Memorandum

DATE: September 13, 2024 (initial 6.24.2024)

TO: Jim Cach – Coleman Oil
John Mefford – Washington Department of Ecology

FROM: Tom Mergy, LHG

PROJECT: Coleman Oil Yakima Bulk Plant
Ecology Agreed Order No. DE23182
PBS No. 41392.000, Phase 00021

REGARDING: **Pilot Test Work Plan – Amended 9/13/2024**

A. Cleanup Action Overview

The selected cleanup action will employ surfactant-enhanced bioremediation (SEB) through a designed injection/recovery treatment system. Surfactant technology uniquely enables the selective desorption of contaminants, making non-aqueous phase liquid (NAPL) – also known as floating product – miscible in the aqueous phase, thereby enhancing mass removal. The surfactants will also desorb contaminants from soil surfaces and NAPL layers, making them more accessible for *in-situ* or *ex-situ* remediation. This process increases the bioavailability of the contaminants dissolved in water for microbial degradation. The collected NAPL and contaminated water will be pumped into a separator and treatment system, and then reinjected into the impacted areas to create a recirculation treatment zone. Bioventing may also be utilized as a supplementary remedy to address vadose zone contamination in conjunction with SEB.

B. Purpose

The purpose of this pilot study is to determine the optimal spacing and placement of surfactant injection and recovery wells, ensuring that an effective zone of influence is achieved for maximum LNAPL removal and optimal surfactant delivery. This study will include measuring the physical and chemical parameters of NAPL and the injected surfactant at specific wells located near the injection and extraction wells.

The sequence of field tests is as follows:

1. Perform one event of surfactant injection and total fluids recovery pump tests to evaluate the placement, volume, and extraction rate for recovery of NAPL across the site.
2. Perform a soil vapor extraction field test to evaluate soil vapor extraction as a contingent remedy.
3. Perform a soil vapor bio-venting field test to evaluate bioventing as a contingent remedy.

The results from these pilot tests will guide the engineering specifications for the full-scale remediation system design, which will be documented by PBS in a separate Engineering Design Report (EDR).

C. Pilot Test Work Plan

The pilot test activities are described in the following sections.

1. Surfactant Injection and Total Fluids Recovery Well Test

The surfactant pilot test is designed to evaluate the effectiveness of surfactants in enhancing the mobilization and recovery of LNAPL at the site. This test will utilize a push-pull method (injecting and extracting fluids from the same well), with RW-1, a centrally located well, serving as both the injection and extraction point for the IVEY-SOL surfactant. The primary objective is to assess the surfactant's ability to increase LNAPL recovery rates and improve the overall efficiency of the remediation process.

The surfactant pilot test will consist of a single application, designed to ensure thorough interaction between the surfactant and LNAPL, with adequate monitoring of its effects. The primary focus is to observe changes in LNAPL thickness, water surface tension behavior before and after the surfactant application, using IVEY-SOL field tests to monitor surfactant concentration, and measure effective drawdown in well during pump test. A copy of the IVEY-SOL product sheet is included in Attachment A.

The following tasks are proposed for the surfactant application at the site:

- UIC Permit
  - Obtain an Underground Injection Control (UIC) permit from the Washington Department of Ecology for limited injection of the IVEY-SOL product into the groundwater. Since the permit may take up to 45 days for approval, permit application will be the first step in scheduling the field pilot test.

- Baseline Data Collection:
  - Measure the initial LNAPL thickness and groundwater levels at RW-1 and observation wells (MW-1, MW-2, MW-3, MW-5, MW-11, and/or MW-12) using an interface probe. Use a disposable bailer to collect, visually observe, and photograph the LNAPL within RW-1.
  - Conduct initial IVEY-SOL field tests to establish baseline groundwater conditions. These tests provide a qualitative measure of groundwater surface tension as an indicator of IVEY-SOL concentration.
  - Insert data loggers in two of the monitoring wells (MW-1 and MW-3) in proximity to RW-1 to record pressure and water levels before, during and after the pump test.

- Surfactant Injection and Monitoring:
  - Mix the prescribed IVEY-SOL solution in a 275-gallon IBC tote with water on-site.
  - Inject the surfactant solution into RW-1 using a hose through gravity feed.
  - Monitor and record changes in LNAPL thickness and groundwater levels after injection. Use a downhole data logger to record water level changes in RW-1.
  - Use IVEY-SOL field test kits periodically to check surfactant concentration levels in RW-1 and nearby monitoring wells during the residence period.

- Extraction Phase:
  - After 20-24 hours, begin extracting the mixture of groundwater and mobilized LNAPL from RW-1. Continuously use field test kits to monitor surfactant concentration changes during extraction.
  - Use a downhole data logger to record water level changes in RW-1 and the closest monitoring wells, MW-1, and MW-3, to measure potential radius of influence of the pumping well.

- o Pump the groundwater and LNAPL into IBC totes. A total volume of 1.5 to 2 times the volume of injected surfactant (up to ~600 gallons) will be pumped. Use field test kits to determine when groundwater surface tension (and thus surfactant concentration) has returned to baseline levels. Once the fluids have been collected and assessed, they will be removed and disposed of by a licensed disposal contractor.

- o Conduct a bench-scale bio-augmentation test on groundwater collected during the pump test. The bench scale test will evaluate the effectiveness of bioaugmentation treatment method in reducing the contaminant concentrations prior to proposed re-injection of water for the full-scale treatment system. The collected samples will be submitted to ETEC Advanced Bioremediation Solutions for analysis of water quality and bioremediation parameters to determine an effective treatment solution. ETEC will conduct a series of tests to evaluate levels of nutrients and electron acceptors to build microbial mass, supply enzymes to increase the bioavailability of contaminants and test for optimal oxygenation levels to induce bioactivity.

- Post-Extraction Monitoring:
  - o After extraction, reassess LNAPL thickness and groundwater levels in RW-1 and the initial monitoring well network to evaluate the surfactant treatment's impact. Conduct IVEY-SOL field testing to observe groundwater surface tension following extraction.

2. Soil Vapor Extraction Test

PBS will conduct a vapor extraction test to evaluate the vapor extraction process and define the flow and vapor concentration parameters necessary for designing a full-scale vapor extraction well network. Pilot test results will be instrumental in determining the total extraction rate, required vacuum to achieve the desired flow rate, and the necessary vapor treatment system size for full-scale implementation. Key factors for determining the soil vapor extraction (SVE) design parameters include:

1. The nature and extent of soil contamination.
2. The permeability distribution within the soil, including any heterogeneities.
3. The concentrations of contaminants in the extracted soil gas.

The pilot test will aim to specify an optimal total gas extraction rate or duration, with the goal of extracting one or more full pore volumes of soil gas from the contaminated zone.

The following tasks are proposed as part of the vapor extraction pilot testing at the site. Detailed test setup, procedures, and reporting are provided in Attachment B.

Installation of Vapor Extraction Well

a. A vapor extraction well (VEW) will be drilled using a sonic drilling rig to a depth of fifteen feet below ground surface, or 3 to 5 feet above the static groundwater surface. The well will be constructed with a 2-inch diameter PVC casing and a 12-inch flush-mount completion. A 5-foot screen interval will be positioned at least five feet above the static groundwater surface, targeting an interval between 10 and 15 feet bgs. Soil types encountered during drilling will be logged, and a well log will be prepared. Two soil samples will be collected from the SEW boring installation. Soil samples will be analyzed for TPH-Gx, TPH-Dx, BTEX, soil moisture, pH, and particle sizing, alkalinity, total iron, and nutrients. The VEW will be placed in a known area of soil and vadose zone contamination as depicted on Figure 2.

b. Three vapor monitoring points (VMP) will be installed at depths of 10 to 12 feet below ground surface at distances of 10, 20 and 40 feet from the VEW to facilitate differential pressure analysis. One vapor monitoring point will be installed to a depth of seventeen feet bgs or one foot above the water table for use in the subsequent bio-vent pilot test. Vapor monitoring points will be installed using sonic drilling methods and completed with a 6-inch flush-mounted seal.

c. The VEW and vapor monitor points will be placed within contaminated soil to ensure the collection of meaningful data.

Vapor Extraction Test

a. Set up the mobile SVE system components, including a blower and moisture separator. Onsite power will be used to operate the blower system.

b. Collect static pressure readings (via magnehelic gauges) and VOC readings (via PID) from the VEW and vapor points before active extraction begins.

c. Initiate the SVE system, adjusting settings to stabilize the system and achieve the desired operational parameters. The SVE pilot testing will typically include three step tests, each involving the incremental closure of the make-up air valve to determine changes in the radius of influence (ROI) at various applied vacuums and flow rates, followed by a constant rate test. The desired operational parameters are as follows:
   - Step 1: Initial Vacuum and Flow Rate: Apply a vacuum of approximately ten inches of water column (in.H2O) with a flow rate of less than 20 standard cubic feet per minute (scfm). Maintain these settings at the extraction well for approximately 60 minutes, ensuring four consecutive readings show no notable change (less than 5% variation in both vacuum pressure and air flow rates) in operating conditions.

   - Step 2: Increased Vacuum and Flow Rate: Increase the vacuum to approximately twenty inches of water column, maintaining a flow rate of less than 20 scfm. Monitor for approximately 45 minutes, ensuring three consecutive readings show stability.

   - Constant Rate Test: Apply a vacuum of thirty inches of water column and maintain a flow rate of forty scfm. Continue this phase for 2 to 3 hours, ensuring that three consecutive readings indicate stable operating conditions.

d. Continuously monitor the system to assess applied vacuum levels and VOC concentrations in the extracted soil gas. Measure and adjust the extraction rate to extract one or more full pore volumes of soil gas from the contamination zones.

e. The vapor extraction test will be conducted over a two-day period.

3. Bio-Vent Test

A bio-vent test will be performed to assess the potential for in situ soil bioremediation and determine the appropriate parameters for designing a full-scale bioventing system. The test will utilize the existing well and vapor monitoring points established during the SVE Test. This pilot bio-vent test is essential for evaluating the effectiveness of microbial activity in reducing contaminant concentrations through biodegradation. The primary objectives are to determine the oxygen demand within the vadose zone, confirm active biodegradation, and define the necessary air injection rates for full-scale operations.

The following tasks are proposed as part of the vapor bio-vent pilot testing work at the site. A detailed operating procedure is presented in Appendix C.

Setup of Bio-Vent System

A vapor monitor point will be installed using a sonic drilling method as described in above Section 2. Zero as the primary air injection point. The VEW and shallower vapor monitoring points (VMP) will be used for monitoring purposes, allowing for differential pressure analysis and the monitoring of oxygen (O_2), carbon dioxide (CO_2), and methane (CH_4) levels.

Bio-Vent Test Procedures

a. Prior to initiating active air injection, collect baseline static pressure, VOCs, and O_2/CO_2/CH_4 concentrations at the VEW and vapor points using appropriate field monitoring devices.

b. Use a small air compressor or blower (approximate one horsepower blower) to inject air into the vadose zone. A Teflon tube will be lowered into the vent well to within 2-feet of the bottom of the screen interval. A surface plug on the well will prevent escape of the injected air, so under pressure the air will enter the subgrade soils. Onsite power will be used to operate the air injection system. A multi-gas meter with an accuracy of ±5% or less will be employed to monitor O_2, CO_2, and CH_4 concentrations.

c. Start the air injection system and gradually increase the flow rate to introduce oxygen into the subsurface. Inject at least 1,000 cubic feet of air into the test well to ensure boundary effects (e.g., potential limitations caused by soil heterogeneity) do not impact the test results, expected to be injected over a 24-hour period. A tracer gas, such as helium, will be used during the injection phase to track the distribution of injected air.

d. Continuously monitor O_2, CO_2, CH_4 concentrations, and tracer gas levels at the VEW and two VMP to assess the respiration rate of the microbial population and confirm active biodegradation. Pressure readings will also be recorded at the wells during the injection and recovery period. Sampling will occur at regular calibrated intervals over a period of up to 24 hours after the air injection is turned off to track changes in gas concentrations. Measurements will be taken until the O_2 and CO_2 levels return to with 5% of the pre-injection levels measured at the monitoring points.

e. The bio-vent test will be conducted over 24 to 48 hours, depending on the observed changes in O_2, CO_2, and CH_4 levels.

Sincerely,
PBS Engineering and Environmental Inc.

10/4/2024

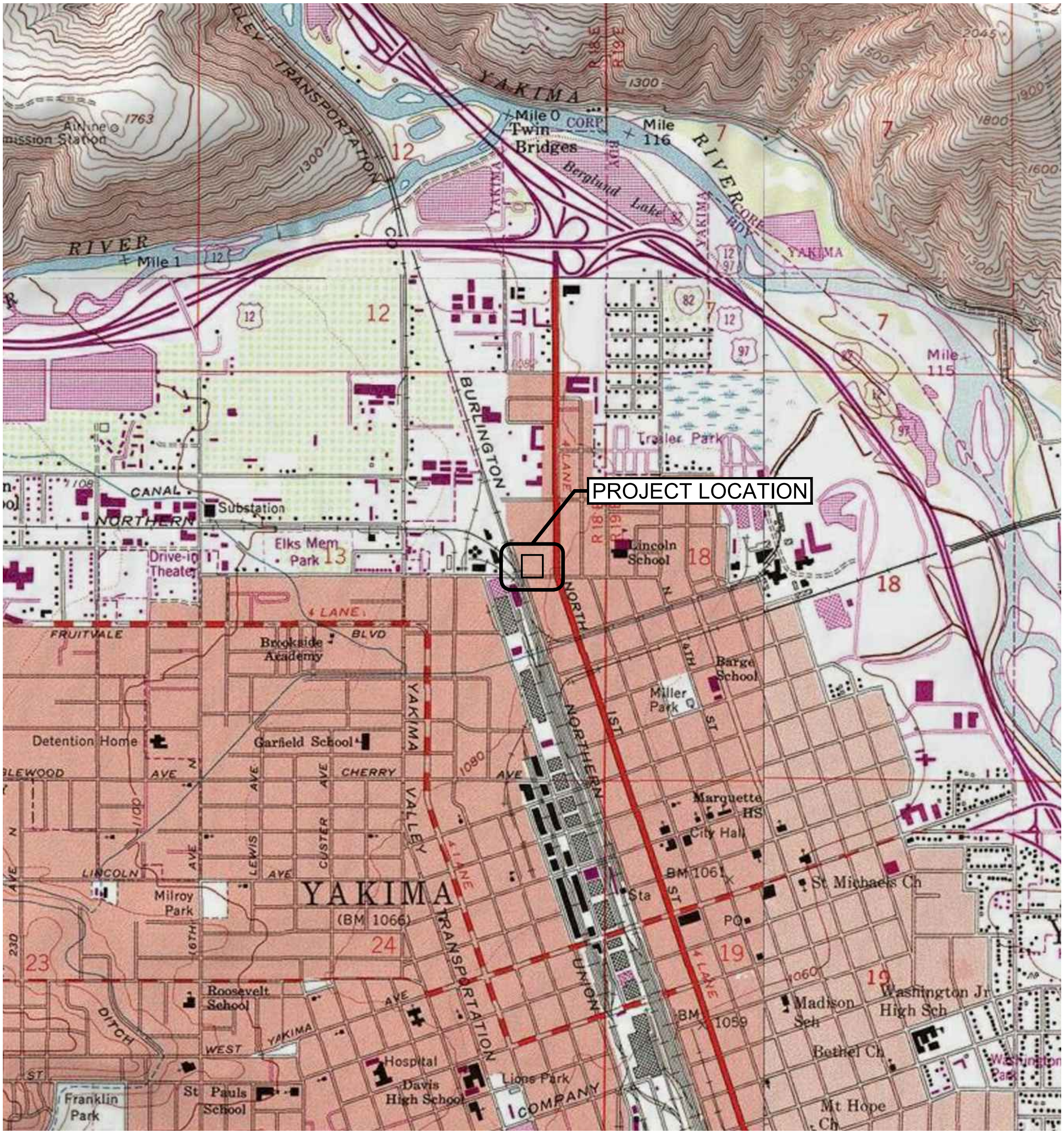
Kyle Johnson, LG
Project Geologist

Date

State of Washington
Ex. 6/20/2025
20120181
Licensed Geologist
Kyle Erik Johnson

Attachment(s):
Figure 1: Vicinity Map
Figure 2: Site Plan – Pilot Test
Figure 2: SVE Pilot Schematic
Appendix A - IVEY-SOL Product Sheet
Appendix B - Soil Vapor Extraction Pilot Test Detail
Appendix C - Bioventing Respiration Test

REVIEWER: Tom Mergy, LHG



SOURCE: USGS YAKIMA WEST, WA QUADRANGLE 1985

Scale 1" = 2,000'

0' 1,000' 2,000' 4,000'

PREPARED FOR: COLEMAN OIL

PBS

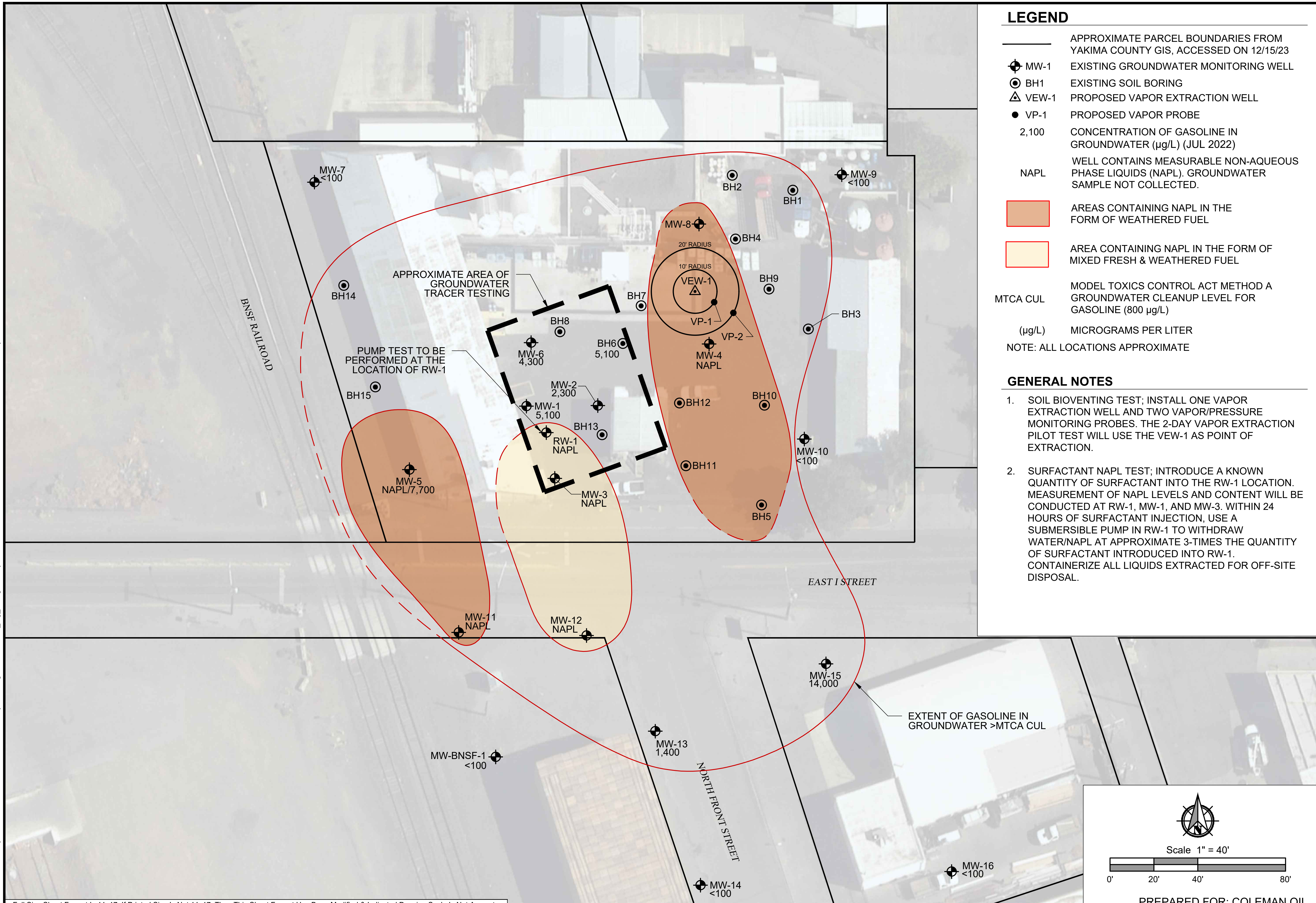
VICINITY MAP

1 EAST I STREET
YAKIMA, WASHINGTON

JUN 2024
41392.000

FIGURE
1

Filename: L:\Projects\41000\41392 Coleman Oil\CAD\RI Report Figures\41392.000_FIG-1.dwg Layout Tab: VICINITY MAP User: Katie Breyman CAD Plot Date/Time: 11/18/2022 9:23:43 AM



LEGEND

(line)	APPROXIMATE PARCEL BOUNDARIES FROM YAKIMA COUNTY GIS, ACCESSED ON 12/15/23
MW-1	EXISTING GROUNDWATER MONITORING WELL
BH1	EXISTING SOIL BORING
VEW-1	PROPOSED VAPOR EXTRACTION WELL
VP-1	PROPOSED VAPOR PROBE
2,100	CONCENTRATION OF GASOLINE IN GROUNDWATER (µg/L) (JUL 2022)
NAPL	WELL CONTAINS MEASURABLE NON-AQUEOUS PHASE LIQUIDS (NAPL). GROUNDWATER SAMPLE NOT COLLECTED.
(dark shading)	AREAS CONTAINING NAPL IN THE FORM OF WEATHERED FUEL
(light shading)	AREA CONTAINING NAPL IN THE FORM OF MIXED FRESH & WEATHERED FUEL
MTCA CUL	MODEL TOXICS CONTROL ACT METHOD A GROUNDWATER CLEANUP LEVEL FOR GASOLINE (800 µg/L)
(µg/L)	MICROGRAMS PER LITER

NOTE: ALL LOCATIONS APPROXIMATE

GENERAL NOTES

1. SOIL BIOVENTING TEST; INSTALL ONE VAPOR EXTRACTION WELL AND TWO VAPOR/PRESSURE MONITORING PROBES. THE 2-DAY VAPOR EXTRACTION PILOT TEST WILL USE THE VEW-1 AS POINT OF EXTRACTION.
2. SURFACTANT NAPL TEST; INTRODUCE A KNOWN QUANTITY OF SURFACTANT INTO THE RW-1 LOCATION. MEASUREMENT OF NAPL LEVELS AND CONTENT WILL BE CONDUCTED AT RW-1, MW-1, AND MW-3. WITHIN 24 HOURS OF SURFACTANT INJECTION, USE A SUBMERSIBLE PUMP IN RW-1 TO WITHDRAW WATER/NAPL AT APPROXIMATELY 3-TIMES THE QUANTITY OF SURFACTANT INTRODUCED INTO RW-1. CONTAINERIZE ALL LIQUIDS EXTRACTED FOR OFF-SITE DISPOSAL.

PREPARED FOR: COLEMAN OIL

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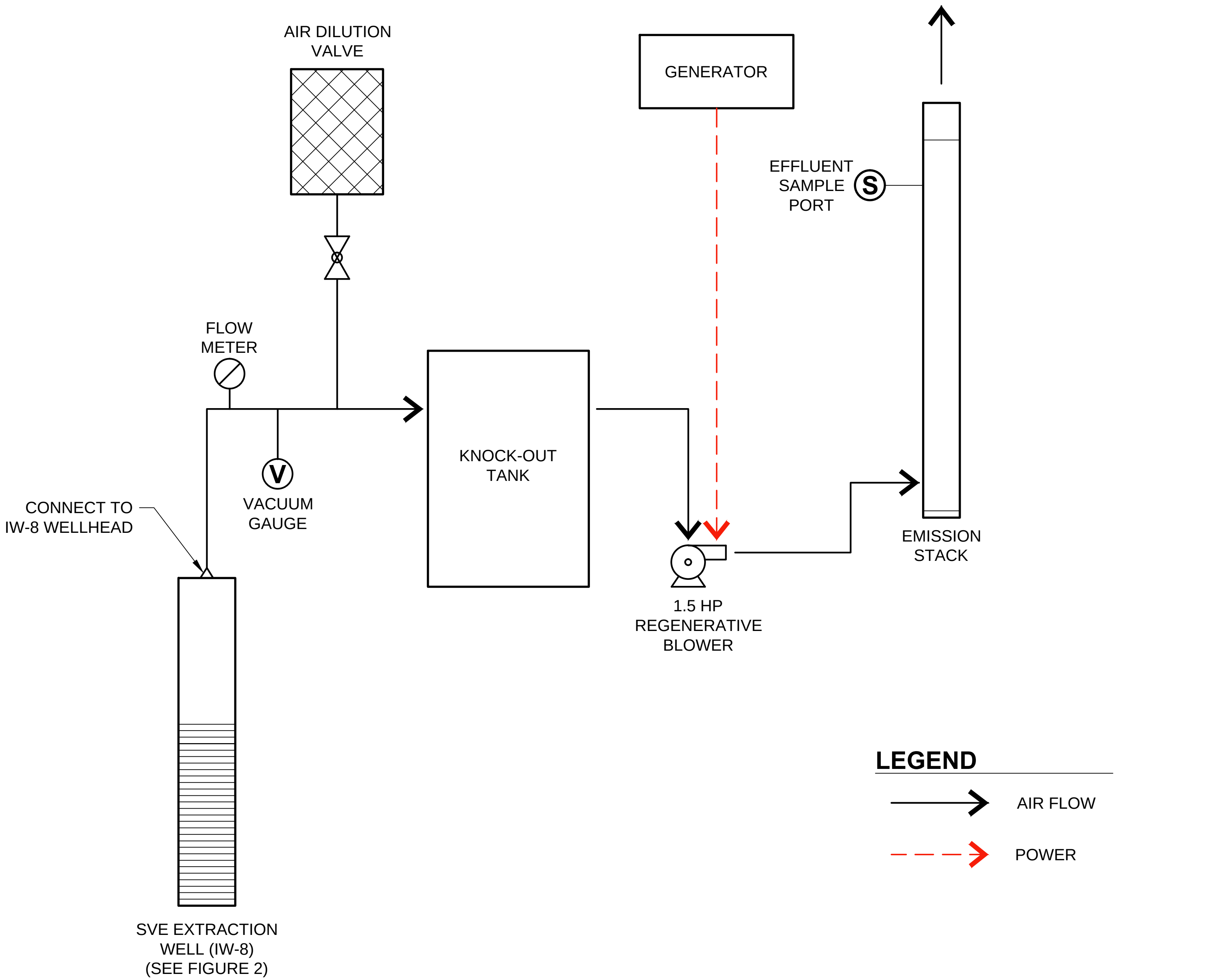
PILOT TEST PLAN
COLEMAN OIL
1 EAST I STREET, YAKIMA, WASHINGTON

PROJECT	41392.000
DATE	JUNE 2024
SHEET ID	2



PREPARED FOR: RESERVE AT LYNNWOOD, LLLP.

PBS

SVE PILOT TEST SYSTEM SCHEMATIC

RESERVE AT LYNNWOOD
19815 SCRIBER LAKE ROAD
LYNNWOOD, WASHINGTON

PROJECT #
41391.000

DATE
JAN 2017

FIGURE
3

APPENDIX A - IVEY-SOL PRODUCT SHEET

SAFETY DATA SHEET **SDS # 231005-08**

Ivey-sol® Surfactant Remediation Technology

Ivey-sol® Formulations: 103, 106, 106 Cl, and 108

1. Identification

Product identifier:	Ivey-sol® 103, 106, 106 Cl, 108
Other means of identification:	Not applicable
Recommended use:	Remediation surfactant
Restriction on use:	Not applicable
Manufacturer/Supplier Address:	Ivey International Inc. Unit 7, 19122-27 Avenue, Surrey, BC Canada V3Z 5T1
Emergency telephone number:	Tel: +1 (604) 538-1168 (Not available 24 hours) Toll Free: +1 800 246-2744

2. Hazard Identification

WHMIS 2015/OSHA Hazcom 2012/GHS Classification:

- Serious Eye Damage/Irritation Category 2
- Skin Corrosion/Irritation Category 3

Label elements:

Signal word: Warning Pictograms: Hazard statements:

H316 – May causes mild skin irritation.
H319 – May causes eye irritation.

Precautionary Statements:
P264 - Wash contacted areas thoroughly after handling.
P280 - Wear eye protection.
P305/P351/P338 - If In Eyes: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do so. Continue rinsing.
P332/P313 - If skin irritation occurs: Get medical advice/attention.
P337/P313 - If eye irritation persists: Get medical advice/attention

3. Composition / Information on Ingredients

Chemical Name	CAS No.	Concentration (v/v)	Other Identifiers
Biodegradable Non-ionic Surfactant 1	Proprietary	1-10%	*Not applicable*
Biodegradable Non-ionic Surfactant 2	Proprietary	1-10%	*Not applicable*
Biodegradable Non-ionic Surfactant 3	Proprietary	1-10%	*Not applicable*
Biodegradable Non-ionic Surfactant 4	Proprietary	1-10%	*Not applicable*
Biodegradable Non-ionic Surfactant 5	Proprietary	1-10%	*Not applicable*
Biodegradable Non-ionic Surfactant 6	Proprietary	1-10%	*Not applicable*

Preservative – DOWICIL 75	4080-31-3	<1%	Food Grade (Optional)
Scent – Pink Grapefruit 100% Natural	8016	<1%	*Optional*
Water	7732-18-5	<90%	*Not applicable*

Regulatory Note: *Chemical names, CAS numbers and actual concentrations have been withheld as part of a confidential business information claim with HMIRA Registry #11724 filed on 2017-07-17*

4. First-aid Measures

Inhalation: No adverse effects anticipated by this route when handled according to section 7 of document. However, if necessary, move person to fresh air.

Skin contact: Generally will not irritate skin. Wash contact areas with soap and water. If irritation persist, seek medical attention.

Eye contact: May cause eye irritation. Flush eyes with plenty of water for at least 15 minutes, remove contact lenses if present and easy to do so. If irritation persists, seek medical attention.

Ingestion: Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth with water. If necessary, seek medical attention.

Most Important Symptoms and Effects, Acute and Delayed

Acute Symptoms:
Eye Contact: May be irritating to the eyes. Occasional contact through splashing is not expected to affect the eyes. If irritation occurs, effect will be transient.

Chronic Symptoms: Not Applicable
Immediate Medical Attention and Special Treatment: Not Applicable

5. Fire-Fighting Measures

Suitable extinguishing media: Not flammable. Use extinguishing media for surrounding fire.
Unsuitable extinguishing media: Not applicable
Specific hazards arising from the hazardous product: Not available
Special protective equipment for fire-fighters: Not available

6. Accidental release measures

Personal Precautions, Protective Equipment:
Observe good industrial hygiene practices. Use personal protective equipment as recommended in Section 8. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Emergency Procedures: Eliminate and/or contain source with inert material (sand, earth, absorbent pads, etc.). Wear basic eye and skin protection. Floor may be slightly slippery; so use care to avoid falling. Avoid discharge to natural waters, and/or dilute with water. Transfer liquids to suitable containers for recovery, re-use or disposal. Contact Ivey for technical assistance if required.

7. Handling and Storage

Precautions for Safe Handling:
Practice good housekeeping. Avoid breathing excessive vapours. Ensure adequate ventilation. Avoid contact with skin and eyes. Wear protective gloves. Wash thoroughly after handling.
Conditions for Safe Storage: Keep closed or sealed when not in use. Do not allow to freeze, keep >0°C.

8. Exposure Controls / Personal Protection

Control parameters: Not available
Appropriate Engineering Controls: General mechanical room ventilation is expected to be satisfactory.
Individual Protections Measures: Eye/face protection: Mono goggles or similar.
Skin protection: Latex gloves, or similar, would be sufficient. Normal work clothes.
Respiratory Protection: None expected to be needed. However, if an engineered / industrial application where vapours and/or misting may occur, wear MSHA/NIOSH approved half mask air purifying respirator

9. Physical and Chemical Properties

Appearance:	Liquid, cloudy
Odour:	Mild
Odour threshold:	Not available
pH:	7 (+/- 0.5) (1% solution)
Melting Point:	~0°C
Freezing point:	~0°C
Boiling Point:	Not available
Flash Point:	Not applicable
Evaporation Rate:	<0.01
Flammability:	Not applicable
Lower flammable/ explosive limit:	Not applicable
Upper flammable/Explosive Limit:	Not applicable
Vapour Pressure:	<0.01 mm Hg
Vapour Density:	>1
Relative Density:	0.99-1.04
Solubility:	100% (Completely miscible in water)
Partition Coefficient:	Not available (n-octanol / water)
Auto-Ignition Temperature:	Not applicable
Decomposition Temperature:	Not available
Viscosity:	Not available

10. Stability and Reactivity

Reactivity: Not reactive.
Chemical Stability: Stable.
Possibility of Hazardous Reactions: Not applicable
Conditions to Avoid: Prolonged excessive heat may cause product decomposition. Freezing should also be avoided as it may cause product decomposition. In some cases freezing may cause irreversible changes.
Incompatible Materials: Normally un-reactive; however avoid strong bases at high temperatures, strong acids, strong oxidizing agents, and materials with reactive hydroxyl compounds. These compounds would damage the mixture and reduce its effectiveness during application.
Hazardous Decomposition products: Not applicable

11. Toxicological Information

Likely Routes of Exposure
Inhalation: No
Skin contact: No
Eye contact: Yes

Ingestion: No
Acute Toxicity:
LD50 - Oral (Rat): = >43.000mg/kg (rat) mg/kg
LD50 - Dermal (Rabbit): >58.000mg/kg (rabbit) mg/kg
Inhalation: Not available
Skin corrosion/irritation: Mild irritation
Serious eye damage/irritation: Eye irritation
Respiratory or skin sensitization: No
Germ cell mutagenicity: No
Carcinogenicity: None known or expected
Reproductive toxicity: No

12. Ecological Information

Toxicity: Low potential to affect aquatic organisms when used in accordance with Ivey International Inc. In-situ and Ex-situ Remediation Application Guidelines.

Acute toxicity	Time	Species	Method	Evaluation	Remarks
LC/50 = 0.07695%	96h	Rainbow trout	OECD 203	Not applicable	Not applicable
LC/50 = 0.11%	48h	Daphnia magna	OECD 202	Not applicable	Not applicable
EC/50 = Not applicable	72h	Algae	OECD 201	Not applicable	Not applicable

Persistence and degradability: >90% biodegradable in < 28 days.*
Bio-accumulative potential: Not available
Mobility in soil: Completely miscible with water.
Other adverse effects: Not available

Based on actual testing or on data for similar material(s). Degradation Biodegradation reached in Modified OECD Screening Test (OECD Test No.301 E) after 28 days: 90 %. Biodegradation reached in CO2 Evolution Test (Modified Sturm Test, (OECD Test No. 301 B) after 28 days: 70 %.

13. Disposal Considerations

Product/Packaging:
For aqueous mixture solutions; aerobic biological wastewater treatment systems are effective in treating said mixtures. Ivey-sol does not have any known negative affect on coagulant or flocculent water treatment processes.

14. Transport Information

UN Number: Not applicable
Proper Shipping Name: Not applicable
Technical Name: Not applicable
Transport Hazard Class: Not applicable
Packing Group: Not applicable
Environmental Hazards: Not applicable
Notes: Not Regulated for Transport. HS Code: 3402.42.00.00

15. Regulatory Information

UN GHS Classification: Classified in accordance with GHS 5th revised edition.
WHMIS Classification: Classified in accordance with HPR August 29, 2016 revised edition.
CPR Compliance: This product has been classified in accordance with the hazard criteria of the CPR, and the SDS contains all the information required by the CPR.
CEPA Compliance: All ingredients of this product are listed on the DSL.

16. Other Information

Creation Date: July 5, 2017
Revision Date: Updated October 2, 2017, October 18, 2018, November 4, 2022, October 6, 2023

Disclaimer: This Safety Data Sheet (SDS) was prepared by iHazmat Regulatory Ltd., (www.iHazmat.com) using information provided by Ivey International Inc. The information in this SDS is offered for your consideration and guidance when working with this product. As per usual practice, accuracy of the information included is based on what was provided by the manufacturer and sole liability for the accuracy of these documents falls to Ivey International Inc.

This Safety Data Sheet may not be changed, or altered in any way without the expressed knowledge and permission of Ivey International Inc.

SDS Created By: iHazmat Regulatory Ltd.
www.iHazmat.com

APPENDIX B - SOIL VAPOR EXTRACTION PILOT TEST DETAIL

I. SVE Pilot Test

The SVE pilot test will be conducted using wells to be installed at the Site as part of this Work Plan. installed at the subject site. The SVE test will be conducted in accordance with the procedures.

1. Vapor Well Installation

a. A vapor extraction well (VEW) will be drilled using a sonic drilling rig to a depth of fifteen feet below ground surface, or 3 to 5 feet above the static groundwater surface. The well will be constructed with a 2-inch diameter PVC casing and a 12-inch flush-mount completion. A 5-foot screen interval will be positioned at least five feet above the static groundwater surface, targeting an interval between 10 and 15 feet bgs. Soil types encountered during drilling will be logged, and a well log will be prepared. Two soil samples will be collected from the VEW boring installation. Soil samples will be analyzed for TPH-Gx, TPH-Dx, BTEX, soil moisture, pH, and particle sizing, alkalinity, total iron, and nutrients. See Table B-1 below for anticipated soil sample analytes and analytical methods. The VEW will be placed in a known area of soil and vadose zone contamination as depicted on Figure 2.

b. Vapor monitoring points (VMP) will be installed using a sonic or push-probe drill rig. Soil cores will be inspected and at least one soil sample per VMP will be collected. See Table B-1 below for anticipated soil sample analytes and analytical methods. Two vapor monitoring points will be installed at depths of 10 to 12 feet below ground surface at distances of 10 and 40 feet from the VEW to facilitate differential pressure analysis. One vapor injection/monitoring point will be installed to a depth of seventeen feet bgs, or one foot above the water table for use in the bio-vent pilot test at 20 -feet from the VEW. Vapor monitoring points will be constructed of 2.0-inch (ID) Schedule 40 PVC, with five feet of 0.02-inch slotted screen per well and completed with a 6-inch flush-mounted seal. The top of each VMP will be fitted airtight with a gas ball valve equipped with a hose barb.

Table B-1: Soil Samples - Analytes, Analytical Methods, and Detection Limits

Analyte	Analytical Method	Reporting Limit (µg/kg)	Sampling Volume (g)	Sample Storage	Sample Holding Time
TPH-Gx	NWTPH-Gx	200 µg/kg	200 g	4°C	14 days
TPH-Dx	NWTPH-Dx	100 µg/kg	200 g	4°C	40 days
BTEX	8260B	0.5 µg/kg	200 g	4°C	14 days
Soil Moisture	ASTM D2216	Not applicable	50 g	4°C	7 days
Grain Size	ASTM D422	Not applicable	100 g	NA	180 days
Total Iron	EPA 6010B	10 µg/kg	50 g	NA	6 months

2. Baseline Field Parameters

Before beginning the SVE pilot test, baseline field parameters will be measured at each of the designated SVE wells and existing monitoring wells included in the test. Baseline field measurements will include: existing well pressures, depth-to-water (DTW), and photoionization detector (PID) to measure volatile organics readings at each of the wells. Baseline field measurements will be recorded on Field Form B-1, Baseline Measurements. The designated well network is presented in Figure 2.

3. SVE Pilot Test System Design

A schematic of the SVE pilot test system is presented in Figure 3. A regenerative blower, capable of applying a vacuum of approximately thirty inches of water, will be connected to one vapor extraction test well, VEW-1 for one approximate 4 to 6-hour test. The blower will be connected to the casings of the extraction test wells with 3-inch-diameter flexible hosing suitable for high-vacuum applications. A moisture knockout tank will be installed before the blower to remove moisture from the recovered vapors. The moisture knockout tank will be equipped with a valve at the bottom of the tank to recover moisture during the test, if needed. The discharge from the blower will exhaust the atmosphere during the pilot test period. An effluent sample port will be installed to monitor the level of volatile organic hydrocarbons (VOCs) extracted during the test.

4. SVE Test Procedure

During the pilot test, the following parameters will be measured and recorded: (1) the air flow rate from the extraction well; (2) the vacuum pressures in the extraction well; and (3) vacuum pressure in each of the selected monitoring points. The air flow rate will be measured with an in-line air flow meter. Vacuum pressures will be measured using suitably scaled vacuum gauges (in the piping connected to the extraction well and at the casing of each monitoring point). Vacuum relief (with a bypass valve) will be provided at the blower unit as necessary to maintain safe operation of the equipment.

Three types of readings will be collected to monitor the performance of the extraction during the pilot test: vacuum, velocity, and VOCs. The measurements will be recorded on Field Form B-2. The readings will be collected concurrently with the measurements at the surrounding wells, Form B-3. The vacuum will be recorded from a vacuum gauge situated at the extraction wellhead. The velocity reading will be collected using an anemometer and will be converted to flow rates based on the pipe diameter at the reading location.

• **Test Equipment and Calibrate** – Test all equipment and battery charges before going into the field. Calibration of the volatile organic compound (VOC) meter or handheld photoionization detector (PID) is necessary. Though relative changes are important, the vacuum gauges must all respond equivalently, and the VOC meter (or PID) must be accurate to estimate actual emission loads.

• **Measure Distances Between Wells and Depths of Wells** – Wells screened above the water table (unsaturated zone, monitoring, or pumping wells) are opened and allowed to equilibrate to atmospheric pressure. Measure distances between wells if there is any question these data were not recorded previously, or the accuracy of the site map is in question. Water levels are then measured, if applicable at wells, to assure screens are above the water table.

Note that there are instances in fine soils where the screen may be only a couple of feet or less above the water table and no vacuum is observed. During the test, the suction may draw the water over the remaining screen resulting in no or low air flow from the well. Also, capillary rise in the formation may inhibit air flow from a well.

• **Cap Vapor/Monitoring Wells** – Vapor points and monitoring wells will be fitted with caps that allow attachment of differential pressure gauges. A tubing port tapped into a PVC cap serves this purpose. Zero all differential pressure gauges. Be sure the atmospheric pressure ports on the differential pressure gauges do not get exposed to high or variable winds. One way to do this is to run a piece of tubing from the high pressure port into the well monument and out of the wind.

If there are more wells than differential pressure gauges, and vacuum readings are desired at those wells, then they should be fitted with a cap or union, and the hose barb port should be plugged when not used. Unmonitored wells should be capped off to prevent possible short circuiting. Wells not being monitored should be plugged.

• **Manifold the Blower and Moisture Separator to the Extraction Well** – The vacuum is commonly applied by connecting a blower to the SVE well. Flexible vacuum hose is much more useful than hard piping. The vacuum hose from the well should be connected to a knock-out tank to collect condensing water. This knock-out tank should have a vacuum gauge attached that reads up to 100-inches of water (or the maximum vacuum capacity of the blower) for measuring the vacuum applied at the SVE well head. Another section of the flexible vacuum hose connects the knock-out tank to the blower. A bleed-in pipe equipped with a gate valve is installed off a tee on the line between the vacuum end of the blower and the extraction well. The bleed-in line allows for control of the vacuum applied to the extraction well. Velocity measurement ports should be installed at three locations: on the pipe to the well, on the bleed-in pipe, and on the stack. The velocity measurement ports should be tapped ports for insertion of a pitot tube at proper distances from flow disturbances.

Regulatory rules or health and safety issues may require the blower exhaust to be passed through a treatment system to remove VOCs or other contaminants from the gas stream.

• **Examine Possible Test Vacuums and Start SVE Testing** – With the bleed valve closed, briefly turn on the blower and measure the maximum possible vacuum that the blower can apply to the well. Also, measure the resulting flow from the well and collect a PID reading.

Use the maximum vacuum data to determine at least two appropriate vacuums that may be applied during SVE testing. SVE tests using at least two extraction vacuums are recommended to obtain sufficient blower selection data. Typically, SVE testing is performed using the maximum vacuum and half of the maximum vacuum or at reasonable SVE design vacuums.

Start SVE testing by turning on the blower and immediately adjusting the bleed valve until the vacuum on the well is at the desired level.

- **Step Test and Constant Rate Test Summary**

The SVE pilot testing will consist of three step tests followed by a constant rate test. The step tests will be performed by incrementally closing the make-up air valve to determine the change in radius of influence (ROI) at different applied vacuums and flow rates. The constant rate test will follow these step tests to establish the sustained effectiveness of the system at a chosen vacuum level. Each step and the constant rate test will be conducted until the system meets the stabilization criteria.

For stabilization, a parameter will be considered stable if three successive readings, taken at regular intervals, show less than 5% variation in both vacuum pressure and air flow rates.

The following operating conditions will be used during the pilot test:

Step 1 – Vacuum of ~10 inches of water column (in.H2O) and a flow rate of less than 20 standard cubic feet per minute (scfm) (dilution air valve partially closed) and maintain at the Extraction Well wellhead for four consecutive reading (~60 minutes).

Step 2 – Vacuum of ~20 inches of water and a flow rate of less than 20 scfm (dilution air valve partially closed) and maintained at the Extraction well for three consecutive readings (~45 minutes).

Constant Rate Test – Vacuum of thirty inches of water and a flow rate of forty scfm (dilution air valve fully closed) and maintained at the Extraction well for a period for 2 to 3 hours after the conclusion of the step 2 test.

• **Extraction Well Data Recording During the Test** – During the test, the following extraction well data is recorded on intervals as frequent as possible.

Vacuum will be measured at the extraction well every minute for the first 5 minutes of the test and every 15 minutes thereafter. The vacuum in the surrounding wells will be monitored and recorded every 10 minutes on Field Form B-3, SVE Test Measurements (Appendix B) throughout the duration of the pilot test. The test will be conducted until the vacuum readings stabilize to within 0.05 inches of water for a minimum of 15 minutes. The stabilization test will be conducted for a maximum of 60 minutes. After the initial test period, the blower will be turned off and the wells will be allowed to equilibrate to atmospheric conditions. The vacuum recovery will be monitored within the vadose zone during this time.

1. Time from start of the test
2. Vacuum at the extraction well
3. Air velocity from the well, air velocity out of the blower, and air velocity in the bleed-in pipe. Use an anemometer or pitot tube or both to monitor velocity.
4. Concentration of VOCs in the air coming out of the well as measured with a PID. (Due to the location of the SVE wells in relation to possible vadose zone impacts, the concentration of VOCs in the extracted air may be at elevated levels).

• **Effluent Samples** - PID measurements should be collected every 15 minutes throughout the duration of the test. One influent and one effluent sample will be collected to determine the VOC concentrations in the air stream during the test. Summa vacuum canisters are preferred for sampling.

• **Monitoring Vacuum Influence During the Test** – Monitor the differential pressure gauges on the surrounding wells as frequently as possible (within every ten to fifteen minutes) during the start of the test (within approximately an hour). Each time a reading is taken, note the time and vacuum level, even if zero or if it has become negative (pressurized). Barometric pressure changes can have a large effect, especially when the ground surface is covered by asphalt, concrete, or building footers. Using a barometer, take an atmospheric pressure reading at the beginning and end of the test. Try to record local barometric pressure data (from an accredited local weather station) if a barometer is not available.

Vacuum should be applied at only one location at a time. If multiple wells are to be assessed, then sufficient time must elapse between tests (minimum 24 hours) to allow subsurface pressures to return to background levels. The waiting period will be a function of soil permeability and surface coverage. During the SVE test, the technician in charge of the test should contact the project engineer immediately if there are any special problems or unexpected results.

• **Data Recording Notes** – Frequency of measurement priority should be given to those to wells closest to the vacuum point. Frequency of measurement should also be adjusted in the field as the results are obtained. For instance, if a monitoring well fifteen feet from the vacuum point has vacuum stabilized at maximum value, then less frequent measurement is necessary. The time when frequent measurement is most useful is when the vacuums start to change. This will be later in the test for more distant wells. However, anisotropies have been known to result in more distant wells showing a response more quickly than closer wells.

• **Upon Completion of the Test** – After vacuum, flow, and VOC concentration data have reached apparent steady state conditions, prepare to shut off the blower. Before shutting off the blower, station observers next to monitoring wells. When the blower is shut off, record the observed change in vacuum at each of the monitoring wells. A marked vacuum drop at a monitoring well following a drop in vacuum at the extraction well may provide another valuable indication of total vacuum influence.

5. Air Quality Monitoring

At intervals during the pilot test, VOC concentrations will be measured at the blower exhaust using a photoionization detector (PID). In addition, one sample of the system effluent will be collected and submitted for laboratory analysis of VOCs (benzene, 1,2-dichloroethane, ethylbenzene, naphthalene, toluene, 1,2,4-trimethylbenzene, 1,3,5 trimethylbenzene, xylenes, n-butylbenzene, and n-propylbenzene) using EPA Method TO-15. The laboratory sample will be collected 30 minutes prior to the conclusion of the test period. The data will be used to assess the effectiveness of the pilot test system, the anticipated mass loading removal rate, and the need for vapor treatment on a full-scale system.

The air sample will be collected into a 6-liter, evacuated, and internally passivated stainless-steel Summa® canister. The Summa® canister will be batch certified by the analytical laboratory, ensuring that any residual target analytes from prior canister usage are not present at levels greater than the method detection limits (MDLs). See Table B-2 below for anticipated effluent vapor sampling analytes and analytical methods:

Table B-2: Vapor Effluent Sampling

Analyte	Analytical Method	Reporting Limit (RL)	Sampling Volume (L)	Sample Storage
Benzene	EPA TO-15	0.5 µg/m3	6	Summa Canister
Toluene	EPA TO-15	0.5 µg/m3	6	Summa Canister
Ethylbenzene	EPA TO-15	0.5 µg/m3	6	Summa Canister
Xylenes (total)	EPA TO-15	0.5 µg/m3	6	Summa Canister
Naphthalene	EPA TO-15	0.5 µg/m3	6	Summa Canister
1,2-Dichloroethane	EPA TO-15	0.5 µg/m3	6	Summa Canister
1,2,4-Trimethylbenzene	EPA TO-15	0.5 µg/m3	6	Summa Canister
1,3,5-Trimethylbenzene	EPA TO-15	0.5 µg/m3	6	Summa Canister
n-Butylbenzene	EPA TO-15	0.5 µg/m3	6	Summa Canister
n-Propylbenzene	EPA TO-15	0.5 µg/m3	6	Summa Canister
Helium	EPA 3C Modified / ASTM D1946 Modified	1 %	6	Summa Canister
Oxygen	ASTM D1946 Modified	0.5 %	6	Summa Canister
Carbon Dioxide	ASTM D1946 Modified	0.5 %	6	Summa Canister
Methane	ASTM D1946 Modified	0.5 %	6	Summa Canister
Nitrogen	ASTM D1946 Modified	0.5 %	6	Summa Canister

Prior to collecting the air sample, Field Form B-4, Air Sample Collection Form will be completed. Observations of meteorological conditions such as barometric pressure, outdoor temperature, humidity, and rainfall will be recorded. The record of the various meteorological parameters may be used to assess the influence that meteorological fluctuations may have on the analytical results.

Prior to Collection of the Sample

1. Check that the valve on the Summa canister is closed. The green knob should be turned completely clockwise.
2. Using a 9/16-inch wrench, remove the brass cap above the valve on the top of the Summa canister.
3. Connect a pressure gauge to the Summa canister.
4. Check the pressure on the Summa canister. If the canister pressure reads less than 28.5 inches of mercury (in Hg), then do not use the canister.

Sample Collection

1. Connect the summa canister to the sample port, after doing the pressure check specified above.
2. When ready to sample, open the canister valve(s). Turn the green knob until there is no resistance (approximately one ¼ turn) counterclockwise, then turn clockwise slightly until resistance is detected. A hissing noise should be heard as the air flows into the evacuated Summa canister.
3. Once the hissing noise stops, let the canister sit another 20 seconds and then close the valve by turning the green knob clockwise. Do not overtighten. Replace the brass cap.
4. Record the final pressure reading for the canister.

6. Data Analysis

Following the collection of the flow and pressure data, an analytical model (i.e., Air2D) will be used to determine the intrinsic air permeability of the formation. Using this calculated permeability, the model will be used to assess the relationship between air flow (and the resultant vacuum pressure) and the potential ROI (a pore-space air velocity of 0.001 cm/sec). This relationship will be used to evaluate proper SVE blower sizing and extraction well spacing.

Air quality data from the summa canister and PID will be used to evaluate the options for SVE effluent treatment.

Field Forms:

B1 – SVE Baseline Measurement

B2 – SVE Vapor Extraction Well Measurements

B3 – SVE Vapor Monitoring Point Measurements

Soil Vapor Extraction Pilot Test

Baseline Measurement Form: B-1
Location: ______________________
PBS Project No. ______________________
Staff: ______________________
DATE: ______________________

Well	Distance from VEW (feet)	Date and Time	Depth to Water (ft)	VOC Headspace (PID Reading)	Vacuum (in. H2O	Notes
VEW						
VMP1						
VMP2						
VMP3						

Water Level Instrument:
Vacuum Gage Instrument: Dwyer Magnehelic
PID Instrument: MiniRae 3000

Calibration Notes:

Soil Vapor Extraction Pilot Test

Form B-2

Vapor Extraction Well Test Measurements

Location: ______________________ **Date:** ____________________

PBS Project No. ____________ **Field Staff:** ____________________

Vapor Extraction Well No: ____________ **Blower Used During Test:** ____________________

Barometric Pressure: ____________ **Air Temperature:** ____________________

Time	Vacuum (in. H2O)	PID - Wellhead	PID - Effluent Air	Air Velocity	Notes

Barametric Pressure: 0.04 in. Hg = 0.54 in. H20

Vacuum Gage Instrument: Dwyer Magnehelic

PID Instrument: MiniRae 3000

Calibration Notes:

Soil Vapor Extraction Pilot Test

Form B-3

Test Well Measurements

Location: ____________________ **Date:** ____________________

PBS Project No. ____________________ **Field Staff:** ____________________

Test Well No: Barometric __________ **Blower Used During Test:** ____________________

Pressure: Distance from __________ **Air Temperature:** ____________________

VEW: Well Screen __________ **Start Time:** ____________________

Interval: __________ **Well Diameter (Inches):** ____________________

Time	Vacuum (in. H2O)	NOTES

Barametric Pressure: 0.04 in. Hg = 0.54 in. H20

Vacuum Gage Instrument: Dwyer Magnehelic

PID Instrument: MiniRae 3000

Calibration Notes:

APPENDIX C – BIOVENTING RESPIRATION TEST[1]

In situ air respiration tests are used to provide rapid field measurement of in situ biodegradation rates. Hinchee et al. (1992) have developed a test protocol for the U.S. Air Force that has been used at many Bio-Vent sites in the United States. This test protocol has been adopted as part of AFCEE's Bioventing Design process and has been endorsed by U.S. EPA in their manual on Bioventing Principles and Practice (Volume II, Leeson and Hinchee, 1995).

(1) The test consists of injecting air and an inert tracer gas (typically helium) into the vadose zone in highest VOC contamination area. Helium is used because it is an inert gas that helps track air movement without affecting biodegradation. The air provides oxygen to the soil, while the inert gas provides data on the escape of the injected air away from the injection point, either through the diffusion of air away from the ground surface and the surrounding soil, or through leakage from a poorly sealed well. The tracer gas also allows verification that the soil gas sampling system does not leak.

(2) Vapor Well Installation

a. The vapor monitoring points (VMP) will be installed using a sonic or push-probe drill rig. Soil cores will be inspected and at least one soil sample per VMP will be collected. Two vapor monitoring points will be installed at depths of 10 to 12 feet below ground surface at distances of 10 and 40 feet from the VEW to facilitate differential pressure analysis. One vapor injection/monitoring point will be installed to a depth of seventeen feet bgs, or one foot above the water table for use in the bio-vent pilot test at 20 -feet from the VEW. Vapor monitoring points will be constructed of 2.0inch (ID) Schedule 40 PVC, with five feet of 0.02-inch slotted screen per well and completed with a 6-inch flush-mounted seal. The top of each VMP will be fitted airtight with a gas ball valve equipped with a hose barb.
b. Three soil samples will be collected from the pilot test area during the installation of the VMPs. One soil sample will be collected from the interval of highest apparent contamination in each of the bores for the VMPs. Soil samples will be analyzed for TPH-Gx, TPH-Dx, BTEX, soil moisture, pH, particle sizing, alkalinity, total iron, and nutrients.

(3) Test implementation

a. Baseline vapor samples (oxygen, carbon dioxide and helium) and pressure readings from the vapor monitoring points will be collected prior to air injection at the vapor injection well.
b. A 1-HP vacuum blower (Gast model 2067-P106) capable of injecting sixteen scfm at 2 psi will be used to conduct the initial air permeability test at this site. The maximum power requirement anticipated for this pilot test is a 230-Volt, single phase, 30 Amp service.
c. Air injection will be used to provide oxygen to soil bacteria and to minimize emissions of volatiles to the atmosphere. Air with 1 to 2 percent helium will be injected into the vapor injection well for a period of 20 to 24 hours, The air injection will be halted, and then the vapor monitoring wells will be monitored for concentrations of O2, CO2, and the tracer gas were monitored for the next 48 hours. Initially, readings will be taken every 2 hours, but the interval may increase to as high as 9 hours overnight. Concentrations of O2 and CO2 will be compared with those measured before the injection began.

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[1] Engineering and Design SOIL VAPOR EXTRACTION AND BIOVENTING, EM 1110-1-400, US Army Corps of Engineers, June 2002.

d. Helium concentrations in the recovered soil gas will be measured using EPA 3C Modified for vapor sample analysis, which can measure helium in ppmV and/or percentage. Alternatively, helium can be analyzed using ASTM D1946 Modified, which also assesses oxygen, carbon dioxide, methane, and nitrogen in addition to helium.
e. A Landtech GEM5000 instrument will be used to collect measurements of Methane, Carbon Dioxide, Oxygen, temperature (when used with optional probe), atmospheric pressure, and differential pressure at the VMP. A Mark 9822 helium detector or equivalent can be used to provide real-time helium data.
f. Helium concentrations in the recovered soil gas will be measured and should be constant close to the injected concentration. (If the helium concentrations decrease significantly, then the validity of the O2 and CO2 data would be suspect since leakage or short-circuiting might be occurring.)

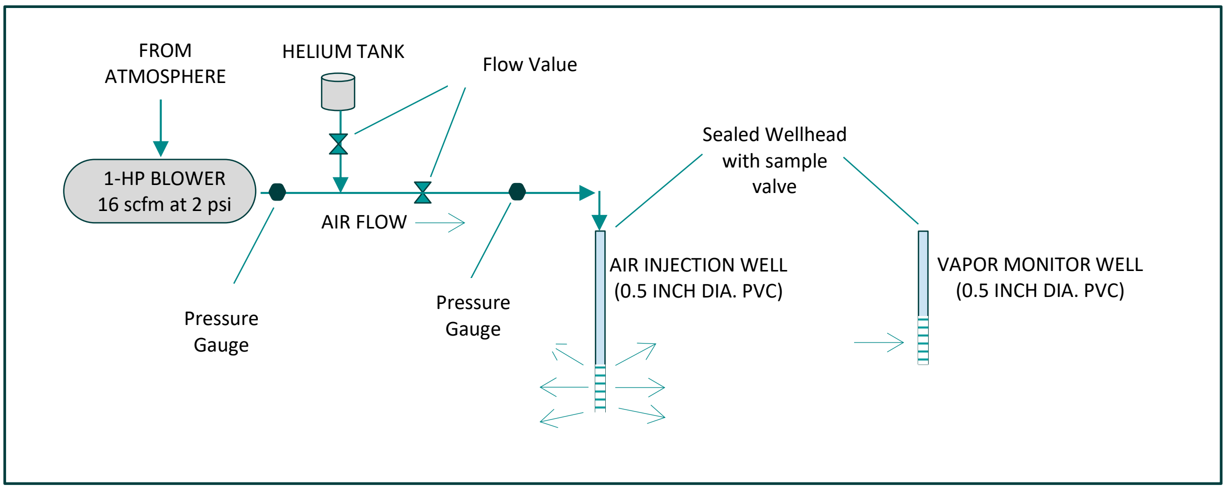

Figure 1: BioVenting pilot test schematic

See Table C-1 below for anticipated effluent vapor sampling analytes and analytical methods:

Table C-1: Vapor Effluent Sampling

Analyte	Analytical Method	Reporting Limit (RL)	Sampling Volume (L)	Sample Storage
Benzene	EPA TO-15	0.5 µg/m3	6	Summa Canister
Toluene	EPA TO-15	0.5 µg/m3	6	Summa Canister
Ethylbenzene	EPA TO-15	0.5 µg/m3	6	Summa Canister
Xylenes (total)	EPA TO-15	0.5 µg/m3	6	Summa Canister
Naphthalene	EPA TO-15	0.5 µg/m3	6	Summa Canister
1,2-Dichloroethane	EPA TO-15	0.5 µg/m3	6	Summa Canister
1,2,4-Trimethylbenzene	EPA TO-15	0.5 µg/m3	6	Summa Canister
1,3,5-Trimethylbenzene	EPA TO-15	0.5 µg/m3	6	Summa Canister
n-Butylbenzene	EPA TO-15	0.5 µg/m3	6	Summa Canister
n-Propylbenzene	EPA TO-15	0.5 µg/m3	6	Summa Canister
Helium	EPA 3C Modified / ASTM D1946 Mod.	1 %	6	Summa Canister
Oxygen	ASTM D1946 Modified	0.5 %	6	Summa Canister
Carbon Dioxide	ASTM D1946 Modified	0.5 %	6	Summa Canister
Methane	ASTM D1946 Modified	0.5 %	6	Summa Canister
Nitrogen	ASTM D1946 Modified	0.5 %	6	Summa Canister

(4) Reporting and Analysis

a. Oxygen utilization rates will be determined from the data obtained during the BioVent tests. The rates are calculated as the percentage change in O2 over time. Prepare graphic and tabular forms of the data, to show the oxygen utilization rate (percent per hour, %/hr). A straight-line reduction in O2 concentration is a typical result.

b. Biodegradation rates will be determined based on the oxygen utilization rates and the stoichiometric relationship between oxygen and a hydrocarbon representative of diesel fuel. This relationship is explained in the following equation:

C6 H14+9.502 →6C02+7 H 2 0