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Feasibility Study Pilot Test Workplan
Air Sparge/Soil Vapor Extraction Remediation
Boeing Field Chevron
10805 East Marginal Way South
Tukwila, WA 98168
Ecology Facility/Site No.: 2551
Agreed Order No.: DE-10947

Prepared for:

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Dear Mr. Sandhu and Mr. Hetrick:

G-Logics is pleased to present this workplan to conduct a Feasibility Pilot Study for the Boeing Field Chevron Site (Figure 1). As you know, G-Logics is working to complete a Draft Remedial Investigation report, per the Agreed Order between Mr. and Ms. Sandhu, RPNP Corporation, Chevron Environmental Management Company, and the Washington Department of Ecology. The Agreed Order requires the parties prepare a Feasibility Study to assess appropriate and feasible remediation methods. To collect information for the Feasibility Study, G-Logics recommended that a Feasibility Pilot Study be performed to assess the effectiveness of Air Sparge and Soil Vapor Extraction remedial technologies, as described in this workplan.

Should you require additional information or have any questions, please contact us at your convenience. Thank you again for this opportunity to be of service.

Sincerely,
G-Logics, Inc.

Rory L. Galloway, LG, LHG
Principal
Geologist

Dan Hatch
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1.0 INTRODUCTION AND OBJECTIVES

G-Logics has prepared this Feasibility Study Pilot Test Workplan (FSPTWP) to describe the methodology and procedures to conduct an air sparge / soil vapor extraction pilot test at the Boeing Field Chevron site (the Site), located at 10805 E. Marginal Way in Tukwila, Washington (Figure 1). The pilot test will be performed to facilitate preparation of a Feasibility Study (FS), which is required per the current Agreed Order for the Site (Agreed Order No. DE 10947).

In general, the information gathered during the course of the pilot test will be used to assess whether air sparge (AS) and soil-vapor extraction (SVE) technologies can implemented as a full-scale remedial method at the Site. The pilot test will assess these technologies in both the upper and lower saturated zones. If the pilot test is successful, the gathered information will be used for engineering and design considerations.

At this time, this pilot test is singularly focused on the application of AS/SVE technologies, but is not intended to exclude other options. Results of this pilot study also will be used to assess other possible cleanup alternatives, which will be considered in the upcoming FS report. Additional pilot studies may be recommended as part of the FS process, based on the findings of this proposed pilot test.

The specific objectives of the pilot test are to assess the following:

1. Can air effectively be extracted from the vadose zone (upper saturated zone)?
2. Can hydrocarbon contaminants be removed from the vadose zone? If so, what are the expected mass removal volumes/rate, and what specific chemical constituents are being removed.
3. Can air be injected into the upper and lower saturated zones at flowrates sufficient to result in effective hydrocarbon contaminant removal and at pressure less than formation fracture pressures?
4. Is the confining layer between the lower and upper saturated zones sufficiently transmissive to allow SVE wells (screened in the vadose zone) to remove/recover air injected into the lower-saturated zone?
5. Can air be injected into the lower saturated zone without creating a new soil-vapor exposure pathway?

The following primary test phases will be completed to meet the pilot study objectives:

- **Day 1: SVE Step Test** – This phase will evaluate the effects of applying SVE to vadose zone soils at the Site. This test will assess the potential vacuum radius of influence (ROI) that can be achieved, the influence of vacuum on groundwater-elevation conditions in the upper-saturated zone, potential hydrocarbon removal rates that could be achieved in vadose-zone soils, and potential preferential vapor pathways (identified via observation wells). The SVE step test is expected to require approximately one day to complete.
- **Day 2: AS/SVE Test in the upper-saturated zone –** The second will evaluate the effects of applying SVE to vadose zone soils while AS is concurrently applied within the upper-saturated zone. Specifically, this test will assess the ability to inject air into the upper-saturated zone, review the effects of the AS on the potential vacuum ROI, evaluate influence on groundwater elevation conditions in the upper-saturated zone, and assess the potential hydrocarbon removal rates (as influenced by the AS). AS/SVE testing in the upper-saturated zone is expected to require approximately one day to complete.
- **Day 3: AS/SVE Test in the lower-saturated zone** – This phase of testing will evaluate the vapor transmissivity between the lower and upper-saturated zones, which if present would allow SVE applied in the vadose zone to capture air injected into the lower-saturated zone. The execution of this phase will be similar to the Day 2 test, except that during this phase AS injections will be focused within the lower saturated zone. This lower saturated zone testing is expected to require approximately one day to complete.

Results of the pilot test will be incorporated into the pending FS, which will be used to identify a preferred cleanup alternative for the Site. If AS/SVE is included in the preferred cleanup alternative, the results of the pilot test will provide site-specific data to facilitate future design of a full-scale AS/SVE remediation system.

2.0 BACKGROUND

This pilot test is based on the results of previous environmental investigations as documented in the Draft Remedial Investigation (DRI) report prepared by G-Logics, dated November 22, 2017. The findings presented in the DRI indicate that petroleum-range hydrocarbon contaminants (predominantly gasoline-range organics (GRO) and benzene) are impacting soil, groundwater, and soil vapor at the Site.

2.1 Nature and Extent of Contamination

Contaminant impacts at the Site have been found to be greatest in the western portion of the Property (see Figures 2 and 3) and extend westward into the adjoining City of Tukwila right-of-way. The DRI data indicate that GRO and benzene contaminants remain present in this area at depths ranging from approximately 5 to 18 feet below the ground surface and are present in both the upper and lower saturated zones. GRO and benzene impacts to soil and groundwater also extend west, off-Property, into the right-of-way of Tukwila International Boulevard (TIB).

G-Logics has identified two saturated zones (upper and lower), separated by a confining layer beginning at an approximate depth of 11 feet, extending to approximate depth of 17 feet. The upper-saturated zone consists of approximately 1-3 feet of saturated soils above the confining layer. Previous findings suggest that the lower-saturated zone is tidally influenced, but the upper saturated zone is not. Additionally, at high tide, the lower-saturated zone exhibits a potentiometric surface above the bottom elevation of the confining layer. Petroleum contamination has been observed in both the upper and lower-saturated zones. Light non-aqueous phase liquid (LNAPL) recently has been measured in only one well (IP-7, screened within the lower saturated zone) but has been present historically at multiple locations in the western portion of the main Property.

2.2 Remedial Technology Selection for the Pilot Test

Ecology's project manager asked G-Logics to complete a preliminary evaluation of remedial technologies likely to be considered in the Site FS. G-Logics determined that in addition to AS/SVE, potential remedial technologies to be evaluated for the Site include, but not limited to, groundwater pump-and-treat, enhanced in-situ biological remediation, in-situ chemical oxidation, and excavation and disposal. Each of these remedial technologies will be fully evaluated in the FS in addition to any other potentially applicable technologies that are identified.

Based on our preliminary evaluation of these technologies with respect to the Site conditions, G-Logics and the project proponents believe that AS/SVE could be an efficient and cost-effective remedial technology. Accordingly, this workplan presents the tasks to be performed to assess whether or not the AS/SVE technology may be viable for mitigating one more exposure pathways at the site.

3.0 INSTALLATION OF TEST WELLS

To conduct the pilot test, the following six additional wells will be installed. Several test wells will be installed in the area of greatest contaminant impacts at the Site (Figure 2). Well construction information, such as depth, screened interval, and diameter, are discussed below and illustrated on Figure 3.

- One 4-inch diameter well (SVE-1) will be installed for SVE testing, which will be used during each phase of the pilot test. This well will be screened from an approximate depth of 5 to 9 feet in the vadose zone (above the upper saturated zone).
- One 2-inch well (AS-1) will be installed for AS injection testing in the upper-saturated zone. This well will be screened from approximately 12 to 14 feet (with sump from 14 to 16 feet).
- One 2-inch well (AS-2) will be installed for AS injection into the lower-saturated zone. This well will be screened from approximately 25 to 27 feet (with sump from 27 to 30 feet).
- Three 2-inch wells (TW-1, TW-2, and TW-3) will be installed as temporary observation wells for the pilot test. These wells are intended to provide additional monitoring points in the vadose zone for measurement of subsurface conditions during each phase of the pilot test. TW-1, TW-2, and TW-3 will be screened from 5 to 9 feet, and will be located approximately 10, 20, and 50 feet from SVE-1, respectively.

Proposed well locations and well-construction details are approximate and may change based on conditions encountered in the field. As with previous drilling activities at the Site, the wells will be installed with the intent of minimizing interruption to the onsite business operations. Access to this area will be limited during well installation work, which is expected to require 2 to 3 days to complete. Planned well-installation activities are described below.

3.1 Underground Utility Clearance

Numerous subsurface utilities are present in the planned drilling areas. Before beginning fieldwork, G-Logics will contact public and private utility-locating services. Subsurface utility locations will be identified by marking their inferred location on the ground surface. Actual boring locations will be identified upon completion of the utility locate and confirmation of access availability. Additionally, at each boring location, the first five to seven feet of soils will be removed using air-knife/vacuum-extraction methods.

3.2 Soil Borings and Soil Sampling

For the planned testing, six soil borings will be drilled in areas indicated on Figures 2 and 3 using standard air-knife and direct-push drilling methods. Actual boring locations may be adjusted based on discovered site conditions. Borings will be drilled to anticipated depths of approximately 9 to 30 feet below surface grade. All boring locations will be cleared using air-knife/vacuum extraction methods. A G-Logics geologist will be present during the drilling to observe and document soil conditions.

Soil samples will be collected continuously to evaluate the nature and extent of the confining layer. Hand-auger sampling equipment also will be used within the first five to seven feet of each boring where air-knife drilling will occur. Soils will be field screened for odors, soil staining, and/or discoloration. Samples also will be screened for the presence of volatile organic compounds using a photoionization detector (PID), with the readings noted on our boring logs. Representative samples from the borings will be submitted to the laboratory based on field screening observations, and analyzed as presented on the Soil Analysis Table.

3.3 SVE Well Construction

One SVE well (SVE-1) will be installed in the location presented on Figures 2 and 3, and screened from 5 to 9 feet. This screen interval was chosen to be deep enough to prevent short-circuiting to the surface, but shallow enough to prevent the well screen from being flooded during periods of high water table.

This SVE well will be constructed of 4-inch diameter Schedule 40 polyvinyl chloride (PVC) piping, with four feet of 0.020-inch slotted screen. The well will be completed with 10/20 silica-sand filter pack extending to approximately one foot above the top of the screened interval. The remainder of the boring will be backfilled with bentonite chips and then hydrated. The surface will be completed with a flush-mounted monument and a concrete seal.

3.4 AS Well Construction

Two AS wells will be installed as part of the pilot study (Figure 2). The first AS well (AS-1) will be completed at the bottom of the upper-saturated zone just above the silt aquitard (see Figures 2 and 3 for location). The second AS well (AS-2) will be completed approximately 10 feet below the bottom of known contamination (approximately 30 to 32 feet deep), within the lower-saturated zone (see Figures 2 and 3). The screened depth of this well is intended to assess the potential ROI for sparging in the lower saturated zone (see Section 4.4).

The AS wells will be constructed of 2-inch diameter Schedule 40 PVC, with a 2-foot length of 0.010-inch slotted screen for the sparge point. Below the screen section, a 2 to 3 foot sump (comprised of blank PVC well casing) will be installed, to act as a silt/fines trap. The wells will be completed with 10/20 silica-sand filter pack extending to approximately 1 foot above the top of the screened interval. The remainder of the boring will be backfilled with bentonite chips and then hydrated. The surface will be completed with a flush-mounted monument and a concrete seal. The top of the AS wells will be completed with a Schedule 80 slip-to-thread reducer bushing glued to the casing.

3.5 Observation Well Construction

For the pilot test, three observation wells will be installed at locations shown on Figures 2 and 3. In order to avoid unnecessary permanent well installations, the observation points will be installed as temporary wells.

Observation wells will be constructed of 2-inch PVC casing with 0.020-inch machine-slotted screened intervals. The observation wells will be screened at the same interval as SVE-1 (from 5 to 9 feet) to assess ROI during the SVE phase of the study. Additionally, TW-1 will be located approximately 10 feet from SVE-1, while TW-2 will be placed approximately 20 feet from SVE-1. TW-3 will be placed approximately 50 feet south of SVE-1. The placement of the observation wells will also help assess the potential for preferential vapor pathways (see Sections 4.3.1 and 4.6.2).

The observation wells will be completed with 10/20 silica-sand filter pack extending to approximately 0.5 foot above the top of the screened interval. The remainder of the boring will be backfilled with bentonite chips and then hydrated with water. Following the completion of the planned field activities, the temporary observation wells will be removed with a probe jack. The hole will be backfilled with bentonite, and the concrete surface restored. If the well casings cannot be removed, they will be closed in place by filling them with bentonite and restoring the surface with concrete.

3.6 Well Development and Sampling

Well development will be performed only on the AS wells as they are the only wells that are expected to be installed into the water table. After sparge-well construction, the wells will be developed. Over pumping, or removing water from the well at a rapid rate, will be the devolvement technique used in all wells. An in-well 12-volt DC submersible pump will be lowered to near the bottom of the well screen and moved through the screened interval during well development. Well development will be based on removal of sediments, water turbidity, and stabilization of field parameters and flow rates. If LNAPL is present in the well, development will be completed by hand bailing using a disposable bailer.

After the AS-well installations and their development, and following an equilibration period of at least 48 hours, groundwater samples will be collected from each of the AS wells. Groundwater sampling will be conducted in accordance with the methods identified in the G-Logics workplan dated September 6, 2016. If the AS well installation coincides with a scheduled quarterly groundwater-monitoring event, the AS wells can be sampled at the same time as the existing Site wells. If the AS-well installation does not coincide with the quarterly schedule, the AS wells will be sampled separately, with data added to the larger Remedial Investigation project.

4.0 PILOT TEST SETUP AND PERFORMANCE

The proposed pilot test will consist of two phases of work: the soil-vapor extraction (SVE) test and the air-sparge soil-vapor extraction (AS/SVE) tests. The SVE system applies a vacuum to unsaturated soils (vadose zone) to remove volatile compounds. The AS system injects air beneath the groundwater surface to facilitate transfer of volatile compounds from the dissolved phase to the vapor phase. Combining the two methods (AS/SVE) allows for the SVE components to remove contaminant vapors originating in the vadose-zone and the contaminants volatilized from the groundwater by the AS system.

4.1 Pilot Test Equipment

Temporary equipment will be furnished and used for the tests, as described below. Figure 4 presents a Process and Instrumentation Diagram (P&ID), which depicts the equipment that will be used during the tests.

4.1.1 SVE Test Equipment

Beginning at the SVE-1 wellhead, the SVE system will consist of the follow components.

- A 4-inch to 2-inch reducing rubberized flexible connector securing the SVE-well casing to a 2-inch diameter schedule 40 PVC pipe, which will be used to connect the remaining equipment.

- A 55-gallon moisture-reduction tank and dilution valve. The inlet piping to the moisture-reduction tank will be equipped with a clear section of PVC pipe to allow visual observation of collected moisture.
- A Rotron EN/CP 505 2-horsepower, 230-volt, single-phase explosion-proof regenerative blower. This blower can produce a maximum flow of 160 standard cubic feet per minute (scfm), a maximum pressure of 62 inches of water (inH^{2}O), and a maximum vacuum of 0 – 60" inH^{2}O.
- A portable generator, set up downwind and away from sampling locations, will be used to power the blower.
- A test assembly with flow-meter manifold consisting of four rotameters measuring specific/graduated flow ranges. Each rotameter will be preceded by a shut-off valve. The test assembly also will include a sampling port to collect PID readings and soil-vapor samples. The test assembly will be installed on the blower-discharge pipe. The discharge pipe will direct recovered vapors away from the breathing zone.
- A dedicated vacuum gauge 0 – 60" inH^{2}O, fitted to the test assembly.
- An activated-carbon vapor-exhaust treatment system. Effluent vapors will be directed through two 55-gallon treatment cells filled with activated carbon before being discharged to the atmosphere.

4.1.2 Observation Well Monitoring Equipment

Each temporary observation well will be fitted with a removable PVC cap and threaded barbed fitting (wellhead adapter) to allow the temporary connection of a differential-pressure gauge manifold (multiple gauges measuring a wide range of pressure/vacuum). This pressure gauge manifold will be used to assess any pressure differences created during the operation of the pilot test. The caps will be removable to allow for visual observation of air bubbles and to measure groundwater depths during testing, if water is present in the wells.

4.1.3 AS Pilot Test Equipment

The second phase of the pilot-testing program will include the introduction of air sparging during SVE-equipment operation. To conduct the AS test in the upper-saturated zone, air will be injected into AS-1. To conduct the AS test in the lower-saturated zone, air will be injected into AS-2. These well locations are shown on Figures 2 and 3.

Beginning at each air sparge wellhead, the AS system will consist of the following.

- A wellhead assembly, which will include the following components,
    - An 18”-long pipe threaded onto the well casing via a slip-to-threaded bushing
    - A pressure gauge tapped into the side of the 18” pipe
    - A quick connect coupler threaded to a reducer bushing at the end of the 18” pipe
- A flexible pneumatic hose will be used to connect the air-sparge system components.
- A flow-meter manifold consisting of four rotameters measuring specific/graduated flow ranges. Each rotameter will be preceded by a shut-off valve.
- Steel piping to be used to connect the pneumatic hose to the compressor. A pressure gauge, pressure regulator, and pressure-reducing valve will be attached to the steel pipe.
- A 5 horsepower, 480-volt, three-phase rotary-claw compressor (Zephyr C-DLR 60 or similar). The compressor can provide up to 40 scfm at 30 psi.
- A 480-Volt 3-phase generator will be used to power the compressor.

4.2 Permitting

The understood permitting requirements are discussed below.

4.2.1 Emissions Permitting

Discharges to the atmosphere are regulated by Title V of the federal Clean Air Act Amendments of 1990 and its implementing regulation 40 CFR Part 70. The Puget Sound Clean Air Agency (PSCAA) provides a comprehensive operating permit program consistent with the above requirements, RCW 70.94.161, and its implementing regulation Chapter 173-401 of the Washington Administrative Code.

To administer these regulations, PSCAA requires new emission sources to be permitted via a Notice of Construction application and an Order of Approval from the agency. However, per PSCAA Article 6, section 6.03(c) #94, a Notice of Construction application and Order of Approval are not required for soil and groundwater remediation projects discharging less than 15 pounds per year of benzene and less than 1,000 pounds per year of toxic air contaminants.

Per a phone conversation with Ms. Sara Conley, an engineer with PSCAA, the regulations and their exemptions are self-regulating. Specifically, if an exemption is believed to be applicable, the exempted party need only have the documentation on-hand that details the understood exemption. Additionally, Ms. Conley commented that pilot studies are generally used to assess the permitting requirements for final design of remedial systems/actions and therefore are not required to be permitted.

Based on our review of the PSCAA regulations, the conversation with Ms. Conley, and this project's status as a pilot test, G-Logics does not intend to submit an application/Notice of Construction to PSCAA for the planned pilot-test work.

4.2.2 Miscellaneous Permitting

Because all work will be performed on Property, right-of-way and/or street-use permits will not be required. Additionally, as the equipment used for this pilot test is temporary and no permanent structures are planned, building permits are not required. A licensed driller will perform the well installations and closures in accordance with Ecology's Well Regulations.

4.3 SVE Step Test

The first phase of the pilot test will consist of performing step tests solely on the SVE system. This phase of testing is expected to be performed on the first day of the study, and will utilize SVE-1 and the observation wells described in Section 4.3.1. The step tests will be performed in increments to evaluate the subsurface response of the SVE application to vadose zone soils. Data collected during this phase of the pilot test will be used to assess the following:

- The potential vacuum ROI that could be achieved with SVE;
- The influence of SVE on shallow groundwater elevation in the upper-saturated zone; and
- Potential hydrocarbon mass-removal rates that could be achieved by SVE application to vadose-zone soils.

In addition to the above objectives, this portion of the pilot test also will be used to assess optimal site-specific SVE parameters (a combination of peak flow and vacuum) to achieve a maximum ROI. To identify these parameters, the observed vacuum and air-flow rates will be compared during each adjustment of the step tests.

Due to the relatively shallow groundwater conditions in the upper-saturated zone where groundwater is typically encountered at depths of approximately 8 to 10 feet, vacuum levels applied during the SVE testing will be limited due to the potential of inducing groundwater mounding in the vicinity of SVE-1, which could submerge the well screen. Therefore, it is expected that applied vacuum levels of approximately 10 to 40 inH_2O will be used for each of the vacuum step tests performed. The vacuum step tests will consist of four vacuum steps (10, 20, 30, and 40 inH_2O), with each step lasting approximately 1.5 to 2 hours. However, actual applied vacuum levels and step durations may vary, based on conditions observed in the field.

4.3.1 SVE Step Test - Observation Wells

SVE-1 will be screened within the vadose zone soils that are present above the upper-saturated zone. Depending on seasonal groundwater fluctuations, the SVE-1 well screen may be partially submerged. However, based on accumulated groundwater elevation data for the Site, G-Logics expects that seasonally high groundwater elevations are not likely to inundate the screen of SVE-1. Observation wells used for the SVE step test also will be screened within vadose-zone soils. Proposed observation wells for this phase of the pilot test will consist of temporary observation wells TW-1, TW-2, and TW-3, and existing monitoring wells IP-4 and MW-26S.

Prior to beginning the SVE step test, observation wells will be fitted with vacuum-tight well caps equipped with a valve-controlled sample port. This port will allow measurement of the pressure/vacuum within the well casing. The well caps will be constructed to allow relatively quick removal and reinstallation to facilitate collection of depth-to-water (DTW) measurements (if present) during the testing.

4.3.2 SVE Step Test - Baseline Data Collection

The baseline data listed below will be collected prior to the start of the SVE step test.

- DTW measurements at SVE-1, TW-1, TW-2, TW-3, IP-4, and MW-26S.
- Well casing vacuum/pressure measurements at SVE-1, TW-1, TW-2, TW-3, IP-4, and MW-26S.

4.3.3 SVE Step Test – Procedure and Timeline

The anticipated SVE step-test schedule is described in detail below. Expected durations for each bulleted task are included. Actual timing may vary based on field conditions.

- **Pre-Test Equilibration** – The identified observation, SVE, and monitoring wells will be opened and allowed to stabilize for 10 minutes. Initial groundwater depths then will be measured. Observation wells will be fitted with wellhead adapters and an initial round of subsurface-atmospheric pressure readings will be collected.
- **SVE Step Test Initiation (0 to 15 minutes) –**The SVE system will be started and allowed to run on 100-percent dilution air. At the end of this period, the SVE-system operating parameters will be recorded (see Section 4.6.3) and a vapor sample will be collected for laboratory analysis.
- **Dilution-Air Adjustment (15 to 30 minutes) –** The dilution valve will slowly be closed until a vacuum of approximately 10 inH_2O is applied to SVE-1. This will occur over a period of approximately 15 minutes.
  - Throughout the adjustment process, vacuum and flow readings will be observed in SVE-1 via the test assembly.
  - Differential pressure will be measured in the observation wells approximately every 5 minutes during this period.
  - During the dilution-air adjustment process, G-Logics will monitor the transparent inlet piping to the moisture-reduction tank for signs of moisture being drawn into the system.
  - If flowing liquid is observed in the transparent inlet piping, the applied vacuum level will be reduced to limit water extraction by SVE.
  - At the end of this process, PID readings will be recorded, a vapor sample will be collected for laboratory analysis, and groundwater depths will be measured in all of the observation wells.
- **SVE System Monitoring, Incremental-Vacuums (each vacuum step: 30 minutes to 2.0 hours)** – The SVE test will be continued for additional vacuum increments. Upon establishing the intended applied vacuum for the step being performed (10, 20, 30, 40 inH_2O), the start time will be recorded. At a minimum, the following data and samples will be collected.
  - SVE-system operating parameters (Section 4.6.3)
  - Vacuum at each of the observation wells
  - DTW at the SVE wellhead and observation wells (if present)

- Vapor samples, to be collected in Tedlar bags at the SVE wellhead and/or blower outlet for field screening analysis using a PID and possible laboratory analysis.
- Select vapor samples will be submitted for laboratory analysis based on the results of field-screening, see Sections 4.6.5 and 4.7. Specifically, the collected samples with the highest PID values will be submitted for analysis.
- Additional monitoring will be performed every 30 minutes for a period of at least 1.5 hours. These additional monitoring activities will follow the data collection and sampling procedures described in the previous bullets.
- After 1.5 hours, the project field manager will evaluate the data collected in order to assess whether a stable ROI has been reached (steady-state conditions). A stable ROI would be indicated by steady differential pressure measurements (+/- 25%) at the surrounding observation wells for the vacuum being assessed. If the data indicate that the system has not yet reached steady-state conditions, additional operation and monitoring at that vacuum step may be warranted.

- **Incremental Vacuum Step Tests (2.0 to 5.0 hours)** – The step test will then be repeated for up to three additional "steps" at vacuums of approximately 20" inH^2O, 30" inH^2O, and 40" inH^2O (depending on water levels at the time of testing), using the methods and timeline described above.

4.4 Upper-Saturated Zone AS/SVE Test

The second phase of the pilot test will be an assessment of air sparging in the upper saturated zone. This phase of testing is expected to be performed on the second day of the study, and will utilize SVE-1, sparge well AS-1, and the observation wells described in Section 4.4.1. Accordingly, the SVE system will be operated at the optimal parameters determined during the SVE step test (performed on Day 1, discussed in Section 4.3).

As previously discussed, the objectives of the AS/SVE testing will be to assess whether a sufficient volume of air can be injected into the subsurface without exceeding the estimated theoretical fracture pressure of the overlying soil column (12 psi), and if so determining the subsurface response to that airflow. For the purpose of this pilot test, the theoretical fracture pressure will be determined based on the initial vertical effective stress and the assumed friction angle (based on lithology). Specifically, the depth of injection (in relation to the vadose and saturated zones within an aquifer) will be used to establish the saturated pore pressure, and thus the vertical effective stress (the difference between the total vertical stress and the pore pressure). A friction angle will be assumed based on the lithology at the Site, in this case medium-grained silty sands (Payne et al., 2008, *Remediation Hydraulics*).

A safety factor of 75 percent of the theoretical formation fracture pressure will be used for the sparge well. Accordingly, pressures greater than 9 psi (75% of 12 psi) will not be applied to the formation during the test. This study will be used to assess an effective sparge pressure for possible full-scale implementation.

Subsurface responses to be evaluated during the AS testing will include:

- The sparge ROI, evaluated by measuring the relationship between the observed subsurface-pressure increases and the DO saturation levels in the surrounding observation wells. This also can be further evaluated by visually observing nearby wells for the presence of air bubbles.
- Potential increases in hydrocarbon removal rates through SVE, evaluated by comparing the relative increase in VOC concentrations in samples collected throughout the test.
- The likelihood for soil fracturing (creating preferential pathways or fugitive vapor emissions that may be caused by AS injections), evaluated by monitoring the injected air pressures needed to achieve flow (pressures approaching 75% of the theoretical soil-fracture pressure will be considered as the failure criteria).

4.4.1 Upper-Saturated Zone AS/SVE Test – Observation Wells

Subsurface-response data collected during this phase of testing will be focused within the upper-saturated zone. Therefore, the observation wells used for this phase of the pilot test will consist of proposed temporary observation wells TW-1, TW-2, TW-3, and existing monitoring wells IP-4 and MW-26S.

4.4.2 Upper-Saturated Zone AS/SVE Test – Baseline Data Collection

The following baseline data will be collected prior to the start of the upper-saturated zone AS/SVE test:

- DTW measurements at AS-1, SVE-1, TW-1, TW-2, TW-3, IP-4, and MW-26S
- Dissolved oxygen (DO) measurements at AS-1, SVE-1, TW-1, TW-2, TW-3, IP-4, and MW-26S

- Well-casing vacuum/pressure measurements at AS-1, SVE-1, TW-1, TW-2, TW-3, IP-4, and MW-26S
- Head-space vapor readings using a PID at AS-1, SVE-1, TW-1, TW-2, TW-3, IP-4, and MW-26S

4.4.3 Upper-Saturated Zone AS/SVE Test - Procedure

AS/SVE testing in the upper-saturated zone will be performed according to the following procedures.

- **Pre-Test Equilibration** – The identified observation, SVE, and monitoring wells will be opened and allowed to stabilize for 10 minutes. Initial groundwater depths then will be measured. Observation wells will be fitted with wellhead adapters and an initial round of subsurface-atmospheric pressures will be collected.
- **SVE-System Initiation and Monitoring (0-30 minutes)** – The SVE system will be started and operated as described in Section 4.3.3. Upon reaching the target vacuum level (optimal SVE conditions established on Day 1), the time will be noted and recorded at the start of the test. At a minimum, the following data and samples will be collected immediately following the start of the test.
    - Applied vacuum at the SVE wellhead
    - Vacuum at each of the observation wells
    - SVE system operating parameters
    - DTW at the SVE wellhead and observation wells
    - Vapor samples, to be collected in Tedlar bags at the blower outlet for field screening analysis using a PID and possible laboratory analysis (see Section 4.3.3).
- **AS Preparation –** Prior to the start of AS injection, and routinely during the sparge-injection test, the ground surface near the AS well and observation wells will be wetted with potable city water (from an exterior hose connection at the service station). Wetting the ground surface may result in the formation of bubbles, which would identify areas where injected air is escaping to the ground surface without being captured by the SVE system. The planter strip immediately west of the proposed test area is currently unpaved and covered with landscaping gravel. To assess potential air leakage, this unpaved area will be covered with 6 mil plastic sheeting, and visually checked for inflation. A PID also may be used to assess for elevated VOC concentrations in the air beneath the sheeting. Observations indicating significant air leakage will be recorded on field logs.

- **AS Test Initiation (0.5 hours to 1.0 hours)** – The initial phase of the AS operation will focus on the ability to inject air at a sufficient flowrate into the subsurface.
    - To conduct this portion of the test, the sparge system will be started, with the ball valve on the sparge well in the fully closed position and the bypass valve on the air-supply manifold in the fully open position.
    - The air pressure regulator will then be adjusted to 75 percent of the theoretical formation fracture pressure for the sparge well (9 psi, Section 4.4).
    - The ball valve on the sparge well will then be opened and the bypass valve on the air supply manifold will be slowly closed in small increments until the rotameter indicates that air flow into the sparge well has been initiated. At this point, the flow-initiation injection pressure and flow rate will be recorded.
    - If flow rate (at any scfm) cannot be achieved without exceeding a safe operating pressure, the test will be concluded.
- **AS Testing (1.0 to 2.5 hours)** – If sufficient air flow into the subsurface can be initiated, the AS/SVE test will be operated at these settings for 1.5 hours. The following data and samples will be collected immediately after the start of sparge injection and thereafter according to the monitoring frequency provided below:
    - DTW measurements in SVE-1 and the observation wells approximately every 30 minutes;
    - Well-casing pressure measurements at SVE-1 and the observation wells every 15 minutes;
    - Headspace vapor concentrations and visual checks for bubbling in the observation wells every 15 minutes;
    - SVE system operating parameters every 30 minutes;
    - AS system operating parameters every 30 minutes;
    - Visual checks for bubbling in response to wetting of the ground surface every 30 minutes;
    - Vapor samples collected every 30 minutes in Tedlar bags at the blower outlet for field screening analysis using a PID;
    - Vapor samples collected in Tedlar bags at the blower outlet for laboratory analysis (based on the results of vapor sample field screening results, see Section 4.7); and
    - DO measurements in the observation wells after the conclusion of the test.

4.5 Lower-Saturated Zone AS/SVE Test

The third and final phase of the pilot test will be an assessment of AS/SVE in lower-saturated zone. This phase of testing is expected to be performed on the third day of the study and will utilize air sparge well AS-2 and extraction well SVE-1, as well as the observation wells described below in Section 4.5.1.

The objectives and methodology for pilot testing AS/SVE in the lower-saturated zone are generally the same as for the upper-saturated zone. However, this phase of testing will also evaluate connectivity (vapor transmissivity) between the lower and upper-saturated zones. If transmissivity is observed, this may allow the SVE (applied in the vadose zone) to capture air injected into the lower-saturated zone.

4.5.1 Lower-Saturated Zone AS/SVE Test – Observation Wells

To assess the feasibility of using AS injection in the lower-saturated zone in combination with SVE in the vadose zone, subsurface response data will be collected within the vadose zone, upper-saturated zone, and lower-saturated zone. The observation wells to be used for this phase of the pilot test will consist of proposed temporary observation wells TW-1, TW-2, TW-3, and existing monitoring wells IP-3, IP-4, IP-5, IP-7, MW-26S, MW-26D, MW-28S, and MW-28D.

4.5.2 Lower-Saturated Zone AS/SVE Test – Baseline Data Collection

The following baseline data will be collected prior to the start of the lower-saturated zone AS/SVE test:

- DTW measurements at AS-1, AS-2, SVE-1, TW-1, TW-2, TW-3, IP-3, IP-4, IP-5, IP-7 (if NAPL is not present), MW-26S, MW-26D, MW-28S, and MW-28D;
- DO measurements at AS-1, SVE-1, TW-1, TW-2, TW-3, IP-3, IP-5, IP-7 (if NAPL is not present), MW-26S, MW-26D, MW-28S and MW-28D;
- Well casing vacuum/pressure measurements at AS-1, SVE-1, TW-1, TW-2, TW-3, IP-3, IP-4, IP-5, IP-7, MW-26S, MW-26D, MW-28S and MW-28D (see Section 4.1.2); and
- Head-space vapor readings using a PID at AS-1, SVE-1, TW-1, TW-2, TW-3, IP-3, IP-5, IP-7, MW-26S, MW-26D, MW-28S, and MW-28D.

4.5.3 Lower-Saturated Zone AS/SVE Test – Procedure

The testing procedures (including monitoring, sampling, and analysis) for performance of the lower-saturated zone AS/SVE test will be the same as those presented above in Section 4.4.3 for the AS/SVE test in the upper-saturated zone, except that the theoretical formation fracture pressure for AS-2 is approximately 27 psi (method discussed in Section 4.4). Accordingly, pressures greater than 21 psi (75% of the theoretical fracture pressure of 27 psi) will not be applied to the formation during the test.

The anticipated schedule for the AS test in the lower saturated zone is described below. Actual timing may vary based on field conditions.

- **Pre-Test Equilibration** – The identified observation, SVE, and monitoring wells will be opened and allowed to stabilize for 10 minutes. Initial groundwater depths then will be measured. Observation wells will be fitted with wellhead adapters and an initial round of subsurface-atmospheric pressures will be collected.
- **SVE-System Initiation and Monitoring (0-30 minutes)** – The SVE system will be started and operated as described in Section 4.4.3 above. Upon reaching the target vacuum level, the time will be noted and recorded at the start of the test. Operating-parameter measurements and samples will be collected (also as described in Section 4.4.3).
- **AS Test Initiation (0.5 hours to 1.0 hours)** – Following the procedure described in Section 4.4.3, pressure will slowly be added to AS-2 in an attempt to obtain a measurable flow. If flow cannot be achieved without exceeding a safe operating pressure (Section 4.5.2), flow to AS-2 will be shut off and the test will be considered complete.
- **AS Testing (1.0 to 2.5 hours)** – If a measurable flowrate can be achieved, the system will then be operated for 1.5 hours.
    - Pressure, flow, DO, and groundwater depths will be monitored and recorded at the intervals described in Section 4.4.3.

4.6 Data Collection and Field Analysis

Data-collection and field-analysis methods for groundwater sampling, vacuum/pressure measurements, vapor-sample collection and screening, and dissolved-oxygen measurements are discussed below.

4.6.1 Groundwater Depth Measurements

Water-level measurements will be referenced to the top of the well casing. The static-water level will be measured in each monitoring well using a conductivity type, water-level probe. The conductivity probe will be lowered into the well until the instrument detects water. The tape on the probe will be used to obtain a depth-to-water measurement, from the reference point, to within 0.01 feet. DTW measurements in SVE-1 will be collected to provide an approximate water level with respect to the well screen. Accordingly, the above-described method is expected to be sufficient.

4.6.2 Differential-Pressure Measurements (Observation Wells)

Differential pressure measurements will be made relative to atmospheric pressure using a master set of test gauges. Differential pressure measurements made at the observation wells will be measured using a series of differential pressure gauges that will provide measurements in increasing ranges from 0 to 50 inH^2O.

4.6.3 Measurement of SVE System Operating Parameters

The following SVE-system operating parameters will be monitored during each step of SVE pilot test, as discussed in Section 4.3. Please see Figure 4 for a piping and instrumentation diagram:

- Applied vacuum at the SVE wellhead;
- Airflow using a hot-wire anemometer between the wellhead assembly and the moisture-reduction tank;
- Moisture in transparent pipe before moisture-reduction tank;
- Vacuum at the inlet of the moisture-reduction tank;
- Liquid level in the moisture reduction tank;
- Temperature after the moisture-reduction tank;
- Vacuum between the moisture-reduction tank and dilution-air inlet valve;
- Air flow using a rotameter between the moisture-reduction tank and the dilution-air inlet valve;
- Vacuum on the blower-inlet side of the SVE system;
- Pressure on the blower outlet side of the SVE system;
- Temperature at the blower outlet;
- Blower outlet air flow using a rotameter at the test assembly;

- SVE system vapor-discharge concentration (Tedlar bag sample field analyzed using a PID, with select samples submitted for laboratory analysis);
- Blower amperage draw using fixed gauge on the generator; and
- Generator fuel level using fixed gauge on the generator.

Periodically throughout the pilot step tests, vacuum and pressure readings will be checked using a secondary master gauge. To allow for this, fixed gauges will be equipped with a sampling port and hose-barb fitting.

4.6.4 Measurement of AS System Operating Parameters

The following data will be collected during each round of AS system operating parameter monitoring:

- Applied pressure at the AS wellhead being tested;
- Air injection flowrate to the AS well (using a rotameter);
- Air injection temperature (fixed gauge);
- Air supply pressure (fixed gauge on pressure regulator);
- Air supply pressure (fixed gauge on compressor);
- Air compressor amperage draw (fixed gauge on the generator); and
- Generator fuel level (fixed gauge on the generator).

4.6.5 Vapor-Sample Collection and Field Screening

Vapor samples will be collected directly from the sample port on the pressure-side of the blower using 1-liter Tedlar bags. Sample collection will occur as described in Sections 4.3, 4.4, and 4.5, and as shown in the Table below.

Vapor-Sample Collection	**Quantity**
SVE Step Test (Day 1)	
Pre Test System Initiation	1
Dilution-Air Adjustment	1
Vacuum Step Test (10 inH_2O)	4
Vacuum Step Test (20 inH_2O)	4
Vacuum Step Test (30 inH_2O)	4
Vacuum Step Test (40 inH_2O)	4
AS/SVE Test Upper Saturated Zone (Day 2)	
Pre-test SVE System Initiation	1
SVE Dilution-Air Adjustment	1
AS Testing	4
AS/SVE Test Lower Saturated Zone (Day 3)	
Pre-test SVE System Initiation	1
SVE Dilution-Air Adjustment	1
AS Testing	4
Total Number of Collected Samples	**30**

The collected vapor samples will be screened using a PID (calibrated to a 100-ppmv isobutylene calibration standard). It is expected that for each phase of the test, samples displaying the highest PID field screening results will be selected for laboratory analysis, approximately 18 samples total.

4.6.6 Dissolved Oxygen

Before and during the air sparge tests, groundwater DO will be measured in the monitoring wells. Measurements will be made using an optical DO meter.

4.7 Lab Analysis

Collected soil samples will be submitted for the following analysis. The quantities described below are the minimum number to be analyzed. Additional samples may be analyzed to characterize conditions, if needed. At least one duplicate soil sample will be collected and analyzed.

Soil Analyses	Quantity
Diesel / Heavy Oil Range Organics (NWTPH-Dx/EPA 8015/AK 102-103)	10
Gasoline Additives (MTBE, TAME, DIPE, ETBE) (EPA 8260)	10
Gasoline /BTEX (EPA 8260/NWTPH-Gx)	20
Lead (EPA 6020/200.8/CVAA)	10

Groundwater samples (collected from AS-1 and AS-2) will be submitted for the following analyses. One duplicate groundwater sample will be collected and analyzed.

Groundwater Analyses	Quantity
Diesel / Heavy Oil Range Organics (NWTPH-Dx/EPA 8015/AK 102-103)	3
Gasoline Additives (MTBE, TAME, DIPE, ETBE) (EPA 8260)	3
Gasoline /BTEX (EPA 8260/NWTPH-Gx)	3
Lead (EPA 6020/200.8/CVAA)	3

Collected vapor samples will be submitted for the following analyses.

Vapor Analyses	Quantity
Volatile Organic Compounds (TO-15)	18
BTEX and MTBE (TO-15)	18
Hydrocarbons C2-C12 (EPA 8015)	18
Sulfur Compounds (TO-15)	6
Lead (6020/741/NIOSH)	6

5.0 INVESTIGATION-DERIVED WASTE DISPOSAL

Soil cuttings and rinse/purge water generated during the pilot-test activities will be temporarily stored on site in 55-gallon Department of Transportation-approved drums. Drums will remain on the Property pending profiling and coordination of off-site transportation and disposal.

6.0 REPORTING

The status of the pilot test will be provided in the monthly progress memos. The findings of the pilot study will be summarized in a technical memorandum (memo) and incorporated into the Draft Feasibility Study (FS) Report. The pilot test memo will document the objectives, methods, and observations of the Pilot Test activities. The memo will include site diagrams showing exploration locations, as well as current and identified former site features. Boring logs, laboratory analytical results, and a discussion of our findings also will be included.

7.0 GENERAL PROJECT SCHEDULE

A general timeline to conduct the pilot test is listed below.

- Fieldwork can begin approximately six to eight weeks following technical approval of this workplan and budget authorization.

- Installation of the test wells is anticipated to require 7 to 10 days to complete. This includes the installation of construction fencing to secure the testing area, as well as development and sampling of the newly installed AS wells following a 48-hour equilibration period. The testing area will remain closed during the duration of the pilot test.
- SVE and AS testing will not begin for 7 days after the wells are installed. This time is needed to allow for an adequate seal around the newly-installed borings.
- SVE and AS testing will require at least six days to complete, which includes equipment setup and breakdown.
- Laboratory analysis is expected to require approximately three weeks.
- Review and compilation of the collected field and laboratory data is estimated to require two to three weeks after receipt of validated laboratory data (G-Logics review).
- Approximately four to six weeks will be required for data review and comment.

The compiled information from the pilot test will be reviewed as part of the Feasibility Study (FS), including comments from Ecology on the pilot test memo, to assess the possible use of SVE and AS systems the upper and/or lower-saturated zones. The analytical data from the SVE test also will be reviewed to assess the need for vapor-discharge treatment.

The FS will be intended to fully evaluate multiple cleanup options for the Site, including options that do not include AS/SVE, regardless of the pilot study results. If the Ecology-approved Feasibility Study concludes that AS/SVE are suitable technologies to implement at the Site as a primary or supplemental technology, this determination will be presented in a pending Cleanup Action Plan (CAP). Following Ecology-approval of the CAP, further refinement of a full-scale design then would be completed in an Engineering Design Report.

8.0 LIMITATIONS

Our services are not designed or intended to identify all potential concerns or to eliminate all risk associated with the subject Property. This work will not provide a guarantee regarding remedial options. This work will not include other services not specifically described above.

G-Logics has prepared this workplan in accordance with the generally accepted standards of care that exist in the state of Washington at the time of this work. This workplan is prepared for the sole use of Boeing Field Chevron and the Chevron Environmental Management Company. The described information may not be appropriate for the needs of other users. Re-use of this document or the findings, conclusions, or recommendations presented herein, are at the sole risk of said user(s).

No warranty, express or implied, is made.

FIGURES

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Property Location Maps

Boeing Field Chevron

10805 East Marginal Way South

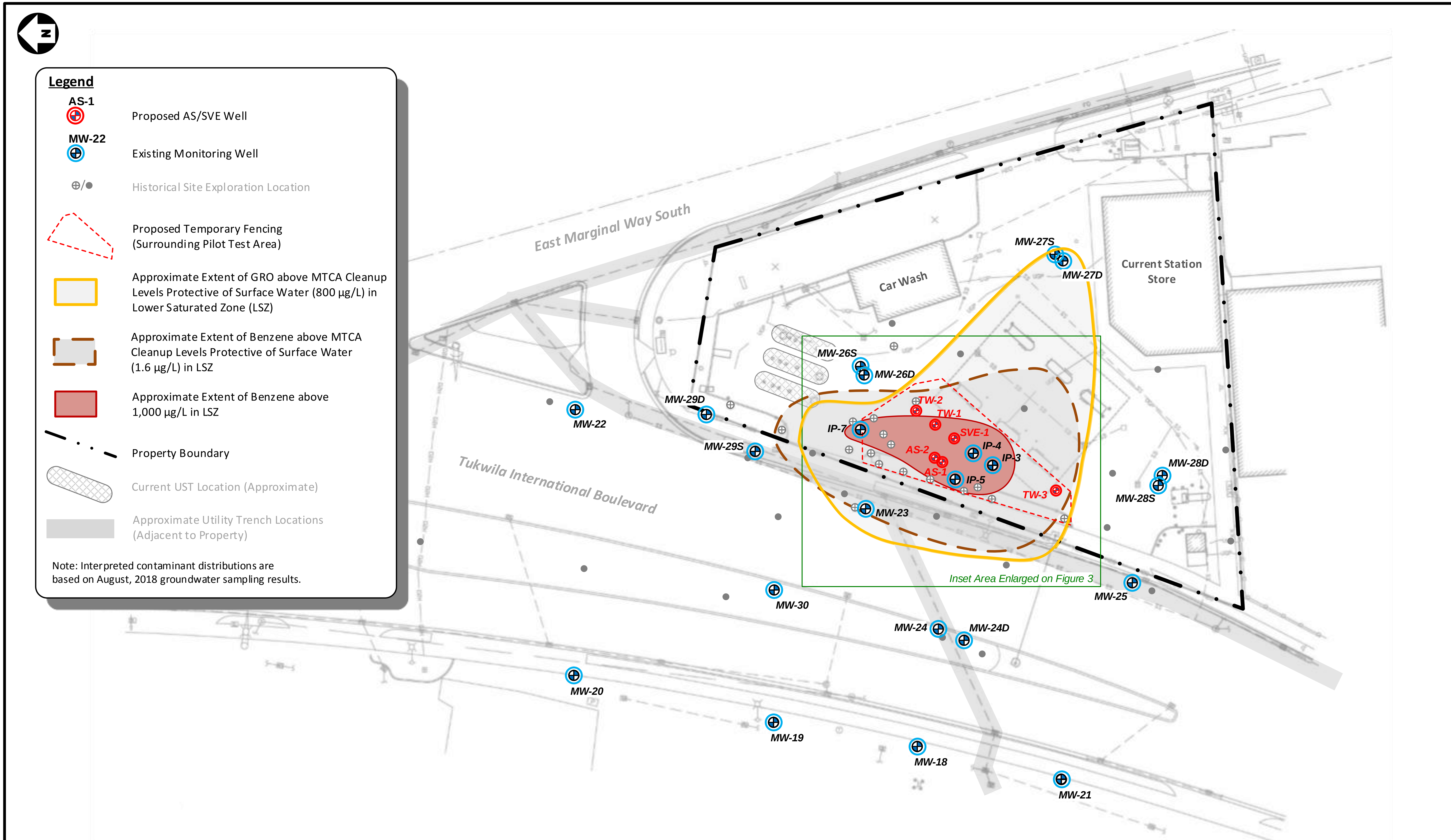
Tukwila, Washington

Figure

1

Project File: 01-0410-L F1.vsd

Mapping Reference: Delorme, King County iMap, and Google Maps



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Note: This figure contains information in color. Black & white photocopies may not be suitable for review.

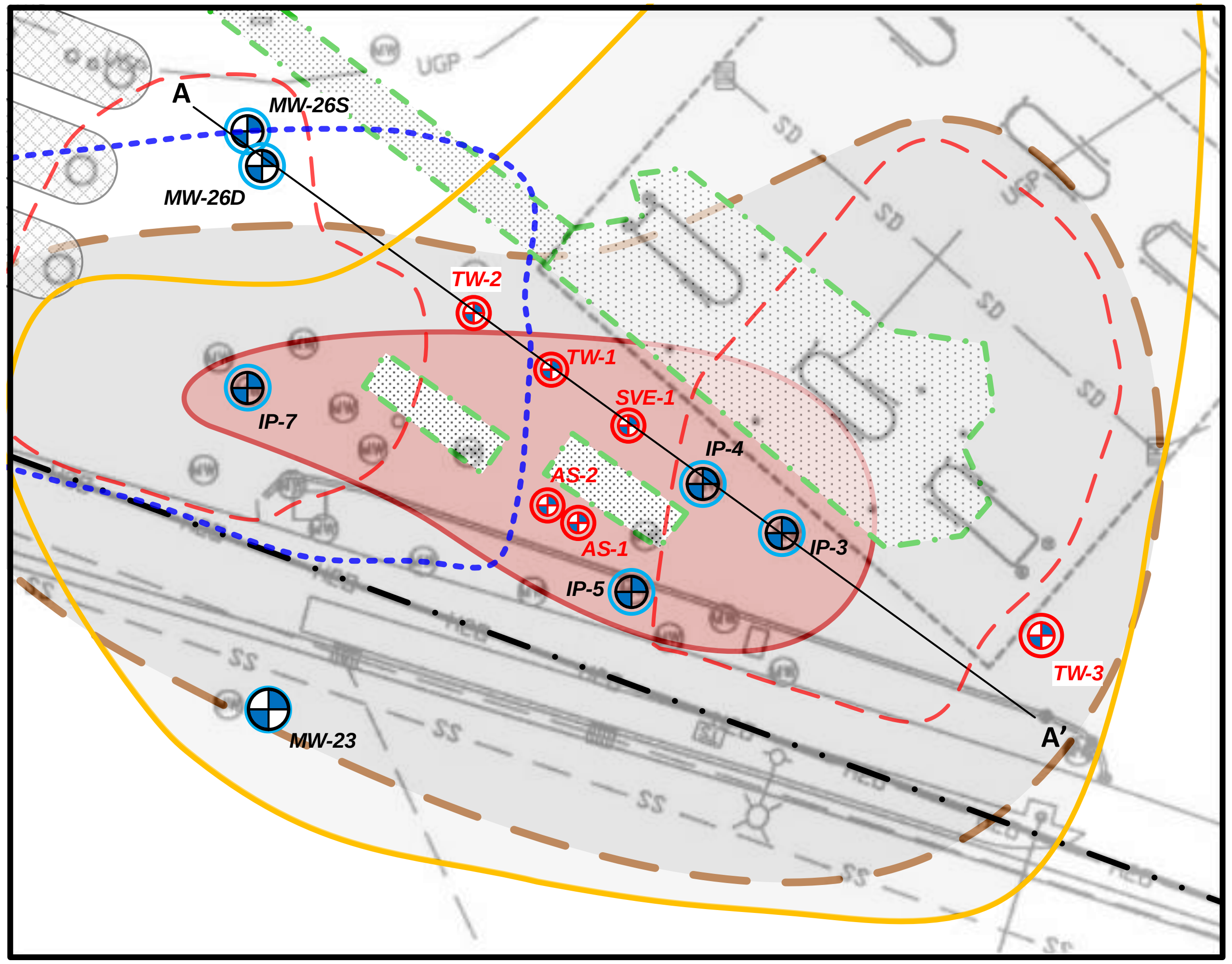
Approximate Drawing Scale: 1" = 40'
0 ft. 24 ft. 40 ft. 80 ft.

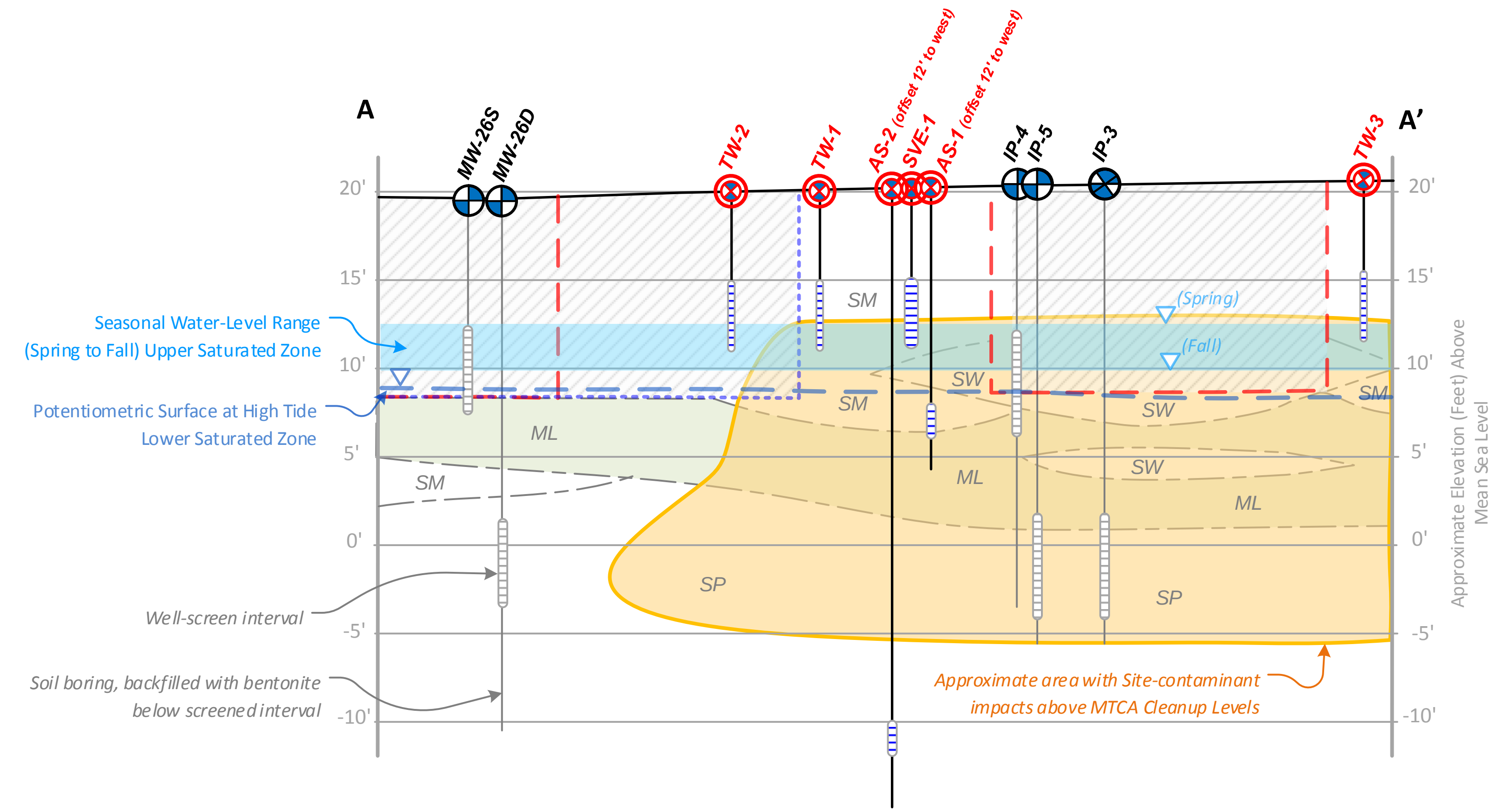
Test Area and LSZ Groundwater Contaminants
Boeing Field Chevron
10805 East Marginal Way South
Tukwila, Washington

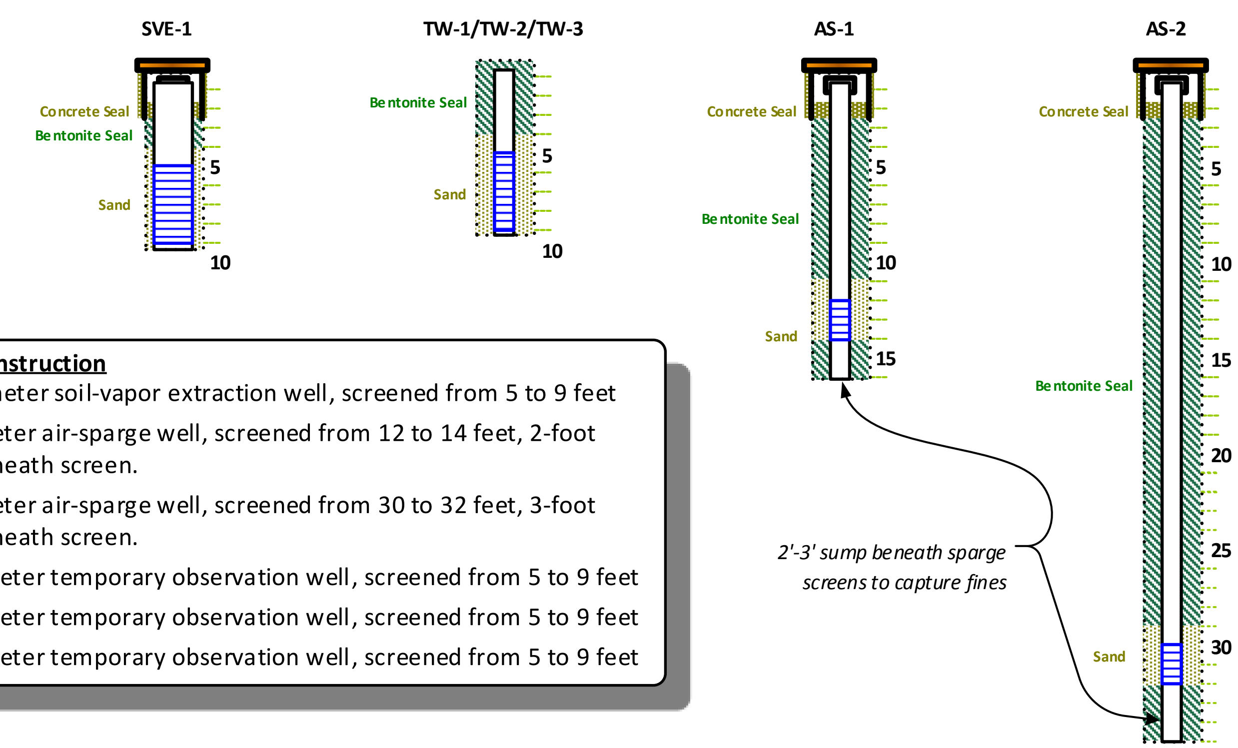
Figure 2

Project File: 01-0410-L F2.vsd

Mapping References: PLS Survey 2016, G-Logics Field Measurements, Previous Site Report Figures.







Legend

	Proposed Pilot-Test Well/ Observation Point		Approximate Hart Crowser Excavation Areas and Depths (1990 and 1992)
	Existing Monitoring Well		Approximate RZA Excavation Areas and Depths (1990)
	Historical Site Exploration Location		Approximate Extent of GRO above MTCA Cleanup Levels Protective of Surface Water (800 µg/L) in Lower Saturated Zone (LSZ)
	Property Boundary		
	Current UST Location (Approximate)		Approximate Extent of Benzene above MTCA Cleanup Levels Protective of Surface Water (1.6 µg/L) in LSZ
ML	Inferred extent of Silt Aquitard		
	New Pavement (Apparent 2004 PNE Excavation Areas)		Approximate Extent of Benzene above 1,000 µg/L in LSZ

Note: See RI text for discussion of previous explorations and remedial efforts.
Interpreted contaminant distributions are based on August, 2018 groundwater sampling results.

Pilot-Test Well Construction

SVE-1: 4-inch diameter soil-vapor extraction well, screened from 5 to 9 feet

AS-1: 2-inch diameter air-sparge well, screened from 12 to 14 feet, 2-foot sump installed beneath screen.

AS-2: 2-inch diameter air-sparge well, screened from 30 to 32 feet, 3-foot sump installed beneath screen.

TW-1: 2-inch diameter temporary observation well, screened from 5 to 9 feet

TW-2: 2-inch diameter temporary observation well, screened from 5 to 9 feet

TW-3: 2-inch diameter temporary observation well, screened from 5 to 9 feet

Project File: 01-0410-L F3.vsd

g-logics

Note: This figure contains information in color. Black & white photocopies may not be suitable for review.

Approximate Drawing Scale: 1" = 20'

0 ft. 12 ft. 20 ft. 40 ft.

Cross-Section, Proposed Pilot-Test Wells

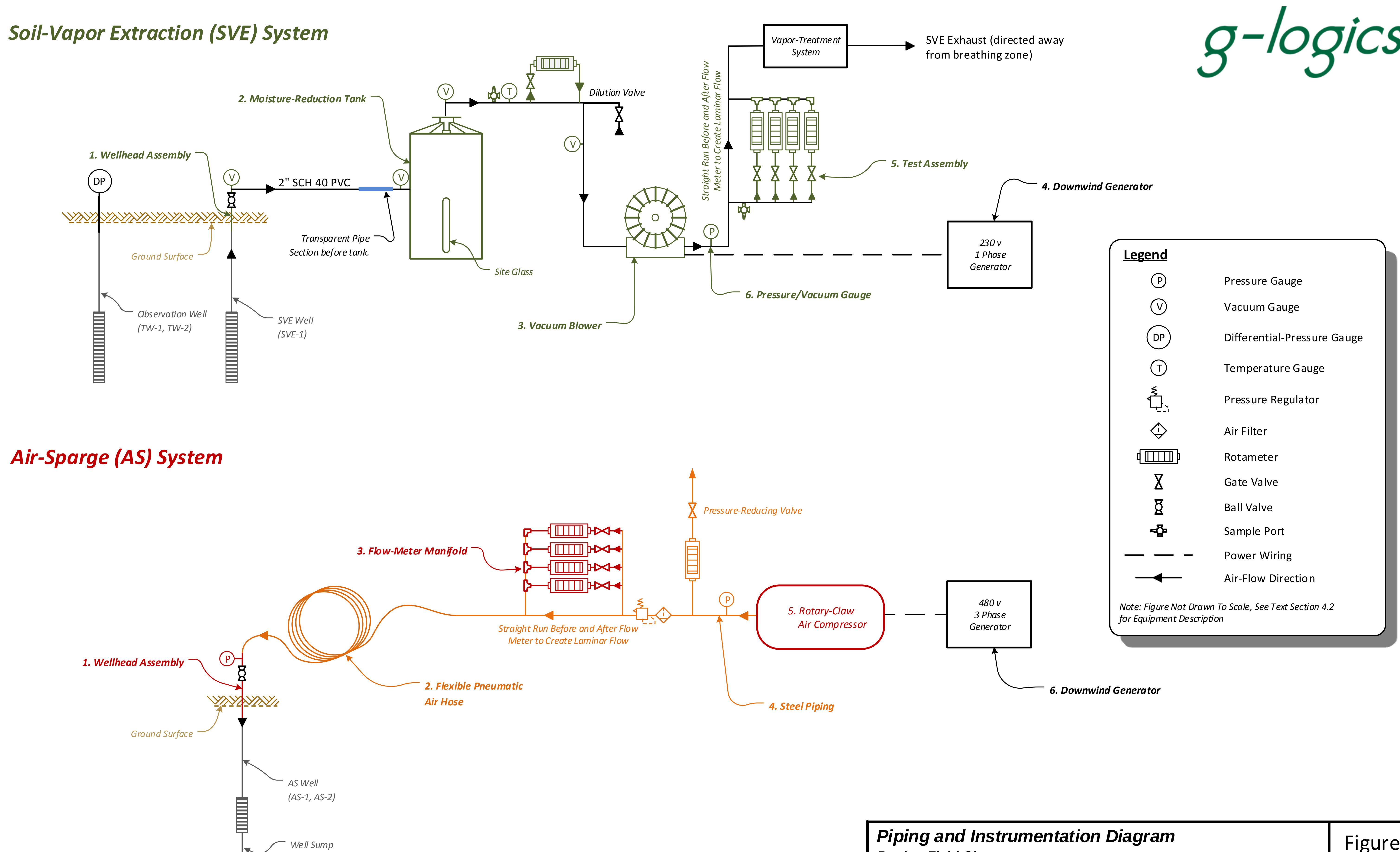
Boeing Field Chevron

10805 East Marginal Way South

Tukwila, Washington

Figure 3

Mapping References: PLS Survey 2016, G-Logics Field Measurements, Previous Site Report Figures.



Piping and Instrumentation Diagram
Boeing Field Chevron
10805 East Marginal Way South
Tukwila, Washington

Figure 4

Project File: 01-0410-L F4 P&ID.vsd