maximum of 5 hours to determine longer term sustainability of the selected vacuum rate. During the constant rate test, vapor extraction flow rates influent vapor concentrations and vacuum readings will be recorded as proposed in the step test on a graduated basis:

Time Elapse (hours)	Frequency
0 - 0.5	5 minutes
0.5 – 1.0	10 minutes
1.0 – 2.0	15 minutes
2.0 – 5.0	30 minutes

System pretreatment vapor samples will be collected from SVE wells VE-1, VE-2, and VE-3 at the manifold sampling point using a sampling pump and tedlar bag. The initial vapor samples will be collected within the first 30 minutes of each SVE constant rate test. Additional effluent samples will be collected for lab analysis based on peak effluent PID readings and at the end of the test following stable PID readings. Vapor samples will be collected in tedlar bags and submitted to a Washington State-certified laboratory for the following chemical analyses:

- Gasoline range organics (GRO) according to Environmental Protection Agency (EPA) Method TO3
- BTEX for EPA Method TO3
- Methane, Oxygen, and Carbon Dioxide by ASTM method D 1946

Pilot test results will be presented in a pilot test summary report or system installation workplan to be submitted to the state under the Voluntary Cleanup Program. A full scale remedial system design will be developed based on the results of the pilot test.

5.3 Sulfate Application Pilot Test

The addition of Epsom salt to the aquifer in the source area will increase the bioavailable sulfate concentrations within target areas of elevated hydrocarbon related impacts and potentially stimulate the already occurring natural biodegradation. Therefore, ARCADIS is proposing a pilot test to evaluate the effectiveness of Epsom salt application to the remaining areas of elevated dissolved phase impacts using newly installed injection wells. Injections will be monitored using existing monitoring wells to determine the effectiveness of enhanced anaerobic bio-oxidation.

The pilot test study area will be confined to the newly installed dual purpose wells VE-1, VE-2 and VE-2 and existing monitoring wells on site (W-1R, W-2 and MW-7). Injection wells will be used for the delivery of the Epsom salt solution. Distribution of delivered electron acceptors via gravity injection and subsequent ambient groundwater flow will establish an anaerobic bio-oxidation reactive zone, which will provide increased sulfate concentrations to sulfate reducing bacteria which may be active in the petroleum hydrocarbon plume.

5.3.1 Technical Background

Aquifers impacted by petroleum hydrocarbons are typically anaerobic because dissolved oxygen (DO) is energetically favorable and is preferentially consumed by indigenous microbes during aerobic oxidation (i.e., biodegradation) of the petroleum hydrocarbons, which serves as an electron donor in the microbial metabolism reactions. Following the depletion of oxygen, alternative electron acceptors (i.e., nitrate, iron, manganese, sulfate, and carbon dioxide) are utilized in the continued anoxic/anaerobic oxidation of petroleum hydrocarbons. The anaerobic oxidation of petroleum hydrocarbons under various dominant electron-accepting processes (e.g., sulfate-reduction, iron-reducing, methanogenesis, etc.) is well-founded in the literature (Anderson, et al., 2000; Aronson and Howard, 1997; Beller et al., 1992; Bordon et al, 1997; Coyne and Smith, 1995; Cunningham et al, 2001; Davis et al, 1999; Schreiber et al., 2004; Wiedemeier, et al., 1999; Suthersan and Payne, 2005; and Foght, 2008). Similar to enhanced aerobic systems, engineered anaerobic approaches rely on redox couples such as nitrate reduction, ferric iron reduction, sulfate reduction, and methanogenesis to facilitate cellular respiration using the petroleum hydrocarbon as an electron donor.

Anaerobic processes generally occur at slower kinetic rates than that observed with oxygen. Non-oxygen electron acceptors (i.e. sulfate) can be advantageous to oxygen injection approaches as they are highly soluble, can be supplied at elevated dissolved concentrations, and have minimal abiotic or non-target reactions that typically limit oxygen persistence in the subsurface. The higher concentrations of sulfate that can be maintained in a petroleum hydrocarbon impacted aquifer accompanied by electron acceptor persistence allows for effective hydrocarbon degradation. Comparatively, oxygen sparging approaches are fundamentally limited by low oxygen solubility in groundwater and gas transfer inefficiencies that limit the effective dissolved oxygen concentrations typically maintained in engineered aerobic reactive zones. Thus, while the kinetic rates of anaerobic hydrocarbon bio-oxidation may be slower than under aerobic conditions, the ability to deliver elevated concentrations of non-oxygen electron

acceptors over a relatively long time period during infrequent events can be cost-effective compared to long-term operation of continuous oxygen sparging or other engineered aerobic treatment alternatives.

5.3.2 Anticipated Effects of Sulfate on Groundwater Chemistry

Short-term effects of sulfate injection on groundwater chemistry may include the following:

- Increase of sulfate concentrations to a calculated concentration of 6.2 grams per liter (g/L) prior to consumption by sulfate reducing bacteria (initially localized to the injected radius of influence)
- Increase in the population of sulfate reducing bacteria, and the reduced form of sulfate – hydrogen sulfide

Long-term effects on groundwater chemistry are expected to be minimal due to dispersion and consumption of the sulfate and the reaction's byproducts.

5.3.3 Hydraulic Conductivity Testing

Prior to pilot test activities, rising-head aquifer testing (slug testing) will be conducted on selected monitoring wells. During these tests a pressure transducer will be placed in the well to measure water level. A weighted "slug" will be placed in the well, and the water level will be allowed to recharge. Once the water level has stabilized, the slug will be removed and the groundwater level will again be allowed to stabilize. The data will be evaluated according to methods established by Bouwer and Rice (1976) or Bouwer (1989) to calculate hydraulic conductivity at the site. The hydraulic conductivity data will be used to better estimate groundwater velocity. Implementation of the remainder of the work plan will be dependent on data from these slug tests.

While sulfate has a high solubility compared to other injectable oxidants, if hydraulic conductivity measurements do not appear to support the proper volume loading into the impacted groundwater zone, sulfate application may not be the appropriate remedial solution for the site and ARCADIS will reassess remedial options for the site.

5.3.4 Well Development

Newly installed wells will be developed using a combination of surging and jetting techniques. Development through jetting introduces high velocity water into the well

screen through a small diameter tube equipped with nozzles. Injected water is purged, effectively keeping the in-well water level equal to the static water level. The well will initially be brushed with a stainless steel 4-inch brush and surged to remove fines by moving the brush the length of the saturated screen. The well will be purged using a bailer following brushing to remove fines. The well will then be jetted following the ARCADIS standard operating procedure. Storage of well development purge water is discussed below under the IDW Management Section. Details describing well jetting are attached in the Well Development-Water Jetting Standard Operating Procedure included as **Appendix B**. Previously constructed well specifications are shown in **Table 3**.

5.3.5 Management of Investigation Derived Waste

Soil cuttings and decontamination water generated during the field activities will be contained in Department of Transportation-approved 55-gallon steel drums. These drums will be appropriately labeled and temporarily stored on-site pending analytical results. Upon receipt of soil analytical results, the drums will be removed from the site and transported to an off-site disposal facility.

5.4 Baseline Groundwater Monitoring

Prior to injection, baseline analytical and biogeochemical data will be collected from select wells inside and outside the plume. The wells to be sampled are as follows:

- upgradient/cross-gradient well – MW-9, MW-10
- petroleum hydrocarbon impacted wells – W-1R, MW-7, W-2
- downgradient wells MW-6R and MW-12

Groundwater samples will be submitted to a Washington state-certified laboratory, for analysis. Chain of custody procedures will be followed from the time the samples are collected until the time the samples are relinquished to the laboratory. The above mentioned monitoring wells along with the newly installed injection wells will be sampled and analyzed for the following:

- GRO by Northwest Method NWTPH-Gx
- BTEX and methyl tertiary butyl ether (MTBE) by EPA method 8260B

- total lead by EPA method 6010

In addition, these wells will be sampled and analyzed for the following biogeochemical parameters:

- total Alkalinity by EPA method 310.1
- sulfate by EPA method 300.0
- sulfide by SM Method 4500-S²⁻F
- total and dissolved iron by EPA method 6010
- methane by method RSK 175
- nitrite/nitrate by EPA method 353.2

Measurements of field parameters including conductivity, pH, and temperature will be collected with a downhole multiparameter meter. If possible, baseline groundwater monitoring will be conducted in conjunction with standard semi-annual groundwater monitoring activities. Groundwater monitoring associated with the sulfate application pilot test will be conducted using three well casing volume purge methodologies. A sampling matrix with the proposed baseline, injection and performance sampling plan is summarized in **Table 4**.

5.5 Sulfate Injection

5.5.1 Injection Setup

Each injection well will be temporarily connected aboveground by 1-inch diameter hose to a distribution manifold staged inside an injection trailer. The manifold will include flow control valves and flow meters to adjust the application rate and quantify injection volumes. Water will be supplied to the trailer via flexible PVC hose and camlock fittings leading to a temporary onsite water tank. Batch mixtures of Epsom salt will be dissolved into four 274 gallon mixing tanks. A 0.5 hp electric trash pump will continually operate to mix the dissolved Epsom salt solution with potable water within the injection trailer. Once the tanks are adequately mixed the Epsom salt solution will be gravity fed simultaneously into the injection wells. ARCADIS personnel will be on-

site to execute the injection process and record injection parameters throughout the event. Well head pressure will be closely monitored to ensure no measurable pressure is allowed to build up, potentially causing soil to fracture and create a preferential pathway to the surface. Breakthrough monitoring activities at dose response wells W-1R, W-2 and MW-7 will be conducted. Dose response wells are situated within the target radius of influence (ROI) of the proposed injection wells. Additional downgradient monitoring of wells MW-8, MW-9, MW-10, W-2, and W-3 will be performed periodically following the injection.

5.5.2 Estimated Injection Volumes

Arrangements will be made to use the on-site water source; however, if the on-site water source is not adequate for the large volumes of injection solution required, an off-site water source will be used. Approximately 12,690 gallons of potable water per injection event will be used to dissolve approximately 3,364 pounds (lbs) of solid Epsom Salt. A target injection concentration of approximately 31.8 g/L of magnesium sulfate will be injected into each well. The target in-situ sulfate concentration is 6.2 g/L assuming a groundwater dilution factor of approximately 2 along the flow path from the injection wells to the dose response monitoring well. This target concentration is based on oxidation stoichiometry and estimated quantities of dissolved phase petroleum hydrocarbons. Stoichiometric equations and estimations are summarized in **Table 5**.

Injection volumes are based on the following equation: target 15-foot ROI per well over 10 feet of vertical well screen and an estimated 8% mobile porosity, which results in an approximate injection volume of 12,689 gallons per event.

$$V_{ing} = \pi * ROI^2 * h * \theta_m * 7.48 \frac{\text{gallons}}{\text{ft}^3} * \text{no. wells}$$

Where:

V_{ing} = injection volume in gallons

ROI = 15-foot target radius of influence

h = well screen length - 10 feet

θ_m = 8%

wells = 3

Injection volumes will be adjusted in the field as necessary to achieve positive confirmation of injected solution at dose response monitoring wells W-1R, W-2 and MW-7.

5.5.3 Breakthrough Monitoring

Prior to injection, a baseline conductivity and pH reading will be obtained from the injection tank, the injection wells, and dose response wells W-1R, W-2 and MW-7. During injection, conductivity and pH measurements will be monitored from dose response wells and compared to baseline values. The dose response wells will be monitored following injection of the first 500 gallons of water and every 250 to 500 gallons of water injected per well thereafter. A downhole multi-parameter meter will be placed in the well and measurements will be recorded. If measurements show an increase or spike in conductivity and sustained elevated conductivity response in the dose response well, injection will cease. A spike and sustained conductivity response indicates that the Epsom salt solution has effectively reached the target radius of influence.

5.5.4 Performance Monitoring

Conductivity measurements and grab samples submitted for laboratory sulfate analysis will be taken from monitoring wells W-1R, W-2 and MW-7 one week following injection. Groundwater sampling of these wells will occur approximately one month and three months following injection and will include the analytes proposed during baseline sampling. Concentration trends of sulfate, biogeochemical parameters and COCs will be analyzed to determine the rate of sulfate reduction within the plume. If concentrations remain above CLs but reducing conditions exist and sulfate is depleted, an additional injection event may be scheduled. Based on the rate of sulfate utilization by the subsurface microbial communities, sulfate concentrations may be adjusted for subsequent injection events.

6. Health and Safety Procedures

The HASP will include methods for protection of site workers and visitors during the remedial activities and will include:

- a list of COC, their characteristics, and the potential routes of exposure;
- action levels for the various COC
- methods for field monitoring for the various COC
- emergency procedures and contact information

- air monitoring
- identification of routes to emergency facilities
- identification of potential physical hazards and response actions for specific remedial tasks
- personal protective equipment (PPE) for specific remedial tasks

PPE will generally consist of hard hats, steel-toed boots, chemical resistant gloves, ear protection, and eye protection. Respiratory protection is not anticipated, but will be available should field particulate monitoring suggest such measures are necessary.

7. Schedule

Injection wells will be installed during the first half of 2011 with injection following one week after installation. Based on sulfate utilization rates observed during groundwater monitoring, additional injections may occur. A progress report will be submitted to Ecology during the second half of 2011, summarizing results of the first injection event.

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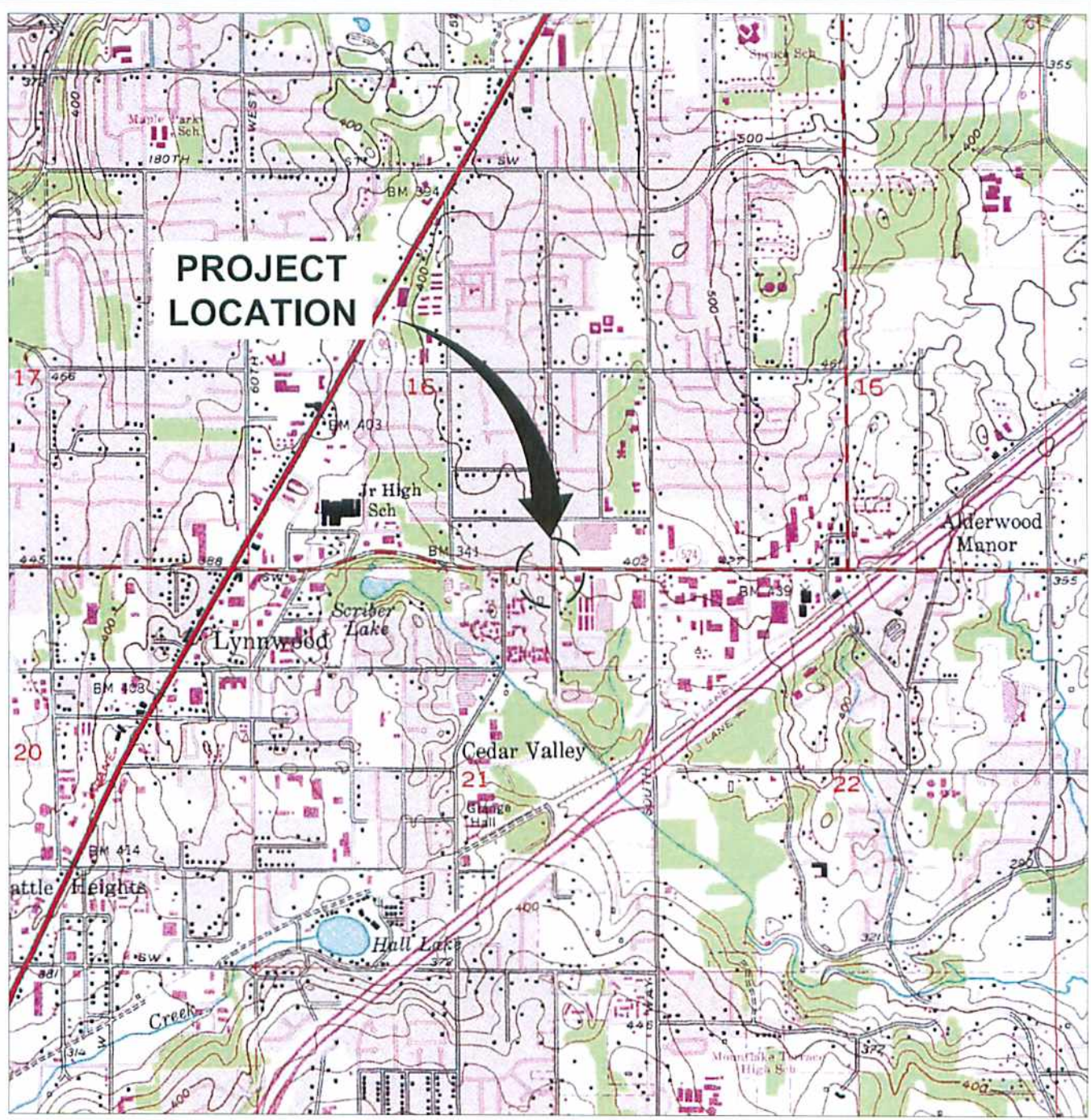
ARCADIS

Tables

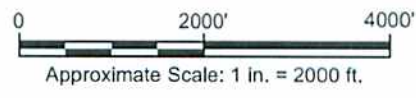
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Figures

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REFERENCE: BASE MAP USGS 7.5. MIN. TOPO. QUAD. EDMONDS EAST, WA, 1983.



ATLANTIC RICHFIELD COMPANY
FORMER ARCO STATION NO. 01835
4812 196TH STREET SOUTH WEST, LYNNWOOD, WASHINGTON
CLEANUP ACTION PLAN

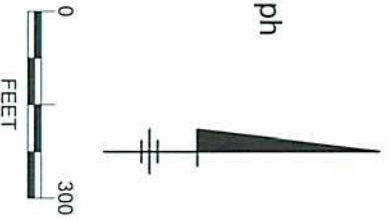
SITE LOCATION MAP



FIGURE
1



NOTE:
Aerial Photograph
Dated 2011



ATLANTIC RICHFIELD COMPANY
ARCO STATION NO. 01835
4812 196TH STREET SOUTHWEST, LYNNWOOD, WASHINGTON
CLEANUP ACTION PLAN

SITE AERIAL MAP



FIGURE
2



- APPROXIMATE PROPERTY BOUNDARY

MW-3 

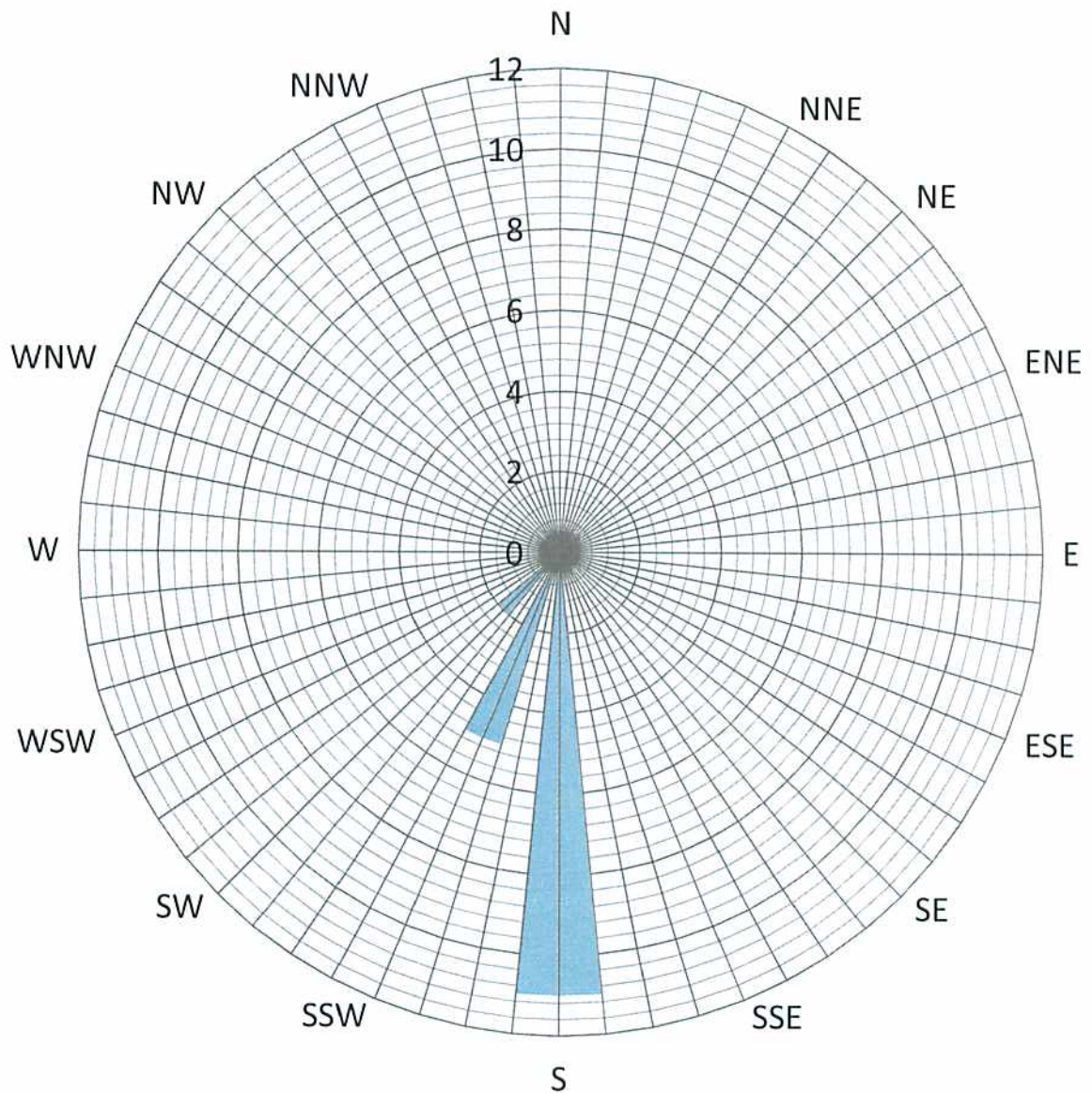


CLEANUP ACTION PLAN

SITE PLAN



FIGURE 3



■ Groundwater Flow Direction

NOTES:

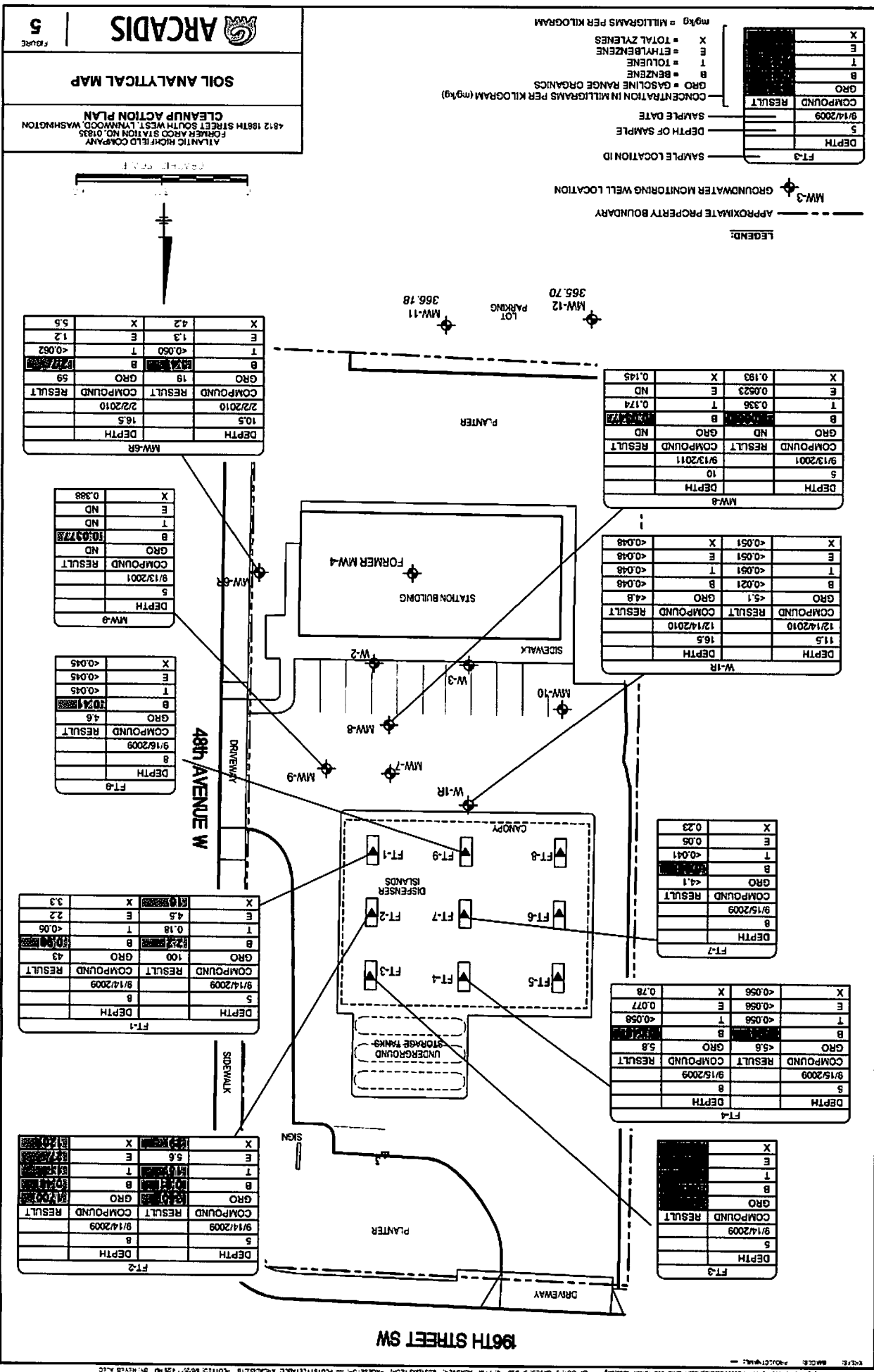
- 1 - Groundwater flow direction based on well MW-7
- 2 -
- 3 -
- 4 -
- 5 -

ATLANTIC RICHFIELD COMPANY
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CLEANUP ACTION PLAN

GROUNDWATER ROSE DIAGRAM



FIGURE
4



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SOIL ANALYTICAL MAP

CLEANUP ACTION PLAN

4812 196TH STREET SOUTH WEST, LYNNWOOD, WASHINGTON

FORMER ARCO STATION NO. 01835

ALANTIC RICHFIELD COMPANY

mg/kg = MILLIGRAMS PER KILOGRAM

X = TOTAL HYDROCARBONS

E = ETHYLENE

T = TOLUENE

B = BENZENE

GRO = GASOLINE RANGE ORGANICS

CONCENTRATION IN MILLIGRAMS PER KILOGRAM (mg/kg)

DEPTH	DEPTH OF SAMPLE	SAMPLE DATE	RESULT
5			
9/14/2009			
COMPOUND			
GRO			
B			
T			
E			
X			

MW-6R

DEPTH	DEPTH OF SAMPLE	SAMPLE DATE	RESULT
10.5			
2/2/2010			
COMPOUND			
GRO			
B			
T			
E			
X			

MW-9

DEPTH	DEPTH OF SAMPLE	SAMPLE DATE	RESULT
5			
8/13/2001			
COMPOUND			
GRO			
B			
T			
E			
X			

FT-9

DEPTH	DEPTH OF SAMPLE	SAMPLE DATE	RESULT
4.6			
9/16/2009			
COMPOUND			
GRO			
B			
T			
E			
X			

FT-1

DEPTH	DEPTH OF SAMPLE	SAMPLE DATE	RESULT
4.3			
8/14/2009			
COMPOUND			
GRO			
B			
T			
E			
X			

FT-2

DEPTH	DEPTH OF SAMPLE	SAMPLE DATE	RESULT
5			
9/14/2009			
COMPOUND			
GRO			
B			
T			
E			
X			

MW-4

DEPTH	DEPTH OF SAMPLE	SAMPLE DATE	RESULT
10			
9/13/2011			
COMPOUND			
GRO			
B			
T			
E			
X			

W-1R

DEPTH	DEPTH OF SAMPLE	SAMPLE DATE	RESULT
11.5			
12/14/2010			
COMPOUND			
GRO			
B			
T			
E			
X			

FT-7

DEPTH	DEPTH OF SAMPLE	SAMPLE DATE	RESULT
8			
9/15/2009			
COMPOUND			
GRO			
B			
T			
E			
X			

FT-4

DEPTH	DEPTH OF SAMPLE	SAMPLE DATE	RESULT
5			
9/15/2009			
COMPOUND			
GRO			
B			
T			
E			
X			

FT-3

DEPTH	DEPTH OF SAMPLE	SAMPLE DATE	RESULT
5			
9/14/2009			
COMPOUND			
GRO			
B			
T			
E			
X			

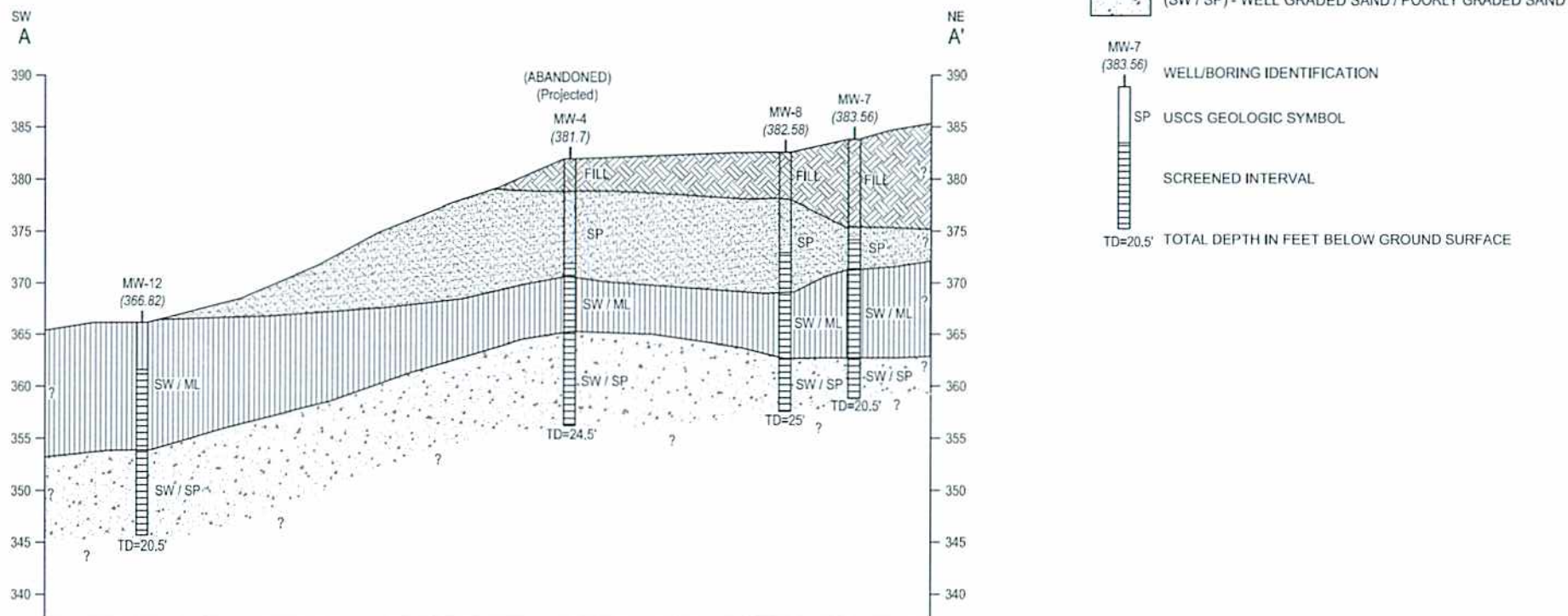


FIGURE
7